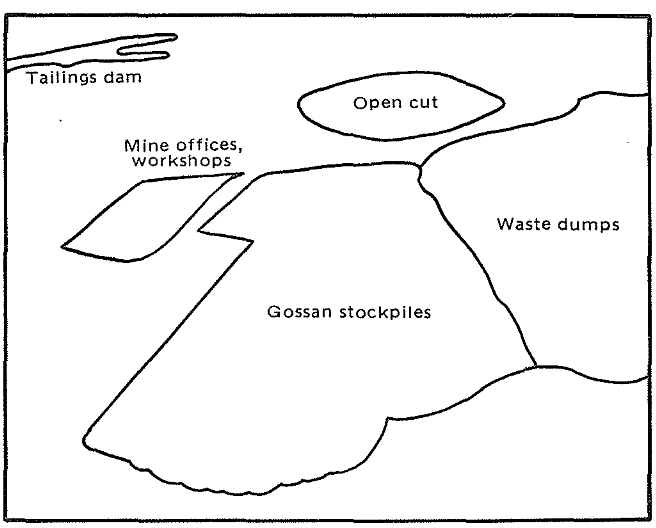
DEPARTMENT OF MINES WESTERN AUSTRALIA

ANNUAL REPORT 1980

Front Cover : Teutonic Bore open cut mine. Bulldozer working at bottom of pit, approximately 100 metres deep.

Back Cover : A selection of photographs showing operations at the Teutonic Bore Mine.

Photographs reproduced with permission of Seltrust Mining Corporation Pty Ltd.



Details of mine site as shown in lower right hand photograph.

REPORT OF THE DEPARTMENT *of* MINES WESTERN AUSTRALIA FOR THE YEAR 1980

Presented to both Houses of Parliament by His Excellency's Command

WILLIAM C. BROWN, Government Printer, Western Australia

To the Honourable the Minister for Mines.

Sir,

I have the honour to submit the Annual Report of the Department of Mines of the State of Western Australia for the year 1980, *together with the reports from the officers controlling Sub-Departments, and Comparative Tables furnishing statistics relative to the Mining Industry.*

D. R. KELLY,
Under Secretary for Mines.

Perth, 1981.

TABLE OF CONTENTS

DIVISION I.

	Page
Part 1.—General Remarks	7
Iron Ore	7
Nickel	7
Alumina	7
Petroleum	7
Gold	7
Coal	7
Other Minerals	7
Part 2.—Comparative Statistics, 1979 and 1980	
Table 1.—Summary of Mineral Production	8
Table 1 (a).—Quantity and Value of Minerals produced other than Gold and Silver	9
Table 1 (b).—Quantity and Value of Gold and Silver exported and minted	10
Table 2.—Royalties	10
Table 3.—Amount of Gold reported from each Goldfield	11
Diagram of Gold output, value and quantity, 1930–1980	12
Table 4.—Coal output, value, men employed, output per man	11
Graph of Coal output, value and quantity, 1950–1980	13
Graph of Coal output of deep and open-cut quantities, 1955–1980	14
Table 5.—Mining Tenements applied for and in force under the Mining Act	15
Table 5 (a).—Mining Leases applied for and in force under Special Acts	15
Table 5 (b).—Permits, Licences and Leases applied for and in force under the Petroleum Act	16
Table 5 (c).—Leases under the Mining Act in force in each Goldfield, Mineral field or District	17
Table 5 (d).—Claims and Authorised Holdings under the Mining Act in force in each Goldfield, Mineral field or District	18
Table 6.—Average number of men engaged in mining	19
Part 3.—State Aid to Mining—	
State Batteries	20
Prospecting Scheme	20
Geological Survey	20
Part 4.—Government Chemical Laboratories	20
Part 5.—Explosives Branch	20
Part 6.—Mine Workers' Relief Act and Miners Phthisis Act	20
Part 7.—Surveys and Mapping Branch	20
Part 8.—Staff	20

DIVISION II.

Report of the State Mining Engineer 21

DIVISION III.

Report of the Superintendent of State Batteries	49
Return of Parcels treated and Tonnes crushed at State Batteries for year 1980	50
Tailings Treatment, 1980	50
Statement of Revenues and Expenditure for year (Milling)	51
Statement of Revenue and Expenditure for year (Tailings Treatment)	52

DIVISION IV.

Report of the Director, Geological Survey 55

DIVISION V.

Report of the Director of The Petroleum Branch 167

DIVISION VI.

Report of the Superintendent, Surveys and Mapping 191

DIVISION VII.

Report of the Director, Government Chemical Laboratories 201

DIVISION VIII.

Report of the Chief Inspector of Explosives 229

DIVISION IX.

Report of the Chairman, Miners Phthisis Board and Superintendent, Mine Workers' Relief Act 237

STATISTICS.

Mining Statistics 243

WESTERN AUSTRALIA

Report of the Department of Mines for the Year 1980

DIVISION I

PART 1—GENERAL REMARKS

I have the honour to submit for your information a report on the mining industry for 1980.

The value of the mineral output of Western Australia (including gold, coal and petroleum) was $2 620·489 million an increase of $485·75 million or 22·8 per cent over the previous year. The increase was due mainly to higher values for most minerals and in particular iron ore, petroleum, nickel and gold.

ROYALTIES

The royalty revenue for the year amounted to $79·642 million which is $21·636 million above the figure for 1979. Iron ore royalties accounted for 77·9 per cent of the total. Full details are shown in Table 2 of Part 2 of this Report.

IRON ORE

The quantity of iron ore for export and local use declined marginally from 85·1 million tonnes to 85 million tonnes in 1980. The value increased from $1 039·6 million to $1 158·4 million.

ALUMINA

Production of alumina by Alcoa of Australia (W.A.) from bauxite mined at Jarrahdale and Del Park decreased by ·28 million tonnes to 3·66 million tonnes the value of which was estimated at $436·01 million.

NICKEL

Nickel concentrate production declined slightly from 413 101 tonnes in 1979 to 396 534 tonnes in 1980. Higher nickel prices offset this decline with the value of the concentrates estimated at $303·75 million, an increase of $85·47 million over 1979.

In addition 86 565 tonnes of nickel ore was produced for sale and the value of this ore is estimated at $18·55 million.

PETROLEUM
(Crude Oil and Natural Gas)

Sales of crude oil produced during 1980 totalled 1·624 million kilolitres valued at $268·78 million compared with 1·421 million kilolitres valued at $140·99 million in 1979.

The large increase in value is a direct result of the Commonwealth Governments policy of pricing indigenous crude oil production on an import parity basis.

The Dongara, Mondarra and Yardarino Gas fields supplied a total of $59·69 million cubic metres of natural gas valued at $25·49 million to sales outlets in the Perth, Fremantle, Kwinana and Pinjarra areas.

GOLD

The estimated value of gold received at the Perth Mint during 1980 was $179·31 million an increase of $70·19 million over the 1979 value. The quantity of gold received was 10 801·166 kilograms which was 856·355 kilograms less than the 1979 figure.

The weighted average price obtained for Western Australian gold as recorded by the Department for 1980 computed to $516·37 per troy ounce compared to $291·90 in 1979.

During 1980 the world price of gold fluctuated from a high of $612 per ounce average for January to a low of $452 average for May, the year average price being estimated at $534.

The Telfer mine operated by Newmont Proprietary Limited was the States biggest producer contributing 4 280·069 kilograms of the State total of 10 801·166 kilograms. Details of gold production reported to the Department as distinct from that received at the Perth Mint are set out in Table 1 of Part 2 of this Report.

The quantity of auriferous ore treated during the year was 1 883 737 tonnes compared to 1 370 878 tonnes in 1979 and the average number of persons engaged in gold mining increased from 996 in 1979 to 1 480 in 1980.

COAL

Coal production from the Collie Coal Field during the year increased 416 240 tonnes over the 1979 figure.

Figures for the last three years are:—

	1978	1979	1980
Tonnes	2 403 503	2 735 230	3 151 470
Total Value	$28 642 245	$44 407 880	$60 717 341
Average value per tonne	$11·92	$16.24	$19.27
Average No. of workers	870	896	918
Proportion of deep mined coal	23·04%	21·64%	20·02%

OTHER MINERALS

Other minerals to realise production valued at more than a million dollars for the year were: Salt $37·5 million; Ilmenite $30·1 million; Rutile $23·3 million; Zircon $20·1 million; By-products of nickel mining Cobalt $13 million; Copper $4·8 million and Palladium $1·8 million; Tantalite $12·2 million; Tin $6·7 million; Leucoxene $5·5 million; Monazite $3·7 million; Limestone $1·8 million; Gypsum $1·1 million. Pig iron valued at $4·2 million was produced by the Wundowie Iron and Steel Industry.

OUTLOOK

The mining industry in Western Australia continued to expand during 1980 with the value of mineral production up 22·8 per cent on the 1979 total.

Increased prices were received for most minerals including iron ore, but quite substantial increases occurred in respect of gold, petroleum and tantalite.

The high price of gold has resulted in the expansion of existing mines and the re-opening of many old mines in former notable producing areas.

Exploration for gold, coal, uranium, petroleum, diamonds, tantalite continued throughout the State at a high level.

Overall the prospects for the mining industry in Western Australia are good, however, uncertainties in the world's economy indicate that a short term levelling of the growth rate of recent years may occur.

PART 2—COMPARATIVE STATISTICS

TABLE 1

SUMMARY

Mineral Production: Quantity and Value

	1979	1980	Variation	
IRON ORE—				
Tonnes	85 171 982	**84 971 629**	—	200 353
Value ($A)	$1 039 594 173	**$1 158 386 783**	+	$118 792 610
ALUMINA—				
Tonnes	3 945 445	**3 663 989**	—	281 456
Value ($A)	†$422 162 615	**†$436 014 961**	+	$13 852 346
NICKEL—				
Tonnes (Ore and Concentrates)	479 119	**483 099**	+	3 980
Value ($A)	$227 304 194	**$322 306 570**	+	$95 002 376
PETROLEUM—CRUDE OIL—				
Kilolitres	1 420 730	**1 624 748**	+	204 018
*Value ($A)	$140 987 361	**$268 782 192**	+	$127 794 831
GOLD—				
Reported to Department (Mine Production)—				
Ore Treated (Tonnes)	1 370 878	**1 883 737**	+	512 859
Gold (Kilograms)	11 582	**11 233**	—	349
Average Grade (grams per tonne)	8·45	**5·96**	—	2·49
Mint and Export (Realised Production)—				
Gold (Kilograms)	11 658	**10 801**	—	767
Estimated Value ($A) (including Overseas Gold Sales Premium)	$109 124 526	**$179 314 357**	+	$70 189 831
COAL—				
Tonnes	2 735 230	**3 151 470**	+	416 240
Value ($A)	$44 407 880	**$60 717 341**	+	$16 309 461
MINERAL BEACH SANDS—				
Tonnes	1 621 426	**1 713 989**	+	92 563
Value ($A)	$73 514 046	**$82 781 670**	+	$9 267 624
OTHER MINERALS—				
Value ($A)	$77 640 210	**$112 184 705**	+	$34 544 495
TOTAL ALL MINERALS—				
Value ($A)	$2 134 735 005	**$2 620 488 579**	+	$485 753 574

* Based on the price assessed from time to time by the Commonwealth Government for Barrow Island crude oil at Kwinana.

† Value based on the average Australian value of Alumina as published by the Bureau of Mineral Resources in the Australian Mineral Industry Review.

TABLE 1 (*a*)

Quantity and Value of Minerals other than Gold and Silver produced during 1979 *and* 1980
Western Australia

Mineral	1979		1980		Increase or Decrease for Year Compared with 1979	
	Quantity	Value	Quantity	Value	Quantity	Value
	Tonnes	$	Tonnes	$	Tonnes	$
Alumina (from Bauxite)	3 945 445	422 162 615	**3 663 989**	**436 014 691**	— 281 456	+ 13 852 076
Barytes	34 658	482 235	**26 602**	**650 042**	— 8 056	+ 167 807
Building Stone (Quartzite)	1 135	13 775	**1 535**	**19 230**	+ 400	+ 5 455
(Quartz)	1 674	46 994	**2 448**	**94 973**	+ 774	+ 47 979
(Spongolite)	152	2 268	**260**	**3 887**	+ 108	+ 1 619
Clays (Cement Clay)	21 348	53 369	**25 328**	**63 319**	+ 3 980	+ 9 950
(Fire Clay)	386 968	171 659	**364 608**	**146 990**	— 22 360	— 24 669
(White Clay—Ball Clay)	619	7 428	**1 131**	**11 094**	+ 512	+ 3 666
(Kaolin)	827	4 960	**163**	**978**	— 664	— 3 982
(Fullers Earth)	10 067	181 206	**11 407**	**204 325**	+ 1 340	+ 23 119
Coal	2 735 230	44 407 880	**3 151 470**	**60 717 341**	+ 416 240	+ 16 309 461
Cobalt (By-product of Nickel Mining)	216	2 660 628	**983**	**13 023 142**	+ 767	+ 10 362 514
Copper (By-product of Nickel Mining)	1 741	2 256 476	**3 132**	**4 751 650**	+ 1 391	+ 2 495 174
Dolomite	585	3 510	....	....	— 585	— 3 510
	Carats		Carats		Carats	
Emeralds (cut)	1 205	7 230	**13 000**	**78 000**	+ 11 795	+ 70 770
	Tonnes		Tonnes		Tonnes	
Feldspar	1 929	82 999	**2 568**	**116 932**	+ 639	+ 33 933
Garnet Sands	42	3 480	**76**	**7 540**	+ 34	+ 4 060
Glass Sand	278 091	425 288	**129 367**	**39 283**	— 148 724	— 386 005
Gypsum	243 210	966 783	**293 370**	**1 126 629**	+ 50 160	+ 159 846
Iron Ore (Pig Iron Recovered)	54 181	4 767 928	**61 327**	**4 241 104**	+ 7 146	— 526 824
(Exported and locally used)	78 941 664	916 075 194	**84 952 689**	**1 157 998 681**	+ 6 011 025	+ 241 923 487
(Pellets)	6 230 318	123 518 979	**18 940**	**388 102**	— 6 211 378	— 123 130 877
Limestone	679 596	1 560 229	**607 812**	**1 792 235**	— 71 784	+ 232 006
Manganese (Metallurgical Grade)	1 395	24 427	**1 693**	**36 738**	+ 298	+ 12 311
Mica	310	65 773	**352**	**79 225**	+ 42	+ 13 452
Mineral Beach Sands (Ilmenite)	1 143 286	27 699 090	**1 256 720**	**30 084 556**	+ 113 434	+ 2 385 466
(Monazite)	17 352	4 033 271	**10 978**	**3 684 252**	— 6 374	— 349 019
(Rutile)	94 351	19 887 292	**91 667**	**23 292 830**	— 2 684	+ 3 405 538
(Leucoxene)	29 196	3 919 851	**26 911**	**5 545 374**	— 2 285	+ 1 625 523
(Zircon)	337 197	17 920 552	**327 692**	**20 142 466**	— 9 505	+ 2 221 914
(Xenotime)	44	53 990	**21**	**32 192**	— 23	— 21 798
Nickel Concentrates	413 101	218 281 967	**396 534**	**303 751 597**	— 16 567	+ 85 469 630
Nickel Ore	66 018	9 022 227	**86 565**	**18 554 973**	+ 20 547	+ 9 532 746
Ochre	222	3 772	**53**	**897**	— 169	— 2 875
	kg		kg		kg	
Palladium (By-product of Nickel Mining)	214	625 772	**328**	**1 834 614**	+ 114	+ 1 208 842
Platinum (By-product of Nickel Mining)	86	862 865	**64**	**954 184**	— 22	+ 91 319
	kls		kls		kls	
Petroleum—Crude Oil (kilolitres)	1 420 730	140 987 361	**1 624 748**	**268 782 192**	+ 204 018	+ 127 794 831
	$m^3 10^3$		$m^3 10^3$		$m^3 10^3$	
Natural Gas ($m^3 10^3$)	836 175	19 953 906	**859 688**	**25 494 035**	+ 23 513	+ 5 540 129
	Tonnes		Tonnes		Tonnes	
Condensate	2 368	N.A.	**2 435**	N.A.	+ 67	N.A.
Salt	3 731 854	27 024 382	**3 680 844**	**37 553 115**	— 51 010	+ 10 528 733
	kg		kg		kg	
Semi-precious Stones	4 973	9 600	**3 012**	**8 982**	— 1 961	— 618
	Tonnes		Tonnes		Tonnes	
Talc	110 359	N.A.	**113 211**	N.A.	+ 2 852	N.A.
Tanto/Columbite Ores and Concentrates	172	7 454 069	**159**	**12 233 116**	— 13	+ 4 779 047
Tin Concentrates	695	7 542 231	**558**	**6 721 875**	— 137	— 820 356
Vermiculite	....	....	**159**	**1 590**	+ 159	+ 1 590
		2 025 235 511		**2 440 278 971**		+ 415 043 460

TABLE 1 (*b*)

Quantity and Value of Gold and Silver received at the Perth Mint during the years 1979 *and* 1980

Mineral	1979		1980		Increase or Decrease for Year Compared with 1979	
	Quantity	Value	**Quantity**	**Value**	Quantity	Value
	kg	$	kg	$	kg	$
Gold	*11 657·521	109 124 526	***10 801·166**	**179 314 357**	— 856·355	+ 70 189 831
Silver	*1 856·650	374 968	***2 049·809**	**895 251**	+ 193·159	+ 520 283
Total		109 499 494		**180 209 608**		+ 70 710 114
Grand Total		2 134 735 005		**2 620 488 579**		+485 753 574

* Includes gold and silver contained in gold-bearing and silver-bearing material exported.

TABLE 2

ROYALTIES

Mineral	Royalty Collected		Increase or Decrease Compared with 1979
	1979	**1980**	
	$	$	$
Alumina	2 498 926.32	**4 659 327.03**	+ 2 160 400.71
Amethyst	31.83	**31.24**	— .59
Barytes	1 605.46	**1 315.42**	— 290.04
Building Stone	384.94	**446.40**	+ 61.46
Chalcedony	8.10	**.07**	— 8.03
Chrysoprase	10.00	....	— 10.00
Clay	24 310.33	**23 866.21**	— 444.12
Coal	59 437.81	**81 295.91**	+ 21 858.10
Cobalt	16 964.15	**35 529.52**	+ 18 565.37
Dolomite	29.25	....	— 29.25
Emeralds	65.80	**240.00**	+ 174.20
Felspar	97.45	**140.58**	+ 43.13
Fullers Earth	....	**1 056.42**	+ 1 056.42
Glass Sand	14 716.27	**4 980.13**	— 9 736.14
Gold	....	**10.00**	+ 10.00
Gypsum	11 078.61	**13 239.47**	+ 2 160.86
Heavy Mineral Sands concentrate	825.00	....	— 825.00
Ilmenite	355 468.20	**497 624.16**	+ 142 155.96
Iron Ore	47 124 898.18	**62 027 689.47**	+ 14 902 791.29
Leucoxene	63 495.98	**80 633.12**	+ 17 137.14
Limestone	26 181.51	**30 577.07**	+ 4 395.56
Manganese	179.82	**265.65**	+ 85.83
Mica	238.87	**471.47**	+ 232.60
Monazite	75 031.89	**48 508.30**	— 26 523.59
Moss Opal	10.93	**2.36**	— 8.57
Natural Gas	973 278.19	**1 242 650.01**	+ 269 371.82
Natural Gas (Condensate)	7 323.13	**14 643.95**	+ 7 320.82
Nickel	2 118 367.27	**3 556 529.68**	+ 1 438 162.41
Ochre	17.65	**2.65**	— 15.00
Oil (Crude)	3 586 455.13	**5 829 563.23**	+ 2 243 108.10
Palladium	4 926.50	**1 814.55**	— 3 111.95
Platinum	1 819.84	**1 859.13**	+ 39.29
Rutile	336 734.27	**633 282.61**	+ 296 548.34
Salt	242 185.52	**209 997.70**	— 32 187.82
Talc	11 330.58	**15 430.45**	+ 4 099.87
Tanto-Columbite	20 810.56	**54 535.54**	+ 33 724.98
Tin	95.22	**137.30**	+ 42.08
Vermiculite	....	**7.25**	+ 7.25
Xenotime	....	**1 723.66**	+ 1 723.66
Zircon	428 334.12	**572 580.36**	+ 144 246.24
Total	58 005 674.68	**79 642 008.07**	+ 21 636 333.39

TABLE 3

Gold production reported to the Mines Department for every goldfield, the percentage for the several goldfields of the total reported and the average yield in grams per tonne of ore treated

Goldfield	Reported Yield		Percentage for each Goldfield		*Average Yield per tonne of ore treated	
	1979	**1980**	1979	**1980**	1979	**1980**
	kg	**kg**	Per Cent.	**Per Cent.**	Grams	**Grams**
Kimberley	.028	**3.287**	....	**.03**	2.1	....
West Kimberley	....	....	....	....	....	....
Pilbara	5 310.123	**4 312.577**	45.85	**38.39**	12.06	**8.97**
West Pilbara	....	**40.098**	....	**.36**	....	....
Ashburton	....	....	....	....	....	....
Gascoyne	....	**4.557**	....	**.04**	....	**17.86**
Peak Hill	8·731	**6·324**	·08	**·06**	·4	**1·36**
East Murchison	·753	**27·121**	·01	**·24**	3·1	**17·36**
Murchison	41·981	**107·600**	·36	**·96**	6·5	**·70**
Yalgoo	8·050	**9·434**	·07	**·08**	23·5	**13·07**
Mount Margaret	43·015	**133·382**	·37	**1·19**	4·7	**6·23**
North Coolgardie	34·926	**70·704**	·30	**·63**	5·6	**7·54**
Broad Arrow	34·413	**45·175**	·30	**·40**	3·3	**5·38**
North-East Coolgardie	2·522	**6·290**	·02	**·06**	2·8	**3·84**
East Coolgardie	3 479·699	**3 474·951**	30·04	**30·93**	4·7	**3·72**
Coolgardie	268·929	**491·129**	2·32	**4·37**	18·9	**4·25**
Yilgarn	72·471	**112·481**	·63	**1·00**	3·7	**2·51**
Dundas	2 272·397	**2 357·798**	19·62	**20·99**	16·5	**12·04**
Phillips River	3·950	**3·012**	·03	**·03**	22·0	**10·87**
South West Mineral Field	....	....	....	....	....	....
State Generally	....	**27·023**	....	**·24**	....	....
	11 581·988	**11 232·943**	100·00	**100·00**	8·4	**5·85**

* Averages exclude alluvial and dollied gold, but include gold won by treatment of sands.

TABLE 4

Total Coal Output from Collie River Mineral Field, 1979 *and* 1980, *Estimated Value therefrom, Average Number of Men Employed and Output per man.*

Year	Total Output	Estimated Value	Men Employed			Output per Man Employed		
			Above Ground	Under Ground	Open Cuts	In Open Cuts	Under Ground	Above and Under Ground
Deep Mining—	Tonnes	$A	No.	No.	No.	Tonnes	Tonnes	Tonnes
1979	591 950	12 288 410	108	320	....	....	1 850	1 383
1980	630 760	14 545 006	100	321	....	....	1 965	1 498
Open Cut Mining—								
1979	2 143 280	32 119 470	....	....	468	4 580	....	....
1980	2 520 710	46 172 335	....	....	497	5 072	....	....
Totals—								In All Mines
1979	2 735 230	44 407 880	108	320	468	....	....	3 053
1980	3 151 470	60 717 341	100	321	497	....	....	3 433

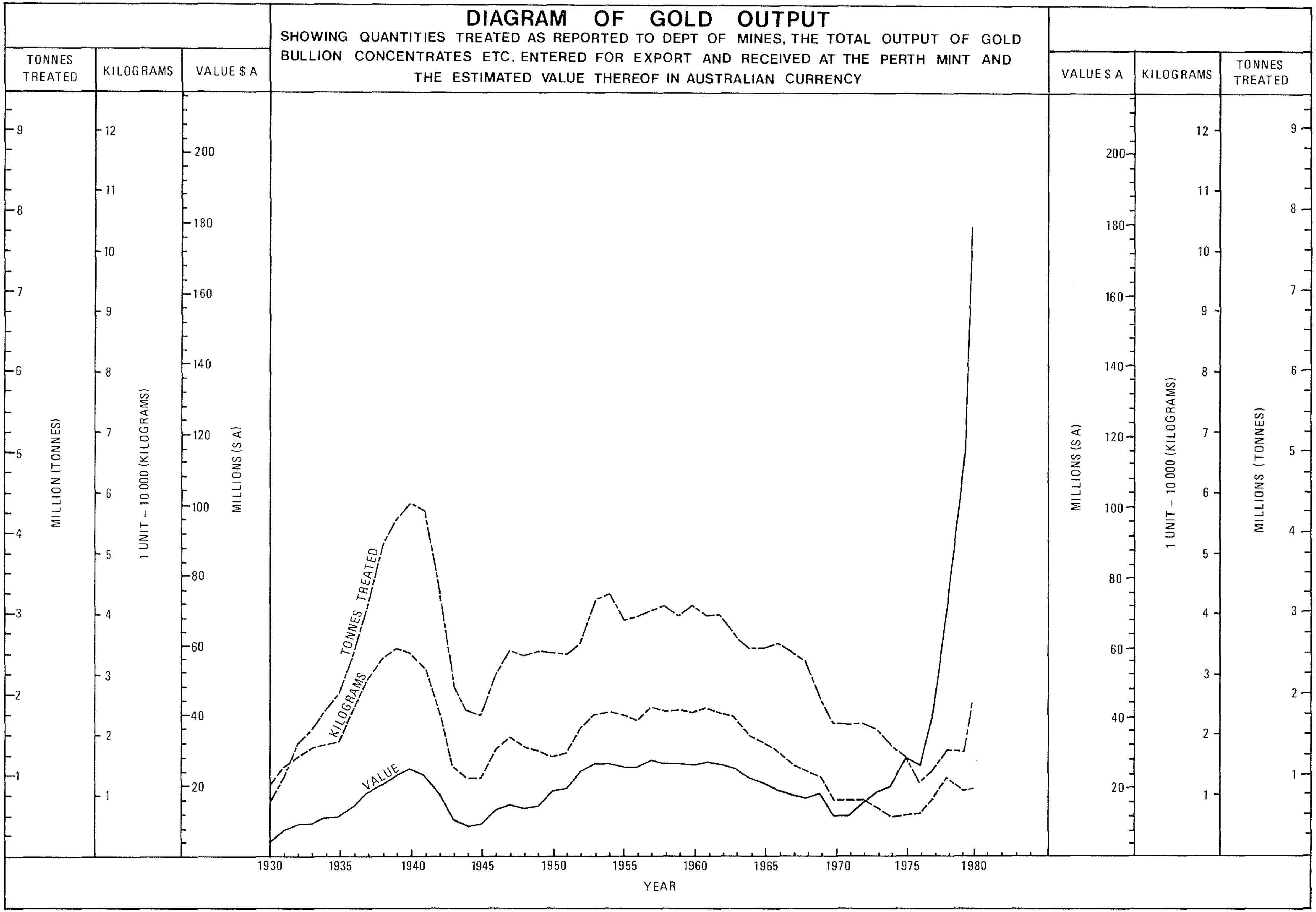
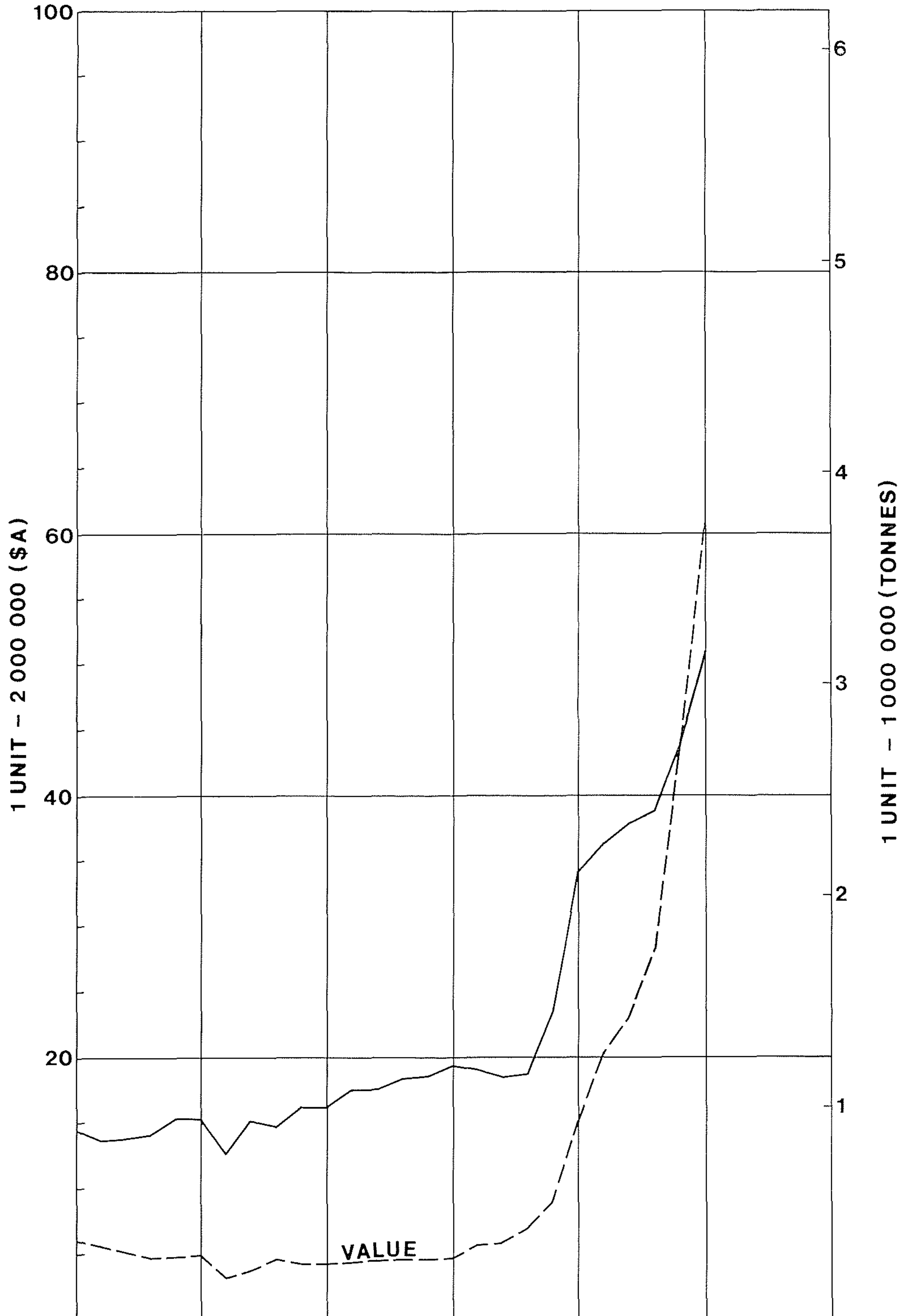


DIAGRAM OF GOLD OUTPUT
SHOWING QUANTITIES TREATED AS REPORTED TO DEPT OF MINES, THE TOTAL OUTPUT OF GOLD BULLION CONCENTRATES ETC. ENTERED FOR EXPORT AND RECEIVED AT THE PERTH MINT AND THE ESTIMATED VALUE THEREOF IN AUSTRALIAN CURRENCY
TONNES TREATED
KILOGRAMS
VALUE $ A
MILLION (TONNES)
1 UNIT – 10 000 (KILOGRAMS)
MILLIONS ($ A)
MILLIONS (TONNES)
TONNES TREATED
KILOGRAMS
VALUE
YEAR
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980

GRAPH OF COAL OUTPUT

SHOWING QUANTITIES AND VALUES AS REPORTED TO DEPT. OF MINES



YEAR	VALUE $A	TONNES
1955	6 264 148	918 298
1956	5 595 012	843 330
1957	5 105 310	852 120
1958	4 560 398	884 860
1959	4 713 064	932 159
1960	4 878 390	937 197
1961	3 260 518	778 030
1962	3 961 556	933 864
1963	3 970 120	916 980
1964	4 678 934	1 003 268
1965	4 409 972	1 009 691
1966	4 562 087	1 078 126
1967	4 765 503	1 079 199
1968	4 816 725	1 104 831
1969	4 804 089	1 108 033
1970	5 827 291	1 216 957
1971	5 734 353	1 190 429
1972	5 907 162	1 167 544
1973	7 048 726	1 171 069
1974	9 144 982	1 446 048
1975	15 073 668	2 113 979
1976	20 468 874	2 268 728
1977	23 172 093	2 358 006
1978	28 642 245	2 403 503
1979	44 407 880	2 735 230
1980	60 717 341	3 151 470
1981		
1982		
1983		
1984		
1985		

GRAPH OF TREND IN COAL OUTPUT

SHOWING COMPARISON OF ANNUAL QUANTITY AND PERCENTAGES BETWEEN DEEP AND OPEN CUT MINING

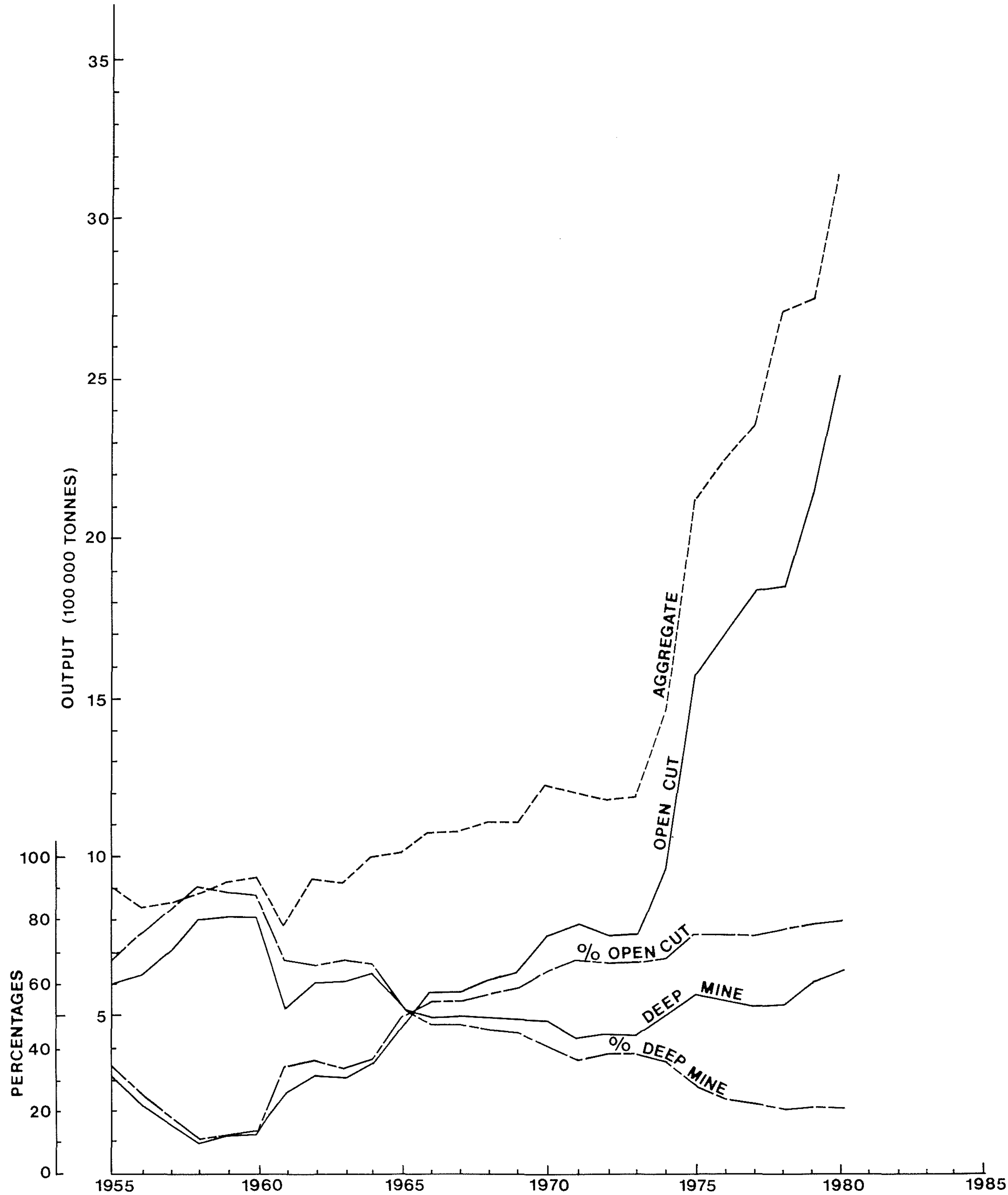


TABLE 5

MINING ACT, 1904

LEASES AND OTHER HOLDINGS UNDER VARIOUS ACTS RELATING TO MINING

Total Number and Area of Mining Tenements applied for during 1980 *and in force as at* 31*st December*, 1980 (*compared with* 1979)

	Applied for				In Force			
	1979		**1980**		1979		**1980**	
	No.	Hectares	No.	Hectares	No.	Hectares	No.	Hectares
Gold—								
Gold Mining Leases	1 510	12 788	**5 058**	**44 938**	2 719	22 022	**3 173**	**26 425**
Dredging Claims	56	4 036	**446**	**32 589**	20	554	**58**	**2 864**
Prospecting Areas	610	5 051	**886**	**7 589**	481	4 004	**478**	**3 925**
Temporary Reserves	20	2 379	**267**	**29 781**	71	8 252	**320**	**36 271**
Totals	2 196	24 244	**6 657**	**114 897**	3 291	34 832	**4 029**	**69 485**
Coal—								
Coal Mining Leases	749	89 758	**6 789**	**764 457**	161	16 118	**273**	**32 479**
Prospecting Areas	10	8 727	**15**	**12 855**	3	645	**1**	**1 199**
Temporary Reserves	156	2 408 227	**200**	**3 382 487**	117	1 664 599	**229**	**3 968 013**
Totals	915	2 506 712	**7 004**	**4 159 799**	281	1 681 362	**503**	**4 001 691**
Other Minerals—								
Mineral Leases	9	73	**446**	**46 788**	930	90 994	**759**	**72 465**
Dredging Claims	705	75 905	**222**	**37 889**	284	14 422	**419**	**27 819**
Mineral Claims	8 808	987 179	**13 860**	**1 568 840**	13 952	1 427 543	**14 551**	**1 524 879**
Prospecting Areas	9	87	....	....	14	118	**7**	**59**
Temporary Reserves	366	5 653 251	**280**	**4 324 868**	630	9 683 213	**620**	**9 339 392**
Totals	9 897	6 716 495	**14 808**	**5 978 385**	15 810	11 216 290	16 356	**10 964 614**
Other Holdings—								
Miners' Homestead Leases	2	192	**1**	**2**	314	12 810	**249**	**10 932**
Miscellaneous Leases	9	73	**12**	**88**	179	756	**99**	**913**
Residential Areas	....	....	....	....	45	16	**43**	**17**
Business Areas	....	....	**1**	**1**	16	7	**16**	**6**
Machinery Areas	3	5	**5**	**9**	22	30	**24**	**34**
Tailings Areas	1	2	....	....	24	60	**21**	**32**
Garden Areas	18	24	**5**	**7**	79	124	**77**	**120**
Quarrying Areas	54	485	**81**	**652**	272	2 423	**301**	**2 527**
Water Rights	4	8	**27**	**12 329**	84	241	**101**	**3 821**
Licenses to Treat Tailings	440	....	**876**	....	157	....	**338**	....
Totals	531	1 075	**1 008**	**13 088**	1 092	16 467	**1 269**	**18 402**
Grand Totals	13 539	9 248 240	**29 477**	**10 266 169**	20 474	12 948 951	**22 157**	**15 054 192**

TABLE 5 (*a*)

SPECIAL ACTS

Leases applied for during 1980 *and in force as at* 31*st December*, 1980 (*Compared with* 1979)

	Applied for				In Force			
	1979		**1980**		1979		**1980**	
	No.	Hectares	No.	Hectares	No.	Hectares	No.	Hectares
Bauxite	....	....	**1**	**1 111 882.00**	7	1 269 618.00	**7**	**1 269 618.00**
Iron	....	....	....	....	10	365 361.00	**10**	**365 361.00**
Salt	....	....	....	....	5	257 465.96	**5**	**257 465.96**
Other	1	871.14	....	....	4	222 671.54	**4**	**222 671.54**
Totals	1	871.14	**1**	**1 111 882.00**	26	2 115 116.50	**26**	**2 115 116.50**

TABLE 5 (*b*)

PETROLEUM ACTS

Permits, Licences and Leases applied for during 1980 *and in force as at* 31*st December*, 1980 (*Compared with* 1979)

Holding	Applied for				In Force			
	1979		**1980**		1979		**1980**	
	No.	Blocks	No.	Blocks	No.	Blocks	No.	Blocks
Onshore—								
Petroleum Act, 1967—								
Exploration Permits	69	9 052	**50**	**8 081**	35	2 816	**66**	**8 350**
Production Licences	....	....	....	....	2	9	**2**	**9**
Petroleum Leases (Barrow Island)	....	....	....	....	1	8	**1**	**8**
Totals	69	9 052	**50**	**8 081**	38	2 833	**69**	**8 367**
Offshore—								
Petroleum (Submerged Lands) Act 1967—								
Exploration Permits	21	3 629	**22**	**1 674**	45	8 106	**49**	**8 001**
Production Licences	....	....	....	....	....	....	**6**	**27**
Petroleum Leases (Barrow Marine)	....	....	....	....	1	12	**1**	**12**
Totals	21	3 629	**22**	**1 674**	46	8 118	**56**	**8 040**
Grand Totals	90	12 681	**72**	**9 755**	84	10 951	**125**	**16 407**

(A block contains between approximately 75 km^2 to 85 km^2 and the numbers given above include part blocks)

Holding	Applied for				In Force			
	1979		**1980**		1979		**1980**	
	No.	Km	No.	Km	No.	Km	No.	Km
Onshore—								
Petroleum Pipelines Act, 1969—								
Pipeline Licences	....	....	....	....	5	444.87	**5**	**444.87**
Totals	....	....	....	....	5	444.87	**5**	**444.87**
Offshore—								
Petroleum (Submerged Lands) Act, 1967—								
Pipeline Licences	....	....	**1**	**134**	....	....	....	....
Totals	....	....	**1**	**134**	....	....	....	....
Grand Totals	....	....	**1**	**134**	5	444.87	**5**	**444.87**

TABLE 5 (*c*)

MINING ACT, 1904

Leases in Force as at 31st December, 1980 in each Goldfield, Mineral Field or District

Goldfield, Mineral Field or District	Gold Mining Leases		Mineral Leases		Miner's Homestead Leases		Miscellaneous Leases		Coal Mining Leases	
	No.	Hectares	No.	Hectares	No.	Hectares	No.	Hectares	No.	Hectares
Ashburton	4	38.72	12	1 456.80	....	....	....	....	....	....
Black Range	33	282.98	4	453.12	....	....	....	....	....	....
Broad Arrow	85	640.59	....	....	....	....	....	....	....	....
Bulong	50	439.38	....	....	....	....	....	....	....	....
Collie	....	....	....	....	....	....	1	64.70	65	7 516.51
(Private Property)	....	....	....	....	....	....	....	....	2	210.43
Coolgardie	195	1 528.24	371	41 439.08	13	678.63	3	14.70	....	....
Cue	97	897.79	2	50.07	....	....	....	....	....	....
Day Dawn	39	347.52	....	....	1	8.09	1	2.02	....	....
Dundas	514	4 565.07	5	600.00	....	....	11	202.68	....	....
East Coolgardie	417	3 064.89	5	463.45	55	750.38	45	401.76	....	....
Gascoyne	8	66.99	....	....	....	....	....	....	....	....
Greenbushes	....	....	75	3 969.39	6	168.14	....	....	....	....
(Private Property)	....	....	1	8.09	....	....	....	....	....	....
Kanowna	61	490.59	5	229.41	1	202.53	....	....	....	....
Kimberley	16	131.89	....	....	....	....	....	....	....	....
Kunanalling	45	363.24	....	....	1	203.34	1	0.25	....	....
Kurnalpi	14	135.63	....	....	....	....	....	....	....	....
Lawlers	52	562.58	....	....	4	441.08	....	....	....	....
Marble Bar	227	1 825.72	62	6 965.35	....	....	10	74.73	....	....
Meekatharra	209	2 115.96	....	....	6	471.58	....	....	....	....
Menzies	72	589.15	1	28.73	1	8.09	....	....	....	....
Mount Magnet	241	1 938.10	....	....	....	....	....	....	....	....
Mount Malcolm	83	660.80	5	599.70	6	307.53	1	0.30	....	....
Mount Margaret	80	725.46	59	6 011.61	3	12.53	....	....	....	....
Mount Morgans	52	427.66	....	....	....	....	....	....	....	....
Niagara	40	331.98	....	....	....	....	....	....	....	....
Northhampton	....	....	8	626.47	....	....	....	....	....	....
(Private Property)	....	....	....	....	....	....	....	....	....	....
Nullagine	26	170.38	....	....	1	8.89	1	9.71	....	....
Peak Hill	33	236.13	5	270.31	4	99.94	....	....	....	....
Phillips River	3	12.13	24	1 297.39	104	5 661.32	1	2.42	....	....
(Private Property)	....	....	....	....	....	....	....	....	....	....
South West	....	....	....	....	....	....	1	2.02	48	4 954.93
(Private Property)	3	20.30	18	1 367.72	....	....	....	....	30	3 426.62
Ularring	31	260.77	....	....	....	....	....	....	....	....
West Kimberley	....	....	36	1 147.81	....	....	6	52.64	128	16 370.71
West Pilbara	28	253.01	27	1 460.44	2	4.44	8	59.85	....	....
Wiluna	52	463.90	23	2 657.66	17	1 538.42	2	1.20	....	....
Yalgoo	59	440.42	5	421.96	1	9.00	....	....	....	....
Yerilla	89	750.01	....	....	....	....	....	....	....	....
Yilgarn	199	1 503.50	10	940.11	23	358.42	7	23.97	....	....
(Private Property)	16	143.36	....	....	....	....	....	....	....	....
Outside Proclaimed	....	....	....	....	....	....	....	....	....	....
Totals	3 173	26 424.84	759	72 464.67	249	10 932.35	99	912.95	273	32 479.20

	No.	Hectares
Gold Mining Leases on Crown Land	3154	26 261.18
Gold Mining Leases on Private Property	19	163.66
Mineral Leases on Crown Land	740	71 088.86
Mineral Leases on Private Property	19	1 375.81
Miner's Homestead Leases on Crown Land	249	10 932.35
Other Leases on Crown Land	99	912.95
Other Leases on Private Property	....	....
Coal Mining Leases on Crown Land	241	28 842.15
Coal Mining Leases on Private Property	32	3 637.05

TABLE 5 (*d*)

MINING ACT, 1904

Claims and Authorised Holdings in Force at 31*st December,* 1980 *in each Goldfield, Mineral Field or District*

Goldfield, Mineral Field or District	Prospecting Areas		Dredging Claims		Mineral Claims		Residence Areas		Business Areas		Machinery Areas		Tailings Claims		Garden Areas		Quarrying Areas		Water Rights	
	No.	Hectares	No.	Hectares	No.	Hectares	No.	Hectares	No.	Hectares	No.	Hectares	No.	Hectares	No.	Hectares	No.	Hectares	No.	Hectares
Ashburton	5	48·40	....	....	480	51 671·34	....	....	....	....	....	....	....	....	....	....	3	18·31	....	....
Black Range	22	188·36	....	....	192	20 421·21	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Broad Arrow	50	444·54	....	....	121	13 799·46	....	....	....	....	....	....	....	....	....	....	3	1·64	1	8·00
Bulong	9	82·50	....	....	78	8 831.00	....	....	....	....	....	....	....	....	....	....	2	19·22	....	....
Collie	....	....	....	....	....	....	....	....	....	....	1	2·00	....	....	....	....	1	4·21	....	....
(Private Property)	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Coolgardie	86	680.37	....	....	264	25 998·55	3	1·20	....	....	1	2·02	....	....	7	11·73	32	266·35	8	46·44
Cue	35	304·37	....	....	238	24 443·31	1	0·10	....	....	....	....	....	....	....	....	1	9·71	....	....
Day Dawn	8	72·48	....	....	27	3 167.33	....	....	....	....	....	....	....	....	4	8·08	....	....	....	....
Dundas	8	55·25	....	....	113	8 651·33	....	....	....	....	....	....	1	2·02	....	....	2	19·36	2	4·85
East Coolgardie	22	198·33	....	....	146	15 796·39	28	11·20	....	....	1	0·80	10	18·57	12	21·80	14	105·11	12	13·29
Gascoyne	1	9·70	2	165·91	579	56 946·40	....	....	....	....	....	....	....	....	....	....	1	8·09	....	....
Greenbushes	....	....	....	....	2	12·13	....	....	....	....	....	....	....	....	8	13·59	....	....	2	13·50
Kanowna	24	190·33	....	....	133	14 548·82	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Kimberley	....	....	32	3 378.39	1 392	158 746·87	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Kunanalling	17	129·19	....	....	6	619·00	....	....	....	....	....	....	....	....	....	....	....	....	1	1·00
Kurnalpi	11	98·60	....	....	48	5 538·60	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Lawlers	5	47·80	....	....	580	62 368·65	....	....	....	....	....	....	....	....	....	....	29	282·10	....	....
Marble Bar	17	57·20	349	17 346·88	1 138	110 394·85	1	0·20	2	0·80	11	18·81	1	2·02	16	26·65	60	535·65	30	3 683·07
Meekatharra	33	269·48	4	393·63	190	22 122·83	....	....	....	....	....	....	....	....	....	....	....	....	3	2·84
Menzies	15	116·85	....	....	131	13 173·22	....	....	....	....	....	....	....	....	1	0·04	....	....	....	....
Mount Magnet	27	221·82	....	....	110	12 812·86	1	0·40	....	....	....	....	....	....	7	3·60	....	....	3	2·00
Mount Malcolm	14	132·34	....	....	426	46 092·78	....	....	....	....	....	....	1	2·00	7	10·48	2	19·20	2	0·80
Mount Margaret	3	25·79	....	....	351	38 864·68	....	....	....	....	....	....	....	....	1	2·02	3	29·04	1	0·40
Mount Morgans	6	35·12	....	....	262	29 858·22	....	....	....	....	....	....	....	....	....	....	....	....	1	0·40
Niagara	3	28·84	....	....	5	600·95	....	....	....	....	1	1·00	....	....	....	....	....	....	3	2·40
Northampton	....	....	....	....	52	3 186·06	....	....	....	....	....	....	....	....	....	....	....	....	....	....
(Private Property)	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Nullagine	5	39·51	19	1 933·40	457	36 405·19	....	....	....	....	1	0·40	3	1·60	1	0·20	....	....	11	10·67
Peak Hill	7	67·80	8	869·00	507	55 478·97	....	....	2	0·80	3	5·02	2	3·30	3	5·24	7	67·90	1	3·68
Phillips River	1	0·81	....	....	108	7 961·30	....	....	....	....	1	0·80	1	0·80	....	....	1	2·02	....	....
(Private Property)	....	....	....	....	30	2 966·60	....	....	....	....	....	....	....	....	....	....	....	....	....	....
South West	1	1 199·00	20	1 959·24	480	34 645·80	....	....	....	....	....	....	....	....	....	....	2	12·70	1	2·40
(Private Property)	....	....	....	....	887	74 712·57	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Ularring	2	14·56	....	....	23	2 331·01	....	....	....	....	1	0·40	2	1·61	....	....	....	....	3	1·60
West Kimberley	1	9·70	41	4 621·40	3 121	361 853·06	....	....	....	....	1	1·00	....	....	3	6·02	24	147·21	....	....
West Pilbara	1	1·82	2	15·37	439	42 056·73	4	1·60	6	2·40	....	....	....	....	4	7·67	110	954·65	9	16·94
Wiluna	5	38·81	....	....	418	48 580·76	....	....	....	....	....	....	....	....	....	....	....	....	1	0·40
Yalgoo	20	184·13	....	....	498	53 321·25	....	....	6	2·40	....	....	....	....	....	....	3	14·72	....	....
Yerilla	5	42·06	....	....	158	18 018·99	....	....	....	....	....	....	....	....	....	....	....	....	5	4·82
Yilgarn	18	147·54	....	....	355	37 417·09	6	0·65	....	....	2	2·01	....	....	3	2·57	1	9·71	1	1·66
(Private Property)	....	....	....	....	3	275·00	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Outside Proclaimed	....	....	....	....	3	189·38	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Totals	486	5 183·40	477	30 683·22	14 551	1 524 879·44	43	17·35	16	6·40	24	34·26	21	31·92	77	119·68	301	2 526·90	101	3 821·16

TABLE 6

MEN EMPLOYED

Average Number of Men employed in Mining during 1980

Goldfield	District	Gold	Other Minerals	Total
Kimberley	....	10	....	10
West Kimberley	....	....	555	555
Pilbara	Marble Bar	112	1 327	1 439
	Nullagine	4	....	4
West Pilbara	....	....	5 761	5 761
Ashburton	....	....	122	122
Gascoyne	....	2	8	10
Peak Hill	....	13	3 931	3 944
East Murchison	Lawlers	11	....	11
	Wiluna	....	....	....
	Black Range	18	....	18
Murchison	Cue	4	7	11
	Meekatharra	65	....	65
	Day Dawn	....	....	....
	Mt. Magnet	20	....	20
Yalgoo	....	22	2	24
Mt. Margaret	Mt. Morgans	27	....	27
	Mt. Malcolm	61	....	61
	Mt. Margaret	33	257	290
North Coolgardie	Menzies	30	....	30
	Ularring	12	....	12
	Niagara	4	....	4
	Yerilla	25	....	25
Broad Arrow	....	58	....	58
North East Coolgardie	Kanowna	9	....	9
	Kurnalpi	7	....	7
East Coolgardie	East Coolgardie	320	24	344
	Bulong	6	....	6
Coolgardie	Coolgardie	116	1 584	1 700
	Kunanalling	31	....	31
Yilgarn	....	107	144	251
Dundas	....	346	2	348
Phillips River	....	7	....	7
South West Mineral Field	....	....	3 928	3 928
Northampton Mineral Field	....	....	....	....
Greenbushes Mineral Field	....	....	201	201
Outside Proclaimed Goldfield	....	....	....	....
Collie Coalfield	....	....	918	918
Total—All Minerals	....	1 480	18 771	20 251

Minerals Other Than Gold	1980
Alumina	3 176
Barytes	23
Building Stone	7
Clays	21
Coal	918
Emeralds	7
Felspar	2
Garnet Sands	2
Glass Sand	8
Gypsum	15
Iron Ore	11 365
Limestone	28
Manganese	3
Mica	2
Mineral Beach Sands	635
Nickel	1 860
Petroleum (Crude Oil)	122
(Natural Gas)	9
Salt	254
Semi Precious Stones	10
Talc	40
Tin/Tantalite	264
	18 771

PART 3—STATE AID TO MINING

(A) STATE BATTERIES

At the end of the year there were 15 State Batteries including the Northampton gravity plant.

From inception to the end of 1980, gold, silver, tungsten, lead, copper, tantalite and garnet ores to the value of $61 152 635 have been treated at the State Batteries. $58 543 940 came from 4 168 952 tonnes of gold ore; $501 146 from 85 380 tonnes of tin ore; $97 674 from 5 544 tonnes of tungsten ore; $1 650 061 from 72 702·7 tonnes of lead ore; $11 932 from 224 tonnes of copper ore; $207 030 from 3 123 tonnes of tantalite ore; $131 001 from 3 740 tonnes of garnet ore; and silver valued at $9 851 from the cyanidation of gold tailings.

During the year 58 593·2 tonnes of gold ores were crushed for 474·403 kilograms of bullion estimated to contain 402·060 kilograms of fine gold equal to 6·86 grams per tonne. The average value of sands after amalgamation was 2·61 grams per tonne, making the average head value 9·47 grams per tonne. Cyanide plants produced 41·590 kilograms of fine gold giving a total estimated production for the year of 443·65 kilograms of fine gold valued at $7 616 799.

The working expenditure for all plants was $2 538 786 which does not include depreciation, interest or Superannuation. Since the inception of State Batteries, the Capital expenditure has been $2 232 329 made up of $1 505 663 from General Loan Funds, $641 850 from Consolidated Revenue Funds, $57 243 from Gold Mining Industry, and $27 573 from Assistance to Metalliferous Mining.

Head Office expenditure, including Workers' Compensation Insurance and Pay Roll Tax was $345 291 compared with $282 409 for 1979.

The actual expenditure from inception to the end of 1980 exceeds revenue by $18 163 437.

(B) PROSPECTING SCHEME

At the end of 1980 there was no one in receipt of prospecting assistance as the assistance to Mr. A. Bernardi the one remaining man on the scheme was officially cancelled as from December 1979 on July 23, 1980.

Two further applications for assistance were received during 1980 being Neil Eric Easterbrook and Raymond John Francis. Both applications were subsequently refused on January 5, 1981.

Total expenditure for 1980 was $77·50 with no refunds during the year.

Progressive total figures since the inception of the scheme are:—

Expenditure—$1 057 251.50
Refunds—$205 089
Ore Crushed—131 245 tonnes
Gold Won—1 813·275 kilograms

(C) GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

In addition to information given directly to mining companies and individuals, the Survey has published comprehensive studies of tin and copper mineralization in the State, a report on the lead-zinc mineralization of the Bangemall Basin, and a detailed geophysical study of the Carnarvon Basin.

Forty-one rolls of microfilm were added to the open-file collection of mineral exploration reports, and 18 packages of microfilm data to the open-file petroleum reports.

A field excursion to recently mapped areas of the Gascoyne Province was well attended by company personnel.

The Kalgoorlie Regional Office continues to provide access to the open-file exploration reports as well as information and advice in that area.

Details of the Geological Survey's activities are given in Division IV of this Annual Report.

PART 4—GOVERNMENT CHEMICAL LABORATORIES

The Laboratories continued to provide professional and technical chemical, metallurgical and mineralogical consultancy and service to Government Departments and instrumentalities, to private industry and the general public. The varied functions included assistance to the mining industry, to agricultural research, water quality assessment, control and treatment, food quality, forensic chemical support to the police, environments and materials testing. Research and development, essential to progress and efficiency in each area of operation, was hampered by the load of service work.

Details of the breadth of work carried out in the various divisions of the Laboratories can be found in Division VII of this report.

Again there have been an appreciable increase in the number of samples received in the order of 11 per cent over 1979. The major increases were from the Department of Agriculture, the Police Department and samples in doping control in sport.

PART 5—EXPLOSIVES BRANCH

The functions of the Explosives and Dangerous Goods Branch are to ensure that the quality and use of explosives and the modes of transport and storage of explosives and dangerous goods comply with statutory safety requirements.

Throughout the year a total of 797 licences and 1 505 permits were issued for various purposes related to explosives import, manufacture, storage, conveyance, sale and use.

Both general and professional officers of the Branch made 5 375 inspections during the year to give advice on the safe storage of dangerous goods at licensed and non-licensed premises and also checked vehicles conveying flammable liquids in bulk through the State. A total of 5 095 licences were issued for the storage of flammable liquids.

PART 6—MINE WORKERS' RELIEF ACT AND MINERS' PHTHISIS ACT

Under arrangements with this Department, the State Public Health Department continued the periodic X-ray examination of mine workers throughout the year.

A total of 4 927 examinations were made under the Mine Workers' Relief Act. Of the examinations under the Mine Workers' Relief Act, 4 030 were new applicants and 494 were re-examinees.

Compensation under the Miners' Phthisis Act paid during the year was $3 718 compared with $4 087 in the previous year. The number of beneficiaries under the Act as at 31/12/1980 was 14, being 2 ex-miners, and 12 widows.

PART 7—SURVEYS AND MAPPING BRANCH

The staff in all Branches of the Division faced enormous pressures from all sections of the industry for services of many kinds. Map sales outstripped all previous records, applications for tenements and temporary reserves could not be processed during normal hours and overtime programmes were introduced. The need for more base plans and mapping work for Geological Survey also had to go into overtime to meet the demand, all resulting in further pressures on the Reprographic section for printing and processing. Requests for survey remained high and the section found it difficult to issue sufficient instructions. Overall, some staff shortages were evident, and the need for re-organisation of the Division became apparent.

PART 8—STAFF

Members of the staff in Perth and the Outstations have carried out their duties during the year under review in a most satisfactory manner and I am pleased to record my sincere appreciation of work done by all concerned.

In this summary I have referred only to specific items of the Department's activities.

Detailed reports of Branches are contained in Divisions II to IX.

D. R. KELLY, B.E. (Hons), Ph.D., M.I.E. Aust.
Under Secretary for Mines.

Department of Mines,
Perth

DIVISION II

Report of the State Mining Engineer for the Year 1980

Under Secretary for Mines

For the information of the Hon. Minister for Mines, I submit the Annual Report for the State Mining Engineer's Branch. Activities in the Perth, Kalgoorlie, Karratha and Collie inspectorates are covered in separate reports by the Mining Engineer—Senior Inspector of Mines for that inspectorate. Also included are reports by the Principal Senior Inspector, the Drilling Engineer and the Secretaries to the various Boards of Examiners and the Ventilation Board.

As part of the Statewide ground water investigation the Drilling Section completed 3 367 metres of exploratory drilling at sites at Salvado, Quindalup, Dwellingup, Bunbury and Lake Clifton. Drilling was continued at Manjimup as part of a study into the effects of logging in the area and at Canning Vale on effluent disposal. In addition, 1 818 metres of water well drilling was completed at widely spaced centres such as Warburton, Laverton, Guilderton, Gosnells, Dardanup, Noonkanbah and Go Go. Borehole inspection using the Section's television camera unit has proved popular during the year as it is believed that this type of equipment is not readily available in Western Australia.

The value of mineral production (excluding petroleum and construction materials) at $2 326 173 069 was 18 per cent higher than the value of output for the previous year. The sale of just over 85 million tonnes of iron ore at $1 162 million represented 50 per cent of the total value of mineral production for the year.

Alumina production valued at $436 million had the second highest value of production followed by nickel at $322 million, gold at $179 million and coal at $61 million. The beach sand mining industry total return of $83 million was from the sales of ilmenite, rutile, leucoxene, zircon, monazite and xenotime.

ACCIDENTS

There were 5 fatal and 541 serious accidents reported during the year in a workforce totalling 23 808 persons. The accident rate per 1 000 men employed was thus 0·21 for fatal accidents and 22·72 for serious accidents. In the previous year there were 7 fatal and 451 serious accidents.

STAFF

Retirements—

Sullivan, T. M., Workmen's Inspector of Mines	30/6/80
Spencer, A. D., Workmen's Inspector of Mines	10/7/80

Resignations—

Sanford, A. W., Workmen's Inspector of Mines	29/2/80
Fraser, R. D., Mining Engineer—Special Inspector of Mines (Ventilation)	18/4/80
Cheah, Y. C., Ventilation Officer	15/8/80
Duke, M. H., Engineer	22/8/80

Promotions—

Austin, D. H., Mining Engineer-District Inspector of Mines (Ventilation)	3/7/80

Appointments—

Boucaut, J. P., Mining Engineer—District Inspector of Mines	2/1/80
Mather, K. E., Workmen's Inspector of Mines	4/3/80
Tan, B. C., Engineer	5/5/80
Strachan, R. A., Workmen's Inspector of Mines	17/7/80
Lenigas, D. A., Ventilation Officer	1/12/80

J. K. N. LLOYD,
State Mining Engineer.

MINERAL AND METAL PRODUCTION ACCIDENT STATISTICS AND MINE INSPECTION

G. J. Dodge—Mining Engineer/Principal Senior Inspector of Mines

Comprehensive details of mining activity throughout the State are contained in the reports submitted by the Senior Inspectors of Mines located at Kalgoorlie, Karratha and Perth.

The following tables summarise the various mineral and metal production and mine development.

Table 1—Mineral and Metal Production
Table 2—Reported Mine Development
Table 3—Principal Gold Producers
Table 4—Overseas Iron Ore Exports
Table 5—Nickel Producers

ACCIDENT STATISTICS

Accident statistics are compiled from reports submitted by the Mining Industry to the District Inspectors of Mines and cover all classes of mining accidents associated with the mining and extraction of minerals, metals, rock and coal. They are presented as follows:

Diagram of Fatal Accidents—This diagram shows the number of fatal accidents per year since 1957.

Table A—*Serious accidents for* 1980—showing serious accidents segregated according to the nature of the injury, and the mining district in which the accident occurred.

Table B—*Accidents Segregated According to Mineral Mined and Processed*—showing all accidents (Fatal, Serious and Minor) segregated according to the mineral (including metal, rock and coal) mined and treated. Also shown, are the numbers of personnel employed in the mining of each mineral.

Table C—*Fatal and Serious Accidents Showing Causes and Districts*—a tabulation of fatal and serious accidents according to their cause, for each Mining District.

Summary Description of Fatal Accidents—A brief description of how, when and where each fatal accident occurred.

Graph No. 1—This graph shows the number of fatal accidents per 1 000 employees in the Metalliferous Mining Industry for the twenty-year period 1960–1980.

TABLE 1

Mineral and Metal Output (excluding Petroleum)

Mineral Production	1979		1980	
	Production	Value	Production	Value
	Tonne (t)	$A	Tonne (t)	$A
Alumina	3 945 445	422 162 615	3 663 989	436 014 691
Barytes	34 658	482 235	26 602	650 042
Building stone	2 961	63 037	4 243	118 090
Clays	419 829	418 622	402 637	426 706
Coal	2 735 230	44 407 880	3 151 470	60 717 341
Cobalt	215.86	2 660 628	982.65	13 023 142
Copper—Metal	1 740.81	2 256 476	3 132.40	4 751 650
Dolomite	585	3 510	....	....
Emeralds—Carats (cut)	1 205	7 230	13 000	78 000
Felspar	1 929	82 999	2 568	116 932
Garnet Sand	42	3 480	76	7 540
Glass Sand	278 091	N.A.	129 367	N.A.
Gold (kg)	11 581.99	108 322 743	10 801.17	179 314 357
Gypsum	243 210	966 783	293 370	1 126 629
Ilmenite (includes upgraded and reduced ilmenite)	1 143 286	27 699 090	1 256 720	30 084 556
Iron Ore	85 171 982	1 039 594 173	84 971 629	1 158 386 783
Iron Ore—Pig Iron	85 051	4 767 928	61 327	4 241 104
Leucoxene	29 196	3 919 851	26 911	5 545 374
Limestone	676 596	1 560 229	607 812	1 792 235
Mica	310	65 773	352	79 225
Manganese	1 395	24 427	1 693	36 738
Monazite	17 352	4 033 271	10 978	3 684 252
Nickel Ore and Concentrates	479 119	227 304 194	483 099	322 306 570
Ochre	222	3 772	53	897
Palladium (kg)	213.89	625 772	38.24	1 834 614
Platinum (kg)	85.88	862 865	63.61	954 184
Rutile	94 351	19 887 292	91 667	23 292 830
Salt	3 731 854	17 024 382	3 680 844	37 553 115
Semi-precious Stones (kg)	4 973	9 600	3 012	8 982
Silver (kg)	1 856.65	374 968	2 049.81	895 251
Talc	110 359	N.A.	113 211	N.A.
Tanto-Columbite	172	7 454 069	159.05	12 233 116
Tin Concentrate	694.9	7 542 231	558.13	6 721 875
Vermiculite	....	....	159	1 590
Xenotime	44	53 990	21	32 192
Zircon	337 197	17 920 552	327 692	20 142 466
Totals		1 972 566 667		2 326 173 069

NOTES:—

1. The value of the mineral and metal output is not complete as the value of some minerals or metals is not available for publication.
2. Production of sand, gravel and aggregates used in the concrete, building and construction industries is not included.
3. The contained information is obtained from figures prepared by the Statistical Branch of the Department. Cobalt, copper palladium and platinum are by-products of nickel mining, whilst silver is a by-product of both nickel and gold mining.
4. Limestone production is incomplete.

TABLE 2

Reported Mine Development Metalliferous

Mineral or Metal	Mining District	Mine Company	Shaft Sinking (metres)	Decline and Incline (metres)	Driving and Cross Cutting (metres)	Raising and Winzing (metres)	Exploratory Diamond Drilling (metres)
Gold	East Coolgardie	Kalgoorlie Mining Associates—					
		Mt. Charlotte	....	409	2 942	532	} 2 984
		Fimiston Leases	....	....	3 215	705	}
		North Kalgurli Mines Ltd	....	....	1 254	8	6 573
	Pilbara	Newmont Holdings Pty Ltd	....	....	....	....	2 566
	Dundas	Central Norseman Gold Corporation N.L.	....	195	615	272	42 004
	Nth Coolgardie	Greenbushes Tin—Aspacia Goldmine	....	....	10	....	383
	Mt. Margaret	Western Mining Corporation Lancefield	....	....	439	129	5 469
	Murchison	Ingliston Gold Mine	....	....	....	54	....
		Nannine Gold Mine	25	....	162	....	....
		Hill 50 Gold Mine—					
		Water Tank Hill	65	....	91	6	} 2 535
		Morning Star	....	....	....	9	}
		Total Gold Development	90	604	8 728	1 715	62 514
Nickel....	Coolgardie	W.M.C. Kambalda Operations	....	2 211	13 378	5 001	100 366
		Metals Exploration Nepean Operations	....	1 103	1 400	536	10 673
	Mt. Margaret	W.M.C. Windara Operations	....	501	1 797	116	4 367
	East Murchison	Agnew Mining Co. Leinster	331	4 478	3 663	961	7 075
		Total Nickel Development	331	8 293	20 238	6 614	122 481
Tin/ Tantalite	South West	Greenbushes Tin N.L.	....	389	....	....	5 500
		Total Development	421	9 286	28 966	8 329	190 495

TABLE 3

Principal Gold Producers

Mine	1979			1980		
	Tonnes Treated	Yield † Kilograms	Grams Per Tonne	Tonnes Treated	Yield † Kilograms	Grams Per Tonne
Kalgoorlie Lake View Pty. Ltd.	....	*81·03	....	23 210	*102.39	3.40
Kalgoorlie Lake View Pty. Ltd. (Mt. Charlotte)	716 791	3 307·80	4·6	859 669	3 188.75	3.71
Central Norseman Gold Corporation N.L.	136 687	2 260·76	16·5	192 526	2 337.34	12.14
Western Mining Corporation (Kambalda)	....	....	....	87 147	78.11	.90
Newmont Pty. Ltd.	439 510	5 292·04	12·0	478 200	4 280.07	8.95
Minor Producers	77 890	556·87	7·1	242 985	1 038.99	4.28
Total State Production	1 370 878	11 498·50	8·4	1 883 737	11 025.65	5.85

* Includes 23·51 kg from mill clean up.

† Does not include alluvial or dollied gold.

NOTE: The calculated value of gold produced in 1980 was $189 293 860. The Gold Producers Association distributed $164 039 423 from the sale of 10 360·24 kilograms.

TABLE 4

Overseas Iron Ore Exports

Company	1979		1980	
	Exported	Grade	Exported	Grade
	(tonnes)	(% Fe)	(tonnes)	(% Fe)
Hamersley Iron Pty. Ltd.	29 159 716	63·61	36 415 755	63.54
Mt. Newman Mining Co. Pty. Ltd.	23 600 402	63·00	20 808 445	63.00
Cliffs W.A. Mining Co. Pty. Ltd.	13 976 711	59·09	12 138 214	56.91
Goldsworthy Mining Ltd.	6 689 032	63·08	5 370 359	62.56
Dampier Mining Co. Ltd.	3 206 035	67·29	2 036 759	66.72
Totals	76 631 896	62·71	76 769 532	62.14

TABLE 5

Nickel Producers

Product and Company	1979			1980		
	Quantity	Grade	Value	Quantity	Grade	Value
	tonnes	% Ni	$A	tonnes	% Ni	$A
NICKEL CONCENTRATES—						
Western Mining Corporation Ltd.—Kambalda	337 962	12·64	189 713 958	285 462	12.61	235 513 421
Western Mining Corporation Ltd.—Windarra	3 964	9·50	893 634	....	....	....
Selcast Exploration Ltd.—Emu Rock	12 482	16·50	9 440 647	16 220	16.5	15 568 753
Agnew Mining Co. Pty. Ltd.—Agnew	58 693	10·79	18 233 728	94 852	10.39	52 669 423
Total Concentrates	413 101	12·46	218 281 967	396 534	13.17	303 751 597
NICKEL ORE—						
Metals Exploration N.L.—Nepean	66 018	3·67	9 022 227	86 565	3.62	18 554 973

DIAGRAM OF FATAL ACCIDENTS

SEGREGATED ACCORDING TO CLASS OF MINING

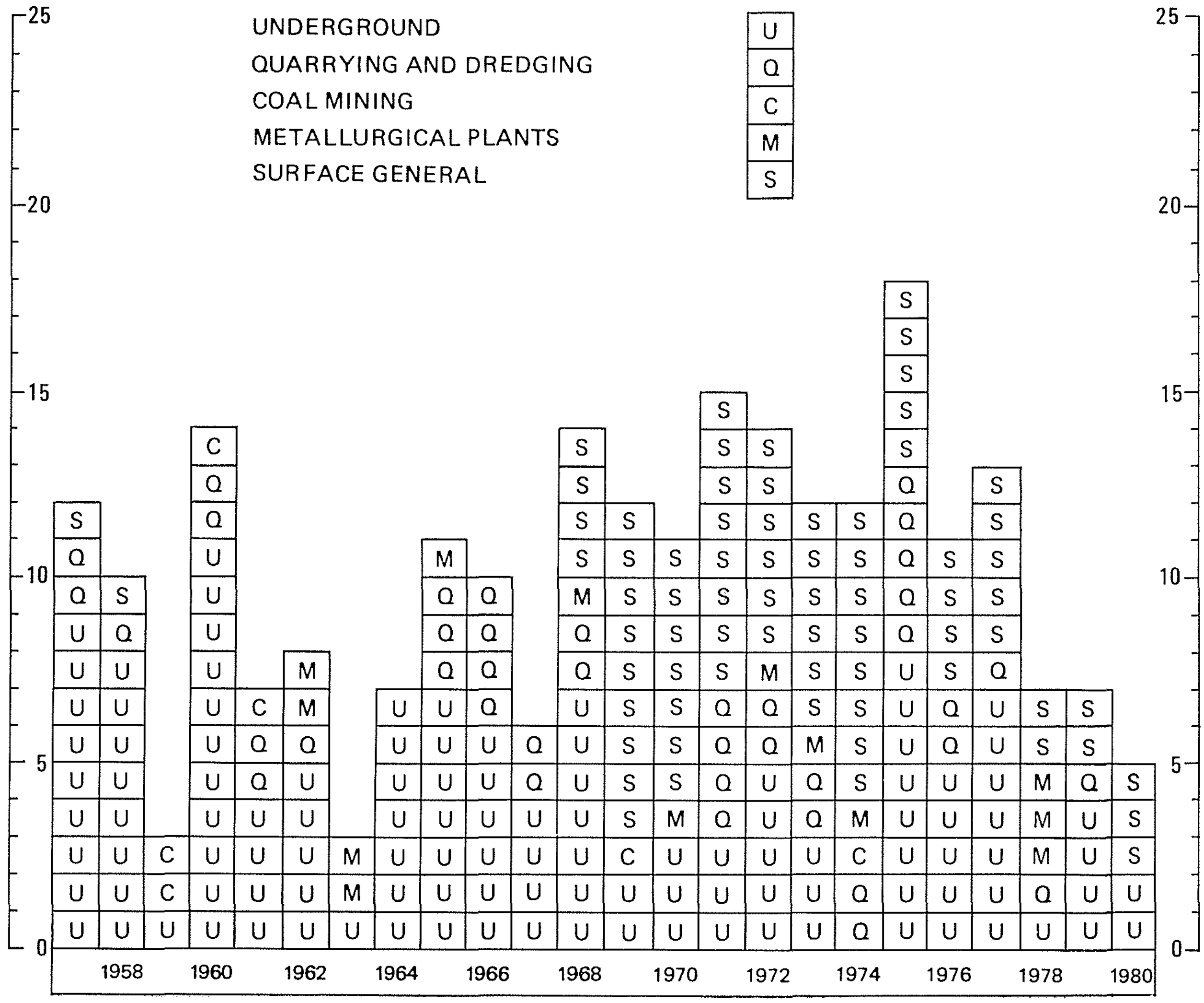


TABLE "A"
SERIOUS ACCIDENTS FOR 1980

Class of Accident	Pilbara	West Pilbara	Peak Hill	Gascoyne	Mt. Margaret	East Coolgardie	Coolgardie	Dundas	South West	Greenbushes	Yilgarn	East Murchison	Collie	Murchison	West Kimberly	Philips River	Total
Major Injuries (exclusive of fatal)—																	
Fractures—																	
Head	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Shoulder	1	....	....	....	....	1	....	....	1	....	....	....	1	....	....	....	4
Arm	3	1	1	....	....	1	1	....	....	....	....	....	2	....	....	....	5
Hand	2	2	....	....	....	....	....	....	2	....	....	....	4	....	....	....	10
Spine	....	....	1	....	....	....	....	....	....	....	....	....	....	....	....	....	1
Rib	....	1	....	....	....	....	1	1	1	....	....	....	1	....	....	....	6
Pelvis	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Thigh	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	1
Leg	....	1	....	....	....	....	2	....	....	....	....	1	1	....	....	....	5
Ankle	....	1	....	....	....	1	1	....	3	....	....	....	....	....	....	....	6
Foot	....	....	....	....	....	1	....	....	3	....	....	1	1	....	....	....	6
Amputations—																	
Arm	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Hand	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Finger	1	2	....	....	1	....	....	....	2	....	....	....	....	....	....	....	6
Leg	....	1	....	....	....	....	....	....	....	....	....	1	....	....	....	....	2
Foot	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Toe	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Loss of Eye	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Serious Internal	....	....	....	....	....	....	....	....	1	....	....	....	....	....	....	....	1
Hernia	1	....	....	....	....	....	....	....	6	....	....	....	1	....	....	....	8
Dislocations	....	....	....	....	1	2	....	....	....	....	....	1	....	....	....	....	4
Other Major	....	....	....	....	....	....	....	....	2	....	....	....	....	....	1	....	3
Total Major	9	9	2	....	2	6	5	1	22	....	....	4	11	....	1	....	72
Minor Injuries—																	
Fractures—																	
Finger	4	1	1	....	....	3	4	....	3	....	....	1	2	....	....	....	19
Toe	....	1	....	....	1	....	....	....	3	2	....	....	....	....	....	....	7
Head	1	....	2	....	....	....	1	....	1	....	....	1	3	....	....	....	9
Eyes	2	....	1	1	....	1	7	1	2	....	....	....	....	....	....	....	14
Shoulder	1	2	2	....	....	3	1	1	4	....	....	3	8	1	....	....	26
Arm	1	2	2	....	....	2	3	....	5	1	1	....	3	....	1	....	21
Hand	10	9	4	....	1	15	5	2	11	5	....	2	4	....	1	....	69
Back	19	21	10	1	....	18	7	6	27	2	....	....	32	1	1	1	146
Rib	....	....	....	....	....	....	3	2	....	....	....	....	....	....		....	5
Leg	9	7	6	1	2	6	16	2	14	....	1	1	6	....	2	....	73
Foot	3	2	2	....	1	10	3	5	7	....	....	5	8	....	1	....	47
Other Minor	1	....	....	....	....	3	2	4	14	....	....	....	8	....	1	....	33
Total Minor	50	45	30	3	5	61	52	23	91	10	2	13	74	2	7	1	469
Grand Total	59	54	32	3	7	67	57	24	113	10	2	17	95	2	8	1	541

TABLE "B"

ACCIDENTS SEGREGATED ACCORDING TO MINERAL MINED AND PROCESSED

Mineral	Persons Employed	Accidents		
		Fatal	Serious	Minor
Bauxite (Alumina)	3 545	1	60	145
Coal	910	....	85	475
Gold	1 637	....	88	192
Ilmenite etc.	752	1	25	72
Iron	12 415	....	148	726
Nickel	2 954	3	94	242
Salt	489	....	8	57
Tin	300	....	12	14
Other Minerals	431	....	8	15
Rock Quarries	375	....	13	44
Totals	23 808	5	541	1 985

TABLE "C"

FATAL AND SERIOUS ACCIDENTS SHOWING CAUSES AND DISTRICTS

District	Explosives		Falls		Shafts		Fumes		Miscellaneous Underground		Surface		Total	
	Fatal	Serious	Fatal	Serious	Fatal	Serious	Fatal	Serious	Fatal	Serious	Fatal	Serious	Fatal	Serious
Kimberley	....	....	....	....	....	....	....	....	....	....	....	....	....	....
West Kimberley	....	....	....	....	....	....	....	....	....	....	....	8	....	8
Pilbara	....	....	....	....	....	....	....	....	....	....	....	59	....	59
West Pilbara	....	....	....	....	....	....	....	....	....	....	....	54	....	54
Ashburton	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Peak Hill	....	....	....	....	....	....	....	....	....	....	....	32	....	32
Gascoyne	....	....	....	....	....	....	....	....	....	....	....	3	....	3
Murchison	....	....	....	....	....	1	....	....	....	1	....	....	....	2
East Murchison	....	....	....	1	....	3	....	....	....	4	1	9	1	17
Yalgoo	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Northampton	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Mount Margaret	....	....	....	1	....	....	....	....	....	4	....	2	....	7
North Coolgardie	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Broad Arrow	....	....	....	....	....	....	....	....	....	....	....	....	....	....
North East Coolgardie	....	....	....	....	....	....	....	....	....	....	....	....	....	....
East Coolgardie	....	....	....	4	....	....	....	....	....	36	....	27	....	67
Coolgardie	1	....	1	14	....	....	....	....	....	36	....	7	2	57
Yilgarn	....	....	....	....	....	....	....	....	....	....	....	2	....	2
Dundas	....	....	....	2	....	....	....	....	....	10	....	12	....	24
Phillips River	....	....	....	....	....	....	....	....	....	....	....	1	....	1
Greenbushes	....	....	....	....	....	....	....	....	....	....	....	10	....	10
South West	....	....	....	....	....	....	....	....	....	....	2	113	2	113
Collie	....	....	....	4	....	....	....	....	....	47	....	34	....	85
Nabberu	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Warburton	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Eucla	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Total for 1980	1	....	1	26	....	4	....	....	....	138	3	373	5	541
Total for 1979	....	1	1	19	2	7	....	1	1	98	3	325	7	451

Hereunder is a brief description of the fatal accidents reported during the year:—

Name and Occupation	Date	Mine	Details and Remarks
D. L. Peake (Mobile Plant Operator)	18/2/80	Alcoa of Australia Ltd—Pinjarra	Died of multiple injuries received when the scraper he was driving got out of control, struck a bank and threw him out of the cabin and beneath the wheels.
K. B. Jones (Mobile Plant Operator)	20/6/80	Allied Eneabba Pty Ltd—Eneabba	He received multiple injuries when the front end loader he was driving traversed too far under a grizzly bridge and forced the cabin of the loader onto him.
S. R. C. Cox (Miner)	24/7/80	Western Mining Corporation Ltd—Kambalda	He apparently initiated a round of explosives in a borehole rise whilst positioned near the upper collar of the hole. Concussion and flyrock up the hole inflicted severe head injuries.
T. M. Colgrave (Scraper Driver)	28/8/80	Western Mining Corporation Ltd—Kambalda	He was scaling the backs of a stope after firing when a large rock fell on him.
M. D. Hobart (Electrician)	3/12/80	Agnew Mining Co. Ltd—Agnew	He was replacing electrical cable on a surface switch box when he inadvertently caught a live wire of the earth leakage system between the head of a bolt and a terminal. Upon tightening, the insulation fractured and energised the terminal.

Graph No. 2—This graph shows the number of serious accidents per 1 000 employees in the Metalliferous Mining Industry for the twenty-year period 1960–1980.

Graph No. 3—This graph shows the number of minor accidents per 1 000 employees in the Metalliferous Mining Industry for the twenty-year period 1960–1980.

WINDING MACHINERY ACCIDENTS

Twenty-six mishaps involving winding machinery and associated equipment were reported. Brief details are as follows:—

Rope Failure or Damage

On March 26, at Long Shaft (W.M.C. Ltd) a skip was lowered onto accumulated spillage below No. 17 level loading pocket. The capel and detaching hook fouled shaft sets and required replacement.

On September 1, at the Ajax Shaft (C.N.G.C. N.L.) several wires of the kibble sling were broken when the shaft doors closed prematurely and deflected the counterweight-kibble into the shaft gates.

On October 23, at the Ajax Shaft (C.N.G.C. N.L.) the sling suspending the kibble below the counterweight was cut when it fouled the central guide of the crossarm in the sky shaft.

On November 6 at the Durkin Haulage Shaft (W.M.C. Ltd) the Capel detaching hook, jack catches and skip bonnet were damaged when the skip accelerated away from the brace into the skyshaft. An electrical design fault did not permit safety and speed zone equipment to operate when both skips were at the brace.

On November 14, at the Croesus Shaft (North Kalgurli Mines Ltd) a rope failed immediately above the top rope clamp. Water was being bailed at the time and constant flexing of the rope as the bailing skip entered the water caused a fatigue failure.

Cage Skip Hang-ups

On January 2, at the Lake View Shaft (K.M.A.) a new skip hung up in the shaft for no apparent reason.

On February 4, a skip hung up between the No. 5 and No. 6 level of the Durkin Haulage Shaft (W.M.C. Ltd). A large rock was loaded into the empty skip and caused the locking arms to disengage. These fouled the shaft timbers when the skip was raised. The skip was damaged.

On February 26 at the Silver Lake Shaft (W.M.C. Ltd) a cage hung up in the shaft when pipes being transported fouled a wall plate. The cagedoor and gripper arms were damaged.

On March 11 at the Regent Shaft (C.N.G.C. N.L.) the north skip was derailed by a build-up of ore on the rails. A skip axle and shaft timber were damaged.

On March 17 at the Durkin Shaft (W.M.C. Ltd) a skip hung up at the No. 8 level loading station. A large rock loaded into the skip caused the locking arm to disengage and the skip to come off the guide. There was no damage.

On July 3 at the Regent Shaft (C.N.G.C. N.L.) a skip was derailed by a rock lodged between shaft timber and rails. A skip axle and shaft timber were damaged.

Another derailment occurred on July 7, possibly due to spillage on line. Damage to a rail and shaft timber occurred.

On August 20 at the Perseverance Shaft (K.M.A.) a skip hung up in the tipping scrolls. A faulty locking arm is believed to have been the cause. No damage.

On November 18 at the Silver Lake Shaft Haulage Winder (W.M.C. Ltd) the north skip hung up in the tipping scroll when a large rock jammed between the skip door and tipping launder. No damage occurred.

On December 22, at the Croesus Shaft (North Kalgurli Mines Ltd) the bailing skip became jammed when it fouled an obstruction below the water level.

Miscellaneous

On January 21 at the Long Service Shaft (W.M.C. Ltd) the cage was lowered below the water level. The cage was raised and the weight of water forced cage gates to open and foul shaft timber. Damage confined to shaft gates.

On February 18 at Agnew Mining Co. Pty Ltd shaft sink, the sinking stage tilted whilst being raised. Some decking and a stabilising jack were damaged.

On April 1, at the Regent Shaft (C.N.G.C. N.L.) a depth indicator system failed. No damage resulted.

On August 1 at Mt Charlotte Man and Supply Shaft (K.M.A.) the open cage gates were damaged when the cage was taken away from the plat after a pre-arranged "rest" signal was misinterpreted.

On August 20, at the Durkin Shaft (W.M.C. Ltd) the locking arms of a skip disengaged when a large rock was loaded into the skip.

On September 5, at the Silver Lake Mine (W.M.C. Ltd) an unmanned locomotive was inadvertently pushed into the service shaft by another locomotive. Only minor damage to shaft timber resulted.

On November 4, at the Perseverance Shaft (K.M.A.) the locking arms of a skip did not engage properly and subsequently caused minor damage to shaft timber.

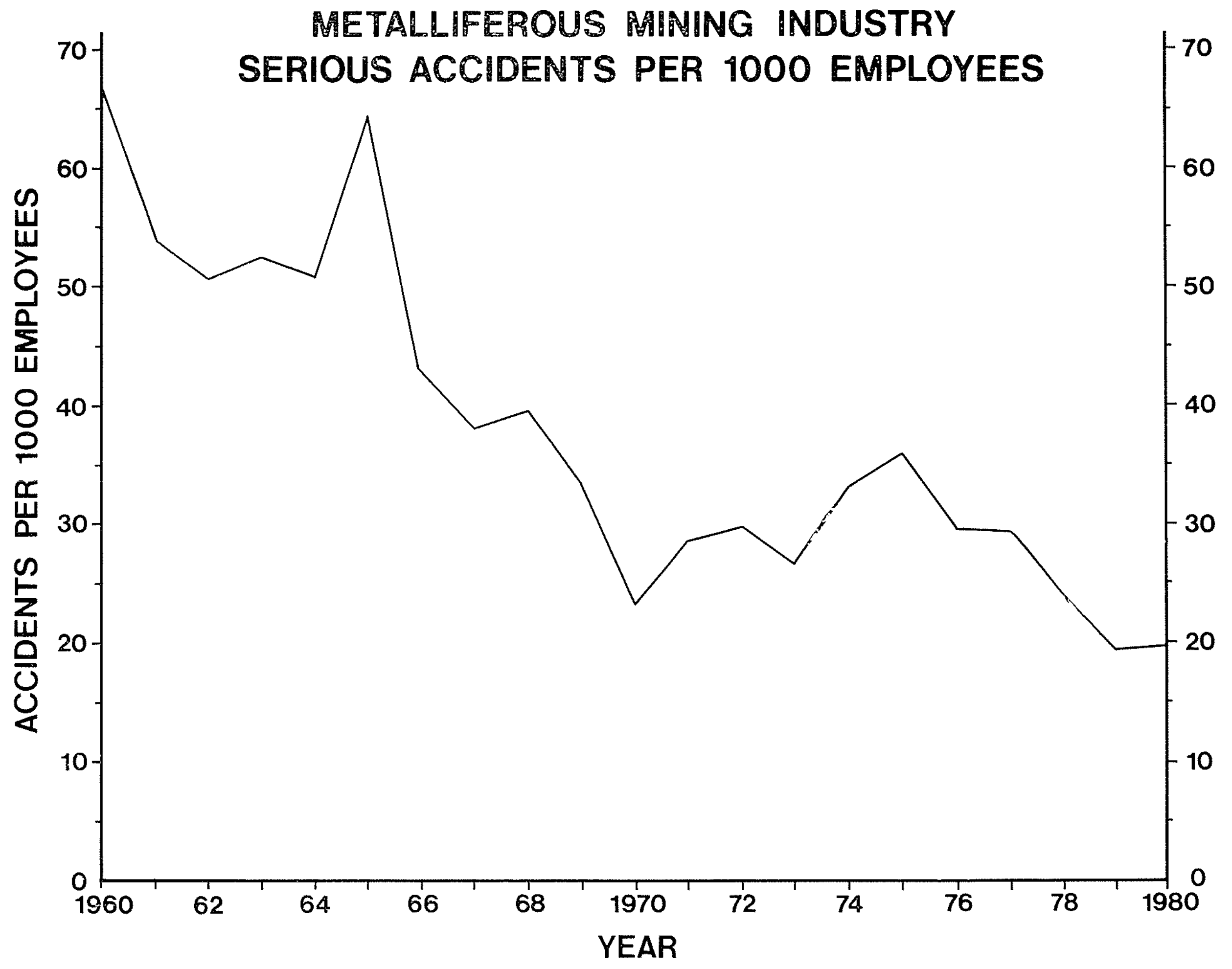
On November 15 at Mount Charlotte Mine (K.M.A.) a centralising cross arm was damaged when a diesel loader was used to pull heavy machinery (which had been lowered to No. 9 level) from the shaft onto the plat.

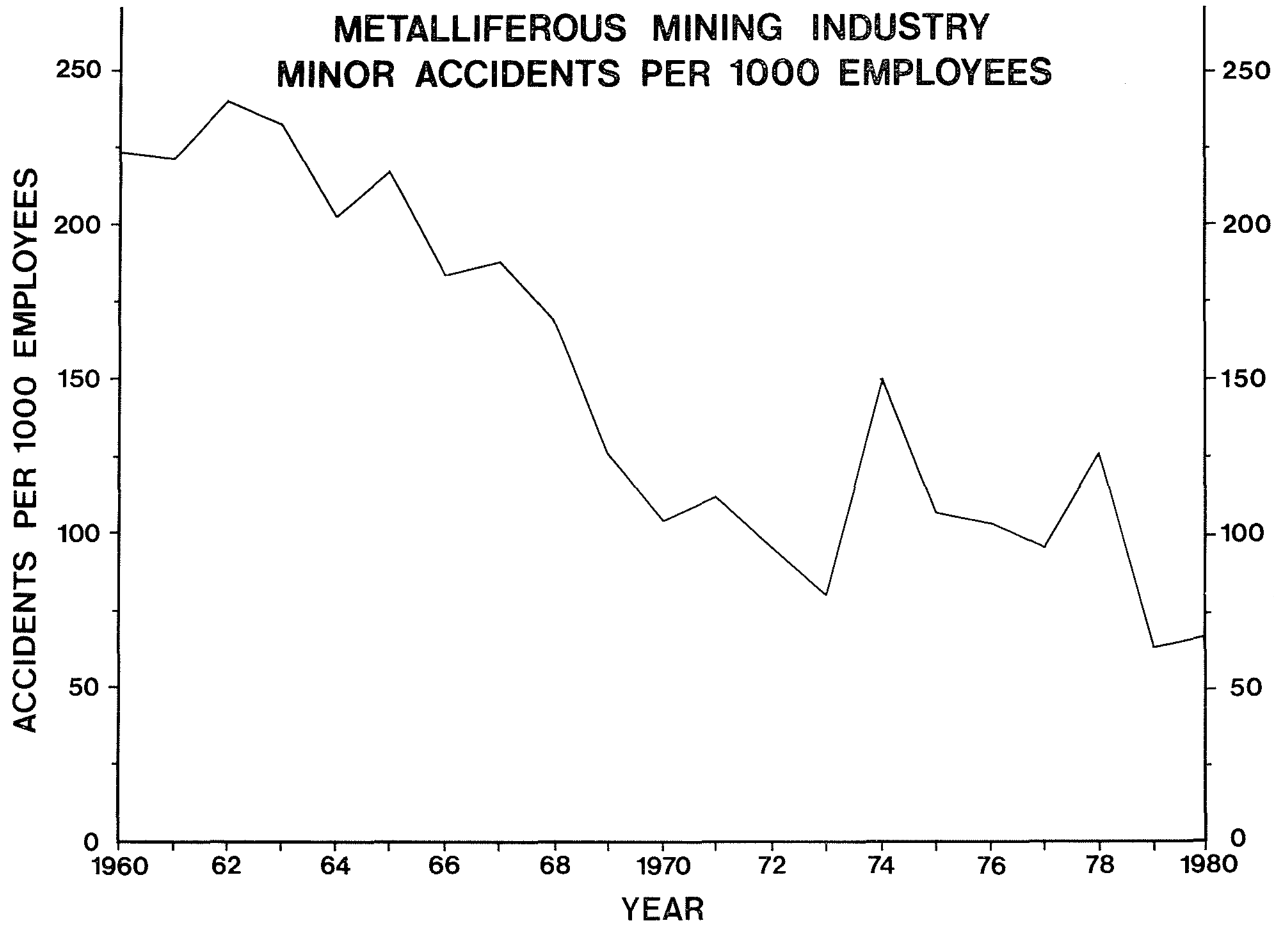
On November 19 at Mt Charlotte Man and Supply (K.M.A.) the emergency overspeed brake tripped in when the cage was travelling between No. 9 and No. 13 level. It was found to be out of adjustment.

On November 25 at the Ajax Shaft (C.N.G.C. N.L.) the monkey was not arrested due to skip change-over gate being open. When raised the monkey caught the gate causing minor damage to the gate and monkey.

On December 24 at the Main Shaft (North Kalgurli Mines Ltd) the cage was raised as a locomotive was being unloaded on No. 9 level. The locomotive was tipped onto the plat and almost fell down the shaft. A fault in the Shaft bell signal plunger was responsible for a signal being received by the winder driver.


METALLIFEROUS MINING INDUSTRY
FATAL ACCIDENTS PER 1000 EMPLOYEES
ACCIDENTS PER 1000 EMPLOYEES
2·0
1·5
1·0
0·5
0·0
1960
62
64
66
68
1970
72
74
76
78
1980
YEAR


METALLIFEROUS MINING INDUSTRY
SERIOUS ACCIDENTS PER 1000 EMPLOYEES
ACCIDENTS PER 1000 EMPLOYEES
70
60
50
40
30
20
10
0
1960
62
64
66
68
1970
72
74
76
78
1980
YEAR



PROSECUTIONS

No prosecutions were initiated during the year, however, prosecutions commenced in 1978 following the deaths of two workmen at the Kwinana Nickel Refinery on the 8th June, 1978, were concluded.

The Magistrate's findings were handed down on the 28th May, 1980. The registered manager was found guilty on two counts: one against Section 54 and one against regulation 8.13(1) of the Mines Regulation Act 1946–74 and Regulations. He was fined $20 on each count. The company was found guilty of an offence against regulation 8.13(1) and fined $100. The foreman responsible for the work being undertaken by the men, prior to their deaths, was found guilty on two counts: one against section 54 and the other against regulation 19.2. He was fined $20 for each offence.

All charges were heard together, but even so, the hearing lasted six days. The magistrate instructed the parties to meet their own costs.

CERTIFICATES AND PERMITS

Certificates of Exemption—Section 46

There were no certificates of exemption granted under section 46 of the Mines Regulation Act during the year.

Authorised Mine Surveyors Certificates

The survey board issued ten certificates during 1980 of which seven were re-issued under Regulation 10.4 of the Mines Regulation Act 1946–74 and the remaining three were initial certificates.

Certificates were issued to:

R. F. Milnes—Certificate No. 043
B. G. Curran—Certificate No. 044
G. J. Sloan—Certificate No. 045
G. J. S. Cook—Certificate No. 046
K. Peek—Certificate No. 047
J. A. Cedro—Certificate No. 048
D. R. Holly—Certificate No. 049
R. H. Poole—Certificate No. 050
R. J. Lea—Certificate No. 051
W. Vasy—Certificate No. 052

Power Shovel Operators Certificates of Competency

The State Mining Engineer's Branch issued 31 Power Shovel Operator's Certificates of Competency under the provisions of Regulation 17.3. All were issued to applicants in the Karratha Inspectorate.

Sunday Labour Permits

Thirteen permits covering 21 shifts and involving a total of 66 men were issued to 5 mining companies, all in the Kalgoorlie Inspectorate. The permits were issued for a number of various reasons, but were primarily for work undertaken to improve safety or install or remove equipment which would have necessitated cessation of normal production if the works had to be carried out during normal working hours.

Permits to Fire Outside Prescribed Times

W.M.C. Kambalda Nickel Operations—Four permits were issued for development work, one for each of the Foster, Carnilya Hill, Mt Edwards and Fisher mines.

Agnew Mining Co.—Agnew Nickel Mine—A permit was granted to advance two development headings. A second permit issued to allow firing at any time in a particular stope, for a trial period, was never used because the stope had been worked out by the time the necessary investigations preceding the granting of the permit, had been completed.

W.M.C. Windarra Nickel Project—This operation was granted one permit to strip out a ventilation rise.

North Kalgurli Mines Ltd—A restricted permit was issued to facilitate development on the 6 level during the initial stages of re-opening the mine. A further permit was later issued for firing development headings on three levels.

Greenbushes Tin N.L.—A permit was issued to allow blasting as required during the development of the "John Mac" decline.

All permits related to isolated mine workings and were subjected to conditions designed to ensure that adequate safety was maintained.

ELECTRICAL INSPECTIONS

For many years, the State Mining Engineer's Branch has been assisted by one or more Special Inspectors of Mines—Electrical such personnel being officers of the State Energy

Commission. Until recently their main function has been to investigate serious electrical accidents on mines and undertake occasional inspections.

The Inspection Services Section of the State Energy Commission has now been re-organised and seven of their inspectors are now gazetted as Special Inspector of Mines—Electrical. These personnel are based in Perth. Collie, Karratha and Kalgoorlie and have re-organised their areas of responsibility to conform with Inspectorates within the Department of Mines.

Inspections

Regular electrical safety inspections are now being made on mine sites and the Chief Inspector—Inspection Services reports that his six field officers spent 66 per cent of their total working time undertaking mine site inspections or investigations covering 82 mine sites in the Perth Inspectorate (Including Collie), 115 in the Kalgoorlie and 60 in the Karratha Inspectorate. A total of 652 mine site inspections were carried out during the year.

Accidents

One fatality occurred as the result of an electrical accident during the year. Four serious electrical accidents were investigated and 34 minor electrical accidents were reported.

Miscellaneous

A publication titled "Installation and Use of Electricity in Mines" was prepared and circulated to mining companies, electrical contractors and consultants. The purpose of the publication was to explain the requirements of Part 5 of the Mines Regulation Act, 1946 and Regulations, particularly to those persons associated with electrical installation but not aware that specific regulations exist on mines.

Electrical Staff of C.R.R.I.A. at Cape Lambert were given an address on the requirements of Part 5—Electricity in Mines.

During the year, 9 submissions in accordance with the Mines Regulation Act, Regulation 5.23 (1) were received and processed.

The re-organised inspection system is functioning smoothly and close liaison and co-operation exists between Mines Department and Commission inspectors.

SEISMOGRAPH RECORDINGS FOR BLAST AND MECHANICALLY INDUCED GROUND VIBRATIONS

A Dallas Instruments ST4 Seisomgraph was received in September and was used on 4 tests during the remaining quarter. Three were to test mechanically induced vibrations in built-up areas during ground compacting operations and the other was to test ground vibrations in the Kalgoorlie townsite following a crown pillar blast at Mt Charlotte.

The ST4 has a number of advantages over our older mechanical Sprengnether Seismograph including:—

(a) No communication or time check is required between the operator and the party initiating a blast or other source causing vibrations.

(b) The instrument can be set up and left with a preset value and only vibrations more severe than the preset figure will trigger the system into operation.

If the instrument does not record, any vibrations set up must be less than the preset value.

(c) Each event and relevant time data is recorded on both a cassette tape and on a digital readout. Up to 90 events can be recorded on the tapes.

(d) A fourth channel records the sound pressure of each event.

REHABILITATION

The majority of mining companies in this State are conscious of the need to progressively rehabilitate their operations as they continue to develop. The days of leaving a large hole in the ground surrounded by mounds of unvegetated waste material are gone—even in remote areas, a number of mining companies budget substantial sums of money for their annual rehabilitation programmes. More regard is now taken of the environment in which we work and live, and mine planners are much more conscious of the siting of overburden dumps, tailings dumps and mine plant with regard to their effect upon those environments. It has been noticed that mining companies are outlaying increased amounts of time and money on research into existing flora and fauna with the aim of re-establishing them after mining is completed.

During the eighties we are going to see an increasing trend in the employment of environmentalists in the mining industry. Fortunately, improved technology is providing information on the detrimental effects caused by the processing of mineral products and planning for the control of these effects is now part and parcel of the process design.

Iron Ore Mining

Under the terms of their agreements, the iron ore companies are not required to undertake extensive rehabilitation. The task of establishing vegetation on iron ore waste dumps in the harsh Pilbara climate is one which will require imagination, courage and considerable determination. In spite of the immensity of the problem most companies are making a real effort to establish a worthwhile rehabilitation programme.

The Mount Newman Mining Company Proprietary Limited has been carrying out rehabilitation at the mine site using the indigenous species of vegetation. They have been conducting a number of trials such as slope stabilization by ground landscaping, fertilizer trials, coherex trials, seed broadcasting and hydromulching of slopes over 30°. In the Port area a project of Sand Dune Stabilization using hydromulching has been attempted. Some degree of success has been achieved on completed waste dumps and the more successful trials will be continued. Hamersley Iron Proprietary Limited have been rehabilitating borrow pits created by various construction projects, flatlands disturbed by the mines and waste dumps that have been generated by the extraction of the ore. Hamersley have established a reference Herbarium which provides information collected from a survey of the plant species collected from construction pits. During 1980 at Tom Price, field trials were conducted to establish operational procedures for revegetation of waste slopes when final profiles are completed. Cliffs Robe River Iron Associates have been progressively rehabilitating the Mesa tops since 1978 and have also been carrying out tests on waste materials such as alluvium and shale as potential revegetation soils. A number of control plots have been studied which utilize a variety of treatmnet processes. Regrowth is slow but the work is continuing.

Gold and Nickel Mining

Unfortunately the legacy of the early gold mines remains for the twin towns of Kalgoorlie and Boulder in the Eastern Goldfields. Slime dumps that were commenced in the latter decade of the last century and continued to rapidly build up during the early part of the present century provide a continuing wind blown dust annoyance to local residents. Trials are being carried out by the Goldfields Dust Abatement Committee, but due to lack of funds and a series of trial and error experiments, it will be some time before an effective solution to this dust problem is achieved. Kalgoorlie Mining Associates have embarked on a tree planting programme in all of their presently operating areas. Central Norseman Gold Corporation have been carrying out vegetation trials on their main slime dump with encouraging results, however much work has yet to be done. Management of the nickel industry at Kambalda have always been conscious of the need to retain and encourage natural vegetation and after operating for 14 years in the area have been able to retain most of the indigenous plant growth.

Bauxite Mining

Alcoa of Australia Limited have continued with their rehabilitation efforts in the bauxite mines of the northern jarrah forest, working in close co-operation with the Forests Department. Areas rehabilitated in the Jarrahdale, Del Park and Huntly mines exceeded the areas being opened up for mining by 73 per cent. Even with 17 years of rehabilitation experience behind them, Alcoa is still maintaining research and experimentation into improved species and rehabilitation procedures.

Tin—Tantalum Mining

With the current market of improved metal prices the whole of the Greenbushes mining area—both previous and present—is being re-assessed for mineral potential. During 1981 we may see the commencement of a major co-ordinated open cut/underground mining venture which will include long term plans for the overall rehabilitation of the area. During 1980, overburden from the open cut has been dumped on previously mined areas, top soil re-spread and trees planted as areas are completed. The company provides a substantial nursery that is being expanded to provide the many thousands of trees necessary for their regrowth effort. During the year rehabilitated areas exceeded the area of land opened up for mining and the trend will be for mining to continue in the already disturbed areas unless future drilling indicates otherwise.

Beach Sand Mining

Associated Minerals Consolidated Limited have continued with their efforts in the Capel Area and with 5 000 seedlings planted in June/July the total number planted on restored land since 1975 is 32 000. Mining has continued both south and north of the Boyanup-Busselton railway line and sand tailings areas not required for the storage and drying of clay-slimes were contoured and grassed.

At Eneabba, little worthwhile rehabilitation has been attempted. This continued lack of progress was brought to the attention of the company management by the Mineral Sands Agreement Rehabilitation Co-ordinating Committee.

Cable Sands have fully restored 13·5 hectares of land at Ambergate and contoured, but not seeded, a further 17·1 hectares. At Wonnerup 20 hectares of previously restored areas were sown and fertilized. The Ambergate mining plant has been shifted to the Prowse mine at Capel where removal and stockpiling of topsoil has been completed from above the initial mining area.

Westralian Sands have expended a considerable amount of money on the old Yoganup mine path (mainly on dozer work) recontouring high tailings dumps. Rehabilitation to pasture standards has been carried out in the North Capel area and the main Yoganup Extended area.

Allied Minerals at Eneabba have very nearly reached the stage where the area of land being rehabilitated exceeds the area of land being opened up for mining on an annual basis. Approximately 60 hectares have been rehabilitated by covering with topsoil and applications of a various number of treatments. The general aim of these treatments is to accelerate the direct development of the original low open heath. Unfortunately the continuing drought coupled with the accentuated effect of the prevailing easterly winds has greatly inhibited the regeneration and growth within the rehabilitated areas. However, some progress is being made and the company is increasing its efforts.

Hard-Rock Quarries and Sand Pits

Licences for the mining of sand-pits and hard-rock quarries are normally issued by the Local Government Authority who may impose conditions on the final contouring and rehabilitation of the mined area. Apart from these conditions, more and more quarry operators are realising the need to improve their public image and are putting considerable effort into rehabilitating old workings and are conducting extensive tree planting programmes both in and around the mine sites.

METALLIFEROUS MINING
KARRATHA INSPECTORATE

A. W. Ibbotson
Mining Engineer/Senior Inspector of Mines

The year 1980 represented the first full year of operations from our new headquarters in Karratha.

In January 1980 Mr J. P. Boucaut commenced duties as a Mining Engineer District Inspector of Mines and is based in the Karratha Inspectorate. On 10th July, 1980 Workmen's Inspector A. D. Spencer retired upon reaching the age of 65 years. Inspector Spencer was held in high esteem by all sections of the mining industry.

Company returns indicate an increase of some 3·8 per cent in employments figures over those of 1979.

EMPLOYMENT

Mineral	Full Year		Part Year	
	1979	1980	1979	1980
Barite	23	35	....	....
Crushed Rock	....	34	38	....
Gold	230	240	....	10
Iron	11 613	11 965	....	....
Mica	10	8	....	....
Salt	315	388	....	....
Silver/Lead/Zinc	....	....	16	....
Tin/Tantalite	47	75	6	15
	12 238	12 745	60	25

EXPLORATION

The search for diamonds continued throughout most areas covered by the Karratha Inspectorate, with the most concentrated activity centred within the Kimberley Goldfield. Although none of these projects have yet been classified as mines inspectors have been kept quite busy reporting on claim applications.

The Ashton-C.R.A. joint venture focussed attention on the Mt Nicholas/Smoke Creek area some 8 kilometres west of Lissadell Station Homestead, where some 120 persons are employed.

Diamond drilling of known kimberlite pipes and bulk sampling of alluvial gravels is in progress.

Iron ore deposits received attention, with known deposits being tested by exploration shafts at B.H.P.'s Deepdale deposits, and Hamersley Iron's deposits near current workings at Paraburdoo and Tom Price. The Yandicoogina deposits of C.S.R. were examined by means of a series of deep costeans; this work is scheduled to continue.

BARITE

During 1980 Dresser Minerals International mined a total of 80 050 tonnes of ore and 107 130 tonnes of waste from 5 deposits in the North Pole area. The quoted breakdown of this production was given thus—

Pit	Ore tonnes	Waste tonnes
A	4 990	1 260
A1	900	190
B	—	80 400
H north	14 730	12 740
H south	59 430	12 480

Ore shipped from Port Hedland in the form of finely ground barite powder totalled 24 000 tonnes of average 4·14 specific gravity.

The average number of employees was 35.

A total of 9 330 metres of percussion and 57 metres of diamond drilling was completed in association with other exploration activities during 1980.

CRUSHED ROCK

Specified Services Pty Ltd operated at Paraburdoo and Mt Regal for a production of 90 000 tonnes of aggregate.

The Readymix Group (W.A.) operated quarries and crushing plants at Nillibubbacca and Goldsworthy, to supply 51 000 m^3 of aggregate for the Main Roads Department. One plant spent three months crushing railway ballast at Shaw River and another spent two months at Newman producing concrete aggregate. Production figures are not available for the latter plants.

GOLD

Pilbara Goldfield

Newmont Holdings Pty Ltd operating G.M.L. 45/1421 at Telfer reported the production of 4 064·7 kilograms of gold from a total throughout of 478 200 tonnes of ore. The production of this ore required a total break of 9 606 000 tonnes of material being a ratio of 1:19, ore to waste. The average grade of material treated gave a recovery of 8·5 gms/tonne with minimal values in the tailings.

No additional company equipment of note was introduced during 1980, although the contractors, Quest Mining N.L., obtained new haulage trucks and excavating equipment.

A total of 2 566 metres of exploratory diamond drilling was completed during 1980 and the mine site labour force involved 220 persons, of whom 110 were contractors' employees and 110 were employed by Newmont Holdings Pty Ltd.

Sundry Gold Producers

Apart from an unknown number of fossickers who have located an equally unknown number of gold nuggets, a total of 1 878 tonnes of ore was treated at the Marble Bar State Battery during 1980 for a total recovery of 14·460 kilograms of gold bullion. The most notable crushing came from GML 45/1536 (Charlie) with a recovery of 9·657 kilograms from 273 tonnes on behalf of Monarch Petroleum N.L.

Gascoyne Goldfield

From G.M.L. 09/46 "Star of Mangaroon", the owner Mr R. W. Bennett reported the production of 300 tonnes of ore. From 140 tonnes crushed at Boogardie State Battery 2·985 kilograms of gold bullion were recovered.

Underground development for the year was:—

Shaft sinking—52·2 metres

Driving—20·8 metres

Cross cutting 17·4 metres

PRODUCTION AND SHIPPING (MILLION TONNE UNITS)

Company	Persons Employed	Ore Broken	Ore Shipped			
			Lump	Fines	Pellets	Total ore shipped
Hamersley Iron	4 106	66·477	17·070	21·849	0·019	38·938
Goldsworthy Mining	1 247	5·882	2·766	2·807	....	5·573
C.R.R.I.A.	1 741	15·891	....	13·331	0·696	14·027
Dampier Mining	770	2·556	2·118	0·204	....	2·322
Mt. Newman	4 101	35·805	14·041	13·248	....	27·289
Totals	11 965	126·611	35·995	51·439	0·715	88·149

Comet G.M.

From the cyanidation of 4 827 tonnes of tailings 12·127 kilograms of gold were recovered, representing a recovery of 2·5 grams per tonne.

Six persons were engaged at the Comet G.M. in relation to this work.

IRON ORE

Statistics supplied by the five producing companies show that, in comparison with the year 1979, there was an increase of 3·2 per cent in the number of persons engaged in the industry, an increase of 24·478 million tonnes of ore broken, and an increase of 3·787 million tonnes of ore shipped.

Hamersley Iron Pty Limited

The operations of Hamersley Iron comprise open-cut mines at Tom Price and Paraburdoo. Products comprise lump ore (—30 mm + 6 mm), high and low grade fine ore (—6 mm), and pellets (—16 mm + 9 mm). Crushing and screening plants at the mine sites, and a Concentrator at Tom Price, produce lump and fines, whilst pellets are produced from high-grade fines at the port of Dampier, linked to the mines by a 400-kilometres railway system.

Tom Price

During 1980 mining at Tom Price took place over 17 operating benches, each of 15 metres height. Principal items of heavy mining equipment remained basically static the exceptions being the reduction of one 60 R drill and the replacement of 5 X 3200 B Trucks with 3 MK36 Unit Rig Trucks.

Paraburdoo Mine

During 1980 mining took place over 7 operating benches each of 14 metres height.

Two quarry trucks were added to the fleet and one 2 100 B shovel was replaced by a 2100 BL, otherwise the principal items of equipment remained static.

The port system comprises stockpiling and shiploading facilities at Parker Point, with 2 000 000 tonne capacity of stockpiles and a berth to handle ships of up to 120 000 Dwt, and facilities at East Intercourse Island which accommodates ships of up to 160 000 Dwt and has a stockpile capacity of 3 000 000 tonnes of products. Stockpiles at Parker Point also handle feed and product for the 2·8 million tonne per annum capacity iron oxide pellet plant. The pellet plant incorporates an ore dryer, followed by dry grinding, balling with discs and a straight grate indurating machine. Pellet production ceased February 29, 1980, and the plant has been placed on care and maintenance.

Material Broken (million tonnes)

Location	High Grade Ore	Low Grade Ore	Waste	Total
Tom Price	21·345	14·499	8·132	43·976
Paraburdoo	14·872	3·471	5·659	24·002

New Plant and Equipment Installed

Major items of equipment introduced during the year—

Tom Price—Commissioning and work-up of the Concentrator loadout tunnel continued throughout 1980.

Dampier—A new barrel was installed in the East Intercourse Island car dumper. Substantial modifications to the Parker Point car dumper are progressing.

Rail—A new locomotive washing facility was commissioned.

New Developments

Development of 4W orebody at Paradurboo is underway.

Exploratory Drilling (metres)

	Rotary	Percussion	Diamond Drilling
Tom Price	Nil	26 129	1 513
Paraburdoo	Nil	21 736	824

Underground Development

Shaft sinking—exploration at Tom Price 89 metres (2 shafts).

Shaft sinking—exploration at Paradurboo 59 metres (2 shafts)

Cliffs Robe River Iron Associates

The Cliffs operation during 1980 changed in character from a pellet and sinter fines production system to one producing sinter fines only. The operation of the pellet plant with a capacity of nearly 5 million tonnes per year, was suspended at the end of April 1980 and a corresponding tonneage of sinter fines production was scheduled in substitution.

The operation begins near Pannawonica where the pisolitic Robe River Ore, occurring on mesa tops 75 metres above the Robe River, is drilled blasted, loaded into 120 tonne and 170 tonne haulage trucks by 9 m^3 electric shovels, delivered to large feeders which place the ore in 105 tonne ore cars for the 160 km trip on the Company's railroad to the port crushing and harbour facility at Cape Lambert. The ore is crushed through four stages to 6 mm and loaded to ore carriers from a high finger type ore wharf. Design capacity is 20 million tonnes per year.

New Mine Developments

Work commenced on preparing roads to open up mesas in the Eastern Deepdale area. Full scale railway and mine site construction will commence in 1981.

Exploratory Drilling—Vacuum drilling 1 440 metres.

Dampier Mining Company Limited
Koolan Island

Koolan Island exports a run of mine ore primarily to Japan, with small quantities being exported to South Korea.

The iron ore, once drilled and blasted from the main orebody is primary and secondary crushed, resulting in a product of 100 per cent —100 mm which is then stored through a mobile distributor in a 60 000 tonnes capacity storage bin.

Ore is drawn from the storage bin and loaded directly into vessels via a travelling shiploading boom. The size of vessels loaded varies between 50 000 and 100 000 tonnes capacity.

New plant and equipment installed during 1980—

- 2 Euclid R85 haulage trucks (additional)
- 1 Dart D600 front end loader (additional)
- Major additional quarry power feeder and isolator extensions
- 1 Bucyrus Erie 60R Diesel drill (additional)
- 1 Caterpillar 16G grader (additional)
- 1 Komatsu D355 dozer (replacement)
- 1 Favco hydraulic crane (additional)
- Power Station Workshop

Exploration Drilling—

Percussion—	
Mineral exploration	741 metres
Water exploration	493 metres
Diamond—	
Mineral exploration	466 metres
Rock mechanics studies	171 metres

Surface development—

Main Orebody—one bench on R.L. 50.

Acacia—Nil, but capping totally developed, ready for primary drilling.

Cockatoo Island

Work was concentrated at the eastern end of the quarry, excavating for the Fines Stockpile/Loadout Facility and establishing the trench cut below sea level for commencement of the final bench.

Ore is crushed with a primary jaw crusher (213 mm x 1 420 mm opening) and two secondary crushers (915 mm x 600 mm openings). Setting and crushing rates are dependent on ore specifications with a maximum rate of 1 000 tonnes per hour, this feeds to a 55 000 tonne capacity storage bin and then to the fixed shiploading plant, loading at a maximum rate of 2 000 tonnes per hour.

New Plant and Equipment:—

New Sanki conveyor system installed in tunnel area of secondary crushers.

Commenced construction of two product handling stockpiles and reclaim facilities, including conveyors, hoppers and weighbridge.

Commenced assembly of Demag H241 hydraulic backhoe which will be used for mining of the final bench.

Goldsworthy Mining Limited

This Company mines ore at Goldsworthy, Shay Gap and Sunrise Hill. The primary crushed ore is transported by rail to Finucane Island, for further crushing, screening and storage pending shipment to Japan.

Production during 1980 (million tonne units)—

Goldsworthy—2·211 M Dry Tonnes ore

Shay Gap—0·697 M Dry Tonnes ore

Sunrise Hill—2·974 M Dry Tonnes ore

New Plant and Equipment Installed—

1 new Caterpillar D9 dozer

3 new 120-ton Wabco Haulpaks

Exploratory Drilling—

Percussion 9 629 metres.

Mt Newman Mining Co. Pty Limited

The iron ore mining operations of Mt Newman Mining Co. Pty Limited are centred on Mt Whaleback south of the Opthalmia Range. Production capacity of the mining operation is more than 40 million tonnes of ore and 60 million tonnes of waste per annum.

High grade ore from the mine is reduced in size by crushing and screening before being transported 426 kilometres by rail to the port facility at Nelson Point. Here the ore is put through a tertiary crushing and screening process, after which it is stockpiled prior to being shipped.

A beneficiation plant constructed and commissioned in 1979, with a capacity of 6·8 million tonnes of feed per annum, was operated throughout the year. Treatment in the beneficiation plant of lower grade contact ore, previously stockpiled or taken to waste dumps, has increased ore reserves and extended the life of the mining project.

A further trial involving blending of Marra Mamba and Mt Whaleback ores was commenced in July, 1980 and will continue into 1981. Should this blend be acceptable to customers, a mining operation capable of producing up to 3 million tonnes per annum of Marra Mamba ore is proposed.

The average number of persons employed by Mt Newman Mining Co. Pty Limited during 1980 was 4 101. A total of 35·8 million tonnes of ore and 42·6 million tonnes of waste were broken at Newman and ore shipped from Nelson Point was 14·041 million tonnes of lump and 13·248 million tonnes of fines.

MICA

Pilbara Mica Corporation Pty Limited reported the production of 351·31 tonnes of processed mica valued at $77 225.

The ore was mined from the Pippingarra deposit and transported by road to the upgrading plant at Wedgefield, where modifications for the purpose of increasing throughput to achieve a production target of 2·0–2·5 tonnes of pinite (fine mica) per day, are in progress.

All units of the processing plant are under vacuum control and surface dust is controlled by watering.

Six persons, plus contract road hauliers, were engaged on this project.

Dampier Salt (Operations) Pty Ltd—Dampier Division

Production of salt by solar evaporation—

Harvested during 1980—2 897 000 tonnes

Shipped during 1980—2 708 000 tonnes

Stockpile 31/12/80—552 000 tonnes

As in 1979 production was obtained from—

6 pre concentration ponds totalling 8 237 ha

30 crystallisers—735 ha

Bitterns (waste ponds)—1 226 ha

Major items of plant introduced during 1980 were—

2 x D 8640 tractors

30 x 20 tonnes bottom dump trailers

1 x Harvester

1 x D6 tractor

1 x 475 B loader

2 x KT 450 prime movers

2 x NTC 350 prime movers

1 x Service truck

Number of persons employed during 1980, including staff and contractors—204 persons.

Dampier Salt (Operations) Pty Ltd—Lake Macleod Division

Reconstruction of the mine following major damage by cyclone Hazel in March 1979 continued throughout the first half of the year. The work was completed and production recommenced during October.

The operation at Lake Macleod is one of extraction of a concentrated brine by pumping from a naturally occurring aquifer in Lake MacLeod, deposition of the sodium chloride content of this brine by solar evaporation in constructed crystallisers, harvesting of the evaporite by mechanical harvesters and transport to a salt washing plant by trucks. At the washplant the product is washed in brines to remove contaminants and stockpiled by conveyor system for drainage.

After drainage the product is reclaimed by front end loader, trucked to Cape Cuvier where it is stockpiled by conveyors.

The product is reclaimed from this stockpile by dozing onto a jetty conveyor system to a fixed location, slewing, buffing boom shiploader and thence on board ships.

Ship Product (tonnes of salt)—

Harvested during 1980	194 000
Shipped	Nil
Stockpiled Washplant 31/12/80	194 000
Stockpiled Cape Cuvier 31/12/80	Nil

Existing policy is to use 16 crystalliser ponds (330 ha) and to develop a further six crystallisers which have been completed but have not yet been brought into service.

Major items of plant introduced during the year—

Reconstructed jetty and shiploader.

New washplant

Power distribution system

Workforce increased from 54 to 116 during 1980 as production started up.

Number of construction contractors working on site varied as reconstruction activity varied, but peaked at approximately 80 dropping to 10 at the end of the year.

Leslie Salt Co.

The concentrator system was severely damaged as a result of three cyclones which passed over the area early in 1980.

The majority of the levees were severely eroded and only two of the ponds (No. 7 and No. 8) remained intact. Reconstruction of these levees commenced in April 1980 and sufficient ponds were closed off to allow pumping to re-commence in May. Further ponds were repaired sufficiently to contain the brine as the system began to refill and the entire system was back to normal operation by September 1980.

The cost of reconstruction of the concentrator system is expected to be $8 400 000 of which $4 600 000 was spent in 1980. The $3 800 000 to be spent in 1981 is to add further clayfill to the levees and then protect the levees with rock Rip-Rap.

The damage sustained in the concentrator system disrupted the flow of brine to the crystalliser area however, the Company was able to maintain production of salt for shipment throughout the year (although at a slightly reduced annual tonneage). This was achieved by depleting the stock of solid phase salt in the crystallisers.

Mining Tenement Applications

During the year, the inspectorate staff reported on the following Mining Tenement applications.

Mining Registrar	Mineral Claims	Dredging Claims	Quarry Areas	A.T.M's	Others	Total
Broome	858	46	24	30	....	958
Carnarvon	528	136	2	12	1	679
Kununurra	2 508	353	8	1 028	....	3 897
Marble Bar	1 495	283	32	54	17	1 881
Meekatharra	101	2	....	....	....	103
	5 490	820	66	1 124	18	7 518

Tonnes of salt (NaCl)—

Harvested during 1980	979 760
Shipped during 1980	870 618
Stockpiled at 31/12/80	221 592

Ponds in use—

9 Concentrating ponds—total area 7 100 ha

18 Crystallising ponds—total area 600 ha

A major overhaul and replacement programme was undertaken on the Washing Plant during the year.

Number of employees—

Average 67.

TIN AND TANTALITE

Futuris Corporation Limited carried out exploratory testing of tin and gold deposits on Yandeearra Station on holdings acquired from Friendly Creek Mining during 1980.

Although the operation was brought to a standstill through insufficient water for treatment, the group are apparently sufficiently satisfied with the prospects as they have decided to instal a larger capacity treatment plant.

While the availability of alluvial gold and tin-bearing material does not appear to be in doubt, such a project cannot succeed until an adequate and continuous water supply is established.

The Company reported the recovery of 15·303 kilograms of gold and 68 tonnes of cassiterite consequential to their testing operations from an estimated 165 000 tonnes of alluvial material.

An average of 20 persons were employed during the period when operations were in progress.

Exploratory drilling carried out during 1980—

Percussion	480 m
Rotary air blast	5 000 m

Pilgan Mining Pty Limited operating at Pilgangoora reported the recovery of 44·4 tonnes of 34 per cent Ta_2O_5 concentrates from the treatment of 144 547 m^3 of alluvial material obtained from shallow creek beds and processed through their 70 m^3 per hour scrubbing and jigging plant.

A primary upgrading plant is being established in the pit area to decrease the cartage of waste material excessive distances to the existing plant site.

Eighteen persons are employed on this project, which suffered damage during two cyclones early in 1980.

Pilgan Mining Pty Limited operated a smaller plant for part of 1980 near Yinnietharra Station in the Gascoyne Goldfield.

From approximately 10 000 tonnes of material treated, 7 tonnes of 18 per cent Ta_2O_5 concentrates were recovered.

Towards the end of 1980 this plant was relocated near Trig Hill out from Hillside Station in the Pilbara.

Four persons are engaged.

Goldrim Mining Australia Limited operating at Wodgina reported the recovery of 13·07 tonnes of 52·5 per cent Ta_2O_5 and 8·5 tonnes of 73 per cent Sn from the treatment of some 35 000 tonnes of material.

A new plant is being erected at the Wodgina site and the existing plant will be shifted to the Strelley/Tabba Tabba area.

New equipment acquired during 1980 comprises—

1 x Caterpillar 225 excavator

1 x Caterpillar D6C dozer

1 x Caterpillar generator

1 x Caterpillar loader

1 x Mack truck

Jigs and screens

An average of 10 persons were employed on this project, which also suffered damage from two cyclones early in 1980.

Endeavour Resources Limited operating at Moolyella reported the recovery of 165·7 tonnes of Sn O_2 concentrates from the treatment of 224 609 m^3 of alluvial material

The concentrating plant has the capacity to treat 100 m^3 per hour and an average of 33 persons are engaged upon this work.

Jervois Sulphate N.T. Ltd. Late in 1980 this group began to establish a campsite and treatment plant some 6–8 kilometres north of Hillside Station for the purpose of recovering tantalite and tin from known alluvial deposits in that locality.

Metana Minerals N.L. This group have advised that during 1980 they tested tin and tantalite deposits in the Woogina area and intend to establish a pilot plant capable of a throughput of some 150 tonnes/day during 1981.

ACCIDENTS

The total number of serious accidents during 1980 was 155 and there were 780 minor accidents. Figures for 1979 were 2 fatal, 127 serious, 620 minor.

VENTILATION

Surface Dust Sampling

Dust suppression and control in the iron ore industry has continued to improve during 1980.

There has been increased use of water cannons in quarries and on stockpiles, and reticulated water sprays on haulroads. Practically all drilling is now carried out using water injection and some drills are fitted with foam injection.

Exposure of some maintenance workers to high dust concentrations, which has been cause for concern, has been decreased by washing down the work areas before maintenance work begins.

The use of industrial vacuum cleaners for removal of settled dust in their crushing and screening plants is being evaluated by two major iron ore producers.

Exposure of track crews to dust from ballasting operations has been decreased by addition of water to the ballast before dumping. One mining company has opened a new ballast quarry to replace a quarry producing highly siliceous material.

Some mobile plant operators have been exposed to high dust concentrations caused by leaks in the cabs of their machines. These tend to be the older machines where cabs were fitted after the machines were introduced into service. Efforts have been made on some mines to improve the situation by fitting larger airconditioners to increase pressurisation.

Surface Gas Sampling

The use of cleaning and degreasing fluids was examined on iron ore mines. During the year there has been a general movement away from chlorinated hydrocarbon solvents to degreasing oils. The use of atomising sprays with these solvents has been discouraged and has largely ceased.

Some workers handling metal cleaners incorporating hydrofluoric acid were found to be ignorant of its hazards.

Twenty-four mercury vapour samples were taken and a significant number were above the standard of purity. Men involved in the handling of mercury and lead have been checked by means of urine samples to ensure their health is not affected by working with these materials.

Fumings

One fuming was reported and investigated. A workman was overcome by trichloroethylene fumes while applying adhesive to the inside of a bin being fitted with linatex.

PERTH INSPECTORATE

B. J. D. van der Hoek
Mining Engineer/Acting Senior Inspector of Mines

Activities in the Perth Inspectorate were highlighted by the go ahead for the Worsley Alumina Project, the announcement by Greenbushes Tin N.L. of a major tantalite ore deposit at Greenbushes and the recommencement of mining operations at Mt Magnet by Hill 50 Gold Mines N.L.

Mining of bauxite and mineral sands have remained the dominant activities in the inspectorate, however, gold has attracted many small operators into the field to mine shallow low grade deposits.

ALUMINA

Alcoa of Australia Ltd—13 980 500 tonnes of bauxite were mined from a total area of 173·9 hectares at the Huntly, Del Park and Jarrahdale minesites.

The refineries at Kwinana and Pinjarra produced slightly in excess of 3 500 000 tonnes of alumina. Kwinana and Bunbury remained the two ports for shipment.

Average depth mined was 3·76 metres at Del Park and Huntly and 3·66 metres at Jarrahdale.

The total number of persons employed was 3 545.

Rehabilitation of mined areas was achieved over 301·35 hectares.

Additional and replacement equipment introduced at the various sites included:—

Jarrahdale—Three 777 haul trucks, a 992C loader, a 16G grader, three 677D scrapers, a 54 000 litre water truck and an RD16B drill.

Del Park and Huntly—one D10 bulldozer, two 992C loaders, two 16G graders and a 637D scraper.

Kwinana—a new flash tank in building 30 and computerised control of the digestion process.

Construction work at the Wagerup refinery site continued throughout the year.

Worsley Alumina—preliminary site works and construction commenced on this project.

ATTAPULGITE

Mallina Holdings Ltd continued to mine and treat attapulgite at Lake Nerramyne and Narngulu respectively. Five thousand three hundred and forty-one tonnes of material was treated to produce products varying from oil drilling muds to kitty litter.

BUILDING STONE

Products under this title include railway ballast, road metal, armour stone, aggregate for concrete and granite blocks.

Operations at 15 quarries were reported, however, it is probable that other small quarries worked for short periods during the year.

Adelaide Quarry Industries Ltd operated quarries at Narrogin, Roelands, Yaringa, Mt Magnet and Moora to supply crushed aggregate for the Main Roads Department, various shires and private industry. Approximately 109 000 tonnes of crushed aggregate was produced.

Bell Basic Industries Pty Ltd continued to operate their quarry at Maddington throughout the year. Development of the new quarry is proceeding.

Forty-four persons were employed.

Bruce Rock Shire Council operated a granite quarry during the summer months. Seven thousand two hundred and thirteen tonnes of crushed aggregate were produced and six persons were employed.

John Holland (Constructions) Pty Ltd re-opened the Meckering quarry to provide an additional 58 673 tonnes of crushed aggregate for rail ballast and sleeper construction. Six men were employed.

Pioneer Concrete (W.A.) Pty Ltd operated quarries at Herne Hill, Byford and Walkaway. Fifty-eight persons were employed at the 3 operations.

New equipment introduced at Herne Hill included a 988 front end loader and a 750 cfm compressor.

The Readymix Group (W.A.) operated quarries throughout the year at Gosnells and Bunbury and for the latter part of the year at Chris Hill.

Product from the Chris Hill quarry is being used by Westrail for rail ballast.

A central control system in the crushing and screening section at Gosnells was introduced and has operated with few problems.

Sixty-two persons were employed at the 3 operations.

Wells Bros (Walkaway) this small quarry operated intermittently throughout the year to produce 6 071 cubic metres of crushed aggregate. Three persons were employed to operate the quarry.

Magnet Metal Industries Ltd produced 2 133 tonnes of quartz aggregate from their Mukinbudin felspar-quartz quarry.

CLAYS AND SHALES

Clays and shales suitable for brick manufacturing are mined at Maylands, Muchea, Bullsbrook, Cardup, Byford, Orange Grove and Bukerup.

These resources are becoming increasingly difficult to locate and mine in the Perth metropolitan area and manufacturers are being forced to transport the materials over longer distances.

Midland Brick Company Pty Ltd continued as the largest producer, employing 58 men and excavating 1 030 000 tonnes.

EMERALDS

Emerald Mining and Market Pty Ltd developed underground workings at the Aga Khan on behalf of Lightning Ridge N.L. and Great Eastern Mines N.L. Eight thousand carats of emerald valued at $48 000 were recovered.

FELSPAR

Chandilla Exploration and Investment Pty Ltd produced 328 tonnes of screened felspar from their Goodinow open cut in the Yalgoo Goldfield.

Magnet Metal Industries produced 2 240 tonnes of felspar from their Mukinbudin quarry in addition to the quartz aggregate mentioned under building stone.

GARNET

Target Minerals N.L. recovered 1 626·55 tonnes of clean garnet sand from 6 708 tonnes of sand treated at their pilot plant adjacent to the Northampton State Battery. Two men were employed.

GOLD

Peak Hill Goldfield

Ralgo Pty Ltd commissioned a 20 tonne/hour alluvial treatment plant on their Horshoe gold prospect.

Ore reserves of 500 000 tonnes of 3+ grams have been established.

Peak Hill Goldmines operated a sluicing plant at Peak Hill, when water was available, for a reported return of 2·971 kilograms of gold.

Murchison Goldfield—Meekatharra District

Whim Creek Consolidated N.L. commissioned their heap leach process early in the year. Lump material only is placed on heaps to permit the percolation of cyanide solutions. Fines are to be treated in a 450 tonne per day capacity carbon pulp plant.

One hundred and four thousand nine hundred and seventy-seven tonnes of ore were mined. Thirty men were employed.

Ingliston Gold Mine—The syndicate operating this mine treated 1 974 tonnes of ore for a return of 37·353 kilograms of gold. Fifty-four metres of winzing below No. 6 level proved the extension of the ore lense to No. 7 level.

A 5 tonne per hour ore treatment plant was installed and commissioned to treat ore mined by the syndicate at Meekatharra and Nannine.

MINERAL SANDS PRODUCTION STATISTICS

Company	Average Number Persons Employed	Tonnes Ore Mined (millions)	Minerals Produced (tonnes)						Total
			Ilmenite	Leucoxene	Monazite	Rutile	Xenotime	Zircon	
Allied Eneabba Pty. Ltd.	249	4·917	294 945	....	8 025	54 938	....	101 515	459 423
Associated Minerals Consolidated Ltd.—Capel	114	3·450	397 540	5 584	2 280	....	19	35 042	440 465
Associated Minerals Consolidated Ltd.—Eneabba	156	4·155	156 000	....	....	35 000	....	63 000	254 000
Cable Sands Pty. Ltd.	83	1·273	122 986	5 512	1 008	....	11	11 139	140 656
Westralian Sands Ltd	150	2·250	393 888	14 170	1 910	....	....	36 192	446 160
Total	752	16·045	1 365 359	25 266	13 223	89 938	30	246 888	1 740 704

Nannine Mining Pty Ltd continued to develop the mine until December when Bond Resources became the new owners. Twenty-five metres of shaft sinking, 114 metres of driving and 48 metres of crosscutting were completed.

Eight hundred and eighty-three tonnes of ore were mined, 199 tonnes of this being from stoping. Three hundred and sixty-five tonnes were treated at the Meekatharra State Battery for a return of 2·119 kilograms of gold and 0·345 kilograms of silver. Ten persons were employed.

A.M.V. Nominees commenced open cut mining at Gabanintha. One thousand four hundred and forty tonnes of ore were treated at the Meekatharra State Battery for a return of 2·228 kilograms of gold.

A number of prospectors are active in the area operating alluvial plants, small open cuts and metal detectors. No significant finds were reported.

Cue District—Australian Consolidated Minerals and Metals Exploration continued exploration on their Big Bell prospect. Feasibility studies are now underway.

Consolidated Resources N.L. re-opened the Comet mine at Pinnacles. A pneumatic conveyor unit to aid development of ore reserves has been installed.

Mt Magnet District

Hill 50 *Gold Mines N.L.* The orebody at the Morning Star has been re-evaluated and production from this mine is expected to commence in April 1981. In addition, ore will be obtained from the Water Tank Hill and Saturn prospects nearby.

Sixty-five metres of shaft sinking, 90 metres of crosscutting and driving and 13 metres of rising were completed.

New equipment installed at the mine includes a 45 kW Perry winder and headframe, a 336 kW MB Wild winder, a 800 kW Detroit generator and three 1 250 m^3 Sullair compressors.

Twenty-six houses have also been established in Mt Magnet.

V. & D. Ridolfo Pty Ltd are erecting a 6–8 tonne per hour gold treatment plant on their Black Cat lease. This will service ore won from the company's leases near Mt Magnet.

Many prospectors were active in the area. The only significant crushing was 284 tonnes for a return of 2·88 kilograms gold from the Leap Year mine.

Yalgoo Goldfield—Paynes Find District

Ark Gold Mine commissioned a 20 tonne/day treatment plant at Paynes Find and processed 1 600 tonnes of ore for a return of approximately 45 kilograms of gold.

The Ark shaft/stope advanced 30 metres to 260 metres. Potential ore lenses on adjoining leases are being investigated.

The Carnation, Scorpio and Horse Hole leases are the only other leases of interest being worked at Paynes Find. A total of 307 tonnes of ore were treated for a return of 2 kilograms of gold from these leases.

M. & S. Mining are treating tailings dumps in the area. An estimated 6 kilograms of gold have been extracted.

GYPSUM

Shark Bay Gypsum—gypsum continued to be mined in conjunction with salt extraction at Useless Loop. Two hundred and seven thousand one hundred and forty-eight tonnes of gypsum were exported.

Gypsum Industries of Australia Pty Ltd mined 11 606 tonnes of gypsum from Lake Cowcowing.

Swan Portland Cement mined 11 060 tonnes from the Lake Hillman deposits near Kalannie.

IRON

Australian Iron and Steel Pty Ltd produced 495 285 tonnes of pig iron from 839 554 tonnes of ore, a reduction of 30 per cent on the previous year. Three hundred and fifty persons were employed.

Agnew Clough Ltd (*Wundowie Iron and Steel*) Project produced 40 218 tonnes of pig iron from 67 478 tonnes of ore. One hundred persons were employed.

LIMESTONE

A total of 23 limestone quarries operate either on a full or part time basis in the metropolitan area and 7 operate in major country centres. The majority produce road base material. Armour and building stone are produced when required.

Cockburn Cement Company supplement their quarry product with limesand dredged from Cockburn Sound.

Bond Resources have become the largest producer of limestone materials in the metropolitan area since they acquired control of quarries previously operated by Balcatta Limestone and Kargotich and Orton.

Excluding truck drivers approximately 52 men were employed in this industry.

MANAGNESE

Universal Milling continued to selectively mine open cut deposits in the Mt Frazer Area of the Peak Hill Goldfield. One thousand six hundred and ninety-three tonnes with an average grade of 47·5 per cent Mn were produced.

MINERAL SANDS

Total production from the mineral sands operators increased by 111 242 tonnes over the previous year. A reduction of 48 persons in the workforce was reported.

Allied Eneabba Pty Ltd mined in a north easterly direction away from the primary wet plant at Eneabba. Ore haulage distances are now significant and as a result the company has introduced a scraper-truck system to reduce costs.

Hydrofluoric acid storage and mixing facilities at the Narngulu treatment plant have been modified to accept the anhydrous form of this acid.

Associated Minerals Consolidated Ltd

Capel Operations—mining operations continued in a south westerly direction and are now 4 kilometres from the secondary plant.

The "A" beneficiation plant was re-commissioned in January and operated throughout the year.

Eneabba Operations—throughput tonnage was increased to offset the lower grade ores being mined. Two additional thickners, a trommel and a tray plant have been installed and the mine feeder unit and primary concentrator were upgraded to meet the demand.

Cable Sands Pty Ltd—mining of the Ambergate orebody near Busselton was completed on 12 September and the primary wet concentrator was transferred to the Prowse Leases at Capel. Production at this site commenced on 27 October.

The Reichert Cone Concentrators at this plant were replaced with spiral concentrators to increase efficiency and throughput.

Additions to the Bunbury plant included a crossbelt in the ilmenite circuit; a four-roll high tension separator in the conductor circuit of the secondary dry plant and increased attritioning capacity in the secondary wet plant.

Westralian Sands Ltd—mining continued throughout the year at the Yoganup Extended and North Capel deposits.

Work was commenced on the conversion of the ilmenite dryer from oil to coal fired.

NICKEL

Western Mining Corporation Ltd—Kwinana Nickel Refinery

Production from the refinery was down by almost 21 per cent on the previous year, 17 448 tonnes of nickel being produced.

By-products produced were ammonium sulphate 101 226 tonnes, copper sulphide 2 274 tonnes and mixed sulphides 1 534 tonnes.

Three hundred and ninety-seven persons were employed.

SALT

Shark Bay Salt Joint Venture operations at Useless Loop continued throughout the year in conjunction with Shark Bay Gypsum.

Six hundred and seventy thousand five hundred and sixty tonnes of salt were harvested and 538 579 tonnes were exported.

A new salt harvester with laser operated automatic controls for filling trucks was commissioned.

SAND

Thirty-five sand pits were operated in the metropolitan area and 15 in major country areas. Many work on an intermittent basis, especially those controlled by Bond Resources.

Bell Basic Industries Ltd and The Readymix Group continued to produce silica sand for export.

Australian Glass Industries operated a sand pit to obtain sand for the manufacture of glass.

Excluding truck drivers approximately 55 persons were employed in these operations.

SCHEELITE

A 300 tonne trial parcel of scheelite ore from a prospect at Noongal (north of Yalgoo) was treated at the Northampton State Battery and gave a return of 2 972 kilograms of saleable concentrate.

Exploration work on the prospect is continuing.

TALC

Three Springs Talc Pty Ltd extended their pit in a south westerly direction, necessitating the removal of the office, laboratory and workshop. New facilities have been erected to the south east of the orebody.

Talc is now railed to and shipped from the port of Geraldton.

Additional equipment introduced includes three 25 tonne trucks, a front end loader and a drill.

One hundred and thirty-four thousand six hundred and ten tonnes of talc were mined of which 134 270 tonnes were saleable.

Fifteen persons were employed.

Westside Mines Pty Ltd—Inclement weather conditions and a competitive market dramatically affected production at the Mt Seabrook mine. Fifty-three thousand one hundred and twenty-seven tonnes of ore were produced for a return of 27 383 tonnes of saleable talc.

TIN AND TANTALITE

Greenbushes Tin N.L.—The sustained high world prices for tin and tantalite have permitted the company to continue mining the lower grade sections of the orebody. One million five hundred and forty-five thousand four hundred and eighty-three cubic metres of ore were treated for a return of 552·635 tonnes of mineral concentrate.

A decline was commenced and advanced 389·2 metres to intersect the north western end of the major tantalite ore deposit announced in October 1980.

A tin smelter was commissioned in June. Since then all cassiterite concentrate has been smeltered on site to produce 151·695 tonnes of tin metal.

Construction of a tailings retreatment plant was commenced and this is due for commissioning in March 1981.

New items of equipment introduced include an International TD25C bulldozer, a Caterpillar 988B loader and a Tamroc Hydraulic Two boom Jumbo.

Average number of persons employed was 225.

The Bowen Syndicate prepared a small quantity of saleable tantalite concentrate at their Warda Warra minesite by hand picking broken ore stocks.

Goldrim Mining (Australia) Pty Ltd purchased this mine late in the year and are currently upgrading treatment facilities.

VANADIUM

Agnew Clough Ltd completed the construction phase of their Coates Vanadium Project in July and have since treated 8 044 tonnes of ore for a return of 25 tonnes of Ammonium Vanadate. Further processing of this product to obtain Vanadium Pentoxide was delayed because of commissioning problems. These should be overcome early in the new year.

The orebody is lateritic in appearance and in the initial stages will be mined by shallow open cut methods similar to those employed in the bauxite industry.

The basic treatment process consists of crushing and screening, calcination, leaching, filtration, precipitation, drying and fusion.

VENTILATION

Staff shortages adversely affected the volume of work accomplished by the ventilation section of the State Mining Engineer's Branch. Notwithstanding this the two officers visited most mines in the inspectorate.

One hundred and thirty-two personal gravimetric dust samples were taken on employees working at various mine sites to test compliance with the Regulations. Thirty-six (27 per cent) of the samples taken exceeded the Standard of Purity. In addition to the above, 36 positional samples were taken.

Twelve respirable dust samples taken were found to contain less than 5 per cent free silica.

SUMMARY OF DUST SAMPLING

	Total Dust		Respirable Dust		Positional
	—SoP	+SoP	—SoP	+SoP	Other
Hard Rock Quarries	9	....	33	19	1
Mineral Sands	7	3	2	....	7
Talc	3	4	....	....	....
Aluminium	16	2	2	....	17
Gold	1	1	....	....	....
Iron	11	3	....	....	4
Nickel	6	1	....	....	1
Vanadium	1	1	....	....	....
Miscellaneous	5	2	....	....	6
Total	59	17	37	19	36

—SoP—less than the Standard of Purity
+SoP—greater than the Standard of Purity

Six diesel engined vehicles for use underground at Greenbushes were tested and issued with permits. The workload in this area will increase dramatically in the next year or so as Greenbushes Tin N.L. develops its underground mining operations.

Dust emissions in hard rock quarries and associated crushing and screening plants have improved generally.

The use of toxic and corrosive chemicals was examined on some mines. The inspections were carried out by a Ventilation Inspector and a chemist from the Government Chemical Laboratories.

Chlorinated hydrocarbons, peroxides, acids, alkalis, fluorides, and various solvents were investigated. Generally, the hazards involved with such chemicals were not widely known, and steps were taken to either educate the users of such chemicals, or to change to less toxic substances.

No prosecutions were brought during the year. A prosecution case against Western Mining Corporation Ltd commenced in 1978 was concluded. Details of the case are discussed elsewhere in the State Mining Engineer's report.

One fuming was investigated. A sand blaster connected his hood to a nitrogen gas main instead of an air-line. Different connections are now fitted.

KALGOORLIE INSPECTORATE

I. W. Loxton

Mining Engineer/Senior Inspector of Mines

GENERAL

The mining activity generated by the rising price of gold in 1979 has continued to expand in 1980 and the Goldfields region has enjoyed boom conditions.

During the year gold prices rose to a peak of $752.50 (Aust.) per ounce but had settled back to around $500 (Aust.) per ounce by December 31. This price has attracted mining companies and individuals from all over Australia and overseas to congregate in the Goldfields region of the State to prospect for gold.

Redevelopment of the Fimiston leases on the Golden Mile have been speeded up and Kalgoorlie Mining Associates expect to be producing in excess of 90 000 ounces of gold annually by the end of 1983. Estimated cost of re-opening the Fimiston leases and upgrading of the Oroya treatment plant is $25 million.

Kia Ora Gold Corporation N.L. commenced dewatering of the Marvel Loch Gold Mine in January and production from the mine commenced mid year. The mine was officially opened by the Hon. Minister for Mines Mr Peter Jones on August 24.

Negotiations have been completed for the re-opening of the South Paringa shaft and Consolidated Gold Mining Areas have announced a redevelopment and plant construction programme which will involve expenditure of over $8·5 million.

Western Mining Corporation recorded an additional bonus during the year when rich gold intersections were discovered at the Hunt decline nickel mine. Further rich strikes of gold were found at Snake Hill, some 90 km north west of Menzies and at the Rabbit Warren on Braemore Station, some 8 km north of Leonora. Prospecting for gold using metal detectors became very popular during 1980 and there have been many nuggets found, some weighing in excess of 200 ounces.

Construction of the Metallurgical Research Plant at Kalgoorlie was completed and metallurgical testing of uranium ore from Yeelirrie commenced.

Operations at the Seltrust nickel mine near Spargoville ceased during January, some 4·5 years after production commenced. Most of the surface facilities will be transferred to the Teutonic Bore copper, zinc and silver project where mining and milling operations are expected to commence early in 1981.

An oil shale exploration programme involving the expenditure of $17 million was announced during February. The area involved amounts to between 13 000 and 14 000 square kilometres mainly to the south of Kalgoorlie.

The North Kalgurli Mines custom gold treatment facilities were in great demand during the year and the decision to retain this facility for prospectors after the Company starts full scale mining activity on its own account early in 1981 was well received.

Prospecting activity was very prominent and the Departmental compressors were again in great demand.

Perhaps the most controversial issue involving mining during 1980 was the proposed new Mining Act. Opposition has come from many quarters and it is still uncertain if or when this Act will become law.

The number of persons employed in the mining industry within the Kalgoorlie Inspectorate increased during 1980 and was estimated at 4 289.

The activities which occurred during 1980 within the Inspectorate are summarised under the individual heading of mineral or metal mined and are as dollows.

ARSENIC

A small fuming plant was constructed on the old Wiluna Gold Mine lease to extract arsenic trioxide from surface tailings. No production nor sales were recorded.

CLAY

Chandler Clay Pty Ltd. A new dust extraction and collection system has been installed together with two new silos, at this operation. Production from tailings dumps continued to increase with new outlets being found in the Eastern States. To the year ended December 31, 1980, 5 283 tonnes of material were produced. Three men are employed on site at the mine and at the Kewdale packing plant an average of 9 men were employed.

CRUSHED ROCK

The Readymix Group (W.A.) were quite active during the year with mobile plants operating at Agnew, South Boulder and Esperance. At South Boulder some 59 000 tonnes of railway ballast was mined and crushed, together with sufficient smaller size metal to maintain production of their concrete sleeper operation at Parkston. Thirteen men were employed for five months at the Esperance quarry where rock was mined, crushed and stockpiled for future use in industry.

The crushing plant at Agnew produced screenings from mine waste material and operated for about three months.

R. & N. Palmer Pty Ltd re-opened a quarry near Mount Merrivale some 16 km east of Esperance for about 6 months. During that time they mined and transported rock fragments for the Esperance groyne.

The old Shire of Boulder crushing plant run by Caddy Pty Ltd operated sporadically during the year and crushed waste material obtained from the Mount Charlotte Gold Mining operations.

At Koolyanobbing, 12 915 tonnes of granite screenings were mined and crushed at the Wundowie Iron & Steel plant for the Main Roads Department.

COBALT

Western Mining Corporation continued mining cobalt from the "Patch" pit near Siberia and some 21 000 tonnes were produced. An active exploration programme in search of this mineral was continued throughout the year by Western Mining Corporation.

A limited geological sampling programme was completed by Norseman Mining N.L. on old workings north of Ravensthorpe. This project has since been abandoned.

COPPER

Progress at the Teutonic Bore Mine of Seltrust Mining Corporation Pty Ltd has reached the stage where commissioning of the 1 000 tonne per day treatment plant is imminent. Overburden stripping in the pit to a depth of approximately 70 metres amounted to 12 million tonnes and has exposed the cap of the ore body. A total of 2 723 metres of diamond drilling and 855 metres of percussion drilling was completed. Ore reserves are estimated at 1 927 000 tonnes @ 3·40 per cent copper, 10·01 per cent zinc, 0·73 per cent lead and 140 g/t silver. Power for the project will be supplied from the Agnew Mining Co. operations at Leinster and water from 8 wells in the Teutonic area. A mining work force of 90 personnel were employed at the end of the year. A sealed road is currently under construction from Leonora to Leinster and will pass by Teutonic. Concentrates will be sent to Leonora by road and then by rail to Esperance or to the Eastern States.

A small amount of fertilizer grade ore was crushed from the Marion Martin mine late in the year and sold to C.S.B.P. at Esperance. The Elverdton and Cattlin mines lie dormant at present.

GOLD

The announcement by Southern Goldfields that a geological survey had shown that a possible extension to the Golden Mile could exist under the western portion of the Kalgoorlie townsite was greeted with some scepticism by sections of the public and mining fraternity. To date several shallow percussion holes have been drilled by the Company in the western section of the townsite including the racecourse.

Kalgoorlie Mining Associates continued to increase production at their Mt Charlotte operation. Ore broken amounted to 741 000 tonnes while treatment throughout rose by 10 per cent to 793 000 tonnes and despite a drop in ore grade, some 2 904 kg of gold was recovered. The decline has advanced to below the 20 level of the main ore body and testing of the southern ore body at the 17 level is still in progress. A surface drilling programme has confirmed the continuance of the Mt Charlotte ore bodies at depth and plans are in hand to commence sinking a new shaft in 1981.

At the Fimiston leases development work continued off the Perseverance and Lake View shafts. Stoping operations were also commenced. Because of the poor condition of the upper portion of the Perseverance shaft, the shaft was refurbished with steel sets to the 4 level. Ore broken at Fimiston amounted to 57 900 tonnes, of which 27 600 tonnes were treated without roasting and the gold recovered amounted to 96 kg.

Tributes were phased out by the Company and only 1 200 tonnes were mined from open cut operations.

Expansions to the Oroya treatment plant have commenced and include the construction of a fluo-solids roaster, additional crushing, grinding and flotation circuits plus a thickner tank. It is expected that the plant will be fully operational by mid 1981. Proven ore reserves are quoted as: Mt Charlotte—4·8 million tonnes @ 4·9 g/t; Fimiston—1·2 million tonnes @ 8·2 g/t. The average number of employees for 1980 was 464.

North Kalgurli Mines Ltd made good progress with its Main shaft rehabilitation and development programme, Following the completion of a surface diamond drilling programme, development work has commenced off the Main shaft at the 10, 19 and 20 levels to intersect targets established from the diamond drilling.

Dewatering operations were commenced at the Croesus shaft and by the end of the year the water level had been lowered to below the 10 level. Shaft repairs have been completed to this horizon. Due to shaft mishaps, which included a winding rope breaking, operations were not going as smoothly as planned towards the end of the year.

To enable the refractory suplhide ore to be treated from their Fimiston leases, North Kalgurli has let a contract for the design, construction and commissioning of a fluo-solids roaster at the Croesus plant. The contract is expected to be completed about August, 1981.

Other plant expansion included a carbon in pulp circuit to treat part of the State Battery dumps which have been purchased from the W.A. Government.

The custom mill treated 98 000 tonnes of prospectors ore while the Company stockpiled 18 000 tonnes of sulphide ore from development and stoping operations.

Average number of men employed during the year amounted to 151.

Consolidated Gold Mining Areas have announced that approximately $20 million will be spent on re-opening the Paringa leases at Fimiston. The leases, which are situated on the north eastern side of the Golden Mile, have been the subject of a detailed feasibility study by the Company in recent months.

Refurbishing of the south shaft has commenced and a small amount of ore has been mined from an open cut south of the Paringa south shaft.

At the Daisy mine at Mount Monger, work has commenced to re-open the Milano shaft and it is hoped to establish a connection with this shaft and the Daisy main shaft by developing in ore at about the 3 level horizon. Ore reserves at the main shaft are about exhausted and this shaft could possibly close down during 1981. At the present time an average of five men are employed at the mine.

Hampton Areas have tributed their White Hope mine out to a five-man syndicate who have to date broken some 3 000 tonnes of ore despite many setbacks to the development of a hydraulic winder. The mine produces an average of 40 tonnes per day from a large shrink stope above the 5 level.

In the Ora Banda area, Dampier Mining was very active in the exploration field, completing thousands of metres of percussion drilling.

W.M.C. commenced an open pit operation at Camperdown, north of Siberia, and had stockpiled over 5 000 tonnes by the end of the year.

Gold production also commenced in earnest at the Hunt decline and Silver Lake shaft with 63 871 grams of gold being won from 60 500 tonnes of ore. Gold ore reserve figures at Kambalda now stands at 1·1 million tonnes averaging 4·7 grams per tonne.

Substantial developments marked another year of expansion for the Central Norseman Gold Corporation at Norseman. Ore reserves increased markedly to 641 000 tonnes. Production was up over 50 per cent to 141 500 tonnes whilst the ore treated through the Phoenix Plant increased by 10 per cent to 146 900 tonnes. The increased plant throughput only resulted in a slight increase in gold recovered, thereby signifying a general lowering of ore grade.

The North Royal headframe winder and associated support buildings were removed and No. 3 open pit commenced. It had reached a depth of 15 metres by the end of the year with over 1·5 million cubic metres of overburden having been removed. The Royal decline was completed at 660 metres of decline length and connections were made to the 4 and 5 level of the Royal mine.

The Ajax shaft was cleaned out and refurbished with steel sets to a depth of 330 metres.

Work is continuing, and preparations are now being made to pump out the Butterfly mine via the Brown shaft.

The new North Royal wash plant was commissioned in February 1980 and has treated over 68 000 tonnes of ore.

The Phoenix Plant continued to be upgraded. A new warehouse was built and the 3 fine-ore bins were reclad. Four secondhand generating sets were installed in the powerhouse.

Average number of employees was 366, which represents a 46 per cent increase on last year. To accommodate the workforce, 30 additional houses were provided in Norseman.

The Company continued to be active in exploration around Norseman, having pegged over 200 Mineral Claims. Seven new Gold Mining Leases were also applied for.

Various other Companies have been very active in the Norseman area and one that stands out is Australis Mining, a Company which controls some 25 square kilometres around the town of Norseman. During the year the Company announced a joint venture with the exploration division of C.R.A. to diamond drill predetermined areas.

At Kundip, located south of Ravensthorpe, Norseman Mining N.L. cleaned out the Harbour View shaft for an underground sampling programme and also conducted a diamond drilling programme to try and prove up sufficient ore reserves to warrant re-opening the Elverdton plant. The project was not successful. Several private mines also operated in the Ravensthorpe district periodically during the year, together with one tailings treatment project.

In the Yarria district, Pennzoil of Australia continued their diamond drilling programme of the Porphyry Mine ore body. The Company were also very active in obtaining options over small gold mines in the district.

A syndicate have re-opened the Yilgani Queen mine and had repaired the Melody shaft and built a five-head stamp battery by the end of the year. Several successful crushings had been put through from development ore on the 5 level. Stoping has commenced on the 4 level. About 8 men were employed.

No significant new ore discoveries were made at the Aspacia mine at Menzies during the year, even though 383 metres of diamond drilling were completed. The Company will have to sink the shaft now to remain in production. As most of the year was spent stoping, production rose almost 50 per cent to 1 053 tonnes. Six men are still employed. Ten metres of driving was completed during the year and the Company recovered 13 247 grammes of impure gold from crushings at the State Battery.

The Yunndaga Sands Retreatment enterprise was sold during the year and a major upgrading programme has commenced. It is anticipated that 1 000 tonnes of tailings per day will be treated by the carbon in pulp method when the upgrading programme is completed in mid 1981.

Spargos Exploration and Queen Margaret Gold Mines spent most of the year at Mt Ida gearing up to commence production by upgrading the surface facilities to house a thirty-man permanent workforce, building a complete new plant and refurbishing the Timoni shaft to the 6 level. A limited amount of stoping from the 3 level south, was undertaken, and about 1 000 tonnes of ore was stockpiled on the surface. Twenty-three metres of driving was done off the Timoni shaft and the winder upgraded to haul 1-tonne skips.

Three men continued to mine the Corida ore body south of Mt Ida and produced 900 tonnes of ore. Some 57 metres of driving on ore was completed and a 6-metre winze was also sunk.

Towards the end of the year, Jones Mining commenced shaft sinking at the Goodenough mine east of Menzies. Only the collar area was prepared and a few metres of shaft sunk before Christmas. Three men were employed.

A small rich gold strike at Snake Hill near Mt Ida received some publicity towards the end of the year and was drilled by Queen Margaret Gold Mines under option from the prospector. No results were announced.

Most of the Kookynie-Tampa area is now pegged and also the Callion-Daveyhurst district. A small plant was built at Callion but no production was recorded.

In the Mount Margaret Goldfield the most significant development during the year was the re-opening of the Lancefield gold mine by Western Mining Corporation. This mine will be worked in conjunction with the Windarra Nickel Operation where the concentrating plant is to be modified to accept both free milling and refractory gold ores. Initial investigations of the northern extension of the main ore body were made through an existing shaft down to the No. 3 level. This led to a decision to sink a new vertical shaft to a depth of 180 metres. Preliminary work on this new shaft has begun

The Tower Hill mine at Leonora produced a large amount of rich ore, the majority of which was transported to the custom mill at Kalgoorlie by a road train owned by the 4-man syndicate who operate the mine on tribute from Golden Valley Mines.

The Sons of Gwalia leases continued to produce worthwhile parcels for 3 groups of prospectors operating in the oxidised zone.

Open cut mines around Laverton, Linden and Abednego Hill and Tarmoola also produced worthwhile returns for prospectors.

A frenzy of pegging activity took place in the area of the "Rabbit Warren", some 8 kilometres north east of Leonora, following news of 2 prospectors unearthing a patch of gold using gold detectors. The tenements were much sought after by various Companies. To the end of the year, only one hole about 3 metres deep had been sunk on the prospect.

At Mertondale, a syndicate commenced installing a pachuca tank system to retreat some 80 000 tonnes of residues on the old Merton's Reward gold mine.

Goldstock Mines Pty Ltd have erected and commissioned a gold tailings treatment plant at the old Youanmi gold mine, south of Sandstone. The plant is capable of treating 400 tonnes per 12-hour day using the carbon in pulp technique and is operated by 5 men. Some 30 000 tonnes have been treated.

Also at Youanmi, 3 men have rehabilitated the Conomara gold mine and have taken out ore parcels from the 38- and 49-metre horizons for crushing at the Boogardie State Battery.

At Barrambie, the Scheelite gold mine was worked spasmodically to produce 30 ounces of gold from 82 tonnes of ore. Twenty metres of development and 600 metres of percussion drilling were done during the year. The old Barambie gold mine was entered during the year and a parcel of 45 tonnes of ore extracted from underground but gold return was very low.

Prospectors were very active in the Yilgarn Goldfield. Two carbon in pulp treatment plants are operating adjacent to the Frasers mine at Southern Cross and another erected at the Rickies gold mine at Parkers Range.

Boomalli Limited have also been very active during the year and have constructed a 10-head battery some 2–3 kilometres south west of Southern Cross.

An extensive drilling programme of the Nevoria gold mine was commenced during the year by Dampier Mining Company Ltd.

Kia Ora Gold has dewatered and rehabilitated the Marvel Loch gold mine and production has commenced from the 300 and 400 levels. Modifications have been carried out to the existing headframe and a self tipping skip placed into service for ore haulage. The original shaft winder has been upgraded to suit regulation requirements and recommissioned.

The Company was also active outside the Marvel Loch area and acquired options over the old Corinthian Mine and the Lenneburg gold leases. At the Corinthian mine an open cut was developed and a substantial sampling programme carried out prior to exercising the option. Because of low gold values this operation closed down towards the end of the year. In the treatment plant, a carbon in pulp section has been added to the gold circuit and a stripping plant constructed.

Golden Valley Mines N.L. have acquired various gold mining operations formerly owned by West Australian Gold Development. The Francis Furness Gold Mine located some 8 kilometres south of Marvel Loch has been the main source of ore supply for Golden Valley Mines during the year.

Work is also in progress to dewater and refurbish the Frasers No. 3 shaft so that a re-appraisal of the mine's potential can be made.

The Radio gold plant located 8 kilometres north west of Bullfinch was substantially upgraded during the year. The circuit was redesigned and a new rod mill and an agitating cyanide tank was installed. A carbon in pulp circuit and desorption process has also been introduced to the gold circuit. Because company ore production was not sufficient to keep the mill running at full capacity, some custom milling was carried out for prospectors operating in the Yilgarn Goldfield.

GYPSUM

Mining of gypsum from the shores of Lake Seabrook continued with 31 403 tonnes being railed from the Koolyanobbing rail terminal to the metropolitan area. Three contractors are employed by W.A. Plaster Mills and carry out the work of loading screening and carting the gypsum to the rail site.

H. B. Brady Co. Pty Ltd railed some 22 289 tonnes of gypsum from the Lake Brown deposit with 26 205 tonnes being harvested and 15 488 tonnes being stockpiled. Two men are employed at the mine site.

IRON

Dampier Mining Company continued Iron Ore mining with a significant increase in total ore production as compared to the previous year's figures. Ore reserve figures also increased from 197 million tonnes to 221 million tonnes. Little progress was made on bench 9 at the Dowd's Hill deposit as the Company continued to advance the upper benches. From the "D" deposit tonnes railed increased by 228 per cent over the previous year to allow for blending with the Dowd's Hill deposit to meet required phosphor content contained in the ore. No exploratory diamond or percussion drilling was carried out but work was in progress on "F" deposit to clear drill sites to prove the potential of this area. Ore broken during the year amounted to 1 899 407 tonnes and the number of full time employees was 116.

It appears that Wundowie Iron & Steel are experiencing difficulties. A total of 53 086 tonnes of iron ore was railed which was a decrease of 41 946 compared to the previous year. The grade of ore remained static at 62·5 per cent iron.

MAGNESITE

Norseman Mining N.L. also attempted to re-open their magnesite deposit at Bandalup. A trial parcel of some 3 000 tonnes was mined for overseas assessment, however no plans for large scale mining were forthcoming.

NICKEL

The world market for nickel remained satisfactory during the year and hence Companies mining this metal were able to maintain and in some cases increase production.

Western Mining Corporation continue as the largest producer and were very active in the exploration field where diamond drilling increased by 24 per cent and percussion drilling by 174 per cent.

The Carnilya Hill joint venture operation and the newly sunk Long shaft commenced to add appreciably to the Kambalda nickel production figures.

At the Foster Shoot, work is in progress to commence access to the known ore bodies in this area. Workshops, changerooms and administration buildings are now being installed in preparation for the underground work.

Exploratory diamond drilling revealed extensions to the Edwin, Foster and Carnilya Hill nickel ore bodies and although 1·4 million tonnes of ore was mined from the Kambalda field, ore reserves for the 1980 year increased by 0·6 million tonnes.

The Otter Juan ore body continues to be the highest individual producer of nickel ore in that it produces approximately 35 per cent of the total monthly tonnage at Kambalda.

Ore production at the Silver Lake shaft fell steadily during the year. This shaft, which was the first producing nickel shaft, has made a valuable contribution to the Kambalda Nickel Operations.

W.M.C. has acquired an option on the Mount Edward mine of International Nickel and development work was commenced on the 600 and 800 levels to substantiate current quoted reserves and to obtain ore for metallurgical testing.

In the nickel concentrator at Kambalda, a Reichert Cone gravity gold circuit was established to treat the gold ores being won from the various operations. During treatment through this circuit, approximately 60 per cent of the gold is recovered. This is a free milling circuit and the gold not recovered continues on through the nickel concentrator and finishes up in nickel matte produced at the Smelter. Plans are now in hand to build a new cyanide plant near the concentrator so that a better recovery of gold is obtained.

There were no significant changes to operations at the W.M.C. Nickel Smelter during the year. Slightly less concentrate was treated during the year, partly because of wet weather at Leinster preventing Agnew shipments. Less cobalt laterite was treated also.

On January 19, 1980, the Spargoville mining operation of Selcast Exploration Ltd ceased production. Fill was introduced into the open stope areas of the mine to stabilise the areas. The surface pillar above the open stopes was also cable bolted.

Metals Exploration Ltd maintained a 3-shift per day operation at their Nepean mine. Nickel metal production increased by some 35 per cent. Upper level ore reserves are depleted and main production is now confined to the 900, 1 100 and 1 200 foot horizons. During the year a decline was commenced from the 1 100 level to develop the remaining ore below the 1 200 level. Additional equipment including a 2-boom jumbo and two 2–3 cubic metre LHD diesel units have been purchased for this work. It is anticipated that the decline will be advanced to the 1 400 level horizon. A further expansion of the Company's housing scheme at Coolgardie was carried out at a cost of $336 000.

A study has been initiated by Metals Exploration to evaluate the feasibility of mining the Wannaway nickel deposit under agreement with Outokumpu Oy of Finland. At Wannaway, 6 diamond drill holes totalling 4 220 metres have been completed to test the depth extension of nickel sulphide minerisation previously outlined by Anaconda and C.R.A.

Agnew Mining Company Pty Ltd pushed ahead with their major shaft sinking programme whilst developing and mining the narrow high grade ore shoots through the decline access. At the close of the year the shaft had reached a depth of 989 metres following a decision to extend the shaft to a final depth of 1 165 metres.

A new service double drum winder having 6·1 metre diameter drums equipped with disc brakes, has been installed in readiness when shaft sinking and headframe construction is completed. All ore production came from the decline mine where 6 stopes are worked with trackless diesel equipment. Floor pillar extraction had begun in one of the stopes. A wide section of the ore body was being prepared for long blast hole drilling. Development of lower levels was actively pursued as the decline reached planned development horizons. At the end of the year, the decline face was about 270 metres vertically below the surface. Ore production almost doubled from the previous year but the workforce increased by only 32 personnel to a total of 286.

At the Western Mining Corporation's Windarra Nickel Project, development and stope preparation work was somewhat increased from the previous year's performance. Resultant ore was stockpiled as the treatment plant remained idle. Preparations were made for construction of a vertical haulage shaft which is anticipated to commence early in 1981. Depth extension of the decline reached about 500 metres vertically below the surface, or about 5 kilometres from the portal. This development has increased ore reserves at the Mt Windarra mine by almost 1 million tonnes to 6·8 million tonnes averaging 1·55 per cent nickel. No work was done on the South Windarra ore body.

SALT

W.A. Salt continued production of this product in the Esperance area and some 17 000 bags of salt were produced. At their Lake Deborah operations some 9 976 tonnes of salt was harvested.

Due to an increased demand for salt, Lefroy Salt Pty Ltd recommenced production at Lake Lefroy during the year with 134 144 tonnes of granular salt being produced and 135 658 tonnes being exported through the port of Esperance.

In March, 1980, Sumitomo Corporation of Japan withdrew from the project and the whole of its interest was purchased by Norseman Gold Mines N.L. In November, 1980, Forestwood Australia Pty Ltd of Sydney acquired a 51 per cent interest in Lefroy Salt from Norseman Gold Mines.

SILICA

At Western Mining Corporation's Siberia operations, the deepening of the open pit produced another 207 000 tonnes of silica flux for consumption at the Nickel Smelter. Private contractors using road trains transported 23 000 tonnes to the Smelter.

TIN

Agreement was reached with Western Mining Corporation Ltd for the Aberfoyle Tin Company to construct a pilot plant at the Nickel Smelter to metallurgically test 3 000 tonne of tin ore shipped from Tasmania. This site was selected because of the availability of a high stack to disperse any high concentrations of toxic substances that could form during the testing of the ore.

URANIUM

Western Mining Corporation operating as Yeelirrie Management Services Pty Ltd, excavated a pit at Yeelirrie to supply uranium ore to the Kalgoorlie Research Plant. The pit, some 125 metres in diameter, attained a depth of 10 metres and produced 120 286 dry tonnes of ore assaying +0·05 per cent U_3O_8 and 25 044 dry tonnes of waste assaying —0·05 per cent U_3O_8. From September, the ore was progressively transported to Kalgoorlie and by the end of the year it amounted to 1 775 dry tonnes. Some 79 962 metres of rotary drilling was completed in the main ore zone to define ore potential for future mining. Ore reserve is quoted at 33·8 million tonnes at 0·14 per cent U_3O_8 using a cut-off grade of 0·05 per cent U_3O_8. During the year the workforce varied between 30 and 40, however mining operations had ceased by the end of December.

Construction of the Kalgoorlie Research Plant was completed during the latter part of the year and on September 22, the first parcel of ore was fed to the plant.

Some exploration work was completed by the Delhi consortium at Lake Way during the year. No results are available.

VERMICULITE

Vermiculite Industries report a slackening of demand for their product on local markets. Only 159 tonnes were transported from their mine stockpile at Young River.

VENTILATION

Dust Sampling

A total of 429 gravimetric dust samples were collected by ventilation staff during the past year. A breakdown of these samples is as follows:

(a) Personal samples—242, of which 56 (23·1 per cent) exceeded the SOP for the particular dust sampled.

(b) Workplace samples—116, of which 14 (12·1 per cent) exceeded the SOP for the particular dust sampled.

(c) In addition, 71 positional-total dust samples were taken.

Due to the siliceous nature of various rock types, some of the nickel mines are now sampled for respirable dust.

The presence of oil mists and vapour in underground mine air may be contaminating respirable samples. An investigation into this aspect will be undertaken during 1981.

Underground—Diesel Engines and Associated Gas Sampling

Eighty-five permits for diesel engined equipment to be used underground were issued in 1980. (This compares with 62 permits issued in the previous year). Approximately 50 per cent of these new permits were allocated to various types of personnel carriers. A larger number of diesel engined air compressor permits were also issued. Several Companies now utilise large diameter hole drilling techniques and the compressors are required to supplement the normal underground air supply.

The undiluted exhaust emissions of 271 vehicles were tested for Carbon Monoxide and Nitrous gas concentrations. Of these, 4 (1·5 per cent) were found to exceed the CO limit of 2 500 ppm, whilst 2 (0·7 per cent) exceeded the limit of 2 000 ppm for oxides of nitrogen.

Frequently, underground loaders were found to be operating with an undiluted exhaust gas temperature in excess of 93°C. High temperatures were due mainly to empty water reservoir tanks or blocked cooling sprays.

Temperatures

Temperature and humidity conditions were routinely checked at all underground work places visited. Only 11 (1·3 per cent) of 857 areas tested were found to contravene Mine Regulations. Generally, ventilation conditions were found to be satisfactory, but problems observed included:

(a) Ventilation ducting too far back from the work face.

(b) Ventilation duct in poor repair.

(c) Poor location of ventilation fans—recirculation problems.

Companies were reminded that closer supervision was required to reduce the regular occurrence of the above problems.

Underground Airflows

Primary ventilation curcuit problems existed in two mines. Short circuiting of airflows due to changing stoping conditions existed in one mine, whilst the other mine had its primary exhaust airflow severely restricted due to salt encrustation blockages in the raise holes. In some instances, the cross-sectional area of the raises was reduced by up to 50 per cent.

Ventilation conditions at one Kambalda mine have improved. During the year, a major exhaust air raise was constructed from the No. 11 level to the surface, and an additional raise from the No. 17 level to the No. 11 level is in progress.

Underground and Surface—Natural Gas Emissions

Pockets of gases were encountered in a drill hole collared on the Kalgoorlie State Battery Reserve. This hole was being bored for a local mining company to test potential gold ore zones. This Company also experienced a gas flow in one of their underground development headings. Previous history predicts that similar occurrences may be expected in the future.

Two other minor gas flows were investigated in the Kalgoorlie Inspectorate. Tests were carried out at each occurrence and minor percentages of methane, carbon dioxide and carbon monoxide could be detected.

Fumings

During 1980, there were 5 reported fuming accidents, of which 4 were underground incidents.

Two electricians reportedly became ill after cleaning down an electric motor with compressed air. Investigation revealed that it was highly unlikely that the workmen were overcome with toxic gases. In the process of cleaning the motor, they had created a considerable amount of dust and this had caused a great deal of irritation and discomfort.

None of the underground fumings were regarded as very serious, as each of the workmen involved had returned to his normal duties the following day. Three involved diesel fumes and the other involved blasting gases.

Fires

Two underground and 2 surface fires were reported.

A fire in a surface compressed air receiver was possibly caused by a "hot spot" generated from a broken delivery valve on a compressor. The fire ran through connecting pipework to the receiver where a minor explosion may have occurred, followed by burning of oil residue.

The other surface fire occurred in a screen house. Hot welding slag ignited rubber liners and caused considerable damage.

Both underground fires involved mobile diesel equipment. One was attributed to a burst hose spraying hydraulic fluid onto the hot exhaust, and the other was caused by short circuiting of electrical wiring.

Miscellaneous

Officers of this Department assisted the management of a local company in the cleanup and securing of asbestos insulating material used in an electrical substation. Conditions are now satisfactory.

The majority of mine employees exposed to lead now undergo blood lead tests in preference to urine analyses. This method is more accurate and less tedious.

New dust and gas sampling equipment is continually tested and appraised by ventilation staff. Several new instruments were purchased during the year to assist the Department and Companies in monitoring programmes.

STAFF

Mr G. Huxtable completed his 3 year term with the State Mining Engineers branch as the Special Inspector of Mines (Machinery) and returned to Perth early in the year. His replacement was Mr David House, who commenced duties on January 14, 1980.

Mr R. Fraser, Special Inspector of Mines (Ventilation) terminated his employment with the Department on April 11, 1980. His replacement, Mr D. Austin, was appointed as District Inspector of Mines (Ventilation).

Ventilation Officer Y. C. Cheah resigned from his position on August 15, 1980 and Mr D. Lenigas was appointed to this position on December 1, 1980.

Mr T. Sullivan, Workmens Inspector of Mines retired on June 30, 1980 and at the subsequent election for two Workmens Inspectors of Mines, Mr R. Leggerini was re-elected and Mr R. Strachan replaced Mr T. Sullivan.

COAL MINING

R. S. Ferguson

Mining Engineer—Senior Inspector of Coal Mines

An output of 3 000 000 tonnes of coal was attained and exceeded for the first time. This followed a series of 5 consecutive years in which over 2 000 000 tonnes of coal were produced annually. The output of 3 151 469 tonnes produced during 1980 was 416 239 tonnes more than the previous record output of 2 735 230 tonnes produced during 1979.

The open cut component of the total output from the field was won from the Muja and Western No. 5 Open Cut Mines and amounted to 2 520 708 tonnes or practically 80 per cent of the year's output.

The total value of the coal produced during 1980 was $60 717 343, an increase of $16 309 463 compared with the 1979 value of $44 407 880.

Western Collieries Limited—Western Mine No. 2

The new record output of 630 761 tonnes of coal produced during the year was 38 111 tonnes more than the previous year's then record output of 592 650 tonnes. The increase was practically the same as for the previous year when it was 38 101 tonnes. This was the fifth successive year in which the output from this mine exceeded 500 000 tonnes. The output from this mine was the entire underground mined production for the field and was practically 20 per cent of the output of the coalfield.

The continuous miner installations in No. 3B East District "A" Panel where a Dosco Dintheader has been operating since September, 1979, and where an Alpine AM50 commenced production in July, 1980, have demonstrated that, in pre drained areas of the mine where firm, competent floors exist and hydraulically induced roof weight is not a problem, continuous mining units may, providing ventilation and dust control requirements are met, be viable alternatives to the cyclic, semi mechanised production methods involving drilling, blasting and loading out by trackless diesel powered front end loaders.

The workings which are being developed in from the South East Entries where work commenced in May 1976 are commonly referred to as the East Extended Area and are physically separate from the other extensive workings of the colliery. The dip development drivages where gradients of 1:8 are being encountered are generally to the west of the original entries and are widely separated from the workings in No. 1 South "C" Panel which is at the southern limit of the colliery "take" and is constrained between the Wyvern Seam subcrop line and a major fault. A new axial flow fan is to be installed in the near future to ventilate these East Extended Area workings from which a quantity of 228 171 tonnes of coal was won during the past 4½ years.

Panel layout modifications approved by the Hon. Minister for Mines during the year were for the East Extended No. 1 South "C" Panel and for the following areas where pillar splitting proposals were approved: No. 4A West District "C" Panel; No. 6A West District "A1" Panel and No. 6A East District "C" Panel. Pillar splitting was completed in the lower sub panels of the latter area and also, in No. 3B West "A" Panel".

The highest coal production areas are generally in dry or relatively dry, blocked out and rise working places while extremely wet and difficult conditions exist in some of the development headings and dip workings. Roof collapses accompanied by heavy inflows of water provide some difficulties.

Extensions to the current main pumping arrangements provided mainly by five continuously operated S.E.C. borehole submersible pumps, backed up by the colliery's pumping installation of tandem centrifugal pumps, through a rising main borehole are being considered.

Positive moves were made toward securing necessary compliances with the regulations in regard to the guarding and fencing of machinery, rationalising and improving the handling of explosives and detonators and providing multi-purpose fire extinguishers throughout the colliery.

Western Collieries Limited—Western No. 5 Open Cut

This mine was the only unit to show a decrease in output when compared with the previous year. All of the orders for coal were met and the year's production of 783 421 tonnes was 98 338 tonnes less than the previous year's record output of 873 759 tonnes. This was, however, the third successive year in which the mine produced over 750 000 tonnes of coal.

The coal winning and overburden removal sites were mainly at Widespread areas of the south end of the Main Excavation and at the separate Western No. 5B Excavations. Difficult, heavily watered ground conditions were experienced in the former area where continual close supervision and selection of highly skilled operators were necessary. The Western No. 5B Area was extensively opened out and included complex geological structures with step and scissor faulting and steep gradients.

The extensively backfilled areas of the Main Excavations appeared to be satisfactory in all respects, from the topsoiled area at the north end to the "active" or current dumping sites where edge dumping was practised on height limited, terraced profiles. Systematic backfilling of Western No. 5B overburden into the mined out Western No. 5A Excavation continued with maximum heights of truck dumped "lifts" being kept to 15 metres, to maintain stability. These ranged from surface level down to the bottom lift near the scraper formed "key" or bund along the bottom of the high wall. Systematic dumping procedures to provide for the containment of slurry type overburden were essential in the ongoing programme of integrated mining/backfilling. These matters were influenced by weather, site conditions and safety considerations.

At the completion of winter seeding in mid August, approximately 25 hectares were completed, mainly on dumps, bringing the total area now treated to approximately 85 hectares. Areas topsoiled and seeded during the year and rehabilitation completed prior to 1980 were delineated on a plan relating to the Company's Fifteen Years Programme of Rehabilitation. The seed mixture of 20 different native species should provide a quick ground cover and assist in preventing erosion in the widespread areas concerned. The "dished" or catchment shaped tops being formed on scraper dumps are expected to minimise water erosion and scouring of sides and also, make water available for vegetation.

Lighting was well provided, with effective use made of pole mounted clusters of lamps arranged with the poles bottoms wedged into holes in concrete set in tyres on steel sledges. The flexibility of this system, with the extended main lighting around the roads and surface areas provided adequate lighting in and around the workings.

A Komatsu HD 1200M-1 Dump Truck was put into service late in the year. This 120 tonne, mechanical drive vehicle is a prototype unit, the performance of which is being carefully assessed.

The Griffin Coal Mining Company Limited—Muja Open Cut

There was a large increase of 467 766 tonnes in output from this mine where the output of 1 737 287 tonnes was a 37 per cent increase over the previous year's then record output of 1 269 521 tonnes. This was the fifth successive year in which over one million tonnes of coal were produced from this mine, the largest single producer on the field.

The extensive excavations at this widespread mine included coal winning from the 9 seams from and inclusive of "Ate" down to "Iona". The excavations were at various levels from forward stripping of top overburden with mobile scrapers on Block No. 10 down to exposure to Iona Seam coal on Block No. 8 at a depth of approximately 110 metres.

The two Demag H241 Hydraulic Excavators and the complementary fleet of WABCO Haulpak 120 tonne dump trucks were at the vanguard of the significant progress made on Blocks Nos 8 and 9, East Section Panel No. 7, and the North Extension. Other extensive ranges of high capacity excavation and haulage equipment were in use throughout the mine.

Safety aspects of backfill dumping received considerable attention. Monitoring of pore water pressures, maintenance of correct profiles, proper drainage, and selection of debris for placement were important factors in maintaining stability. These and other geotechnical aspects relating to the depressurisation of sub artesian aquifers under the floor strata, dewatering of sediments above and below the Hebe Seam, and minimisation of ground water access to the excavations were under constant review. Success with the depressurisation programme enabled winning of the Iona Seam to be contemplated in the area between the toe of the backfill and the Hebe Seam coal face line.

All Hebe Seam coal on the upthrow side of the fault along the East Extension was exposed to the northern limit of the currently opened out excavations. Most of this coal was also won.

At the steeply inclined west wall, there was a creep of sedimentary strata over the granite where the coal measures contact with the edge of the basin was encountered. Remedial works were effected and the area was worked safely.

A major programme was under way for the construction of new workshops and administration offices, including the extension of existing ones. Major mine dewatering and drainage programmes, including new borehole submersible pumping arrangements to handle water from the abandoned Hebe Mine to Muja Power Station were in progress.

Lighting arrangements were generally very good in and around the excavations. Steel constructed, sledge mounted lighting towers, ranging in height from 12·2 to 18·3 metres, mainly the latter, are fitted with 4 x 400 watt mercury vapour lamps. One thousand watt lamps were installed on the tower in the forward stripping area.

The Company's Mining and Environmental Programme was considered at a number of meetings of the newly constituted Collie Coal Mines Rehabilitation Committee, from April onwards. Future requirements are being anticipated in current works, including contouring of dumps, backfilling, and trials plots areas.

General

There were 560 reported accidents of which 475 were minor and 85 were classified as serious where an employee was absent from work for 14 days or more.

There were 910 persons employed in the coal mining industry at Collie at the end of the year.

The 3 current operating mines have together produced 29 637 521 tonnes of coal or 48·59 per cent of the total output of 60 997 328 tonnes won from the field since mining commenced 82 years ago in 1898.

The total value of the coal produced from the 3 operating collieries amounted to 74·62 per cent of the total value of $352 328 325 for all coal produced throughout the life of the field, to the end of 1980.

The years of commencement of coal production and the total outputs and values of coal produced from the 3 operating collieries to the end of 1980 are summarised as follows:—

Mine	Commenced Production	Output Tonnes	Value $
Western No. 2 Mine	1952	9 370 760	95 182 471
Western No. 5 Open Cut	1970	5 141 310	45 572 311
Muja Open Cut	1953	15 125 451	122 135 042
		29 637 520	262 889 824

Great challenges will face all concerned with the development of the coal industry at Collie in the coming years, if the recently evident progress and expansion is to continue on a sound basis, to consolidate the industry's long term future.

The careful utilisation of reserves and maximisation of coal extraction, consistent with maintenance of safe working conditions and a satisfactory environment will continue to be primary goals. Current developments in the educational, research, environmental and safety areas indicate that inincreasing attention is being directed to these important considerations.

DRILLING OPERATIONS

D. A. Macpherson
Drilling Engineer

During 1980 the Drilling Section was responsible for the drilling of 5 848 metres in 120 bores, the development of aquifers in 95 bores and the testing of aquifers in 15 bores. The work was carried out by Departmental employees and equipment. The total metreage drilled is 2 290 metres less than the figure for 1979.

The reduction in metreage was due to deferment of two major projects of the Geological Survey of Western Australia due to financial restrictions and the lack of alternative work.

A brief resume of each job follows and a table of the work carried out is given at the end of this report.

Comments on staff and plant matters are also given.

Quindalup Line This job forms part of the statewide groundwater investigation carried out by the Geological Survey of Western Australia and is financed by the Department of Mines. The line commences West of Busselton and extends East through Quindalup towards Donnybrook.

This job was required to provide information on stratigraphy and groundwater conditions to a projected depth of 1 200–1 500 metres at selected sites on the line.

This was effected by drilling one bore to target depth to provide strata samples, Geophysical bore logs and sidewall cores. This bore was cased to bottom and cemented then perforated at 2 intervals. Each perforated interval was isolated by a packer and steel tubing and separately developed and airlifted to provide accurate water samples and water levels. Additional bores were drilled at sites to provide water quality and water level measurements for aquifers at other levels. The bores were left in appropriate condition for long term water level observation.

At the start of the year all drilling work had been completed except for a secondary bore at site 9. This bore was completed and developed and further development was undertaken on 2 other existing bores to remove oil from the surface of the water (the oil was a residual substance from previous development). Minor modifications and repair work were carried out to the surface installations at 6 existing bores on the line.

This job was completed during the year.

Bunbury (Shallow Aquifers) Job This job forms part of the State groundwater investigation carried out by the Geological Survey of Western Australia and is financed by the Department of Mines. The work is being done in the Bunbury/Busselton area. The job is required to provide information on stratigraphy and groundwater conditions to a projected depth of 100 metres at selected sites in the area. This was done by drilling one bore at each site to target depth to provide strata samples and Geophysical bore logs. This bore was then screened and tested. On completion of the main bore, one or two shallower bores were drilled at each site to provide additional information on water levels in the area.

During the year, one bore was drilled on this job, one bore was pump tested and development and repair work was carried out on 8 existing bores.

This job was completed during the year.

Lake Clifton Job This job is an investigation of the shallow groundwater resources of the Perth Basin in the Mandurah-Australind area. Lake Clifton is a dominant geographic feature in the area. The investigation is required to provide sufficient information to assess the shallow groundwater resources of the coastal plain west of Harvey and Waroona between Whitehill in the north and Binningup in the south and to establish approximate water balance for the coastal plain lakes. This job is being carried out for the Geological Survey of Western Australia and is financed by the Department of Mines. The investigation results are of considerable interest to Public Works Department because of the irrigation being carried out from this resource.

The work consists of constructing one or more bores for water level and water quality monitoring purposes at selected sites on a number of east-west lines through the area. This work is followed by construction of pumping test bores at selected sites and comprehensive pumping testing of these bores.

During the year 7 bores were drilled, 6 were developed, 2 were pump tested and one bore was abandoned.

It is expected that this work will be continued in 1981.

Manjimup Woodchip Industry Job This job forms part of an investigation into the effects of logging for the Manjimup Woodchip Industry on the groundwater regime in the area.

The work is being carried out for an investigation committee and is financed by the Department of Mines and the Investigation Committee. The work generally consists of drilling a bore partly by continuous coring hollow auger method at each of a number of selected sites and completing the bores as water sampling and groundwater level measuring points for long term recording of groundwater variations in the area. Pumping tests are also carried out on selected sites.

During the year, 6 investigation bores were drilled and developed. Sixteen seismic shot holes were also drilled to facilitate a seismic survey being carried out in the area.

It is expected that work will be continued on this job in 1981.

Dwellingup Job This job forms part of an investigation into the effects of Bauxite mining on the groundwater regime in the Dwellingup area. The work is being carried out for an investigation committee and is financed by the Department of Mines and the Investigation Committee. The work generally consists of drilling a bore partly by continuous coring hollow auger method at each of a number of selected sites and completing the bores as water sampling and groundwater level measuring points for long term recording of groundwater variations in the area.

During the year 17 bores were drilled and developed, it is not expected that this work will continue in 1981.

Salvado Job This job forms part of the statewide groundwater investigations carried out by the Geological Survey of Western Australia and financed by the Department of Mines. The job covers the coastal plain between Guilderton in the south and Lancelin in the north. The job is required to provide information on stratigraphy and groundwater conditions to a projected depth of approximately 100 metres at selected sites in the area. This is done by drilling one bore at each site to target depth to provide strata samples and geophysical bore logs. The bores being finalised as water level and water quality monitoring points. Subsequently from information gained, sites are selected for pumping test bores and these are constructed and tested.

During the year 41 bores were drilled, 30 were developed and 9 were pump tested. In the course of the work, 11 bores were abandoned during construction due to very localised lost circulation and caving strata conditions. It was cheaper to abandon troublesome holes and drill ones in better strata than to persevere with the troublesome ones.

This job was completed during the year.

Guilderton Job This job was carried out for and financed by the Gingin Shire Council, it was located in Guilderton. The purpose of the work was to determine whether a suitable supply could be obtained from groundwater for watering of recreation areas in the Guilderton Township.

One bore was drilled and tested, and the water obtained was too salty for watering of recreation areas. The screens were raised in the bore and some improvement of water quality was obtained. It was found that by pumping at relatively low rate, suitable water could be obtained. At the end of the year the Council was using the bore on a trial basis and if results are satisfactory, a second bore will be constructed to attempt to obtain a larger supply of suitable quality. The results of the work will set a pattern for future production bores for the town area.

Canning Vale Job This job was carried out for and financed by the Metropolitan Water Supply Sewerage and Drainage Board. The work was located at the Boards Canning Vale sewerage effluent disposal works, the purpose of the work was to investigate recharge and sewerage effluent disposal effects on groundwater in the area.

Nineteen bores were drilled, of these 18 were developed and one was subjected to full scale pumping test. One bore was abandoned due to extremely loose strata. The job programme was completed during the year.

Gosnells Job This job was carried out for and financed by the City of Gosnells. The work was carried out to determine whether suitable supplies of groundwater could be obtained to water 2 recreation ovals in the City area. It consisted of drilling exploratory bores to determine strata and water quality. Bores with suitable strata and water quality were completed as pumping bores and tested.

Four bores were drilled, one of these was developed and tested, the others being abandoned. This showed that water was available at one of the recreation areas, but was not available from shallow aquifers at the other.

Dardanup Job This job was carried out for and financed by the Public Works Department. The work consisted of constructing 2 bores using fibreglass casing for the Dardanup water supply as an experimental operation to determine that fibreglass casing could be satisfactorily used for the purpose. The bores were required to replace 2 existing bores where the water was contaminated by the steel casing.

Two bores were drilled, developed and pumping tests carried out. The work was successfully completed.

Noonkanbah and Go Go Jobs These jobs were carried out for and financed by Amax Petroleum to provide water supplies for oil drilling operations on Noonkanbah and Gogo Stations. The work was satisfactorily completed. Two bores were drilled on Gogo station as the first one did not yield a supply of water.

Warburton Job This job was carried out for and financed by the Public Works Department. The work was located in the Warburton and Central Australian Aboriginal Reserves and was carried out to determine whether suitable groundwater supplies for the indigenous population could be obtained at selected sites. This was done by drilling an investigation bore at each site and if results were satisfactory, completing the bore as a low yield production facility.

Seventeen bores were drilled and 6 of these were abandoned because of unsatisfactory supply, the other 11 were completed as production facilities.

The work was not completed during the year because of the need for geological re-appraisal of some areas and the onset of the summer, and lack of access to some of the sites. It is expected that the work will be completed during 1981.

Laverton Job This job was carried out for and financed by the Laverton Shire Council. The work was done to determine whether a suitable groundwater supply could be obtained for watering the Laverton recreation oval.

One bore was drilled and successfully completed, but the yield is only just sufficient for the Councils purposes.

Borehole Television Camera Jobs Forty-one bores were examined during the year using the Department's borehole television camera unit. Satisfactory video tape recordings were made of most of the bores examined, however, in some cases the quantity of suspended matter in the water in the boreholes prevented an intelligible picture being obtained.

Staff On 22/8/80 Mr M. Duke (Engineer Level 1) resigned and at the end of 1980 action was underway to replace him.

Plant At the end of the year modifications to the hydraulic system of the Midway Skytop rig were in progress. These modifications were intended to give greater reliability and better efficiency for the unit. The modifications should be completed early in 1981. Various items of general equipment which had reached the end of their economic life were written off and sold and replaced where necessary.

TABLE SHOWING WORK CARRIED OUT BY DEPARTMENT OF MINES DURING YEAR ENDED 31/12/80

Place	Purpose	Type of Work	No. of Bores	Meterage
Salvado	Groundwater Investigation	Rotary Drilling	41	2358·56
		Development	30	
		Pump Test	9	
		Abandoned	11	
Guilderton	Shire Council	Rotary Drilling	1	33
Manjimup	Investigate effect of Forest clearing of groundwater and surface water	Rotary Drilling	6	245·73
		Seismic	16	
		Development	6	
Dwellingup	Groundwater Investigation	Rotary Drilling	17	405·22
		Development	17	
Quindalup	Groundwater Investigation	Rotary Drilling	1	366
		Development	3	
		Repair Work	6	
Bunbury Shallow	Groundwater Investigation	Rotary Drilling	1	76
		Repair Work & Development	8	
		Pump Test	1	
Lake Clifton	Groundwater Investigation	Rotary Drilling	7	161
		Development	6	
		Pump Test	2	
		Abandoned	1	
Dardanup	Public Works	Rotary Drilling	2	122
		Development	2	
		Pump Test	2	
Canning Vale	Investigation of recharge and sewerage effluent disposal on groundwater	Rotary Drilling	19	417·08
		Development	18	
		Pump Test	1	
		Abandoned	1	
Gosnells	City of Gosnells	Rotary Drilling	4	103·2
		Development	1	
		Abandoned	2	
Noonkanbah	Amax	Rotary Drilling	1	561·66
Gogo	Amax	Rotary Drilling	2	246·41
		Abandoned	1	
Warburton	Public Works	Rotary Drilling	17	669·93
		Development	11	
		Abandoned	6	
		Airlift	2	
Laverton	Shire Council	Rotary Drilling	1	82
		Development	1	
Various	Various	TV camera scan	41	
		TOTALS:		
		Drilling	129	5847·79
		Development	95	
		Pump Test	15	
		Seismic	8	

BOARD OF EXAMINERS

FOR MINE MANAGER'S AND UNDERGROUND SUPERVISOR'S CERTIFICATES OF COMPETENCY

S. J. Winchcomb
Secretary

MINING LAW EXAMINATION

The examination in Mining Law for the Mine Manager's Certificate of Competency was held on April 28th, 1980. Details of the examination are as follows:—

Entries	14
Admitted	13
Passed	5
Did not sit	4

The names of the successful candidates were:—

J. R. Wilson
M. U. Safak
J. P. Boucaut
T. A. Lee
M. A. Wilson

Examinations were conducted at the centres of the Kalgoorlie, Leinster and Karratha.

UNDERGROUND SUPERVISOR'S EXAMINATIONS

In view of the interest shown and as an aid to the industry the Board conducted a supplementary examination on the 26th May, 1980 in addition to the normal examination which was held on the 6th October, 1980.

Details of the examination held on the 26th May, 1980 are:—

Applications —

Received	31
Accepted	30
Passed	26
Failed	3
Did not sit	1

Written examinations were conducted at Kalgoorlie, Leinster, Norseman and Perth and oral examinations at Kalgoorlie and Leinster.

The examination on the 6th October, 1980 had the following details:—

Applications—

Received	33
Accepted	32
Passed	22
Failed	8
Did not sit	2

Written and oral examinations were conducted at Kalgoorlie, Windarra and Mt Magnet.

Certificates of Competency have been issued to the successful candidates as follows:—

Gane, G.	McLeay, G. G.
Stewart, B. A.	Harding, K. W.
Kerr, P. K.	Harman, C. E.
Green, S. W. H.	Fyfe, P. T.
Phillis, L. D.	Warburton, N. F.
Farley, J. P.	Hancock, J. C.
Thomas, G. N.	Heather, S. J.
Lahti, J. K.	Williams, R.
Bermingham, V. C.	McKenzie, J. D.
McNally, D.	Larke, R.
Denison, S. L.	Vitali, M.
Wilson, J. R.	Hunter, D.
Reder, H.	Downer, K.
Demark, A.	Barnard, P. N.
Rowe, J. E.	Lahti, R. K.
Chapple, W. H.	Morys, S.
Harrison, R. A.	Fauntleroy, K. N.
Wilson, C. J.	Williamson, R.
Samson, J. J.	Knight, L. P.
Juengling, E. B.	Dekker, R. G. P.
Henderson, J. H.	Dowding, L. H.
Rogers, L. N.	Smith, D. H.
Coe, L. J.	Thompson, A. W.
Brockhoff, B. L.	Duff, A. C.

MINE MANAGER'S CERTIFICATES

The following were successful applicants for the First Class Mine Manager's Certificate of Competency:—

C. A. McIntyre	V. A. Bullo
E. S. M. Mein	B. White
J. R. Wilson	M. A. Wilson
T. A. Lee	J. P. Boucaut
M. U. Safak	

GENERAL

The Board held meetings on March 27th, May 15th, June 17th, September 9th and November 11th, 1980.

Mr S. J. Winchcomb commenced as Secretary of the Board for 1980.

BOARD OF EXAMINERS FOR QUARRY MANAGER'S CERTIFICATES

J. A. Suda
Secretary

EXAMINATIONS

During the year examinations were held to accommodate applicants for Quarry Manager's and Restricted Quarry Manager's Certificates of Competency.

QUARRY MANAGER'S CERTIFICATE OF COMPETENCY

A Mining Law Examination was held on 12th May, 1980.

14 applications were received and accepted.
11 applicants passed.
3 applicants failed.

Quarry Manager's Certificates of Competency were issued to:—

R. Hardy	P. Heydon
R. Mathieson	J. Fletcher
C. F. Cheong	S. P. Reid
P. D. Hallam	R. E. De Jongh
D. Jeffery	W. Burrow
M. Tomasini	R. Renton
J. C. Downie	V. L. Brown
G. K. Markin	

Four of these persons, having previously passed the Mining Law examination, were issued with certificates as the necessary statutory requirements were met.

RESTRICTED QUARRY MANAGER'S CERTIFICATES OF COMPETENCY

Mining Law and Quarrying examinations were held in May, 1980.

12 applications were received and accepted.
10 applicants were successful in the examinations.
2 applicants failed.

Restricted Quarry Manager's Certificates of Competency were issued to:—

R. A. Cordery	J. F. Fradd
G. J. Larkin	J. L. Ey
A. Roberts	P. J. Ryan
J. F. Singleton	R. A. McIntyre
F. Patrick	C. G. Warren
N. Jastremski	

Five persons issued with certificates had passed the Mining Law examination in previous years but had not met all statutory requirements at the time of examination.

Four applicants who passed the Mining Law examination could not be issued with Certificates during 1980 as they had not met all other statutory requirements.

GENERAL

Two meetings were held during the year and a total of 26 certificates were granted.

Some Board members visited Koolan Island, Goldsworthy and Paraburdoo to interview applicants and conduct oral examinations for the Restricted Quarry Manager's Certificate of Competency.

Mr Christopher Lee was welcomed to the Board as the Chamber of Mines Representative replacing Mr B. Grieve who left the State.

Members of the Board of Examiners as at December, 1980 were:—

Mr J. K. Lloyd (Chairman)—Department of Mines
Mr G. J. Dodge—Department of Mines
Mr H. Duncan—Education Department
Mr C. Lee—Chamber of Mines of W.A.
Mr J. C. Argus—Chamber of Mines of W.A.

BOARD OF EXAMINERS FOR COAL MINING CERTIFICATES OF COMPETENCY

R. S. Ferguson
Secretary

Four Board meetings were held during the year at the Department of Mines Office, Collie, under the chairmanship of the Acting Chief Coal Mining Engineer, Mr J. K. N. Lloyd.

Statutory examinations were held in the months of April and October.

The following Certificates of Competency were granted:

First Class Mine Manager:
- A. W. Evans, Certificate No. 44

Second Class Mine Manager:
- R. J. Tyler, Certificate No. 18
- E. J. Donovan, Certificate No. 19

Open Cut Mine Manager:
- W. J. Holly, Certificate No. 6
- R. T. Calnan, Certificate No. 7

Deputy (Open Cut):
- A. L. Piavanini, Certificate No. 5
- D. J. Ritchie, Certificate No. 6

Mr A. W. Evans was granted the First Class Mine Manager's Certificate of Competency in recognition of his qualifications obtained in the United Kingdom.

Messrs Holly and Calnan were granted the Open Cut Mine Manager's Certificate of Competency without further examination as they held Limited Mine Manager's Certificates of Competency from Queensland.

An application by a candidate for the First Class Mine Manager's Certificates was refused as his academic qualification was inappropriate and he had insufficient suitable practical experience.

Two candidates were unsuccessful in obtaining the Second Class Mine Manager's Certificate of Competency.

There were 4 candidates for the Third Class (or Deputy) Certificate of Competency but one was not allowed to take the examinations as he did not possess a First Aid certificate. The other candidates were not successful, and one in particular appeared to be inadequately prepared.

Two applications to take the written examination in Mining Law and the oral examination for the Open Cut Mine Manager's Certificate of competency were refused. These candidates possessed academic qualifications but their practical experience in open cut coal mining was inadequate.

An applicant for the examinations for the Deputy (Open Cut) Certificate of Competency did not have suitable verification for his practical experience and was not permitted to sit, whilst another applicant failed in the examination.

It is a matter of concern that no Third Class (Deputy) Certificates of Competency were granted during the year as there is a shortage of Deputies in the industry.

The holding of regular statutory examinations for only limited numbers of candidates entails considerable work and the poor results reflect a lack of preparation by some of the candidates. It is expected that formal tuition programmes to be arranged on the coalfield will ensure that sufficient numbers of properly prepared candidates are forthcoming to justify the holding of twice yearly examinations, and that adequate statutorily qualified persons to meet the future needs of the coal mining industry will result.

VENTILATION BOARD

J. Suda
Secretary

The composition of the Ventilation Board remained constant throughout the year and was comprised of the following officers:—

Mr J. K. N. Lloyd (Chairman)—State Mining Engineer
Dr F. Heyworth—Director, Occupational Health
Mr R. A. Powell—Principal Assistant, Clean Air
Mr G. J. Dodge—Principal Senior Inspector of Mines
Mr I. Loxton—Senior Inspector of Mines

During the year, the Board held 9 meetings, and made 3 tours of inspection.

The Board is pleased to report that the exposure to dust, of workmen in the mining industry, is continuing to be reduced. This is particularly evident in the iron ore industry, and to a lesser degree, in underground diesel mines, where the large volumes of air required for the removal of exhaust fumes quickly dilute and remove dust from the working places.

In those mines where inert dust is the contaminant, e.g. Iron Ore, Mineral Sands and Nickel Mines, sampling results indicate that the statutory limit of 15 mg/m^3 of dust in the atmosphere is being met in the majority of locations and work categories. The one main exception being high dust exposure of treatment plant maintenance workers brought about by the displacement and disturbance of fine dust trapped in and about the machinery. The most effective way of overcoming this problem appears to be by washing down before work commences. Because of electrical and other design problems, this is not possible in many old plants. The Board is now actively encouraging mining operations to design future plants to a standard which will permit regular washing down, but particularly just prior to maintenance.

Mineral and Gold mining operations which produce siliceous or other non-inert dusts are, in the main, now complying with the particular limits relevant to each operation. However, the re-opening of the Golden Mile is expected to cause problems, as dust suppression in these mines may be difficult.

Unfortunately, similar improvements cannot be claimed for the extractive industry associated mining operations which produce crushed rock and aggregate for the building industry. The majority of these operations generate highly siliceous dust, and with the exception of one or two quarries which have installed wet screening, high dust concentrations still occur. This has resulted in an inspection burden upon the Inspectors of Mines disproportionate to the size of the operations.

MINDUST SYSTEM

The Mindust system became firmly established early in the year with regular monthly print-outs of the dust sampling results supplied by each Mining company. The Board examined the print-outs and made recommendations accordingly. These were directed through the Principal Senior Inspector of Mines who is in the position to liaise between the Board and the Inspector of Mines.

The Board has written to each Company expressing its views on the progress, or otherwise, made during the year with respect to reducing dust concentrations in the working environment. A copy of each Company's respective Mindust print-out was enclosed.

TOXIC GASES AND VAPOURS

The Board continued its investigation into ways and means of measuring toxic gases and vapours. A working group involving Mines Department and Public Health Department officers was set up. Investigations have commenced at the Kalgoorlie Nickel Smelter with the aim of establishing equipment and procedural methods for use in measuring Sulphur Dioxide.

VISITS

Mining operations in the Yilgarn were visited in August, and in November the Board travelled to Kalgoorlie to visit Gold Mines, the Nickel Smelter and the W.M.C. Research Plant. The Board also inspected the mineral sands operations of Associated Minerals Consolidated Ltd and Cable Sands Ltd at Capel and Bunbury respectively.

The primary aim of these later visits was to gain first hand knowledge of the problems associated with the handling of Monazite which is slightly radioactive. Radiation exposure of workmen is being continuously monitored under the supervision of officers from State X-Ray Laboratories.

MATTERS OF PARTICULAR INTEREST

The Board is watching closely the developments at the Vanadium plant of Agnew-Clough at Wundowie. Although a number of workmen have complained of various skin, throat and chest symptoms since working in the plant, tests by the Public Health Department have all indicated low levels of vanadium ingestion.

The Company is continuing to improve its dust suppression system and is tackling the problem in a professional manner.

In response to a request from the Public Health Department, the Ventilation Board initiated a sampling programme to test Pilbara Iron Ore dust for asbestiform fibres. Although the programme is not yet finished, no asbestiform fibres have been detected.

CO-OPTED MEMBERS

During the year the Board co-opted Dr B. Hartley, Physicist State X-Ray Laboratories for one meeting at which radiation matters associated with the processing and bagging of monazite were discussed.

The Board also co-opted Mr H. Jones an Environmental Superintendent with B.H.P. Mr Jones has specialised knowledge in the field of environmental atmospheric control and is the Chairman of the Dust and Ventilation Committee, Chamber of Mines. Mr. Jones has been of considerable assistance to the Board during the past few months.

DIVISION III

Report of the Superintendent of State Batteries—1980

Under Secretary for Mines

For the information of the Hon. Minister for Mines, I submit my report on the operations of the State Batteries for the year ending 31st December, 1980.

CRUSHING GOLD ORES

One 20-head, five 10-head, eight 5-head mills and one Ball Mill crushed 58 593·2 tonnes of ore made up of 634 separate parcels, an average of 96·37 tonnes per parcel. The bullion recovered amounted to 474·4 kilograms, estimated to contain 402 kilograms of fine gold, equal to 6·86 grams per tonne of ore.

The average value after amalgamation but before cyaniding was 2·61 grams per tonne, giving an average value of ore received of 9·47 grams per tonne, compared with 8·13 grams per tonne for 1979.

The cost of crushing 58 593·2 tonnes was $34.88 per tonne. In 1979, 59 315·65 tonnes were crushed at the gold plants for a cost of $27.85 per tonne.

CYANIDING

Nine plants treated 18 814.5 tonnes of tailings from amalgamation for a product of 41·59 kilograms of fine gold. The average content was 3 grams per tonne before cyanidation, while the residue after treatment was 0·74 grams per tonne, giving a theoretical recovery of 75·3 per cent. The actual extraction was 73·38 per cent. The cost of cyaniding was $23.31 per tonne, higher than the previous year when 15 485 tonnes were treated at a cost of $15.16 per tonne.

During this year a small carbon-in-pulp extraction and stripping plant was constructed and operated at Kalgoorlie. The cost of cyaniding 4 645 tonnes was $17.98 per tonne which produced 6·771 3 kilograms of fine gold valued at $92 951·35. The operating costs are expected to reduce with experience, improved services and higher tonnages.

Silver recovered by the cyaniding of gold tailings was valued at $1 991.53.

TREATMENT OF ORE OTHER THAN GOLD

Lead Ores

The Northampton Battery crushed 290 tonnes of lead ore for the recovery of 17·39 tonnes of concentrates.

Tungsten Ores

The Northampton plant crushed 483·8 tonnes of Scheelite ore for a recovery of 2 972 kilograms of concentrates.

Tin Ore

The Marble Bar Magnetic Plant treated 2·15 tonnes of tin ores for sample preparation.

Tantalum Ores

The Marble Bar Magnetic Plant also treated 2 tonnes of Garnet Sands for the recovery of 733·26 tonnes of Garnet concentrates.

Value of Production

The estimated value of production from the State Batteries since their inception, excluding the value of gold tax paid to the Commonwealth is:—

GOLD

	1980 $	Since Inception $
Gold	7 616 819	58 543 940
OTHER METALS		
Silver	1 991	9 851
Tin (Concentrate)	....	501 146
Tungsten (Concentrate)	23 910	97 674
Copper (Ores for Agricultural Use)	....	11 932
Lead and Zinc (Concentrate)	6 760	1 650 061
Tantalite—columbite (Concentrate)	106 680	207 030
Garnet (Concentrate)	58 660	131 001
Total Other Metals	198 001	2 608 695
Grand Total	7 814 820	61 152 635

FINANCIAL

	Tonnes	Expenditure $	Receipts $	Loss $
Crushing Gold Mills	58 593·2	2 043 743	409 903	1 633 840
Crushing Northampton Lead Plant	2 461·4	81 270	9 106	72 164
Magnetic Separator	4·15	....	249	....
Cyaniding	18 814·5	413 774	187 208	226 566
	79 873·25	2 538 787	606 466	1 932 570

The loss of $1 932 321 is an increase of $299 424 on the previous year. It does not include depreciation and interest on capital. Capital expenditure was incurred as follows:—

	$
Kalgoorlie—	
Housing & Equipment	33 313
Carbon-in-Pulp	8 551
Boogardie—Equipment	1 671
Coolgardie—Housing	13 214
Laverton—Battery Re-build	11 450
Marble Bar—Equipment	473
Marvel Loch—Housing	1 597
Meekatharra—Equipment	9 900
Menzies—Buildings	180
Norseman—Buildings	9 817
Northampton—Ramp Re-build	4 808
Paynes Find—Equipment	675
Sandstone—Tanks	1 031
Yarri—Weightometer	2 300
	98 980

Cartage Subsidy

Comparative figures on cartage subsidy paid on ore carted to State Batteries during the last three years are:—

Year	Tonnes Crushed	Tonnes Subsidised	% Subsidised
1978	57 325·9	7 844 ·9	13·68
1979	60 910·0	12 977 ·1	21·30
1980	61 058·75	19 999 ·0	32·75

There has been no cartage subsidy paid on ore carted to private plants during the last 3 years.

Administrative

Expenditure was $345 291 equal to $4.32 per tonne crushed and cyanided, compared with an expenditure of $282 409, $3.70 for 1979.

	1979	1980
	$	$
Salaries	107 846	115 796
Payroll Tax	59 785	70 937
Workers' Compensation	94 170	142 566
Travelling and Inspection	17 201	11 930
Sundries	3 407	4 062
	282 409	345 291

General

The average price for gold during the year was $534 an ounce. This was a rise of $258.30 on the previous average.

The Ball Mill operations at Meekatharra did not reach the expected treatment rates because of low amalgamation recovery from this type of grinding. Various modifications were tried but were unsuccessful in improving the amalgamated or gravity recovery to that obtained from the same ore treated by Stamp Battery operations.

In view of this problem, an impact pulveriser (Barker Mill) was purchased and installed at Coolgardie. This mill has yet to be fully tested; however, initial tests show acceptable amalgamation from the ground material. This type of unit could be used as a supplement to a five-head battery to improve through-put at more acceptable operating costs.

The carbon-in-pulp treatment at Kalgoorlie was operated by the staff under adverse conditions of equipment and services. Results obtained, however, were enough to supply confidence in the operation and a larger and more efficient unit, has been ordered for installation at the Coolgardie State Battery.

The Battery at Laverton was fully reconditioned during the year and a start made on improving the units at Paynes Find and Marvel Loch.

E. J. GREEN,
Superintendent, State Batteries

Schedule No. 1

NUMBER OF GOLD ORE PARCELS TREATED, TONNES CRUSHED, GOLD YIELD BY AMALGAMATION AND HEAD VALUES FOR THE YEAR ENDING 31st DECEMBER, 1980

Battery	Number of Parcels Treated	Tonnes Crushed	Yield by Amalgamation		Amalgamation Tailings Content Fine Gold Kilograms	Contents of Ore—Fine Gold	
			Bullion Kilograms	Estimated Fine Gold Kilograms		Kilograms	Grams Per Tonne
Boogardie	53	2 430	23·331 8	19·784 0	11·115 7	30·899 7	12·71
Coolgardie	77	6 742·8	28·599 7	24·238 1	18·278 7	42·516 8	6·30
Kalgoorlie	201	14 998	161·852 0	137·169 6	28·160 0	165·329 6	11·02
Laverton	19	2 652·1	8·744 7	7·411 0	4·256 2	11·667 2	4·39
Leonora	79	7 383	57·935 2	49·099 6	27·673 5	76·773 1	10·39
Marble Bar	20	1 878	19·402 2	16·443 3	3·910 1	20·353 4	10·83
Marvel Loch	31	3 834	28·949 7	24·534 1	11·637 2	36·171 3	9·43
Meekatharra	30	3 312	69·194 0	58·641 4	7·700 6	66·342 0	20·03
Menzies	20	2 114·4	24·416 1	20·692 1	16·266 9	36·959 0	7·69
Norseman	29	3 473·8	20·050 0	16·990 2	6·288 9	23·279 1	6·70
Ora Banda	38	5 001·6	13·293 1	11·265 7	7·387 1	18·652 8	3·73
Paynes Find	9	423	4·320 5	3·661 3	0·779 6	4·440 9	10·49
Sandstone	7	276	1·106 6	0·937 6	0·464 7	1·402 3	5·08
Yarri	15	2 841	11·101 8	9·408 3	4·290 7	13·699 0	4·82
Meekatharra B/Mill	6	1 233·5	2·106 0	1·784 5	4·870 7	6·655 2	5·39
	634	58 593·2	474·403 4	402·060 8	153·080 6	555·141 4	9·47

Average Per Parcel .... 96·37 tonnes
Average Yield by Amalgamation (Fine Gold) .... 6·86 grams per tonne
Average Tailing Grade (Fine Gold) .... 2·61 grams per tonne

Schedule No. 2

DETAILS OF EXTRACTION—TAILINGS TREATMENT 1980

Battery	Tonnes Treated	Head Value		Tail Value		Calculated Recovery		Actual Recovery	
		Grams Per Tonne	Total Content Kilograms	Grams Per Tonne	Total Content Kilograms	Kilograms	%	Kilograms	%
Coolgardie	223·5	3·89	0·871	0·97	0·216 8	0·654 2	75·10	0·545	62·57
Kalgoorlie	4 450	3·46	15·406	0·86	3·848	11·558	75·0	11·511 1	74·71
Kalgoorlie C-in-P	4 645	2·14	9·929 5	0·48	2·232 6	7·696 9	77·5	6·771 3	68·19
Leonora	4 200	2·82	11·881 5	0·87	3·24	8·641 5	72·7	8·369	70·43
Marvel Loch	1 276	4·30	5·492 4	0·94	1·198 7	4·293 7	78·1	4·295	78·19
Meekatharra	2 160	3·68	7·965 6	0·92	1·989 6	5·976	75·0	5·976	75·02
Menzies	1 250	1·47	1·847 1	0·37	0·461 6	1·385 5	75·0	1·584	85·75
Norseman	367	6·1	2·238 7	1·5	0·550 5	1·6882	75·6	1·763	78·75
Ora Banda	243	4·3	1·044 9	1·08	0·262 4	0·782 5	74·9	0·776	74·26
	18 814·5	3·01	56·676 7	0·74	14·000 2	42·676 5	75·3	41·590 4	73·38

Schedule No. 3

DIRECT PURCHASE OF TAILINGS YEAR ENDED 31st DECEMBER, 1980

Battery	Tonnes of Tailings Purchased	Initial Payment to $28.00 per ·0311 kg
Boogardie	129·6	85·45
Coolgardie	616·0	1 149·56
Kalgoorlie	1 449·2	1 486·99
Leonora	2 259·0	4 991·93
Marble Bar	319·2	174·58
Marvel Loch	226·5	2 440·71
Meekatharra	270·0	53·98
Menzies	246·2	178·24
Norseman	133·2	523·03
Sandstone	73·8	163·83
Total	5 725·2	11 248·30

Schedule No. 4

STATEMENT OF RECEIPTS AND EXPENDITURE FOR YEAR ENDED 31st DECEMBER, 1980

Milling

Battery	Tonnes	Management and Supervision	Wages	Stores	Expenditure Total Working	Cost Per Tonne	Repairs and Renewals	Sundries	Gross Expenditure	Cost Per Tonne	Receipts	Receipts Per Tonne	Profit	Loss
		$	$	$	$	$	$	$	$	$	$	$	$	$
Boogardie	2 430	32 664·75	39 075·77	21 428·18	93 168·70	38·34	9 740·18	23 731·82	126 640·70	52·12	15 992·60	6·58	....	110 648·10
Coolgardie	6 742·8	28 025·81	62 859·93	36 548·78	127 434·52	18·90	12 702·95	38 608·43	178 745·90	26·51	43 187·59	6·40	....	135 558·31
Cue	....	....	....	....	....	....	....	....	....	....	1 542·00	....	1 542·00	....
Kalgoorlie	14 998	113 850·78	193 580·11	83 661·45	391 092·34	26·08	44 328·47	106 122·03	541 542·84	36·11	106 712·85	7·12	....	434 829·99
Laverton	2 652·1	14 549·20	45 991·99	14 671·61	75 212·80	28·36	14 641·29	18 739·61	108 593·70	40·95	17 836·10	6·73	....	90 757·60
Leonora	7 383	11 796·96	63 812·36	20 195·08	95 804·40	12·98	7 322·44	40 762·30	143 889·14	19·49	52 505·37	7·11	....	91 383·77
Marble Bar	1 878	15 332·02	49 748·28	10 285·53	75 365·83	40·13	5 356·70	12 624·80	93 347·33	49·71	12 881·80	6·86	....	80 465·53
Marvel Loch	3 834	20 033·00	65 024·31	16 570·22	101 627·53	26·51	3 324·46	22 251·28	127 203·27	33·18	27 298·50	7·12	....	99 904·77
Meekatharra	3 312	37 386·39	87 170·66	13 004·57	137 561·62	41·53	6 801·32	26 413·15	170 776·09	51·56	28 853·50	8·71	....	141 922·59
Meeka B/M	1 233·5	....	....	12 354·63	12 354·63	10·02	2 795·54	9 963·92	25 114·09	20·36	4 370·75	3·54	....	20 743·34
Menzies	2 114·4	12 275·95	49 872·20	11 918·91	74 067·06	35·03	4 874·17	16 304·67	95 245·90	45·05	14 639·75	6·92	....	80 606·15
Norseman	3 473·8	22 244·81	63 756·63	17 953·40	103 954·84	29·93	5 336·05	22 743·02	132 033·91	38·01	24 123·63	6·94	....	107 910·28
Ora Banda	5 001·64	13 354·90	67 981·26	26 691·43	108 027·59	21·60	5 090·65	26 185·86	139 304·10	27·85	29 257·45	5·85	....	110 046·65
Paynes Find	423	6 353·04	13 713·05	4 964·70	25 030·79	59·17	6 026·04	7 779·66	38 836·49	91·81	2 855·50	6·75	....	35 980·99
Peak Hill	....	....	....	....	....	....	....	....	....	....	240·00	....	240·00	....
Sandstone	276	3 510·82	8 126·95	2 810·73	14 448·50	52·35	1 905·49	3 225·55	19 579·54	70·94	2 010·65	7·28	....	17 568·89
Yarri	2 841	12 390·47	45 119·48	15 899·95	73 409·90	25·84	5 063·52	24 416·24	102 889·66	36·22	19 622·00	6·91	....	83 267·66
Head Office	....	....	....	....	....	....	....	....	....	....	5 973·37	....	5 973·37	....
Sub total	58 593·2	343 768·90	855 832·98	308 959·17	1 508 561·05	25·75	135 309·27	399 872·34	2 043 742·66	34·88	409 903·41	7·00	7 755·37	1 641 594·62
Mag. Plant	4·15	....	....	....	....	....	....	....	....	....	249·00	60·00	249·00	....
Northampton	2 461·4	19 697·95	21 623·50	15 219·44	56 540·89	22·97	6 761·57	17 967·38	81 269·84	33·02	9 106·24	3·70	....	72 163·60
Total	61 058·75	363 466·85	877 456·48	324 178·61	1 565 101·94	25·63	142 070·84	417 839·72	2 125 012·50	34·80	419 258·65	6·87	8 004·37	1 713 758·22

Schedule No. 5

STATEMENT OF RECEIPTS AND EXPENDITURE FOR YEAR ENDED 31st DECEMBER, 1980

Cyaniding

Battery	Tonnes	Management and Supervision	Wages	Stores	Expenditure Total Working	Cost Per Tonne	Repairs and Renewals	Sundries	Gross Expenditure	Cost Per Tonne	Receipts	Receipts Per Tonne	Profit	Loss
		$	$	$	$	$	$	$	$	$	$	$	$	$
Boogardie	....	....	1 286·00	115·02	1 401·02	....	771·48	360·00	2 532·50	....	....	....	....	2 532·50
Coolgatdie	223·5	....	3 197·67	221·28	3 418·95	15·30	335·40	3 184·45	6 938·80	31·05	209·69	·94	....	6 729·11
Kalgoorlie	4 450·	1 233·42	49 650·19	37 442·86	88 326·47	19·85	3 237·28	44 683·87	136 247·62	30·62	9 523·72	2·14	....	126 723·90
Lake Darlot	....	....	....	....	....	....	....	....	....	....	13 159·11	....	13 159·11	....
Laverton	....	....	....	....	....	....	....	536·10	536·10	....	....	....	....	536·10
Leonora	4 200·	....	48 041·22	19 922·86	67 964·08	16·18	379·84	21 561·68	89 905·60	21·41	14 398·35	3·43	....	75 507·25
Marble Bar	....	....	....	9·60	9·60	....	....	....	9·60	....	....	....	....	9·60
Marvel Loch	1 276·	....	13 417·83	17 257·27	17 257·27	13·52	91·25	4 678·73	22 027·25	17·26	32 193·65	25·23	10 166·40	....
Meekatharra	2 160·	....	6 737·50	16 454·68	16 454·68	7·62	707·05	9 550·58	26 712·31	12·37	4 257·70	1·97	....	22 454·61
Menzies	1 250·	1 223·00	16 489·24	23 602·23	23 602·23	18·88	646·07	3 056·83	27 305·13	21·84	836·26	·67	....	26 468·87
Norseman	367·	....	1 627·10	2 921·39	2 921·39	7·96	....	1 840·88	4 762·27	12·98	19 432·35	52·95	14 670·00	....
Ora Banda	243·	2 736·64	7 262·61	12 183·15	12 183·15	50·14	1 090·74	....	13 273·89	54·63	107·69	·44	....	13 166·20
Sub Total	14 169·5	5 193·06	147 709·36	80 636·42	233 538·84	16·48	7 259·11	89 453·12	330 251·07	23·31	94 118·52	6·64	37 995·59	274 128·14
Kal. C.I.P.	4 645·	7 547·38	9 205·60	37 093·32	53 846·30	11·59	6 882·44	22 793·74	83 522·48	17·98	92 951·35	20·01	9 428·87	....
Total	18 814·5	12 740·44	156 914·96	117 729·74	287 385·14	15·27	14 141·55	112 246·86	413 773·55	21·99	187 069·87	9·94	47 424·46	274 128·14
Special Agreements														
Nth Kalg.	....	....	....	....	....	....	....	....	....	....	3 458·00	....	3 458·00	....
Mt Ida	....	....	....	....	....	....	....	....	....	....	1 000·00	....	1 000·00	....
						....	....	....	413 773·55	....	191 527·87	....	51 882·46	274 128·14
							Less Interset Paid to Treasury				4 320·00			4 320·00
									413 773·55		187 207·87			278 448·14

STATE BATTERIES

TRADING AND PROFIT LOSS ACCOUNT FOR THE YEAR ENDED 31st, DECEMBER, 1980

1979 $	1979 $		1980 $	1980 $
		Trading Costs—		
1 158 564		Wages	1 410 579	
271 323		Stores	441 908	
120 726		Repairs, Renewals and Battery Spares	156 212	
376 372		General Expenses and Administration	530 087	
	1 926 985			2 548 649
		Earnings—		
	294 890	Milling and Cyaniding and Mag Plant Charges		606 467
	1 632 095	**Operating Loss for Year**		1 942 182
		Other Charges—		
		Interest on Capital		
63 435		Depreciation	63 435	
34 980		Superannuation—Employers Share	43 810	
54 788			52 157	
	153 203			159 402
	1 785 298	Total Loss for Year		2 101 584

STATE BATTERIES BALANCE SHEET AS AT 31st DECEMBER, 1980

FUNDS EMPLOYED

1979		1980	1980
	Capital—		
1 505 663	Provided from General Loan Fund	1 505 663	
529 526	Provided from Consolidated Revenue Fund	641 850	
2 035 189			2 147 513
	Reserves—		
57 243	Commonwealth Grant—Assistance to Gold Mining Industry	57 243	
27 573	Commonwealth Grant—Assistance to Metalliferous Mining	27 573	
84 816			84 816
	Liability to Treasurer—		
3 078 224	Interest on Capital		3 141 659
	Other Funds—		
16 167 452	Provided from Consolidated Revenue Fund (Excess of payment over collections)		18 163 437
21 365 681			23 537 425
	Deduct—		
	Profit and Loss:		
19 512 162	Loss at Commencement of Year	21 297 460	
1 785 298	Loss for Year	2 101 584	
21 297 460	Total Loss from Inception		23 399 044
68 221			138 381

EMPLOYMENT OF FUNDS

1979		1980	1980
	Fixed Assets—		
2 024 107	Plant, Buildings and Equipment	2 136 431	
1 778 473	*Less* Depreciation	1 822 283	
245 634			314 148
	Current Assets—		
93 557	Debtors	83 294	
96 109	Stores	100 586	
44 191	Battery Spares	75 010	
	Purchase of Tailings:		
47 352	Treasury Trust Account	46 661	
49 298	Tailings not Treated	52 318	
14 428	Estimated Gold Premium	17 153	
344 935			375 022
590 569	Total Assets		689 170
	Deduct—		
113 428	Current Liabilities: Creditors	84 657	
393 843	Liability to Treasurer (Superannuation—Employers Share)	446 000	
	Purchase of Tailings:		
649	Creditors	2 979	
14 428	Estimated Premium Due	17 153	
522 348			550 789
68 221			138 381

DIVISION IV

Annual Report of the Geological Survey Division of the Mines Department for the Year 1980

CONTENTS

	Page
INTRODUCTION	57
STAFF	58
ACCOMMODATION	58
OPERATIONS	58
Hydrogeology Branch	58
Engineering Branch	60
Sedimentary Branch	60
Regional Geology Branch	60
Mineral Resources Branch	60
Common Services Branch	61
ACTIVITIES OF THE COMMONWEALTH BUREAU OF MINERAL RESOURCES	61
PROGRAMME FOR 1981	61
PUBLICATIONS	63

REPORTS

HYDROGEOLOGY

1. The hydrogeology of the Swan Valley, Perth Basin, Western Australia; by A. D. Allen 64
2. The geology and hydrogeology of the Quindalup borehole line; by P. H. Wharton 79

SEDIMENTARY GEOLOGY AND PALAEONTOLOGY

3. Mesozoic and Cainozoic sediments in the western Fortescue plain; by J. C. Barnett 87
4. The Yoganup Formation and Ascot Beds as possible facies equivalents; by J. L. Baxter and R. Hamilton 94
5. Molluscs from the Ascot Beds from the Cooljarloo heavy mineral deposit, Western Australia; by George W. Kendrick 96
6. On the age of the Merlinleigh Sandstone, Carnarvon Basin; by A. E. Cockbain 96
7. Petroleum exploration in Western Australia in 1980; by K. A. Crank 99
8. The Tumblagooda Sandstone, Western Australia: its type section and sedimentology; by R. M. Hocking 105
9. An alluvial fan—fluvial plain depositional model for the Devonian Willaraddie Formation and Munabia Sandstone of the Carnarvon Basin, W.A.; by H. T. Moors 114

PRECAMBRIAN GEOLOGY

10. Estimated pressure and temperature conditions from some Western Australian Precambrian metamorphic terrains; by D. F. Blight and M. E. Barley 119
11. The Logue Brook Granite: age and significance of deformation zones along the Darling Fault Scarp; by D. F. Blight, W. Compston, and S. A. Wilde 124
12. The relationship of new Rb-Sr isotopic dates from the Rudall Metamorphic Complex to the geology of the Paterson Province; by R. J. Chin and J. R. de Laeter 132
13. Mercury in some Western Australian mineralized rocks; by R. Davy, R. J. Marston and C. J. Dodd 139
14. Small conical stromatolites from the Archaean near Kanowna, Western Australia; by K. Grey 142
15. A definitive 3 350 m.y. age from banded gneiss, Mount Narryer area, Western Gneiss Terrain; by J. R. de Laeter, I. R. Williams, K. J. R. Rosman, and W. J. Libby 146
16. Rb-Sr geochronology of alkaline granitic rocks in the Eastern Goldfields Province; by W. G. Libby and J. R. de Laeter 150
17. Felsic dykes of the Mount Edgar batholith; by J. D. Lewis and R. Davy 155
18. Rb-Sr dating of tectonic events in the Proterozoic Mount Barren Group near Hopetoun; by R. Thom, J. R. de Laeter and W. G. Libby 161

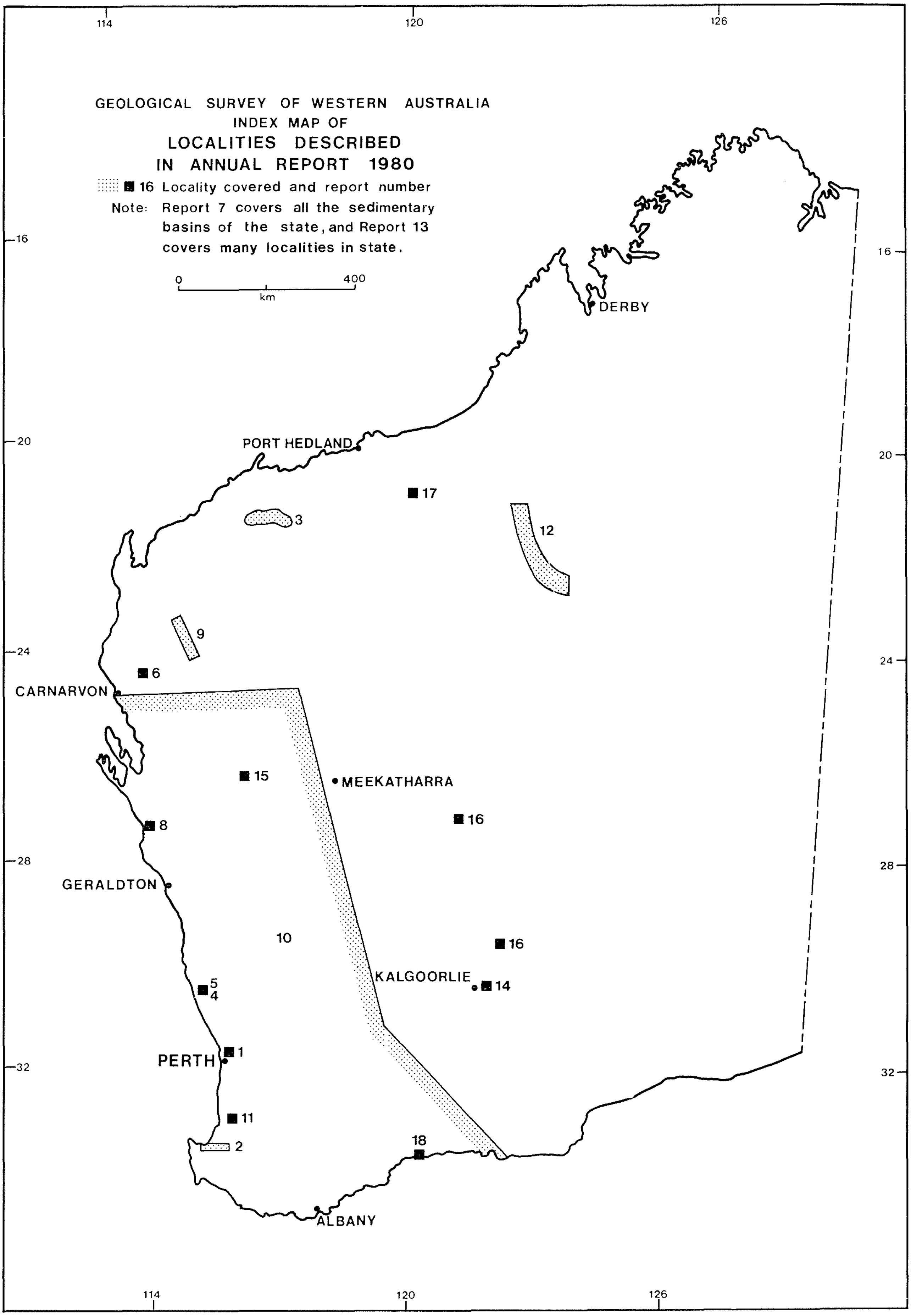


Figure 1 Index map showing areas and localities described in the Annual Report 1980.

DIVISION IV

•

Annual Report of the Geological Survey Division of the Mines Department for the Year 1980

•

Under Secretary for Mines:

My report on the activities and progress of the Geological Survey of Western Australia during 1980 is herewith forwarded for the information of the Honourable Minister for Mines. As is customary, the report is accompanied by a selection of technical papers which present the results of representative investigations and studies carried out in accordance with the objectives of the Department during that year.

INTRODUCTION

The activities of the Geological Survey of Western Australia during 1980 were generally subject to three factors which combined to make it a year of transition, rather than one in which any major programme was either completed or initiated. These factors were a change of Director, a massive increase in the work load of some sections owing to the exploration boom which began in 1978 and gained momentum during 1979, and finally the loss of many geologists to private industry as a further response to the same boom. As in the "nickel boom" of 10 years ago, it is paradoxical that at times when the greatest demands for the services of the Survey are made, it is least able to satisfy them. In general, what should have been a year of finalization of many long-standing projects and active preparation for new programmes in 1981, became instead a year in which much planned work had to be curtailed or postponed to maintain essential ongoing responsibilities. A more optimistic note at the end of the year was that the prospect of filling vacancies appeared hopeful; the accomplishment of all the work listed in the programme for 1981 below is dependent on the early achievement of a full professional staff establishment.

The consolidation of the exploration boom through 1980 was marked by a continued high level of interest in uranium, gold, and diamond, and a marked increase of interest in coal and oil shale. The demand for Temporary Reserves is a useful indicator of mineral exploration activity, and the following Table uses this to illustrate growth during recent years.

Temporary Reserves

Year	New applications approved during year	Total in force at year end
1976	117	439
1977	92	411
1978	228	528
1979	290	818
1980	747	1 169

At the end of 1980, 320 Temporary Reserves were held for gold, 229 for coal and 134 for iron ore. Of the Temporary Reserves held for other minerals, diamond figured among the chief commodities under search together with uranium, which has been the subject of a high level of exploration for many years.

Diamond was sought in many parts of the State. The Kimberley remains the main scene of activity though exploration continues in the Carnarvon Basin and new ground was acquired under Temporary Reserves for diamond in the Fraser Range some 200 km southeast of Kalgoorlie by Stockdale Prospecting Limited.

In the Kimberley, the Ashton Syndicate with Conzinc Riotinto of Australia (CRA) as operator, began evaluation of their important prospect on Smoke Creek at Lake Argyle near Kununurra. To date the Syndicate has discovered some eighty kimberlites in the Kimberley but only three, Smoke Creek and Ellendale pipes A and B (some 150 km southeast of Derby) are considered potentially economic. At Smoke Creek, the prospect consists of an elongate kimberlite pipe (AK1) some 45 ha in surface area. From the pipe, diamondiferous alluvial gravels extend downstream for 32 km to Lake Argyle. These gravels are subdivided into an upper terrace about a kilometre in length near the head of Smoke Creek and a lower terrace extending over the remainder of the total length. Very high diamond contents are present in the alluvials of the upper terrace. However, the proportion of gemstones (less than 20 per cent) at Smoke Creek is lower than at Ellendale and the average value per carat is correspondingly less. Mining the Smoke Creek alluvials may commence in 1981.

Gold maintained the high prices reached during 1979 and stimulated interest in old gold workings in many former notable producing areas. The major producers, Telfer, Mount Charlotte and Central Norseman mines were joined by the Marvel Loch mine, which Kia Ora Gold Corporation re-opened in August. Other important developments included Western Mining Corporation's move to include a cyanide circuit to treat gold ore encountered in their nickel operations at Kambalda, the decision of Kalgoorlie Mining Associates to re-open the Fimiston leases, and the dewatering of the Morning Star gold mine at Mount Magnet, which was closed down in 1976.

Exploration for uranium continued in many parts of the State with more attention being paid to the possibility of uranium occurring in sandstones within Phanerozoic sedimentary basins. Preparations for the development of the Yeelirrie deposit continued, and the possibility of mining the Lake Way deposit near Wiluna was renewed.

Iron ore in the Hamersley Basin was the subject of continuing steady exploration throughout 1980.

A feature of exploration in 1980 was a significant increase of interest in coal, and particularly in the possible occurrence of low-grade but extensive resources of Tertiary lignite in incised drainage channels cut into the southern areas of the Yilgarn Block and elsewhere. Several Permits granted under the Petroleum Act to explore for oil shale were granted to seek hydrocarbon-richer facies of essentially the same strata, and it may be necessary to rationalize existing legislation to adequately provide for the exploitation of this material if economically significant deposits are located. No results had been reported by the end of the year.

In the area of conventional petroleum exploration, drilling activity onshore increased in 1980 with 33 exploration wells drilled in the Perth, Carnarvon, Officer and Canning Basins. These include 11 new-pool wildcats in Barrow Island. Attention has been focussed on the onshore Perth Basin where the Woodada 1 and 2 wells flowed significant quantities of gas on initial tests. These wells indicate that previously unsuspected reservoirs exist in the Permian sequence in the Perth Basin. All the other exploration wells drilled onshore during the year were abandoned as dry holes. Offshore drilling activity maintained a steady pace with 12 wells being drilled. One of these was in the far north of the state in the Bonaparte Gulf Basin, and another was off the south coast—offshore in the Eucla Basin. All of the others were on the North West Shelf, Browse Basin, or Exmouth Plateau. One of these Phoenix 1, had the first significant gas shows encountered to date in the offshore Canning Basin.

Seismic activity increased in 1980 when compared to the downturn in 1979. Offshore, one marine seismic crew was occupied on the northwest and western coasts from mid-March to the end of the year with a break to carry out about one month's work in Northern Territory waters. A second crew was similarly occupied in Western Australian and Northern Territory waters between early June and the end of December.

Onshore, there was a considerable increase in seismic activity. One land crew began a 2½ month survey in the Perth Basin late in January, and, during the northern dry season, up to five crews were working at any one time. From August through to the year end, four crews were working continuously. A land gravity survey was also conducted in the Bonaparte Gulf Basin for one month.

One unforeseen and unwelcome result of this exploration boom has been the resignation of some professional staff before they were able to complete the writing up of the intensive field work carried out in order to complete the 1:250 000 geological mapping of the State. It will be necessary to re-examine some sheets in order to maintain the uniformly high standard of previously published sheets. The finalization of this work will free staff for the urgent task of re-mapping early sheets, and for attending to the many problems which this reconnaissance-scale mapping has revealed, and whose solution is vital to an understanding of the factors controlling the distribution and occurrence of the State's mineral deposits.

Field excursion: A public excursion was organized to the Gascoyne Province. Two well-attended lectures were presented at the Gascoyne Junction Shire Hall on the evening of September 22. This was followed by a three day safari-type field excursion to parts of the Glenburgh and Mount Phillips 1:250 000 Sheets.

Public lectures: Following the practice initiated in 1977, public lectures were presented at Mineral House on 10 April and the morning of 11 April 1980. There was an average attendance of 43 at the 11 talks delivered by staff geologists.

Regional Offices: The first Regional Office of the Geological Survey was established at Kalgoorlie in mid-1979 with three geologists. The resignations of two of these towards the end of 1979 adversely affected operations during the first part of 1980, but from May onwards two geologists maintained services at Kalgoorlie. The two main functions of the office, to provide a regional focus for public and industry assistance, and to serve as a basis for local geological studies, were maintained during 1980, but it is clear that at least three geologists are desirable to maintain an efficient service and working unit, and further experience is essential to determine whether the maintenance of a Regional Office at Kalgoorlie is justifiable in strict cost-benefit terms. Office accommodation is now available at Karratha for the second Regional Office, but housing will not be available until 1981.

Study tour: In June and July Dr R. D. Gee, Supervising Geologist of the Regional Geology Branch, spent three weeks in South Africa and three weeks in Canada in an intensive study tour of areas of Precambrian geology and associated mines. Dr Gee had become widely recognized as having made a major contribution to Precambrian geology in Western Australia, and the experience of comparable more intensively studied areas overseas will be invaluable to the ongoing work of the Survey. Five officers attended the 26th International Geological Congress in Paris in July at their own expense, and two of these presented papers; the value of the experience so gained to the State should be recognized and noted.

STAFF

An important staff change during 1980 was the retirement in February of Mr J. H. (Joe) Lord, who on his promotion to the position of Government Geologist in May 1961 was the fifth and last person to bear that formal title, and the first to hold the formal title of Director, since the foundation of the Geological Survey in 1896. In all Mr Lord had spent 25 years on the staff of the Survey (1947–53 and 1961–80) and for nearly the last 19 of these he had been in administrative charge. In this latter period, during which the Geological Survey expanded significantly in both size and in the scope of its activities, his strong guidance and deep professional commitment to the Survey and its work earned the respect of all staff and of a wide range of others both in the mineral and petroleum industries and elsewhere. His decision to take early retirement was characteristic of his adherence in personal practice to all the principles in which he believed—and in this case the belief that guided him was that all organizations periodically benefit from a fresh appraisal of traditional practices. He made a major contribution not only to the Geological Survey and the Mines Department but to the geological profession in the State.

In addition to the retirement of Mr Lord there were 13 resignations from the professional staff, reflecting the continuation and intensification of the exploration boom whose initiation was noted in 1979 and which has already been referred to in this report. A disturbing feature of these resignations is the number of more experienced geologists who left to join industry: between them those who resigned had 77 man years of experience with the Survey, disregarding experience already possessed at the time of joining, and their departure represents a substantial loss of irreplaceable experience and expertise. There is an urgent need for a review of the wide discrepancies between the rewards presently available to geologists in industry and those in Government services, and also of the overall scope for experienced geologists to achieve satisfactory career levels within the Geological Survey by comparison with both other professions within the public service and with professional opportunities outside it. While it is in the best interest of the State that there should be a degree of professional interchange between the Survey and industry the gross imbalance in this interchange during 1980 will certainly be harmful if it remains unchecked.

PROFESSIONAL

Name	Position	Effective Date
Appointments		
Barley, M. Ph.D.	Geologist L1	2/1/80
Beere, G. B.Sc. (Hons)	Geologist L1	6/2/80
Mory, A. J. B.Sc. (Hons)	Geologist L1	4/3/80
Griffin, T. B.Sc. Ph.D.	Geologist L1	9/4/80
Seymour, D. B.Sc. (Hons)	Geologist L1	11/4/80
Thorne, A. B.Sc., Ph.D.	Geologist L1	10/9/80
Kevi, L. B.Sc., D.I.C.	Geologist L2	2/12/80
Promotions		
Trendall, A. F.	Director	25/2/80
Playford, P. E.	Deputy Director	15/5/80
Gee, R. D.	Assistant Director	24/7/80
Resignations		
Brakel, A.	Geologist L2	29/2/80
Muhling, P. C.	Geologist L2	26/3/80
Archer, R. H.	Geologist L2	18/4/80
Denman, P. D.	Geologist L3	9/5/80
Morrison, J. R.	Geologist L2	21/5/80
Nowak, I. R.	Geologist L2	23/5/80
Daetwyler, N. A.	Geologist L1	23/5/80
Lewis, I. H.	Geologist L2	30/5/80
Thom, R.	Geologist L2	4/7/80
Tuckson, M.	Geologist L1	21/11/80
Barnett, J. C.	Geologist L2	28/11/80
Marston, R. J.	Geologist L3	17/12/80
Barley, M.	Geologist L1	19/12/80

CLERICAL AND GENERAL

Name	Position	Effective Date
Appointments		
Martin, S.	Laboratory Assistant	26/2/80
Walker, R. M.	Typist	6/5/80
Sadgrove, G.	Geological Assistant	8/5/80
Eddy, A.	Geological Assistant	12/5/80
Bicknell, D.	Technical Assistant	10/7/80
Crossley, L.	Laboratory Assistant	15/9/80
Giles, K.	Technical Assistant	22/10/80
Promotions		
Thomas, H.	Technical Officer	21/2/80
Transfer Out		
McKenzie, J.	Clerk	11/1/80
Toohey, J.	Technical Assistant	29/4/80
Mountier, A.	Typist	5/5/80
Resignations		
Walker, I.	Geological Assistant	1/2/80
Bryce, A.	Laboratory Assistant	9/4/80
Wall (Kirov), H.	Technical Assistant	4/7/80
Evans, D.	Technical Assistant	10/9/80

ACCOMMODATION

No changes to available accommodation took place during 1980. The location of the Hydrogeology and Engineering Geology Branches at 196 Adelaide Terrace continued to inconvenience the most effective operation of those groups, and there is an urgent need for additional construction on the Mineral House site so that the operations of the geological survey as a whole can be more efficiently integrated.

OPERATIONS

HYDROGEOLOGY BRANCH

T. T. Bestow (Supervising Geologist), A. D. Allen, A. T. Laws (Senior Geologists), J. C. Barnett, D. P. Commander, W. A. Davidson, K-J. B. Hirschberg, L. J. Furness, J. Hall, M. Martin, J. S. Moncrieff, R. Smith, M. Tuckson, P. H. Wharton.

The amount of drilling undertaken by the Mines Department for water resources investigations fell sharply from an aggregate depth of about 6 300 m in 1979 to less than 3 000 m in 1980. It was necessary to suspend further work on the highly successful Perth Basin deep drilling programme for 12 months. This unfortunate decline in an important aspect of the work of the Department resulted from the effects of cost inflation and a reduced budgetary provision for drilling.

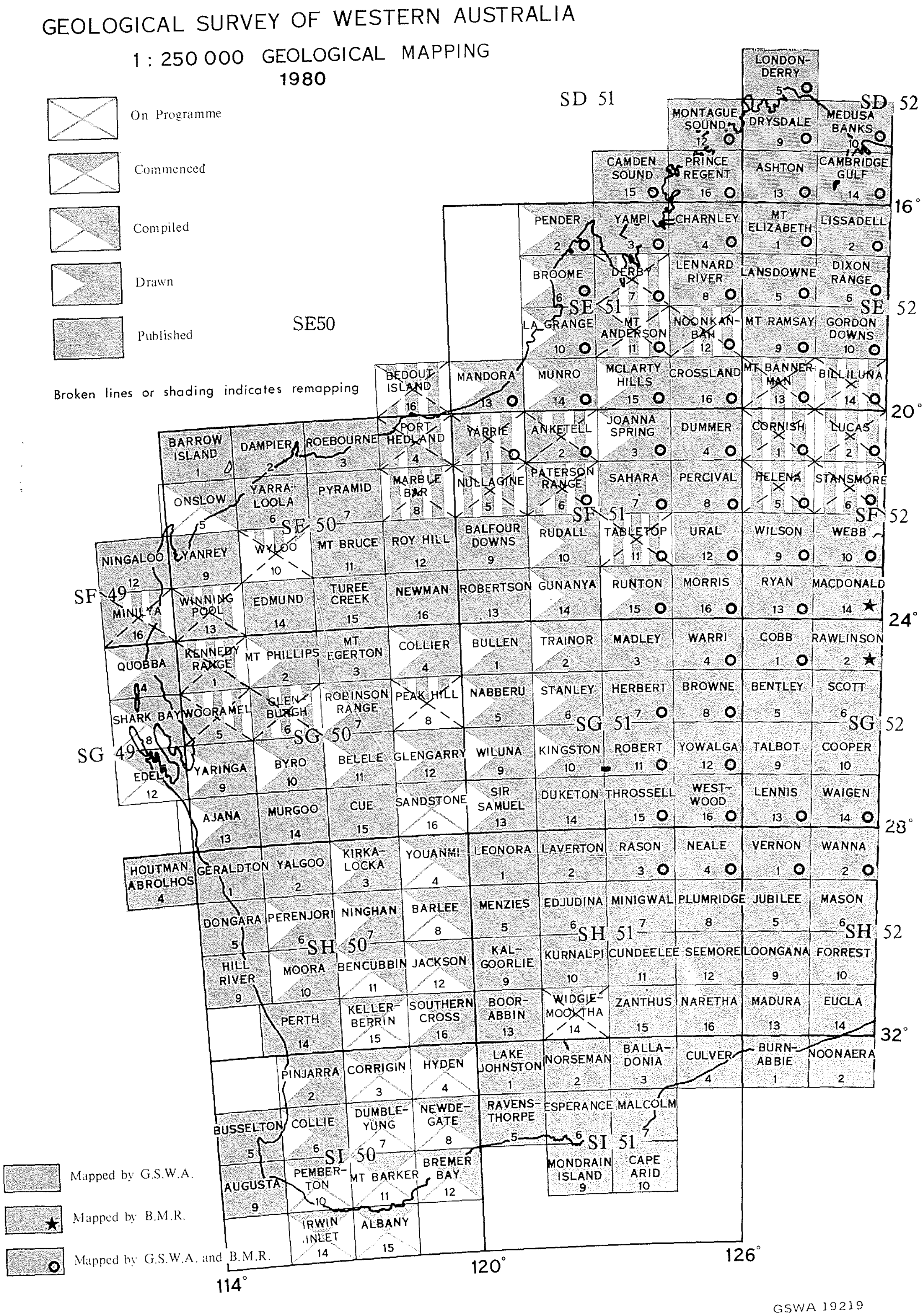


Figure 2 Progress of 1:250 000 and 4 mile geological mapping at the end of 1980.

Two thirds of the drilling effort was devoted to establishing monitoring and test-pumping bores north of the Gingin Brook as part of the Salvado shallow groundwater resources investigation. Twenty sites were drilled to depths of 38 to 126 m. Substantial resources of domestic quality water have been located as a result of this work. The second phase of drilling in the South West Coastal Groundwater Area has commenced with the construction of pumping bores on two sites near Lake Clifton.

Exploration of the deeper aquifers in the Perth area by the Metropolitan Water Supply Board has been further extended by drilling 11 bores to depths of between 327 and 755 m. The information provided will be of great value to the planning of water supply expansion. Liaison with officers of the Board continues to be close, particularly with respect to groundwater development and management. In addition, assistance has been provided with the assessment of consultants' reports on Yanchep-Two Rocks and urban water balance studies. A report has been prepared on the water resources of the Swan Valley Groundwater Control Area.

Reports have been written concerning public water supplies at Cue, Allanooka (Geraldton), Hopetoun, Mandurah, Peaceful Bay, and potential emergency supplies at Mendel-Wongoondy. The results of a drilling programme at Harvey were assessed and reported. Assistance was also provided to the Public Works Department with an investigation of a proposed saline river diversion involving the Tone and Kent rivers. An evaluation of the effects of groundwater abstraction by mining companies at Eneabba was completed, and comments made on consultants' reports on the expansion of Mount Newman Water Supply.

At the request of the Commonwealth Department of Aboriginal Affairs an important programme of drilling and testing was commenced in the Central Aboriginal Reserve surrounding Warburton and recommendations made regarding Cundeelee water supply. Sites have been successfully selected to locate water supplies for compaction along highway routes through Halls Creek and Mount Newman for the Main Roads Department.

A preliminary assessment of the geothermal resources of the State was commenced.

Groundwater pollution surveys were undertaken in three areas and assessments were made of consultants', and other reports, on accidental discharges of industrial effluents into shallow groundwater systems at Kwinana. Advice continued to be provided to the Public Works Department on the management of acid effluent disposal at Australind.

The effects on groundwater and stream salinities of bauxite mining and of the woodchip industry continued to be the subject of inter-departmental study. A drilling programme was undertaken to establish bores in the George Forestry Block to monitor the effects of different forest associations on rainfall infiltration.

The demand for hydrogeological investigations and advice has continued to expand to the extent that all available staff have been fully committed, and some highly desirable and important work has had to be postponed. This has unfortunately included the commencement of hydrogeological mapping in wheatbelt areas to be used as a basis for emergency water supply planning and possibly drought relief. However, advice has been given to the Farm Water Supply Committee and eight Shires with respect to specific water supply problems. A steady demand by farmers and other landowners for water supply advice was experienced and resulted in 122 inspections being completed. The borehole record system continued to be augmented by information collected by census; the southern Perth Basin and Perenjori area have been completed and work has commenced at Northam.

In response to an upsurge in mineral exploration and development there was some increase in groundwater exploration in the Goldfields by consultants to mining companies. Close liaison has been maintained with both the other government departments and the companies involved.

ENGINEERING GEOLOGY BRANCH

R. P. Mather (Supervising Geologist), G. W. A. Marcos, I. H. Lewis, and N. A. Daetwyler.

Activities were largely confined to investigations for other Government Departments and instrumentalities, including:

Department of Public Works:

(*a*) Reconnaissance of dam sites between Waroona and Collie, and in the Manjimup area.

(*b*) Geological and geophysical studies of the Ord River Dam spillway.

(*c*) Minor investigations including geological advice on Harding-Karratha Pipeline, Ravensthorpe bitumen catchment, and Kalbarri sewerage treatment plant.

Metropolitan Water Board:

(*a*) Geological mapping during the construction of the Wungong and Bibra tunnels.

(*b*) Geological and geophysical studies at a Little Dandalup dam site.

(*c*) Geological mapping in support of safety reviews of several existing dams.

In addition, miscellaneous minor investigations were carried out on behalf of Westrail, the State Energy Commission, the Department of Conservation and Environment and the Commonwealth Department of Housing and Construction. Contributions were also made to urban geology maps and to a report on the Cadoux earthquake. A feature of the year's work was the number of reports completed and issued in connection with past studies.

REGIONAL GEOLOGY BRANCH

Supervising Geologist (vacant following the promotion of R. D. Gee), I. R. Williams (Senior Geologist), R. J. Chin, S. J. Williams, T. J. Griffin, D. B. Seymour, A. M. Thorne.

Compilation and production of 1st edition 1:250 000—scale sheets, mapped prior to 1980, is nearing completion. Field mapping commenced on Wyloo 1:250 000 Sheet (2nd edition). This project marks the beginning of a long-term reappraisal of the Ashburton Fold Belt and the southern margin of the Hamersley Basin.

One officer, based in the Kalgoorlie Regional Office, commenced remapping the Widgiemooltha 1:250 000 Sheet (2nd edition).

Sampling of banded gneiss for Rb-Sr geochronological work has been undertaken on the Byro 1 250 000 Sheet.

Work on the Bangemall Bulletin is complete, and the Nabberu Basin Bulletin is nearing completion. Field reassessment for a synthesis of Gascoyne Province was completed.

SEDIMENTARY BRANCH

M. H. Johnstone (Supervising Geologist), K. A. Crank, H. T. Moors (Senior Geologists), M. N. Megallaa (Senior Geophysicist), R. M. Hocking, B. P. Butcher, A. J. Mory, G. M. Beere.

The processing of data received from petroleum exploration companies continued on a routine basis. During 1980, 18 packages of microfilm data were prepared from this material for dissemination to the petroleum industry. Thirty-six petroleum exploration permits were issued during the year.

Preparation of the bulletin on the offshore and onshore portions of the Carnarvon Basin continued during the year. Finalization of the maps and preparation of the explanatory notes for the Wooramel, Kennedy Range and Winning Pool-Minilya 1:250 000 Sheets continued. A field party commenced mapping the Western Australian part of the Bonaparte Gulf Basin during 1980.

Preliminary maps for an assessment of the reserves of the Collie Coal Field were prepared during the year.

MINERAL RESOURCES BRANCH

J.G. Blockley (Supervising Geologist), J. D. Carter (Senior Geologist), J. L. Baxter, D. F. Blight, A. H. Hickman, S. L. Lipple, S. A. Wilde.

In co-operation with the Regional Mapping Branch, a start was made on the remapping of the Wyloo 1:250 000 Sheet. Compilation of the Pemberton Sheet was completed and the Explanatory Notes were almost finished.

The manuscript of a Mineral Resources Bulletin on nickel in Western Australia was completed and is in the hands of the editors. Further studies leading to a Bulletin on bauxite were undertaken.

Field investigations of the Warriedar Fold Belt were finalized and a report commenced. Work continued on the study of the Mount Monger area being undertaken from the Kalgoorlie Regional Office.

Assessments of the State's gold and manganese resources were completed. Forty-one rolls of microfilm were added to the library of open file reports on mineral exploration.

For the second Archaean Symposium held in May, divisional staff helped prepare four papers and assisted in running three field excursions. One staff member contributed to a course in heavy-mineral mining run by the Kalgoorlie School of Mines for the Australian Aid and Development Agency; another helped edit papers for a forthcoming issue of Economic Geology dealing with Western Australian nickel deposits; and a third organized a colloquim on the stratigraphy of the Marra Mamba Iron Formation.

Miscellaneous investigations included inspections of a proposed townsite in the Hamersley Range area, a manganese deposit in the Fitzgerald River National Park, a tungsten prospect near Nanutarra, a marble quarry on Wyloo Station and a new gold find near Leonora.

COMMON SERVICES BRANCH

Petrology

W. G. Libby, J. D. Lewis and M. E. Barley.

Demand for petrographic services eased slightly, with 74 petrological reports completed covering 1 408 thin sections. Further thin sections were studied for incorporation into the computer index system.

During the year a major report on the Cadoux earthquake was completed and several shorter papers were prepared for publication. Studies on kimberlites, the Corunna Downs and Mount Edgar batholiths, and on alkaline granites of the Eastern Goldfields continued.

The cooperative geochronology programme with the Western Australian Institute of Technology resulted in the publication of two papers and the preparation of four more papers. Nineteen projects were active in 1980; eleven are scheduled for 1981.

The laboratory prepared 1 767 petrographic thin sections, 327 sedimentary thin sections and 60 polished mounts. Two hundred and fifty nine samples were prepared for chemical or geochronological analysis. Two hundred and fifty one specific gravity determinations, 84 mineral separations and 31 grain size analyses were completed.

The Government Chemical Laboratories continued to identify mineral samples and to provide access to X-ray diffractometer and computer facilities.

Palaeontology

A. E. Cockbain, J. Backhouse, K. Grey.

During the year 71 reports were written and 550 samples added to the fossil collection. Some 8 000 palaeontological samples from relinquished petroleum tenements were catalogued. Most of the section's work involved Perth Basin Mesozoic palynomorphs (for the Hydrogeology Division), Precambrian fossils (for the Regional Geology Division) and various Palaeozoic invertebrate fossils from the Bonaparte Gulf Basin (for the Sedimentary Division).

Geophysics

D. L. Rowston, L. Kevi.

Well-logging activity increased from 77 logging operations in 1979 to 148 in 1980; the aggregate total depth of all bores was 38 880 m. Much of the increase can be attributed to re-entry to a number of the deeper stratigraphic water bores in the Perth Basin to obtain temperature logs for an assessment of geothermal energy resources. Forty-three deep bores were logged for this reason.

Seven seismic refraction surveys were undertaken during the year. Water catchment salinity investigations at Collie, Lake Toolibin and George Block were augmented by the resultant seismic sections. The bedrock configuration was mapped at prospective dam sites at Manjimup and Little Dandalup and overburden velocity characteristics used to evaluate probable scouring of auxiliary spillways at the Ord Dam. Seismic velocities and depths to the bedrock refractor indicated the rippability of superincumbent material and depths to bedrock adequate for the construction of cuttings without encountering hard rock along the Worsley Alumina railway alignment.

A pulse induction metal detector with a penetration greater than those presently employed in the Warnbro Shell clearance project was evaluated. The ability to detect shells at about two metres was offset by difficulties in pinpointing the target.

Groundwater salinity prospects involved 300 conductivity measurements of samples from monitoring bores and salinity determinations for the public amounted to 200. Public enquiries on geophysical matters remained steady at about 85.

Environmental Geology

E. R. Biggs, R. H. Archer.

Work continued on the 1:50 000 Urban Geology map series with the completion of the De Witt - Picard Sheet and some progress on sheets in the Port Hedland and Bunbury areas.

Geological information was supplied for a variety of projects, including seven town planning scheme amendments, eight environmental review and management proposals and various nature conservation recommendations and studies. The section was involved in a continuing study of basic raw materials, such as clay, limestone and sand, in the Perth metropolitan area.

Appraisal also continued on all applications for mineral tenements in the South West Mineral Field in order to lessen the impact of mining on the environment.

Geochemistry

R. Davy.

Work was centred on three continuing studies: The geochemistry of the Pilbara granitoids (the Mount Edgar and Corunna Downs Batholiths), the geochemistry of Pilbara volcanic suites and problems in studying the chemistry of iron-formations.

A preliminary report on the Mount Edgar Batholith was given to the Archaean Symposium in Perth.

Technical Information

W. B. Hill, M. E. Blight, J. F. Cameron, P. Hind.

Two sheets in the 1:250 000 geological series with explanatory notes were published by the Geological Survey during 1980. One preliminary map in this series was received from the B.M.R.

This year the annual report, one bulletin, two mineral resources bulletins, one report, two geological maps with explanatory notes, two urban geology maps, and the booklet 'Mineral Resources of Western Australia' were published. The 1:1 000 000 map of the Pilbara Block was released (prior to the publication of the accompanying bulletin) for an excursion during the Archaean Symposium.

One bulletin and four explanatory notes were sent to press making a total of 7 explanatory notes and maps with the Government Printer. Eleven records were published and also issued on microfiche. One information pamphlet was revised

Requisitions raised on the Surveys and Mapping Branch for drafting, photography and copying totalled 1 341.

Public enquiries continued at a high level. The section answered 1 880 requests for information, including rock identifications, 546 of which required detailed research.

Book and periodical loans to the staff totalled 8 497, and loans to and from other libraries 462; 5 472 members of the public visited the library for research purposes.

Forty-one rolls of microfilm were added to the 'M' Series. Public users of the microform facilities totalled 1 363.

Survey publications (especially those out of print) were progressively copied on to microfiche. Bulletins 1–115 and the more recent records became available for sale in this form.

ACTIVITIES OF THE COMMONWEALTH BUREAU OF MINERAL RESOURCES

No geological field work was carried out by the Bureau of Mineral Resources in Western Australia during 1980, except for systematic collection of samples for chemical analysis from the Pilbara Block in support of its continuing joint geochemical project with this Survey.

The Geophysical Branch conducted airborne magnetic and radiometric surveys over the following 1:250 000 sheet areas: Pemberton (western third), Collie, Gordon Downs (southern half), Billiluna, Lucas and Stansmore.

With the co-operation of the CSIRO Division of Applied Geomechanics, the BMR Geophysics Branch made 9 in situ stress measurements in the South West Seismic Zone. Five of these were in the vicinity of Cadoux, the others farther south.

PROGRAMME FOR 1981

(Items marked * will be carried out from the Kalgoorlie Regional Office; the commencement of those marked † will depend on recruitment of adequate staff.)

HYDROGEOLOGY BRANCH

1. Continuation of the hydrogeological survey of the Perth Basin, including deep drilling on the Boyanup line and planning of the Gillingarra line.

2. Hydrogeological assessments and/or exploratory drilling for groundwater in the following areas:
   (a) Millstream-Weelumurra
   (b) East Pilbara
   (c) Collie Basin
   (d) Lake Clifton
   (e) Harvey-Waroona irrigation area
   (f) Rottnest Island

3. Town water supply investigations and/or drilling for: Mount Magnet, Bunbury, Lancelin-Salvado, Madora, Singleton, Pellhurst.

4. Hydrogeological investigations for the Metropolitan Water Supply Board, including:
   (a) Deep drilling for artesian monitoring scheme
   (b) Planning new wellfield at Pinjar

(c) Assessment of the effects of pumping at Mirrabooka, Wanneroo, Gwelup, and Jandakot
(d) Continuing study of water balance of coastal lakes
†(e) Assessment of recharge to the Gnangara Mound using tritium tracer
(f) Commencement of publication on Perth metropolitan groundwater resources
(g) Miscellaneous other evaluation, assessment, and advice.

5. Interdepartmental studies concerning groundwater salinity problems in the Darling Range bauxite and woodchip areas.

6. Regional hydrogeological studies, including:
(a) systematic bore census of selected areas
†(b) complete 1:250 000 scale hydrogeological mapping of Perenjori sheet, and commence Collie and Perth sheets.

7. Hydrogeological advice on groundwater pollution control in various areas including: Australind, Gnangara, Kwinana, and the Perth Metropolitan Area generally.

8. Continuing study of the feasibility of using geothermal energy resources.

9. Miscellaneous investigations and inspections as required by Government departments and the public.

ENGINEERING GEOLOGY BRANCH

1. South-West Division dam site investigations and/or continuing advice including: Manjimup, Waroona-Collie area, Wungong, South Canning, North Dandalup, Little Dandalup.

2. Continuing North West dam site and pipeline investigations.

3. Spillway studied for Ord River Dam.

4. Geological studies and advice during construction of the Wungong and Bibra tunnels.

5. Maintain an interest in geological aspects of earthquake activity.

6. Geological advice on quarry sites and miscellaneous problems for various Government Departments and authorities, including Public Works Department, Westrail, and State Energy Commission.

REGIONAL GEOLOGY BRANCH

1. Completion of compilation and explanatory notes for the remaining 1:250 000 first edition geological maps of Western Australia. Completion of additional field work needed to co-ordinate preparation of Kellerberrin, Corrigin, and Dumbleyung sheets.

2. Completion of geological synthesis of the Gascoyne Province.

3. Continuation of re-mapping of Wyloo and commencement of re-mapping of Cue 1:250 000 sheets.

4. Completion of the re-mapping of Peak Hill 1:250 000 sheet.

*5. Continuation of the re-mapping of the Widgiemooltha sheet.

6. Detailed mapping of the Mt Narryer metamorphic belt.

SEDIMENTARY BRANCH

1. Maintain an active interest in the progress and assessment of exploration and potential for fossil fuels in Western Australia, including the checking and assessing of all company reports on exploration, and preparation of microfilm open-file system.

2. Completion of the study of the surface and subsurface geology of the Carnarvon Basin, and submission for publication.

3. Continuation of mapping and study of the Bonaparte Gulf Basin, and commence mapping of the Ord Basin.

†4. Commencement of a reappraisal of the geology and coal resources of the Collie Basin.

5. Minor geological investigations as required.

MINERAL RESOURCES BRANCH

1. Maintain an active interest in the progress and assessment of exploration and potential for minerals other than fossil fuels in Western Australia, including the checking and assessing of all company reports on exploration, and preparation of microfilm open-file system.

2. Completion of study of the Warriedar fold belt.

3. Continue study of the bauxite of the Darling Range area.

4. Completion of assessment of iron ore on Ministerial Reserves.

5.† Study of economic geology of the Murchison Province.

6. Investigation of the geology and economic potential of the lower part of the Fortescue Group in the southwestern part of the Hamersley Basin.

7.* Detailed mapping and mineral study of the Mount Monger area.

8. Miscellaneous investigations as required.

COMMON SERVICES BRANCH

Petrology

1. Carry out petrological investigations as required by other Divisions.

2. Special topics for investigation (all continuing):
(a) Alkaline granitoids of the Eastern Goldfields
(b) Rb-Sr Geochemistry of the Black Range dolerite
(c) Petrology of the Kimberlites and related rocks of the Kimberley
(d) Petrology of the Corunna Downs and Mount Edgar batholiths.

3.† Study of regional metamorphic patterns in the Southern Cross Province of the Yilgarn Block.

Palaeontology

1. Carry out palaeontological investigations as required by other Divisions.

2. Completion of palynological study of the Early Cretaceous of the Perth Basin.

3. Completion of study of Nabberu Basin stromatolites, and continuation of miscellaneous stromatolite studies.

4. Completion of study of biostratigraphy and systematics of Devonian radiolarians from the Canning Basin.

5. Completion of study of Gneudna stromatoporoids (Carnarvon Basin).

6. Study of miscellaneous invertebrate material from Bonaparte Gulf Basin.

7. Initial review of Mesozoic palynology of Carnarvon Basin, including North West Shelf.

Geophysics

1. Well logging on groundwater drilling projects as required.

2. Seismic traverses to assist hydrogeological studies on the Perenjori, Perth, and Collie Sheets.

3. Seismic surveys required for dam site investigations.

4. Gravity surveys to assist geological interpretation:
(a) Southern Cross-Bullfinch area
(b) Warriedar Fold Belt.

5. Geothermal logging of bores in support of geothermal energy resource investigation.

6. Investigation of effects of jointing in crystalline rocks on seismic velocity.

7. Miscellaneous other geophysical investigations as required.

Geochemistry

1. Completion of geochemical studies of the Mount Edgar and Corunna Downs batholiths.

2. Completion of studies on:
(a) Mercury in sulphides
(b) Yarrie ironstones.

3. Continuation as required of geochemical studies on Warriedar Fold Belt, Mount Monger area, kimberlites, and Weeli Wolli Formation.

4. Maintain an active interest in exploration geochemical work carried out by companies.

Environmental Geology

1. Complete compilation of urban geology maps of the Bunbury, Harvey, and Port Hedland areas.

2.† Commence fieldwork for urban geology maps of the Perth, and possibly Carnarvon areas.

3. Assessment of environmental reports as required.
4. Mineral tenement appraisals as required.
5. Examination of miscellaneous environmental geological problems as required.

PUBLICATIONS

Issued during 1980

Annual Report 1979

Bulletin 126: The Meckering and Calingiri earthquakes October 1968 and March 1970.

Mineral Resources Bulletin 12: The tin deposits of Western Australia with special reference to the associated granites.

Mineral Resources Bulletin 13: Copper mineralization in Western Australia.

Report 10: A chemical and mineralogical study of low-grade zinc mineralization at three localities in the Proterozoic Bangemall Basin of Western Australia.

Geological map of Nullagine 1:250 000 sheet (SF51-5 International Grid) with explanatory notes.

Geological map of Yanrey-Ningaloo 1:250 000 sheet (SF50-9, SF49-12 International Grid) with explanatory notes.

Urban geology maps 1:50 000: Dampier, Roebourne.

Mineral Resources of Western Australia.

(*Available in microfiche*)

Record 1980/1 Wells drilled for petroleum exploration in Western Australia to the end of 1979; by K. A. Crank.

Record 1980/2 Explanatory notes on the Ninghan 1:250 000 geological sheet, Western Australia; by S. L. Lipple, J. L. Baxter and R. J. Marston.

Record 1980/3 Explanatory notes on the Kirkalocka 1:250 000 geological sheet, Western Australia; by J. L. Baxter, S. L. Lipple and R. J. Marston.

Record 1980/4 Explanatory notes on the Glenburgh 1:250 000 geological sheet, Western Australia; by S. J. Williams, I. R. Williams and R. M. Hocking.

Record 1980/5 Explanatory notes on the Byro 1:250 000 geological sheet, Western Australia; by I. R. Williams, I. W. Walker, R. M. Hocking and S. J. Williams.

Record 1980/6 Explanatory notes on the Belele 1:250 000 geological sheet, Western Australia; by M. Elias (in prep.).

In press

Bulletin 127: Geology of the Pilbara Block and its environs

Geological map of Broome 1:250 000 sheet (SE/51-6 International Grid) with explanatory notes.

Geological map of Bullen 1:250 000 sheet (SG/51-1 International Grid) with explanatory notes.

Geological map of Derby 1:250 000 sheet (SE/51-7 International Grid) with explanatory notes.

Geological map of Gunanya 1:250 000 sheet (SF/51-14 International Grid) with explanatory notes.

Geological map of Joanna Spring 1:250 000 sheet (SF/51-3 International Grid) with explanatory notes.

Geological map of Kingston 1:250 000 sheet (SG/51-10 International Grid) with explanatory notes.

Geological map of La Grange 1:250 000 sheet (SE/51-10 International Grid) with explanatory notes.

Geological map of Mandora 1:250 000 sheet (SE/51-13 International Grid) with explanatory notes.

Geological map of McLarty Hills 1:250 000 sheet (SE/51-15 International Grid) with explanatory notes.

Geological map of Mount Anderson 1:250 000 sheet (SE/51-11 International Grid) with explanatory notes.

Geological map of Munro 1:250 000 sheet (SE/51-14 International Grid) with explanatory notes.

Geological map of Noonkanbah 1:250 000 sheet (SE/51-12 International Grid) with explanatory notes (second edition).

Geological map of Pender 1:250 000 sheet (SE/51-2 International Grid) with explanatory notes.

Geological map of Pinjarra 1:250 000 sheet (SI/50-2 International Grid) with explanatory notes.

Geological map of Robinson Range 1:250 000 sheet (SG/50-7 International Grid) with explanatory notes.

Geological map of Rudall 1:250 000 sheet (SF/51-10 International Grid) with explanatory notes.

Geological map of Trainor 1:250 000 sheet (SG/51-2 International Grid) with explanatory notes.

In preparation

Bulletin 128: Geology of the Bangemall Group—the evolution of a Proterozoic intra-cratonic sedimentary basin.

Bulletin: The geology of the Earaheedy Group, Nabberu Basin.

Mineral Resources Bulletin: Nickel

Report 11: The Cadoux earthquake, 2 June 1979

Report: Gascoyne Province

Geological maps 1:250 000 with explanatory notes, the field work having been completed: Ajana, Albany, Anketell, Barlee, Belele, Bencubbin, Bremer Bay, Byro, Collie, Collier, Corrigin, Dumbleyung, Glenburgh, Glengarry, Hyden, Irwin Inlet, Jackson, Kellerberrin, Kirkalocka, Moora, Mount Barker, Mount Phillips, Nabberu, Newdegate, Ninghan, Onslow, Paterson Range, Pemberton, Perenjori, Port Hedland, Quobba, Sandstone, Shark Bay-Edel, Southern Cross, Stanley, Wiluna, Yaringa, Yarrie, Youanmi.

Urban Geological maps 1:50 000: Boodarrie, de Witt-Picard, Port Hedland, and two sheets in the Bunbury-Harvey area.

Reports in other publications

Allen, A.D., 1979, Availability of groundwater from riverine environments in northern South Australia: South Australia Engineering and Water Supply Department Pub. 79/51.

Barley, M. E., 1980, Relations between magma types in the Warrawoona Group: Continuous or cyclic evolution?: Intern. Archaean Symposium, Second, Perth 1980, Geol. Soc. Australia Extended Abstracts p.30-31.

——— 1980, Resource development in Archaean Shields: Second International Archaean Symposium, Perth, Western Australia, 12-16 May, 1980: Episodes v. 1980(3), p. 36-37.

Biggs, E. R., 1980, Geological hazards in Western Australia, *in* Hofmann, G. W. (ed.) Proceedings of the Third Urban and Environmental Geologists Symposium, Brisbane, 1980: Geol. Survey Queensland Rec. 1980/37.

Biggs, E. R., and Mather, R. P., 1980, Environmental and engineering mapping techniques, *in* Hofmann, G. W. (ed.) Proceedings of the Third Urban and Environmental Geologists Symposium, Brisbane, 1980: Geol. Survey Queensland Rec. 1980/37.

Cockbain, A. E., 1980, Conversion of microscope-stage coordinates: Micropaleontology v. 26, p. 95-96.

Commander, D. P., 1980, Groundwater flow in the northern Perth Basin: Int. Geol. Congress, XXVI, Abstracts p.1098.

Davy, R., and Lewis, J. D., 1980, Geochemistry of the Mount Edgar batholith, Pilbara area, Western Australia: Intern. Archaean Symposium, Second, Perth 1980, Geol. Soc. Australia Extended Abstracts p.43-44.

Davy, R., Rossiter, A. R., and Wall, L. N., 1980, Stream sediments: Jour. Geochem. Exploration v. 12(2/3), p. 131–133.

Davy, R., and Ryall, W. R., 1980, Plants: Jour. Geochem. Exploration v. 12(2/3), p. 136–137.

——— 1980, Atmospheres: Jour. Geochem. Exploration v. 12(2/3) p. 137–138.

Gee, R. D., Williams, I. R., Wilde, S. A., and Baxter, J. L., 1980, Crustal development of the Yilgarn Block: Intern. Archaean Symposium, Second, Perth 1980, Geol. Soc. Australia Extended Abstracts p. 79–80.

Glikson, A. Y., and Hickman, A. H., 1980, Geochemical stratigraphy of Archaean greenstone sequences, eastern Pilbara Block, Western Australia: Intern. Archaean Symposium, Second, Perth 1980, Geol. Soc. Australia Extended Abstracts p. 28–29.

Grey, K., 1980, Aspects of Proterozoic stromatolite biostratigraphy in Western Australia: Intern. Geological Congress, XXVI, Abstracts p. 588.

Groves, D. I., and Gee, R. D., 1980, Regional geology and mineral deposits of the Kalgoorlie-Norseman region: Intern Archaean Symposium, Second, Perth 1980, Geol. Soc. Australia Excursion Guide.

Hamilton, P. J., Evensen, N. M., O'nions, R. K., Glikson, A. Y., and Hickman, A. H., 1980, Sm-Nd dating of the Talga-Talga Subgroup, Warrawoona Group, Pilbara Block, Western Australia: Intern. Archaean Symposium, Second, Perth 1980, Geol. Soc. Australia Extended Abstracts p. 11–12.

Hickman, A. H., 1980, Archaean geology of the Pilbara Block: Intern. Archaean Symposium, Second, Perth 1980, Geol. Soc. Australia Excursion Guide.

Hickman, A. H., 1980, Crustal evolution of the Pilbara Block: Intern. Archaean Symposium, Second, Perth 1980, Geol. Soc. Australia Extended Abstracts p. 78–79.

de Laeter, J. R., Libby, W. G., Trendall, A. F., and Fletcher, I. R., 1980, The older Precambrian geochronology of Western Australia: Intern, Archaean Symposium, Second, Perth 1980, Geol. Soc. Australia Extended Abstracts p. 9–10.

Marston, R. J., and Groves, D. I., 1980, The metallogenesis of Archaean base-metal deposits in Western Australia: Intern. Archaean Symposium, Second, Perth 1980, Geol. Soc. Australia Extended Abstracts p. 46–47.

Marston, R. J., and Kay, B. D., 1980, The distribution, petrology, and genesis of nickel ores at the Juan Complex, Kambalda, Western Australia: Econ. Geol. v. 75(4), p. 546–565.

Playford, P. E., 1980, Devonian "Great Barrier Reef" of Canning Basin, Western Australia: Amer. Assoc. Petroleum Geologists Bull. v. 64, p. 814–839.

——— 1980, Australia's stromatolite stronghold: Natural History v. 89, No. 10, p. 58–61.

Wilde, S. A., 1980, The Jimperding Metamorphic Belt in the Toodyay area, and the Balingup Metamorphic Belt and associated granitic rocks of the southwestern Yilgarn Block: Intern. Archaean Symposium, Second, Perth 1980, Geol. Soc. Australia Excursion Guide.

THE HYDROGEOLOGY OF THE SWAN VALLEY PERTH BASIN, WESTERN AUSTRALIA

by A. D. Allen

ABSTRACT

The Swan Valley is situated at the eastern edge of the Perth Basin and is underlain by up to 13 000 m of Phanerozoic sedimentary rocks. The formations with significant groundwater resources extend to a depth of about 1 000 m. They occur in a gentle syncline overlain by a thin veneer of flat-lying surficial sediments.

The main aquifers containing fresh water are the Quaternary "superficial formations", and the Cretaceous Osborne and Leederville Formations. Of these, the Leederville Formation, which contains a regional groundwater flow system is by far the most important. It is recharged directly from the "superficial formations" or via the Osborne Formation, and has an upper fresh-water zone (<1 000 mg/L TDS) and lower brackish-water zone, each about 160 m thick. Annual throughflow of fresh groundwater is estimated to be 5 x 10^6 m^3/y, and private annual abstraction, mainly for irrigation of vineyards, is about 3·5 x 10^6 m^3/y. Only limited scope for increased abstraction is possible before a "mining situation" is reached. A further limitation is the underlying brackish groundwater, which has an upward head, and which may be induced to move upwards to cause an unacceptable increase in salinity.

INTRODUCTION

LOCATION

The name Swan Valley is applied to a broad area adjacent to the Swan River, an area which extends from where the Swan River enters the coastal plain to its confluence with the Helena River (Fig. 1), near the towns of Midland and Guildford. The statutory Swan Groundwater Area of about 170 km^2 (Fig. 1) includes most of the area generally regarded as the Swan Valley.

BACKGROUND

Vineyards were first established in parts of the Swan Valley in 1850. Since then, it has become the major grape-growing area in Western Australia, producing wine, table grapes and dried fruit.

Prior to the late 1950s, apart from some local irrigation, grape production relied mainly on rainfall. Since then, irrigation of the vineyards during the summer from artesian and sub-artesian bores has become a generally accepted practice. Between 1960 and 1970, about 200 bores were drilled, and currently there are about 400 non-domestic bores in use, mainly for irrigation of vineyards.

In the early 1970s, concern was expressed about the decline in artesian head and reputed increase in salinity of groundwater from some bores. A preliminary assessment of the groundwater resources was made by Allen (1975), and subsequently, on 10 September 1975, the Swan Groundwater Area was proclaimed by the Public Works Department (PWD) under the *Rights in Water and Irrigation Act*, 1914–1976. This enabled the licensing and control of all bores in the statutory area.

CLIMATE AND LAND USE

The climate in the Swan Valley is of the Mediterranean type characterized by mild, wet winters and hot, dry summers.

Average rainfall statistics are available for Guildford and for the Department of Agriculture Research Station in Upper Swan, and are given in Table 1.

TABLE 1. AVERAGE MONTHLY RAINFALL (mm), DEPARTMENT OF AGRICULTURE RESEARCH STATION, UPPER SWAN, AND GUILDFORD (COMMONWEALTH BUREAU OF METEOROLOGY DATA)

J	F	M	A	M	J	J	A	S	O	N	D	Average
Guildford (1877–1954)												
8	10	17	43	122	177	172	139	86	56	20	13	863
Department of Agriculture Research Station (1957–1978)												
8	12	13	40	100	149	172	104	68	45	18	10	739

The rainfall tends to decrease northward, and to increase eastward as a result of the orographic effect of the Darling Scarp. Over 85% of the annual rainfall is received in the winter, between May and October. However, the annual rainfall may vary between wide limits, as at Guildford where it has varied from 496 mm (1914) to 1 312 mm (1926). As well, sequences of years of above or below average rainfall are common.

The warmest month is February and the coolest, August; the mean maximum temperatures, as measured at Guildford, are 33·3°C and 17·8°C, and the mean minimum temperatures, 16·2°C and 6·4°C respectively. The average potential evaporation, which is about three times the annual average rainfall, is greatest in January (331 mm), least in June (79 mm), and has an annual average of 2 156 mm (Department of Agriculture Research Station).

With the exception of the townsites, clay pits and associated brick and tile manufacturing plants, the Swan Valley is a rural area, divided into small and medium holdings which are mainly under pasture and used for cattle raising, horse breeding and training, kennels, poultry farms, piggeries, and cereal production. Irrigated agriculture is practiced mainly on suitable soil types adjacent to the Swan River (Pymm, 1955). In these areas, there are irrigated vineyards (about 12 km^2) and smaller areas of citrus orchards, olive trees, and market gardens (Fig. 9).

SOURCES OF DATA

Geological, salinity and head data are available from the Geological Survey (GSWA) for about 1 000 bores and wells located during a bore census in March and July 1969 and September 1970. Similar data are available from 20 PWD monitoring bores, and exploratory bores drilled by the Metropolitan Water Supply Sewerage and Drainage Board (MWB).

Wire-line logs, mainly gamma-ray and long- and short-normal resistivity, are available for about 90 bores in the Swan Valley. Most have been obtained since 1962 by the GSWA, and a few, by a private contractor. Most deep bores drilled since 1975 have been logged, and these provide the most reliable data on geology and groundwater salinity.

Chemical analyses of groundwater from selected deep and shallow bores, and of surface waters have been made by the Government Chemical Laboratories and are on file at the GSWA.

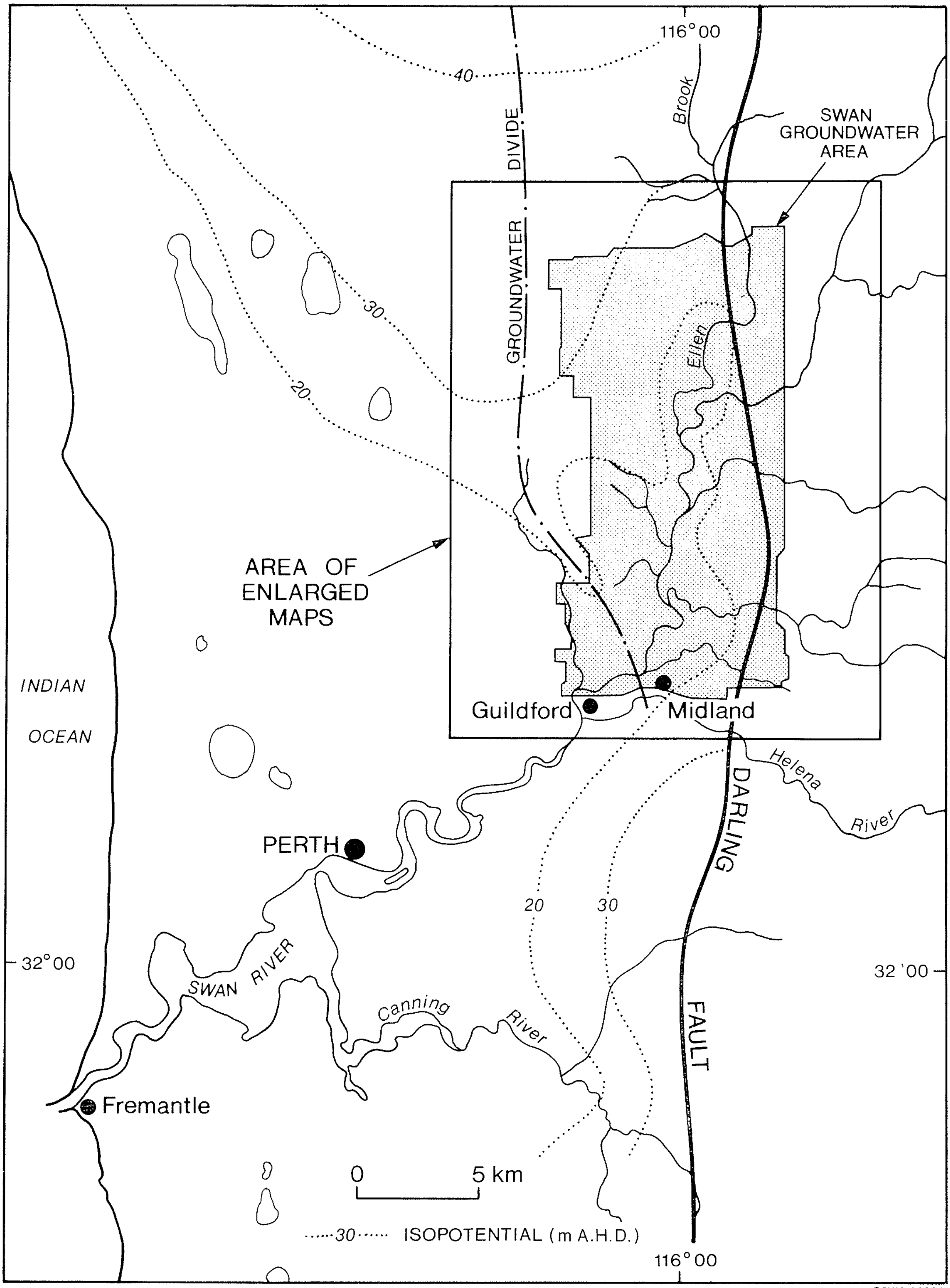


Figure 1 Locality map showing area of larger scale maps, Swan Groundwater Area, and regional isopotentials in the Leederville Formation.

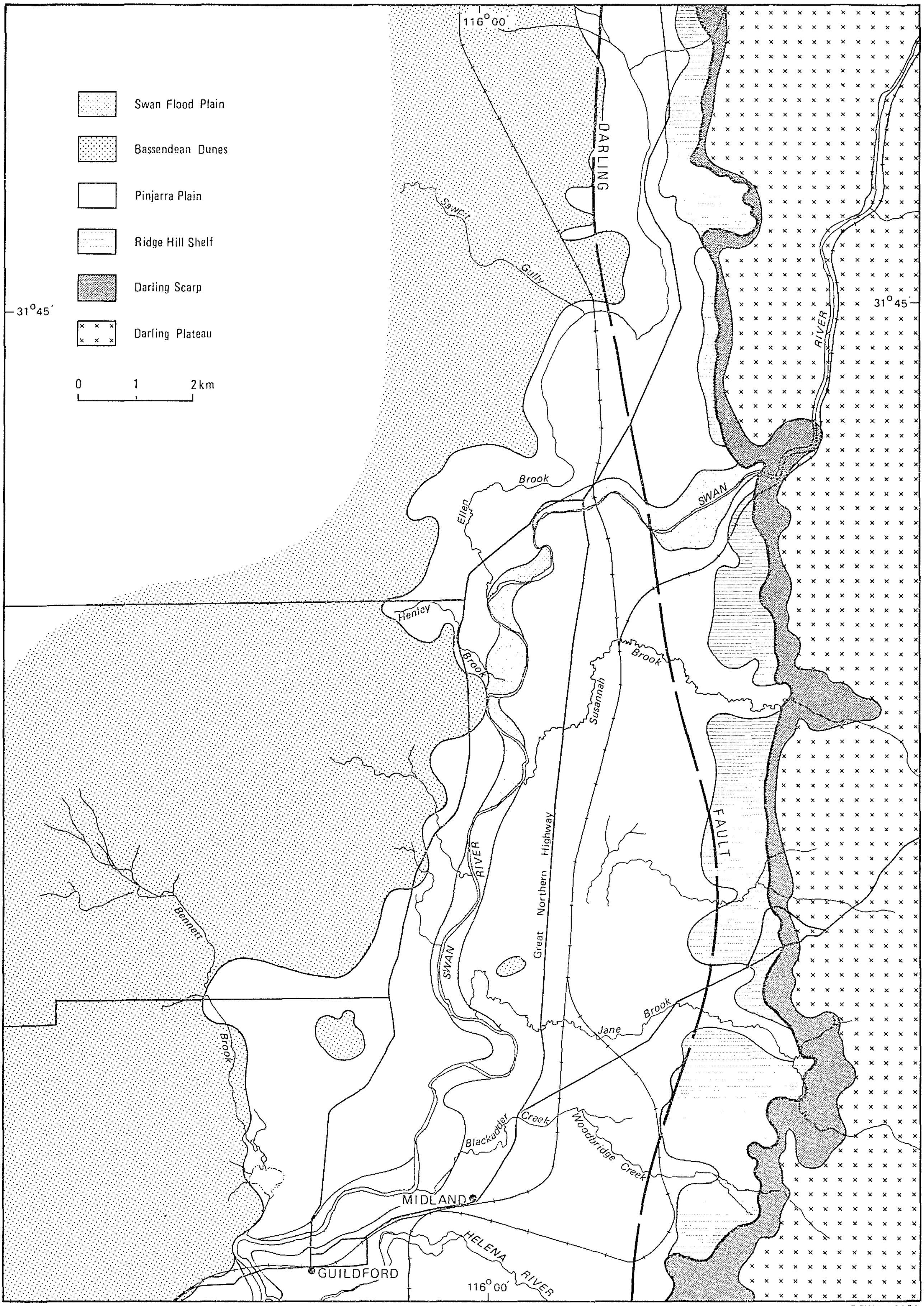


Figure 2 Physiographic divisions of the Swan Valley.

PHYSIOGRAPHY

LANDFORMS

The Swan Valley is at the eastern edge of the Swan Coastal Plain, adjacent to the Darling Plateau (Playford and others, 1976). The Darling Scarp, which forms the boundary between the Swan Coastal Plain and the Darling Plateau, originated as the edge of an upthrown fault-block and has subsequently undergone several periods of shoreline erosion resulting in the retreat of the scarp up to 2 km inland from the fault (Fig. 2).

At the base of the scarp is the Ridge Hill Shelf (Woolnough, 1918), a wave-cut platform 25–50 m above sea level, consisting of lateritized Cretaceous sedimentary rocks overlain by eolian sand. It merges westward with the Pinjarra Plain (McArthur and Bettenay, 1960), a relatively smooth alluvial plain 5–25 m above sea level. The Pinjarra Plain has been incised by the Swan River which has formed a flood plain (up to 0·5 km wide), levees, and silt-covered terraces (Somerville, 1920; Aurousseau and Budge, 1921). Locally overlying the Pinjarra Plain, and forming its western boundary are the Bassendean Dunes (McArthur and Bettenay, 1960). The Dunes reach 45 m above sea level and have smoothed areas in the vicinity of swamps which result from groundwater outflow.

DRAINAGES

The Swan River is the major drainage. It has a catchment area of about 7 000 km^2 on the Darling Plateau. The reach of the river in the Swan Valley follows a mature meandering course within the flood plain. The river is perennial and tidal to about Guildford. It has a low gradient and is only about 10 m above sea level where it leaves the Darling Plateau. The main flow in the river occurs during the winter, and major floods exceed 500 m^3/s (Anon., 1978). There are no systematic salinity data, but Moncrieff (1974) recorded salinities ranging from 2 110 to 9 720 mg/L TDS and observed that the salinity tended to increase at the onset of the first major winter flow, then decrease, and afterwards increase gradually until the following winter or major flow. He noted significant dilution downstream of the freshwater tributaries, Ellen and Henley Brooks.

The main tributary to the Swan River is the Helena River. It rises on the Darling Plateau and has a catchment of about 2 500 km^2. Flows to 150 m^3/s can occur, but these are regulated by Mundaring Weir. The flows and salinity vary seasonally as for the Swan River except that flows are fresh and the salinity more constant, varying between 200 and 500 mg/L TDS (Anon., 1978).

The next most important tributary is Ellen Brook, whose catchment covers about 600 km^2. It carries runoff from the Darling Plateau and groundwater discharge from the Coastal Plain. The brook is intermittent, and during the summer may only persist as a series of groundwater-fed pools. Major flows are to 40 m^3/s, and the runoff has a weighted average salinity of 485 mg/L TDS (Anon., 1978).

A number of small tributaries to the Swan River rise on the Darling Plateau and are referred to as scarp drainages. These include Susannah and Jane Brooks and Blackadder Creek, which have loop-shaped courses, flowing initially northwestward from the scarp and then, at about the 20 m topographic contour, diverting sharply to the southwest. Jane Brook is perennial; the others are intermittent but maintain some permanent pools along their courses. They carry runoff as well as groundwater outflow and show a seasonal pattern of salinity variation similar to that of the Swan River. Maximum salinities vary from 220 to 3 840 mg/L TDS; the highest value was recorded from Jane Brook (south branch), presumably reflecting the salinity of groundwater base-flow (Moncrieff, 1974).

A number of drainage lines rise on the coastal plain and are referred to as plain drainages. The major plain drainages are Bennett and Henley Brooks, which are tributaries to the Swan River. Several ill-defined minor drainages originate in extensive areas of seasonal swamps (wetlands), which are groundwater discharge areas. Flows are small and intermittent, occurring mainly during the winter months and, in many cases, are enhanced by drainage systems and canalizing of the drainage lines. The lower reaches of the drainages are often deeply incised and suggest higher flow rates during more pluvial conditions in the past. The salinity of the runoff is not known but is expected to be in the range 200 to 500 mg/L TDS, similar to the unconfined groundwater.

GEOLOGY

SETTING

The Swan Valley is situated about midway along the eastern edge of the Perth Basin (Playford and others, 1976). At this locality, the margin of the basin is the Darling Fault, which separates about 13 000 m of Phanerozoic sediments in the basin from Archaean crystalline rocks of the Yilgarn Block. The Basin also includes up to 200 m of Cretaceous and Quaternary sediments which overlie a shelf cut into the Yilgarn Block, and extend up to 2 km east of the Darling Fault (Fig. 5).

STRATIGRAPHY

Fresh and brackish groundwater resources may occur to a depth of about 1 000 m beneath the Swan Valley. The various formations which are recognized to this depth are given in Table 2, together with brief notes on their lithology and groundwater potential. More detailed descriptions of the formations, with the exception of the Yarragadee Formation and South Perth Shale, are given below. For descriptions of the last two, reference should be made to Playford and others (1976) or Allen (1979).

MESOZOIC

Leederville Formation

The Leederville Formation (Cockbain and Playford, 1973) is grey, or mottled white, red, and yellow (where weathered near the Darling Scarp), fine to coarse, poorly sorted, unconsolidated to lightly cemented sandstone; and grey to black, laminated, carbonaceous, slightly micaceous siltstone and shale. Locally, the sandstones may be pyritic or glauconitic and, adjacent to the scarp, may contain well-rounded cobbles and small boulders of granite, dolerite, and quartz. The sandstones consist of angular to subangular quartz in discontinuous beds up to 10 m thick but averaging 3 m. Sandstone comprises about 50% of the formation in cyclical sequences of sandstone, siltstone, and shale. In general, sandstone is more common in the lower part of the formation. The formation was deposited in a fluviatile environment in the east, and paralic and marine environments in the west (Whincup, 1966).

The Leederville Formation conformably overlies the South Perth Shale and is either conformably overlain by the Osborne Formation, or unconformably overlain by the "superficial formations" where the Osborne Formation has been removed by erosion (Fig. 3). The contact with the Osborne Formation is usually distinctive on gamma-ray logs. The formation extends throughout the subsurface west of the Darling Fault,

TABLE 2—STRATIGRAPHIC TABLE FOR THE SWAN VALLEY

Formal age		Rock unit	Maximum thickness (m)	Lithology	Hydrogeology
CAINOZOIC	Quaternary	"Superficial formations" (a)	50	Sand; limestone; clay; minor gravel	East of Swan River, minor aquifer, small supplies of fresh to brackish water; west of Swan River, major aquifer, large supplies of fresh water except in vicinity of river.
				UNCONFORMITY	
MESOZOIC	Late Cretaceous	Osborne Formation	160	Shale; siltstone; sand; silty sand	Local aquifer, moderate supplies of fresh water
	Early Cretaceous	Leederville Formation	325	Interbedded sandstone	Major aquifer, moderate to large supplies of fresh water in the upper half of the formation; brackish water in the lower half.
	Early Cretaceous	South Perth Shale	110	Shale and siltstone	Aquiclude
				UNCONFORMITY	
	Early Cretaceous-Middle Jurassic	Yarragadee Formation	2 500	Interbedded sandstone, siltstone and shale	Major aquifer, large supplies brackish water.

(a) Informal name

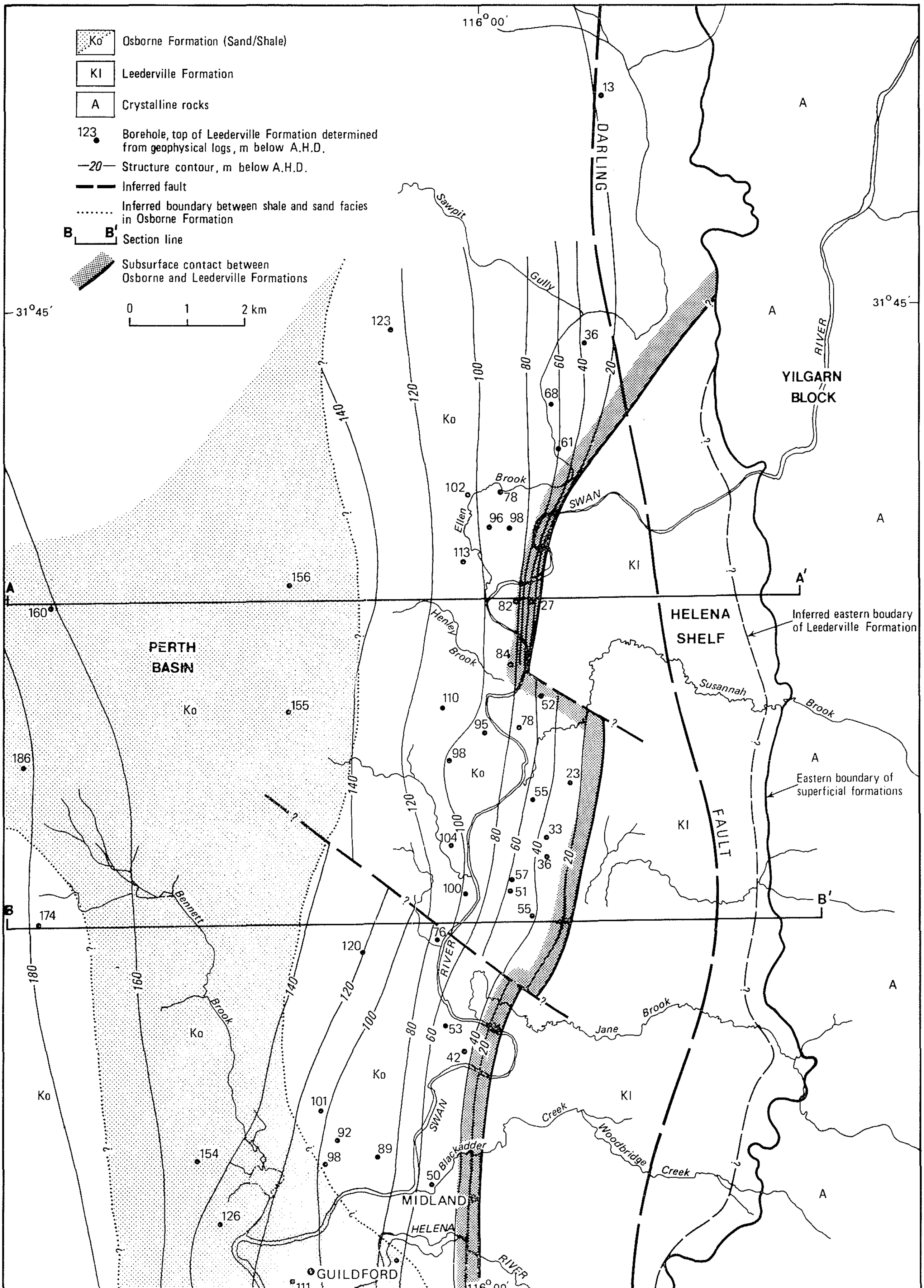


Figure 3 Subcrop map and structure contours on the stratigraphic top of the Leederville Formation.

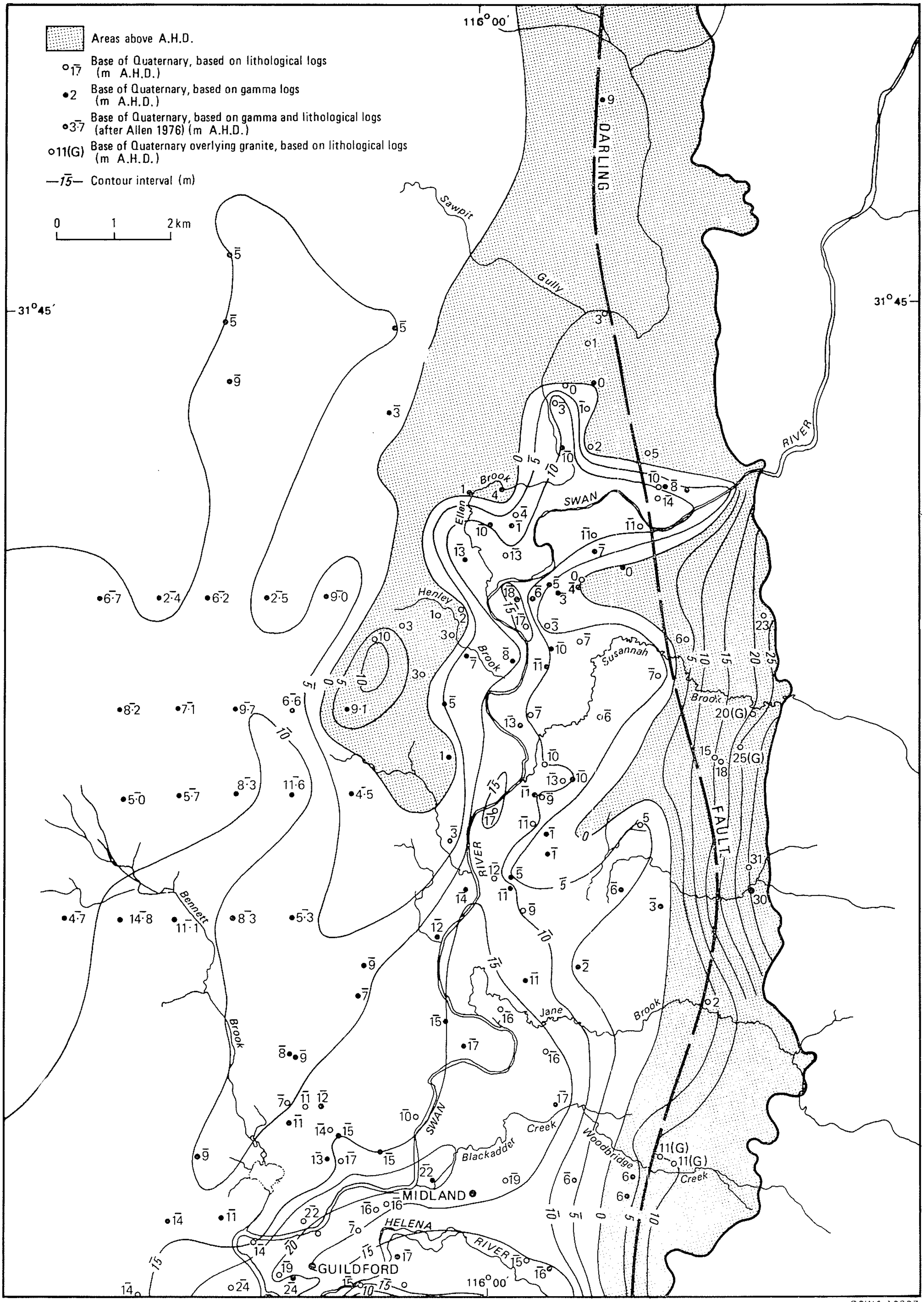


Figure 4 Contours on unconformity surface at the base of the "superficial formations".

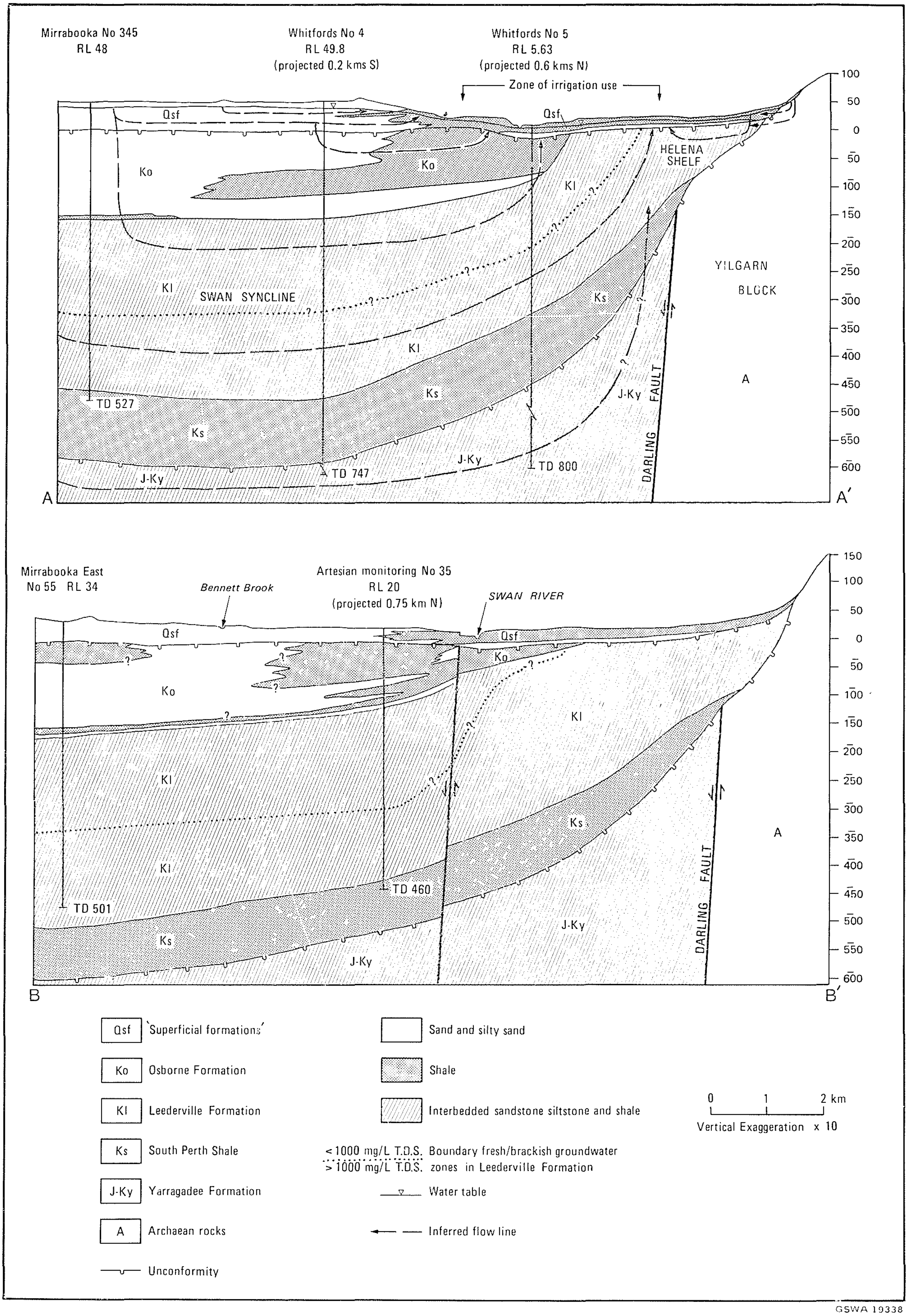


Figure 5 Hydrogeological cross-sections of the Swan Valley.

but to the east, where it laps on to the Yilgarn Block, its subsurface extent is not reliably known. Locally, as in Loton Road, it is poorly exposed. The formation is up to 325 m thick west of the Darling Fault and up to 200 m thick where it laps on to the Yilgarn Block.

Osborne Formation

The Osborne Formation (McWhae and others, 1958) consists of laterally and vertically variable, black to olive-green sandy shale and siltstone, and of olive-green to grey, silty and clayey, well-sorted, glauconitic, fine to medium, rounded to well-rounded, sand that was deposited in a shallow-water marine environment. The formation appears to exhibit marked vertical and lateral facies variations between sand, siltstone and shale. Allen (1977) interpreted unfossiliferous glauconitic sand ("channel sand") in the East Mirrabooka well field, as the infilling of a submarine channel with material derived from the Late Cretaceous formations. Subsequent drilling by the MWB has shown that a more likely explanation is that it is a sandy facies interfingering with siltstone and shale within the Osborne Formation (Fig. 5).

The Osborne Formation overlies the Leederville Formation and is unconformably overlain by the "superficial formations". It occurs in the subsurface to about 2 km west of the Darling Fault except in the north where both the Osborne and Leederville Formations extend across the fault and on to the Yilgarn Block (Fig. 3). West of the Darling Fault, the partly eroded Osborne Formation is up to 160 m thick, but to the east its thickness and extent are uncertain.

CAINOZOIC

"Superficial formations"

The "superficial formations" (Allen, 1976; 1977) are a complex series of sediments in which various formations are recognized (Playford and others, 1976) but which for convenience are considered as one unit. From the bottom upwards they consist of erosional remnants of limestone; fine to very coarse, bimodal, heavy-mineral-rich sand; coarse feldspathic sand grading eastward into sandy clay and southwards into carbonaceous clay; medium-grained eolian sand; clayey and gravelly colluvium and alluvium; and alluvial sand, gravel, and silt. In general, to the east of the Swan River the "superficial formations" are predominantly clayey, whereas to the west they are mainly sandy, The "superficial formations" were deposited in shallow-water marine, paralic, estuarine, eolian, colluvial and alluvial environments during oscillations in sea level and various climatic phases during the latter part of the Cainozoic.

The "superficial formations" unconformably overlie the Archaean granitic rocks, the Leederville, and the Osborne Formation, and extend from the foot of the Darling Scarp westward across the coastal plain (Fig. 5). They exhibit complex intra-unit unconformities, disconformities, cut and fill, and facies variations. The "superficial formations" are up to 50 m thick depending on the topography and the elevation of the basal unconformity, but tend to thicken toward the northwest.

STRUCTURE

The main elements of the geological structure in the Swan Valley are the Perth Basin and Yilgarn Block, separated by the Darling Fault. Within the Perth Basin, the Yarragadee Formation forms a gently east-dipping block of sediments (Playford, 1976), on which is superimposed the Swan Syncline (Allen, 1979), which appears to result from differential compaction of the pre-existing sediments (Cope, 1972). The eastern limb of the Swan Syncline extends across the Darling Fault on to a 2 km-wide shelf, here referred to as the Helena Shelf (Fig. 3), along the western edge of the Yilgarn Block. The Swan Syncline is overlain and concealed by a flat-lying cover of "superficial formations" that rest on an irregular erosion surface in which an ancestral valley of the Swan River is evident (Fig. 4).

HYDROGEOLOGY

FLOW SYSTEMS

In the Swan Valley, the "superficial formations", and the Osborne, Leederville and Yarragadee Formations are multilayer aquifers. They contain strata-controlled flow systems which may cross formation boundaries at intake and discharge areas.

The groundwater in the aquifers originates from rainfall. The location of the intakes and discharge areas, and configuration of the flow systems is determined by the topography and geological structure. The relationship of the flow system is shown diagrammatically in Figure 5, Section A-A'.

AQUIFERS

"Superficial formations"

General: The "superficial formations", despite wide variability in lithology, form a distinct aquifer. However, the major drainages, form hydraulic boundaries to the groundwater which is contained by the "superficial formations", and several distinct areas are recognizable (Fig. 6). Of these, the Swan-Helena area is described here.

For a description of the part of the Gnangara Mound in the western part of the Swan Valley, reference should be made to Allen (1976 and 1977).

Groundwater occurrence: The "superficial formations" in the Swan-Helena area are composed primarily of clayey sediments and subordinate beds of sand and gravelly sand. They contain a groundwater flow system bounded by hydraulic boundaries formed by the Swan and Helena Rivers. The flow system is probably in lateral hydraulic connection with groundwater in the Archaean crystalline rocks and is in downward (east) and upward (west) hydraulic connection with the Leederville Formation on the Helena Shelf (Fig. 5, Section A-A').

Recharge: Recharge is directly from rainfall, lateral movement of groundwater from the crystalline rocks, and upward discharge from the Leederville Formation (Fig. 5). The main sites of rainfall recharge, as indicated by the water table contours (Fig. 6) and by the groundwater salinity (Fig. 7), are on the Ridge Hill Shelf and on the interfluves between the scarp drainages. Near the Swan River, upward heads, and the preponderance of clay in the "superficial formations", limit recharge, apart from a small downward accretion to the water table each winter. Moncrieff (1974) observed that the water table rose 1 to 4·5 m during the winter and that the main changes occurred near drainage lines. This may be related to flow stage in the drainages over intake areas, or to raised heads in the Leederville Formation where it discharges into the "superficial formations".

Movement and discharge: Groundwater movement is westward toward the Swan River. Discharge occurs into the Swan River and the major scarp drainages as indicated by the re-entrants on the groundwater contours, and by permanent flow and pools on some of the drainages. Discharge is also presumed to occur from extensive areas of low-lying land, which are waterlogged during the winter as a result of the raised water table and from which drains and evapotranspiration remove large volumes of water.

Storage and throughflow: The Swan-Helena area extends from the hydraulic boundaries formed by the Swan and Helena Rivers to the edge of the Perth Basin sediments (Fig. 6). The approximate volume of groundwater in storage for the area (52 km^2), assuming an average saturated thickness of 12·5 m (Figs. 4 and 6) and specific yield of 0·05 is:

$$V = 52 \times 10^6 \times 12{\cdot}5 \times 0{\cdot}05 = 33 \times 10^6 \text{ m}^3$$

The groundwater throughflow past the 10 m water-table contour between the Swan and Helena Rivers (Fig. 6) can be calculated from the form of the Darcy equation:

$$Q = KbIL \quad .... \quad .... \quad .... \quad (1)$$

where Q = throughflow (m^3/d)
K = hydraulic conductivity (m/d)
b = thickness of saturated aquifer (m)
I = groundwater gradient (dimensionless)
L = width of flow section (m)

The average saturated aquifer thickness is 18 m, of which 40% is assumed to be sand (Figs. 3 and 5); the flow section is 18 km wide and has a groundwater gradient of 0·004 5 (Fig. 6). If the hydraulic conductivity is assumed to be 5 m/d then the throughflow (Q) is:

$$Q = 5 \times 18 \times 0{\cdot}40 \times 0{\cdot}004\,5 \times 18\,000 = 2\,916 \text{ m}^3\text{/d (or } 1{\cdot}1 \times 10^6 \text{ m}^3\text{/year)}$$

Quality: An isohaline map showing spatial variation in groundwater salinity is given in Figure 7. It is based mainly on field analyses (TDS by conductivity) of groundwater from about 700 wells sunk 3–4 m below the water table and shows in an extremely generalized fashion the variation of groundwater salinity at the water table. The groundwater salinity generally increases with depth so that groundwater with a higher salinity than indicated on the map can be obtained from deeper bores or wells.

The groundwater salinity varies from 150 to 5 000 mg/L TDS. The lowest salinities occur at the intake on the Ridge Hill Shelf, and the highest salinities occur adjacent to the discharge areas near the scarp drainages. Some analyses of groundwater from the "superficial formations" in the Swan-Helena area are given in Table 3 and by Moncrieff (1974).

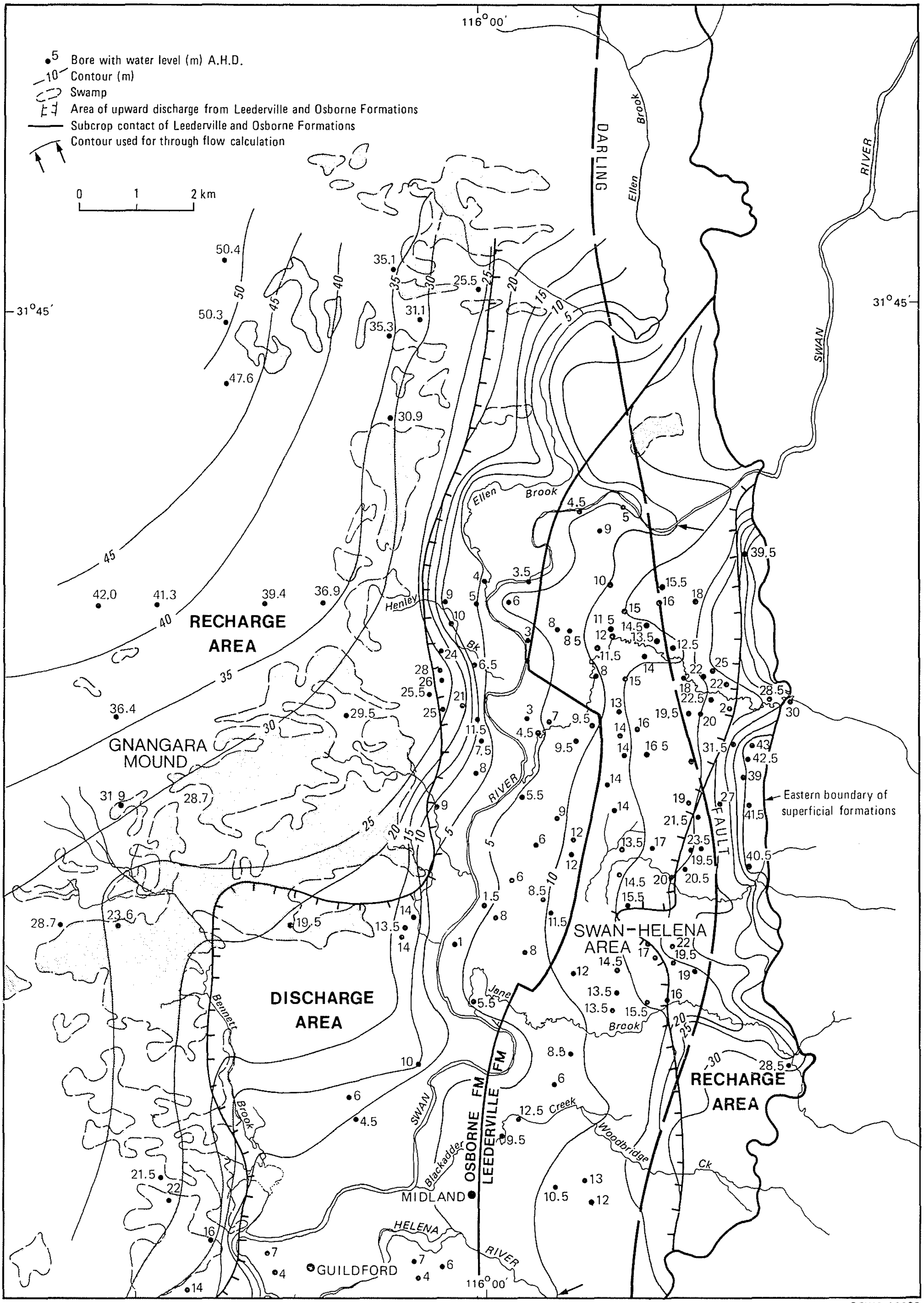


Figure 6 Non-synoptic water-table map, showing swamps and area of upward recharge from the Osborne and Leederville Formations.

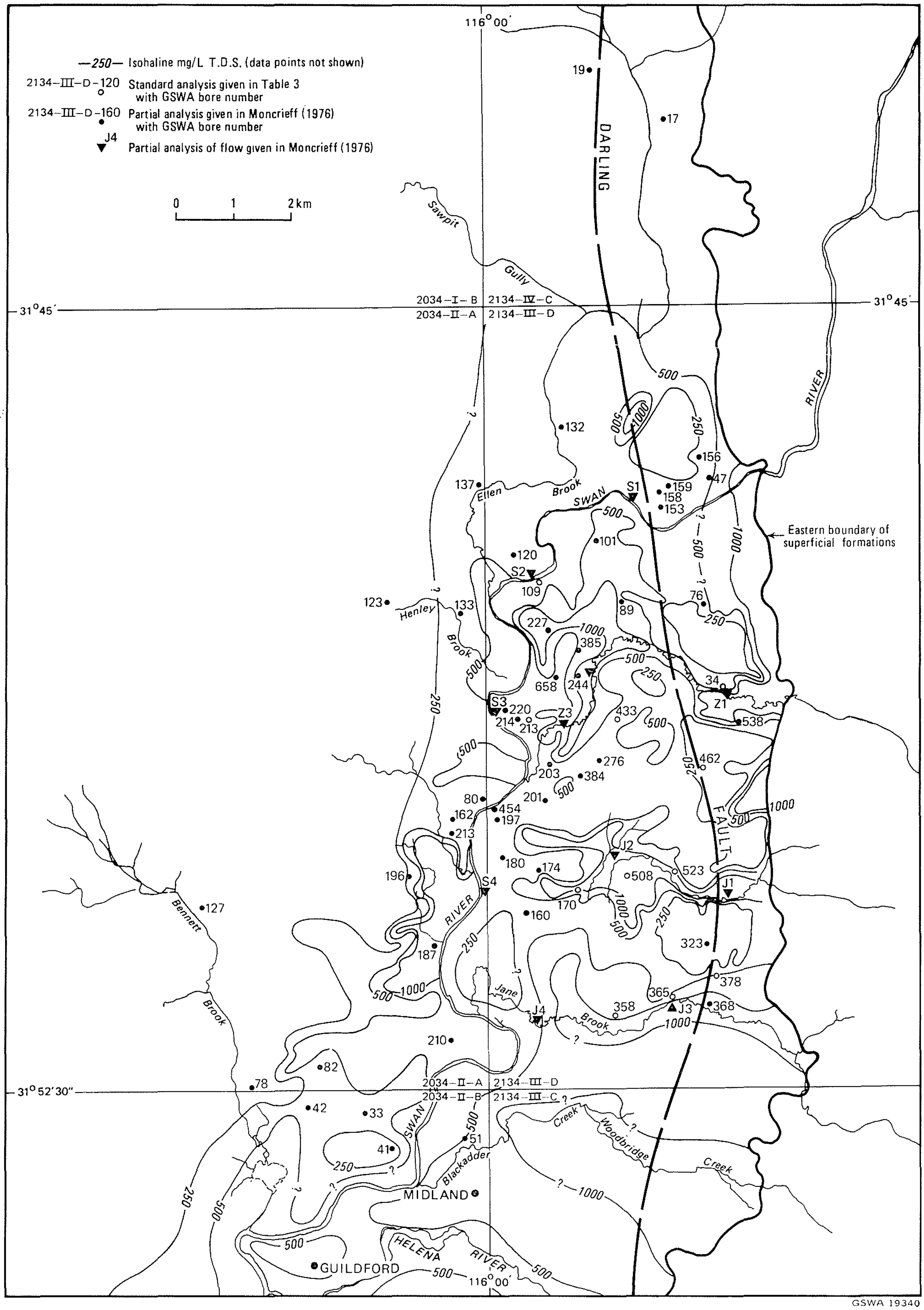


Figure 7 Isohaline map for "superficial formations" and location of standard and partial water analyses.

Development: Prior to 1976 almost every allotment had a bore or well for domestic or reticulation use. Since then, the MWB has provided scheme water, and most of the bores and wells are disused or have been abandoned. Many wells have been infilled with household refuse and may be sources of groundwater pollution.

In the Swan-Helena area, groundwater yields from the "superficial formations" are generally low (5 m^3/d or less) because of the clayey nature of the sediments. For this reason, most of the supplies were obtained from wells, some of which had their supplies enhanced by the construction of horizontal drives or, by the drilling of shallow bore(s) from the bottom of the well. The latter technique allows groundwater under higher heads in the deeper sands of the "superficial formations" or the top of the Leederville Formation to flow into the well.

The annual abstraction from the Swan-Helena area is not known but is expected to be less than $0 \cdot 5 \times 10^6$ m^3/year. Future large-scale abstraction is not expected because of the low yields and variable salinity.

Osborne Formation

General: The Osborne Formation was previously considered to be an aquiclude and to have only limited groundwater potential from sands occurring at the base of the formation. However, the discovery of an extensive silty-sand facies within the formation, toward the axis of the Swan Syncline, has changed this view and shown that, locally, the formation may be a significant aquifer and may be an important source of recharge to the underlying Leederville Formation.

Groundwater occurrence: Groundwater in the formation originates as downward seepage from the "superficial formation". It is in downward hydraulic continuity with groundwater in the Leederville Formation to the northwest of the Swan Valley, and in upward continuity with that in the "superficial formations" in the vicinity of the Swan River and Bennett Brook (Fig. 6). Artesian flows may occur in the areas of upward head.

The configuration of the potentiometric surface is only known in the Mirrabooka well field (Fig. 7). Elsewhere it is expected to be similar to that in the underlying Leederville Formation except that heads would be higher at intakes and lower in discharge areas.

Recharge: Recharge to the Osborne Formation is by downward leakage from the "superficial formations" to the west and northwest of the Swan Valley (Fig. 8), and by upward leakage from the Leederville Formation in the vicinity of the Swan River. The area of Osborne Formation subcrop where there is potential for recharge is given in Allen (1979, Fig. 3) and is approximately 400 km^2.

Movement and Discharge: Groundwater movement in the Osborne Formation is toward the south and southeast (Fig. 8). Discharge is presumed to occur by upward leakage into the "superficial formations" in the vicinity of the lower reaches of Bennett Brook and along the Swan River, where it is ultimately lost by evapotranspiration or as streamflow. Discharge by downward leakage into the Leederville Formation occurs to the northwest of the Swan Valley. Presumably, downward leakage is impeded by interbedded shale and siltstone, but because of the large area over which downward head gradients occur, discharge to the Leederville Formation is probably quite large.

Storage and throughflow: Groundwater storage in the Osborne Formation must be very large, judged from the extent and thickness of the formation (Figs 3 and 5), and the proportion of sand, silty sand, and siltstone.

Groundwater flow is approximately normal to sections A-A' and B-B' given in Figure 5 and, judged from the isopotentials in the Leederville Formation, would ultimately be discharged in the Swan Valley. The throughflow can be calculated from the form of the Darcy equation:

$$Q = KAI \quad \ldots \quad (2)$$

where Q = throughflow (m^3/d)
K = hydraulic conductivity (m/d)
A = vertical area through which flow occurs (m^2)
I = groundwater gradient (dimensionless)

The hydraulic conductivity was taken as $2 \cdot 5$ m/d (Davidson, 1979); the area of sand was measured from Figure 5; and the hydraulic gradient was measured from contours given in Figure 8. Solving equation (2) the throughflow in section A-A' is:

$$Q = 2 \cdot 5 \times 1\,125\,000 \times 0 \cdot 002\,0$$
$$= 5\,625 \text{ m}^3/\text{d (or } 2 \cdot 05 \times 10^6 \text{ m}^3/\text{y)}$$

and in section B-B' is:

$$Q = 2 \cdot 5 \times 1\,031\,250 \times 0 \cdot 002\,9$$
$$= 7\,477 \text{ m}^3/\text{day (or } 2 \cdot 70 \times 10^6 \text{ m}^3/\text{y)}$$

The average throughflow for the two sections ignoring any recharge from the "superficial formations" or loss to the Leederville Formation is about $2 \cdot 4 \times 10^6$ m^3/y.

Quality: Groundwater salinity in the Osborne Formation estimated from wire-line logs ranges from 190 to 750 mg/L TDS and averages about 300 mg/L TDS. Partial analyses of groundwater from the proposed extension of the Mirrabooka well field (Allen, 1977) show the groundwater salinity is similar to that estimated. Several standard analyses of groundwater from the Osborne Formation are given in Table 3.

Development: Bores in the Osborne Formation are known, to yield up to 3 000 m^3/d (depending on the bore construction) but are generally lower yielding than bores in the Leederville Formation. There are about 30 bores in the Swan Valley known to abstract from the Osborne Formation. Their annual abstraction is unknown but is estimated to be about $0 \cdot 6 \times 10^6$ m^3/y. Further abstraction from the formation is possible, which, should it exceed throughflow, will be compensated for by increased leakage from the "superficial formations".

Leederville Formation

Groundwater occurrence: The Leederville Formation is a multi-layer aquifer consisting of interbedded sandstone, siltstone, and shale, in which the individual beds of sandstone are discontinuous. In the Swan Valley, the formation is believed to contain two flow systems (Fig. 5, Section A-A′): a very small system originating at the foot of the Darling Scarp on the Helena Shelf (eastern system) and a regional system beneath the Gnangara Mound (western system). An isopotential map based on non-synoptic head measurements from bores of different depth, and poorly controlled elevation and head data is given in Figure 8. The isopotentials show a regional groundwater divide in the west and an apparent minor divide about 3 km east also extending into the Swan Valley. The complexity of the isopotentials in the Swan Valley probably result from it being a discharge area, the effect of pumping, and nature of the available data.

The eastern system is in downward hydraulic continuity with the "superficial formations" at the foot of the Darling Scarp and upward continuity in the west near the inferred discharge area between the subcrop contact of the Osborne and Leederville Formations and the Darling Fault. In some areas adjacent to the Darling Scarp, there may be direct infiltration of rainfall or runoff into the formation, and lateral hydraulic connection with the crystalline rocks.

The western system is in downward hydraulic continuity with the "superficial formations" and the Osborne Formation over the inferred recharge area, and upward continuity in the discharge area (Fig. 5). Adjacent to the Darling Fault, the flow system may be in upward hydraulic connection with the Yarragadee Formation as indicated in MWB Whitfords 5 and 5A, where the head is nearly equal in the two formations. The inter-relationship between the eastern and western flow systems is inferred to be as shown in Figure 5.

Recharge: Recharge to the eastern system is from rainfall, either directly on small areas of outcrop or via the "superficial formations". Localized recharge may occur along drainage lines at the foot of the Darling Scarp and possibly by lateral inflow of groundwater from the Archaean crystalline rocks. The recharge area, determined by overlaying Figure 6 on Figure 8, is shown in Figure 8, it lies mainly on the Helena Shelf and has an area of about 16 km^2. If it is assumed that 5% of the annual rainfall (860 mm) on the intake area is recharge, then the approximate recharge is $16 \times 10^6 \times 0 \cdot 86 \times 0 \cdot 05 = 0 \cdot 69 \times 10^6$ m^3/y. Some runoff may also contribute to the recharge but the contribution is likely to be small.

The western flow system has a recharge area of about 1 300 km^2 and is recharged directly via the "superficial formations" or via the Osborne Formation, where downward heads between the "superficial formations" and Leederville Formation occur (Allen, 1979). The inferred area of recharge adjacent to the Swan Valley is shown in Figure 8; it appears to form a mound in the isopotential surface which coincides with the sandy facies of the Osborne Formation.

Movement and Discharge: Groundwater flow in the eastern system is to the west. Groundwater discharge is presumed to occur where the two flow systems meet (Fig. 5, Section A-A′) by upward flow into the "superficial formations" from which it is lost by evapotranspiration and surface outflow along the lower reaches of the scarp drainages.

In the western system, the regional direction of groundwater flow is southeastward till it reaches the Darling Fault, where it is discharged as the flow is deflected southward. Discharge takes place in the vicinity of the Swan River via the "superficial formations" between the subcrop contact of the Osborne and Leederville Formations and the Darling Fault.

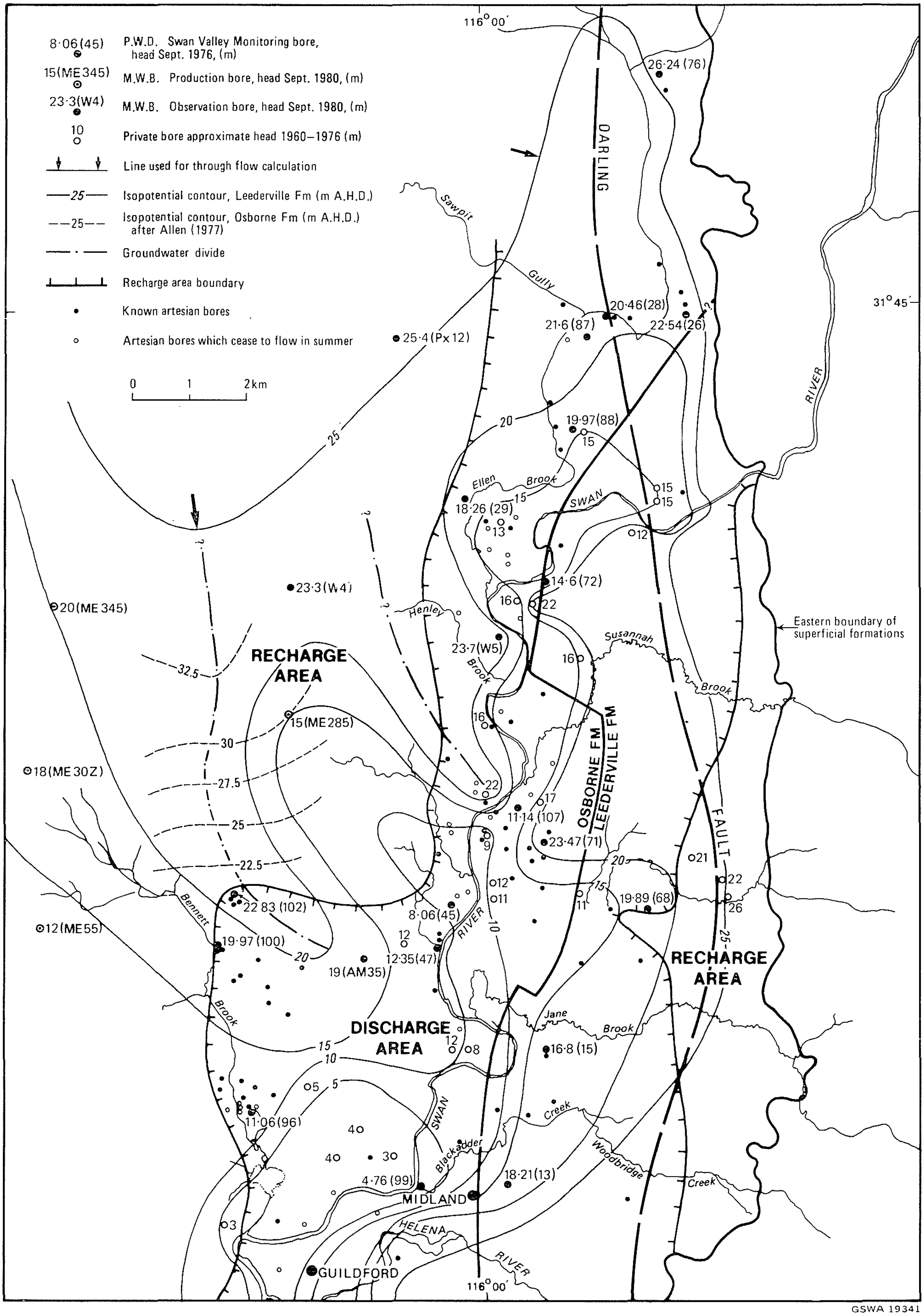


Figure 8 Non-synoptic isopotential contours for groundwater in the Leederville Formation (upper zone), recharge and discharge areas, and location of artesian bores.

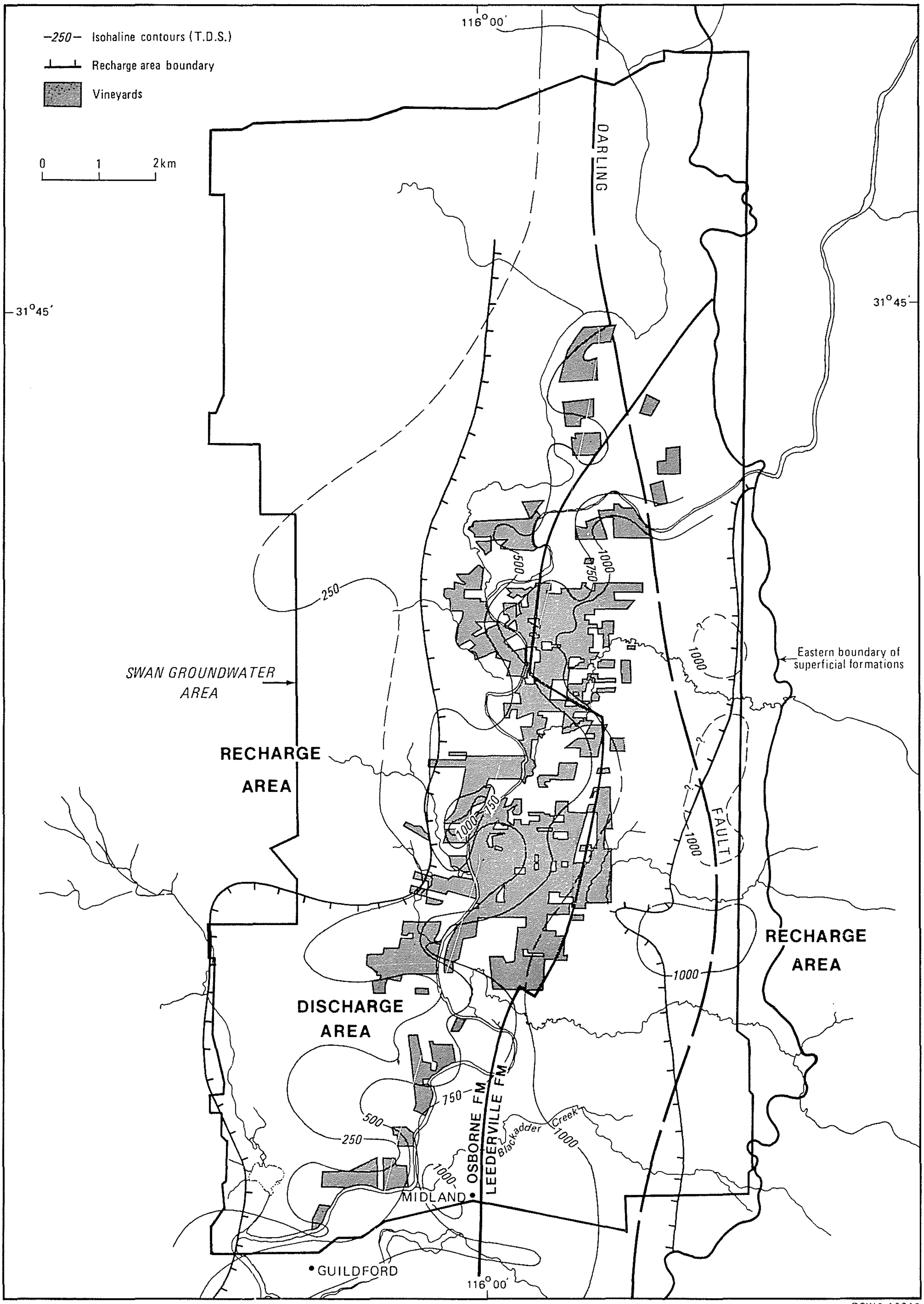


Figure 9 Isohaline map of lowest salinity groundwater in the Leederville Formation (upper zone) with respect to the discharge area and location of vineyards.

TABLE 3. STANDARD ANALYSES OF GROUNDWATER

Geological Survey Number	Name	Government Chemical Laboratories No.	pH	Conductivity mSm @ 20°C	Total Dissolved Solids by Conductivity (mg/L)	Total Dissolved Solids by Evaporation (mg/L)	Total Hardness as $CaCo_3$ (mg/L)	Total Alkalinity as $CaCo_3$ (mg/L)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Chloride (Cl)	Sulphate (SO_4)	Nitrate (NO_3)	Silica (SiO_2)	Boron (B)	Fluoride (F)	Iron (Fe)	Formation	Depth (metres)
									mg/L													
SH/50–14:																						
2134–III–D–174	Svicarovich	6095/69	7·6	910	640	540	111	72	25	12	140	13	88	228	38	<1	32	....	....	<0·1	LF	121·9
–180	Bignell AR	6096/69	8·0	580	410	350	57	93	11	7	108	9	113	144	6	<1	22	....	....	<0·1	LF	91·8
–197	Purnich S	6097/69	7·6	990	690	590	104	65	22	12	164	14	79	270	32	<1	32	....	....	<0·1	OF	83·8
–203	Thorn	6098/69	7·5	970	680	580	99	62	18	13	166	13	76	263	42	<1	34	....	....	<0·1	LF	97·6
–220	Barrett	6099/69	7·7	670	470	420	61	65	13	7	118	10	79	166	30	<1	38	....	....	<0·1	LF	107·9
2034–II–B– 59	Morris B	6100/69	7·7	1 420	990	830	114	50	13	20	257	16	61	415	57	<1	28	....	....	<0·1	LF	186
2134–III–D–164	Houghton Wine	6101/69	7·5	1 110	780	670	108	52	17	16	187	14	64	311	40	<1	35	....	....	<0·1	LF	201·2
–454	Sokal D	6102/69	7·9	1 000	700	600	109	57	19	15	166	14	70	272	44	1	32	....	....	<0·1	LF	147·9
–214	Hatch G	6103/69	7·7	1 060	740	640	98	48	16	14	182	14	58	292	48	1	32	....	....	<0·1	LF	152·4
–368	Erhardt	6104/69	8·1	5 050	3 540	3 380	313	273	53	44	1 190	32	332	1 730	220	5	14	....	....	<0·1	LF	129·3
–IV–C– 19	Rogold Inc	1817/71	6·1	410	290	290	35	38	4	6	69	7	46	104	9	<1	62	....	....	0·34	OF	61
– 17	Higgins Inc	1818/71	6·4	1 690	1 180	950	291	128	31	52	242	7	156	476	28	<1	54	....	....	0·06	LF	91·5
–III–D–127	Ag Dept	1819/71	6·8	560	390	360	56	55	11	7	87	10	67	128	23	<1	45	....	....	31	LF	78·7
–156	Worthington	1820/71	6·0	200	140	150	18	17	4	2	32	4	21	42	2	18	29	....	....	<0·03	?SF	27·4
–153	Pavlinovich	1821/71	6·4	1 060	740	590	103	70	17	15	169	14	85	277	28	<1	35	....	....	<0·05	LF	47·3
2034–II–A–213	Lendich	1812/71	6·6	1 570	1 100	930	128	62	15	22	282	17	76	463	45	<1	22	....	....	0·19	LF	169·2
–127	Whiteman	1813/71	6·1	270	190	160	33	24	7	4	43	3	34	74	<1	1	7	....	....	1·8	OF	54·3
–II–B– 42	Sarich	1814/71	7·3	420	290	280	11	100	3	1	90	7	122	81	2	<1	40	....	....	0·46	OF	48·8
–II–A– 78	Schwinkowski	1815/71	6·6	310	220	210	59	57	19	3	42	6	70	71	<1	1	19	....	....	1·1	SF	18·3
–II–B– 41	Antunovich	1816/71	7·6	340	240	230	56	108	11	7	54	8	131	53	<1	1	28	....	....	0·19	OF	93·3
2134–III–D–201	Harkness	8294/70	7·7	950	670	570	96	60	19	12	164	14	73	260	42	<1	27	....	....	<0·1	LF	152·4
–538	Bowman	8295/70	7·6	870	610	530	82	62	15	11	150	13	76	230	37	<1	27	....	....	<0·1	LF	153·4
2034–II–A– 82	Taylor W	8296/70	8·0	410	290	240	72	117	11	11	63	11	143	74	2	<1	4	....	....	<0·1	OF	133·5
–162	Yakich	8297/70	7·8	1 120	780	660	98	67	16	14	196	14	82	308	39	<1	26	....	....	<0·1	LF	181·4
–187	Beros M	8298/70	7·4	1 220	850	730	106	65	16	16	217	16	79	343	48	<1	27	....	....	<0·1	LF	189·0
2134–III–D–120	Mateljan	8290/70	7·6	520	360	340	50	78	10	6	98	9	95	121	25	<1	38	....	....	0·2	LF	132·3
2034–II–A–133	Yujnovich	8291/70	7·7	530	370	340	51	76	12	5	97	10	92	123	24	<1	36	....	....	0·3	LF	170·7
2134–III–D– 80	Rosic	8292/70	5·3	1 470	1 030	850	123	5	15	21	256	18	6	402	125	1	20	....	....	<0·1	LF	182·9
2034–II–B– 42	Sarich P	8293/70	7·5	710	500	390	64	95	14	7	124	11	116	177	1	3	11	....	....	<0·1	OF	48·8
2134–III–D–227	Udiljack	6130/69	6·8	1 380	970	840	151	110	26	21	237	12	134	377	39	1	35	....	....	<0·1	LF	76·2
–384	Swan Athletic Club	6131/69	7·1	910	640	540	91	77	17	12	152	12	95	233	44	<1	30	....	....	<0·1	LF	67·1
–276	Klematis	6132/69	6·5	1 080	760	640	159	37	16	29	162	5	46	311	35	5	28	....	....	<0·1	LF	45·1
–399	Gorizinski	6133/69	5·9	1 900	1 330	1 100	400	62	27	81	249	7	76	623	9	<1	31	....	....	0·4	LF	25·6
2024–II–A–123	Meakins	1822/71	6·9	330	230	220	93	93	34	2	34	3	113	55	<1	<1	13	....	....	1·8	SF	....
2134–III–D–383	Sangalli	1823/71	6·2	2 140	1 500	1 290	295	60	16	62	343	5	73	666	47	1	39	....	....	0·05	LF	46·7
–323	Petrich	1824/71	4·8	340	240	220	13	2	2	2	65	2	3	73	41	11	17	....	....	<0·05	?SF	....
2034–II–A–196	O'Brien	1825/71	7·5	300	210	190	59	98	12	7	41	7	120	41	<1	1	28	....	....	0·09	?OF	....
–II–B– 33	Lovreta	1826/71	7·1	800	560	470	82	83	15	11	137	5	101	187	39	<1	15	....	....	<0·05	LF	....
–II–A–210	Roe	1811/71	7·4	460	320	280	59	103	12	7	74	11	125	88	7	1	26	....	....	0·34	?OF	....
2134–III–D–158	Burgh	2997/69	6·7	770	540	460	81	67	11	13	125	12	82	194	27	<1	23	....	....	0·1	?SF	30·5
–159	Hebiton (River land)	2998/69	7·3	5 010	3 510	3 480	563	170	97	78	1 048	36	207	1 782	194	3	10	....	....	0·1	LF	166·2
2034–II–A–137	Barrett-Lennard	2999/69	7·0	490	340	320	51	75	12	5	91	9	91	114	24	<1	25	....	....	3·3	LF	147·9
2134–III–D–385	Mateljan	3000/69	6·7	1 700	1 190	1 030	151	80	24	22	309	15	98	509	42	<1	16	....	....	0·1	LF	82·9
– 47	Hebiton	71/68	7·1	4 600	3 220	3 240	434	263	78	58	1 050	34	320	1 630	192	1	14	....	....	0·1	LF	....
–132	Kendall D	85879/78	7·1	*62	400	†340	55	73	12	6	94	9	89	131	22	<1	14	0·13	0·3	....	OF	....
–658	Rullo B	85880/78	7·6	*178	1 140	†980	148	70	25	21	294	17	85	463	69	<1	29	0·26	0·3	....	LF	29·8
–101	U Swan School	85881/78	7·1	*138	880	†730	121	89	14	21	219	6	109	377	5	<1	20	0·18	0·2	....	LF	....
–214	Hatch	85882/78	7·4	*101	650	†560	89	61	16	12	152	14	74	247	39	<1	31	0·14	0·2	....	LF	....
–244	Newman Bros	85883/78	7·0	*178	1 140	†950	175	46	14	34	279	6	56	476	62	<1	32	0·16	0·1	....	LF	21·3
	Hampton Hatchery	19859/78	5·5	540	380	340	47	28	4	9	96	6	34	156	14	<1	32	0·1	0·1	0·9	....	....

* mSm @ 25°C † calculated.

LF = Leederville Formation OF = Osborne Formation SF = "superficial formations"

Storage and throughflow: In the Swan Valley, the volume of groundwater in storage in the Leederville Formation is extremely large. However, because of inadequate data about the thickness and extent of the zone of fresh groundwater, it is not possible to make reliable estimates of the relative volumes of fresh and brackish groundwater in the eastern and western flow systems.

Data is also not reliable enough to estimate the throughflow in the eastern flow system. It is expected, from the limited extent of fresh groundwater, to approximate to the estimated recharge of $0 \cdot 69 \times 10^6$ m^3/y.

In the western flow system, the throughflow is difficult to estimate because of the complexity of the isopotentials. The isopotentials given in Figure 8 show that all groundwater throughflow between the main groundwater divide and the Darling Fault moves into the Swan Valley. The throughflow past the 25 m isopotential between the bounding flow lines (Fig. 8) may be estimated by assuming that: the average thickness of the formation is 320 m (Fig. 5); half the formation is sand with an hydraulic conductivity of 10 m/d (Allen, 1979); the average groundwater gradient (Fig. 8) is 0·001 5; and the width of the flow section is 9·7 km (Fig. 8). Then substituting in equation (1), the throughflow (Q) is:

$$Q = 10 \times 320 \times 0 \cdot 5 \times 0 \cdot 001\,5 \times 9\,700$$
$$= 23\,280 \text{ m}^3/\text{d (or } 8 \cdot 5 \times 10^6 \text{ m}^3/\text{y)}$$

Because the fresh water zone is about half the aquifer thickness, the fresh water throughflow is estimated to be $4 \cdot 2 \times 10^6$ m^3/y. However, the quantity of freshwater throughflow entering the Swan Valley exceeds this figure as the flow section lies upstream of areas of recharge (Fig. 8), and the throughflow ultimately discharging in the Swan Valley is probably about 5×10^6 m^3/y.

Quality: In the eastern system, groundwater salinity varies from 250 to 4 000 mg/L TDS but averages about 1 500 mg/L TDS. In general, the salinity increases with depth and toward the west. Thin zones of fresh groundwater may occur on the Ridge Hill Shelf beneath areas of fresh groundwater in the "superficial formations".

In the western system, the upper half of the Leederville Formation contains a zone of groundwater with a salinity ranging from 250 to 1 000 mg/L TDS. Below this, the lower half of the formation contains groundwater of 1 000 to 3 500 mg/L TDS. The thickness of these zones, as determined from wire line logs, is shown in Figure 5. They are remarkably constant except near the discharge area in the Swan Valley, where there is a marked decrease in the thickness of the zone of fresh groundwater.

An isohaline map based on analyses from bores of various depths, but mainly in the upper zone is given in Figure 9. It shows groundwater salinity increasing westward in the eastern flow system and eastward in the western flow system toward the discharge area. Standard analyses for groundwater from some bores (Fig. 9) in both systems are given in Table 3.

Development: In the eastern system there are about 30 non-domestic bores in the Leederville Formation. Their abstraction is unknown but is likely to be less than $0 \cdot 5 \times 10^6$ m^3/y. In addition, particularly in the Herne Hill area, there are 15 known wells, which have bores sunk from their bottom allowing artesian flow into the well (presumably mainly from the Leederville Formation). However, most of the land is unsuitable for viticulture, and the groundwater salinity is generally too high for irrigation.

In the western system there are about 400 licensed non-domestic bores up to 215 m deep but averaging about 120 m. About 100 of these in the discharge area (Fig. 8) are, or were, artesian. Yields from bores may be as high as 8 000 m^3/d but average 1 000 m^3/d. The usual method of construction is to use screens, but in older bores slotted-casing, or occasionally, open-hole, construction was used.

PWD data indicate that bores in the Leederville Formation abstract about $3 \cdot 6 \times 10^6$ m^3/yr of fresh and brackish groundwater. Of this, about 80% is used for irrigation of vineyards. There is scope for further development of the aquifer provided there are no problems of ingress of brackish groundwater from the underlying brackish zone.

CONCLUSIONS

In the Swan Valley, the major fresh groundwater resources occur in the upper half of the Leederville Formation in the western part of the Swan Valley. The zone of fresh water only extends about 2 km east of the Swan River. Consequently the eastern part of the Swan Valley from about the Great Northern Highway eastwards, is underlain by Leederville Formation containing brackish groundwater.

About 75% of the estimated renewable groundwater resources (throughflow) are being used so that there is only moderate scope for increased abstraction. Should abstraction exceed throughflow groundwater "mining" will occur, possibly leading to an increase in salinity of groundwater from production bores. This could result because most of the bores are situated in an area of upward head-gradients where groundwater will tend to move upward from the underlying zone of brackish groundwater.

REFERENCES

Allen, A. D., 1975, Swan Valley: Outline of the occurrence of groundwater resources and proposals for management: West. Australia Geol. Survey Hydro. Rept 1257 (unpublished).

——— 1976, Outline of the hydrogeology of the superficial formations of the Swan Coastal Plain: West. Australia Geol. Survey Ann. Rept 1975, p. 31–42.

——— 1977, The hydrogeology of the Mirrabooka East Area, Perth: West. Australia Geol. Survey Ann. Rept 1976, p. 14.

——— 1979, An outline of the confined groundwater resources in the vicinity of Perth, Western Australia: West. Australia Geol. Survey Ann. Rept 1978, p. 30.

Anon., 1978, Streamflow records of Western Australia to 1975: West. Australia Public Works Dept Water Resources Section Publication.

Aurousseau, M. and Budge, E. A., 1921, The terraces of the Swan and Helena Rivers and their bearing on recent displacement of the strand line: Royal Soc. West. Australia Jour., v. 7, p. 24–43.

Cockbain, A. E. and Playford, P. E., 1973, Stratigraphic nomenclature of Cretaceous rocks in the Perth Basin: West. Australia Geol. Survey Ann. Rept 1972, p. 26–31.

Cope, R. N., 1972, Tectonic style in the southern Perth Basin: West. Australia Geol. Survey Ann. Rept 1971, p. 46–50.

Davidson, W. A., 1979, East Mirrabooka 172 pumping test: West Australia Geol. Survey Hydro Rept 1975 (unpublished).

McArthur, W. M. and Bettenay, E., 1960, The development and distribution of the soils of the Swan Coastal Plain, Western Australia (2nd Edition 1974): Australia CSIRO, Soil Pub. no. 16.

Moncrieff, J. S., 1974, The relationship between geology, drainage and shallow groundwater in the Middle-Upper Swan Area, Western Australia: Uni. West. Australia B.Sc. Hons thesis (unpublished).

Playford, P. E., Cockbain, A. E., and Low, G. H., 1976, Geology of the Perth Basin, Western Australia: West. Australia Geol. Survey Bull. 124.

Pymm, L. W., 1955, Soils of the Swan Valley vineyard area, Western Australia: Australia CSIRO Division of Soils, Soils and Land Use Series No. 15.

Somerville, J. L., 1920, Evidence of uplift in the neighbourhood of Perth: Royal Soc. West. Australia Jour., v. 6, p. 1–20.

Whincup, P., 1966, Hydrogeology of the Pinjar exploratory drilling: West. Australia Geol. Survey Ann. Rept 1965, p. 19–24.

Woolnough, W. G., 1918, The Darling peneplain of Western Australia: Royal Soc. N.S.W. Jour., v. 32, p. 385–396.

THE GEOLOGY AND HYDROGEOLGY OF THE QUINDALUP BOREHOLE LINE

by P. H. Wharton

ABSTRACT

The Quindalup borehole line consists of sixteen boreholes at ten sites, drilled to depths of between 54 m and 1 469 m. The line extends across the Perth Basin, from 16 km west of Busselton to 8 km south of Donnybrook.

Drilling has shown that the Sue Coal Measures (Early Permian), Cockleshell Gully Formation (Early Jurassic), and the Yarragadee Formation (Middle to Late Jurassic) occur in major fault blocks, and are unconformably overlain by the Bunbury Basalt (Early Cretaceous) and the Leederville Formation (Early Cretaceous). These formations are concealed by a thin veneer of flat-lying Quaternary sediments on the Swan Coastal Plain.

The Leederville Formation is a multilayered aquifer consisting of sandstone interbedded with siltstone and shale. In low-lying areas, bores in the formation commonly flow. The salinity of groundwater in the formation is generally less than 500 mg/L TDS, except near the coast between Busselton and Dunsborough where salinities up to 42 000 mg/L TDS result from a salt-water wedge which extends inland.

The Yarragadee Formation is composed of sandstone and shale, with the percentage of sandstone ranging from about 90% near the base of the formation (in Q4) to about 25% in the younger part of the formation and towards the Darling Fault. Fresh groundwater, generally less than 500 mg/L TDS, extends to a depth of between 770 m and 1 250 m below sea level. Groundwater in the formation moves northwards, and is recharged by rainfall on the Blackwood Plateau, possibly in areas where the lateritized surface of the formation crops out.

The Cockleshell Gully Formation contains fresh groundwater, probably to a depth of about 450 m below sea level, although there is some saline water in the top of the formation near the coast. Between the Busselton and Darling Faults the formation is deeper than 500 m below sea level, and contains brackish or saline groundwater.

Major fresh groundwater resources which are virtually unexploited occur across the southern Perth Basin in the Leederville Formation, in the Yarragadee Formation between the Busselton and Darling Faults, and in the Cockleshell Gully Formation between the Busselton and Wirring Faults.

INTRODUCTION

The Quindalup Line consists of sixteen bores drilled at ten sites on an east-west line across the Perth Basin at about latitude 33°39′ south, from 16 km west of Busselton to 8 km south of Donnybrook (Fig. 1).

The drilling was carried out in two stages. Quindalup bores Q1 to Q5 were drilled primarily to determine the availability of groundwater between Busselton and Dunsborough (Probert, 1967). Later, bores at sites Q6 to Q10 were drilled to complete the section across the Perth Basin, and form part of a long-term drilling programme to evaluate the deep groundwater resources, and to investigate the stratigraphy and structure of the basin.

PHYSIOGRAPHY

The Quindalup Line bores are situated in the southern Perth Basin, where two major physiographic units are recognized (Fig. 2): the Blackwood Plateau (Low, 1972) and the Swan Coastal Plain (Saint-Smith, 1912). These units are bounded to the west by the Leeuwin-Naturaliste Ridge, and to the east by the Darling Plateau.

The Blackwood Plateau has an elevation of about 130 m, occasionally up to 200 m, above sea level, and is dissected by well-developed consequent drainage systems. The northern and northwestern margin of the plateau is formed by the Whicher Scarp, a Late Tertiary or Pleistocene shoreline (Playford and others, 1976).

The Swan Coastal Plain lies to the north and northwest of the Whicher Scarp, and can be sub-divided into three physiographic units (Low, 1972): the Pinjarra Plain, formed by fine-grained alluvial and piedmont deposits; the Bassendean Dunes,

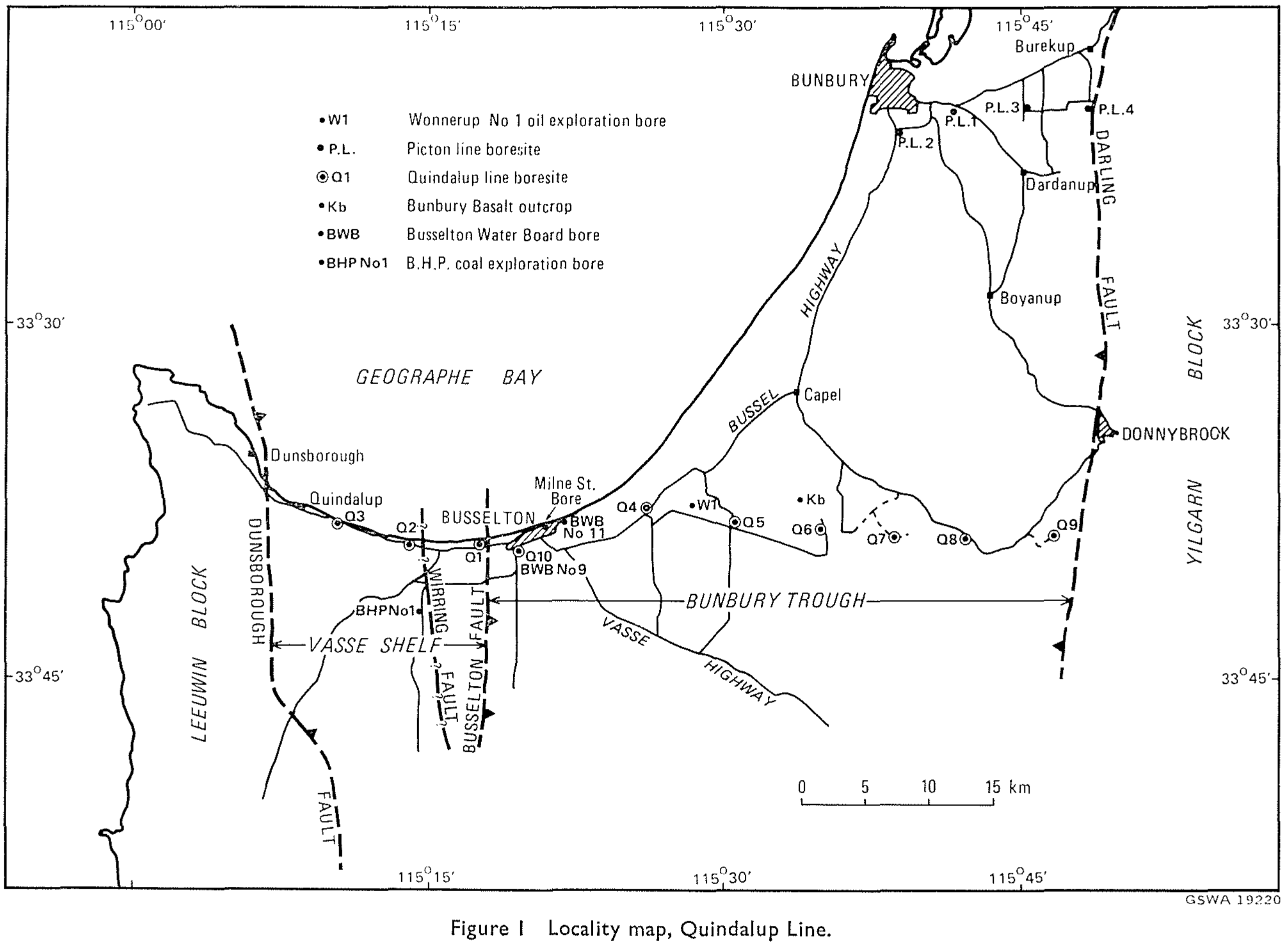


Figure I Locality map, Quindalup Line.

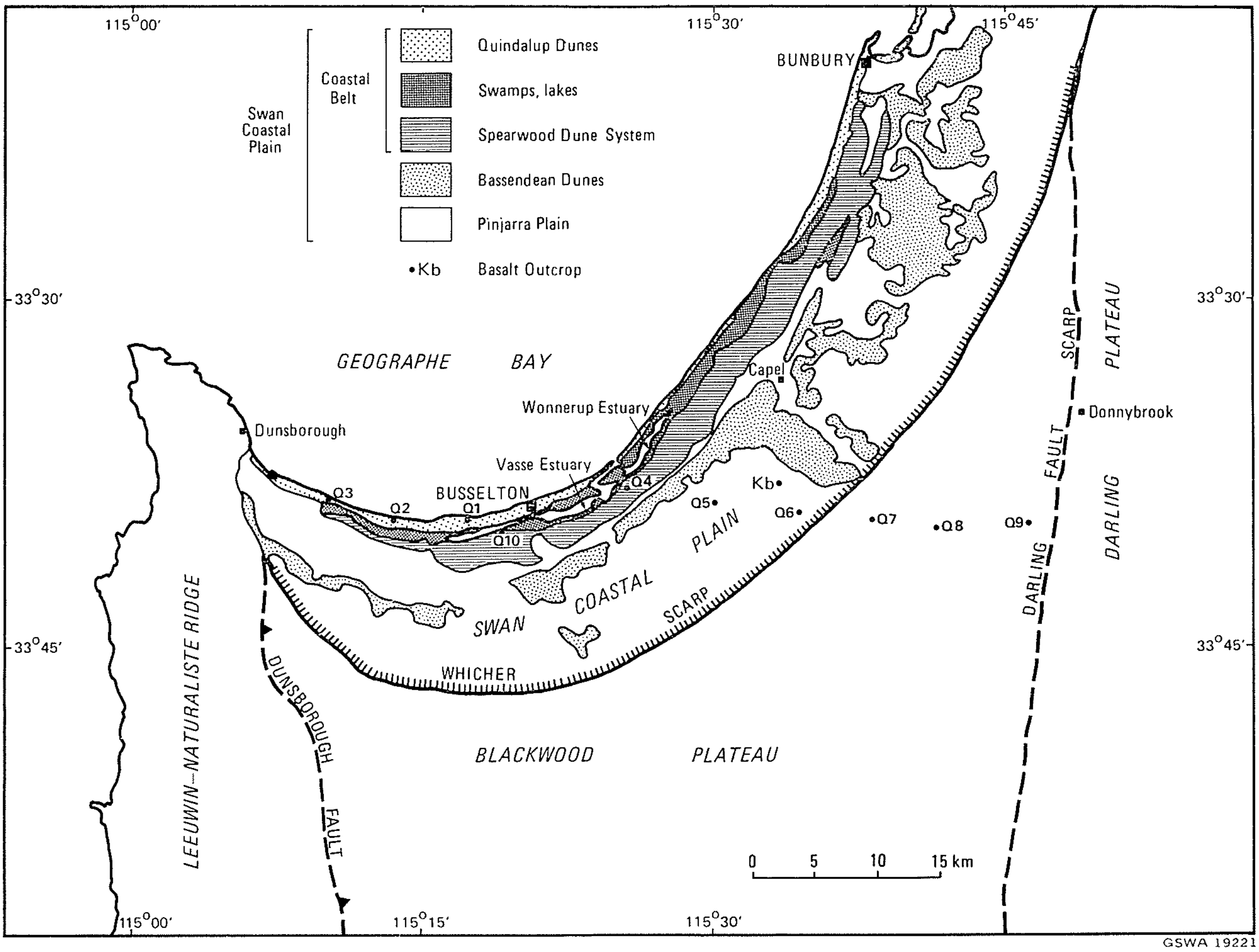


Figure 2 Physiographic subdivisions.

which comprise low dunes of quartz sand overlying the Pinjarra Plain; and the Coastal Belt, which consists of a narrow belt of active dunes along the coast (Quindalup Dunes), separated from an inland band of fixed calcified dunes (Spearwood Dune System) by lagoons, estuaries and swamps.

INVESTIGATION PROGRAMME

A summary of drilling and bore information is given in Table 1. The bores were drilled using mud-flush rotary rigs, and all bores were drilled by the Mines Department Drilling Section, except Q6 which was by private contract.

Sludge samples were collected at 3 m intervals except where conventional cores were taken in bores Q1 to Q5, at about 50 m intervals. A 3-m core barrel was used but recovery was generally poor. On completion of drilling, gamma-ray and long- and short-normal resistivity logs were run in each bore (except Q9C and Q9D), and various other wire-line logs were run in the bores as required. Sidewall cores were recovered from shale or siltstone beds at about 40 m intervals in the deep bores at sites Q6 and Q10.

In bores Q1 to Q5 the groundwater from 5 to 10 aquifer intervals was sampled using a formation tester, but the method proved to be unreliable. Static water-level measurements made by this method were inaccurate, and have been disregarded. After the formation tests, bores Q1 to Q3, and Q5 were sealed with cement plugs and abandoned. Q4, a flowing bore, was fitted with a gate-valve so the bore could be used as an emergency water supply.

The bores at sites Q6 to Q10 were completed as observation bores, and were constructed so that one or more aquifer intervals could be tested or monitored in each bore. Each interval was developed either by air-lifting and surging, or with a swabbing tool, until the water cleared and the salinity stabilized. Water samples taken after development were analyzed by the Government Chemical Laboratories.

A detailed account of the investigation procedures and bore construction methods is given by Wharton (in prep.).

GEOLOGY

SETTING

The Quindalup Line bores were drilled in the southern Perth Basin between the Leeuwin Block in the west, and the Yilgarn Block in the east. The southern Perth Basin is subdivided into two major structural units; the Bunbury Trough and the Vasse Shelf (Fig. 1). The Bunbury Trough, between the Darling and Busselton Faults, is a deep graben which probably contains at least 10 000 m of Phanerozoic sediments. The Vasse Shelf lies between the Bunbury Trough and the Leeuwin Block, and is bounded by the Busselton and Dunsborough Faults. Sediments on the shelf are about 3 000 m thick and are mostly of Permian age, but include a relatively thin sequence of Mesozoic sediments.

STRATIGRAPHY

The formations intersected by the Quindalup Line bores range in age from Quaternary to Early Permian. The stratigraphic succession is given in Table 2, and the formations are described below.

Permian

Sue Coal Measures: The Sue Coal Measures, intersected in bores Q2 and Q3, are composed of generally well-consolidated sandstone (locally calcareous) with some siltstone and shale. The sandstone is light grey, white, or green (chloritic), generally fine- to coarse-grained, commonly clayey, and with poor or moderate sorting. Accessory minerals include feldspar, mica, and heavy minerals, and seams and partings of coal and carbonaceous material are common.

The Sue Coal Measures are 1 838 m thick in Sue 1, an oil exploration well located 45 km south of Busselton. The maximum thickness intersected by a Quindalup Line bore was 442 m in Q2. The formation unconformably overlies the Precambrian basement in Sue 1, and is unconformably overlain by the Leederville Formation in bores Q2 and Q3.

The palynology of cores from the Sue Coal Measures indicated that the formation is younger at Q3 than at Q2. In Q2, samples from 150 m to 300 m depth are of Late Artinskian age, and samples from 400 m to 500 m depth are of Early Artinskian

TABLE 1. SUMMARY OF BORE DATA

Bore	Latitude S	Longitude E	Drilling: Commenced	Drilling: Completed	Elevation (m AHD): Surface	Elevation (m AHD): Casing Top	Total Depth (m)	Tested Interval (m bns)	Head (m AHD) 15/10/80	Salinity TDS by summation (mg/L)	Aquifer (Formation)	Status
Q1	33°39′36″	115°17′41″	26/9/66	23/12/66	~2	....	588	Various formation tests	....	742–2 813	....	Abandoned
Q2	33°39′26″	115°13′55″	27/1/67	3/3/67	~2	....	551	do.	....	....	....	do.
Q3	33°38′37″	115°10′30″	19/4/67	22/5/67	~3	....	453	do.	....	1 346–8 779	....	do.
Q4	33°38′13″	115°26′00″	30/5/67	1/7/67	5·0	6·21*	585	Various formation tests 18–96	11·6	243–512	Leederville	Flowing observation bore
Q5	33°38′38″	115°30′22″	12/7/67	18/8/67	~20	....	613	Various formation tests	....	330–651	....	Abandoned
Q6	33°38′56″	115°35′02″	14/6/74	15/7/74	42·38	43·18	1 118	237–245	~14·4	252	Yarragadee	Abandoned
								370–378	~14·7	281	do.	do.
								615–623	~15·4	241	do.	do.
								829–837	~15·1	298	do.	do.
								1 017–1 025	14·03	412	do.	Observation bore
						101·386		917–923	14·51	230	do.	do.
Q7A	33°39′05″	115°38′39″	8/9/78	10/11/78	100·83	101·25	1 049	429–435	20·37	296	do.	do.
Q7B	do.	do.	30/10/78	21/3/79	99·70	100·552	123	104–110	56·17	245	Leederville	do.
Q8A	33°39′17″	115°42′12″	21/11/78	6/4/79	58·94	59·496	1 160	1 065–1 071	18·57	390	Yarragadee	do.
						59·420		786–792	18·89	274	do.	do.
						59·794	....	402–408	30·08	260	do.	do.
Q8B	33°39′17″	115°42′12″	6/4/79	8/5/79	59·05	59·770	436	256–262	31·56	350	do.	do.
Q8C	33°39′17″	114°42′12″	4/4/79	10/4/79	59·55	61·475	54	48–54	62·98	317	Leederville	Observation bore (flowing)
Q9A	33°39′06″	115°46′52″	17/5/79	3/9/79	96·1	96·720	1 469	1 200–1 315	13·50	543	Yarragadee	Observation bore
						96·666		902–908	17·85	452	do.	do.
Q9B	33°39′06″	115°46′52″	12/9/79	4/12/79	....	....	371	356–362	....	452	do.	Abandoned
Q9C	33°39′06″	115°46′52″	22/11/79	29/11/79	96·23	96·505	135	127–133	61·00	806	Leederville	Observation bore
Q9D	33°39′06″	115°46′52″	5/12/79	13/2/80	96·20	96·46	367	356–362	44·44	468	Yarragadee	do.
						3·72	....	808·5–814·5	~12	1 940	Cockleshell Gully	Abandoned
Q10	33°39′53″	115°19′26″	31/10/79	19/12/79	2·20	3·71	1 064	726–732	12·35	461	Yarragadee	Observation bore
								430–436	10·09	354	Leederville	do.

AHD—Australian Height Datum. bns—below natural surface *—centre of 25 mm gate-valve

age, whereas in Q3 samples from the formation are Late Artinskian to ?Tatarian age. The younger sediments intersected in Q3 may indicate that the fault block has been tilted, with a dip of a few degrees to the west; bedding dips of about 5° were measured in cores from Q2. The palynology of samples from the formation in bores Q2 and Q3 indicate a non-marine environment of deposition.

Triassic

Lesueur Sandstone: The Lesueur Sandstone was not intersected by the Quindalup Line bores, but conformably underlies the Cockleshell Gully Formation between the Wirring and Darling Faults. The formation is not relevant to the hydrogeology of this area, and is not discussed further.

Jurassic

Cockleshell Gully Formation: The Cockleshell Gully Formation was intersected in bores Q1 and Q10. It comprises interbedded sandstone and grey shale, with minor seams of coal and carbonaceous shale. The sandstone is mainly clayey, fine to very coarse, variably sorted, and weakly to moderately consolidated. The shale is commonly silty, and well consolidated. Coal and carbonaceous material were common in sludge samples in bores Q1 and Q10, but only in Q1 were thin coal seams (up to 1 m thick) indicated on the wire-line logs. The formation is about 1 500 m thick in the Bunbury Trough (Playford and others, 1976), and possibly about 1 000 m thick on the Vasse Shelf between the Busselton and Wirring Faults. The maximum thickness of this formation intersected by the Quindalup Line bores was 504 m in Q1.

The formation conformably overlies the Lesueur Sandstone, and is in turn overlain, conformably by the Yarragadee Formation in the Bunbury Trough, and unconformably by the Leederville Formation on the Vasse Shelf (Fig. 3). The Eneabba Member of the Cockleshell Gully Formation was intersected in Q1, as erosion on the Vasse Shelf removed the upper part of the formation prior to deposition of the Leederville Formation. The Cattamarra Coal Measures member was intersected in Q10.

The lithology and palynology of all samples from the formation are consistent with a non-marine environment of deposition.

Yarragadee Formation: The Yarragadee Formation was intersected at sites Q4 to Q10. It consists of interbedded sandstone, shale and minor siltstone, with the percentage of sandstone ranging from about 90% in Q4 to about 25% in the top 500 m of the formation in Q9A (Fig.3). The sandstone is generally pale grey, clean or slightly clayey, and is composed of weakly consolidated, fine to very coarse sand or granules, mostly with poor or moderate sorting. The shale is generally dark grey or brown-grey, slightly silty or sandy, and well consolidated. Carbonaceous material is common, and ranges from carbonaceous shale or carbonized plant material to hard vitreous coal. It occurs in thin seams and lenses, rarely up to 2 m thick, and as coal chips embedded in shale. Layers containing heavy minerals and pyrite are also common.

The Yarragadee Formation is absent on the Vasse Shelf. The formation in the Bunbury Trough is about 300 m thick (in Q10) to 1 400 m thick (in Q9). It conformably overlies the Cockleshell Gully Formation, and is unconformably overlain by the Bunbury Basalt at Q6, and between Q8 and Q9, and elsewhere by the Leederville Formation.

Palynomorphs from the Yarragadee Formation indicate a Middle or Late Jurassic age. Some samples have distinct assemblages which can be assigned to bio-stratigraphic zones erected by Filatoff (1975) and Backhouse (1978), shown in Figure 3. One sample from the formation in Q5 contains reworked Permian spores and pollen (Backhouse, 1980), suggesting that Permian sediments were being eroded, possibly from the Vasse Shelf, during deposition of the Yarragadee Formation. The palynology of all samples from the formation is consistent with a non-marine environment of deposition.

Cretaceous

Bunbury Basalt: The Bunbury Basalt was intersected in Q6, between 32 m and 104 m depth, and has been intersected in private bores between Q8 and Q9. A previously unrecorded outcrop was discovered in a small swampy area located approximately 2·8 km northwest of Q6, at latitude 33°37′46″S and longitude 115°33′57″E (Fig. 1). The outcrop consists of a few boulders of slightly weathered basalt, and, according to the landholder, the basalt occurs at about 1 m depth beneath the swamp.

The Bunbury Basalt is believed to have filled valleys eroded into the Yarragadee Formation. Its age is probably Neocomian (Playford and others, 1976). It is generally unweathered with columnar jointing, but may weather to a chocolate-brown clay.

The basalt in Q6 contains an interbedded layer of clay between 52 m and 55 m. This clay may be a sediment rather than weathered basalt as it has relatively high gamma radiation on the gamma-ray log, whereas basalt (weathered or fresh) usually has low radiation. A sludge sample from this interval contains palynomorphs which indicate a possible Early Cretaceous age. If this age is correct, then the presence of a sediment in the basalt indicates at least two flows of basalt which are possibly contemporaneous with deposition of the Leederville Formation.

Leederville Formation: The Leederville Formation was intersected in all Quindalup Line bores. It consists of interbedded sandstone, siltstone, and shale, with rare conglomerate and coal seams. The sandstone is composed of weakly consolidated, poorly to moderately sorted, fine- to very coarse-grained sand, with varying proportions of intergranular clay. The siltstone and shale are generally dark grey or brown-grey, micaceous,

TABLE 2. STRATIGRAPHIC SUCCESSION INTERSECTED IN THE QUINDALUP LINE BORES

Age	Formation	Member	Thickness (m) Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q 8	Q9	Q10	Summary of Lithology	Remarks
Quaternary	....	....	?9	?9	10	11	7	11	....	....	....	3	Sand, clay, limestone	Minor local aquifer
Tertiary	....	....	....	....	....	....	....	....	?1	4	?1	....	Laterite	
E. Cretaceous	Leederville	....	75	100	199	78	144	21	?138	249	?349	?495	Sandstone, siltstone, and shale	Multilayered aquifer
E. Cretaceous	Bunbury Basalt	....	....	....	....	....	....	72	....	....	....	....	Basalt	Local aquiclude
M.—L. Jurassic	Yarragadee	....	....	....	....	>496	>462	?>1 014	>905	>905	>1 115	?298	Sandstone, minor shale	Major aquifer
E. Jurassic	Cockleshell Gully	Cattamarra Coal Measures	....	....	....	....	....	....	....	....	....	>268	Sandstone and shale	Contains brackish or saline groundwater
E. Jurassic	Cockleshell Gully	Eneabba	>504	....	....	....	....	....	....	....	....	....	Sandstone and shale	Minor multilayered aquifer
E. Permian	Sue Coal Measures	....	....	>442	>244	....	....	....	....	....	....	....	Sandstone, some shale and siltstone	?Minor aquifer

moderately- to well-consolidated, and are commonly carbonaceous. Accessory minerals include feldspar, heavy minerals and pyrite. A conglomerate was intersected near the base of the formation in Q5, and includes boulders of granite, basalt and greywacke. Chloritic shale is common in bores Q1 to Q3. Carbonaceous material in the Leederville Formation ranges from carbonaceous shale and carbonized plant material to lignite. It occurs mostly in thin lenses or as disseminated chips in shale; only minor thin coal seams up to 1 m thick were indicated on the short-normal resistivity and point-resistance logs.

The Leederville Formation unconformably overlies the Sue Coal Measures, the Cockleshell Gully Formation and the Yarragadee Formation; conformably overlies the Bunbury Basalt; and at some localities unconformably overlies Precambrian rocks of the Leeuwin and Yilgarn Blocks. A thin layer of Quaternary sediments unconformably overlies the Leederville Formation on the Swan Coastal Plain. The formation crops out on the Blackwood Plateau where it has been deeply weathered and lateritized.

The thickness of the Leederville Formation ranges from 21 m (Q6) to about 500 m (Q10) in the Quindalup Line bores, and the formation has been completely removed by erosion where the Bunbury Basalt crops out near Q6.

The formation in this area is mainly non-marine, with minor marine intercalations indicated by the palynology of some samples from Q5, Q9 and Q10, and the presence of glauconite in some samples from Q2 and Q3.

Several samples from the lower part of the Leederville Formation at sites Q7 and Q9 contain mixed Leederville and Cretaceous Yarragadee Formation assemblages of non-marine spores and pollen (Backhouse, 1980). These assemblages indicate probable re-working of the Cretaceous Yarragadee Formation during deposition of the Leederville Formation, which implies that deposition in the Bunbury Trough commenced while Mesozoic sediments were still being eroded in other areas of the Perth Basin.

Thick beds of shale with minor sandstone occurring at the base of the Leederville Formation in Q2, Q3 and Q9 may be equivalent to the South Perth Shale (Playford and others, 1976) on the basis of lithology and stratigraphic position. However, the shale is non-marine, at least in Q9, and it is not known whether the shale is older than the Leederville Formation.

Tertiary

Laterite: Laterite and associated sand were intersected in bores at sites Q7, Q8 and Q9 on the Blackwood Plateau. The laterite ranges from massive to pisolitic gravel, and in places overlies a mottled zone developed in weathered shale of the Leederville Formation. The sand is commonly iron-stained, generally poorly sorted, and fine to coarse grained. The laterite ranges from 1 m to 4 m thick where intersected by the Quindalup Line bores.

Laterite in the Perth Basin is presumed to be Tertiary or Pleistocene in age (Playford and others, 1976).

Quaternary

Guildford Formation: The Guildford Formation was not intersected by the Quindalup Line bores. It underlies the Pinjarra Plain (Fig. 2) and consists of clay and clayey sand with rare lenses of gravel. A band of ferruginized sand ("coffee rock") commonly occurs in the formation near the water-table.

Bassendean Sand: The Bassendean Sand was intersected by bores Q5 and Q6, and consists of light grey or yellow-grey sand, moderately to well sorted, mostly medium to coarse grained, and subangular to rounded. The thickness of the formation is 7 m in Q5 and 11 m in Q6. The formation unconformably overlies the Leederville Formation at both sites.

Tamala Limestone: The Tamala Limestone was intersected in bores Q4 and Q10. It consists of light brown or orange-brown, medium- to coarse-grained (in Q10) or fine- to very coarse-grained (inQ4) sand and limestone, containing abundant shells and shell fragments. The formation is 3 m thick in Q10 and approximately 11 m thick in Q4, and unconformably overlies the Leederville Formation in both bores.

Calcilutite: A calcilutite was intersected beneath the Safety Bay Sand in bores Q1 and Q3. It consists of light brown, calcareous clay with abundant shell fragments and minor thin bands of grey clay, and is considered to be an estuarine deposit. The calcilutite is 3 m to 4 m thick, and unconformably overlies the Leederville Formation.

Safety Bay Sand: The Safety Bay Sand was intersected in bores Q1 to Q3, and consists of calcareous sand and shell fragments with minor limestone bands. The sand is light

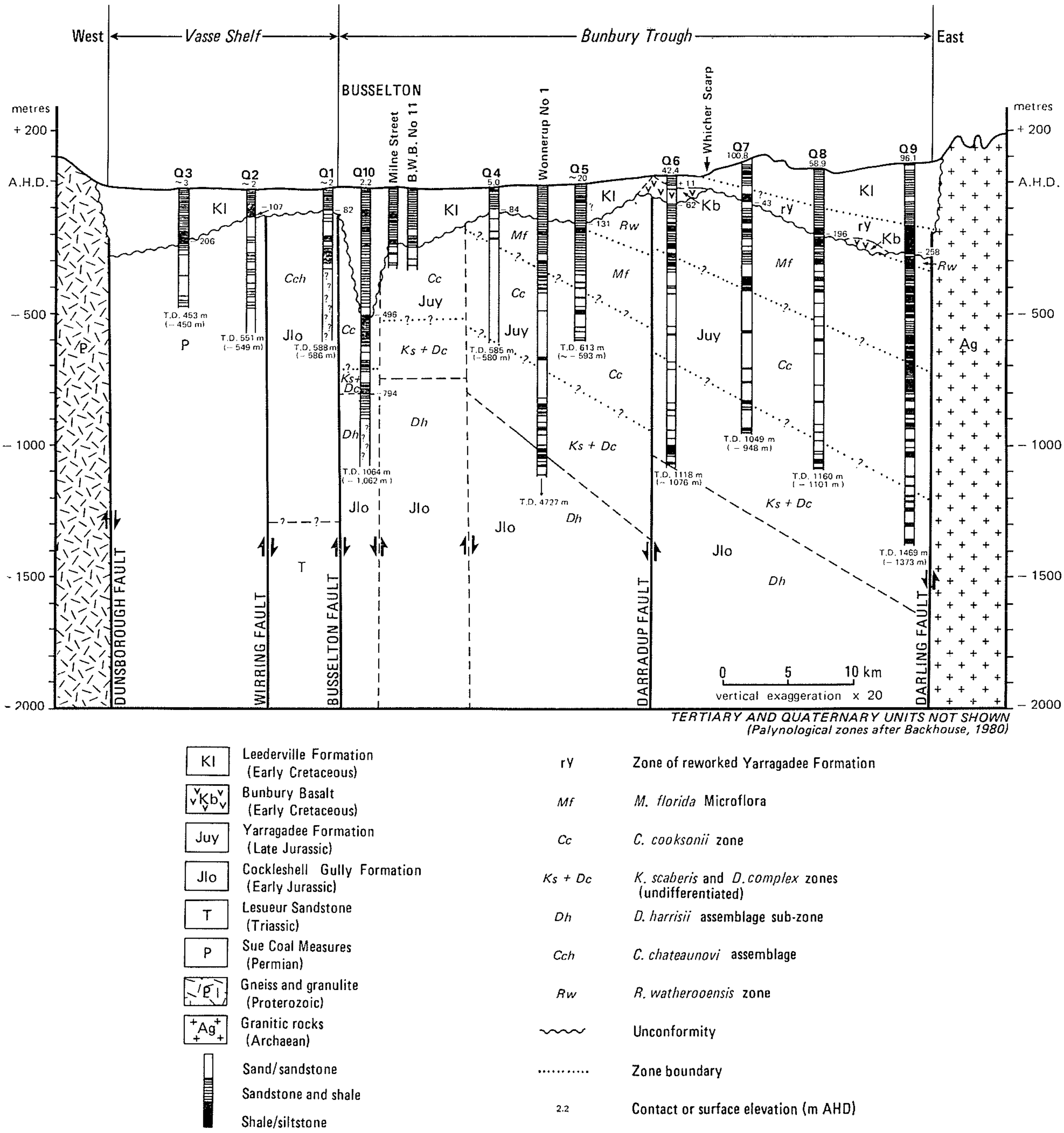


Figure 3 Geological section.

GSWA 19222

grey, light brown, and white, and fine to medium grained. The Safety Bay Sand is 9 m to 10 m thick, and overlies the calcilutite.

STRUCTURE

The inferred geological structure is illustrated by a section through the Quindalup Line bores (Fig. 3).

Pre-Cretaceous sediments in the southern Perth Basin have been block-faulted along north-south trending faults, dividing the basin into two major structural elements: the Vasse Shelf, between the Busselton and Dunsborough Faults, and the Bunbury Trough, between the Busselton and Darling Faults. The Vasse Shelf is itself block-faulted by the Wirring Fault, resulting in the juxtaposition of the Sue Coal Measures and the Cockleshell Gully Formation.

The Cockleshell Gully and Yarragadee Formations thicken and gently dip towards the east. These sediments are cut by several faults, including the Darradup Fault (Fig. 3) which has a down-throw of about 300 m to the west.

The positions of faults and formation boundaries shown in Figure 3 have been determined from geological evidence from the drilling of the Quindalup Line, and from geological sections and structural contour maps based on geophysical surveys, given in Playford and others (1976).

The Bunbury Basalt unconformably overlies the Yarragadee Formation in the Bunbury Trough, and is overlain by the Leederville Formation except where the basalt is exposed near Q6. The Leederville Formation unconformably overlies Jurassic and Permian sediments, and occasionally the crystalline rocks of the Leeuwin and Yilgarn Blocks. The formation is draped over the underlying fault blocks in a series of anticlines and synclines which result from deposition accompanying differential compaction of the Phanerozoic sediments over a faulted basement, as proposed by Cope (1972).

The Quaternary formations form a flat-lying cover over the Leederville Formation on the Swan Coastal Plain, except where the Bunbury Basalt crops out.

HYDROGEOLOGY

INTER-RELATIONSHIP OF AQUIFERS

A section showing the apparent vertical component of groundwater flow in the Leederville and Yarragadee Formations is given in Figure 4. Water-levels measured in bores Q1 to Q3 are unreliable, and could not be used to determine groundwater flow directions to the west of Busselton.

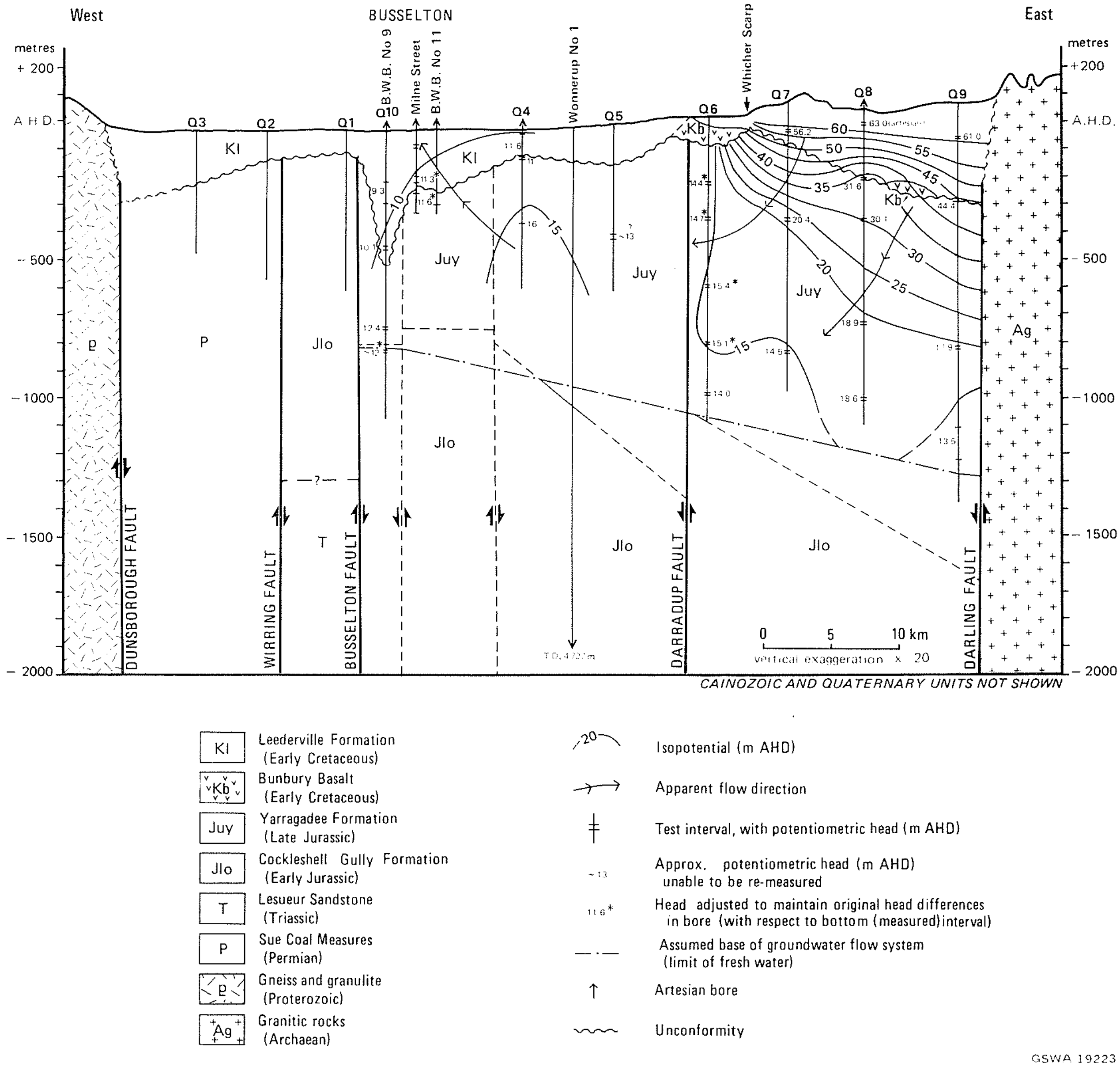


Figure 4 Isopotentials, and apparent groundwater flow directions (15 October, 1980).

The groundwater flow system can be divided into two sections based on the vertical hydraulic gradient; one in the Leederville Formation and the upper part of the Yarragadee Formation east of the Darradup Fault, the other in the lower part of the Yarragadee Formation east of the Darradup Fault and the Yarragadee and Leederville Formations west of the fault. The groundwater flow is predominately northwards (Commander, in prep.), with only a small component of flow in the vertical and east-west directions.

The abrupt change from fresh to saline groundwater at depths of between -770 m AHD (Australian Height Datum) (in Q10) and -1 250 m AHD (Q9) marks the lower limit of relatively rapid groundwater movement, and is assumed to be the base of the groundwater flow system. The saline groundwater at depth indicates that there is only minor groundwater movement as a result of confinement by shale beds, increased consolidation, friction losses, and high formation pressures.

The high, downward head-gradient east of the Darradup Fault indicates a low vertical permeability in the Leederville Formation and the shaly section of the Yarragadee Formation, and also the potential for recharge to the Yarragadee Formation from the Leederville Formation. The upward head-gradient between the Darradup Fault and Busselton shows there is some discharge from the Yarragadee Formation to the Leederville Formation, and presumably to the sea via the Quaternary sediments.

AQUIFERS

Safety Bay Sand

The Safety Bay Sand is a minor aquifer along the coast, and contains a layer of fresh groundwater overlying saline groundwater. The aquifer is recharged directly from rainfall, discharges to the sea, and yields small supplies of fresh groundwater from shallow depths.

Tamala Limestone

The Tamala Limestone crops out parallel to the coastline and inland of the low-lying area which includes the Wonnerup and Vasse estuaries.

Groundwater supplies of up to 2 400 m^3/day are recorded from the formation, however in some areas the formation contains slightly brackish or, rarely, saline groundwater with with a salinity of up to 6 000 mg/L TDS. High iron concentrations are also common in water from the limestone.

Groundwater from the Tamala Limestone is used for stock and domestic water supplies.

Bassendean Sand

The area underlain by the Bassendean Sand is largely undeveloped, consequently very few bores intersect the formation in this area. However the larger areas of Bassendean Sand (Fig. 2) are likely to contain large volumes of fresh groundwater recharged directly from rainfall.

Guildford Formation

Groundwater in the Guildford Formation is generally fresh near the Whicher Scarp, but is mostly brackish in areas away from the scarp. The salinity ranges from 200 mg/L TDS to more than 8 000 mg/L TDS, but is mostly less than 2 000 mg/L TDS. The moderately high salinity is due to a combination of high evaporation and transpiration losses from the shallow water-table, and the slow movement of water through the formation. High iron concentrations are common in water from the formation.

The Guildford Formation underlies most of the intensively farmed areas, and yields small stock and domestic water supplies of usually less than 100 m^3/day.

Leederville Formation

The Leederville Formation is a multilayered aquifer system which extends across the Perth Basin near the Quindalup Line, except for an area near Q6 where the Bunbury Basalt crops out (Fig. 3). The Leederville Formation has a maximum thickness of about 500 m (Q10) and an average thickness of about 200 m. The formation consists of discontinuous beds of sandstone, siltstone and shale, generally less than 5 m thick.

Groundwater in the formation is recharged from rainfall on the Blackwood Plateau, as indicated by the downward head gradient (Fig. 4), with infiltration occurring via the laterite and sand capping. Near the coast between the Busselton and Darradup Faults, the formation recieves some recharge from the underlying Yarragadee Formation, in which there is an upward head gradient.

Groundwater moves northwards in the Leederville Formation east of Q6 (Commander, in prep.) and is presumed to move northwards west of Q6. It is confined, except where sandstone beds underlie Quarternary sands on the Swan Coastal Plain and Tertiary deposits on the Blackwood Plateau. Bores in the formation commonly flow when drilled in low-lying areas of the coastal plain, or in valleys cut into the Blackwood Plateau (Q8C).

The salinity of groundwater in the Leederville Formation in the Bunbury Trough is less than 400 mg/L TDS (Fig. 5), except in bores Q5 and Q9, where salinity is up to 900 mg/L TDS. High salinity is attributed to the restriction of groundwater movement by beds of shale and siltstone. The salinity of groundwater in the formation intersected by bores Q1, Q2 and Q3 on the Vasse Shelf, ranged from 600 mg/L TDS to more than 40 000 mg/L TDS. The bores, all about 300 m from the coast, probably intersected a salt-water wedge, whereas private bores which are more than 1 km from the coast yield fresh groundwater from the formation. Evidence for the existence of a salt-water wedge comes from two private bores near the coast between Q1 and Q2. One bore intersected fresh water, but salt water intruded after pumping commenced, and the other intersected fresh water overlying saline water at depth. In a confined aquifer it is unusual for a salt-water wedge to be inland at such a shallow depth, and, because groundwater in the formation is virtually unexploited in this area, it is inferred that the formation discharges to the swamps, drains and estuaries which parallel the coastline behind the Quindalup dunes.

Water from the Leederville Formation commonly has a high iron concentration (3·5 mg/L in Q10) and at Busselton requires treatment before use for town water supplies.

Groundwater from the Leederville Formation is used for urban water supplies at Quindalup, Busselton, Capel and Donnybrook, and for some farm, irrigation and industrial supplies. The formation is a major aquifer, the most important on the Vasse Shelf. It is capable of substantial further development.

Yarragadee Formation

The Yarragadee Formation underlies the Leederville Formation in the Bunbury Trough, and is composed of weakly consolidated sandstone with minor beds of shale. The formation is generally at least 70% sandstone, however the percentage decreases to about 25% in the upper part of the formation and adjacent to the Darling Fault (Fig. 3). This change was also found in the Picton Line bores (Wharton, 1980). The thickness of the formation intersected in the Quindalup Line bores varies from about 300 m (Q10) to greater than 1 115 m (Q9).

Recharge to the Yarragadee Formation is presumed to originate from rainfall on the Blackwood Plateau. Outcropping Yarragadee Formation has not been recognized on the plateau, however the large thickness of fresh water in the formation, and the low vertical permeability of the Leederville Formation, suggests predominantly direct recharge to the Yarragadee Formation, rather than downward movement through the Leederville Formation. In addition, the salinity of water in the Yarragadee Formation is sometimes lower than is found in the Leederville Formation where intersected by the Quindalup Line bores (Fig. 5). The Leederville Formation is absent on the Blackwood Plateau where the Bunbury Basalt crops out, and is likely to be absent in other areas.

Groundwater in the Yarragadee Formation is confined by shale and siltstone within the formation and in the overlying Leederville Formation, and bores between Q5 and Busselton may flow where the surface elevation is between 10 m and 15 m above sea level.

The salinity of groundwater in the Yarragadee Formation ranges from 200 mg/L TDS to more than 20 000 mg/L TDS, and averages about 400 mg/L TDS. The fresh groundwater extends to depths of between —770 m AHD (Q10) and —1 250 m AHD (Q9) in the formation, with brackish or saline water below (Fig. 5). The eastward increase in thickness of fresh groundwater corresponds with the increase in thickness of the Yarragadee Formation, which is less consolidated and contains less shale than the underlying Cockleshell Gully Formation. The thickness of fresh groundwater may also be directly related to the distance from the recharge area; fresh groundwater extends to a greater depth below the Quindalup Line than below the Picton Line (Wharton, 1980), which is further from the recharge area.

Dissolved iron in groundwater from the formation ranges from 0·55 mg/L to 9·5 mg/L.

The Yarragadee Formation is the most important aquifer in the region, and contains an extremely large volume of fresh groundwater in storage. Large supplies of groundwater are available from the formation and are used for town water and industrial supplies at Busselton and Capel. The Milne Street bore in Busselton is 300 m deep and yields 3 800 m^3/day with 14 m drawdown. The groundwater resources in the formation are capable of substantial further development.

Cockleshell Gully Formation

The Cockleshell Gully Formation is composed of interbedded sandstone and shale. The sandstone is weakly to moderately consolidated and commonly contains intergranular clay. The formation occurs at depth between the Wirring and Darling Faults, but is only at a sufficiently shallow depth to contain fresh groundwater between the Wirring and Busselton Faults on the Vasse Shelf (Fig. 3). The salinity of groundwater in the formation in Q10 is 1 900 mg/L TDS, and is expected to increase with depth, as the formation in the Bunbury Trough is below the main groundwater flow system (Fig. 4).

The salt-water wedge intersected in the Leederville Formation in Q1 extends into the top of the underlying Cockleshell Gully Formation. Brackish or saline groundwater was intersected in the Cockleshell Gully Formation to a depth of about 275 m, and was underlain by fresh water to about 450 m depth (Fig. 5). The fresh-water layer between 275 m and 450 m depth probably results from an increasing potentiometric head with depth, which prevents salt water intrusion. The brackish to saline groundwater below 450 m depth is probably a result of a reduction in groundwater flow with depth, rather than being part of the salt-water wedge.

The Cockleshell Gully Formation between the Wirring and Busselton Vaults, and inland from the salt-water wedge. is likely to contain fresh groundwater to a depth of about 450 m. Groundwater in the formation is not being used, but large supplies of fresh groundwater could be obtainable in this area.

Sue Coal Measures

The Sue Coal Measures lie unconformably beneath the Leederville Formation between the Wirring and Dunsborough Faults on the Vasse Shelf, at a depth of between —100 m AHD and —300 m AHD. In bores Q2 and Q3, the Sue Coal Measures are composed of consolidated sandstone with some siltstone and shale. A core of the sandstone from Q2 had a porosity of 22%.

Groundwater in the formation is probably recharged by leakage from the overlying Leederville Formation. The direction of groundwater flow is not known, as no reliable head measurements were made, but is expected to be northwards as for the Leederville Formation.

The salinity of groundwater in the Sue Coal Measures generally increases with depth, and in Q1 and Q2 ranges from 1 370 mg/L TDS to approximately 9 000 mg/L TDS (Fig. 5). A coal exploration bore drilled by Broken Hill Proprietary Co Ltd, Busselton 1 (Fig. 1), intersected Sue Coal Measures between 102 m depth and 462 m (total depth). The bore flowed during construction, both from the Leederville Formation and from the Sue Coal Measures. A water sample taken after drilling was completed, and with casing run to below the Leederville Formation, had a salinity of 1 400 mg/L TDS.

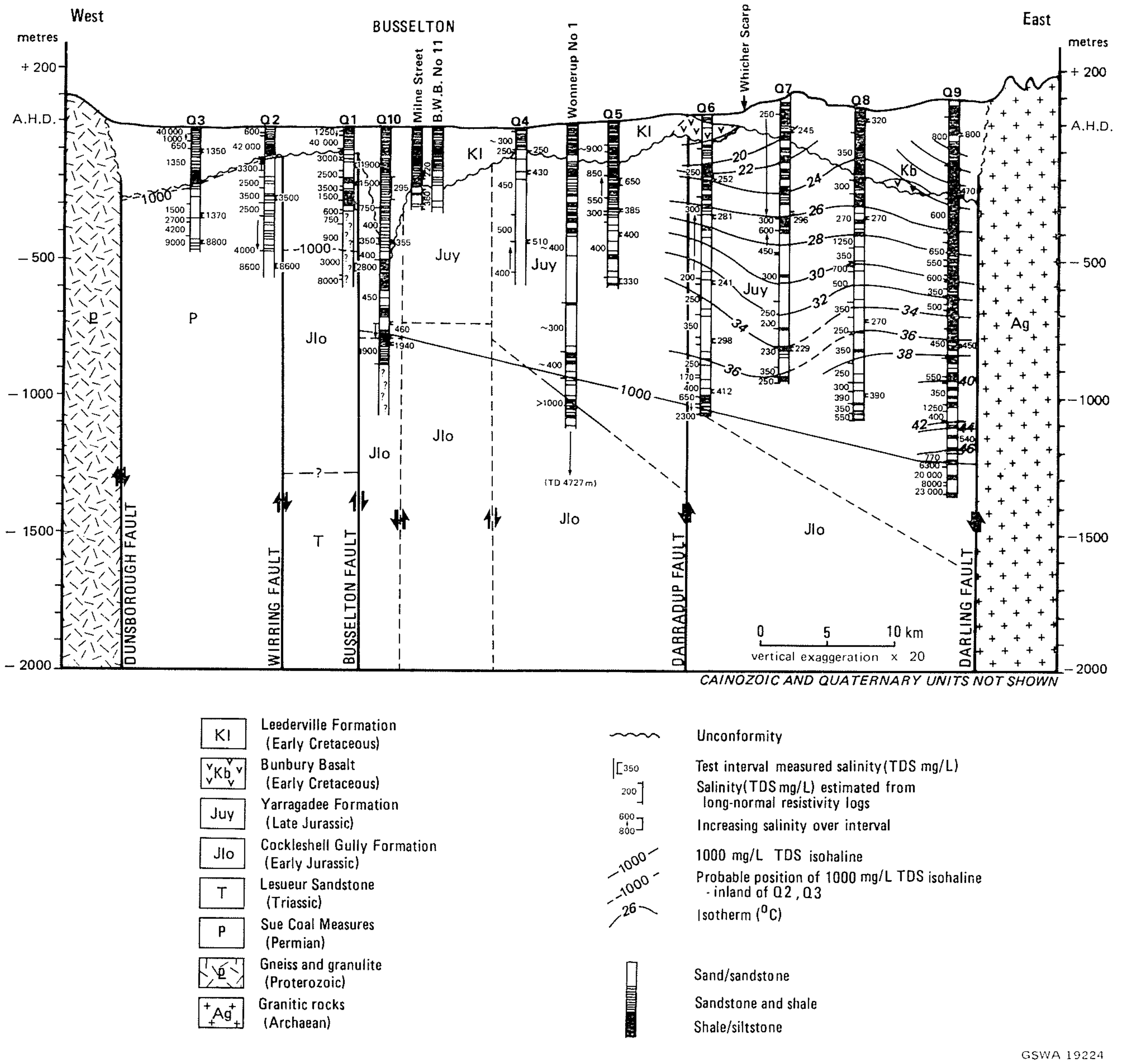


Figure 5 Variation in groundwater salinity, and geothermal temperatures.

Groundwater in the Sue Coal Measures is not being used, but could be developed for stock or industrial supplies.

GROUNDWATER TEMPERATURE

Differential temperature logs were run to the top of the packers in bores Q6, Q7A and Q8A, and through the packer to the top of the cement plug in Q9A.

The average temperature gradients over the measured intervals are 1·8°C/100 m (Q7A, Q8A), 2·3°C/100 m (Q6) and 2·4°C/100 m (Q9A). The results are shown as isothermal contours in Figure 5.

CONCLUSIONS

Drilling of the Quindalup Line bores has provided considerable new geological and hydrogeological information on a section across the Perth Basin from west of Busselton to Donnybrook.

The Yarragadee Formation, the Cockleshell Gully Formation and the Sue Coal Measures have been juxtaposed by faults trending north-south. The Leederville Formation is draped unconformably over the fault blocks in the form of small anticlines and synclines, which are believed to have developed by differential compaction of the underlying sediments.

A major groundwater flow system exists in the Leederville and Yarragadee Formations between the Busselton and Darling Faults. Fresh groundwater with a salinity generally less than 500 mg/L TDS extends to a depth of between —770 m AHD and —1 250 m AHD. West of the Busselton Fault a coastal salt-water wedge was intersected in the Leederville Formation, but further inland the formation yields large supplies of fresh groundwater.

Groundwater in the Leederville and Yarragadee Formations is presumed to be recharged by rainfall on the Blackwood Plateau.

Further drilling is required on the Blackwood Plateau, south of the Quindalup Line, to locate intake areas and to provide the hydrogeological data necessary to caclulate annual throughflow.

The Leederville and Yarragadee Formations contain a very large volume of fresh groundwater which is capable of substantial further development.

REFERENCES

Backhouse, J., 1978, Palynological zonation of the Late Jurassic and Early Cretaceous sediments of the Yarragadee Formation central Perth Basin Western Australia: West. Australia Geol. Survey Report No. 7.

———— 1980, A reassessment of palynological investigations in the Quindalup Line boreholes: West. Australia Geol. Survey Palaeont. Report No. 18/1980 (unpublished).

Commander, D. P., in prep., Bunbury area groundwater investigation: West. Australia Geol. Survey Rec.

Cope, R. N., 1972, Tectonic style in the southern Perth Basin: West. Australia Geol. Survey Ann. Rept 1971, p. 46–50.

Filatoff, J., 1975, Jurassic palynology of the Perth Basin, Western Australia: Palaeontographica Abt. B, v. 154.

Low, G. H., 1972, Explanatory notes on the Phanerozoic rocks of the western part of the Collie 1:250 000 geological Sheet, Western Australia: West. Australia Geol. Survey Rec. 1972/10 (unpublished).

Playford, P. E., Cockbain, A. E. and Low, G. H., 1976, Geology of the Perth Basin, Western Australia: West. Australia Geol. Survey Bull. 124.

Probert, D. H., 1967, Groundwater in the Busselton area, progress report on exploratory drilling: West. Australia Geol. Survey Rec. 1967/15 (unpublished).

Saint-Smith, E. C., 1912, A geological reconnaissance of a portion of the South-West Division of Western Australia: West. Australia Geol. Survey Bull. 44.

Wharton, P. H., 1980, The geology and hydrogeology of the Picton borehole line: West. Australia Geol. Survey Ann. Rept 1979, p. 14–19.

————in prep., The geology and hydrogeology of the Quindalup borehole line: West. Australia Geol. Survey Rec.

MESOZOIC AND CAINOZOIC SEDIMENTS IN THE WESTERN FORTESCUE PLAIN

by J. C. Barnett

ABSTRACT

The western part of the Fortescue plain is underlain by a complex sequence of alluvial, lacustrine, and colluvial sediments, ranging in age from Cretaceous to Holocene. The sediments are up to 120 m thick and have been deposited in a valley incised in Proterozoic rocks. The valley formed by headward erosion along the strike of the Proterozoic rocks, at least as long ago as the Late Jurassic; it is not a rift valley.

The sediments infilling the valley include conglomerate, massive and pisolitic ironstone, clay, and dolomite. The dolomite contains fossils of brackish- and fresh-water origin and formed in a lacustrine environment.

The catchment of the Fortescue plain has been captured twice from the northwest, first by the Robe River, and then by the Fortescue River.

INTRODUCTION

Much information on the stratigraphy, thickness, and extent of Mesozoic and Cainozoic sediments underlying the western part of the Fortescue plain has been gained as a result of drilling for groundwater during the last twelve years. The geology of these sediments is described in this paper, and a formalized stratigraphy is proposed for the Cainozoic strata.

The sediments have economic importance as a source of groundwater; more recently, they have been investigated for other possible economic deposits that may have accumulated in the Fortescue valley, for example iron ore and lignite. Since 1968, a bore field near Millstream has supplied groundwater by pipeline to the coastal towns of Cape Lambert, Dampier, Karratha and Wickham.

The Fortescue plain occupies a broad valley that bisects the Pilbara region of Western Australia. It is about 450 km long, ranges in width from 8 to 72 km, and is wider in the east than in the west; it covers an area of about 13 000 km² (Fig. 1). The plain is bounded on the south by the Hamersley Range, and on the north by the Nullagine plateau. The area discussed in this report is that part of the plain between its western end and Weelumurra Creek, some 120 km to the east.

The regional geology of the area has been described by Kriewaldt and Ryan (1967) and Williams (1968). Since 1967, about 100 exploratory bores have been drilled by the Mines and Public Works Departments (Fig. 2) in the search for water on the western part of the Fortescue plain. Geological data from the initial drilling in the Millstream area are given by Davidson (1969), and a summary of the geology of the western part of the plain is given by Barnett and others (1977).

PHYSIOGRAPHY

LANDFORMS

The western part of the Fortescue plain ranges in width from 10–25 km; it has a very low gradient, sloping from about 345 m above sea level at Weelumurra Creek, to about 315 m at the Robe-Fortescue watershed 90 km to the west. Coalescing alluvial fans form a piedmont slope, 5–10 km wide, flanking

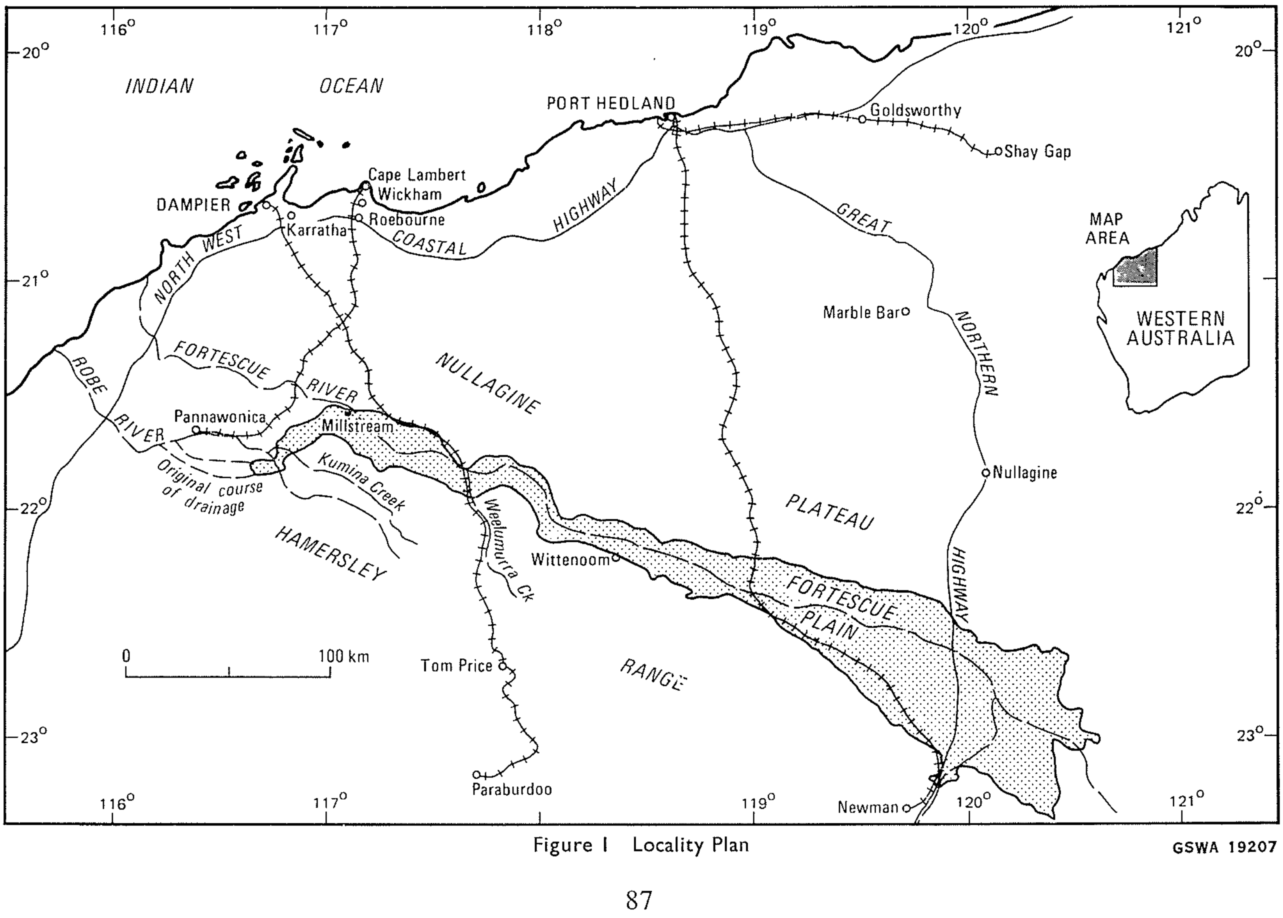


Figure 1 Locality Plan

GSWA 19207

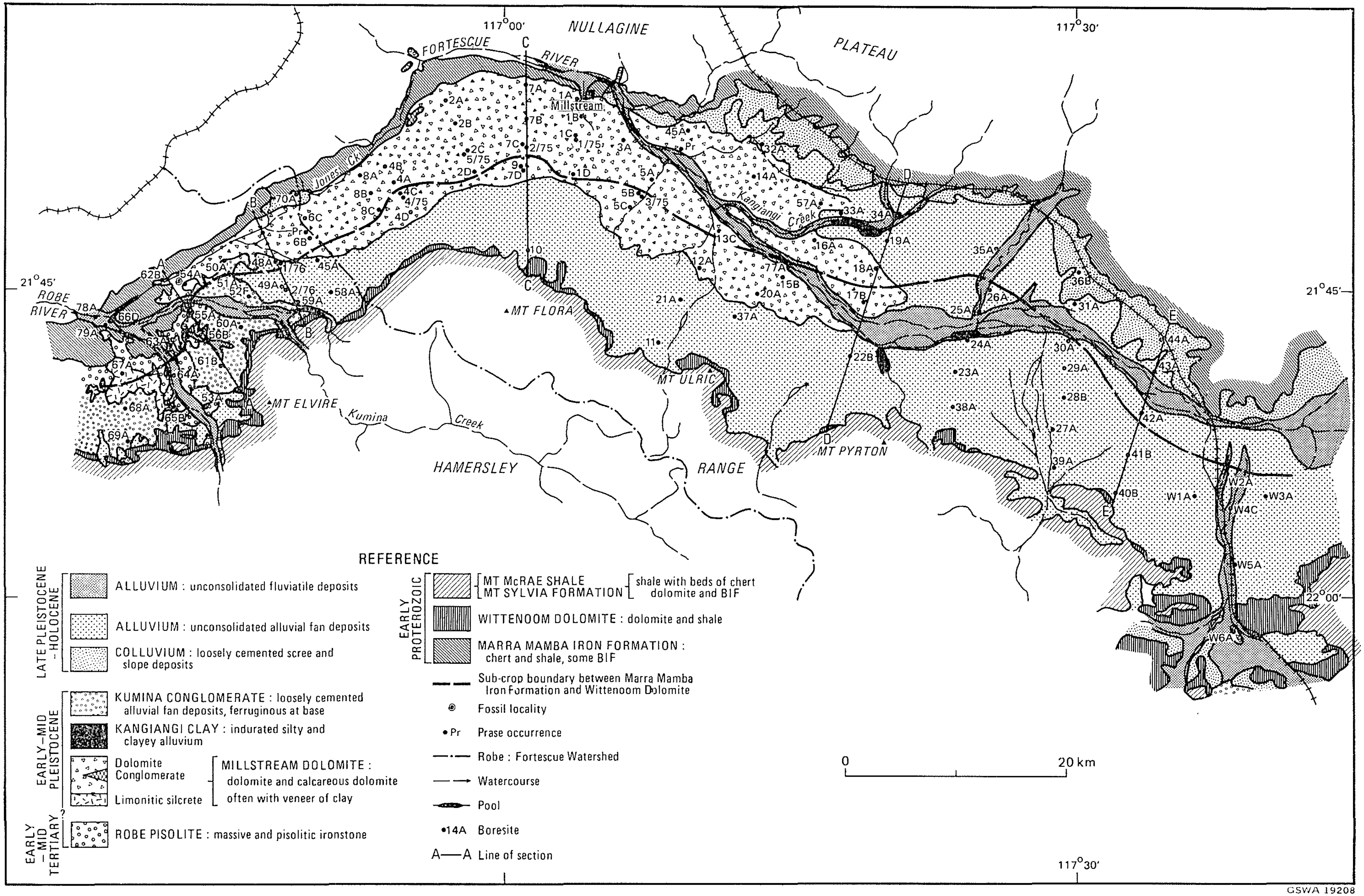


Figure 2 Revised and modified geology, after Kriewaldt and Ryan (1967) and Williams (1968).

the Hamersley Range; a talus slope up to 5 km wide borders the Nullagine plateau. The Millstream surface (Kriewaldt and Ryan, 1967) is the erosional surface corresponding to the Fortescue plain.

The Fortescue plain is bounded to the south by a steep erosion scarp that forms the edge of the Hamersley Range, which reaches a maximum elevation of 842 m above sea level at Mount Pyrton in the western Fortescue area. The Nullagine plateau, which borders the northern side of the plain, is more subdued, rising to just over 400 m. The plateau of the Hamersley Range and Nullagine plateau form an erosional surface, known as the Hamersley surface (Campana and others, 1964).

DRAINAGE

The Fortescue River follows a braided course along the plain as far west as Millstream, where the river becomes constricted and diverts to the northwest through a series of rocky gorges incised in the Nullagine plateau. Several pools up to 14 m deep, have formed near Millstream where the river is constricted. They are permanent and are maintained by springs from a dolomite aquifer beneath the plain.

The watershed between the Robe and Fortescue Rivers crosses the plain near its western end (Fig. 2), which is defined by the limit of headward erosion by the Robe River and its tributaries. Between Millstream and the watershed, the northern margin of the plain is being eroded by the Fortescue River and its tributaries, including Jones Creek.

Tributaries of the Fortescue drain the Nullagine plateau and the Hamersley Range. Those draining the Hamersley Range mainly dissipate into alluvial fans before reaching the main course of the river.

GEOLOGY

GENERAL

The Fortescue plain is underlain by a complex sequence of alluvial, colluvial, and lacustrine sediments, ranging in age from Cretaceous to Holocene; the sediments are flat lying and apparently not affected by folding or faulting.

This sequence of sediments has been deposited in a valley incised in the Proterozoic Hamersley Group, which forms the bedrock beneath the Fortescue plain. Except for minor undulations superimposed on the regional dip, the Proterozoic rocks dip gently to the south. The stratigraphy of the Hamersley Group, insofar as it is relevant to this paper, is given in Table 1 and is not discussed in any further detail.

Jutson (1950) considered the eastern part of the Fortescue plain to be a rift valley, but this view is not supported. In the western Fortescue plain, there is no evidence of faulting along the flanks of the plain, nor of the vulcanism which is normally associated with rift valleys. The plain, which follows the strike of the Proterozoic rocks, formed along a drainage which first developed along the strike of the Wittenoom Dolomite and then migrated slowly downdip to the south.

The surface geology is shown in Figure 2, upon which is also shown the subsurface boundary between the Marra Mamba Iron Formation and the Wittenoom Dolomite. Representative diagrammatic sections are shown on Figure 3.

MESOZOIC

Yarraloola Conglomerate

At bore 65 (Fig. 2), 36 m of conglomerate, which is overlain by Robe Pisolite, was encountered above the Wittenoom Dolomite; this conglomerate is correlated on lithological grounds with the Yarraloola Conglomerate, which outcrops about 25 km to the west of bore 65, beyond the margin of the Fortescue plain. The conglomerate contains subrounded to rounded pebbles of chert, quartzite, jaspilite, and quartz (up to 50 mm in diameter) in a matrix of sand, silt, clay, and a little carbonized wood. It contains layers of yellow and grey silty clay and is very clayey towards the base.

Bore 56, 7 km north-northeast of bore 65, penetrated 30 m of conglomerate, which consists almost entirely of angular to rounded clasts of Wittenoom Dolomite. This conglomerate may also be equivalent to the Yarraloola Conglomerate, as it underlies Robe Pisolite.

Yarraloola Conglomerate is absent from other bores in this area, and appears to be confined to a narrow channel (Fig.3, section A–A).

The Yarraloola Conglomerate is thought to be transgressive on to Early Cretaceous marine deposits (Nanutarra Formation) in the Carnarvon Basin further to the west (Williams, 1968).

CAINOZOIC

Robe Pisolite

The Robe Pisolite has a diverse lithology, ranging from massive ironstone to cemented pisolitic ironstone. In places, pisolitic ironstone overlies massive ironstone; but over most of the area, only one type is present in any particular bore. The formation contains layers of yellow limonitic clay, grey clay, and ferruginous shale; a layer of clay with pebbles, a few metres thick, is common at the base. In places, for example bores 53A and 3/75, there are thin layers of calcrete and calcareous clay.

The massive ironstone is siliceous and goethitic. It is usually dark brown, but may also be red brown, and has irregular vugs ranging in size from 1 mm to greater than 0·3 m; these vugs are commonly lined with limonite or translucent chalcedony.

The pisolitic ironstone contains pisoliths, which are generally less than 2 mm in diameter but range up to 12 mm; they are mainly composed of goethite or goethite-hematite. Some of the pisoliths are magnetic and some have skin of limonite; they are cemented by goethite and limonite.

Scattered clasts of chert, banded iron-formation, and hematite shale occur in the ironstone, but they are more common towards the base of the formation. "Ghost" pebbles, entirely replaced by hematite and goethite are common. Fossil wood is common in both the massive and pisolitic ironstone and it shows well-preserved cell structures.

The Robe Pisolite ranges in thickness from 3–33 m; it crops out along both sides of the Robe River, is widespread in the subsurface, unconformably overlies either the Proterozoic bedrock or the Yarraloola Conglomerate, and is disconformably overlain by younger Cainozoic deposits.

Previous workers (MacLeod and others, 1963; Harms and Morgan, 1964; MacLeod, 1966; Zimmerman and others, 1973) have postulated that the Robe Pisolite formed in a fluviatile

TABLE 1. STRATIGRAPHIC SEQUENCE OF THE WESTERN FORTESCUE PLAIN

Age	Stratigraphic unit	Maximum recorded thickness (m)	Lithology and remarks
Late Pleistocene-Holocene	Alluvium	15	Alluvium along present water-courses
	Calcareous silt	5	Grey calcareous silt with tufa
	Residual clay	3	Residual clay overlying Millstream Dolomite
	Alluvium	3	Alluvial fan deposits, unconsolidated
	Colluvium	5	Colluvium
Early-Mid Pleistocene	Kumina Conglomerate	120	Boulders, cobbles, gravel and sand in matrix of silty clay. Commonly ferruginous at base. Consolidated
	Kangiangi Clay (a)	47	Indurated well-bedded silty clay with sand and gravel beds. Ferruginous at base
	Millstream Dolomite (a)	50	Dolomite and calcareous dolomite with layers of silcrete, clay and gravel
Early-Mid Tertiary	Weelumurra Beds (b)	34	Dark grey pyritic shale
	Robe Pisolite (b)	33	Massive and pisolitic ironstone, with clayey layers
Early Cretaceous	Yarraloola Conglomerate	36	Fluviatile conglomerate
Proterozoic	Hamersley Group		
	Wittenoom Dolomite	150	Grey calcitic crystalline dolomite. Upper part mainly shale
	Marra Mamba Iron Formation	20	Interbedded shale and chert, minor BIF
	Fortescue Group		
	Roy Hill Shale	35	Black carbonaceous shale with bands and nodules of marcasite and pyrite

(a) These units are penecontemporaneous. (b) The relative age of these two units is uncertain.

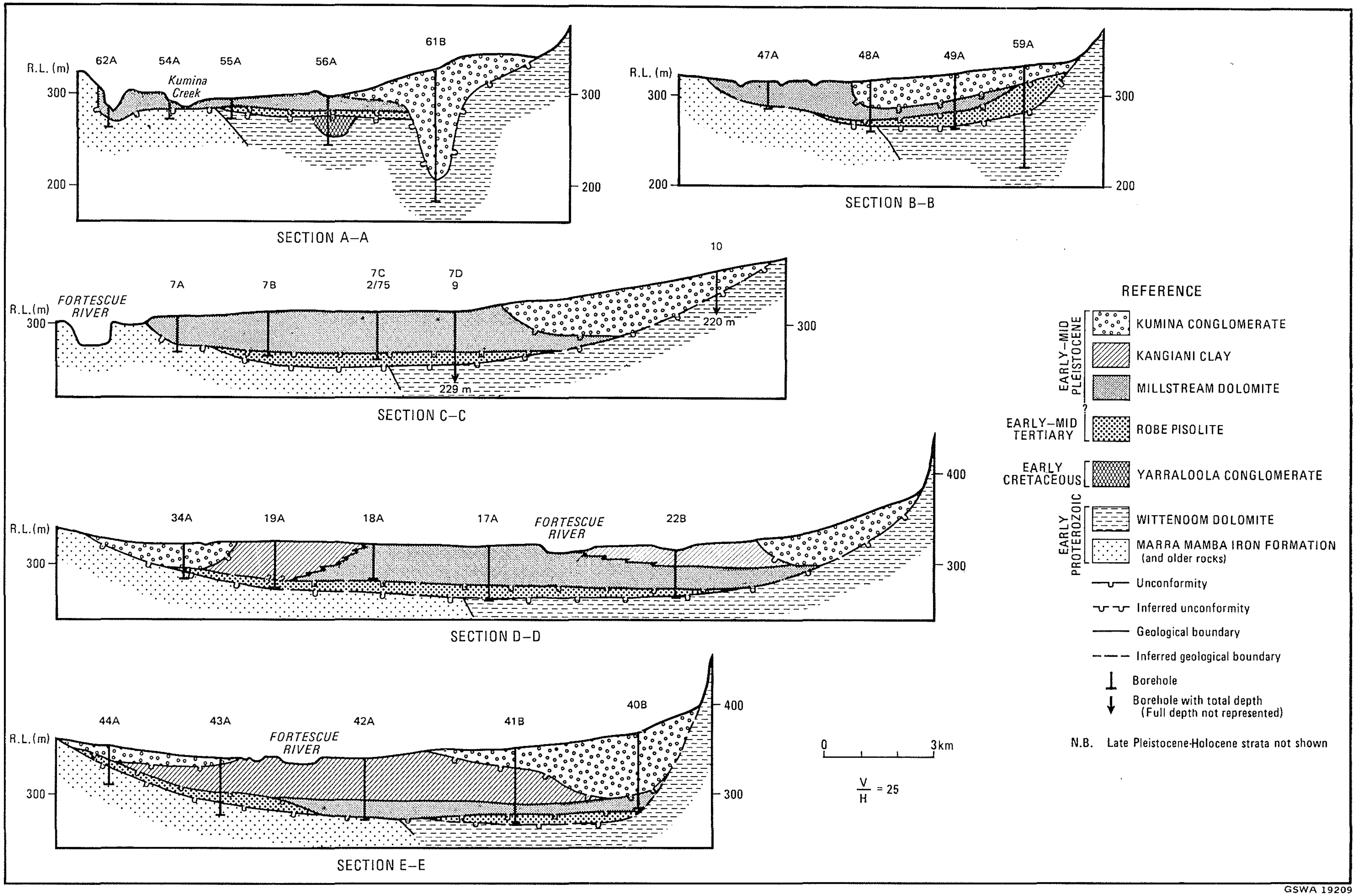


Figure 3 Diagrammatic cross section.

TABLE 2. CHEMICAL ANALYSES OF ROBE PISOLITE

Lab. sample No.	Bore	Percent on dry basis							Remarks
		Fe	Al	Si	P	S	V	Ti	
26301	5/75....	41·1	3·1	11·6	0·006	>0·001	>0·01	0·26	Massive Ironstone (Core)
26302	36B	35·9	2·2	16·5	0·018	>0·001	>0·01	0·31	Massive Ironstone (rotary cuttings)
26305	49A	39·3	2·0	15·4	0·034	>0·001	0·02	0·22	Ferruginous gravel (rotary cuttings)
62006/78	59A	57·7	4·75	8·47	0·039	0·03	>0·01	0·17	Cemented pisolite (rotary cuttings)

Analyst—Government Chemical Laboratories

environment by direct precipitation of iron as pisoliths and ferruginous cement, or by replacement of fluviatile sediments by iron-charged waters, or by a combination of these processes. The general lack of coarse clastic material in the ironstone has been ascribed to the fact that little erosion could occur because of stabilization of valley slopes by vegetation (Harms and Morgan, 1964). However, in the western Fortescue plain, "ghost" pebbles attest to at least some replacement of clastic material by iron oxides.

Previous authors agree that the formation was probably deposited during a time of warm pluvial climate in the early to mid Tertiary. MacLeod (1966) considered that the Robe Pisolite formed at a late stage of the development of the Hamersley surface. On the other hand, Harms and Morgan (1964) and Zimmerman and others (1973), concluded that the Robe Pisolite postdates the Hamersley surface. In the western Fortescue plain, the Robe Pisolite appears to be laterally equivalent to the duricrust which caps the Hamersley surface.

At Pannawonica (Fig.1), the Robe Pisolite is mined as iron ore by Cliffs Robe River Iron Associates. Three samples of Robe Pisolite from the western Fortescue Plain were analysed; the results are given in Table 2.

Weelumurra Beds

A sequence of clay, recorded only in bore W6A, is referred to in this paper as the Weelumurra Beds. The sequence is 34 m thick; the upper 13 m is pale grey and pale brown, the lower 21 m, dark grey or black and pyritic. Thin veins of white and clear quartz are present in the basal 9 m of the deposit. Early Tertiary palynomorphs, of possible lacustrine origin, have been identified from the clay (Backhouse, 1975).

The Weelumurra Beds overlie a dark-grey shale, which is presumed to correlate with a shale zone in the Wittenoom Dolomite, and are overlain by gravelly conglomerate and calcrete, which are probably equivalent to the Millstream Dolomite. The Weelumurra Beds are probably a lacustrine deposit which formed behind a bedrock bar across the ancestral Weelumurra Creek where it discharged on to the Fortescue plain from the Hamersley Range.

Millstream Dolomite

The Millstream Dolomite has been referred to informally in the past as the Millstream Calcrete. However, in view of the different senses in which the term calcrete has been used in Western Australia (Carlisle, 1978), and its implication of a dominantly calcium carbonate composition, it is proposed in this paper to formally name the formation Millstream Dolomite, after Millstream homestead (latitude 21°35′40″, longitude 117°04′20″) The type section, in bore 3/75, comprises 46 m of dolomite with layers of silcrete, illite-nontronite clay, and calcareous clay; the summary lithological log of bore 3/75 is set out below.

Depth (m)	Description
0– 4·0	Silcrete and calcified clay
4·0–13·0	Dolomite, earthy
13·0–15·5	Silcrete
15·5–22·1	Dolomite, hard, grey-brown
22·1–25·4	Silcrete and silicified dolomite
25·4–30·5	Dolomite, brown and buff
30·5–34·7	Clay, illite-nontronite, waxy, mottled green and yellow
34·7–37·3	Dolomite, white and yellow
37·3–38·7	Ferruginous silcrete
38·7–44·6	Dolomite, yellow, grey and white
44·6–46·3	Calcareous clay, white

The dolomite, which ranges from soft and earthy to hard and massive, may be white, pink, yellow buff, or may have a marbled appearance. Isolated grains of quartz and ironstone pisoliths are common. In thin section, the dolomite can be seen to consist of either a matrix of very fine-grained carbonate cut by veins of coarser grained carbonate, or of patches of fine-grained carbonate in a coarser matrix of carbonate.

Some layers consist of irregular nodules of carbonate in a matrix of calcareous clay; in some cases, "ghost" nodules of carbonate are visible in more massive varieties of dolomite. In places, the dolomite contains broken fragments of carbonate in a siliceous matrix, and can be described as breccia.

The dolomite is usually vuggy, and often cavernous; cavities up to 0·5 m high are known. The vugs and cavities are best developed at or near the present water table and are commonly lined with botryoidal chalcedonic silica. In places there are small sinkholes at the surface.

Beds of calcified clayey alluvium and red-brown clay occur throughout the formation, but are more common in the upper part. Along the northern margin of the formation at the western end of the outcrop area, there are a few metres of partly calcified pebble conglomerate at the base. There is within the dolomite sequence at latitude 21°36′30″, longitude 116°55′10″, a lens of conglomerate which consists mainly of pisoliths derived from the Robe Pisolite and of banded iron-formation and shale clasts from the Marra Mamba Iron Formation.

Over most of the area, the lower 10–15 m of the formation contains layers of illite-nontronite clay, which, in places, make up the entire lower part of the formation; it is green, dark green, blue grey, or yellow, and usually has a waxy appearance and feel.

Veins and bands of silica occur throughout the formation. There are two persistent layers of silcrete, one at an elevation of about 294 m, which is at the present water-table level, and one at about 310 m, which may represent a past water table level.

A layer of limonitic silcrete is generally present in the lower part of the formation, usually at or near the base. The silcrete is mottled, yellow, white, and occasionally greenish, and displays manganese dendrites; it is usually 2–3 m thick, but ranges up to 6 m. Where the limonitic silcrete outcrops near the Robe River, it contains sub-rounded pebbles and cobbles of Robe Pisolite and chert up to 0·15 m in diameter.

Analyses of the formation (Table 3) show that it is dolomite below, and calcareous dolomite above, the water-table. The Proterozoic Wittenoom Dolomite has a similar chemical composition to the dolomite below the water-table, and an analysis of the Wittenoom Dolomite is given in Table 3 for comparison. The analyses of silcrete show a reduction of MgO relative to CaO, indicating that the silica preferentially replaces magnesium carbonate.

Manganese occurs in the dolomite as dendrites or staining; cryptomelane was identified in one sample (lab. no. 17721/76) by the Government Chemical Laboratories.

There are a few surface occurrences of prase, where the silcrete is coloured green and one sample (lab. no. 16941/76) contains 2 000 ppm chromium. The origin of this chrome is unknown. A few samples of bright green and yellow clayey material, occurring as pockets in dolomite, were scanned by scintillometer, but no anomalous levels of radioactivity were detected.

Fragments of organic remains, including ostracod valves, have been recorded in borehole cuttings and samples from bores 3A, 3/75 and 5/75 (Davidson, 1969; Cockbain, 1976). At the western end of the plain (latitude 21°44′25″, longitude 116°42′45″). There are well-preserved gastropods, bivalves, and plant remains including opalized wood. G. W. Kendrick of the Western Australian Museum has identified the gastropods *Plotiopsis* sp. (now known as *Thiara* sp.), which is a fresh-water snail with some tolerance for brackish water; and *Coxiella* cf. *gilesi*, which is a brackish water snail (Cockbain, 1977). The bivalves are probably freshwater mussels. *Thiara* is known from the Miocene onwards, *Coxiella gilesi* from Late Pleistocene to Holocene, but their ranges are not fully known.

The Millstream Dolomite crops out over much of the central and northern part of the Fortescue plain (Fig. 2) and has been shown by drilling to be present in the subsurface in the south-east and east, almost as far as Weelumurra Creek (Fig. 3 sections D–D and E–E).

TABLE 3. CHEMICAL ANALYSES OF MILLSTREAM DOLOMITE AND WITTENOOM DOLOMITE

Laboratory Sample No.	Bore	Interval (m)	Rock Description	Per cent on dry basis CaO	MgO	Loss on ignition	Acid in-soluble	Remarks
17706	1/75	21·5–21·6	Massive dolomite	29·5	22·5	45·8	2·0	Water-table 11·0 m
26289		26·2–26·3	Vuggy dolomite	27·4	20·2	44·3	4·44	
17707		37·0–37·1	Vuggy dolomite	30·8	22·0	46·6	0·6	
17708	2/75	8·4–8·5	Dolomite breccia	31·1	16·0	38·3	13·9	Water-table 21·7 m
17709		20·0–20·1	Marbled dolomite	31·1	15·0	40·1	10·8	
26290		22·8–22·9	Silcrete	12·2	2·45	13·4	71·7	
17710		27·0–27·1	Vuggy dolomite	30·2	21·5	46·0	0·9	
17711	3/75	14·7–14·8	Silcrete	30·3	5·0	28·9	34·9	Water-table 19·4 m
26292		16·6–16·7	Dolomite	27·3	15·9	39·4	14·9	
26293		19·1–19·2	Dolomite	30·1	20·6	45·4	4·23	
26294		20·4–20·5	Dolomite	29·5	20·6	46·6	2·16	
17712		23·9–24·0	Siliceous dolomite	26·6	18·0	39·3	16·5	
17713		28·5–28·6	Dolomite	30·5	20·5	44·7	3·5	
26295		38·2–38·3	Ferruginous silcrete	0·61	0·73	2·9	92·0	
17714		41·5–41·6	Dolomite	30·3	21·5	46·0	1·4	
26296		51·2–51·3	Dolomite	28·3	20·6	45·6	3·07	
26297	4/75	8·7–8·8	Dolomite	27·7	15·9	38·8	17·1	Water-table 23·3 m
17715		20·4–20·5	Siliceous dolomite	22·2	14·0	32·3	31·7	
17720		27·1–27·2	Vuggy dolomite	32·2	21·0	46·9	>0·1	
17716		37·3–37·4	Dolomite	30·1	21·5	45·9	1·7	
17717	5/75	4·6–4·8	Calcified alluvium	25·5	14·5	34·2	21·4	Water-table 23·1 m
17718		6·9–7·0	Silcrete	8·2	1·0	10·0	80·6	
26299		21·6–21·7	Dolomite	49·8	3·65	43·3	2·8	
26300		25·8–25·9	Dolomite	44·5	7·96	42·9	4·24	
17719		37·2–37·3	Dolomite	25·5	21·0	41·5	9·9	
26298	4/75	51·4–51·6	Dolomite	30·2	21·2	46·6	1·22	Wittenoom Dolomite

Analyst: Government Chemical Laboratories

The formation unconformably overlies the Robe Pisolite in much of the area, and onlaps the Marra Mamba Iron Formation to the north, and possibly the Wittenoom Dolomite to the south. In the southeast and east, the upper part of the dolomite passes laterally into the Kangiangi Clay; on the southern side of the plain, the formation is unconformably overlain by the Kumina Conglomerate. Much of the outcrop area is covered by a veneer of clay or gravelly sand that has been omitted from Figure 2.

There are two small outcrops of dolomite in the southeast of the area near bore W6, with underlying beds of gravelly conglomerate; these are probably equivalent to the Millstream Dolomite and Kangiangi Clay.

Sanders (1974) considered that valley calcretes similar to the Millstream Dolomite were formed by precipitated carbonate from groundwater replacing valley-fill deposits. Mann and Horwitz (1979) propose that "groundwater calcretes" have been formed in an arid climate, by the precipitation of carbonate at the water table of alluvial drainages, where the water table was within 5 m of the surface, so that calcium and magnesium ions in the groundwater become concentrated by evapotranspiration. They postulated that progressive deposition of carbonate at the water table displaces the previously formed calcrete upwards to form pods and domes.

The Millstream Dolomite, in the area where gastropods, bivalves, and plant remains are found, is well bedded, with a sharp abutment unconformity against a buried cliff of Marra Mamba Iron Formation. Scattered angular clasts of iron-formation are common within the dolomite close to the cliff, but diminish in number away from it. There is a slight dip away from the cliff, and there are small-scale slump structures. These features indicate a lacustrine origin for the formation. The presence of brackish-water, as well as fresh-water fossils, shows that the salinity of the lake varied seasonally. This indicates that there were pronounced annual wet and dry seasons during the Pleistocene, as is the case at the present time.

The layers of alluvium and conglomerate within the sequence probably represent local accumulations of clastic material derived by episodic flooding, particularly along the northwestern margin of the lake near the Nullagine plateau.

In the eastern and southeastern part of the area, the upper section of the Millstream Dolomite passes laterally into the Kangiangi Clay, indicating a facies change to shallower water, or shorter lived lacustrine conditions.

The nodular, veined and brecciated appearance of the dolomite suggests later modification by circulating groundwater. Circular airphoto patterns may indicate the doming process proposed by Mann and Horwitz.

The fact that the formation is more dolomitic below the water table suggests that it has been dolomitized by the groundwater, which is dominantly of magnesium bicarbonate type (Barnett and others, 1977). The Wittenoom Dolomite is the obvious source for the magnesium and calcium carbonate. Secondary silicification has taken place at present and past water-table levels.

Thus, the Millstream Dolomite apparently originated as a sequence of lacustrine limestone and clay, with minor intercalations of alluvium. These original sediments have subsequently undergone extensive diagenetic changes, including dolomitization and silicification.

The age of the Millstream Dolomite is probably Late Tertiary to Pleistocene; the ranges of the fossils found in the formation are insufficiently known to permit a more precise dating.

Kangiangi Clay

This is a newly defined formation, named after Kangiangi Creek, in which it outcrops (latitude 21°41′35″, longitude 117°18′00″). The type section is taken as bore 42A, where the formation reaches its maximum recorded thickness of 47 m. It consists of red-brown and yellow-brown silty clay with interbeds of sand and gravel containing pebbles. The coarser beds are poorly sorted and contain generally subangular to subrounded clasts of chert, banded iron-formation and hematitic shale derived from the Proterozoic rocks. The formation is well bedded; it is cemented by carbonate, iron oxides, and silica; and, in places, stained by manganese. There is usually a basal layer, up to 15 m thick, of pisolitic ironstone gravel in a matrix of clay; an analysis of the basal section is given in Table 4.

TABLE 4. ANALYSIS OF PISOLITIC GRAVEL (KANGIANGI CLAY)

Lab. sample	Bore no.	Percent on dry basis Fe	Al	Si	P	S	V	Ti	Remarks
26304	43A	46·0	6·2	6·7	0·028	<0·001	0·03	1·36	Pisolitic gravel (rotary cuttings)

Analyst: Government Chemical Laboratories

The formation is widespread in the subsurface east and southeast of the area of calcrete outcrop, but it only outcrops in Kangiangi Creek south of bore 33A, and near bores 22N and 24A.

The formation appears to be mainly lacustrine, with alluvial intercalations; the basal, gravelly layer is apparently alluvial, and derived by reworking of Robe Pisolite. The Kangiangi Clay apparently interfingers laterally with the Millstream Dolomite, and represents a facies change to a shallower water environment. It conformably overlies the lower part of the Millstream Dolomite, overlapping the Robe Pisolite in places. It is overlain unconformably by the Kumina Conglomerate, or by a thin veneer of later alluvium and colluvium.

Kumina Conglomerate

This is a newly defined formation, named after Kumina Creek, where the type section (15 m thick) is exposed in a cliff alongside the creek (latitude 21°46′20″, longitude 116°46′05″).

Similar conglomeratic deposits are widespread throughout the northwest of Western Australia, and have been termed Wiluna Hardpan by Bettenay and Churchward (1974). The term *hardpan*, although descriptive of the cemented nature of the deposit, is inappropriate for such a thick alluvial sequence; Kumina Creek Formation is therefore proposed for the deposits in the western Fortescue plain.

The formation is composed of boulders, cobbles, gravel, and sand in a matrix of silty brown clay, usually with a ferruginous section at the base; it includes some lenses of silty clay.

The clasts are generally subrounded to rounded and consist of chert, banded iron-formation, hematite shale, and pisolitic ironstone which were derived from the Proterozoic bedrock and Robe Pisolite. Sorting ranges from very poor to good. Some horizons show traces of rootlets.

The deposits are loosely cemented, mainly by iron oxides, but also by carbonate and silica; where the formation outcrops, the topmost few metres are more strongly cemented by iron oxides. The basal section of the deposit is usually a poorly bedded ferruginous conglomerate, consisting mainly of clasts of Robe Pisolite and Hamersley Group banded iron-formation from the bedrock.

The deposits range up to 120 m thick. The thickest recorded section, in bore 61B, appears to be filling a narrow incised channel, or a collapsed doline structure in the underlying Wittenoom Dolomite. The basal ferruginous section of the Kumina Conglomerate ranges from 5–25 m, but is usually 5–10 m thick.

The formation outcrops at the western end of the Fortescue plain. It is widespread in the subsurface below the southern part of the plain, and to a lesser extent below the northern part. It unconformably overlies Robe Pisolite, Millstream Dolomite, and Kangiangi Clay, and overlaps the Proterozoic rocks along the margins of the plain. Over most of the area, it is overlain by a thin veneer of alluvial fan deposits of Late Pleistocene or Holocene age.

MacLeod (1966) described a ferruginous conglomerate ("canga"), similar to the basal section of the Kumina Conglomerate, as being transitional to Robe Pisolite in the upper Robe River area. In the western Fortescue plain, however, the ferruginous conglomerate is apparently younger than the Robe Pisolite, as the Kumina Conglomerate overlies the Millstream Dolomite.

The Kumina Conglomerate is alluvial, and was deposited mainly as piedmont alluvial fans by creeks debouching vigorously from the Hamersley Range. Some contribution also comes from the Nullagine plateau.

Late Pleistocene to Holocene superficial deposits

Colluvium: Scree deposits flank the Nullagine plateau along the northern end of the plain east of Millstream homestead. They are loosely cemented and poorly sorted; clasts are angular to subangular. They overlie Proterozoic bedrock and Robe Pisolite, and either interfinger with, or overlie, the Kangiangi Clay. Most of the colluvium is probably Pleistocene in age, but some may be Holocene.

Alluvial fan deposits: Younger piedmont alluvium overlies the Kumina Conglomerate and Kangiangi Clay, flanking the Hamersley Range, and the Nullagine plateau east of Millstream. The alluvium has similar lithology to the Kumina Conglomerate, but is uncemented, and has a different pattern on airphotos. These deposits are probably Late Pleistocene to Holocene in age.

Residual clay: Red-brown clay, up to 3 m thick, covers much of the area of outcrop of the Millstream Dolomite; it is omitted from Figure 2. The clay is silty and sandy in places, and often contains loose fragments and blocks of Millstream Dolomite. It dries out at the end of each wet season to form gilgai (a soil with large, deep cracks). The clay is derived mainly by weathering of the Millstream Dolomite, and partly from alluvium at the toe of alluvial fans along the Hamersley Range. It is Late Pleistocene to Holocene in age.

Calcareous silt: A delta of grey calcareous silt has been deposited at the mouth of a tributary creek where it joins the Fortescue River near Millstream homestead (latitude 21°35′05″, longitude 117°04′15″). The silt contains shells of fresh- and brackish-water snails, and layers of calcareous tufa. It is probably about 5 m thick; the surface of the deposit is about 4 m higher in elevation than the present river course. The tributary creek is fed by springs from the Millstream Dolomite, upstream from from the delta. The calcareous silt appears to have been laid down in an area of swampy springs when the rainfall was higher than at present, and the spring outflow was consequently greater. The deposit is probably Late Pleistocene to Holocene in age.

Alluvium: Alluvium is being deposited at present along the Fortescue and Robe Rivers and their tributary creeks, following intermittent flooding. It is up to 15 m thick, and consists of banks of sand and gravel, and sheets of red-brown clay and silty clay.

GEOLOGICAL HISTORY

The inferred Phanerozoic geological history of the area is summarized in Table 5.

The ancestral Fortescue River occupied a valley which formed by headward erosion along the strike of the Hamersley Group, and can therefore be regarded as a subsequent river. It has since been captured twice from the northwest, first by the Robe River and then by the lower reaches of the present Fortescue River. The original course of the valley, and the Robe and Fortescue Rivers, are shown on Figure 1.

The original valley was apparently in existence in the Late Jurassic, as indicated by a thick pile of deltaic sediments offshore to the west beneath Barrow Island (Crank, 1973); the sediments are of Late Jurassic to Early Cretaceous age.

The oldest Phanerozoic deposit beneath the Fortescue plain is the Yarraloola Conglomerate, a fluviatile conglomerate deposited along the course of the original valley during the Early Cretaceous. The Hamersley surface may have been forming at this time.

TABLE 5. GEOLOGICAL HISTORY OF WESTERN FORTESCUE PLAIN

Age	Event
Holocene	Capture of Fortescue plain catchment by Fortescue River
	REJUVENATION
	Formation of Millstream surface
	EROSION
Late Tertiary to Pleistocene	Deposition of Kumina Conglomerate
	Erosion of channel along southern side of Fortescue plain
	REJUVENATION
	Lacustrine deposition of Millstream Dolomite and Kangiangi Clay
?	EROSION
	Fluviatile deposition of Robe Pisolite, and duricrust formed on Hamersley surface
Early-Mid Tertiary	Capture of Fortescue plain catchment by Robe River
	REJUVENATION
Cretaceous	Regional tilting to northwest
	Fluviatile deposition of Yarraloola Conglomerate; formation of Hamersley surface
Late Jurassic	Active erosion along strike of Proterozoic rocks
	Deltaic sediments deposited to west, in Carnarvon Basin

Possibly as a result of regional tilting to the northwest, the original valley was captured by the Robe River, which rejoins the original valley further downstream (Fig. 1). The capture must have occurred before deposition of the Robe Pisolite in the Early to Mid Tertiary, as the pisolite is present along the course of the Robe River downstream from the point of capture. The Robe Pisolite was deposited in a warm pluvial climate, when the landscape was well vegetated. Duricrust on the Hamersley surface apparently formed at the same time.

A period of erosion followed deposition of the Robe Pisolite; after which, in the Late Tertiary and Pleistocene, the Millstream Dolomite and Kangiangi Clay were deposited in a lake within the original valley. The lake dried out seasonally, and the water became brackish, suggesting an arid climate with a pronounced wet and dry season. The dolomite was probably deposited in a deeper part of the lake which was the last area to dry out each year. Periods of more intense rainfall caused sheets of coarser clastic material to be deposited in the lake, particularly at the margins. The lake may have developed because of constriction of the Robe River course by sediment; any such barrier has since been removed by erosion.

A period of rejuvenation followed, and a channel was eroded along the southern side of the Fortescue plain, adjacent to the Hamersley Range. This channel, and its tributaries, then filled with coarse alluvium, the Kumina Conglomerate, which was mainly deposited by creeks from the Hamersley Range.

A further period of erosion resulted in the formation of the Millstream surface, probably near the end of the Pleistocene. The silcrete layer at 310 m above sea level within the Millstream Dolomite may have formed at a water table at about the same time.

At the end of the Pleistocene, or the beginning of the Holocene, the Fortescue plain catchment was again captured from the northwest, by the Fortescue River. Following this capture, the water table within the Millstream Dolomite fell from about 310 m to about 294 m above sea level, because of the lowering of the base level of the Fortescue River, into which the groundwater now discharges by way of springs. The Robe River was also rejuvenated, and the western margin of the plain is now being actively eroded by the Fortescue and Robe Rivers and their tributaries.

As a result of the two episodes of river capture, the watershed between the Robe and Fortescue River Systems now crosses the Fortescue plain.

REFERENCES

Backhouse, J., 1975, Palynology of Weelumurra W6 borehole: West. Australia Geol. Survey Palaeo. Rept 106/1975 (unpublished).

Barnett, J. C., McInnes, D. B., and Waterton, C. A., 1977, Measurement of the specific yield of a Carbonate Aquifer—an unconventional approach: West. Australia Geol. Survey Rec. 1976/23.

Bettenay, E., and Churchward, H. M., 1974, Morphology and stratigraphic relationships of the Wiluna Hardpan in arid Western Australia: Geol. Soc. Australia Jour. v. 21, p. 73–80.

Campana, B., Hughes, F. F., Burns, W. G., Whitcher, I. G., and Muceniekas, E., 1964, Discovery of the Hamersley iron deposits: Australasian Inst. Mining Metall. Proc. 210.

Carlisle, D., 1978, The distribution of calcretes and gypcretes in southwestern United States and their uranium favourability, based on a study of deposits in Western Australia and South West Africa (Namibia): Open file report prepared for US Department of Energy.

Crank, K. A., 1973, Geology of Barrow Island Oil Field: Australian Petrol. Explor. Assoc. Jour v. 13, pt 1, p. 49–57.

Cockbain, A. E., 1976, Calcrete and silcrete samples from Millstream: West. Australia Geol. Survey Palaeo. Rept 34/1975 (unpublished).

———— 1977, Fossils from the Millstream calcrete: West. Australia Geol. Survey Palaeo. Rept 80/77 (unpublished).

Davidson, W. A., 1969, Millstream Hydrogeological investigation: West. Australia Geol. Survey Rec. 1969/3.

Davy, R., 1975, A geochemical study of a dolomite-BIF transition in the lower part of the Hamersley Group: West. Australia Geol. Survey Ann. Rept 1974, p. 88–100.

de la Hunty, L. E., 1965, Mount Bruce, W.A.: West. Australia Geol. Survey 1:250 000 Geol. Series Explan. Notes.

Harms, J. F., and Morgan, B. D., 1964, Pisolitic limonite deposits in northwest Australia: Australasian Inst. Mining Metall. Proc. 212, p. 91–124.

Hickman, A. H., in press, The Geology of the Pilbara Block and its environs: West. Australia Geol. Survey Bull.

Jutson, J. T., 1950, The Physiography (Geomorphology) of Western Australia: West. Australia Geol. Survey Bull. 95.

Kriewaldt, M., and Ryan, G. R., 1967, Pyramid, W.A.: West. Australia Geol. Survey 1:250 000 Geol. Series Explan. Notes.

Mann, A. W., and Horwitz, R. C., 1979, Groundwater calcrete deposits in Australia: some observations from Western Australia: Geol. Soc. Australia Jour. v. 26, p. 293–303.

MacLeod, W. N., de la Hunty, L. E., Jones, W. R., and Halligan, R., 1963, A preliminary report on the Hamersley Iron Province, North-West Division: West. Australia Geol. Survey Ann. Rept 1962 p. 44–54.

MacLeod, W. N., 1966, The geology and iron deposits of the Hamersley Range area, Western Australia: West. Australia Geol. Survey Bull. 117.

Sanders, C. C., 1974, Calcrete in Western Australia: West. Australia Geol. Survey Ann. Rept 1973, p. 12–14.

Williams, I. R., 1968, Yarraloola, W.A.: West. Australia Geol. Survey 1:250 000 Series Explan. Notes.

Zimmerman, D. O., Adair, D. L., and Collings, P. S., 1973, Geology of the Upper Robe River Iron Deposits: Australasian Inst. Mining Metall. Ann. Conf., Perth, 1973, Papers p. 143–152.

THE YOGANUP FORMATION AND ASCOT BEDS AS POSSIBLE FACIES EQUIVALENTS

by J. L. Baxter and R. Hamilton*

ABSTRACT

A thin sequence of Pliocene marine sediments unconformably overlies Cretaceous and Eocene-Palaeocene deposits in the Perth Basin. The sequence is a barrier sand with carbonate and siliciclastic facies, which have been referred to as Ascot Beds and Yoganup Formation respectively. The Ascot Beds have been intersected in numerous water boreholes in the central part of the Perth Basin between Cataby and Gosnells. The Yoganup Formation, which occurs along the eastern limit of the Swan Coastal Plain, has been traced discontinuously from Eneabba in the north, to Busselton in the south. Correlation of these formations was first suggested by Kendrick (pers. comm.) and is supported by results of a heavy mineral sand exploration programme at Cooljarloo by Western Mining Corporation. It is suggested that phosphate nodules and phosphatized fossil remains in the Ascot Beds were derived from Cretaceous deposits. However, the presence of both siliciclastic and carbonate sediments as facies equivalents and the preservation of heavy mineral sands and phosphorite in the deposits indicate a shoreline system with little terrigenous and carbonate input.

INTRODUCTION

The known areal distribution of the Ascot Beds, a richly fossiliferous marine limestone, was extended by the discovery of shelly material in drill cuttings from Cooljarloo during heavy mineral sand exploration by Western Mining Corporation (Fig. 1). The molluscan fauna of the Ascot Beds at Cooljarloo is listed by Kendrick (1981), who concluded that it indicates a Pliocene age. Kendrick (pers. comm.) has suggested a correlation of the Ascot Beds with the Yoganup Formation based on comparison of younger transgressive cycles on the Swan Coastal Plain. The proximity of Yoganup Formation and Ascot Beds at Cooljarloo (Fig. 1) has improved the confidence of this correlation.

*Western Mining Corporation

The data reported here have been obtained from samples supplied by Western Mining Corporation from Cooljarloo, and from other samples obtained from bores in the metropolitan area.

STRATIGRAPHY

Quilty (1974a, 1974b), Allen (1976), and Playford and others (1976) have described the Tertiary stratigraphy of the Perth Basin, and, although the individuality of the units was recognized in separate areas, it was not generally appreciated that the Yoganup Formation and Ascot Beds could be correlated.

Ascot Beds

The Ascot Beds are generally less than 2 m thick and rest unconformably on Cretaceous and Palaeocene formations. They contain a diverse fauna with a large number of molluscs. The beds contain nodules which have been found to contain 26·0% P_2O_5, (see table). The phosphate, which is distributed uniformly through the nodule is in the form of phosphorite.

ANALYSES OF PHOSPHORITE NODULES FROM COOLJARLOO

Fe_2O_3	3·9%
P_2O_5	26·0%
S	2·1%
U	55ppm

Analyst: Government Chemical Laboratories

The matrix of the Ascot Beds is a poorly-sorted fine- to medium-grained predominantly bioclastic sandy calcarenite which contains no phosphate. The nodules contain *Inoceramus* prisms, foraminifers and radiolarians of Cretaceous age, and consequently must have been reworked into the Ascot Beds (Cockbain, 1980). The formation is interpreted as a marine calcarenite which was deposited in a sub-littoral inner shelf environment at a time of low supply of terrigenous sediment.

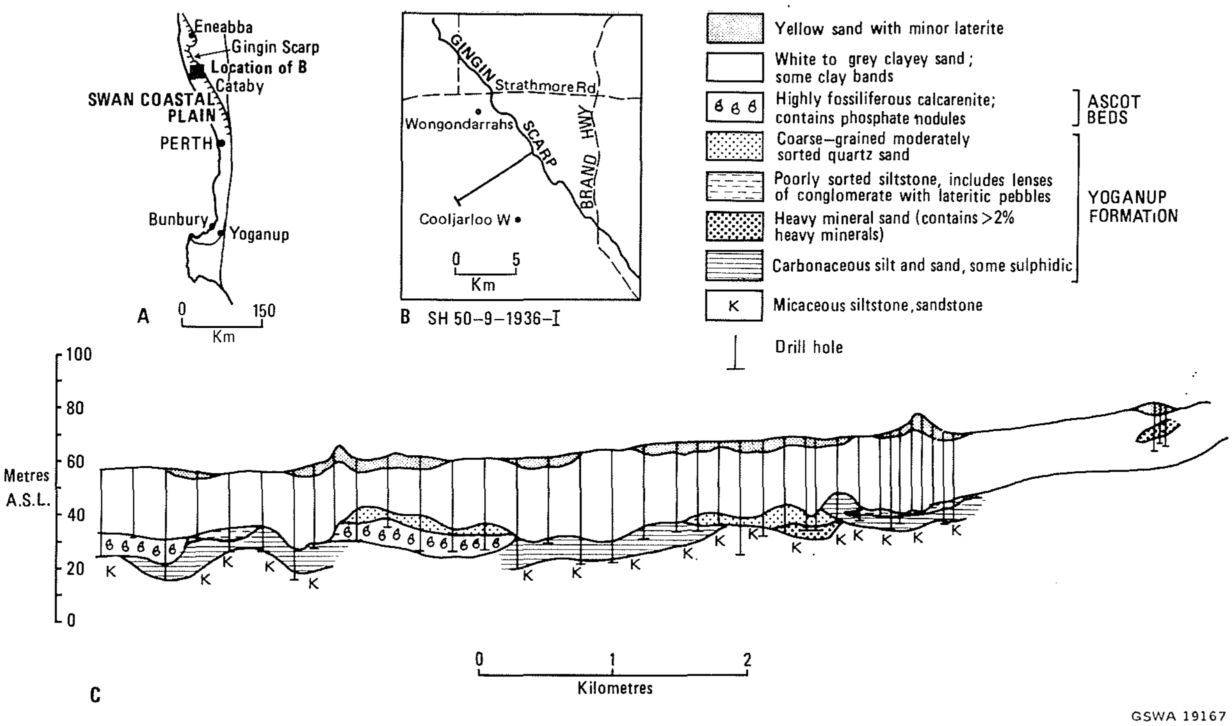


Figure 1 A—Location of the Swan Coastal Plain, Gingin Scarp and the area covered in B; B—Location of the drilled section at the Cooljarloo heavy mineral sand prospect. C—Cross section of a drilled traverse showing the lithologies encountered in Cainozoic units overlying ?Cretaceous sediments and the location of drill holes. Vertical scale exaggerated.

Yoganup Formation

The Yoganup Formation is generally less than 6 m thick and rests unconformably on Cretaceous sediments. It is unconformably overlain by up to 3 m of yellow sand. No fossils have been recorded from the formation. Baxter (1979) correlated all the shoreline deposits at the eastern margin of the Swan Coastal Plain with the Yoganup Formation. The formation consists of parallel, interfingering, lenticular beds of conglomerate, sand and clay. Heavy minerals (ilmenite, zircon, rutile, etc.) which concentrated in the sandy units, have been mined from northern and southern parts of the coastal plain at Eneabba and Yoganup (Baxter, 1977). The Yoganup Formation is interpreted as a paralic sequence, the sandy units being barrier sheets whereas the clay beds may represent interdunal or estuarine deposits (Baxter, 1981). The unit contains ferruginous cemented "coffee rock" layers which reflect past water-table fluctuations.

CORRELATION OF THE UNITS

The drilled section at Cooljarloo has demonstrated the complex facies variation that develops at the base of the Cainozoic in the Perth Basin (Fig. 1). The highly fossiliferous calcarenite is correlated with the Ascot Beds because it contains a similar fauna (Kendrick, 1981) and is of comparable lithology. The remaining units at the base of the sequence are correlated with the Yoganup Formation: the coarse-grained quartz sand and the heavy mineral sand representing barrier sands; and the siltstone and carbonaceous beds representing lagoonal and estuarine deposits. The overlying clayey sand and yellow sand are probably of terrestrial origin. Considering the vertical exaggeration of the section it is apparent that the Ascot Beds and Yoganup Formation are in juxtaposition and are reasonably interpreted as facies equivalents. The entire sequence is at the foot of the Gingin Scarp and thus compares geomorphically with the position of the Yoganup Formation in the southern part of the Basin.

ORIGIN OF THE PHOSPHATE

The restriction of phosphate to nodules containing *Inoceramus* etc., indicates that the phosphatization occurred in the Cretaceous prior to development of the Ascot Beds. Phosphorite has previously been recorded from the Cretaceous Coolyeena Group (Matheson, 1948).

The most probable interpretation of the palaeoenvironment is that coarse-grained material forming barrier sands (nodules, pebbles and sand) was swept eastward on a transgressive shoreline (Warren and others, 1981), ultimately being deposited in the Ascot Beds between the shallow inner shelf zone and the shoreline. Subsequent regressive and transgressive cycles do not appear to have brought phosphatic material onshore as there are no nodules in the Yoganup Formation. This may be because the preserved heavy-mineral-bearing sequence was deposited during later transgressive cycles.

REFERENCES

Allen, A. D., 1976, Outline of the hydrogeology of the superficial formations of the Swan Coastal Plain: West. Australia Geol. Survey Ann. Rept 1975, p. 35–41.

Baxter, J. L., 1977, Heavy mineral sand deposits of Western Australia: West. Australia Geol. Survey Min. Resources Bull. 10.

——— 1979, Mineral sands, *in* Prider, R. T., (ed.), Mining in Western Australia: Univ. West. Australia Press.

——— 1981, Geology of mineral sand deposits in Western Australia, *in* Selective Reference Papers for Mineral-Sand Mining: Western Australia School of Mines, WAIT-AID Ltd, Perth.

Cockbain, A. E., 1980, Cretaceous fossils in phosphatic nodules from the Ascot Beds: West. Australia Geol. Survey Palaeontological Rept 44/1980 (unpublished).

Kendrick, G. W., 1981, Molluscs from the Ascot Beds from the Cooljarloo heavy mineral deposit, Western Australia: West. Australia Geol. Survey Ann. Rept 1980, p. 44.

Matheson, R. S., 1948, The Dandaragan Phosphate Deposits: West. Australia Geol. Survey Min. Resources Bull. 4.

Playford, P. E., Cockbain, A. E., and Low, G. H., 1976, Geology of the Perth Basin, Western Australia: West. Australia Geol. Survey Bull. 124.

Quilty, P. G., 1974a, Tertiary stratigraphy of Western Australia: Jour. Geol. Soc. Australia, v. 21, p. 301–318.

——— 1974b, Cainozoic stratigraphy of the Perth area: Royal Soc. West. Australia Jour., v. 57, p. 16–31.

Warren, J., Hocking, R. M., and Baxter, J. L., 1981, Barrier Island hydro-sedimentary genesis for heavy mineral sands of southern and western Australia, *in* Selective Reference Papers for Mineral-Sand Mining: Western Australia School of Mines, WAIT-AID Ltd, Perth.

MOLLUSCS FROM THE ASCOT BEDS FROM THE COOLJARLOO HEAVY MINERAL DEPOSIT, WESTERN AUSTRALIA

by George W. Kendrick*

Fossils have been collected by R. Hamilton of Western Mining Corporation from an exploratory drill hole in the Cooljarloo heavy mineral sand prospect. The material was obtained from a calcarenite with intercalated carbonaceous sediment intersected from 10·5 to 12·0 m in a bore (R.L. about 60 m ASL) located on the Western Mining Corporation grid at 25 000N and 7 200E. The grid is 50 m south of Strathmore Road and 14·35 km west of the junction with the Brand Highway (latitude 30°33′S, longitude 115°18′E). This calcarenite is in a similar stratigraphic position to fossiliferous calcarenite (described by Baxter and Hamilton, 1981) from a section 10 km to the south, assigned to the Ascot Beds. The fossils discussed in this report are stored in the palaeontological collections of the Western Australia Museum (WAM) under catalogue numbers 80.1039 to 80.1095 and P.80.4.

Forty-four mollusc species (23 bivalves, 1 scaphopod, and 20 gastropods) have been identified; the sample also includes bryozoans, brachiopods, echinoderms and fragments of fossil wood, the latter being probably reworked from the Cretaceous. The sample is a small one and unlikely to be fully representative of the fauna. Shells are mostly well-preserved but have been damaged during recovery. The species present are typical of the shallow, sandy, inner shelf on an open coast, with well-circulated water of normal marine salinity. The bivalves are mostly infaunal filter feeders; the gastropods include herbivores, parasites, scavengers and carnivores.

Species in the list below marked with an asterisk are those which, in the Perth Basin, are at present known only from the Ascot Beds and are possibly charasteristic of that formation. At least 14 species, (*Limopsis beaumariensis*, *Cuna* sp., *Donax* sp., *Dosinia* sp., *Placamen* sp., *Tawera* spp., *Corbula* sp., *Gadila infans*, *Bankivia* (*Leiopyrga*) sp., *Bittium subgranarium*, *Hartungia* sp., *Nassarius* sp. and *Acteocina aptycha*) appear to be extinct and, in most cases, also undescribed. The *Hartungia*, represented only by fragments, is probably *H. dennanti chavani* Ludbrook described from the Roe Calcarenite of the Eucla Basin (Ludbrook, 1978). The assemblage compares well with material from other bores on the Swan Coastal Plain which is considered to be derived from the Ascot Beds. Of these bores, the most informative are Rando's 1 and 2 bores (WAM collection), Thornlie, from which the arcoid bivalve *Cucullaea* has been recovered. The presence of this genus in the Ascot Beds is considered to be of significance in the age determination of the formation; it occurs in Eocene to Pliocene deposits throughout southern Australia, but is unrecorded there from post-Pliocene strata (T. A. Darragh, pers. comm.). At least seven of the species (*Lissarca rubricata*, *Divalucina cumingi*, *Kellia australis*, "*Bornia*" *trigonale*, *Saltocuna obliquissima*, *Gomphina undulosa* and *Alaba fragilis*) are extant and a further four possibly belong to living species.

*Western Australian Museum

The molluscs of the Ascot Beds form a distinctive assemblage, which, on present knowledge, cannot be correlated readily with other better-known faunas of broadly comparable age in southern Australia. Though sharing many common species, the Ascot Beds fauna is nevertheless quite distinct from that of the "Jandakot beds" of the Perth Basin; fewer living species and a higher proportion of extinct species distinguish the Ascot Beds fauna from the other, younger fauna. A substantial proportion of both faunas remains unidentified and there seems no point at present in attempting any detailed Lyellian assessment of the two. Indications are that the Ascot Beds are likely to be of Pliocene age. This conclusion will be substantiated more fully in another contribution now in preparation.

MOLLUSCS FROM THE ASCOT BEDS AT COOLJARLOO

Bivalves: *Nuculana* (*Scaeoleda*) sp. (fragments), *Limopsis beaumariensis* Chapman*, *Lissarca rubricata* (Tate), *Glycymeris* sp. (juveniles), *Divalucina cumingi* (A. Adams and Angas), *Mysella* sp., *Kellia australis* (Lamarck), "*Bornia*" *trigonale* (Tate), *Saltocuna* (*Propecuna*) *obliquissima* (Tate), *Cyclocardia* (*Scalaricardita*) sp. (fragments), *Cuna* sp. cf. *C. edentata* Verco, *Cuna* sp.*, cardiid fragments cf. *Fulvia tenuicostata* (Lamarck), *Mactra* sp. (fragment), *Mactra* (*Electomactra*?) sp.*, *Abra*? sp.*, *Donax* sp.*, *Dosinia* sp.*, *Gomphina undulosa* (Lamarck), *Placamen* sp. aff. *P. subroborata* (Tate)*, *Tawera* sp. cf. *T. pernitida* (Woods)*, *Tawera* sp., *Corbula* sp*.

Scaphopod: *Gadila infans* (Tate)*.

Gastropods: *Amblychilepas* sp. (juvenile), *Bankivia* (*Leiopyrga*) sp. cf. *B.* (*L.*) *octona* (Tate), *Bankivia* (*Leiopyrga*) sp.*, *Botelloides* sp., *Rissoina* sp., vitrinellid, genus and species undetermined, *Alaba* sp. cf. *A. fragilis* (Thiele), *Bittium subgranarium* Ludbrook*, *Hartungia* sp.* (fragments), *Polinices* (*Conuber*) sp. (juveniles), *Nassarius* (*Niotha*) sp., *Marginella* (*Austroginella*) *johnstoni* Petterd (new subspecies), *Cystiscus* sp.*, *Mangelia* sp. (juvenile), *Pervicacia* sp., *Odostomia* sp., *Syrnola* sp., *Ringicula* sp. cf. *R. tatei* Cossmann, *Acteocina aptycha* (Cossmann), *Acteocina* (?) sp.

REFERENCES

Baxter, J. L., and Hamilton, R., 1981, The Yoganup Formation and Ascot Beds as possible facies equivalents: West. Australia Geol. Survey Ann. Rept 1980, p. 42–43.

Ludbrook, N. H., 1978, Quaternary molluscs of the western part of the Eucla Basin: West. Australia Geol. Survey Bull. 125.

ON THE AGE OF THE MERLINLEIGH SANDSTONE, CARNARVON BASIN

by A. E. Cockbain

ABSTRACT

The foraminifers *Maslinella chapmani*, *Crespinina kingscotensis*, *Operculina* sp. and *Rotalia* sp. occur in a sample of Merlinleigh Sandstone collected near the type section. *M. chapmani* and *C. kingscotensis* suggest that the unit is Middle and Late Eocene in age, more probably the latter.

INTRODUCTION

The Merlinleigh Sandstone is a unit of quartz sandstone which outcrops intermittently in the Merlinleigh Sub-basin. It contains ". . . silicified wood and a rich fauna of bivalves, gastropods, echinoids, foraminifers, corals and nautiloids" (Playford and others, 1975, p. 301). To this should be added hydrozoans (Pulley, 1959) and bryozoans (herein). Of these fossils only the coelenterates *Millepora*, *Cyphastrea* and *Duncanopsammia* (Pulley, 1959) and the nautiloid *Aturia clarkei* (Teichert, 1944) have been figured and described.

The age of the formation has been deduced from the molluscs. Teichert (1944) erected the species *Aturia clarkei*, the holotype and paratypes of which came from the Merlinleigh Sandstone in the Kennedy Range. The species also occurs in the Pallinup Siltstone (Plantagenet Group) which Teichert (1944), following Chapman and Crespin (1934), considered to be of Early Miocene age and consequently ". . . a Miocene age can, therefore, also be assumed for the *Aturia* beds of the Kennedy Range" (Teichert, 1944, p. 79). Subsequently Glaessner (1953) suggested that the Plantagenet Group was probably of the same age as Late Eocene beds containing *A. clarkei* (Tortachilla Limestone, Blanche Point Marl) in South Australia. Glenister and others (1956, p. 495) in discussing the age of the Merlinleigh Sandstone remarked that "Recent detailed field work has revealed the presence of a large fauna of pelecypods, gastropods, and echinoids, which R. O. Brunnschweiler (pers. comm.) believes to be Lutetian" (Middle Eocene). Accordingly the unit is now considered to be of Middle and Late Eocene age.

However, Pulley (1959) in describing corals from the formation stated that, while Brunnschweiler and Dickins regarded the shelly fauna as late Middle Eocene, the corals appeared to be younger; *Cyphastrea* does not occur before the Miocene in the East Indies and *Duncanopsammia axifuga* is known only from living reefs in northern Australia. More recently, molluscs have been collected by personnel from the Western Australian Museum and the National Museum of Victoria.

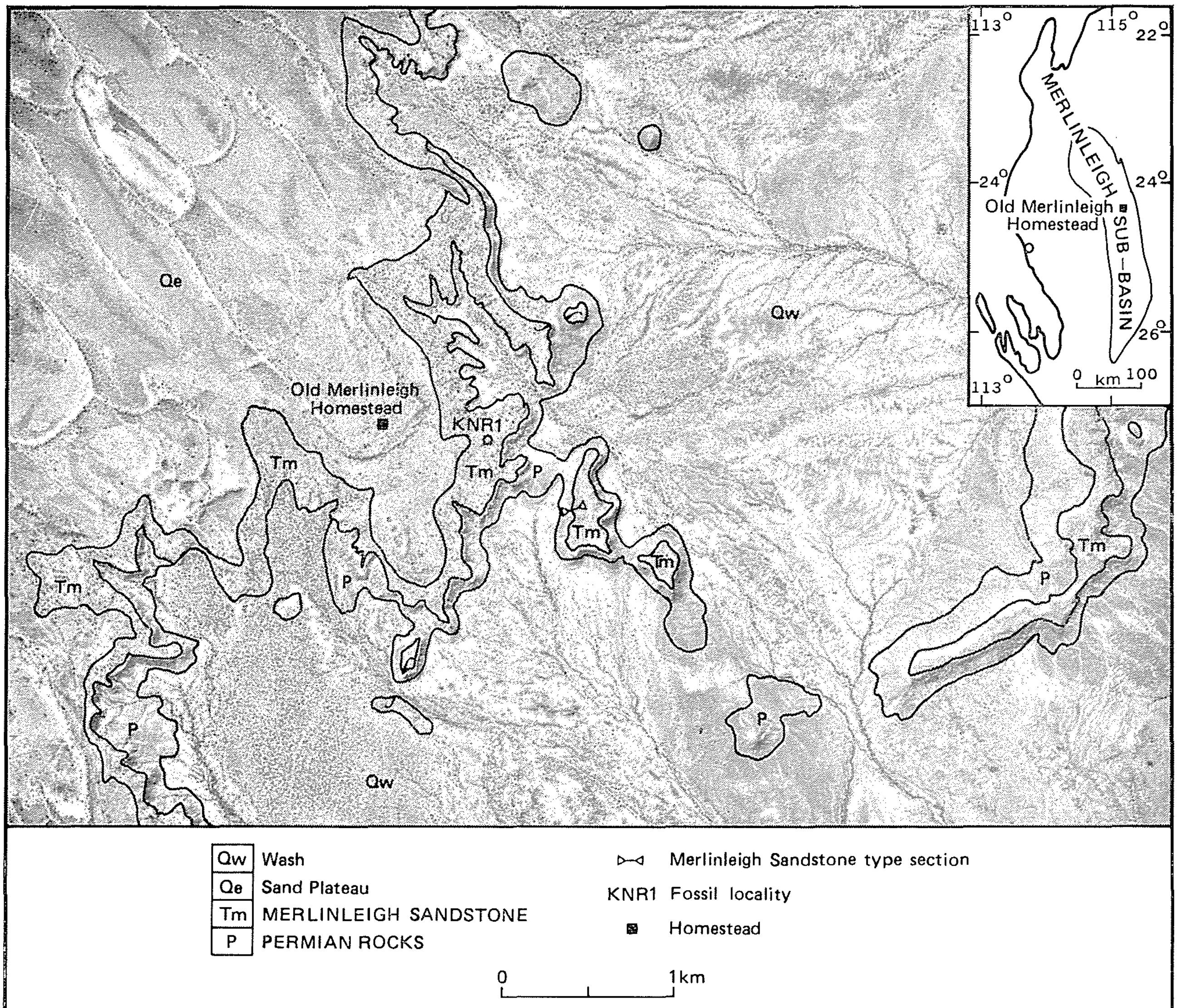


Figure 1 : Locality Map (Kennedy Range, WA 862, run 6, photo 5144)

GSWA 19205

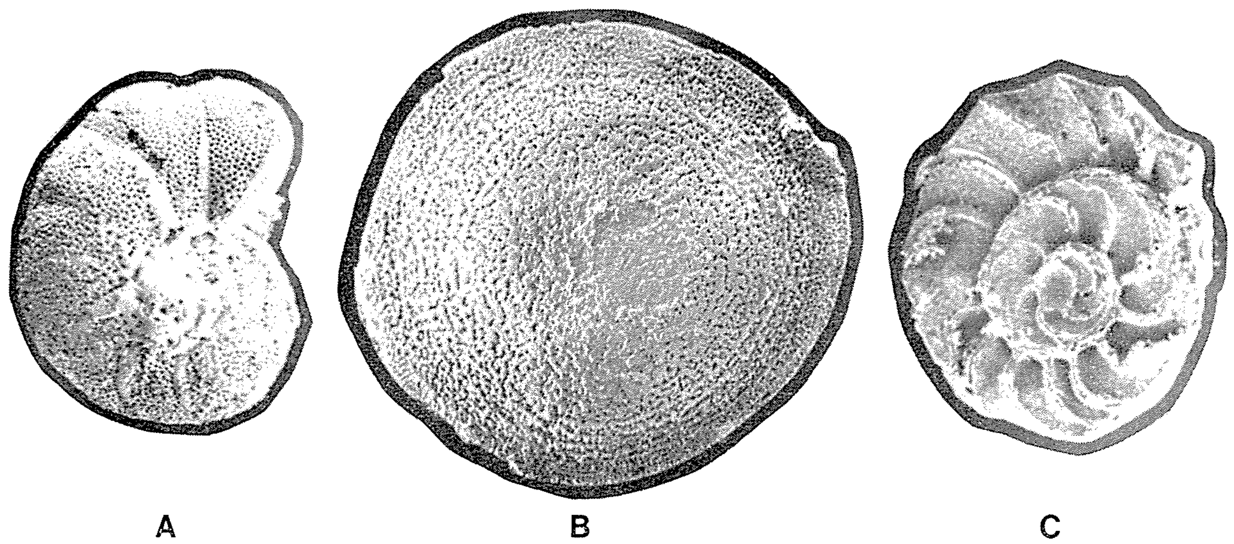


Figure 2 : Photographs of specimens

A – *Maslinella chapmani* (x 30)

B – *Crespinina kingscotensis* (x 30)

C – *Operculina* s p. (x 30)

All from sample F11293 collected from fossil locality KNR1

GSWA 19206

T. A. Darragh (pers. comm., 1980) considers that ". . . the [mollusc] fauna is not diverse enough to allow any precise correlation . . . [It] looks quite modern in aspect . . .".

In order to see whether any independent evidence for the age of Merlinleigh Sandstone could be obtained, a bryozoan-rich sample was examined for foraminifers with the following results.

FORAMINIFERS

The sample was collected by K. J. McNamara and G. W. Kendrick of the Western Australian Museum and bears the number WAM 79.2877/87 of that institution; a portion has been retained by the Geological Survey and given the registered fossil number F11293. The material came from a breakaway in the Kennedy Range, 1 km east of Old Merlinleigh homestead (Fig. 1) and is consequently from slightly to the northwest of the type section (GSWA fossil locality No. KNR1). Lithologically it is a sandstone with silicified bryozoa, molluscs and foraminifers. Foraminifers are quite common in the sample although only a few species are present (Fig. 2). Preservation is variable but there is no reason to suspect reworking. The following taxa have been identified (r = less than 10 specimens, c = 10–100 specimens):

Maslinella chapmani Glaessner and Wade	c
Crespinina kingscotensis Wade	r
Operculina sp.	c
Rotalia sp.	r

The critical species for age determination are *M. chapmani* and *C. kingscotensis*. *Maslinella chapmani* was originally described as being confined to Upper Eocene strata (Glaessner and Wade, 1959, p. 202), but Ludbrook (1963) recorded the species from the middle Eocene part of the Wilson Bluff Limestone. It ranges no higher than the Late Eocene in South Australia (Lindsay, 1969, p. 23). Western Australian occurrences are:

(1) Wilson Bluff Limestone (see Lowry, 1972 plate 4).

(2) Toolinna Limestone (see Lowry, 1973 plate 4).

(3) Werilup Formation (Quilty, 1968; Backhouse, 1970).

(4) Giralia Calcarenite (Glaessner and Wade, 1959, p. 202 (their record from Rough Range South 1, 1170–1175 ft is from this formation); Condon and others 1956, p. 47 (record what is probably this species as *Crespinella* sp. 1); Cockbain, 1967, p. 68).

Crespinina kingscotensis was described from South Australia (Wade, 1955) where it ranges no higher than the Upper Eocene (Lindsay, 1969, p. 23). Ludbrook (1963) records the species from the Upper Eocene, but not from the Middle Eocene. Western Australian records are:

(1) Werilup Formation (Quilty *in* Hodgson and others, 1962).

(2) Norseman Limestone (Cockbain, 1968).

The southern Australian occurences of these two species are important since they are associated there with planktonic foraminifers. Details are documented by Ludbrook (1963) and Lindsay (1967, 1969) and may be summarised as suggesting that *M. chapmani* is Middle and Late Eocene in age and *C. kingscotensis* is probably confined to the Late Eocene.

CONCLUSIONS

The foraminifers from the Merlinleigh Sandstone suggest that the unit is Late Eocene in age with a possibility that it ranges into the Middle Eocene. The Giralia Calcarenite is of Middle and Late Eocene age and contains several fossils in common with the Merlinleigh Sandstone, namely *Maslinella chapmani*, *Operculina* sp. and *Aturia* (*A. australis* in the Merlinleigh Sandstone, *A.* cf. *australis* in the Giralia Calcarenite; Glenister and others, 1956). The two formations were deposited at the same time, the Merlinleigh Sandstone being laid down near the shoreline and the Giralia Calcarenite deposited under more open marine conditions.

REFERENCES

Backhouse, J., 1970, Foraminifera from the Plantagenet Group east of Esperance, Western Australia: West. Australia Geol. Survey Ann. Rept 1969, p. 40–42.

Chapman, F. M. and Crespin, I., 1934, The palaeontology of the Plantagenet Beds of Western Australia: Royal Soc. West. Australia Jour., v. 20, p. 103–136.

Cockbain, A. E., 1967, *Asterocyclina* from the Plantagenet Beds near Esperance, W.A.: Australian Jour. Sci., v.30, p. 68.

Cockbain, A. E., 1968, Eocene Foraminifera from the Norseman Limestone of Lake Cowan, Western Australia: West. Australia Geol. Survey Ann. Rept. 1967, p. 59–60.

Condon, M. A., Johnstone, D., Pritchard, C. E. and Johnstone, M. H., 1956, The Giralia and Marilla anticline, North West Division, Western Australia: Australia Bur. Mineral Resources Bull. 25.

Glaessner, M. F., 1953, Conditions of Tertiary sedimentation in southern Australia: Royal Soc. South Australia Trans., v. 76, p. 141–146.

Glaessner, M. F. and Wade, M., 1959, Revision of the foraminiferal family Victoriellidae: Micropaleontology, v. 5, p. 193–212.

Glenister, B. F., Miller, A. K. and Furnish, W. M., 1956, Upper Cretaceous and early Tertiary nautiloids from Western Australia: Jour. Paleontology, v. 30, p. 492–503.

Hodgson, E. A., Quilty, P. J. G. and Rutledge, D. I., 1962, The geology of the south coast in the vicinity of Cheyne Bay, W.A.: Univ. West. Australia Sci. Hons. thesis (unpublished).

Lindsay, J. M., 1967, Foraminifera and stratigraphy of the type section of Port Willunga Beds, Aldinga Bay, South Australia: Royal Soc. South Australia Trans., v. 91, p. 93–110.

Lindsay, J. M., 1969, Cainozoic Foraminifera and stratigraphy of the Adelaide Plains Sub-basin, South Australia: South Australia Geol. Survey Bull. 42.

Lowry, D. C., 1970, (published, 1972), The geology of the Western Australian part of the Eucla Basin: West. Australia Geol. Survey Bull. 122.

Ludbrook, N. H., 1963, Correlation of the Tertiary rocks of South Australia: Royal Soc. South Australia Trans., v. 87, p. 5–15.

Playford, P. E., Cope, R. N., Cockbain, A. E., Low, G. H. and Lowry, D. C., 1975, Phanerozoic, *in* Geology of Western Australia: West. Australia Geol. Survey Mem. 2, p. 233–433.

Pulley, J. M., 1959, Corals from the Merlinleigh Sandstone of the Carnarvon Basin, Western Australia: Australia Bur. Mineral Resources Rept 38, p. 113–118.

Quilty, P. J. G., 1968, Studies in Tertiary Foraminifera, Part 1 Upper Eocene Foraminifera from the Plantagenet Beds southwestern Western Australia: Univ. Tasmania Ph.D. thesis (unpublished).

Teichert, C., 1944, The genus *Aturia* in the Tertiary of Western Australia: Jour. Palaeontology, v. 18, p. 73–82.

Wade, M., 1955, A new genus of the Chapmanininae from southern Australia: Cushman Foundation, Foraminiferal Res. Contrib., v. 6, p. 45–49.

PETROLEUM EXPLORATION IN WESTERN AUSTRALIA IN 1980

by K. A. Crank

ABSTRACT

There was a significant increase in petroleum exploration in Western Australia in 1980, continuing the upward trend started in 1976. In 1980, 32 exploration wells were completed compared with 17 in 1979, and 6 were drilling ahead at the end of the year, for a total penetration of 91 733 m, an increase of 25 305 m, or 38%, compared with the previous year. Expressed in rig months, the increase was 63% compared with 1979. Drilling activity in 1980 would have been considerably higher but for a severe shortage of offshore drilling rigs. Six development wells were completed in the Barrow Island Oil Field and two in the Dongara Gas Field in 1980.

Highlights of the year included the discovery of gas at Woodada in the northern Perth Basin; and a significant gas show at Phoenix 1, the first such discovery in the offshore Canning Basin. Hydrocarbon shows were encountered in several other wells.

There was a considerable increase in onshore seismic surveys, from 909 km to 4 898 km. However, there was a small decrease in marine seismic activity, which declined by 27% compared with 1979, and totalled 19 089 km.

INTRODUCTION

Exploratory drilling for petroleum in Western Australia over the past two years is illustrated in the following tables:

Type of well	Wells completed 1979	Wells completed 1980	Wells drilling on 31 December 1979	Wells drilling on 31 December 1980
New field wildcats	15	21	4	4
New pool wildcats	1	11	0	0
Extension tests	1	0	0	2
Total	17	32	4	6

Basin	Metres drilled—by Basin 1979 Onshore	1979 Offshore	1980 Onshore	1980 Offshore
Bonaparte Gulf	0	2 863	0	3 589
Browse	....	6 474	....	13 058
Canning	6 940	0	5 447	4 880
Carnarvon	796	20 232	11 554	11 845
"Exmouth Plateau"	....	29 123	....	16 284
Perth	0	0	18 383	0
Eucla	0	0	0	2 573
Officer	0	....	4 120	....
Totals	7 736	58 692	39 504	52 229
	66 428		91 733	

One gas discovery was made in 1980, at Woodada, in the northern part of the Perth Basin, and excellent gas shows were reported in the Phoenix 1 well, the first such discovery in the offshore Canning Basin. At Mount Horner 3 a small oil pool was discovered; this oil had previously been thought to be non-commercial when originally encountered by West Australian Petroleum Pty Ltd in 1965. Several new small pools of oil were also delineated on Barrow Island within the Barrow Island Oil Field.

Figure 1 summarizes seismic activity since 1968. Geophysical survey activity in 1979 and 1980 is shown below:

Type of survey	Line km 1979	Line km 1980
Land seismic	909	4 898
Marine seismic	26 312	19 089
Land gravity	0	226
Marine gravity	9 626	1 328
Marine magnetic	4 903	3 587

DRILLING

DRILLING OPERATIONS

Expressed in rig months, overall exploration operations increased by 63% to 73·2 rig months in 1980, compared with 44·8 rig months in 1979. Offshore operations increased by 18% compared with 1979 (47·3 compared with 40·0 rig months), but the big increase was in onshore activity (25·9 compared with 4·8 rig months). In addition, 6·2 rig months were spent on development drilling in the Barrow Island and Dongara fields, compared with 11·0 rig months in 1979.

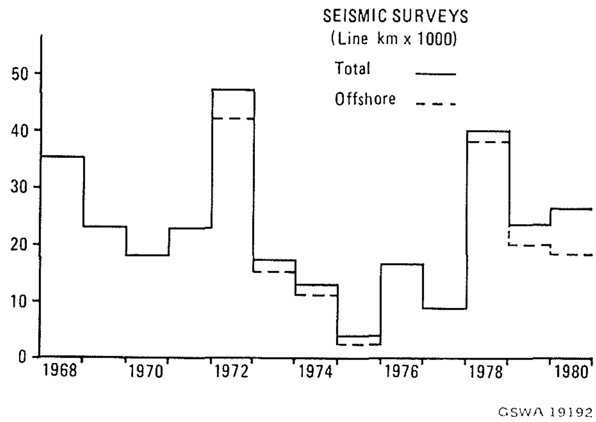


Figure 1 Seismic surveys since 1968

A total of 13 rigs, six offshore and seven onshore, operated in Western Australia. A shortage of drilling rigs in 1980 reduced considerably the expected increase in offshore operations. After drilling Barcoo 1 and Sirius 1 respectively, the drill-ships Sedco 445 and Sedco 472 left Western Australian waters. The semi-submersible Ocean Digger was not utilized prior to drilling Phoenix 1 and, after this well, it also left Western Australian waters. Other details of rig deployment are shown in Figure 2.

Four tropical cyclones interrupted drilling operations in January and February. A total of 55 rig days were lost due to cyclones "Amy", "Brian", "Dean" and "Enid". The wells affected were Buffon 1 (14 days), Vinck 1 (9 days), Barcoo 1 (20 days) and Parker 1 (12 days).

Figure 3 is a summary comparison of drilling operations for the 13-year period 1968–1980.

WELLS COMPLETED IN 1980

The locations of wells drilled for petroleum exploration in Western Australia during 1980 are shown in Figure 4. Details relating to wells drilled during the year are given in Table 1. All petroleum wells drilled in Western Australia up to the end of 1980 are listed in the Geological Survey Record 1981/1 (Crank, 1981). A summary follows of the principal results of drilling in each basin during the year.

Bonaparte Gulf Basin

Only one well was completed in the Bonaparte Gulf Basin in 1980, Lesueur 1, drilled by Australian Aquitaine Petroleum Pty Ltd in Exploration Permit WA–18–P. This was drilled on an anticlinal structure, 169 km north of the town of Wyndham and 57 km north of the coast. The main objectives were sandstones of Permian age and Early Carboniferous carbonates and sandstones, but only minor gas shows were encountered and the well was plugged and abandoned in Early Carboniferous rocks at a total depth of 3 589 m.

Browse Basin

Woodside Petroleum Development Pty Ltd completed three wells in the Browse Basin: Barcoo 1, Buffon 1 and Brewster 1A.

Barcoo 1 was drilled in WA–32–P in 720 m of water on a large anticline in the southwest part of the basin, about 100 km west of Lombardina 1 and 80 km northwest of Lynher 1. The objectives were Late Triassic and Early to Middle Jurassic sandstones, and although good porosities and permeabilities were encountered, only very low gas readings were detected. The well was plugged and abandoned at 5 109 m in Upper Triassic rocks.

Buffon 1, in WA–37–P, in 720 m of water, was drilled on an anticlinal structure in the northern part of the basin, 100 km north-northwest of Scott Reef 1. Objectives were Middle to Late Jurassic and Triassic Sandstones. The Triassic was not reached and Middle Jurassic volcanics were encountered between 3 825 and the total depth. Good gas shows occurred

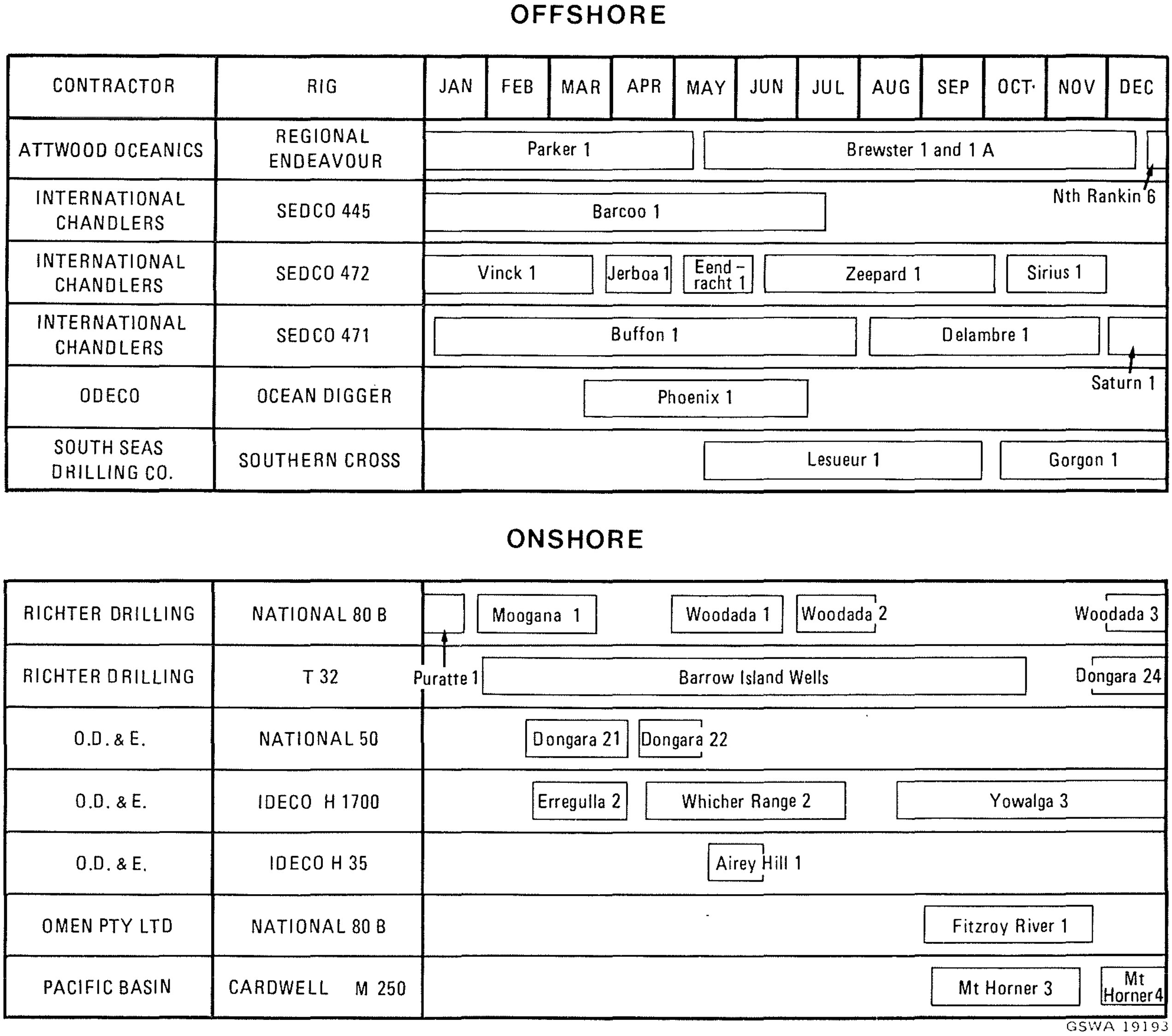


Figure 2 Rig utilization, 1980

in the volcanic section but a drillstem test of the interval 3 739 m to 4 246 m yielded only salt water and a trace of gas. The well was plugged and abandoned at the total depth, 4 757 m.

Brewster 1A was drilled in 250 m of water, in WA–35–P, in the northern part of the basin on a low-relief anticlinal structure. Objectives were sandstones of Lower Jurassic to Lower Cretaceous (Neocomian) age. Brewster 1 was abandoned at 633 m because of mechanical problems. The 1A well also encountered Jurassic volcanics (between 4 565 m and 4 630 m), and gas shows were seen in sandstones below 3 942 m but porosities were low. The drill pipe became stuck after drilling to 4 464 m and it was necessary to drill a sidetrack hole to the total depth of 4 703 m, after which the well was plugged and abandoned.

Canning Basin

In the Canning Basin one offshore and three onshore wells were completed in 1980. One of these, Puratte 1, reached its total depth at the end of 1979 but was completed as a dry hole early in January 1980. This well, drilled by Esso Australia Ltd in EP–104, was sited to test an integrated Devonian pinnacle reef, but no reef rock was encountered and there were no significant shows.

Esso drilled a second well in EP–104 in the onshore Canning Basin, Moogana 1, to test Devonian carbonates in a tilted fault block. Only thin carbonates were penetrated, and there were no shows. Total depth was 2 213 m, in Precambrian graphitic shale and dolerite.

The third onshore well, Fitzroy River 1, was put down by Amax Iron Ore Corporation in EP–97. Total depth was 3 134 m in probable Early Carboniferous rocks, although the main objective had been Devonian carbonates. Only very minor gas shows were encountered, and thin sandstone beds between 2 743 m and 2 800 m tested gas flows too small to measure. The well was plugged and abandoned.

The offshore well, Phoenix 1, was drilled by BP Petroleum Development Australia Pty Ltd on a large elongate anticline in the central part of the offshore basin in Exploration Permit WA–62–P. The main objective in Phoenix 1 was middle to Late Triassic sandstones, and thick sandstones below 4 113 m yielded significant gas shows. At the total depth (4 880 m) gas shows were still being encountered in Middle Triassic sandstones, but the well had to be suspended because it was considered unsafe to continue operations with available pressure-control equipment. BP hopes to return to this location later.

Carnarvon Basin

Two exploration wells offshore were completed by Woodside during the year. Onshore, one new field wildcat and eleven new pool wildcats were completed. Two offshore exploration wells drilling at the end of 1980 were Gorgon 1, a new field wildcat put down by West Australian Petroleum Pty Ltd, and North Rankin 6, an extension test in the North Rankin Field.

Woodside's first well was Parker 1, commenced near the end of 1979 in WA–28–P, located to test a tilted fault block on the southern part of the Kendrew Terrace, south of the productive Rankin Trend. Objectives were sandstones in the Jurassic and Late Triassic, but the Triassic was not reached and the well had to be abandoned at 4 737 m due to mechanical problems.

TABLE 1. WELLS DRILLED FOR PETROLEUM EXPLORATION IN WESTERN AUSTRALIA DURING 1980

Basin	Well	Concession	Operating Company	Type	Position		Elevation and water depth (m)			Dates			Total depth (or depth reached) (m)	Bottomed in	Status on 31 Dec.
					Latitude South	Longitude East	GL	RT	WD	Commenced	Reached TD	Rig released			
Bonaparte Gulf	Lesueur 1	WA-18-P	Aquitaine	NFW	13°57′09″	128°07′33″	....	22	37	16/5/80	22/8/80	30/9/80	3 589	Carboniferous	Gas shows, P & A
Browse	Barcoo 1	WA-32-P	Woodside	NFW	15°20′37″	120°38′12″	....	11	720	14/12/79	29/6/80	12/7/80	5 109	U. Triassic	Dry, P & A
	Buffon 1	WA-37-P	Woodside	NFW	13°23′38″	122°11′00″	....	10	533	4/1/80	18/6/80	3/8/80	4 787	L. Jurassic	Gas shows, P & A
	Brewster 1	WA-35-P	Woodside	NFW	13°54′47″	123°15′29″	....	8	253	13/5/80	16/5/80	23/5/80	633	Tertiary	Mechanical problems, P & A
	Brewster 1A	WA-35-P	Woodside	NFW	13°54′49″	123°15′28″	....	8	250	23/5/80	8/12/80	19/12/80	4 703	Jurassic	Gas shows, suspended
Canning	Puratte 1	EP-104	Esso....	NFW	17°05′16″	123°14′17″	27	33	....	4/11/79	2/1/80	17/1/80	3 750	?U. Devonian	Dry, P & A
	Moogana 1....	EP-104	Esso....	NFW	16°56′17″	122°41′27″	32	38	....	27/1/80	8/3/80	17/3/80	2 313	Precambrian	Dry, P & A
	Phoenix 1	WA-62-P	BP	NFW	18°38′07″	118°47′07″	....	30	139	22/3/80	18/6/80	10/7/80	4 880	M. Triassic	Gas shows, suspended
	Fitzroy River 1	EP-97	Amax	NFW	18°29′39″	124°52′50″	76	81	....	29/8/80	14/11/80	23/11/80	3 134	?L. Carboniferous	Dry, P & A
Carnarvon	Parker 1	WA-28-P	Woodside	NFW	20°00′08″	115°40′08″	....	8	80	26/11/79	1/4/80	4/5/80	4 737*	L. Jurassic	Gas shows, P & A
	Barrow R38	PL1H	WAPET	NPW	20°46′50″	115°22′07″	23	27	....	3/2/80	10/2/80	15/2/80	1 037	L. Cretaceous	Oil well
	Barrow T12	PL1H	WAPET	NPW	20°44′43″	115°23′33″	42	46	....	17/2/80	23/2/80	27/2/80	1 190	L. Cretaceous	Shut-in gas well
	Barrow F48	PL1H	WAPET	NPW	20°50′38″	115°23′58″	12	16	....	29/2/80	4/3/80	7/3/80	901	L. Cretaceous	Shut-in
	Barrow L45M	PL1H	WAPET	NPW	20°48′55″	115°23′21″	52	56	....	22/4/80	9/5/80	11/5/80	976	L. Cretaceous	Oil well
	Barrow Y24M	PL1H	WAPET	NPW	20°43′08″	115°26′56″	29	33	....	17/5/80	23/5/80	29/5/80	1 250	L. Cretaceous	Oil well
	Airey Hill 1	EP-166	Monarch	NFW	23°04′02″	113°52′20″	68	72	....	23/5/80	6/6/80	11/6/80	1 037	L. Permian	Dry, released as water well
	Barrow J46....	PL1H	WAPET	NPW	20°48′42″	115°19′51″	14	18	....	4/7/80	8/7/80	10/7/80	783	L. Cretaceous	Oil well
	Barrow R36	PL1H	WAPET	NPW	20°46′50″	115°21′35″	11	15	....	12/7/80	18/7/80	19/7/80	774	L. Cretaceous	Oil well
	Barrow R28	PL1H	WAPET	NPW	20°46′37″	115°22′07″	26	30	....	15/8/80	20/8/80	22/8/80	789	L. Cretaceous	Oil well
	Delambre 1	WA-90-P	Woodside	NFW	18°31′05″	116°41′48″	....	10	884	6/8/80	17/11/80	28/11/80	5 495	Triassic	Dry, P & A
	Barrow T24	PL1H	WAPET	NPW	20°44′48″	115°23′57″	41	45	....	23/8/80	28/8/80	30/8/80	820	L. Cretaceous	Under test
	Barrow Q46M	PL1H	WAPET	NPW	20°47′08″	115°23′31″	56	60	....	2/9/80	20/9/80	23/9/80	1 052	L. Cretaceous	Oil well
	Barrow E31M	PL1H	WAPET	NPW	20°50′22″	115°24′10″	17	21	....	24/9/80	6/10/80	8/10/80	945	L. Cretaceous	Under test
	Gorgon 1	WA-25-P	WAPET	NFW	20°34′43″	114°46′22″	....	21	259	11/10/80	....	....	4 231	....	Drilling
	North Rankin 6	WA-1-L	Woodside	EXT	19°32′46″	116°08′27″	....	8	124	24/12/80	....	....	460	....	Drilling
"Exmouth Plateau"	Vinck 1	WA-97-P	Esso....	NFW	20°35′04″	112°11′34″	....	10	1 362	20/12/79	17/3/80	25/3/80	4 600	U. Triassic	Gas shows, P & A
	Eendracht 1	WA-96-P	Esso....	NFW	19°54′26″	112°14′09″	....	10	1 353	8/5/80	30/5/80	5/6/80	3 410	U. Triassic	Gas shows, P & A
	Zeepard 1	WA-96-P	Esso....	NFW	20°44′14″	114°25′22″	....	10	740	8/6/80	10/10/80	16/10/80	4 215*	U. Triassic	Gas shows, P & A
	Sirius 1	WA-97-P	Esso....	NFW	20°55′04″	112°41′21″	....	10	1 176	18/10/80	26/11/80	2/12/80	3 500	U. Triassic	Gas shows, P & A
	Saturn 1	WA-84-P	Phillips	NFW	19°54′36″	114°56′41″	....	10	1 177	1/12/80	....	....	3 074	....	Drilling
Perth	Erregulla 2	EP-23	Mesa	NFW	29°22′31″	115°23′51″	241	248	....	20/2/80	10/4/80	13/4/80	3 577	M. Triassic	Dry, P. & A
	Whicher Range 2	EP-130	Mesa	NFW	33°50′31″	115°22′56″	150	157	....	25/4/80	24/6/80	27/7/80	4 330	U. Permian	Gas shows, P & A
	Woodada1	EP-100	Hughes	NFW	29°47′44″	115°08′21″	35	40	....	29/4/80	12/6/80	21/6/80	2 546	L. Permian	Gas well
	Woodada 2	EP-100	Hughes	NFW	29°47′43″	115°09′07″	37	42	....	28/6/80	26/7/80	3/8/80	2 468	L. Permian	Gas well
	Mt Horner 3	EP-96	XLX	NFW	29°07′42″	115°05′00″	195	198	....	3/9/80	5/11/80	19/11/80	1 558	L. Permian	Oil well
	Mt Horner 4	EP-96	XLX	NFW	29°07′49″	115°05′24″	215	218	....	28/11/80	....	....	1 470	....	Drilling
	Woodada 3	EP-100	Hughes	EXT	29°45′16″	115°09′21″	42	43	....	9/12/80	....	....	2 434	....	Drilling
Eucla	Jerboa 1	WA-126-P	Esso....	NFW	33°30′15″	127°36′03″	....	10	771	2/4/80	24/4/80	29/4/80	2 573	Precambrian	Dry, P & A
Officer	Yowalga 3	EP-178	Shell	NFW	29°08′58″	125°55′00″	476	483	....	19/8/80	....	....	4 120	....	Drilling

* Does not include sidetracked hole

Aquitaine: Australian Aquitaine Petroleum Pty Ltd
Woodside: Woodside Petroleum Development Pty Ltd
Esso: Esso Exploration and Production Aust. Inc.
BP: BP Petroleum Development Aust Pty Ltd
Amax: Amax Iron Ore Corporation
WAPET: West Australian Petroleum Pty Ltd
Monarch: Monarch Petroleum N.L.
Phillips: Phillips Australian Oil Co.
Mesa: Mesa Australia Ltd
Hughes: Hughes & Hughes
XLX: XLX N.L.
Shell: The Shell Co. of Australia Ltd

NFW: New field wildcat well
NPW: New pool wildcat well
EXT: Extension test well
P & A: Plugged and abandoned
GL: Ground level
RT: Rotary table
WD: Water depth

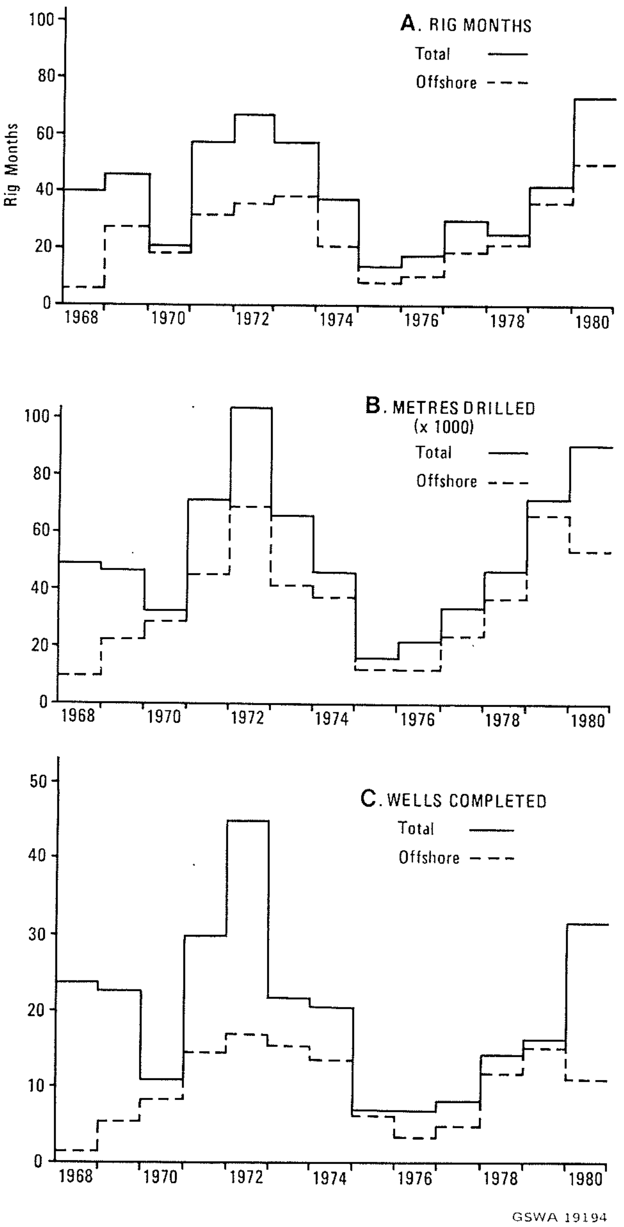


Figure 3 Drilling operations since 1968

The second well completed by Woodside was Delambre 1 in WA–90–P, drilled in the extreme northern part of the Carnarvon Basin. Objectives were Triassic and Jurassic sandstones. The well was abandoned as a dry hole at 5 495 m after the objective sands were found to be water-bearing.

Onshore, a shallow test was drilled by Monarch Petroleum NL in EP–166, about 100 km south of Learmonth. The objective was Cretaceous Birdrong Sandstone, but no hydrocarbon shows were encountered, and after reaching 1 037 m in Early Permian rocks it was released as a water well.

West Australian Petroleum Pty Ltd (WAPET) drilled a total of eleven wells classed as new pool wildcats within the area of the Barrow Island Oil Field. Seven of these were producing oil, two were shut in, and two were under test at the end of the year. The status of these wells at the end of 1980 is shown in Table 2.

Barrow Island development wells

During 1980 six development wells were drilled by WAPET within the Barrow Island Oil Field. One of these, L63 was classed as a water-source well. In the field, 4 513 m of development drilling were completed. The status of these wells at the end of the year is also shown in Table 2.

Exmouth Plateau area

Four wells were completed by Esso in the Exmouth Plateau area in water depths from 740 m to 1 362 m. At the end of the year Phillips Australian Oil Company was drilling Saturn 1 in WA–84–P.

TABLE 2. STATUS OF BARROW ISLAND WELLS

Well name	Total depth (m)	Status
		New Pool wildcats
R38	1 037	Oil producer—Windalia
T12	1 190	Shut-in gas well—Windalia
F48	901	Shut-in
L45M....	976	Oil producer—Munderong
Y24M	1 250	Oil producer—Munderong
J46	783	Oil producer—Windalia
R36	774	Oil producer—Windalia
R28	789	Oil producer—Windalia
T24	820	Under test
Q46M	1 052	Oil producer—Barrow
E31M....	945	Under test
		Development Wells
F64	857	Shut-in observation well
B16B	713	Oil producer—Windalia
J78	789	Under test
J88	792	Oil producer—Windalia
L63	1 372	Water-source well
L14	754	Oil producer—Windalia

Vinck 1, commenced late in 1979, was drilled in WA–97–P about 250 km northwest of North West Cape. The water depth was 1 362 m. Objectives in this well were Triassic sandstones and Late Jurassic-Early Neocomian deltaic sandstones. Minor gas and condensate were recovered from formation interval tests and the well was plugged and abandoned as non-commercial at a total depth of 4 600 m.

Esso's second well was Eendracht 1 in WA–96–P about 80 km north-northeast of Vinck 1. Water depth was 1 353 m. In this well the objective was Late Triassic sandstones in a large fault block closure. Formation interval tests yielded both gas and condensate between 2 467 and 2 652 m but the well was plugged and abandoned as non-commercial at 3 410 m.

Zeepard 1 was drilled in WA–96–P about 90 km west of Barrow Island, close to the northern margin of the Exmouth Sub-basin. The hole was drilled in 740 m of water and the main objectives were Late Triassic sandstones and Early Neocomian sandstones. Gas was encountered in several thin sandstones between 4 011 m and 4 164 m. One month was lost on fishing and sidetracking before the well was abandoned.

Sirius 1 was located about 65 km southeast of Vinck 1 in 1 176 m of water in WA–97–P. The plays here were for Late Triassic and Jurassic/Cretaceous deltaic sandstones but only thin gas/condensate-bearing sandstones were penetrated. The well was plugged and abandoned as a dry hole at 3 500 m.

Perth Basin

There was no offshore drilling in the Perth Basin, but five onshore wells were completed and two were drilling at the end of the year.

Mesa Australia Ltd drilled two wells, Erregulla 2 and Whicher Range 2, both follow-up wells to earlier WAPET exploration efforts. Erregulla 2 was located 200 m north of Erregulla 1, which was drilled in 1966 in EP–23 and which had encountered excellent hydrocarbon shows in the Early Jurassic and Permian. Attempts to produce commercial oil from the first well had failed and the second well was drilled nearer the crest of the structure. However, no significant hydrocarbon shows were encountered and the well was plugged and abandoned.

Mesa's second well, Which Range 2, in EP–130 in the southern part of the Perth Basin, was also a follow-up to an earlier WAPET well (1968). It was drilled to re-evaluate the potential of Permian sandstones in a structurally higher position than in the original well. Results were disappointing in that the Permian produced only minor amounts of gas. Four drillstem tests were run in Permian rocks, and, although fairly high flow rates were reported (up to 155 750 m^3/day), rapid decline occurred in each case. Of significance was the occurrence of 200 m of intrusive dolerite in the Triassic; this was not present in the No. 1 well.

Hughes and Hughes, on behalf of Strata Oil NL, completed two wells and was drilling a third at the end of the year, on the Woodada structure in EP–100 in the northern Perth Basin. The main objective of the Woodada 1 well was Early Permian Carynginia Formation sandstone which had flowed gas in 1965 at Arrowsmith 1, 25 km to the northeast. However, the well encountered a limestone section within the Carynginia Formation which was considerably thicker than at any other location in the Perth Basin. A drillstem test of the interval 2 297 m to 2 345 m yielded gas at a rate of 233·7 x $10^3 m^3$/day apparently from fracture porosity in the limestone. Woodada 2 penetrated a similar section with good gas flows from the limestone section, i.e. flow rates of up to 920 x $10^3 m^3$/day. Both these wells have been classified as gas producers.

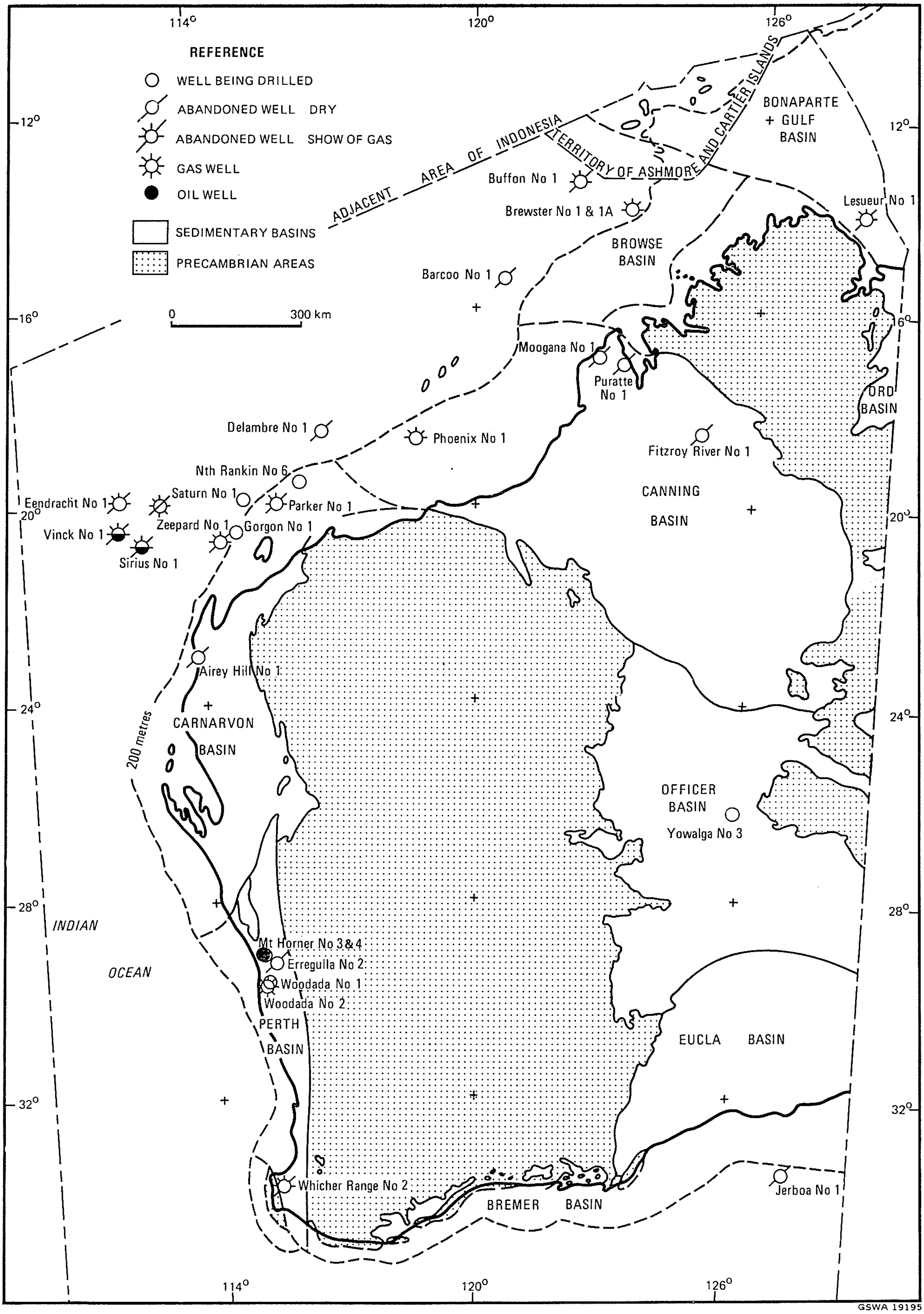


Figure 4 Map showing wells drilled for petroleum in Western Australia during 1980.

In EP–96 in the northern Perth Basin, XLX NL completed one well (Mount Horner 3) and was drilling a second (Mount Horner 4) at the end of the year. Mount Horner 3 was drilled about 195 m from Mount Horner 1 (drilled by WAPET in 1965). The primary objectives were basal triassic sandstones which have produced some oil in the Dongara and Yardarino fields; and minor sands in the Early Triassic, from which some oil was pumped in the No. 1 well during a production test by WAPET. Mount Horner 3 was completed as an oil producer with a production rate of 52 barrels of oil per day from a sand in the Early Triassic. The No. 4 location is about 500 m east of the No. 3 well.

Dongara Field development wells

Within the Dongara Field, two development wells were completed and one was drilling at the end of 1980, for a total of 5 454 m of drilling. Details are shown below:

STATUS OF DONGARA FIELD DEVELOPMENT WELLS

Well name	Total depth (m)	Status	Completed on
Dongara 21	1 889	Shut-in	10/4/80
Dongara 22	1 800	Shut-in water disposal well	14/5/80
Dongara 23	....	Drilling, at 1 765 m	....

Eucla Basin

Esso Australia Ltd drilled one well in Exploration Permit WA–126–P in the offshore Eucla Basin, the first well to be drilled off the south coast of Western Australia. The well, Jerboa 1, located about 250 km southwest of Eucla, was drilled to a total depth of 2 573 m, bottoming in the Precambrian. The objective was to test Neocomian sandstones draped over a titled basement block, but although porous sandstones were penetrated, no shows of oil or gas were encountered and the well was abandoned as a dry hole.

Officer Basin

The Shell Company of Australia Ltd, at the end of 1980, was drilling Yowalga 3, the first exploration well to be drilled in the remote Officer Basin since 1966.

GEOPHYSICAL SURVEYS

Geophysical surveys carried out during the year consisted mainly of seismic work. In line-kilometrage, seismic surveys decreased by about 12 per cent on the 1979 figure. However, there was a considerable increase in the expensive onshore surveys, from 909 km to 4 898 km, mainly due to increased activity in the Perth and Canning Basins.

Other geophysical activities were marine gravity and magnetic surveys, largely in conjunction with seismic surveys. A gravity survey was conducted in the onshore Bonaparte Gulf Basin by Australian Aquitaine Petroleum Pty Ltd.

SEISMIC

During 1980, offshore seismic surveys were conducted in the Perth Basin (1 681 km), Carnarvon Basin (7 395 km), Canning Basin (4 580 km), Browse Basin (1 015 km), Bonaparte Gulf Basin (3 028 km), and in the Exmouth Plateau area (1 390 km). Onshore seismic surveys were conducted in the Perth Basin (551 km), Carnarvon Basin (20 km), Canning Basin (3 733 km) Bonaparte Gulf Basin (209 km) and the Officer Basin (385 km). Details are as follows:

SEISMIC SURVEYS—ONSHORE

Basin	Tenement	Company	Line km
Officer	EP–178–180	The Shell Co. of Aust. Ltd.	385
Perth	EP–100	Hughes & Hughes	100
	EP–105	Mesa Australia Ltd.	60
	EP–111	Jervois Sulphates (N.T.) Ltd.	12
	EP–111	Pancontinental Mining Co.	57
	EP–130	Mesa Australia Ltd.	322
Carnarvon	EP–169	Mergui Holdings Ltd.	20
Canning	EP–104	Esso Exploration & Production Aust. Inc.	842
	EP–107	Era Western Australia Inc.	150
	EP–129	Home Oil Australia Ltd.	863
	EP–134	Mobil Oil Australia Ltd.	797
	EP–175	Getty Oil Development Co. Ltd.	1 081
Bonaparte Gulf	EP–126	Australian Aquitaine Petroleum Pty. Ltd.	209
Total			4 898

SEISMIC SURVEYS—OFFSHORE

Basin	Tenement	Company	Line km
Perth	WA–59–P	Western Mining Corp. Ltd.	833
	WA–113–P	Haoma Gold Mines NL	130
	WA–115–P	Geometals Oil Exploration Pty. Ltd.	304
	WA–135–P	Wainoco International Inc.	414
Carnarvon	WA–1–P	Woodside Petroleum Development Pty. Ltd.	449
	WA–3–L	Woodside Petroleum Development Pty. Ltd.	265
	WA–4–L	Woodside Petroleum Development Pty. Ltd.	22
	WA–24–P	West Australian Petroleum Pty. Ltd.	8
	WA–25–P	West Australian Petroleum Pty. Ltd.	657
	Vacant	West Australian Petroleum Pty. Ltd.	15
	WA–28–P	Woodside Petroleum Development Pty. Ltd.	1 168
	WA–28–P	West Australian Petroleum Pty. Ltd.	42
	WA–58–P	Hudbay Oil (Australia) Ltd.	1 331
	WA–64–P	Offshore Oil N.L.	529
	WA–64–P	West Australian Petroleum Pty. Ltd.	21
	WA–80–P	Otter Exploration N.L.	212
	WA–81–P	Continental Oil Company of Aust. Ltd.	1 275
	Vacant	Esso Exploration & Production Aust. Inc.	297
	WA–102–P	Canada North West Land Ltd.	577
	WA–110–P	CNW Oil (Australia) Pty. Ltd.	527
Canning	WA–58–P	Western Energy Pty. Ltd.	226
	WA–109–P	Esso Exploration & Production Aust. Inc.	1 137
	WA–114–P	Era South Pacific Pty. Ltd	261
	WA–117–P	Pursuit Exploration Pty. Ltd, ...	513
	WA–119–P	Weaver Oil & Gas Corp., Australia	1 013
	WA–120–P	Weaver Oil & Gas Corp., Australia	876
	WA–137–P	B.P. Petroleum Development (Aust.) Pty. Ltd.	554
Browse	WA–104–P	Brunswick Oil N.L.	851
	WA–68–P	Oxoco International Inc.	164
Bonapatre Gulf	WA–18–P	Australian Aquitaine Petroleum Pty. Ltd.	665
	WA–74–P	Mesa Australia Ltd.	367
	Vacant	Mesa Australia Ltd.	49
	WA–77–P	Magnet Metals Ltd.	619
	WA–103–P	Lennard Oil N.L.	641
	WA–128–P	CNW Oil (Australia) Pty. Ltd.	687
Exmouth Plateau	WA–90–P	Woodside Petroleum Development Pty. Ltd.	679
	WA–93–P	Hudbay Oil (Australia) Ltd.	560
	WA–96–P	Esso Exploration & Production Aust. Inc.	52
	WA–97–P	Esso Exploration & Production Aust. Inc.	99
Total			19 089

GRAVITY

One gravity survey was conducted in the onshore Bonaparte Gulf Basin by Aquitaine. Other surveys were carried out in conjunction with marine seismic surveys, as follows:

GRAVITY SURVEYS—ONSHORE

Basin	Tenement	Company	Line km
Bonaparte Gulf	EP–126	Australian Aquitaine Petroleum Pty. Ltd.	226

GRAVITY SURVEYS—OFFSHORE

Basin	Tenement	Company	Line km
Bonaparte Gulf	WA–103–P	Lennard Oil N.L.	641
	WA–128–P	CNW Oil (Australia) Pty. Ltd.	687
Total			1 328

MAGNETIC

Magnetic surveys were carried out in conjunction with marine seismic surveys as follows:

MAGNETIC SURVEYS—OFFSHORE

Basin	Tenement	Company	Line km
Canning	WA–117–P	Pursuit Exploration Pty. Ltd.	370
	WA–119–P	Weaver Oil & Gas Corp. Australia	1 013
	WA–120–P	Weaver Oil & Gas Corp. Australia	876
Bonaparte Gulf	WA–103–P	Lennard Oil N.L.	641
	WA–128–P	CNW Oil (Australia) Pty. Ltd.	687
Total			3 587

REFERENCE

Crank, K. A., 1981, Wells drilled for petroleum exploration in W.A. to the end of 1980: West. Australia Geol. Survey Rec. 1981/1.

THE TUMBLAGOODA SANDSTONE, WESTERN AUSTRALIA ITS TYPE SECTION AND SEDIMENTOLOGY

by R. M. Hocking

ABSTRACT

The Tumblagooda Sandstone is a thick Silurian sequence which was deposited in fluviatile, tidal and coastal environments. The type section is in the lower Murchison River gorge and consists of a number of partial sections, correlation between which is achieved by interpretation of aerial photographs, lithological similarities, or physical tracing of marker horizons. It is unrealistic to construct a single composite vertical section from these partial sections, because the type section is 70 km long and is cut by three faults; but used as a fence diagram, the type section allows palaeogeographic reconstructions for the Tumblagooda Sandstone in the type area. In the east, sedimentation commenced in a low-sinuousity sheet-braided fluviatile environment, with a south-eastern source. Marine influence increased to the northwest. In time, supply lessened and the dominant environment changed to a shallow, largely tidal, marine environment. Fluviatile sands were probably still being deposited to the east. A second sheet-braided phase followed, possibly as a result of a relatively abrupt rejuvenation of the source area. This phase shows indications of waning at the very top of the type section.

INTRODUCTION

BACKGROUND

The type section of the Tumblagooda Sandstone extends down the gorge of the Murchison River from the Hardabut Anticline to Second Gully, a distance of approximately 70 km (Fig. 1). The section was measured twice previously, in 1954 and 1957, and the results recorded by Johnstone and Playford (1955) and Condon (1965) respectively. As the sandstone dips westwards at angles less than 5°, it is neither practicable nor possible to measure a single continuous section. Therefore, partial vertical sections were measured on cliffs with good exposure, and aerial photographs were used to correlate between them. Bedding shows very clearly on photographs, so this provides a generally reliable method of correlation.

It proved necessary to remeasure the type section in 1980 for three reasons:

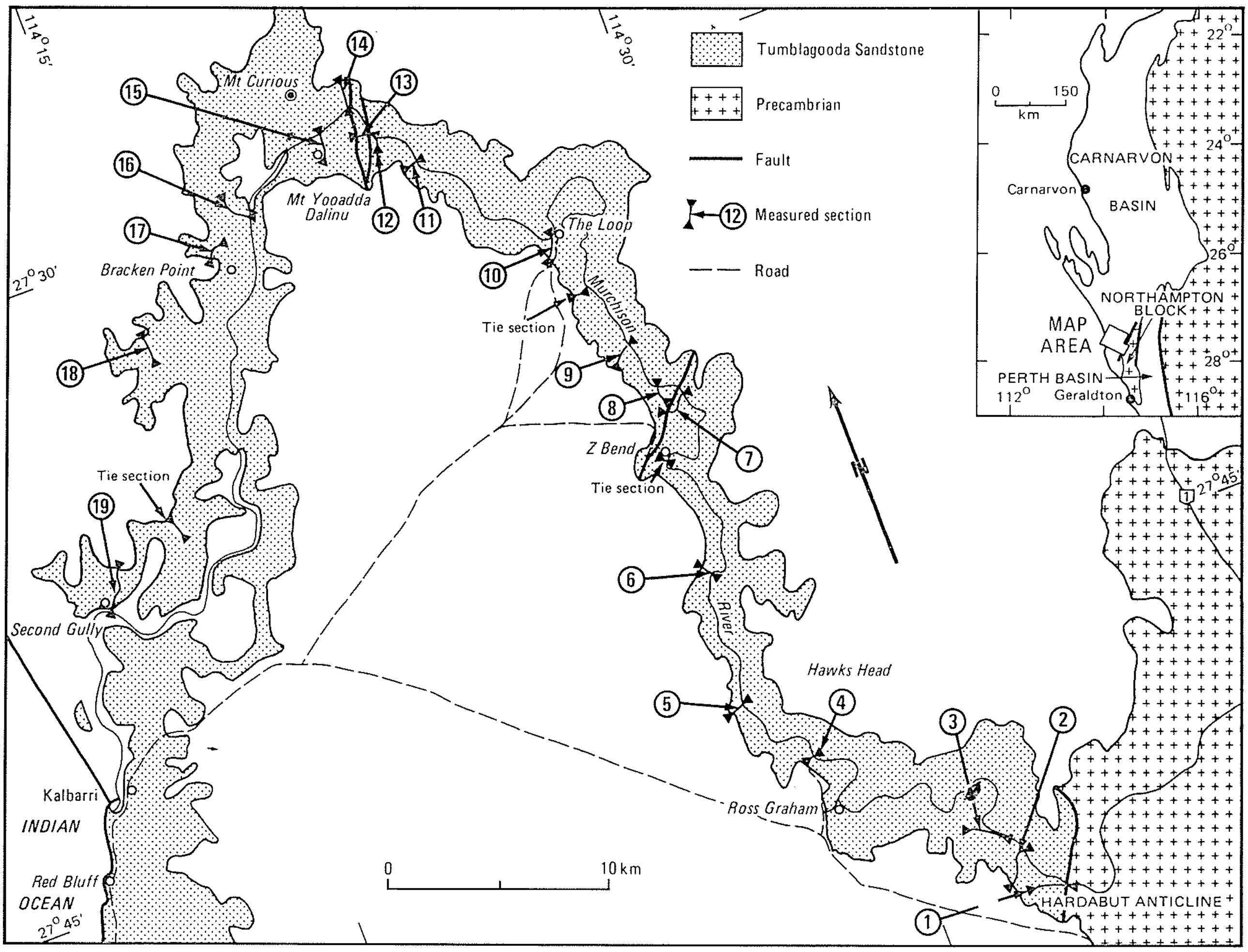
(1) At least two faults cut the section and invalidate previous correlations.

(2) The interpretation of the sedimentology of the Tumblagooda Sandstone in the type section needed more systematic revision than was done by Mandyczewsky (1973) or Hocking (1979).

(3) Previously, the type section was presented as a single, composite, vertical section, which is not a realistic manner of presentation when the lateral extent and probable lateral facies variations within the section are considered.

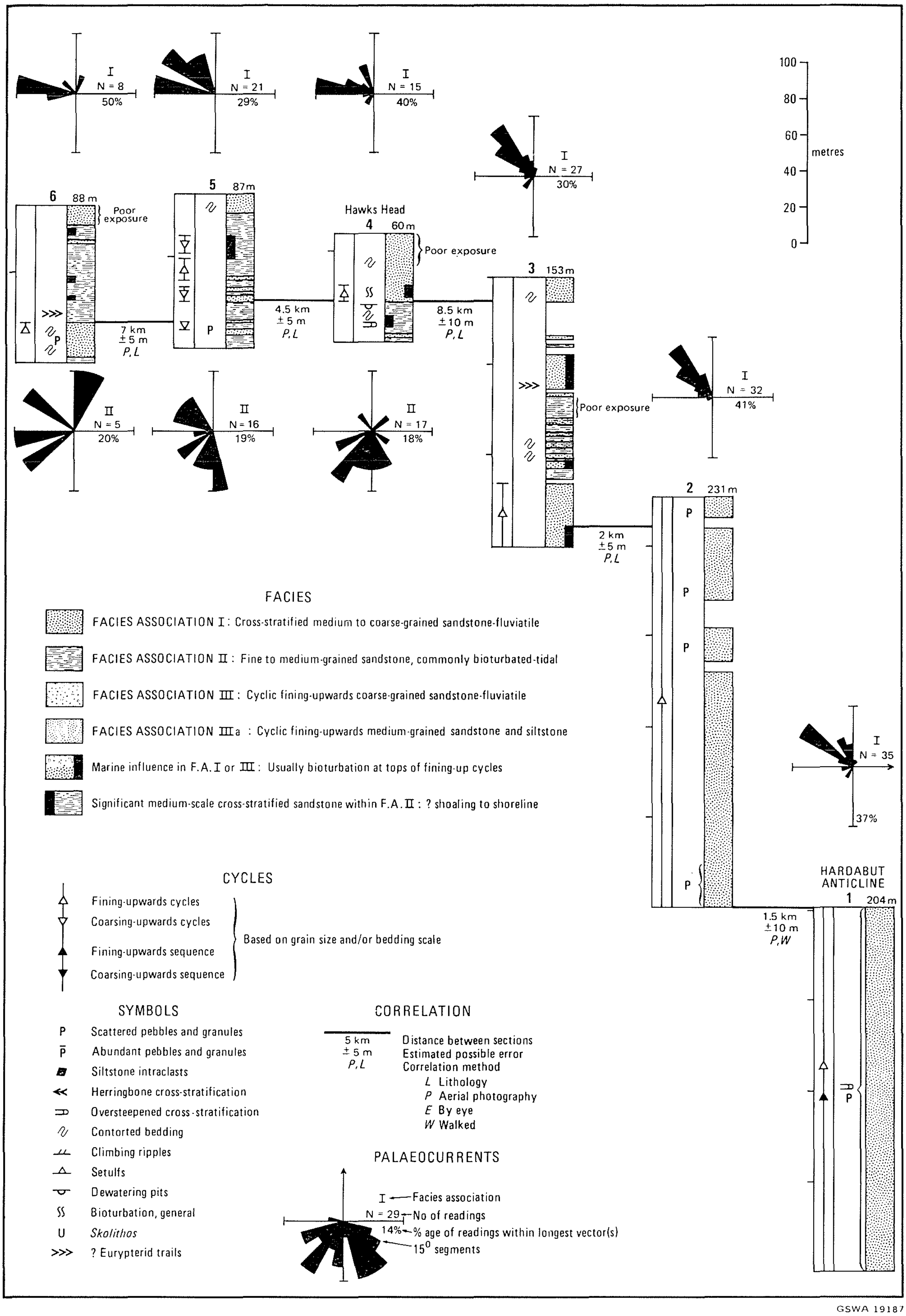
TECHNIQUES

As was the practice of previous authors (Condon, 1965; Johnstone and Playford, 1955), individual sections (22 total, of which 19 are presented here) were measured after detailed interpretation of 1:40 000 aerial photographs. Section locations (Fig. 1) differ in part from those used previously because of access, exposure, and potential for correlation. Final correlation of sections was partly from aerial photographs, partly from lithology (such as facies boundaries, thickness of individual facies units, or sets of fining-upwards cycles), and partly by tracing marker horizons on the ground. Three faults were recognized, all with a probable movement of less

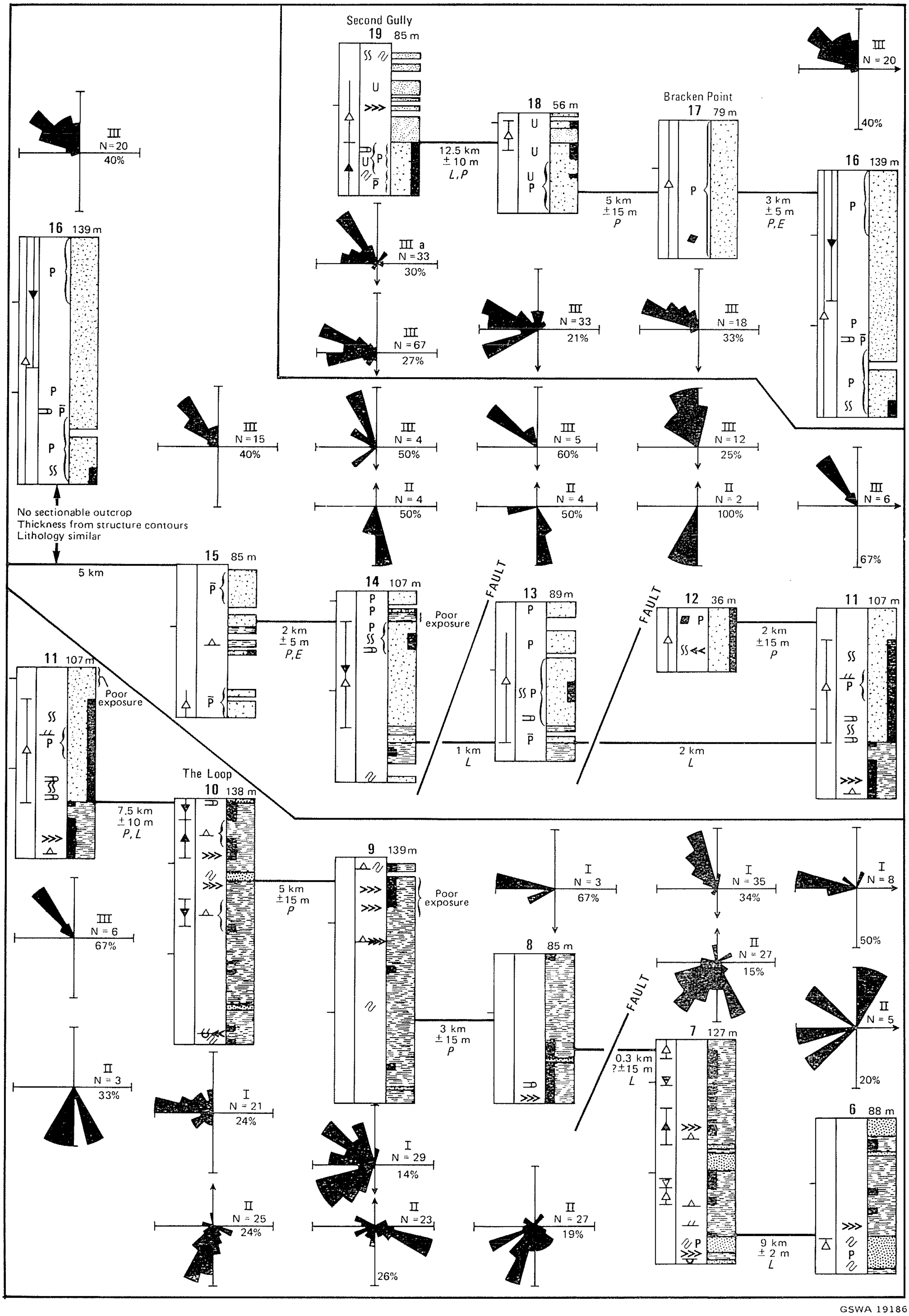


GSWA 19185

Figure 1 The Tumblagooda Sandstone type section, showing locations of faults cutting the section. Numbers refer to measured partial sections which are represented in Figures 2 and 3.



Figures 2 and 3 Partial sections for the Tumblagooda Sandstone type section. Palaeocurrent roses are total palaeocurrents for each facies association within each section. For section locations, see Figure 1.



Second Gully
19 85 m
18 56 m
Bracken Point
17 79 m
16 139 m
12.5 km ±10 m L, P
5 km ±15 m P
3 km ±5 m P, E
III N = 20 40%
IIIa N = 33 30%
III N = 67 27%
III N = 33 21%
III N = 18 33%
III N = 15 40%
III N = 4 50%
III N = 5 60%
III N = 12 25%
II N = 4 50%
II N = 4 50%
II N = 2 100%
III N = 6 67%
No sectionable outcrop
Thickness from structure contours
Lithology similar
5 km
15 85 m
14 107 m
Poor exposure
FAULT
13 89 m
12 36 m
11 107 m
2 km ±5 m P, E
1 km L
2 km ±15 m P
2 km L
Poor exposure
The Loop
10 138 m
7.5 km ±10 m P, L
9 139 m
5 km ±15 m P
8 85 m
3 km ±15 m P
7 127 m
0.3 km ?±15 m L
6 88 m
9 km ±2 m L
I N = 3 67%
I N = 35 34%
I N = 8 50%
II N = 27 15%
II N = 5 20%
III N = 6 67%
II N = 3 33%
I N = 21 24%
I N = 29 14%
II N = 25 24%
II N = 23 26%
II N = 27 19%
GSWA 19186

than 100 m. Correlation over these faults is therefore possible, and was made by means of cycle thicknesses and facies boundaries. The distance between sections, probable maximum error in correlation, and methods of correlation are shown on sections in Figures 2 and 3.

PRESENTATION

The sections are presented in a simplified format using broad facies associations in Figures 2 and 3. Only a single correlation line is shown, although in some cases correlation is based on several datum lines. Detailed representative sections of each facies association are shown in Figure 4, together with total palaeocurrent measurements for each association. Only palaeocurrents measured in 1980 are shown. A detailed version of the type section (GSWA 19200), at 1:500 scale, is in the Geological Survey plan collection.

FACIES ASSOCIATIONS

Three broad facies associations have been recognized in the type section. These are based on grain-size variation, bedding type and scale, and evidence of bioturbation.

FACIES ASSOCIATION I (F.A. I)

Trough cross-stratified, medium- to coarse-grained sandstone and subordinate planar-bedded sandstone outcrop in the eastern, or lower part, of the section, and correspond to Facies 1 of Hocking (1979). The sandstone falls primarily into lithofacies *St* of Miall (1977), with subordinate *Sh* and minor *Sp* (Table 1). Sorting is poor in some more easterly outcrops, but improves markedly to the north and west, or higher in the sequence. Pebbles and granules are present, either scattered through the rock or concentrated in lags and stringers. Fining-upwards cycles, 2 to 10 m thick, can be distinguished in most places. Parabolic recumbent cross-stratification is common (Doe and Dott, 1980), and contorted bedding is locally present. A representative portion of the association, from Section 2, is shown in Figure 4.

Locally poor sortings, sporadic pebbles, and the unimodal palaeocurrent distribution suggests F.A.I. is a fluviatile deposit, whose source was to the southeast. Further, the small scatter of palaeocurrents in each section, together with the absence of clear, incised channels or abandoned-channel deposits, suggests a low-sinuosity sheet-braided depositional environment (Miall, 1980).

FACIES ASSOCIATION II (F.A. II)

Thin-bedded, fine- to medium-grained sandstone, commonly bioturbated, outcrops in the central part of the type section, and corresponds to Facies 2 of Hocking (1979). Bedding is characteristically planar to ripple laminated (Fig. 5A, B), but in many places grades into low- to very low-angle cross-stratification. Megaripples are common, and locally coalesce to form medium-scale cross-stratified units, which are distinguished on the sections where significant. Intensely bioturbated beds characterize the association, and locally develop into laminated-to-burrowed alternations in which the couplets are up to 60 cm thick (Fig. 5C). Tracks and trails attributed to trilobites and eurypterids (Fig. 6A) and collapsed burrows attributed to trilobites (Fig. 5B), as well as non-specific tracks, trails and burrows, are present. *Skolithos* has not been found within this facies association in the type section. Sedimentary structures, such as climbing ripples (Fig. 5D), flat-topped ripples, setulfs (Fig. 6B) (Friedman and Sanders, 1974, 1978), herringbone cross-stratification, contorted bedding (Fig. 7A) and marine trace fossils, suggest that F.A. II was deposited in tidal to very shallow subtidal environments. This is supported by the intimate and repeated association of F.A. I (or F.A. III) and F.A. II sediments, and the mixture of wave and current ripples. Clay-draped surfaces, granule lags (Fig. 7D) and washed-out tracks indicate temporary cessations of supply. Because little basal scouring is present, cross-stratified sand bodies may be tidal sand-ridges (Elliot, 1978a) and shoreline barriers, produced by reworking of fluviatile sands (Elliot, 1978b), rather than channel sand as suggested by Hocking (1979). Figure 4 shows a portion of the association from Section 4 at Hawks Head.

FACIES ASSOCIATION III (F.A. III)

Facies Association III consists of fining-upwards cycles of coarse-grained sandstone and is present in the western part of the type section. Cyclicity is more pronounced than in F.A. I: fining-upwards cycles are 10 to 15 m thick, and sandstones are texturally less mature. In Miall's (1977) classification, the facies present are *St* (Fig. 6G, 7B), *Ss*, and minor *Gt* and *Sp*. Bioturbation and typical F.A. II sediments are present at the top of some fining-upwards cycles (Fig. 7C), and *Skolithos* is sporadically present throughout cycles (Figs. 6D, 8). Parabolic recumbent bedding is present but uncommon, and contorted bedding is known only from the Second Gully area.

Cycles grading upwards from medium- or coarse-grained sandstone to red siltstone (Fig. 8) constitute a subdivision within F.A. III, distinguished as Facies Association IIIa (F.A. IIIa). In Miall's classification (Table 1), they are primarily lithofacies *St* and *Fl*, with minor *Sp*. This association is the "Yalthoo Member" of Johnstone and Playford (1955) and appears to be a low-energy variant of F.A. III rather than a separate association.

Facies Association III, like F.A. I, was deposited in low-sinuousity, sheet-braided fluviatile environments. The energy level, as reflected by grain size, sorting and cycle thickness, was higher than for F.A. I, but waned during deposition of F.A. IIIa. Marine influence in F.A. III is more widespread than in F.A. I, and indicates that deposition was partly in a shoreline setting, where marine processes at times dominated during low energy stages of the braided system. This concept is similar to that of the depositional model for the Eregunda Sandstone Member from the Flinders Ranges, South Australia (Moore, 1980), in which fan-deltas debouched into a shallow epicontinental sea. This produced a sequence in which current-laid sandstones alternated with low-energy tidal deposits.

DEPOSITIONAL HISTORY

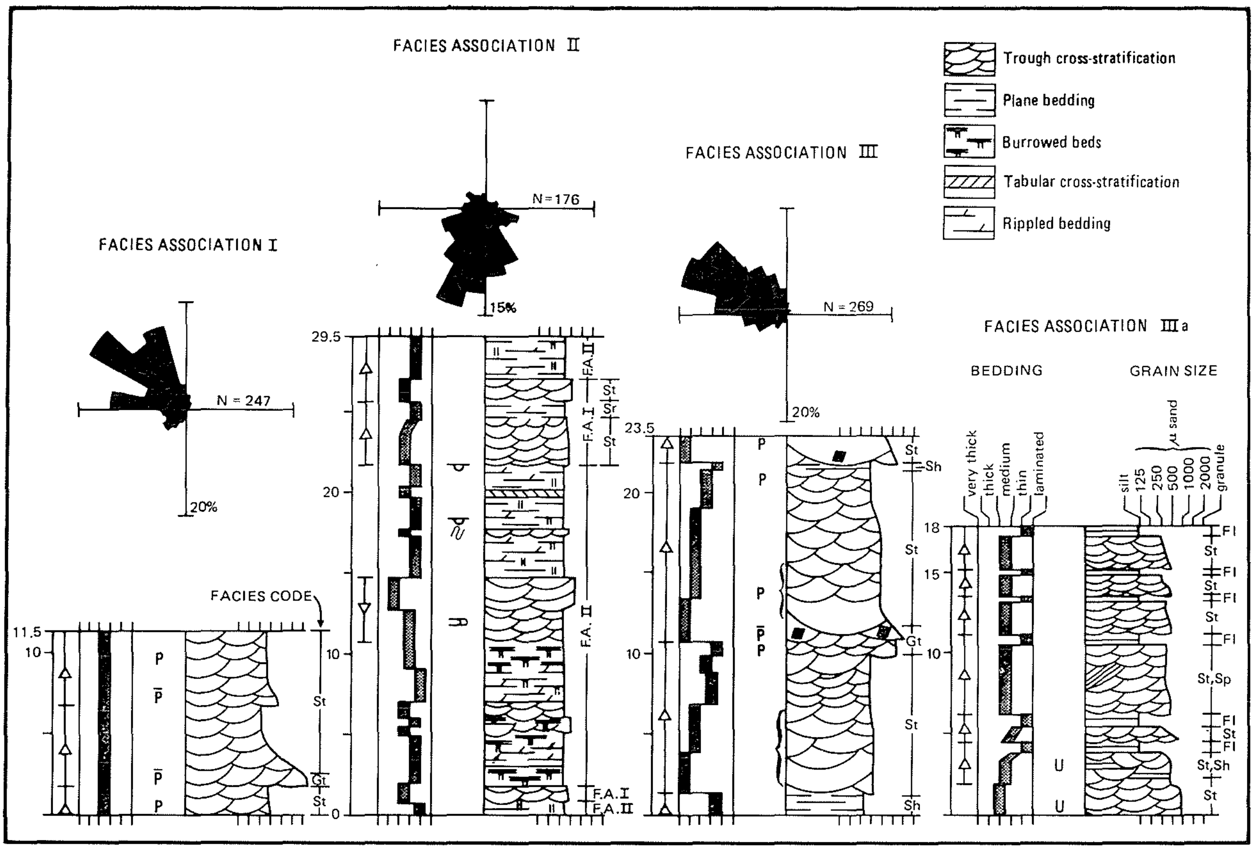
The following additions and modifications to the palaeogeography and geological history suggested by Hocking (1979) are now proposed. Three phases of deposition took place, and these are reflected in three facies associations. In the type section, deposition commenced in a fluviatile environment. A marine-dominated phase followed. The change was not abrupt, because sections show a gradual transition upwards and westwards from the fluviatile first phase. The westwards change from fluviatile to marine deposition (see Sections 3 to 7) suggests that in eastern areas, above the stratigraphic level which is now preserved in the type section, fluviatile deposition may have continued; and that in western areas, now below the level of outcrop, the fluviatile first phase may have graded laterally into marine deposition. The marine-dominated, second phase of deposition was followed by an upper, fluviatile-dominated phase, which shows signs of waning in the Second Gully area. This change from marine to fluviatile was relatively abrupt, indicating a sudden increase in energy levels.

Cyclicity in the section can be distinguished on two scales. Fining-upwards cycles in both the fluviatile phases are autocyclic (Miall, 1980), and formed by lateral shifting of sediment bars and lobes. No external influences, such as tectonic movement are necessary. However, two fining-upwards cycles

TABLE 1. LITHOFACIES, SEDIMENTARY STRUCTURES AND ENVIRONMENTAL INTERPRETATION OF BRAIDED STREAM DEPOSITS BY MIALL (1977)

Facies Code	Lithofacies	Sedimentary Structures	Interpretation
Gm	Gravel, massive or crudely bedded; minor sand, silt or clay lenses	Ripple marks; crossbeds in sand units; gravel imbrication	Longitudinal bars; channel-lag deposits
Gt*	Stratified gravel	Broad, shallow trough crossbeds; imbrication	Minor channel fills
Gp	Stratified gravel	Planar crossbeds	Linguoid bars or deltaic growths from older bar remnants
St*	Medium to very coarse sand, may be pebbly	Solitary (theta) or grouped (pi) trough crossbeds	Dunes (lower flow regime)
Sp*	Medium to very coarse sand, may be pebbly	Solitary (alpha) or grouped (omicron) planar crossbeds	Linguoid bars, sand waves (upper and lower flow regime)
Sr*	Very fine to coarse sand	Ripple marks of all types, including climbing ripples	Ripples (lower flow regime)
Sh*	Very fine to very coarse sand, may be pebbly	Horizontal lamination, parting or streaming lineation	Planar bed flow (lower and upper flow regime)
Ss	Fine to coarse sand, may be pebbly	Broad, shallow scours (including eta cross-stratification)	Minor channels or scour hollows
Fl*	Sand (very fine), silt, mud, interbedded	Ripple marks, undulatory bedding, bioturbation	Deposits of waning floods, overbank deposits

* Present in Tumblagooda Sandstone (see Figure 4).



GSWA 19188

Figure 4 Representative sections of each facies association. Palaeocurrents are total measured palaeocurrents for each facies association. For F.A.IIIa palaeocurrents, see Figure 2, Section 19. Location of sections: F.A.I.—Section 2; F.A.II—Section 4, Hawks Head; F.A.III—Section 17, Bracken Point; F.A.IIIa—Section 19, Second Gully. For explanation of symbols, see Figure 3.

of far greater magnitude can be discerned by pairing F.A. I and F.A. II, and also F.A. III and F.A. IIIa. The size of these two pairs indicates that they were controlled by external influences. The nature of these influences can be deduced from the sharp boundary between the marine depositional phase and the second fluviatile phase. Basinal downwarping would not produce this sharp change, but abrupt upwards movement on a basin-bounding fault (in this case, the Darling Fault) with the basin remaining relatively stable, would. The abrupt uplift was followed by infilling and gentle subsidence in the basin until another major fault movement would again bring in a return to fluviatile deposition.

LIMITATIONS OF THE TYPE SECTION

The type section of the Tumblagooda Sandstone offers a great deal of sedimentological detail, but there are several reasons why it is unrealistic to present only a single composite section as the type section:

(1) The length of the section along the gorge is more than 70 km, which is equivalent to approximately 50 km down the palaeoslope. This is a greater width than that of many coastal plains and continental shelves combined (Glaeser, 1978). This must be considered in any reconstruction of the Tumblagooda Sandstone because significant lateral changes should occur over this distance, especially in a coastal setting.

(2) Alternative correlations between sections (for example, taking the bases of fluviatile lenses rather than the top), can give a significantly different total thickness.

(3) Correlations across faults have been suggested here but it is quite possible that movement on the faults is greater than the depth of the gorge, and the correlation is thus fortuitous and invalid.

Therefore, the type section should be used as an indicator of trends in sedimentation, rather than a single sedimentary section.

REFERENCES CITED

Bryhni, I., 1976, Patterned cones and pits from the Hornelen district, Norway (Old Red Sandstone): Jour. Sedimentary Petrology, v. 46, p. 616–619.

Condon, M. A., 1965, The Geology of the Carnarvon Basin, Part 1: pre-Permian stratigraphy: Australia Bur. Mineral Resources Bull. 77.

Doe, T. W., and Dott, R. H., Jnr, 1980, Genetic significance of deformed cross bedding—with examples from the Navajo and Weber Sandstones of Utah: Jour. Sedimentary Petrology, v. 50, p. 793–812.

Elliot, T., 1978a, Clastic shorelines *in* Reading, H. G. (ed.), Sedimentary environments and facies: Blackwell, Sci. Pub., London.

——— 1978b, Deltas, *in* Reading, H. G. (ed.), Sedimentary environments and facies: Blackwell, Sci. Pub., London.

Friedman, G. R., and Sanders, J. E., 1974, Positive relief bedforms on modern tidal flats that resemble molds of flutes and grooves: implications for geopetal criteria and for origin and classification of bedforms: Jour. Sedimentary Petrology, v. 44, p. 181–189.

Friedman, G. R., and Sanders, J. E., 1978, Principles of Sedimentology: John Wiley & Sons, New York, 792 pp.

Glaeser, J. D., 1978, Global distribution of barrier islands in terms of tectonic setting: Jour. Geology, v. 86, p. 283–297.

Hocking, R. M., 1979, Sedimentology of the Tumblagooda Sandstone (Silurian) in the lower Murchison River area, Western Australia: a preliminary interpretation: West. Australia Geol. Survey Ann. Rept 1978, p. 40–44.

Johnstone, D., and Playford, P. E., 1955, Geology of the Shark Bay-Murchison area, Carnarvon Basin: West Australian Petroleum Pty Ltd Report (unpublished).

Levell, B. K., 1980, Evidence for currents associated with waves in Late Precambrian shelf deposits from Finmark, North Norway: Sedimentology, v. 27, p. 153–166.

Mandyczewsky, A., 1973, Stratigraphy and sedimentology of the Tumblagooda Sandstone, lower Murchison River, Western Australia: Univ. Western Australia Hons. Thesis (unpublished).

Miall, A. D., 1977, A review of the braided river depositional environment: Earth Science Reviews, v. 13, p. 1–62.

——— 1980, Cyclicity and the facies model concept in fluvial deposits: Bull. Canadian Petroleum Geology, v. 28, p. 59–80.

Moore, P. S., 1980, Deltaic sedimentation—Cambrian of South Australia: Jour. Sedimentary Petrology, v. 49, p. 1229–1244.

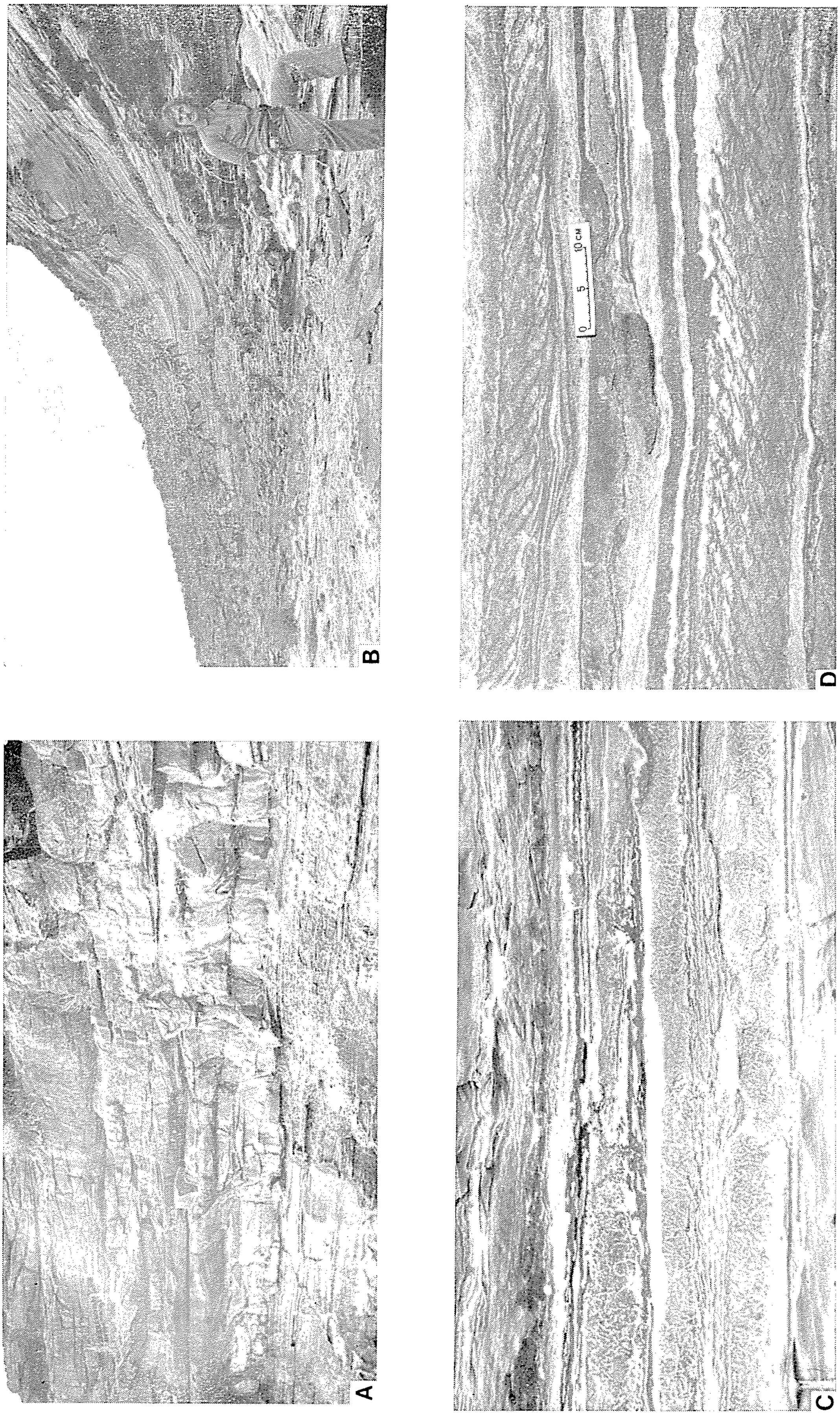


Figure 5 (a) Contact of medium-scale trough cross-stratified sandstone of Facies Association I with thin bedded Facies Association II (below). Hawks Head immediately below lookout.

(b) Typical thin-bedded F.A.II. The Loop.

(c) Intensely bioturbated beds, F.A.II. Lamination between burrowed intervals only poorly shown. The Loop.

(d) Climbing ripples with opposing current directions. F.A.II, base of The Loop.

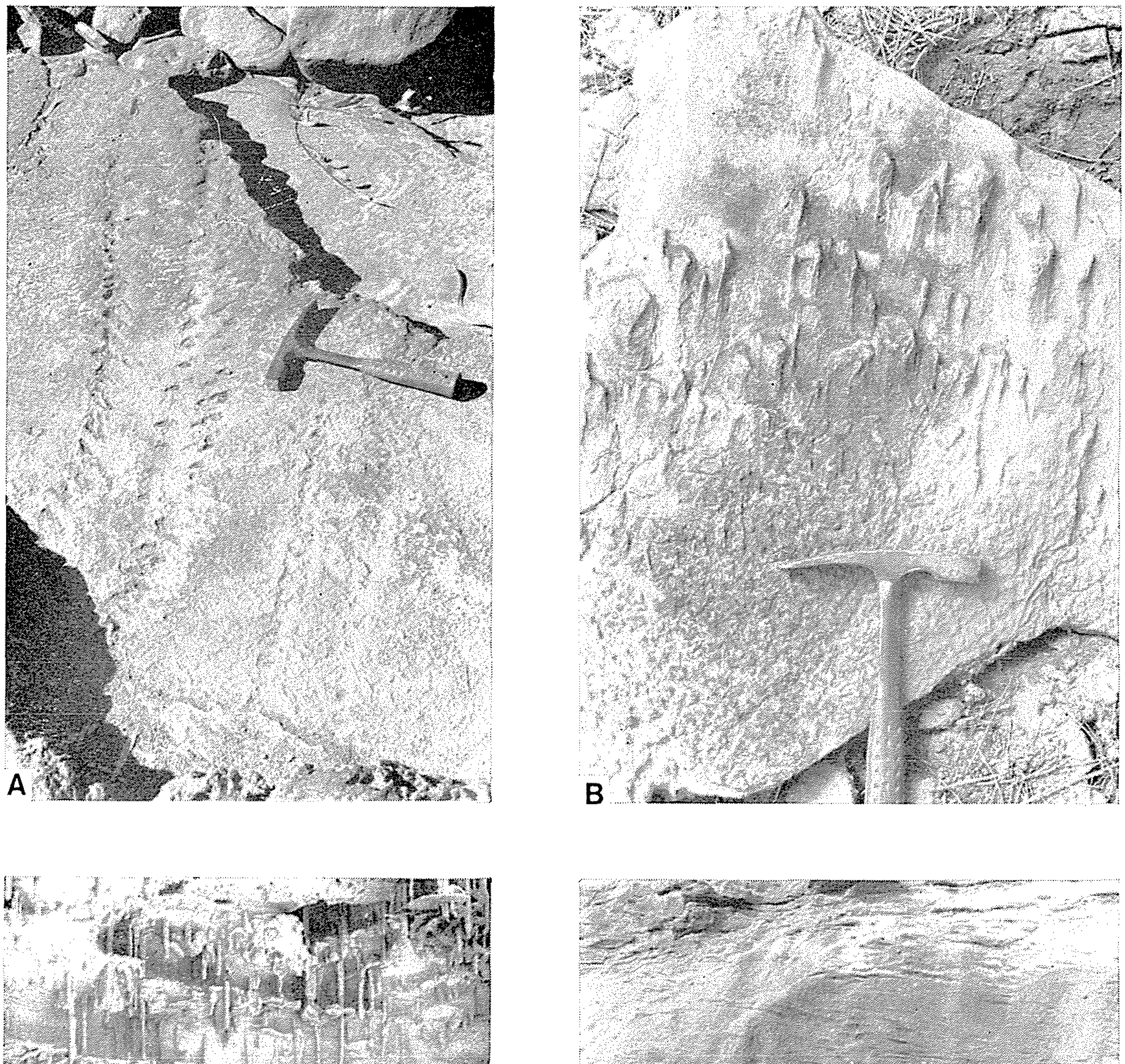


Figure 6 (a) Three sets of eurypterid tracks, one set showing imprint of legs from one side of body only. F.A.II, base of Section 8.
(b) Large setulfs in medium-grained F.A.II sandstone, grading into dimpled surface of uncertain origin (?foam markings). Current down page. The Loop.
(c) *Skolithos* in medium-grained sandstone, F.A.III, south of Kalbarri. Note length of tubes.
(d) Fining-upwards cycle in medium and coarse-grained sandstone with scattered pebbles, F.A.III, 5 km south of Bracken Point. Large-scale cross-stratification at base, overlain by medium-scale cross-stratification, with small scale cross-stratification at top. Top of cycle not shown. Grass on right hand side is 1 m high.

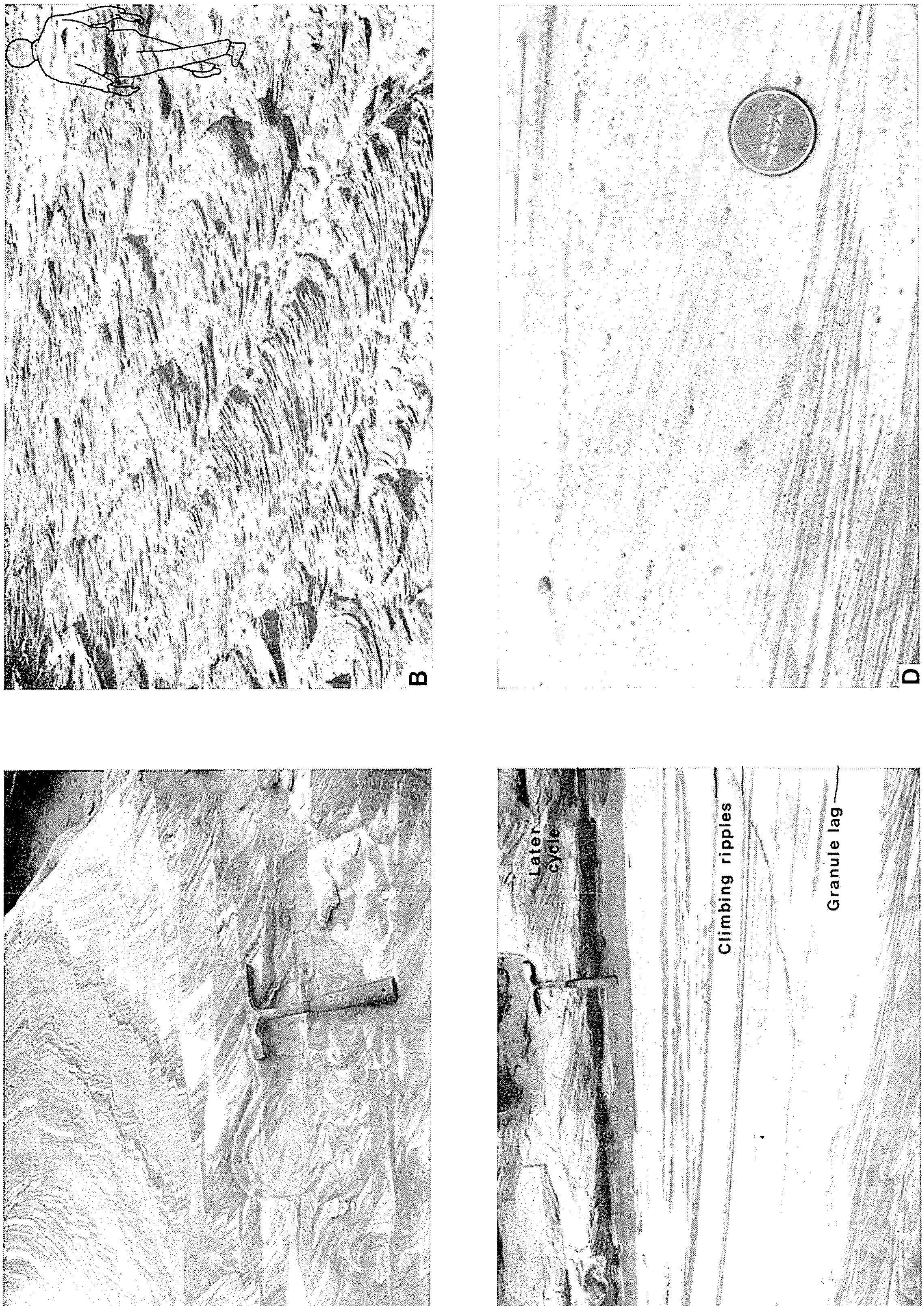


Figure 7 (a) Contorted bedding in 3 m-thick zone, showing recumbent fold with axial-plane faulting. The zone of contortion extends laterally for more than 200 m, in a cliff-face exposure. F.A.II, Section 9.
(b) Medium-scale trough cross-stratification in pebbly, coarse-grained sandstone. F.A.III, Red Bluff.
(c) Top of cycle, F.A.III, Section 11. Northwestwards directed trough cross-stratification at base, truncated by granule lag. Typical F.A.II bedding overlies this, with plane bedding, eastwards-climbing ripples and very low-angle cross-stratification. Geological hammer is balanced in coarse-grained sandstone of the next cycle.
(d) Detail of Figure 7c. Pebbly and granuley cross-stratified sandstone overlain by granule and small-pebble lag. Plane bedded sandstone overlying the lag is of marine origin.

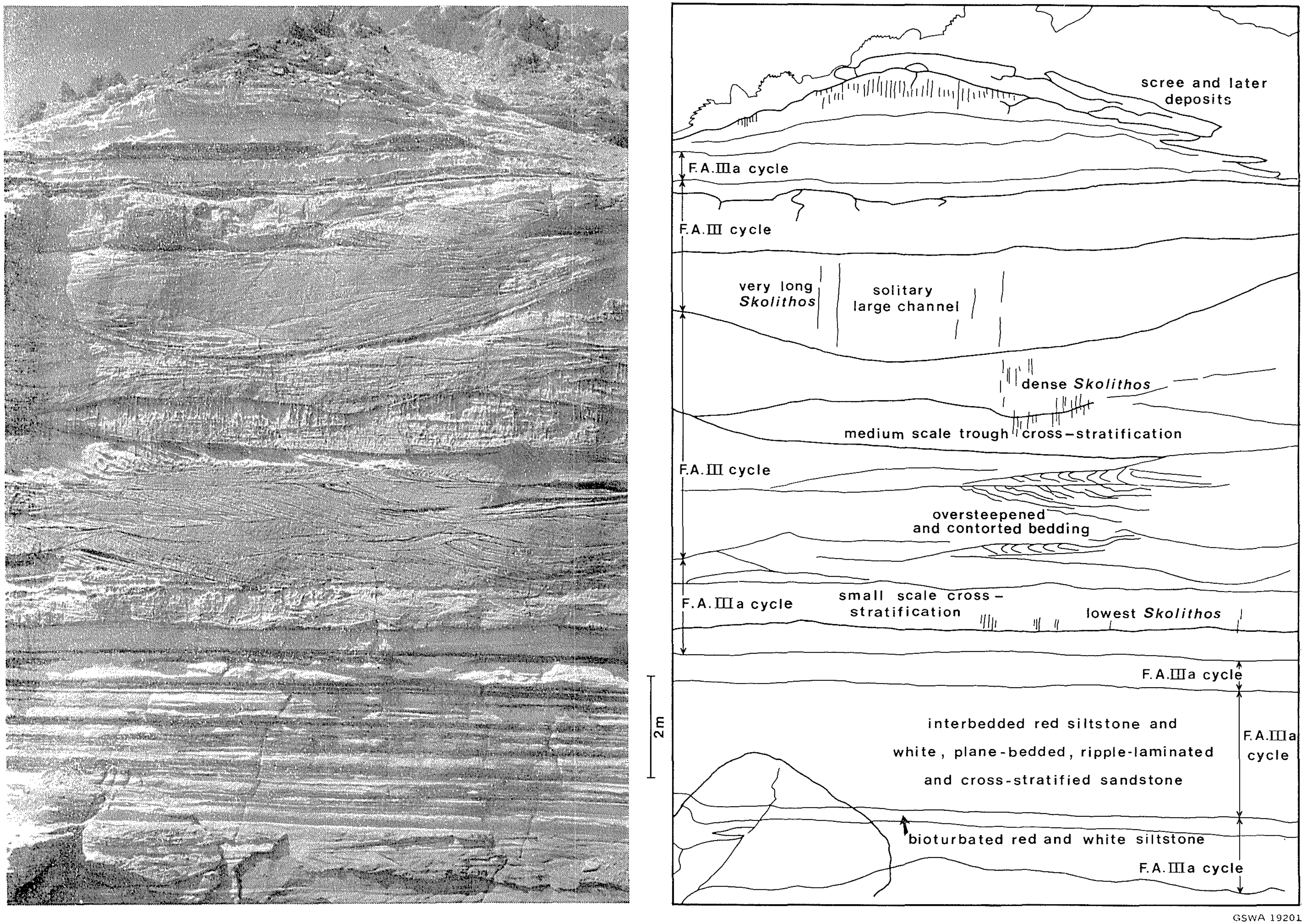


Figure 8 Face of Red Bluff showing F.A.III and F.A.IIIa cycles, oversteepening, *Skolithos*, cross-stratification, and solitary large channel.

AN ALLUVIAL FAN-FLUVIAL PLAIN DEPOSITIONAL MODEL FOR THE DEVONIAN WILLARADDIE FORMATION AND MUNABIA SANDSTONE OF THE CARNARVON BASIN, W.A.

by H. T. Moors

ABSTRACT

From their constituent rock types and field relationships, it is clear that the Munabia Sandstone and Willaraddie Formation are genetically related. Earlier workers regarded both formations as marine sediments, but current field work has shown that the bulk of the two formations are in fact terrestrial deposits.

Though the base of the Munabia Sandstone is clearly marine, and restricted marine incursions occur elsewhere in the section, the bulk of the sequence consists of fining-upwards cycles of sand, with erosional bases, completely devoid of trace or body fossils except for plant fragments. This sequence of beds with their internal organization suggests a fluvial origin. The Willaraddie Formation is typified by coarse sediments of low maturity and poor sedimentary organization, typical of a mid to distal alluvial fan deposit. An alluvial fan model suited to the Willaraddie Formation and a fluvial model suited to the Munabia Sandstone are described.

From palaeocurrent measurements in the formations and their field relationships a reconstruction of the basin of deposition as a wide, northerly-plunging graben with a faulted eastern margin of high relief can be postulated. The central portion of the graben was occupied by a braided fluvial system, while at the base of the fault scarp, alluvial fans accumulated and periodically prograded over the fluvial system. This reconstruction makes the Munabia Sandstone more extensive than previously thought, upgrading its importance as a potential petroleum reservoir.

INTRODUCTION

The Carnarvon Basin underwent a substantial change in shape in the Devonian with the world-wide rise of sea level (North, 1980). The initial deposit, the Nannyarra Sandstone, represents the reworking of the deep soil which had accumulated over a long period on the Precambrian craton. When this was exhausted clear water sedimentation commenced and the dominantly carbonate Gneudna Formation was deposited. This formation extends over a huge area, being recognized in bores from Carnarvon (Pelican Hill) northwards (Cape Cuvier 1) to near Exmouth Gulf (Pendock 1).

This phase of deposition was brought to an end by the reactivation of faults to the east of the present margin of the basin, again providing vast amounts of siliciclastic detritus from the continental block. These sediments have been subdivided into two formations: the dominantly clean sandstone of the Munabia Sandstone, and the Willaraddie Formation consisting of immature sandstone and conglomerate with minor clean sandstone. As the elevation of the source area was reduced, a period of non-deposition took place until a later sea-level rise in the Carboniferous started a new depositional cycle (Fig. 1).

The Devonian sediments outcrop in three meridional, westerly-dipping belts, the largest running from near Mount Sandiman homestead in the south to north of Williambury homestead, a distance of 95 km. The northern third is repeated by faulting west of the main belt and the southern third is preserved on a series of higher fault blocks east of the main belt (Fig. 1).

Probably because of the proximity of the obviously marine Gneudna Formation to the arenaceous formations, Condon (1965) assigned a marine depositional environment to the Munabia Sandstone and Willaraddie Formation. "The Munabia Sandstone was deposited in shallow sea water on a very slowly subsiding bottom; the terrigenous sediment was subjected to the action of waves and currents and a clean quartz sandstone was deposited in cross-laminated beds . . . the change of lithology into the Willaraddie Formation most probably indicates deeper water and a more rapidly subsiding floor." (Condon, 1965, p. 54). The purpose of this paper is to emphasize the depositional textural characteristics of the sediments, which enables a greater confidence in the interpretation of their depositional environment. Though marine sediments are present in the Munabia Sandstone, especially near the base, sedimentary textures indicate the bulk is of fluvial facies. For the Willaraddie Formation, textural criteria suggest an alluvial fan environment is most likely.

It is here suggested that the Munabia Sandstone and Willaraddie Formation are part of the one depositional event, the Willaraddie Formation is an alluvial fan and the Munabia Sandstone is the fluvially reworked distal equivalent.

ALLUVIAL FAN MODEL

Alluvial fans develop only adjacent to areas of high relief, commonly fault induced, where sediment is available in large quantities (Collinson, 1979). They have a radial symmetry in plan and can be subdivided into three main areas with distinctive morphology and sedimentary deposits, distributed in concentric zones. These are the proximal-fan, mid-fan and distal-fan zones (Fig. 2). The relative proportions of these zones varies from fan to fan, and are strongly influenced by climate and the state of vegetation of the landmass. In an arid climate the proximal and mid fan are strongly developed, whereas in a humid climate the proximal zone is insignificant but mid and distal zones are expanded (Collinson, 1979).

The proximal fan occurs near the point where the process of sediment transport becomes ineffectual and sediment is deposited. The flow is confined to deep channels by effective levees (Fig. 2). Proximal deposits are the coarsest in the fan and are typified by erosional bases and sedimentary features indicative of traction transportation processes (Collinson, 1979; Heward, 1978).

On the mid fan the levees are not as well developed so that channels anastomose and overbank deposits become important. Each channel is flanked by lobes of sediment separated by interlobe areas. The sediments of the depositional lobes contain both channel and overbank deposits ranging from debris flows to turbulent flows similar to channel deposits. The build-up of lobes also is an inducement for the abandonment of a channel and not only do channels migrate but they also tend to split into "tributaries". Overbank deposits usually are more abundant than channel sediments. The overall grain size in the mid fan is finer than in the proximal fan so that conglomerate becomes less significant and sand more important. The interlobe areas are sediment-starved and may accumulate fine-grained sediment of substantial lateral extent (Fig. 2). The proportion of lobe areas to interlobe areas varies largely from fan to fan (Collinson, 1979; Heward, 1978).

The distal fan is characterized by the presence of numerous channels which are free to migrate laterally. These sediments are therefore characterized by channel deposits of low sinuosity and may merge imperceptibly into adjacent fluvial deposits (Fig. 2), (Collinson, 1979; Heward, 1978).

FLUVIAL MODEL

Fluvial deposits are readily separated from the fan deposits on the criteria of grain size and maturity. Conglomerate is virtually absent, any that is present being of lag type. Sand shows greater maturity in content of labile grains, degree of sorting, and grain roundness (Figs 5a, b, c). Of the two major subdivisions of fluvial environments, a braided river environment appears to fit the Munabia Sandstone better than a meandering river environment. The lack of fine overbank deposits, the tendency for vertical rather than lateral accretion and the sedimentary structures present are better explained by braided stream deposition.

The principal factor controlling a braided stream is that the confining influences to the channel are low. Thus the channel has little permanency, which inhibits the development of large features such as point bars. Any overbank deposits which might have been deposited also have a low preservation potential because of large-scale lateral movement of the channels. A braided-river bed contains channels, which concentrate the flow of water, separated by a variety of bars and sand flats (Cant and Walker, 1978). For a greater part, erosion takes place in the channels, and aggradation on the bars and flats. Sand moves down the channels and across the bars as sand dunes, waves and ripples, and at times of falling flow may be left behind. Straight-crested dunes result in planar or cross-bedded strata, while those with curved crests produce trough cross-bedding. The falling flow regime also results in a vertical decrease in size of the structures and component sand grains of the deposited sediments (Cant and Walker, 1978; Coleman, 1969).

WILLARADDIE FORMATION

The Willaraddie Formation consists of three rock types in almost equal proportions; the dominant lithology is immature lithic wacke (Fig. 5A), pebbly sandstone is the next most abundant lithology (Fig. 5D), and more mature arenite (Fig. 5B) is the least common. Claystone is the only other lithology to have been deposited, but is usually only found as clasts in sandstone indicating its local presence.

The lithic wackes grade imperceptibly into the pebbly sandstones by an increase in grain size. Both lithologies are very immature texturally and mineralogically. The component grains are poorly size-sorted, and, except where larger grains have a better roundness, are angular in shape. Sphericity is also low, with length-width ratios of quartz grains up to 4:1 (Fig. 5A). The high content of heavy minerals scattered throughout the sand (Edwards, 1952) also indicates poor hydrological separation of grains. In the pebbly sandstones the clasts are always matrix-supported and rarely range up to 30 per cent of the rock in vertical section and 50 per cent in plan view. All the lithologies present as clasts in the conglomerate are present as grains in the wacke indicating a single continuum of supply.

Bedding features are poorly developed and beds are commonly massive. The conglomerate beds frequently show fining-upwards textures but occasionally coarsening-upwards textures are seen, though always only as a minor portion of the bed. Fining-upwards cycles continue from the pebbly sandstone into the sandstone (Fig. 5D), and can be detected when closely examined with a size comparator. Planar cross-bedding is found in both conglomerate and sandstone, but

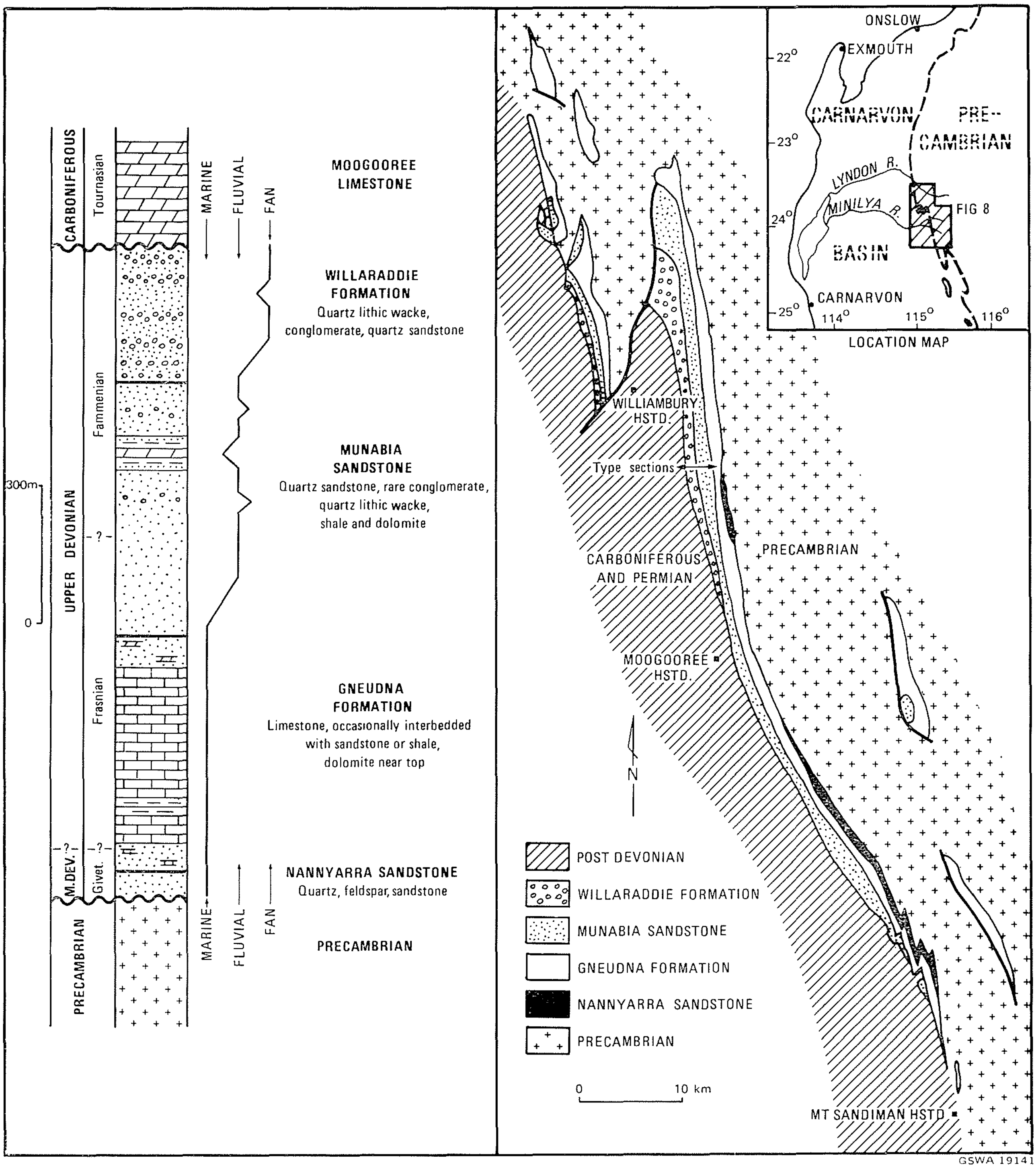


Figure 1 Distribution map of Devonian formations in the Carnarvon Basin, showing location of study area. A stratigraphic column shows the relative positions, age, environment, general lithology and thicknesses of the formations in their type section.

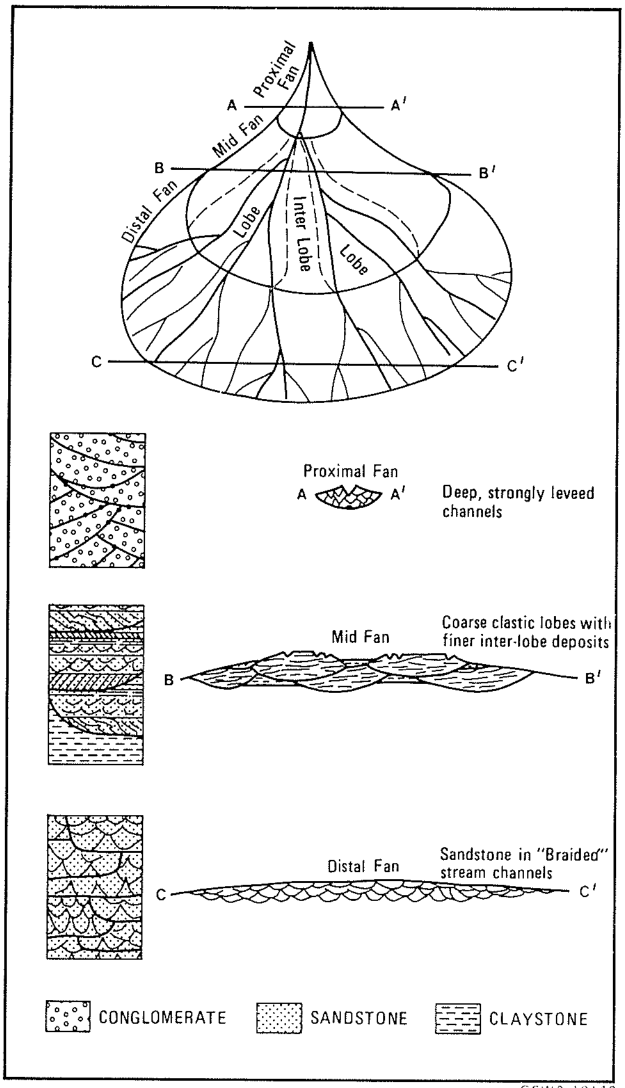


Figure 2 Alluvial fan model. Fan divisible into three zones—proximal, mid and distal. Sediments in proximal fan are the coarsest and were deposited chaotically in deep leveed channels. Mid fan is divided into: sediment lobes surrounding channels built up by overbank sheet-flood or debris flows; and interlobe areas where only fine overbank sediments are deposited in low swamps or lakes. In the distal fan anastomosing of streams has caused dissipation of energy to such a degree that only finest sediments are deposited in an almost fluvial environment. Cross-sections indicate relationships of depositional sequences. Columns represent typical cycles within sequences in respective parts of fan.

trough cross-bedding occurs in the sandstone only. Cross-bedding in the conglomerate beds may be outlined solely by flat clast orientation or strings of clasts, but it is usually obvious in the sandstone beds. Well-developed planar bedding is only present occasionally in the sandstone. No typical vertical sequence can be recognized and beds show a great variation in thickness. Conglomerate beds are usually less than 0·5 m in thickness, rarely passing 1 m, and sandstone beds are usually over 1 m but may also be thin units.

The presence of matrix-supported pebbly sandstones eliminates both traction and suspension as methods of transport of the sediments, and suggests some form of debris-flow mechanism. Though the bases of most coarse beds are sharp, erosion is minimal and the absence of any coarser lag deposit also suggests a temporary sheet flood rather than prolonged channel occupation. Such conditions occur in the mid-fan region of an alluvial fan, where most aggradation occurs, as lobes surrounding channels. True conglomerates are rapidly deposited, while progressively more clast-poor sediments and sands showing upper flow regime structures are indicative of more distal situations (Collinson, 1979). The Willaraddie Formation appears to be in such a distal mid-fan position, where debris flows begin to turn into sheet flood deposits of a more aqueous nature.

The cleaner sandstone, which forms the remainder of the formation, has different characteristics from those already described. It shows much better maturity, reflected in a reduction of labile components, better size sorting and rounding of grains, and shows clearer evidence of transportation by traction currents (Fig. 5B). Bedding is more prominent and becomes organized in a similar way to braided-stream deposits. Grain size decreases upwards and the amplitude of trough cross-bedding becomes smaller upwards, giving way to planar beds. The base may be erosional, though only mildly, but lag deposits of autochthonous clay clasts suggest some permanency of occupation of the channel. These cleaner sandstones represent either channel deposits on the mid fan, or distal fan deposits associated with a decrease in activity of the alluvial fan.

MUNABIA SANDSTONE

This formation is almost entirely sandstone; claystone and conglomerate occur only in minor amounts, and carbonate (dolomite) only occurs as a number of metre-thick beds at specific horizons. The sands themselves are divisible into two classes, those of marine origin and those of fluvial origin. The marine sand is thinly bedded and bedding is generally planar, though small scale planar cross-bedding (often in herringbone sets) occurs, and flaser to linsen fabric is also present. Apart from scarce conodonts, body fossils are absent, but trace fossils (living, resting and feeding traces) can commonly be found. Evidence of emergence in the form of impressions of desiccation flakes of claystone in sandstone also exists. In the field the marine sand is easily distinguished by its brown colour, terrestrial sand being a red colour.

On the other hand, the terrestrial sand contains no body or trace fossils except for rare plant impressions, is much more thickly bedded, and is usually clearly organized into vertical sequences of changing structures and decreasing size of structures and component grains. Typical cycles are illustrated in Figure 3. Usually the base is gently erosive, indicative of channel deposition, but this may only be obvious if there is a substantial grain size contrast across the contact. The initial bed may be a completely massive sand unit a few decimetres thick representing an unstructured lag deposit, but more commonly the lowermost unit is a single, planar to slightly curved cross-bedded set from 0·5 m to 2 m thick. This is interpreted as the result of the down-stream migration of a channel bar. Commonly the cross-bedding shows pronounced

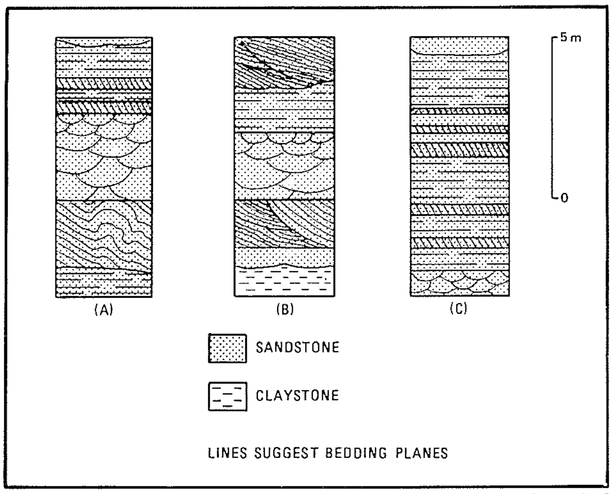


Figure 3 Typical cycles in the Munabia Sandstone, showing different structures present, their variation in size and relationship to each other, and variation in thickness.

(A) initial, thick, planar cross-bedding showing slumping, overlain by trough cross-bedding decreasing in size upwards, overlain by planar and small-scale planar bedding.

(B) coarse massive bed overlain by trough cross-bedding which may be either single or multiple, overlain by, upwardly-decreasing trough cross-bedding and thin planar bedding.

(C) alternations of thin planar bedding and small-scale planar cross-bedding.

distortion: gravity-sliding down the cross-beds resulting in crumpled, isoclinally folded and even overthrust laminae. Coleman (1969) suggested this could be due to increased shear stress accompanying a sudden increase in turbulence across the bar, or by the emergence of the depositing surface and increased hydrological head (see also Bluck, 1980). Rarely, the single cross-bed set may be subdivided into two or more smaller sets. Overlying this zone of planar cross-bedding is a zone of trough cross-bedding 1 m to 3 m in thickness formed when lunate mega-ripples are left behind by the falling water stage (Coleman, 1969). The fall in water-level stage is indicated by a decrease in the size of the sets and a decrease in constituent grain size vertically. The final component of the cycle is dominantly flat-bedded fine sand with occasional decimetre-high cross-bedded units which formed as lower flow regime units on emerging channel bars (Fig. 3C). The cross-bedding is produced by the migration of small-scale straight crested dunes. Rippling appears to be entirely absent.

These cycles range in thickness from 2 m to over 10 m. The internal zones also show a large range in the thickness and in the proportions of each. This is a function of the variation in size of bars in the river and also of the exact part of the bar exposed in outcrop.

Occasionally, the cycles are completed by a bed of silty claystone which may reach over a metre in thickness. The general absence of claystone is probably more a matter of preservation, as clasts of this lithology are frequently found as lag deposits or scattered on cross-bed laminations in some beds. The clay was deposited in temporarily abandoned channels from where it was rapidly eroded during re-occupation.

Zones 10 m to 20 m thick of dirty sand and pebbly sandstone occur occasionally in the formation. In the upper part of the type section a marine incursion is documented by the presence of a thick unit of greenish shale with a number of thin, yellow dolomite beds.

RELATIONSHIP OF WILLARADDIE FORMATION AND MUNABIA SANDSTONE

In all field occurrences, the Willaraddie Formation overlies the Munabia Sandstone. The contact is gradual with lithologies common to both sides, showing that the two formations are intimately related. However, from a study of the depositional environments, it seems plausible that they are coeval facies of the one depositional cycle, and that the overlying relationship is merely a reflection of the eventual progradation of the Willaraddie Formation into this part of the basin. Within the Munabia Sandstone type section, fine conglomerate beds with sheet-flood characteristics occur in association with quartz wacke (not mentioned in text by Condon, 1965, but indicated on his measured section, Fig. 22), and these represent earlier progradations of the edge of the Willaraddie alluvial fan into this area. These incursions were probably due to tectonic activity rejuvenating the provenance of the Willaraddie complex.

Figure 4 shows the three-dimensional relationship of the two formations in a block diagram. A segment has been removed for clarity, the corner of which represents approximately the type sections of the formations. A major fault with variation in throw bounds the basin and creates an upland to the east which provides large amounts of coarse detritus for the basin. Where each fluvial system emerged from the upthrown block an alluvial fan was built up and gradually prograded onto the fluvial plain. Because of the greater throw on the fault plane in the north, the more northerly fans may have prograded directly into the sea, as suggested by the presence of some poorly preserved marine fossils in the Willaraddie Formation (Condon, 1965). Where the fans were close together they may have interfered with each other or overlapped. The main fluvial plain contains a braided river system building up a widespread ribbon of sandstone parallel to the basin margin. When the build-up became too high, the whole river system moved laterally to commence building a new pile of sediment. Periodically, either because of a eustatic rise of sea level or activation

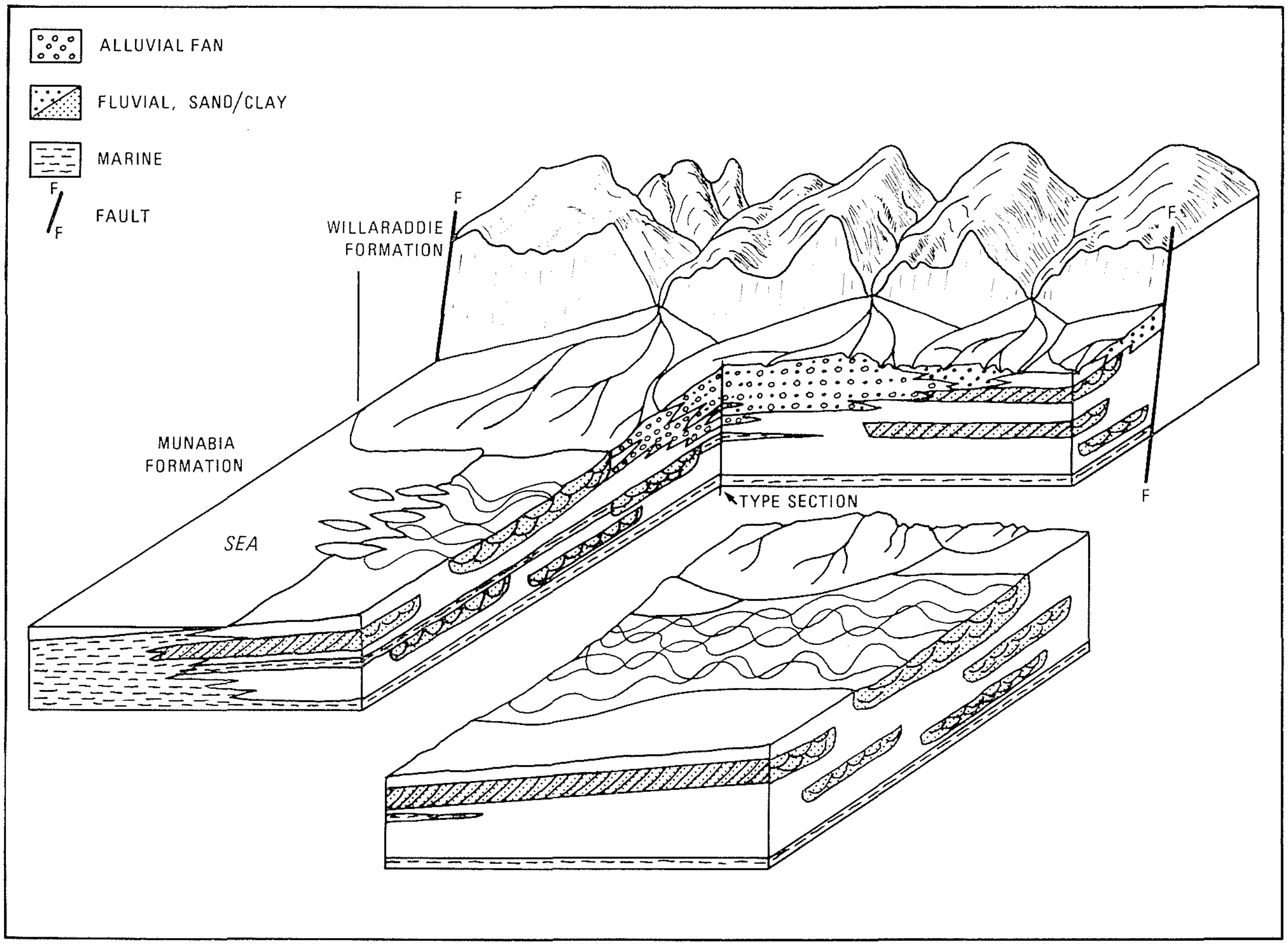


Figure 4 Three dimensional diagram of environment of deposition, and relationship of Munabia Sandstone and Willaraddie Formation. Bounding-fault creates elevated hinterland providing large amounts of sediment. Alluvial fans accumulate at the base of the fault (Willaraddie Formation) and prograde over fluvial plain. On the fluvial plain a braided river channel moves backwards and forwards depositing Munabia Sandstone. Either because of eustatic or tectonic sea-level rise, the shoreline encroaches periodically onto the fluvial plain or fan.

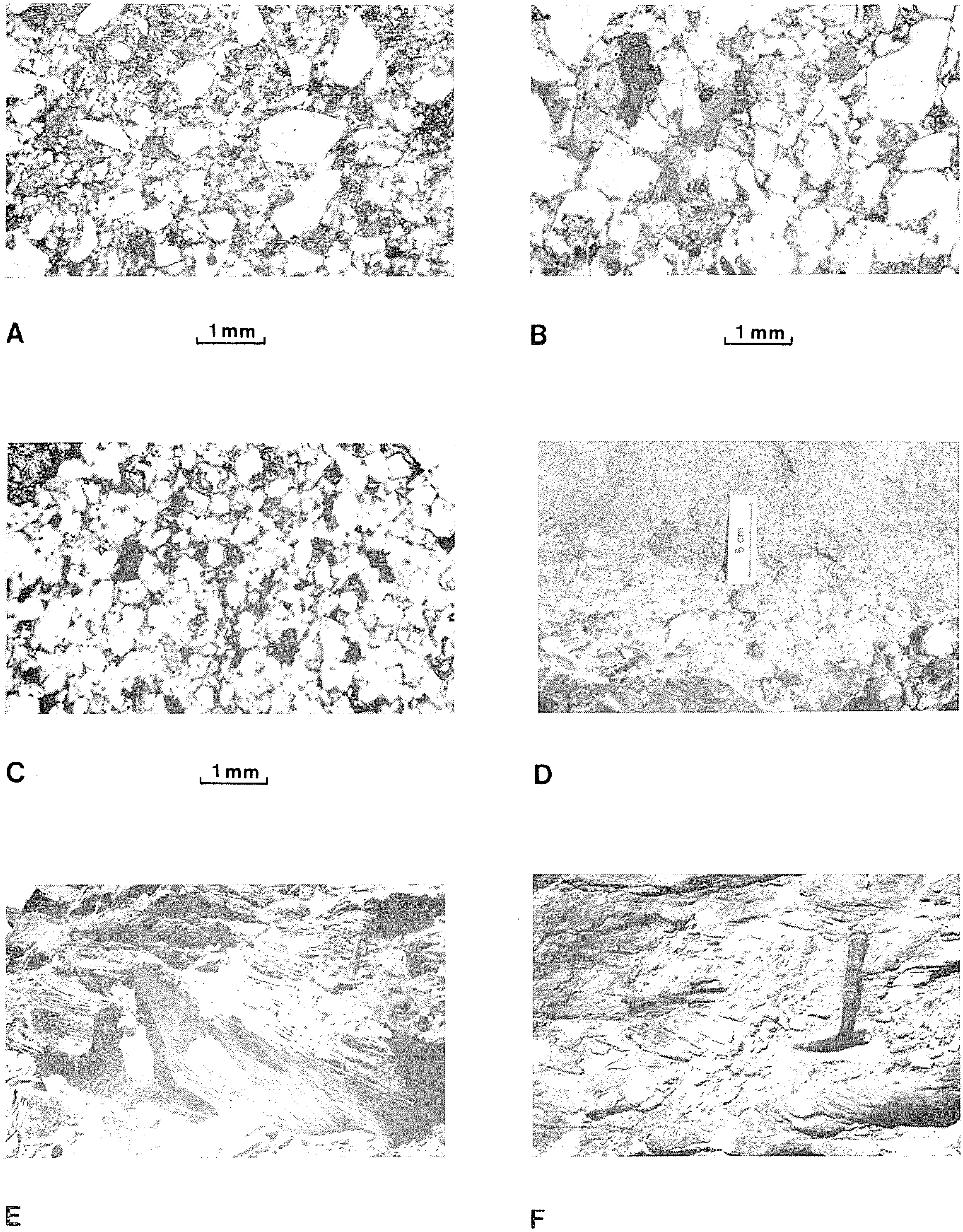


Figure 5 (A) Typical alluvial fan sand showing poor rounding, poor sorting and a high proportion and variation of lithic grains (Willaraddie Formation).

(B) Distal fan sediment showing improved rounding and sorting but great abundance of lithics (Munabia Sandstone).

(C) Typical fluvial sandstone showing relatively good sorting and rounding but still high lithic content, large scale cross-bedding (Munabia Sandstone).

(D) Unusually clast-rich and well-organised pebbly sandstone (Willaraddie Formation). Size of 'grains' decreases upwards with a sympathetic increase in matrix.

(E) Basal unit of fluvial cycle (Munabia Sandstone). Large scale cross-bedding shows strong gravity sliding. Note single cross-bed set replaced by two smaller sets to left.

(F) Thin, planar bedding and small scale cross-bedding typical of upper part of cycle (Munabia Sandstone).

of the bounding fault, the sea transgressed onto the land and carbonates and reworked sands were deposited. In this scheme sediments associated with the alluvial fans would be ascribed to the Willaraddie Formation, and those associated with the fluvial plain to the Munabia Sandstone.

The only part of the Willaraddie Formation which outcrops, represents a distal portion of the alluvial fan. Mid-fan and proximal-fan deposits with different characteristics would have been deposited originally but have since been removed by erosion. The Munabia Sandstone fluvial plain sediments are entirely sandy, either no overbank deposits accumulated or they were removed by erosion during re-establishment of the new river bed. The only shale and carbonate found in the unit are associated with marine conditions at the base of the formation, or related to a period of marine transgression in the upper part.

A large number of palaeocurrent directions were measured from cross-bedding in the Munabia Sandstone. Though varying in detail from location to location, all distributions showed a dominant current flow to the north-northwest. Because of the bad outcrop and poorly developed bedding, palaeocurrent data were less abundant in the Willaraddie Formation. Nevertheless, data from the type section confirmed the tectonic model, with transportation coming from the highland and along the fluvial plain in a north-northwest direction.

CONCLUSIONS

Towards the end of the Frasnian (Upper Devonian) the Carnarvon Basin underwent a phase of tectonism and the eastern margin became strongly faulted. A braided fluvial system flowing northwards became established on the downthrown plain. At the same time the elevation of the Precambrian rocks created a prolific source of coarse material, and alluvial fans were built out from the base of the fault scarp on to the plain. From the field evidence, conglomeratic sediments associated with the fans have been included in the Willaraddie Formation, while the fluvial sands are placed in the Munabia Sandstone.

The effect of climate and rudimentary vegetation cover on the sediments requires more detailed examination. The probable poor stabilization of the soil by vegetation would have encouraged braided rather than meandering river morphology (Miall, 1980), but braiding could also have been in response to steep slopes or a large variation in river flow which was climatically controlled (Collinson, 1979). The present day red and white colouration of the sediments could be due to oxidation during the Holocene deep weathering profile or to the originally oxidizing conditions of deposition.

Condon (1965) downgraded the potential of the Munabia Sandstone as a reservoir by believing that the formation was a marine deposit fringing the basin. This thin ribbon of sand would have had little continuity down dip (westwards), changing rapidly to basinal clay. In this new interpretation, though the western boundary is still unknown, the Munabia Sandstone is expected to have substantial westerly extent, with no rapid deterioration of reservoir quality, and thus could be an important exploration target.

REFERENCES

Bluck, B. J., 1980, Structure, generation and preservation of upward fining, braided stream cycles in the Old Red Sandstone of Scotland: Trans. Roy. Soc. Edinburgh: Earth Sci. v. 71, p. 29–46.

Cant, D. J. and Walker, R. G., 1978, Fluvial processes and facies sequences in the sandy braided South Saskatchewan River, Canada: Sedimentology v. 25(5), p. 625–648.

Coleman, J. M., 1969, Brahmaputra River: channel processes and sedimentation: Sedimentary Geology v. 3, p. 129–239.

Collinson, J. D., 1979, Alluvial sediments, *in* Reading, H. G. (ed.), Sedimentary environments and facies: Blackwell, London, p. 15–60.

Condon, M. A., 1965, The geology of the Carnarvon Basin, Western Australia, Part I, pre-Permian stratigraphy: Australia Bur. Mineral Resources Bull. 77.

Edwards, A. B., 1952, Sandstones from the North West Basin: Mineragraphic Investigations No. 498: Australia Sci. and Industrial Research Organization, Melb.

Heward, A. P., 1978, Alluvial fan and lacustrine sediments from the Stephanian A and B (La Magdalena, Cinera-Matallana and Sabero) coalfields, northern Spain: Sedimentology v. 25, p. 451–488.

Miall, A. D., 1980, Cyclicity and the facies model concept in fluvial deposits: Canadian Petroleum Geol. Bull. v. 28(1), p. 59–80.

North, F. K., 1980, Episodes of source-sediment deposition, 2 The episodes in individual close-up: Jour. Petroleum Geol. v. 2(3), p. 323–338.

ESTIMATED PRESSURE AND TEMPERATURE CONDITIONS FROM SOME WESTERN AUSTRALIAN PRECAMBRIAN METAMORPHIC TERRAINS

by D. F. Blight and M. E. Barley

ABSTRACT

The pelitic mineral assemblage, garnet + cordierite + sillimanite + quartz, can be used to estimate pressure and temperature conditions during metamorphism. Comparison of preliminary results from Archaean and Proterozoic medium- to high-grade metamorphic terrains in Western Australia suggests that this assemblage equilibrated at similar temperatures, but consistently lower pressure in the Archaean terrains.

INTRODUCTION

Only broad generalizations about metamorphic conditions can be obtained from most studies of regional metamorphism in Precambrian terrains. However, recent experimental determinations of the stability fields and compositions of co-existing minerals (see review by Green, 1977) provide the potential for estimating the actual pressures and temperatures at which co-existing minerals equilibrated during metamorphism. In this study we have used thermo-chemical considerations and experimental data for the mineral assemblage, garnet + cordierite + sillimanite + quartz, to estimate pressure and temperature conditions for Precambrian metamorphic terrains in Western Australia. This assemblage occurs in pelitic gneisses in both the Archaean Yilgarn Block and the surrounding Proterozoic mobile belts, and is placed in the upper amphibolite to lower granulite facies (Binns, 1964; Winkler, 1975).

THEORY

The assemblage, garnet + cordierite + sillimanite + quartz, results from the reaction

3(Fe-Mg) cordierite = 2(Mg-Fe) garnet + 4 sillimanite + 5 quartz.

At equilibrium this may be considered as an exchange reaction thus:

(Fe) garnet + (Mg) cordierite = (Mg) garnet + (Fe) cordierite.

The distribution coefficient, Kd, can be calculated from the following equation:

$$Kd = \left(\frac{X^{cord}_{Mg}}{1-X^{cord}_{Mg}}\right)\left(\frac{X^{gnt}_{Fe}}{1-X^{gnt}_{Fe}}\right)$$

where X^{b}_{a} is the mole fraction of component 'a' in phase 'b'

For the above reaction Kd will be dependent upon the pressure and temperature of equilibrium. Using known thermo-chemical data and laboratory experiments it is possible to calibrate this reaction and use it to estimate the pressure and temperature at which natural assemblages equilibrated. Calibrations have been published by Currie (1971), Hensen and

Green (1973), Hutcheon and others (1974) and Wells (1979). The calibrations of Hensen and Green, and Hutcheon and others are considered unsuitable and have been rejected, chiefly because when applied to natural assemblages they give results which fall outside the stability field of sillimanite, an integral component of the equilibrium reaction. For a more detailed discussion see Blight and Oliver (in press).

SAMPLES ANALYSED

Figure 1 is a simplified geological map of part of Gondwana which now comprises southwestern Australia and part of Antarctica. The locations of analysed samples are plotted on this map showing their geological environment. Precise locations and petrographic details of the samples are presented in the Appendix. All samples are pelitic gneisses.

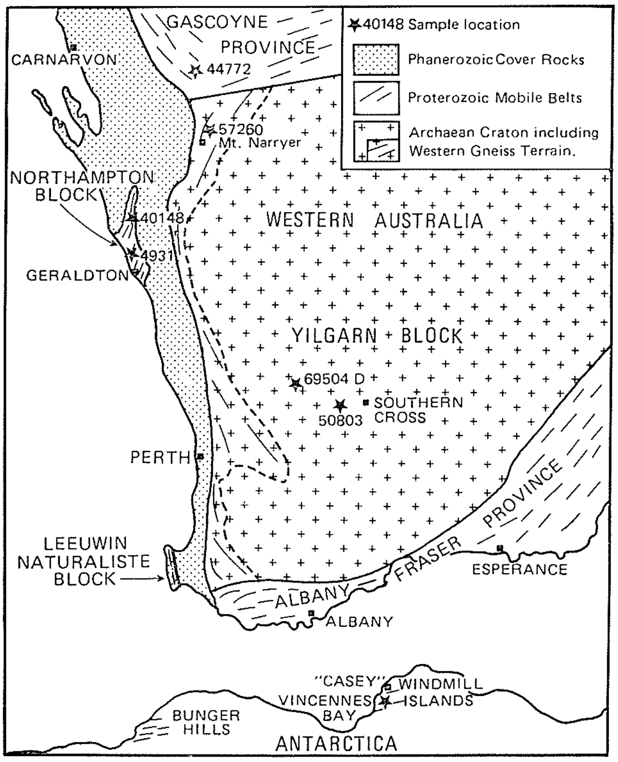


Figure 1 Sample locations shown on a simplified geological map of southwestern Australia and part of Antarctica using the "pre-drift" reconstruction of Norton and Molnar (1977).

Samples 4931, 40148 and 44772 are from Proterozoic mobile belts which surround the Yilgarn Block. Samples 4931 and 40148 are from sequences of pelitic gneisses with intercalated quartzites and mafic granulites within the Northampton Block. Compston and Arriens (1968) considered that these rocks were metamorphosed approximately 1 000 m.y. ago. Sample 44772 is from a sequence of pelitic and quartzofeldspathic gneisses in the Gascoyne Province. It is considered that this sequence is part of the Archaean Western Gneiss Terrain, which has experienced high-grade metamorphism during a major early Proterozoic tectonothermal event (S. J. Williams, pers. comm.). Data obtained from pelitic gneisses from the Windmill Islands, Antarctica (Blight and Oliver, in press) have been included in this study for comparison with the Western Australian data. According to the most favoured pre-drift continental reconstruction, it is considered that the Proterozoic metamorphic terrain in the Windmill Islands is an extension of the Albany-Fraser Province mobile belt (Fig. 1). This view was supported by Oliver (1971) who noted the geological similarity of the Windmill Islands and the Albany-Fraser Province. Thus the pressure-temperature estimates from the Windmill Islands (Table 2) contribute to the circum-Yilgarn data.

Samples 50803, 57260 and 69504D are from the Archaean Yilgarn Block. Sample 57260 is from a sequence of pelitic and quartzofeldspathic gneisses in the Western Gneiss Terrain of Gee and others (in press), near Mount Narryer. Whole-rock Rb-Sr isotopic data indicate that this sequence was metamorphosed approximately 3 350 m.y. ago (de Laeter and others, 1981). Samples 50803 and 69504D are from sequences of medium- to high-grade metamorphosed sedimentary and igneous rocks in small greenstone belts in the granitoid-greenstone terrain, adjacent to its boundary with the Western Gneiss Terrain. It is considered that these samples were metamorphosed during the major tectonothermal event which affected the Southern Cross Province 2 600–2 700 m.y. ago (Chapman and others, in press).

RESULTS

The compositions of the coexisting cordierite and garnet were determined using a MAC electron microprobe. Compositions were determined a number of times using both crystal spectrometers and an energy-dispersive multichannel analyser. Garnets were checked for zoning either by scans across the grains (Fig. 2) or by spot analyses of both the cores and rims of single grains. No zoning was found. Analytical results are listed in Table 1. Elemental concentrations given are mean values of a number of determinations. Analyses of four cordierite-garnet pairs from sample 69504D indicate that the range in estimated pressure and temperature values is ± 10 MPa and ± 15°C for either calibration.

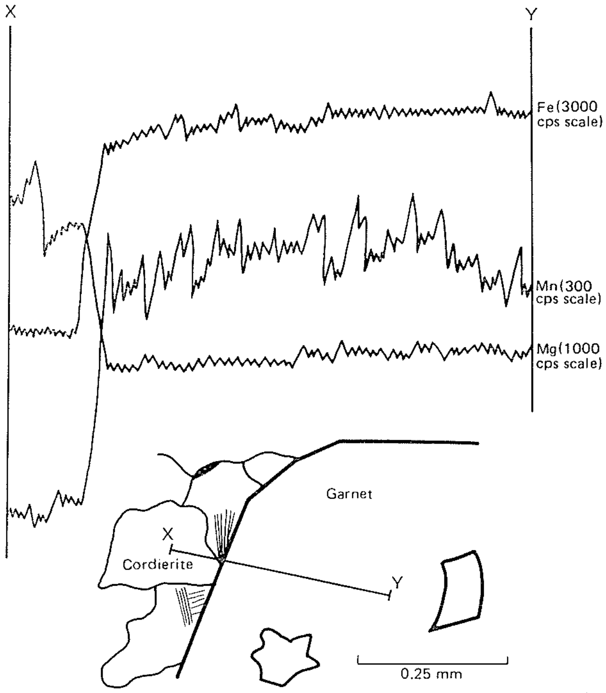


Figure 2 Graphical readout of counts per second of Fe, Mn and Mg wavelength spectrometers, during a traverse from a cordierite grain across an abutting garnet grain in sample 50803, as shown in the accompanying sketch.

When applying the calibrations of Currie (1971) and Wells (1979) to natural assemblages the following conditions should be satisfied:

(1) attainment of equilibrium, at least with regard to partitioning between iron and magnesium;

(2) reasonable freedom of the cordierite and garnet from cations which would complete with Fe^{2+} and Mg for lattice positions; and

(3) besides garnet and cordierite the investigated assemblages must also contain sillimanite and quartz.

Only rocks satisfying condition (3) were chosen for this study. Condition (1) is more difficult to determine. The absence of disequilibrium textures (with the possible exception of 44772) and the lack of zoning within the garnets suggest that equilibrium has been reached.

The only major cation in these minerals which would compete with Fe^{2+} and Mg for site occupancy is Mn. The effect of Mn has not been studied in any great detail; however, Weisbrod (1973) has shown that the presence of 25 mole per cent spessartite in garnet could reduce the equilibrium pressure by about 100 MPa. As most of these samples contain less than 5 mole per cent spessartite the influence of Mn on their equilibrium position is probably minimal. Samples 57260 and 69504D contain slightly more Mn, approximately 10 and 15 mole per cent spessartite respectively, so that Mn may have some influence on their equilibrium position. This influence is unlikely to be very large, perhaps in the order of 50 MPa.

TABLE 1. ANALYSES OF CO-EXISTING GARNET AND CORDIERITE ASSEMBLAGES FROM ARCHAEAN AND PROTEROZOIC METAMORPHIC TERRAINS IN WESTERN AUSTRALIA, AND CALCULATED PRESSURE AND TEMPERATURE ESTIMATES.

Sample	4931		40148		44772		50803		57260		69504D	
Mineral	gnt	cord	gnt	cord	gnt	cord	gnt	cord	gnt	cord	gnt	cord
SiO_2	36·05	48·35	37·02	49·45	36·73	49·36	36·48	47·74	35·55	47·77	36·65	48·72
Al_2O_3	21·47	33·85	21·70	34·15	21·39	34·30	21·35	32·59	21·05	33·56	20·28	32·65
FeO	36·05	9·68	33·16	6·70	34·04	6·10	38·40	14·15	37·85	11·68	36·56	12·51
MnO	0·85	....	0·84	....	1·11	....	1·25	0·16	2·05	0·10	3·11	0·30
MgO	4·49	8·01	6·32	9·65	5·69	10·24	1·75	4·75	2·66	6·69	1·94	5·78
CaO	0·96	....	0·93	....	0·96	....	0·60	0·02	0·60	....	1·33	....
Total	99·86	99·89	99·93	99·95	99·92	100·00	99·83	99·42	99·76	99·80	99·87	99·96
Kd*	6·813		7·552		10·047		7·400		8·203		8·747	
P–T estimates: A. Using method of Currie (1971)												
P (MPa)	570		630		650		460		510		480	
T (°C)	741		765		838		760		785		800	
P–T estimates: B. Using method of Wells (1979)												
P (MPa)	630		700		660		520		550		530	
T(°C)	677		603		562		657		622		607	

* Kd: distribution coefficient

Results of the application of the calibrations of Currie (1971) and Wells (1979) are given in Table 1 and displayed on Figure 3. Data from the Windmill Islands, Antarctica are given in Table 2 and also shown on Figure 3.

DISCUSSION

As can be seen from Figure 3 the estimates of pressure obtained using the calibration of Wells (1979) are approximately the same as those obtained using the calibration of Currie (1971). However, temperatures obtained from the Wells calibration are significantly lower than those obtained from the Currie calibration. This results from the fact that different relationships between the distribution co-efficient (Kd) of Fe^{2+} and Mg between cordierite and garnet, and temperature have been reported for the various sets of experimental data on which these calibrations are based. Other mineralogical data (discussed below) do not indicate clearly which is the more realistic calibration. However, while further experimental work is required to establish the correct relationship between Kd and temperature, it is significant that there are only minor differences in the range of pressure-temperature gradients indicated (Fig. 3).

With the exception of sample 44772, the Proterozoic samples we have studied form a cluster of points on Figure 3, indicating pressures of 560–650 MPa and temperatures between 740 and 800°C (using the calibration of Currie, 1971) or 600–700 MPa and 600–680°C (using the calibration of Wells, 1979). The absence of muscovite and the occurrence of anatectic phenomena in felsic gneisses in the Northampton Block (Playford and others, 1970, p. 11 and 12), restrict pressure and temperature

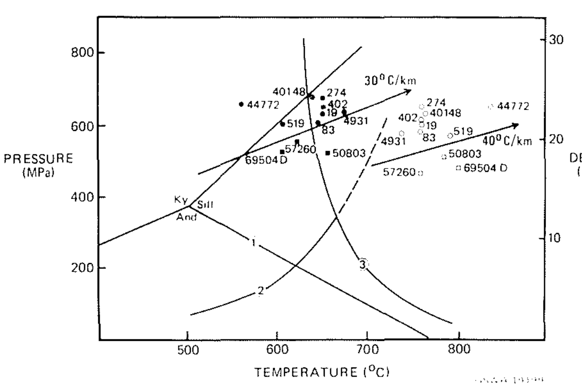


Figure 3 Plot of calculated pressure-temperature conditions of Archaean (squares) and Proterozioc (circles) garnet-cordierite pairs using the calibrations of Currie (1971; open symbols) and Wells (1979; closed symbols).

(1) Al_2SiO_5 stability fields (Holdaway, 1971)

(2) Muscovite breakdown curve (Evans, 1965; Kerrick, 1972)

(3) Melting curve of water-saturated granite (Luth and others, 1964)

conditions for these gneisses to the field above the water-saturated granite-melting curve (Fig. 3), if water pressure was equal to lithostatic pressure during metamorphism. Under these conditions melting in felsic gneisses would be well advanced at temperatures approximately 150°C above the water-saturated granite-melting curve. However, if water pressure was less than lithostatic pressure during metamorphism (i.e. if metamorphism involved a mixed vapour phase or was vapour free) then the stability field of muscovite would be extended as shown on Figure 3 (Kerrick, 1972), and the beginning of melting would occur at higher temperatures than those indicated by the calibration of Wells (1979). The existence of a CO_2-rich vapour phase during granulite facies metamorphism has been suggested by several authors (e.g., Hoefs and Touret, 1975; Collerson and Fryer, 1978).

Sample 44772 plots well into the kyanite stability field using the calibration of Wells (1979), suggesting that either the calibration is incorrect or one of the assumptions regarding the suitability of this sample was incorrect. It is possible that the biotite and sillimanite intergrowths surrounding many cordierites in this sample are the result of the partial breakdown of cordierite to biotite and sillimanite with decreasing temperature after peak metamorphic conditions had been reached or during a period of retrogression. If this is the case, then garnet (which is particularly unreactive under these conditions) would no longer be in equilibrium with the cordierite, rendering meaningless the estimated metamorphic conditions (using either calibration).

The cluster of Proterozoic points on Figure 3 suggests that the pressure and temperature conditions indicated are typical of Proterozoic high-grade regional metamorphism in the mobile belts which surround the Yilgarn Block. The estimated pressure-temperature conditions (using either calibration) fall within the range of pressure-temperature conditions reported for similar Proterozoic terrains by Watson (1978). Also, the geothermal gradients indicated fall within the range of modern regionally maintained crustal geotherms, which range from less than 10°C/km for continental cratons to about 50°C/km in island arcs and other active plate margins (Watson, 1978).

The three Archaean samples studied indicate pressure of 460–510 MPa and temperatures of 760–780°C (using the calibration of Currie, 1971) or 520–550 MPa and 600–660°C (using the calibration of Wells, 1979). The abundance of amphibole and other hydrous minerals in lithologies associated with these samples suggests that the assumption that water pressure was equal to lithostatic pressure during metamorphism is geologically reasonable in this case. Consequently, the presence of muscovite in sample 69504D and the absence of anatectic phenomena in associated felsic gneisses favour the pressure and temperature range indicated by the calibration of Wells (1979). The values obtained are comparable with estimates of 300–500 MPa and 600–680°C obtained by Binns and Groves (1976) for mid to high amphibolite facies metamorphism at Perseverance.

It is considered that the Western Gneiss Terrain represents an older (3350 m.y.) metamorphosed and repeatedly deformed continental sedimentary sequence, which surrounds and underlies the granitoid-greenstone terrain (Gee and others, in press; de Laeter and others, 1981). This basement was partly remobilized during the major tectonothermal event (2 600–2 700

TABLE 2. CALCULATED PRESSURE AND TEMPERATURE ESTIMATES FOR CO-EXISTING GARNET-CORDIERITE ASSEMBLAGES FROM THE WINDMILL ISLANDS PROTEROZOIC METAMORPHIC TERRAIN

[See Blight and Oliver (in press) for details]

Sample	335/19	335/83	335/274	335/402	335/519
Kd*	7·354	7·445	7·453	7·389	8·476
P–T estimates: A. Using method of Currie (1971)					
P(MPa)	610	580	650	610	570
T(°C)	760	762	762	760	794
P–T estimates: B. Using method of Wells (1979)					
P(MPa)	635	600	675	650	600
T(°C)	653	650	650	652	610

* Kd: distribution coefficient

m.y.) which was responsible for the essentially solid-state emplacement of a suite of pre- and syntectonic granitoids and the regional deformation and metamorphism of greenstone sequences. The greenstone sequences were deposited immediately prior to, and during, this episode. Tectonic activity culminated with the widespread emplacement of a suite of magmatic post-tectonic granitoids.

Samples from both the Western Gneiss Terrain and the granitoid-greenstone terrain indicate similar pressure and temperature conditions, suggesting that they are typical of Archaean regional metamorphism at this grade in the Yilgarn Block. The geothermal gradients indicated (from 30°C/km to 45°C/km, depending on calibration used) are higher than equilibrium continental geothermal gradients estimated for the Archaean by Bickle (1978), namely 1·2 to 1·5 heat flow units (equivalent to 25–30°C/km), and within the range of geothermal gradients reported for other granitoid-greenstone and gneiss terrains (Watson, 1978). The widespread occurrence of andalusite in greenstone belts within the Yilgarn Block (Binns and others, 1976) indicates that low-pressure metamorphism (i.e. with geothermal gradients of greater than about 40°C/km) was typical in low- to medium-grade metamorphic terrains. Extrapolation of this trend to the medium- to high-grade terrains reported in this study indicates that the regional metamorphic geotherm observed in the granitoid-greenstone terrain is convex towards the temperature axis of Figure 3, if the calibration of Wells (1979) is used.

The Yilgarn Block is considered to have been relatively stable since Archaean times (Gee and others, in press). Its present crustal thickness ranges from 32 km at Kalgoorlie to about 46 km at the western edge (Gee and others, in press). Our pressure-temperature estimates of those rocks from the Yilgarn Block indicate that they formed at depths around 17 km (Fig. 3). This presumably has since been eroded away, but when added to the present crustal thickness implies that the crust of the Yilgarn Block during Archaean times was in the range of 50–60 km thick. Any evolutionary model for the Yilgarn Block would need to take this considerable thickness into account.

Both calibrations produce two distinct fields of equilibrium conditions. The samples from Archaean terrains indicate similar temperatures, but consistently lower pressures than the samples from Proterozoic terrains. An apparently obvious conclusion that can be drawn from these data is that the Archaean geothermal gradients were greater than those in the Proterozoic terrains. However, this is very much an oversimplification.

Because heat generation from the decay of radioactive nuclides in the earth was much greater in the Archaean, much discussion has revolved around the probability that Archaean geothermal gradients were steeper than those of later times. However, in a comprehensive discussion of Precambrian thermal regimes, Watson (1978) has outlined some of the difficulties encountered in establishing this premise. Evaluation of former thermal regimes depends not only on the estimation of geothermal gradients from individual localities, but also on the correct assessment of the proportion of the crust for which they are representative. Within the framework of modern plate tectonic processes a number of different thermal regimes exist. For example, tectonic environments such as mid ocean ridges and island arcs have higher heat flows and thus higher geothermal gradients than stable continental or oceanic crust. While it is usually possible to distinguish crustal environments for which differing geothermal gradients can be inferred in Phanerozoic and Proterozoic terrains, the recognition of Archaean tectonic environments is much less certain.

Another problem encountered is that metamorphic mineral assemblages do not always reflect equilbrium geothermal conditions. This problem has been reviewed by England and Richardson (1977) who concluded that estimates of geothermal gradients from areas characterized by igneous activity will be biased towards values higher than the equilibrium gradients. Consequently, the mineral assemblages of rocks exposed at the surface in a terrain where crustal thickening and subsequent metamorphism and deformation has been the result of the addition of hot magma, will indicate a metamorphic geotherm convex towards the temperature axis on a pressure-temperature diagram. Estimates of geothermal gradients from terrains which have undergone overthrusting and subsequent burial metamorphism can either be higher or lower than the equilibrium gradient, depending on the depth of burial and rate of uplift. Precambrian amphibolite and granulite facies mineral assemblages presumably equilibrated at sufficient depths such that heating during uplift is unlikely to have elevated the thermal gradient significantly above the equilibrium value.

Nevertheless, despite these uncertainties, some general observations are possible. There is a growing opinion that plate-tectonic processes such as those which have operated from Phanerozoic times onward did not operate during Archaean times (Kroner, 1979; Gorman and others, 1978; and Binns and others, 1976). Furthermore, the Yilgarn Block lacks blueschist metamorphics (Binns and Marston, 1976), and calc-alkaline volcanism is random in distribution rather than conforming to an island arc pattern (Giles, in press). It is also becoming apparent that the Yilgarn Block greenstones formed on sialic crust (Gee and others, in press), thus precluding a mid-ocean-ridge environment.

As the Archaean metamorphosed greenstone belts formed during a major tectonothermal event they reflect a zone of higher heat flow than normal continental crust of that time. The thermal regime represented by the Western Gneiss Terrain is more difficult to evaluate; however, most likely, it represents an Archaean mobile zone and, as such, would also represent a higher heat flow than stable continental crust of similar times. The Proterozoic samples we have examined all come from mobile belts and thus reflect zones of higher heat flow than stable Proterozoic continental area.

Thus, all the samples we have examined are manifestations of zones of higher heat flow than time-equivalent stable continental areas. More difficult to evaluate is the relative flux strength of these higher heat-flow zones. Because the Archaean greenstone rocks formed under a comparable pressure-temperature regime to these rocks of the Western Gneiss Terrain, which in turn are considered to have formed under similar tectonic conditions to the Proterozoic samples (namely, mobile zones) all the rocks examined by us should have relatively the same pressure-temperature conditions of formation. These data indicate this is not the case, and, thus, we conclude that the apparent difference in heat flow, as reflected in geothermal gradients, from the earth in Archaean times compared with that in Proterozoic times, is real.

CONCLUSIONS

Preliminary estimates of pressure-temperature conditions during metamorphism suggest that Archaean pelitic gneisses from the Yilgarn Block equilibrated at similar temperatures, but at lower pressures than Proterozoic pelitic gneisses in the surrounding mobile belts.

We believe this distinction is real and reflects fundamental differences in the thermal regimes of Archaean and Proterozoic metamorphic terrains. There is clearly a need for further studies of this and other suitable mineral assemblages to establish more precisely the variations in pressure and temperature conditions which occurred during the evolution of Precambrian metamorphic terrains in Western Australia.

APPENDIX

4931 Location: Northampton Block. Lat. 28°26′10″S, long. 114°44′27″E.

Geological setting: Proterozoic mobile belt; dominantly pelitic gneisses with intercalated quartzites and mafic granulites. Age of metamorphism approximately 1 000 m.y. (Compston and Arriens, 1968).

Description: A pelitic gneiss with a granoblastic polygonal to interlobate texture, with grain size ranging from 0·1 mm to 4 mm. The mineral assemblage is quartz, cordierite, microcline (perthitic), plagioclase, garnet, sillimanite and biotite, with minor fine-grained opaques. Myrmekite is locally developed where plagioclase and microcline are in contact. A weak parallelism of sillimanite prisms and biotite plates defines a gneissic foliation.

40148 Location: Northampton Block. Lat. 27°50′04″S, long. 114°44′16″E.

Geological setting: As for sample 4931.

Description: A pelitic gneiss with a seriate, granoblastic elongate texture, with grain size ranging from 0·1 mm to 3 mm and some large porphyroblasts of garnet up to 6 mm in size. The mineral assemblage is quartz, cordierite, microcline (perthitic), plagioclase, garnet, sillimanite and biotite, with minor fine-grained opaques. Large garnet porphyroblasts are commonly poikiloblastic. The granoblastic elongate texture and strong parallelism of sillimanite prisms and biotite plates define a gneissic foliation.

44772 Location: Gascoyne Province. Lat. 25°21′40″S, long. 116°11′20″E.

Geological setting: Proterozoic mobile belt; sequence of pelitic and quartzofeldspathic gneisses. Age of metamorphism early Proterozoic (S. J. Williams, pers. comm.).

Description: A pelitic gneiss with a granoblastic elongate texture, with grain size ranging from 0·1 mm to 2 mm. The mineral assemblage is quartz, cordierite, plagioclase, garnet, sillimanite and biotite, with minor microcline and fine-grained opaques. Cordierite is commonly rimmed by fine intergrowths of biotite and sillimanite. The granoblastic elongate tecture and strong parallalism of sillimanite prisms and biotite plates define a gneissic foliation.

50803 Location: Yilgarn Block. Lat. 31°17′30″S, long. 118°38′30″E.

Geological setting: Archaean granitoid-greenstone terrain; sequence of pelitic gneisses, mafic and ultramafic emphibolites and granulites within a small greenstone belt. Age of metamorphism is 2 600–2 700 m.y. (Chapman and others, in press).

Description: A pelitic gneiss with a seriate granoblastic interlobate texture, with grain size ranging from 0·02 mm to 2 mm and with some large porphyroblasts of garnet up to 5 mm in size. The mineral assemblage is quartz, cordierite, plagioclase, garnet, fibrolitic sillimanite, and biotite, with some minor fine-grained opaques. Sillimanite occurs in clusters with a strong preferred orientation and, with biotite plates, defines a gneissic fabric.

57260 Location: Yilgarn Block. Lat. 26°31′30″S, long. 116°23′00″E.

Geological setting: Archaean gneiss terrain; sequence of pelitic and quartzofeldspathic gneisses. Age of metamorphism approximately 3 350 m.y. (de Laeter and others, 1981).

Description: A pelitic gneiss with a granoblastic polygonal to interlobate texture with grain size ranging from 0·05 mm to 2 mm. The mineral assemblage is quartz, cordierite, plagiclase, garnet, sillimanite and biotite, with minor fine-grained opaques. Parallelism of sillimanite prisms and biotite plates defines a gneissic foliation.

69504D Location: Yilgarn Block. Lat. 30°54′50″S, long. 117°49′10″E.

Geological setting: Archaean granitic-greenstone terrain; sequence of pelitic gneisses and para-amphibolites within a small greenstone belt. Age of metamorphism 2 600–2 700 m.y. (Chapman and others, in press).

Description: A fine-grained pelitic gneiss with a granoblastic elongate texture (average grain size, 0·25 mm). The mineral assemblage is quartz, cordierite, plagioclase, garnet, sillimanite and biotite, with minor muscovite and fine opaques. Larger garnet and cordierite grains are commonly poikiloblastic. The granoblastic elongate texture and strong parallelism of sillimanite prisms and biotite plates define a gneissic foliation.

ACKNOWLEDGEMENTS

Assistance with the microprobe analyses by J. Graham, R. Vigers and B. Robinson of the CSIRO, Floreat Park, Western Australia, is gratefully acknowledged.

REFERENCES

Bickle, M. J., 1978, Heat loss from the earth: a constraint on Archaean tectonics from the relation between geothermal gradients and the rate of plate production: Earth and Planetary Sci Letters, v. 40, p. 301–315.

Binns, R. A., 1964, Zones of progressive metamorphism in the Willyama Complex, Broken Hill District, New South Wales: Geol. Soc. Australia Jour., v. 11, p. 283–330.

Binns, R. A., and Groves, D. I., 1976, Iron-nickel partition in metamorphosed olivine-sulfide assemblages from Perseverance, Western Australia: American Mineralogist, v. 61, p. 782–787.

Binns, R. A., Gunthorpe, R. J., and Groves, D. I., 1976, Metamorphic patterns and development of greenstone belts in the eastern Yilgarn Block, Western Australia: *in* Windley, B. F. (ed.), The early history of the Earth: London, Wiley, p. 303–313.

Binns, R. A., and Marston, R. J., 1976, Archaean geology of the Yilgarn Block, Western Australia: 25th I.G.C. Excursion Guide No. 40A.

Blight, D. F., and Oliver, R. L., in press, Aspects of the geological history of the Windmill Islands, Antarctica: *in* Craddock, C. (ed.), Antarctic Geoscience: University of Wisconsin Press.

Chapman, H. J., de Laeter, J. R., Gorton, M. P., Anderson, L. S., Bettenay, L. F., Bickle, M. J., Binns, R. A., and Groves, D. I., in press, Isotopic study of granitic rocks from the Central Yilgarn Block, Western Australia: Geol. Soc. Australia, Special Pub. 7.

Collerson, K. D., and Fryer, B. J., 1978, The role of fluids in the formation and subsequent development of early continental crust: Contr. Miner. Petrol. v. 67, p. 151–167.

Compston, W., and Arriens, P. A., 1968, Precambrian geochronology of Australia: Canadian Jour. Earth Sci., v. 5, p. 561–583.

Currie, K. L., 1971, The reaction 3 cordierite = 2 garnet + 4 sillimanite + 5 quartz as a geological thermometer in the Opincon Lake Region, Ontario: Contr. Miner. Petrol., v. 33, p. 215–226.

de Laeter, J. R., Williams, I. R., Rosman, K. J. R., and Libby, W. G., 1981, A definitive 3 350 m.y. age from banded gneiss, Mount Narryer area, Western Gneiss Terrain: West. Australia Geol. Survey Ann. Rept 1980, p. 94–98.

England, P. C., and Richardson, S. W., 1977, The influence of erosion upon the mineral facies of rocks from different tectonic environments: Geol. Soc. London Jour., v. 134, p. 201–213.

Evans, B. W., 1965, Application of a reaction rate method to the breakdown equilibria of muscovite and muscovite plus quartz: American Jour. Sci., v. 263, p. 647–667.

Gee, R. D., Williams, I. R., Wilde, S. A., and Baxter, J. L., in press, Crustal evolution of the Yilgarn Block: Geol. Soc. Australia, Special Pub. 7.

Giles, C., in press, Archaean calc-alkaline volcanism in the Eastern Goldfields Province of Western Australia: Geol. Soc. Australia, Special Pub. 7.

Gorman, B. E., Pearce, T. H., and Birkett, T. C., 1978, On the structure of Archaean Greenstone Belts: Precambrian Research, v. 6, p. 23–41.

Green, D. H., 1977, Experimental petrology related to extreme metamorphism: Tectonophysics, v. 43, p. 1–5.

Hensen, B. J., and Green, D. H., 1973, Experimental study of cordierite and garnet in pelitic compositions at high pressures and temperature: III. Synthesis of experimental data and geological applications: Contr. Miner. Petrol. v. 38, p. 151–166.

Hoefs, J., and Touret, J., 1975, Fluid inclusions and carbon isotope study from Bamble granulites (south Norway): Contr. Miner, Petrol., v. 52, p. 165–174.

Holdaway, M. J., 1971, Stability of andulasite and the aluminium silicate phase diagram: American Jour. Sci., v. 271, p. 97–131.

Hutcheon, I., Froese, E., and Gordon, T. M., 1974, The assemblage quartz-sillimanite-garnet-cordierite as an indicator of metamorphic conditions in the Daly Bay Complex, NWT: Contr. Miner. Petrol., v. 44, p. 29–34.

Kerrick, D. M., 1972, Experimental determination of muscovite and quartz stability with $P_{H_2O} < P_{TOTAL}$: American Jour. Sci., v. 272, p. 946–958.

Kroner, A., 1979, Precambrian crustal evolution in the light of plate tectonics and the undation theory: Geologie en Mijnbouw, v. 58, p. 231–240.

Luth, W. C., Jahns, R. H., and Tuttle, O. F., 1964, The granite system at pressures of 4 to 7 kilobars: Jour. Geophysical Research, v. 69, p. 759–773.

Norton, I., and Molnar, P., 1977, Implications of a revised fit between Australia and Antarctica for the evolution of the eastern Indian Ocean: Nature, v. 267, p. 338–340.

Oliver, R. L., 1971, Some aspects of Antarctic-Australian geological relationships, *in* Adie, R. J. (ed.), Antarctic Geology and Geophysics: Oslo, Universitetsforlaget, p. 859–864.

Playford, P. E., Horwitz, R. C., Peers, R., and Baxter, J. L., 1970, Geraldton, Western Australia: West. Australia Geol. Survey 1:250 000 Series Explan. Notes.

Watson, J. V., 1978, Precambrian thermal regimes: Royal Soc. London Phil. Trans. A, v. 288, p. 431–440.

Weisbrod, A., 1973, Cordierite-garnet equilibrium in the system Fe-Mn-Al-Si-O-H: Carnegie Institute of Washington Year book, v. 72, p. 515–518.

Wells, P. R. A., 1979, Chemical and thermal evolution o Archaean sialic crust, Southern West Greenland: Jour Petrol., v. 20, p. 187–226.

Winkler, H. G. F., 1975, Petrogenesis of metamorphic rocks (4th ed.): Berlin, Springer-Verlag, 334 pp.

THE LOGUE BROOK GRANITE: AGE AND SIGNIFICANCE OF DEFORMATION ZONES ALONG THE DARLING SCARP

by D. F. Blight, W. Compston* and S. A. Wilde

ABSTRACT

A number of porphyritic granite bodies along the Darling Scarp show fabrics indicative of progressively increasing deformation westward toward the present Darling Fault. We describe petrographic changes, within the Logue Brook Granite near Harvey, that show how the progressive sequence from granite through augen and layered gneiss to mylonite developed by flattening and mineral ductility contrasts. New isotopic data are interpreted to show that the Logue Brook Granite formed around 2 575 m.y. ago and was deformed during or soon after emplacement. The name "proto-Darling Fault" is proposed for this Precambrian shear zone that was to act as the locus for the later Darling Fault.

INTRODUCTION

The southwestern Yilgarn Block consists of a number of Archaean metamorphic belts invaded by granitic rocks (Wilde, 1980). Zircons from gneisses in the Jimperding Metamorphic Belt at Toodyay give maximum ages of around 3 340 m.y.† (Nieuwland and Compston, in press) whereas the granites have an age of about 2 660 m.y. (Arriens, 1971). The granitic rocks vary in texture, but are chiefly adamellite in composition.

There are, however, a number of distinct porphyritic granite (*sensu stricto*) intrusions close to the Darling Fault, between Mogumber in the north and Wellington Dam in the south (Fig. 1). They exhibit a characteristic style of deformation, being overprinted by gneissic and mylonitic fabrics that become more intense to the west. Mylonitization is not confined to these granites (Fig. 1), but its progressive development is best observed within them.

The porphyritic granite extending south from Mogumber almost to the Swan-Avon River reveals increasing cataclastic deformation west toward the Chittering Metamorphic Belt (Wilde and Low, 1978a). Fold axes can be traced from the metamorphic belt into the granite, and layers of augen gneiss—probably representing deformed granite—are infolded with the metasedimentary rocks.

East of Pinjarra, a body of porphyritic granite is progressively converted to augen gneiss containing mylonite zones (Wilde and Low, 1976). The exact relationship with layered gneisses occurring further west on the Darling Scarp is unclear: some of the rocks are undoubted paragneisses, but many appear to be orthogneiss derived from the granite.

This style of increasing deformation is best exposed along the western margin of the Logue Brook Granite in the vicinity of Harvey (Figs. 1 and 2). The Logue Brook Granite occupies approximately 900 km^2 of the Darling Range from east of Waroona to Wellington Dam in the south and takes its name from Logue Brook Dam (lat. 33°00′S, long. 115°59′E). The type area of the granite is the disused quarry near Samson Brook Dam (lat. 32°52′55″S, long. 116°00′20″E). Here, grey porphyritic granite contains abundant microcline megacrysts, up to 3 cm long, set in a medium-grained groundmass of quartz, microcline, plagioclase, biotite, minor opaques, apatite and zircon. There is some evidence of recrystallization, but this is considerably less than in most other areas.

The most westerly exposures of mylonite are less than 1 km from the inferred position of the Darling Fault, a major feature on the earth's surface; it is nearly 1 000 km long and downthrown to the west as much as 15 km. On the Collie 1:250 000 Sheet (Wilde and Walker, 1979), the deformed western portions (orthogneiss) are infolded with a supracrustal sequence consisting of quartzite, banded iron-formation, mica schist and paragneiss. The supracrustal sequence and orthogneiss together constitute the Balingup Metamorphic Belt (Wilde, 1980), which, near Bridgetown, yielded a Rb/Sr age of 2 838 ± 200 m.y. (D. A. Nieuwland, written communication, 1977).

One aim of this study was to attempt to date the granite and the derived gneiss at Logue Brook, as it seemed possible that the granite was older than any other granitic rock so far dated in the Yilgarn Block. This postulate is not substantiated but the petrographic and isotopic data provide some evidence on the nature and origin of these high-strain zones in Archaean rocks close to the Darling Fault.

DEVELOPMENT OF LAYERED GNEISS AND MYLONITE

A detailed petrofabric analysis of a mylonite sample from Cookernup, 11 km north of Harvey, has recently been reported (Price, 1978; Lister and Price, 1978). The mylonite was developed from pre-existing granitic gneisses, and, as previously mentioned, some of these layered gneisses were developed from the porphyritic Logue Brook Granite by deformation and recrystallization. These features are well exposed near Honeymoon Road, approximately 4 km northeast of Harvey, where, over a distance of about 100 metres, various stages of gneiss development can be seen, commencing with weakly deformed porphyritic granite (Fig. 3A) and passing through augen gneiss to well-layered and folded equigranular granitic gneiss (Fig. 3H).

The development of a layered rock by flattening from a parent body was first described by Sclar (1950) and since then many authors have described similar features (Sclar, 1958 and 1965; Prinz and Poldervaart, 1964; Vernon, 1974; Shelley, 1974; Sinha Roy, 1977a and b; Wakefield, 1977; and Myers, 1978). Myers (1978) describes, with many examples, the formation of layered gneiss from a variety of rock types, ranging from granitic varieties to basic volcanics. The layering he describes is generated by extreme flattening of pre-existing structures, such as pillow lavas, xenoliths or vein networks, in the rock being deformed. However, at the Harvey location, the Logue Brook Granite contains no such structures.

The microstructural development of a mylonite has been well documented (Bell and Etheridge, 1973; White, 1973) and most of the processes are the same as those involved in the development of layered gneiss. Sinha Roy (1977a) describes this gneiss development as follows: "An initial shearing stage was followed by a flattening one when the characteristic mylonitic microstructures and banding developed. These stages were punctuated and overlapped by phases of recovery and recrystallization". White (1973) had also recognized that deformation, recovery and recrystallization were continuing and overlapping phases: "This sequence is one of continual recovery, of which dynamic recrystallization is a part, during a basically steady stage flow. Recovery features can and do co-exist with one another, for example, lamellae with subgrains". The recognition of these phases of recovery and recrystallization enables a similar tectonic development to that described by Sinha Roy (1977a), to be observed in the above-mentioned samples of deformed Logue Brook Granite. They preserve various stages of this history, depending upon how much recovery and recrystallization have taken place.

The samples taken from near Honeymoon Road exhibit the following features commensurate with progressive deformation. Sample 50394 still retains its gross porphyritic igneous texture (Fig. 3A); however, it has suffered shear strain, the evidence

* Research School of Earth Sciences Institute of Advanced Studies Australian National University Canberra.

†Literature ages quoted throughout this paper have been recalculated using a ^{87}Rb decay constant of 1·42 x 10^{-11}/year.

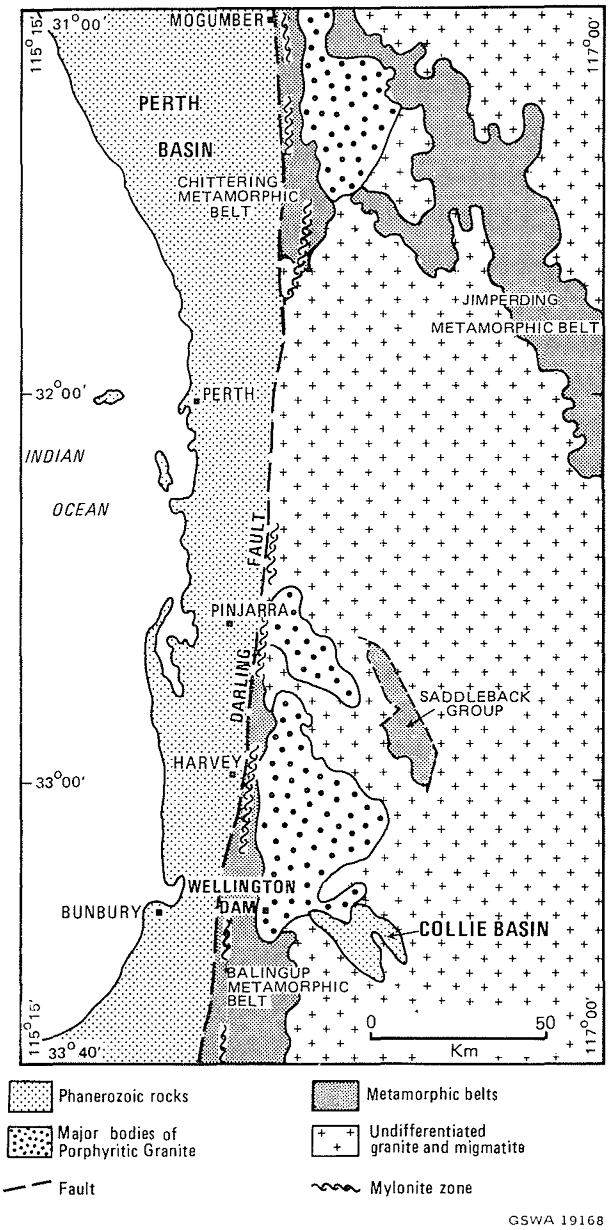


Figure I Geological sketch map of part of the Darling Fault zone.

of which is manifest by a set of conjugate zones that are rich in biotite, and along which recrystallization has occurred (Fig. 3B). The elongate relict microcline phenocrysts become rounded, and biotite-rich aggregates of extremely fine-grained, strained quartz and feldspar occur around the margins. These biotite-rich aggregates presumably represent the beginning of layer development. Between relict phenocrysts (now strictly porphyroclasts), quartz has recrystallized into a fine-grained interlobate to polygonal mosaic. This rock would correspond to stage 2 of Sinha Roy's (1977a) sequence of events.

A strong planar fabric has developed in sample 50393 (Fig. 3C and D) by further flattening of the conjugate shear zones. Mineral segregation has produced a layering such that there are biotite-rich layers alternating with layers of platy quartz. The layers of platy quartz (Q in Fig. 3D) are discontinuous and have possibly been formed by the recrystallization and sub-grain growth of the earlier flattened quartz mosaics. There is also a grain-size layering. Some porphyroclasts (probably those initially oriented at a high angle to the flattening plane) have been broken up and have produced discontinuous layers rich in coarse-grained microcline. Other porphyroclasts, elongated in the fabric direction, have very rounded ends with pressure shadows of fine-grained quartz mosaics (P in Fig. 3C). This corresponds to stage 4 of Sinha Roy's sequence.

In sample 50392, the feldsper grains have been further broken up, and with continued flattening, the compositional layering becomes more pronounced (Fig. 3E and F). All mineral grains in the biotite-rich layers are extremely small, and the platy quartz grains, which formed more continuous layers, have begun to recrystallize into polygonal mosaics.

Samples 50389 and 50391 show how the planar mylonitic fabric, described for samples 50394 and 50392, is destroyed as recrystallization proceeds and produces coarser more equidimensional grains. The mineral layering, which was produced early in the deformation, is still evident and may be accentuated. The eventual product is a poorly equigranular, interlobate textured, medium-grained, layered gneiss with rare microcline porphyroclasts (Fig. 3G and H).

Grocott (1977) has shown that, in a deformation zone, shear strain changes from brittle at shallow levels to more ductile in the deeper crustal levels. Wakefield (1977) considers, from an examination of the Lethakane shear zone in Botswana, that deformation processes of this type were "controlled by a mineralogical heterogeneity: essentially the ductility contrast between quartz and feldspar". The textures in the rocks from Harvey, especially those of quartz, are indicative of syntectonic recrystallization with slow strain rates at elevated temperatures (cf. White, 1975). The regional metamorphic grade is middle to upper amphibolite facies (Blight, 1978; and Wilde and Walker, 1979), and thus it is apparent that this mylonitic deformation operated under amphibolite facies conditions. Sinha Roy (1977a) concludes that the large initial grain size of minerals resistant to deformation and pressure solution (e.g. microcline phenocrysts in a granitic rock) seems to favour the development of layering in mylonites. Within the Logue Brook Granite large microcline phenocrysts appear to be more resistant to ductile deformation and, through a more brittle mode, break up and tend to form layers. In other words, the ductility contrast between the quartz and microcline appears to have considerable control on the deformational style and the production of layering.

Sinha Roy (1977a and b) contends that mylonitic layering is the combined effect of deformation and chemical mobility, and he describes changes in chemistry associated with development of layered mylonites from granitoids. Table 1 displays major and selected trace element analyses of some of the rocks examined in this study. There are no systematic chemical changes associated with progressive deformation of this suite, suggesting that the production of layered gneiss by deformation of homogeneous porphyritic Logue Brook Granite is essentially isochemical.

GEOCHRONOLOGY

MATERIAL ANALYSED

Two main suites of rocks were selected for isotopic analyses for the purposes of determining both the age of granite emplacement and the age of deformation that produced the orthogneiss and mylonite. Samples representing the least deformed Logue Brook Granite available were taken from Site 52478, at a quarry near Samson Brook Dam (lat. 32°52′50″, long. 116°00′20″). A group of rocks representative of the orthogneiss were collected from site 52483, at the Harvey Weir spillway (lat. 33°04′25″, long. 115°55′50″). In addition, selected samples ranging from porphyritic granite to mylonite were taken fron site 52475 on on the northeastern side of Logue Brook Dam (lat. 32°59′40″, long.115°59′00″) and from site 52476, at the Harvey Weir Quarry (lat. 33°04′24″, long. 115°55′50″) (Fig. 2). Individual samples from each site are indicated by upper case letters, and brief petrographic descriptions of the analysed samples are given in Table 2. Samples of unweathered material of at least 5 kg were collected. These were passed through a jaw crusher; then a smaller representative sample of between 100 and 200 gm was taken by means of a sample splitter. This representative sample was pulverized in a ring grinder to less than 200 mesh.

Procedures standard for the ANU laboratory were employed for the determination of Rb and Sr by mass spectrometric isotope dilution. The mixed ^{85}Rb –^{84}Sr tracer used gives an age of 1 415 $\pm$ 2 (σ_m) m.y. for the K-feldspar reference sample SRM 607. The co-efficient of variation for a single $^{87}Rb/^{86}Sr$ measurement is 0·5%, and the precision for $^{87}Sr/^{86}Sr$ is given separately in Table 3 for each analysis. For the Logue Brook samples, experimental error is negligible in comparison with the scatter about the original isochron produced by later geological processes. Ages have been calculated using 1·42 x 10^{-11} per year for the ^{87}Rb decay constant.

THE ORIGINAL AGE OF THE GRANITE

The analytical data obtained are presented in Table 3 and, except for 52478A, displayed in Figure 4. The undeformed biotite-rich sample, 52478A, differs markedly from all others in its much younger model age (Table 3). It has either gained Rb or lost Sr at a time equal to or younger than ~1 020 m.y. Apparently this difference is related to its comparatively high

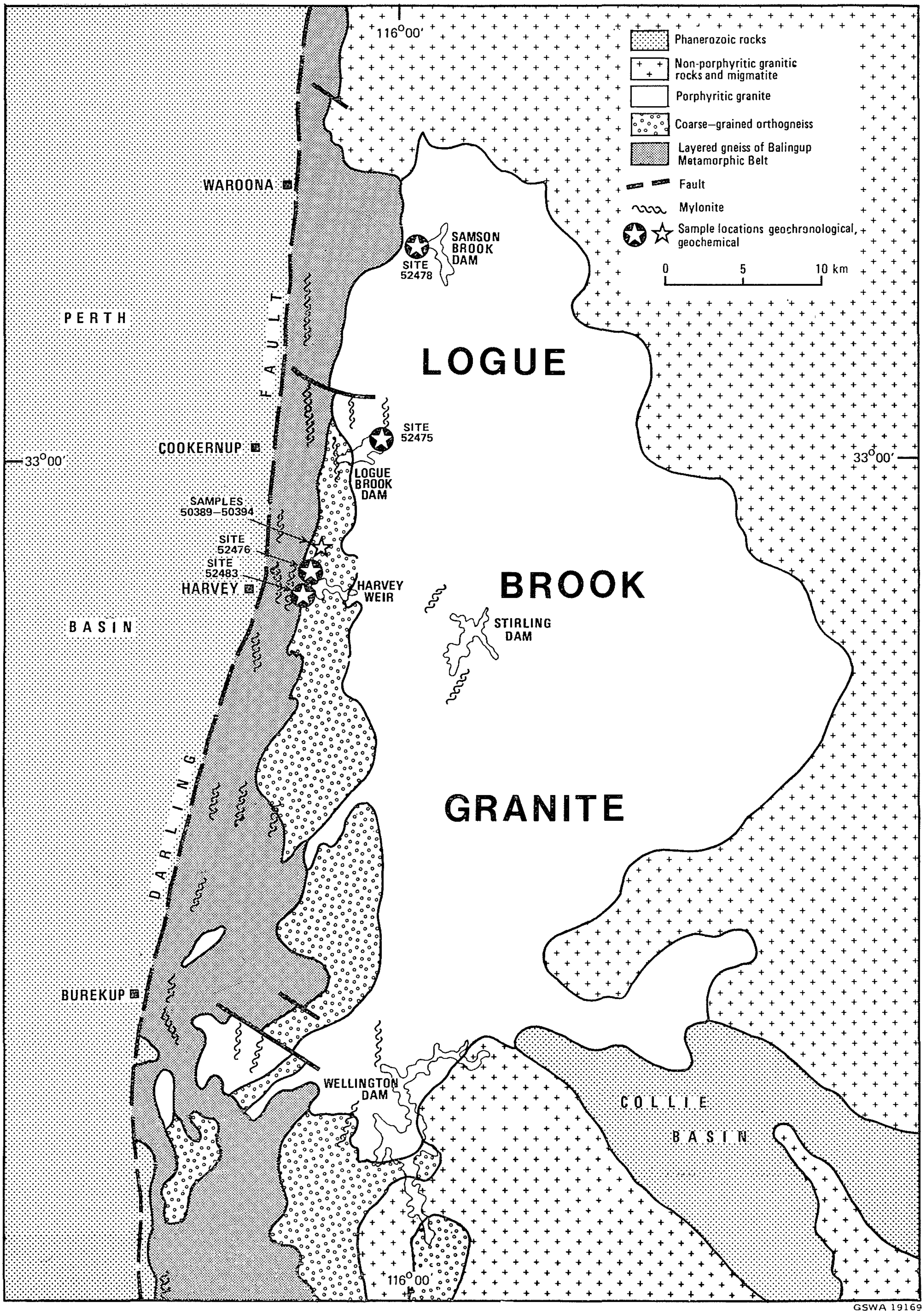


Figure 2 Geology of the Logue Brook Granite.

TABLE 1. WHOLE ROCK AND SELECTED TRACE ELEMENT ANALYSES OF SAMPLES SHOWING THE DEVELOPMENT OF A LAYERED GNEISS FROM A PORPHYRITIC GRANITE BY PROGRESSIVE DEFORMATION

Element	Slightly deformed granite	(Deformation increases to right)				Layered gneiss
	50394	50393	50392	50391	50390	50389
(%)						
SiO_2	74·2	71·4	71·4	71·4	71·7	72·3
Al_2O_3	13·2	14·3	13·6	14·2	13·3	13·3
Fe_2O_3	0·8	1·1	1·8	1·0	1·0	0·8
FeO	1·09	1·29	2·44	1·61	1·61	1·38
MgO	0·38	0·43	0·71	0·58	0·49	0·42
CaO	1·24	1·43	2·19	1·79	1·46	1·27
Na_2O	2·83	2·99	3·26	3·15	2·64	2·87
K_2O	4·70	5·40	3·00	4·60	5·60	5·40
TiO_2	0·28	0·29	0·49	0·31	0·35	0·27
MnO	0·01	0·01	0·03	0·03	0·02	0·01
P_2O_5	0·09	0·11	0·19	0·14	0·17	0·10
H_2O^+	0·60	0·55	0·86	0·54	0·45	0·46
H_2O^-	0·10	0·06	0·10	0·08	0·07	0·06
Total	99·52	99·36	100·07	99·39	98·86	98·64
(ppm)						
As	<1	<1	<1	<1	<1	<1
Ba	670	810	450	680	960	720
Pb	50	65	25	30	35	50
Li	5	5	15	<5	<5	<5
Rb	210	220	190	220	250	230
Sr	90	105	100	115	120	105
Th	60	60	40	45	20	50
U	2	4	<1	<1	<1	2
Zr	210	190	250	220	160	190
Rb/Sr	2·33	2·09	1·90	1·91	2·08	2·19

Figure 2 gives sample locations
Analysts: N. L. Marsh and A. G. Thomas, Western Australian Government Chemical Laboratories.

content of biotite ~15%, Table 2) and to the known propensity of biotite to lose radiogenic ^{87}Sr during later metamorphism. Biotites and feldspars from farther north at Wellington Dam (Riley, 1961) and Canning Dam (Pidgeon and Compston, 1978) give Rb-Sr ages in the range 600 to 700 m.y. while biotite-rich total rock samples from Canning Dam also register young model ages. Libby and de Laeter (1979) showed a progressive westward decrease in biotite ages from 2 500 m.y. at Meckering to about 500 m.y. at the Darling Scarp, thus confirming the young ages close to the western margin of the Yilgarn Block. These young ages presumably reflect a more complete response to the same event that altered sample 52478A.

Other Logue Brook Granite samples would also have been altered, and inspection of Figure 4 shows that such undeformed samples as 52478C and M were indeed open systems subsequent to their original crystallization. Thus our attempted measurements of the age of emplacement of the Logue Brook Granite and of its subsequent deformation must also allow for the unwanted effects of a superposed younger thermal event (taken as 635 m.y.).

The above situation can be modelled by a two-stage Sr-evolution method described by Compston and Collerson (1979) and Cameron and others (in press) in which "geological scatter" about an originally well-fitted isochron is assigned to local Sr-isotope exchange during a single later metamorphism. During the later metamorphism, differences in $^{87}Sr/^{86}Sr$ between adjacent samples which grew with time because of differences in their $^{87}Rb/^{86}Sr$, are smoothed out by diffusive exchange of ^{87}Sr. Subsequently, the same differences in $^{87}Rb/^{86}Sr$ produce correlated y, x residuals, with respect to the undisturbed primary isochron, along a slope corresponding to the age of metamorphism. Cameron and others (in press) give the correct regression method for estimating the original age and initial $^{87}Sr/^{86}Sr$ for this situation, including the recommendation that each point should be weighted as the inverse square of the mean $^{87}Rb/^{86}Sr$ of its local exchange system. In addition, as Compston and Collerson (1979) also discuss, it may be preferable to model the initial $^{87}Sr/^{86}Sr$ rather than attempt to estimate it. For this purpose, the original granite is assumed to be produced from the so-called "unfractionated Sr reservoir" (De Paolo and Wasserburg, 1976) which has a $^{87}Rb/^{86}Sr$ of approximately 0·085 6 and a present-day $^{87}Sr/^{86}Sr$ of approximately 0·704 7 and constitutes a "fixed-point".

Table 4 lists regression analyses of various combinations of the samples by the methods of Cameron and others (in press). Sample 52478A has been excluded from all regressions as its response to the later metamorphism so greatly exceeds

TABLE 2. LOCATION AND BRIEF DESCRIPTION OF ISOTOPICALLY ANALYSED SAMPLES

Site	Locality	Latitude	Longitude	Sample	Notes
52475	Northeast side of Logue Brook Dam	32°59′40″	115°59′00″	C	Pegmatite with 60% microcline phenocrysts. Weakly recrystallized
				F	Porphyritic granite. Partly recrystallized. Granoblastic, seriate interlobate texture.
				H	Granitic blastomylonite. Fine-grained flaser texture with rare porphyroclasts.
52476	Quarry 200 m north of Harvey Weir	33°4′24″	115°55′50″	B, C	Granitic augen gneiss. Granoblastic, seriate polygonal texture over-printing flaser texture.
				I	Granitic gneiss. As B and C except for smaller and rarer porphyroclasts.
52478	Quarry near Samson Brook Dam	32°52′50″	116°00′20″	A	Dark tonalitic pod with up to 15% biotite.
				C	Porphyritic granite, partly recrystallized quartz. Feldspar and biotite marginal to phenocrysts.
				D	Porphyritic granite. Coarser than C and less biotite.
				D (K-Feld)	Large microline crystal separated from D.
				G	Porphyritic granite. Similar to C, but less biotite.
				K	Medium-grained granite/adamellite. Microcline perthitic and slightly coarser than plagioclase. Granoblastic recrystallization.
				L	Porphyritic granite. Megacryst-rich, weakly recrystallized.
				M	Biotite tonalitic gneiss. Origin obscure, but seems to be a vein through granite
				N	Porphyritic granite. Similar to C and G. Fairly typical of Logue Brook Granite.
52483	Harvey Weir Spillway	33°04′25″	115°55′50″	A	Layered granitic gneiss. Granoblastic to mylonitic with rare porphyroclasts. Perthitic microcline.
				B	Granitic augen gneiss. Granoblastic to mylonitic with large microcline augen. Strong biotite fabric. Polygonal recrystallization of quartz.
				C	Layered granitic augen gneiss. Larger augen than B.
				D	Granitic augen gneiss. Similar to B, but smaller augen.
				E	Layered granitic augen gneiss. Similar to C.

TABLE 3. ANALYTICAL DATA OF SPECIMENS OF LOGUE BROOK GRANITE AND ASSOCIATED ORTHOGNEISSES FROM VARIOUS LOCATIONS (see Figure 2).

	ppm Rb	ppm Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	Age based on R_i σ of 0·701
Site 52475 (Logue Brook Dam):					
C	343·5	98·0	10·118	1·081 28 ± 11	2 592 m.y.
F	245·3	76·6	9·237	1·052 75 ± 4	2 633 m.y.
H	233·8	66·1	10·200	1·068 58 ± 4	2 491 m.y.
Site 52476 (North of Harvey Weir Spillway):					
B	159·8	80·5	5·725	0·923 87 ± 7	2 687 m.y.
C	159·4	82·1	5·602	0·925 76 ± 5	2 769 m.y.
I (i)	97·3	105·8	2·653	0·827 51 ± 5	3 281 m.y.
(ii)	100·9	112·5	2·588	0·828 27 ± 6	3 381 m.y.
Site 52478 (Samson Brook Dam):					
A	580·1	32·6	51·25	1·451 3 ± 1	1 023 m.y.
C	354·4	73·5	13·92	1·185 16 ± 5	2 407 m.y.
D	345·9	85·3	11·70	1·129 4 ± 3	2 532 m.y.
D (K-feld)	408·2	98·8	11·92	1·152 8 ± 2	2 620 m.y.
G	247·4	72·1	9·90	1·074 23 ± 5	2 606 m.y.
K	185·2	57·0	9·36	1·061 93 ± 6	2 665 m.y.
L	332·4	76·5	12·53	1·152 35 ± 4	2 492 m.y.
M	231·8	62·0	10·79	1·058 57 ± 8	2 296 m.y.
N	258·1	74·2	10·035	1·083 64 ± 4	2 635 m.y.
Site 52483 (Harvey Weir Spillway)·					
A	164·6	98·8	4·806	0·888 33 ± 6	2 692 m.y.
B	178·2	91·7	5·604	0·916 52 ± 9	2 658 m.y.
C	188·4	91·0	5·977	0·924 31 ± 5	2 583 m.y.
D	199·6	137·5	4·186	0·840 18 ± 5	2 303 m.y.
E	193·2	93·5	5·961	0·918 5 ± 1	2 524 m.y.

The ages are calculated using a ^{87}Rb decay constant of 1·42 x 10^{-11}/year.

the comparatively uniform response of the others. However inspection of the residuals suggest that samples 52476I, 52483D and 52478M also have a greater geological scatter than the remainder, so that our preferred estimate of the original age is 2 577 ± 50 m.y. (regression 4, Table 4). The uncertainties of the free-line estimates of initial $^{87}Sr/^{86}Sr$ are so high as to make the estimates almost worthless.

Although we favour exclusion of sample 52476I from the regression analysis, its position well above the 2 577 m.y. isochron (and hence its very high model age) is nevertheless consistent with the mechanism proposed for metamorphic redistribution. This particular sample absorbed an unusually large amount of radiogenic ^{87}Sr, and may be viewed as an analogue of the mafic pod 52478A, which lost an unusually large fraction of its radiogenic ^{87}Sr. Plagioclases from the Canning Dam area have absorbed even greater fractions of ^{87}Sr and give absurdly old model ages (Pidgeon and Compston, 1978). The presence of sample 52476I is important because it demonstrates that the process of metamorphic disturbance, in the case of the Logue Brook Granite, involves local ^{87}Sr redistribution. Otherwise we could not exclude the possible alternative process discussed by Nieuwland and Compston (in press), of regional loss of radiogenic Sr, in which the oldest model age is a minimum estimate for the original age.

AGE OF DEFORMATION

Inspection of Figure 4 shows that no difference in age can be detected between the deformed and undeformed samples. It follows that either (a) the difference in age between emplacement and deformation of the Logue Brook Granite was small or (b) the deformation process itself did not alter the Rb-Sr total-rock ages and may have occurred at any later date.

TABLE 4. REGRESSION ANALYSES OF TWO GROUPINGS OF LOGUE BROOK GRANITE SAMPLES, USING THE METHODS OF CAMERON AND OTHERS (IN PRESS).

Regression	Number of samples	R_i	Age m.y.
Free-line method			
1. All except 52478A	20	0·721 $^{+16}_{-19}$	2 410 $^{-185}_{+230}$
		*0·718 $^{+17}_{-21}$	*2 440 $^{-185}_{+250}$
2. All except 52478A, 52476I (i), (ii), 52483D, and 52478M	16	0·717 $^{+13}_{-15}$	2 465 $^{-120}_{+135}$
		*0·716 $^{+13}_{-15}$	*2 465 $^{-120}_{+140}$
Fixed-point method			
3. As in 1.	20	0·701 54 $^{+10}_{-11}$	2 574 $^{-78}_{+85}$
		*0·701 54 $^{+10}_{-11}$	2 575 $^{-77}_{+85}$
4. As in 2.	16	0·701 53 $^{+6}_{-}$	2 577 $^{-49}_{+51}$
		*0·701 53 $^{+6}_{-}$	*2 577 $^{-48}_{+52}$

The "free-line" method estimates both the age and initial $^{87}Sr/^{86}Sr$, whereas the "fixed-point" method constrains the initial $^{87}Sr/^{86}Sr$ to bulk earth values and estimates the age only. The age of metamorphism is taken as 635 m.y. Results are also shown, marked with an asterisk, for a maximum age of metamorphism of ∽ 1 020 m.y.

Figure 3 Sequence of photographs illustrating various stages in the production of layered gneiss (50389) from porphyritic Logue Brook Granite (50394). All samples taken from a 100 m-wide section 4 km northeast of Harvey near Honeymoon Road (Fig. 2).

(A) Relatively undeformed Logue Brook Granite, showing the abundant and aligned nature of microcline phenocrysts; slight rounding at the ends of certain phenocrysts is evident . (50394).

(B) Photomicrograph showing how the rounding at the ends of microcline phenocrysts as the result of conjugate shear sets, along with recrystallization has occurred; quartz and feldspar form a fine-grained mosaic that is rich in recrystallized biotite (crossed polars, 50394).

(C) Further flattening of the conjugate shear sets results in a strong planar fabric; mineral segregation and variations in grain-size define a conspicuous layering; microcline porphyroclasts have distinctly tapered ends, with pressure shadows (P) of fine-grained quartz mosaics (plane-polarized light, 50393).

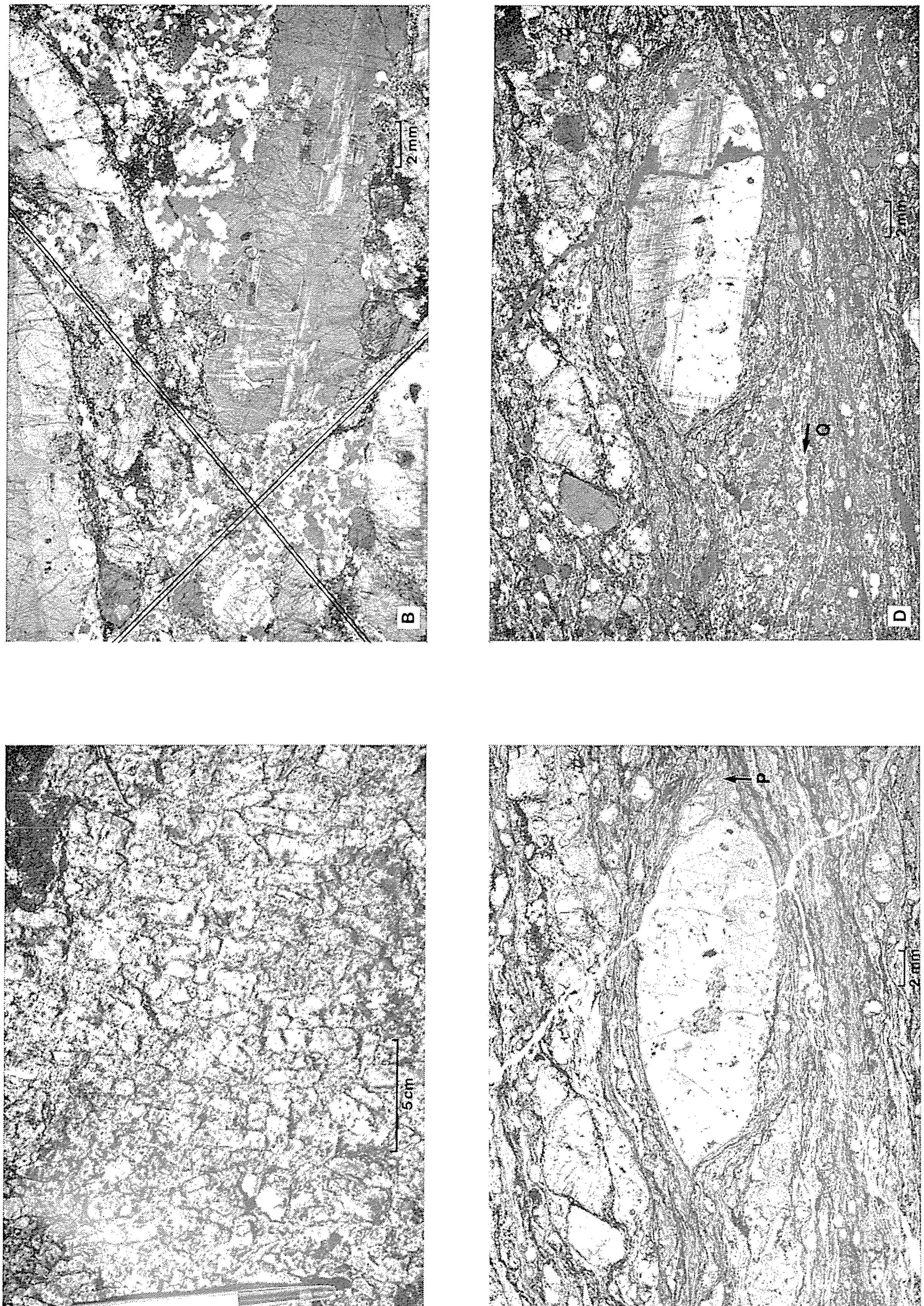
(D) As (c), but illustrating discontinuous layers of platy quartz (Q) possibly formed by recrystallization of previously flattened quartz mosaics (crossed polars, 50393).

(E) Continued flattening and reduction in grain-size of feldspar results in a more pronounced compositional layering, all mineral grains are extremely small in the biotite-rich layers. (plane-polarized light, 50392).

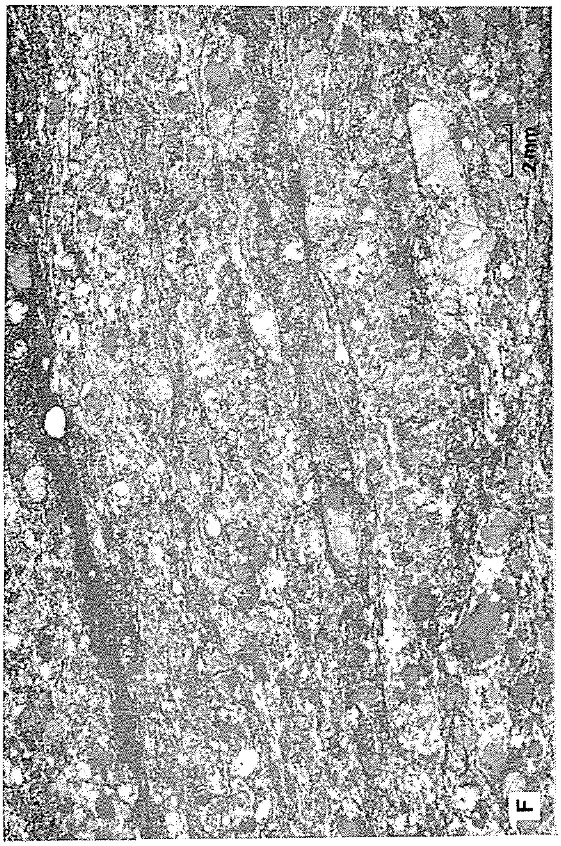
(F) As (e), but emphasizing how the platy quartz grains have begun to recrystallize into polygonal mosaics (crossed polars, 50392).

(G) Further recrystallization results in destruction of the mylonitic fabric, with the formation of coarser, more equidimensional grains; the early mineral layering is not destroyed and may be further emphasized by recrystallization of biotite (crossed polars, 50389).

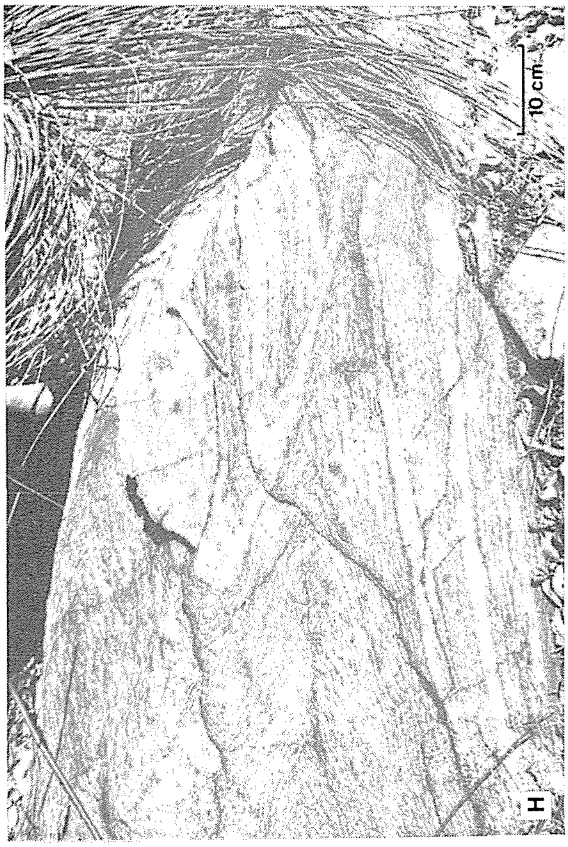
(H) Folded, layered gneiss, approximately 100 m west across strike from 50394 (50389).


A
5cm
B
2 mm
C
2 mm
P
D
2 mm
Q


E
2 mm


F
2 mm


G
2 mm


H
10 cm

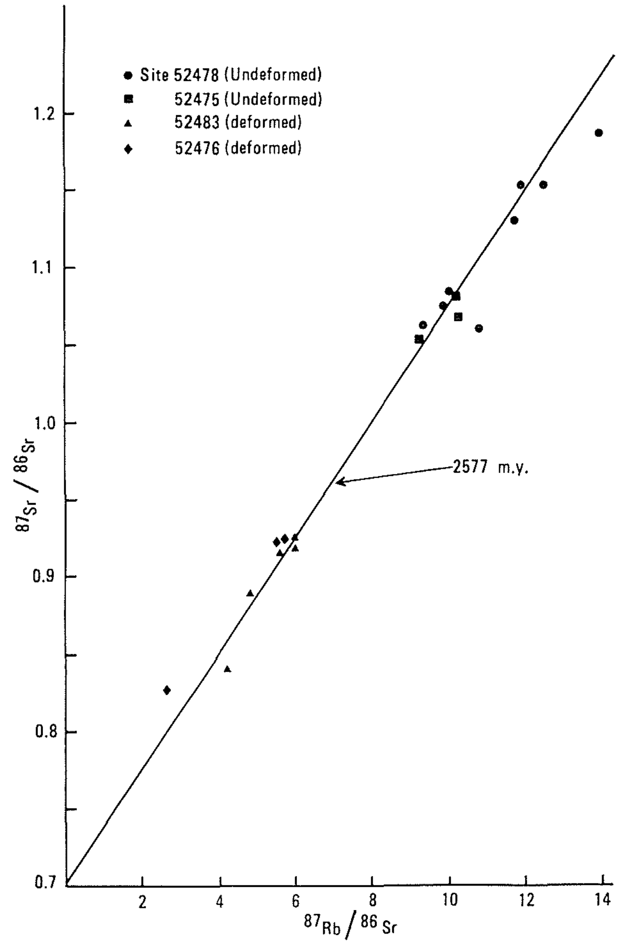


Figure 4 Logue Brook Granite isotopic data and reference isochron.

All the deformed samples which were analyzed isotopically have lower Rb/Sr than the undeformed samples (Figure 5). The 50389–94 series samples, which were not analysed isotopically, also have lower Rb/Sr but there is no difference within this series between the slightly deformed sample 50394 (Table 1) and the progressively more deformed samples. Figure 2 shows that all samples having low Rb/Sr, including the 50389–94 series, belong to the coarse-grained orthogneiss unit. It remains possible therefore, that the transformation of porphyritic granite into orthogneiss was accompanied by a decrease in Rb/Sr, (through gain of Sr) during the recrystallization of original minerals and growth of new minerals. Such a change in Rb/Sr need not be accompanied by a significant change in major element composition. This evidence could be used to support alternative (a). On the other hand, we cannot exclude the possibility that the distribution of Rb and Sr shown in Figure 5 is a primary igneous distribution, and that the apparent difference in Rb/Sr between the deformed and undeformed samples could be due to their having been collected from different parts of the original pluton.

Despite the lack of conclusive evidence for change of Rb/Sr due to deformation, we consider it very likely that local Sr isotopic equilibration would have occurred during the process. As shown in a previous section, the deformation was accompanied by recrystallization and by the growth of new minerals, which would promote rapid isotopic exchange via interstitial fluid and result in isotopic homogenization. Black and others (1979) have shown that different deformational events can be measured by using closely spaced total-rock samples from localities at which a particular deformation is strongly developed. The mineralogical changes believed to accompany the later thermal event (saussuritization, growth of minor epidote and carbonate) are trivial compared with those associated with the development of layered gneiss, yet this apparently minor thermal event was accompanied by substantial ^{87}Sr transfer between total-rock samples. Assuming that local Sr isotopic equilibration did occur during deformation, the Rb-Sr alignment of deformed samples per single locality will approximate to the age of deformation. Figure 4 shows that the mean alignment for deformed samples from the two localities examined is close to the original 2 577 m.y. isochron. Specifically, the apparent ages, using the Cameron and others (in press) free-line method are 3 355 + 1 220 or —945 m.y. for locality 52483, but with an inadmissably-low initial $^{87}Sr/^{86}Sr$, and 2 210 + 400 or —265 m.y. for locality 52476. The age for the combined localities is 2 415 + 1 545 or —560 m.y.

CONCLUSIONS

Isotopic data indicate that the emplacement of the Logue Brook Granite, near Harvey, took place around 2 575 m.y. ago. It has been demonstrated on field and petrographic evidence that augen gneiss, layered gneiss and mylonite have developed from this porphyritic granite by intense shear deformation and that this process was essentially isochemical. Our interpretation of all available data is that deformation occurred during or soon after granite emplacement.

Other bodies of porhpyritic granite cropping out between Mogumber and Harvey (Figure 1) are deformed in a similar fashion to the Logue Brook Granite and have been changed to mylonites. Similar mylonites are also present in adjacent gneissic rocks. These extensive mylonite zones are restricted to within 10 km of the present Darling Fault and extend as far south as Northcliffe, a total distance of 420 km. The mylonites are subparallel to the Darling Fault even where the fault swings south eastward near Northcliffe (Wilde and Walker, in prep.). The intensity of deformation increases westward towards the Darling Fault and it is suggested that the mylonite zones are deep-level manifestations of a major Archaean shear zone.

Various workers (Prider, 1952; Wilson, 1958; Wilson and others, 1960; Wilde and Low, 1978a, b; and Wilde, 1980) have postulated the existence of an Archaean deformation zone subparallel to the present Darling Fault. Prider (1952) referred to this as the "Darling Archaean Fault" and gave evidence of sinistral transcurrent movement. It is also evident that this zone was active during the sedimentation and subsequent deformation of the Proterozoic Cardup, Moora, and Yandanooka Groups. Similarly, dolerite dykes of believed Proterozoic age increase in abundance toward the fault and lie subparallel to that feature. Many have also undergone later shearing, especially along their margins (Klenowski, 1975). Wilson (1958) proposed that there was periodic re-activation along this zone, and this was later substantiated by isotopic data on pegmatites (ca. 1 100 m.y. at Mullalyup; Wilson and others, 1960); on the granitized margins of dolerite dykes (560 to 590 m.y.; Compston and Arriens, 1968) and on biotite from both granite and pegmatite (634 to 740 m.y.; Wilson and others, 1960).

It would thus appear that this zone acted as the locus for the Darling Fault, a major Phanerozoic feature which was initiated during the Silurian as a normal fault (Playford and others, 1976). It underwent its greatest amount of movement between Middle Triassic and Early Cretaceous times resulting in a downthrow to the west of 15 km near Perth. To distinguish clearly between the Darling Fault and this earlier shear zone with possible transcurrent movement, we propose that the name "proto-Darling Fault" be used for the Precambrian deformation zone.

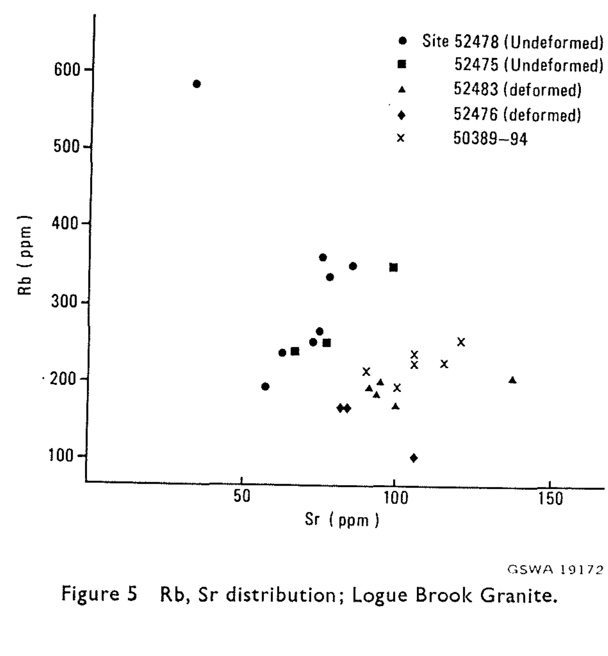


Figure 5 Rb, Sr distribution; Logue Brook Granite.

REFERENCES

Arriens, P. A., 1970, The Archaean geochronology of Australia: Geol. Soc. Australia Spec. Publ. No. 3, p. 11–23.

Bell, T. H., and Etheridge, M. A., 1973, Microstructures of mylonites and their descriptive terminology: Lithos, No. 6, p. 337–349.

Black, L. P., Bell, T. H., Rubenach, N. J., and Withnall, I. W., 1979, Geochronology of discrete structural-metamorphic events in a multiply deformed Precambrian terrain: Tectonophysics, v. 54, p. 103–137.

Blight, D. F., 1978, High-grade retrogressive metamorphism and mineral corona development in basic rocks of the Collie area, Western Australia: West. Australia Geol. Survey Ann. Rept 1977, p. 66–68.

Cameron, M., Collerson, K. D., Compston, W., and Morton, R., in press, Statistical analysis and interpretation of imperfectly fitted Rb-Sr isochrons from polymetamorphic terrains: Geochim. Cosmochim. Acta.

Compston, W., and Arriens, P. A., 1968, The Precambrian geochronology of Australia: Canadian Jour. of Earth Sciences v. 5, p. 561–583.

Compston, W., and Collerson, K. D., 1979, Interpretation of scattered Rb-Sr isotopic data for early Archaean gneisses from Labrador and Greenland: Workshop on Ancient Crusts of the Terrestrial Planets, Lunar and Planetary Science Institute, Contrib. 371, p. 22–24.

De Paolo, D. J. and Wasserberg, G. J., 1976, Inferences about magma sources and mantle structure from variations of $^{143}Nd/^{144}Nd$: Geophys. Res. Lett., 3, p. 743–746.

Grocott, J., 1977, The relationship between Precambrian shear belts and modern fault systems: Geol. Soc. London, Jour., v. 133, p. 257–262.

Klenowski, G., Shear zones in Precambrian rocks of the Darling Range: nature, origin and engineering significance: West. Australia Geol. Survey Ann. Rept, 1974, p. 29–33.

Libby, W. G. and de Laeter, J. R., 1979, Biotite dates and cooling history of the western margin of the Yilgarn Block: West. Australia Geol. Survey Ann. Rept 1978, p. 79–87.

Lister, G. S., and Price, G. P., 1978, Fabric development in quartz-feldspar mylonite: Tectonophysics, v. 49, p. 37–78.

Myers, J. S., 1978, Formation of banded gneisses by deformation of igneous rocks: Precambrian Research, v. 6, p. 43–64.

Nieuwland, D. A., and Compston, W., in press, Crustal evolution in the Yilgarn Block near Perth, W.A.: International Archaean Symposium, 2nd Perth, 1980, Geol. Soc. Aust. Spec. Publ. No. 7.

Playford, P. E., Cockbain, A. E., and Low, G. H., 1976, Geology of the Perth Basin, Western Australia: West. Australia Geol. Survey Bull. 124.

Pidgeon, R. T. and Compston, W., 1978, Geochronology of the western margin of the Yilgarn Block: Australian National University, Research School of Earth Sciences, Annual Report, p. 160–161.

Prinz, M., and Poldervaart, A., 1964, Layered mylonite from Beartooth Mountains, Montana: Geol. Soc. America Bull. v. 75, p. 741–744.

Price, G. P., 1978, Study of heterogeneous fabric and texture within a quartz-feldspar mylonite using the photometric method: Geol. Soc. America Bull. v. 89, p. 1359–1372.

Prider, R. T., 1952, South-west Yilgarnia, *in* Glaessner, M. F. and Rudd, E. A. (eds) Sir Douglas Mawson Anniversary Volume: The University of Adelaide, p. 143–152.

Riley, G. H., 1961, The techniques and application of Rb-Sr geochronology: Univ. Western Australia, Perth, PhD Thesis (unpublished).

Sclar, C. B., 1950, Origin of a layered ultramylonite from southeastern Connecticut (Abstract): Geol. Soc. America Bull. v. 61, p. 501.

———— 1958, The Preston Gabbro and associated metamorphic gneisses, New London County, Connecticut: Connecticut Geol. Nat. History Survey Bull. v. 88, p. 131.

———— 1965, Layered mylonites and the process of metamorphic differentiation: Geol. Soc. America Bull. v. 76, p. 611–612.

Shelley, D., 1974, Mechanical production of metamorphic banding—a critical appraisal: Geol. Mag. v. 111, p. 287–292.

Sinha Roy, S., 1977a, Mylonitic microstructures and their bearing on the development of mylonites—an example from deformed trondhjemites of the Bergen Arc region, S.W. Norway: Geol. Mag. v. 114, p. 445–458.

———— 1977b, Deformation and chemical processes in mylonite genesis: Geologiska Foreningens i Stockholm. Fordandlingar, v. 99, p. 3–9.

Vernon, R. H., 1974, Controls of mylonitic compositional layering during non-cataclastic ductile deformation: Geol. Mag. v. 111, p. 167–277.

Wakefield, J., 1977, Mylonitization in the Lethakane shear zone, eastern Botswana: Geol. Soc. London Jour. v. 133, p. 263–275.

White, S., 1973, Syntectonic recrystallization and texture development in quartz: Nature, v. 244, p. 276–278.

———— 1975, Estimation of strain rates from microstructures: Geol. Soc. London, Jour. v. 131, p. 577–583.

Wilde, S. A., 1980, The Jimperding Metamorphic Belt in the Toodyay area and the Balingup Metamorphic Belt and associated granitic rocks of the Southwestern Yilgarn Block: International Archaean Symposium, 2nd, Perth, 1980, Geol. Soc. Australia, Excursion Guide.

Wilde, S. A. and Low, G. H., 1978a, Perth, Western Australia: West. Australia Geol. Survey 1:250 000 Geological Series Explanatory Notes.

———— 1978b, Explanatory notes on the Pinjarra Western Australia 1:250 000 Geological Sheet: West. Australia Geol. Survey Rec. 1978/5.

Wilde, S. A. and Walker, I. W., 1979, Explanatory notes on the Collie 1:250 000 geological sheet, Western Australia: West. Australia Geol. Survey Rec. 1979/11.

———— in prep., Explanatory notes on the Pemberton-Irwin Inlet 1:250 000 geological sheet, Western Australia: West. Australia Geol. Survey Rec.

Wilson, A. F., 1958, Advances in the knowledge of the structure and petrology of the Precambrian rocks of southwestern Australia: Royal Soc. West. Australia Jour. v. 41, p. 57–83.

Wilson, A. F., Compston, W., Jeffery, P. M. and Riley, G. H., 1960, Radioactive ages from the Precambrian rocks in Australia: Geol. Soc. Australia Jour. v. 6, p. 179–196.

THE RELATIONSHIP OF NEW Rb-Sr ISOTOPIC DATES FROM THE RUDALL METAMORPHIC COMPLEX TO THE GEOLOGY OF THE PATERSON PROVINCE

by R. J. Chin and J. R. de Laeter*

ABSTRACT

The Paterson Province consists principally of a basement of multiply deformed and metamorphosed granite, gneiss and metasediments known as the Rudall Metamorphic Complex, unconformably overlain by sedimentary rocks of the Yeneena Group. This latter sequence has been subject to one major period of folding.

A Rb-Sr geochronology programme to attempt to date the events in the Rudall Metamorphic Complex commenced with a series of nine samples selected from previous reconnaissance collections. A poorly fitted isochron at 1 533 ± 29 m.y. was obtained. Subsequent collecting provided a series of six samples of retrogressed gneiss which gave a well-fitted isochron at 1 333 ± 44 m.y. This date is considered to be the age of the pervasive metamorphism and deformation in the Rudall Metamorphic Complex, and the oldest possible depositional age of the Yeneena Group. Other samples showed a scatter of data indicating that the isotopic system has been disturbed by later metamorphism and alteration. An age of 595 ± 27 m.y. was found from six of these samples and compares favourably with the relatively young age of the granite which intrudes the Yeneena Group near Mount Crofton in the northern part of the province. Pegmatite veins in the metamorphic basement produced an isochron at 1 132 ± 21 m.y., an age which may relate to the deformation of the Yeneena Group.

*Department of Physics, Western Australian Institute of Technology.

Two samples of undeformed adamellite from the southeast part of the Rudall Metamorphic Complex gave an age of about 1 080 m.y., the first indication of granite intrusion of this age in the Paterson Province. This age compares closely with that of younger granite intrusions into the Proterozoic mobile belts of the Musgrave Block and the Albany-Fraser Province. Metamorphic ages from the Rudall Metamorphic Complex are similar to the age of granulite metamorphism in these provinces.

INTRODUCTION

The Paterson Province is located in the remote western part of the Gibson and Great Sandy Deserts. The mining town of Telfer lies in the northern part of the province. It is normally thought of as an exposed part of a Proterozoic orogenic belt, abutting the Pilbara Block and Hamersley Basin to the west, and unconformably overlain by the Proterozoic Bangemall Group and the Phanerozoic Officer and Canning Basins to the south, east and north.

It consists of two principal rock groups, a metamorphic complex and a folded sedimentary cover, the ages of which have been subject to speculation since the first geological reconnaissance was made by H. W. B. Talbot in 1908–09. He recognized the distinction between "granite and crystalline schist" (now known as the Rudall Metamorphic Complex) and the younger sedimentary rocks which are now considered to form part of the Yeneena Group (Talbot, 1910). He initially considered the sedimentary rocks to have a Devonian age, but later (Talbot, 1920) assigned these rocks to the Nullagine Series (Maitland, 1919). No further geological work was carried out in the Paterson Province until 1954 when Traves and others (1956) surveyed the Canning Basin and published the Paterson Range and Tabletop Sheets of the 4-mile Geological Series (Wells, 1959, 1960). They arbitrarily assigned an early Proterozoic age to the rocks of the province. In 1966 and 1969 L. E. de la Hunty and J. G. Blockley of the Western Australian Geological Survey (G.S.W.A.) made reconnaissance trips to assist in the preparation of the 1966 and 1973 editions of the State Geological Map. They thought that the main sedimentary sequence (Yeneena Group) was equivalent to part of the Proterozoic Bangemall Group (Blockley and de la Hunty, 1975). More recent geological mapping (Williams and others, 1976) has demonstrated that the Bangemall Group unconformably overlies the Yeneena Group. Adamellite, which intrudes the Yeneena Group near Mount Crofton in the northern part of the province, was dated by Trendall (1974) using the Rb-Sr technique. The ages determined were 598 $\pm$ 24 m.y. for six granite samples and 581 $\pm$ 1 m.y. for the same samples plus a pegmatite from a cross-cutting vein. These were surprisingly young ages considering the inferred age of the rocks they intrude. Biotite from four of the granite samples gave ages between 556 and 579 m.y. (de Laeter and others, 1977). All ages quoted in this paper from other references have been recalculated using a value of $1 \cdot 42 \times 10^{-11}$ yr^{-1} for the decay constant, of ^{87}Rb.

A geochronology project to clarify the age of rocks in the Paterson Province (including the Gregory Granitic Complex which at that stage was regarded as the most westerly part of the province) was commenced in 1970 using samples in the G.S.W.A. rock collection, which were rather randomly collected by Talbot from several traverses made between 1908 and 1914, and by J. G. Blockley and L. E. de la Hunty in 1966 and 1969. Geochronological results from the Gregory Granitic Complex have been published by de Laeter and others (1977). Initial results from the Paterson Province were broadly referred to by Blockley and de la Hunty (1975), and quoted as "about 1 500 m.y." by Blockley (1974). Systematic mapping of the Paterson Range Sheet (Chin and Hickman, 1977), Ruddall Sheet (Chin and others, 1979), Runton Sheet (Crowe and Chin, 1978), Gunanya Sheet (Williams and Williams, 1977) and Tabletop Sheet (Yeates and Chin, 1979) revealed complex deformation and metamorphism throughout the Paterson Province, and showed the necessity for further collection and analysis of selected samples to arrive at a better understanding of the geological history.

The objectives of the Rudall project were to determine the ages of the important metamorphic events in the Rudall Metamorphic Complex and to define more precisely the age limits of the deposition of the Yeneena Group. It was also hoped that an indication of the age of the parent rocks that gave rise to the Rudall Metamorphic Complex might be found.

REGIONAL GEOLOGY

The regional geology of the Paterson Province (Fig. 1) is characterized by two major rock groups, the Rudall Metamorphic Complex and the unconformably overlying Yeneena Group. Both pass unconformably below Phanerozoic rocks of the Canning and Officer Basins at the northeastern and eastern boundaries. The Yeneena Group passes unconformably beneath the gently dipping Proterozoic Bangemall Group (about 1 050 m.y.) in the south and southwest. The Yeneena Group rests unconformably on the Archaean Gregory Granitic Complex (about 2 590 m.y.) and the Proterozoic Hamersley and Fortescue Groups (about 2 600–2 500 m.y.) on the western side of the province. However, the relationship between the Rudall Metamorphic Complex and the older sequences on this western side is obscured by the Yeneena Group.

Both the basement and the cover rocks in the Paterson Province have been deformed by north-northwesterly folds. A third, restricted, group of Proterozoic rocks in the Paterson Province is the Karara Formation which unconformably overlies the Yeneena Group. Granite and adamellite which lack metamorphic fabric have intruded the Yeneena Group in the northern part of the province and have intruded the Rudall Metamorphic Complex in the extreme southeast.

During the Permian the region was subjected to glaciation. Large U-shaped valleys and striated, polished pavements are still preserved on the exhumed pre-Permian unconformity, and outliers of the Permian glacigene Paterson Formation are present.

RUDALL METAMORPHIC COMPLEX

The Rudall Metamorphic Complex consists of two metamorphic suites. The older suite is of gneissic and granitic rocks, and contains structures produced by an early metamorphic and deformation event (F_1) which predates the formation of the predominantly metasedimentary younger suite. The dominant fabric in both rock suites is produced by a pervasive metamorphic and deformation event (F_2) which has extensively broken down the older metamorphic textures and transposed primary layering in both metamorphic suites. However, sufficient textures and structures are preserved to identify the parent rocks.

The dominant gneissic rock is banded gneiss derived during F_1 from a variety of granitoid types. Although these gneisses exhibit a compositional range between granite and tonalite, adamellite composition is most common. The banding is principally derived by metamorphic differentiation but some is possibly of sedimentary origin. In the Mount Connaughton area, this banded gneiss encloses belts of quartzite, paragneiss and orthogneiss derived from a layered sequence of mafic, ultramafic and sedimentary rocks. Although this gneiss also has undergone retrogression, it still retains relict metamorphic assemblages attained during F_1. In particular, relict staurolite, sillimanite and kyanite in the paragneiss indicate middle to upper amphibolite facies metamorphism. North of Karara Well, migmatite was formed by the veining and partial assimilation of a complex of banded gneiss with enclaves of mafic and ultramafic gneiss and paragneiss, by stockworks of granitic and aplitic dykes. In this same area and in the Rudall River area, large bodies and dykes of medium- and coarse-grained porphyritic and even-grained adamellite intrude the gneiss.

All the rocks described above have a dominant F_2 fabric derived from the breakdown and recrystallization of primary minerals. Associated retrograde minerals, including chlorite, tremolite, epidote and muscovite, characterize all gneisses.

Gneisses in this older metamorphic suite closely resemble those in Archaean cratons. In particular, juxtaposed quartzite, paragneiss, mafic gneiss and banded granitic gneiss which grades into migmatite are characteristic rock types and associations of the West Yilgarn Gneiss Domain (Gee, 1979).

The younger metamorphic suite of the Rudall Metamorphic Complex is dominated by thick, monotonous quartzite horizons with abundant quartz-muscovite schist. The quartzite is derived from a supermature quartz sandstone. Pebble conglomerate beds are present but rare. Less abundant rock types at apparently higher stratigraphic levels are banded iron-formation, quartz-feldspar-mica schist, graphitic schist and interbanded marble and chlorite-carbonate schist. An extensive outcrop of metabasalt with thin intercalated chert bands is thought to be part of the younger suite. Lithologically, this obvious sedimentary sequence contrasts with other sedimentary sequences adjoining the Pilbara Block but resembles the basal units in the Proterozoic Glengarry Subgroup of the Nabberu Basin described by Bunting and others (1977).

The younger metamorphic suite lacks the high-grade gneissic foliation of the older suite, and is strongly folded by the F_2 deformation. The accompanying metamorphism is prograde in nature, with growth of muscovite, biotite and, to a lesser extent, chlorite, along the axial-planar foliation. Porphyroblastic andalusite and garnet is indicative of upper greenschist to low amphibolite facies metamorphism.

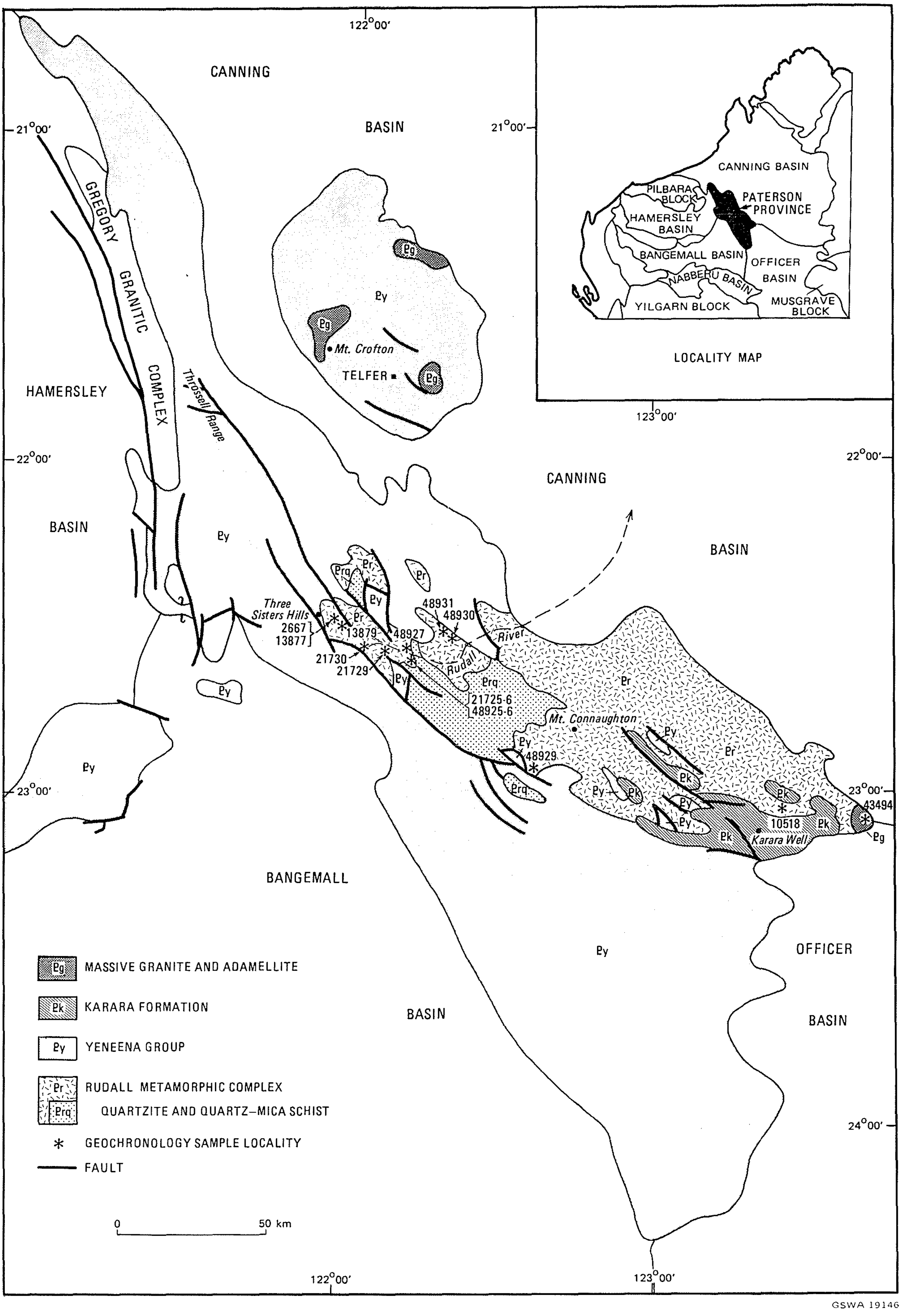


Figure 1 Geological map of the Paterson Province showing geochronology sample locations.

Towards the end of the F_2 event, bodies of serpentinized peridotite and small plugs of altered pyroxenite were emplaced into the metamorphic complex. The largest bodies are up to 1 km in diameter and have sheared margins, suggesting solid-state emplacement. These bodies resemble Alpine-type ultramafics and may, therefore, represent tectonic slices of the mantle emplaced during the deformation.

Pegmatite, dominantly rich in plagioclase, quartz and muscovite, forms dykes and veins which cut the F_2 foliation. Some veins are continuous up to the unconformity with the Yeneena Group have not been found in the Yeneena Group. However, it has not been indisputably proven that the pegmatite predates the unconformity. The mineralogy shows evidence of deformation and recrystallization during the F_3 deformation, which took place after deposition of the Yeneena Group. The pegmatite does not appear to be related to granite activity and was most probably a mobile phase, either generated during the intense F_2 metamorphism and subsequently emplaced into its present position, or generated during the early part of the F_3 event and emplaced before the end of the deformation period.

The last widespread deformation (F_3) produced crenulation and folding in the F_2 foliation of the metamorphic rocks. The resulting foliation trends north-northwesterly and is marked by slight mineral flattening and minor crystallization of sericite and chlorite along the crenulation surfaces.

SEDIMENTARY GROUPS

The Yeneena Group presumably occupied a basin, to the east of the Pilbara Block and Hamersley Basin, which extended throughout the full extent of the Paterson Province. The group consists mainly of an eastern facies of marine sandstone, shale and carbonate, and a western facies of dominantly fluviatile and deltaic conglomerate, sandstone and siltstone. The demarcation between the facies corresponds to an axial zone which controlled sedimentary patterns in the basin. This zone coincides with the western side of the Anketell Gravity Ridge (Fraser, 1974) that runs from the Throssell Range southeast to Karara Well where it swings easterly. It is thought to mark the boundary of a stable shelf to the southwest and a subsiding marine basin to the northeast. This axial zone also marks the zone of most intense thrust faulting, and strongest development of F_3 cleavage within the Yeneena Group. Southwest of this zone, the F_3 folding has an open style with little cleavage development.

The Karara Formation unconformably overlies the Yeneena Group. The uplift of the area of the Paterson Province along the zone of thrust faulting possibly initiated and confined the deposition in the Karara Formation which consists of an 1 800 m thick sequence of conglomerate, sandstone and shale. Its stratigraphic relationship to the Bangemall Group is uncertain.

GRANITE AND ADAMELLITE INTRUSIONS

Several bodies of granite and adamellite intrude the Yeneena Group. In the northern part of the province, they post-date the major folding (F_3) and accompany extensive static metamorphism in this region. The age of 598 $\pm$ 24 m.y. (581 $\pm$ 1 m.y. if a pegmatite sample is included) for one body near Mount Crofton was determined by Trendall (1974) using Rb-Sr isotopic methods.

An even-grained adamellite (informally referred to as the Runton adamellite), which forms part of the present investigation, outcrops in the extreme east of the central part of the province. Although its precise relationship to the Rudall Metamorphic Complex is not evident, the lack of metamorphic foliation suggests it is younger than the F_3 deformation.

MATERIAL ANALYSED

All the samples for Rb-Sr isotopic analyses are from the Rudall Metamorphic Complex, taken from localities shown in Figure 1. The location of sample 2669 collected by Talbot in 1908–1909 is not accurately known.

Samples comprising the randomly selected series in the initial investigation, were from the old field collections of Talbot (1910, 1920) and Blockley and de la Hunty (1975). All are retrograded biotite gneiss from the older gneiss suite. Three samples from this series have subsequently been discarded on the strong suspicion they are exotic glacial erratics, eroded from the Paterson Formation. The Archaean age which they generated was alluded to by Blockley and de la Hunty (1975, p. 116), and led to the presently unsubstantiated suggestion that ". . . remnants of Archaean rocks may have locally retained their isotopic age through a Proterozoic metamorphism". Nine samples in the first investigation were considered acceptable for the more recent dating project, for which further sampling was undertaken.

Seven different rock types were sampled; they included retrograded banded gneiss (48929, 48930), retrograded fine-grained and porphyritic granitic rocks (48925 and 48927, respectively) which intrude the gneiss, serpentinized peridotite (48926) from an ultramafic plug, intrusive pegmatite (48931) from the retrograded gneiss, and two samples (43494) from the undeformed Runton adamellite which intrudes the Rudall Metamorphic Complex. Six samples of each rock type, except 43494, were collected and these are referred to as "series" in this paper. Of these, the serpentinized peridotite (48926) proved to contain too little phlogopite for separation as a source for Rb and Sr, and preliminary XRF analysis showed that the porphyritic adamellite (48927) had insufficient spread of Rb/Sr ratios to warrant isotopic analysis.

The fine-grained adamellite samples (48925 series) were selected from a pile of abandoned drill core obtained by Northwest Oil & Minerals Co., who drilled two serpentinized peridotite plugs and the country rock in the Rudall area. The rock type selected fits most closely with the main surface exposures around the plug south of the Rudall River. The micas are predominantly metamorphic biotite which defines the F_2 foliation. Some later muscovite and chlorite, together with sericitized and epidotized feldspar, are indicative of later metamorphism or alteration.

Banded gneiss of granitic composition (48929 series) was selected from an area measuring 50 m by 100 m situated 18 km southwest of Mount Connaughton. This area is some distance from major faults and unconformities and shows little effects of later (F_3 and F_4) deformation or metamorphism. The F_2 foliation is poorly developed and the texture appears to be entirely granoblastic with no relict igneous texture. As in most samples, chloritization of biotite and saussuritization of plagioclase is widespread throughout this series of samples.

The 48930 series, from a locality 54 km northwest of Mount Connaughton, is gneiss with well-developed compositional banding and obvious retrogressive effects. Metamorphic biotite forms the directional fabric (F_2) but most of this group has extensive alteration products of epidote, muscovite, chlorite and carbonate. Quartz-epidote veining is common. Recrystallization is indicated by well-developed elongate granoblastic texture. One type of banding is represented by sharply bounded veins which formed before the F_2 deformation and metamorphism. These veins are composed of coarse-grained quartz and pink feldspar, and possibly are early pegmatitic segregations. The other type of banding is more diffuse and is expressed by compositional variations from microcline-plagioclase-quartz-biotite granofels to leucocratic granofels which is rich in microcline and devoid of biotite.

The pegmatite (48931 series) was sampled from two northwesterly trending parallel dykes about 120 m apart, located 1 km northwest of sample locality 48930. They crosscut both the gneissic banding and the F_2 metamorphic foliation of the retrograded gneiss, but have a strong F_3 cleavage. One dyke (48931A, B, C) is pegmatite composed of quartz, muscovite and abundant albite. The proportion of microcline varies from almost zero in 48931A to about equal with albite in 48931B. Samples 48931D, E and F from the other dyke are similar except that muscovite is less abundant. Minerals in both dykes are extensively crushed and crenulated by F_3. Fine sericite pervades most of the feldspar.

Two samples (43494A, B) are from the younger adamellite which intrudes the Rudall Metamorphic Complex. Sample 43494A is even-grained adamellite which intrudes weakly foliated adamellite as irregular dykes up to 1 m wide. Sample 43494B is from the weakly foliated phase. Because of similarity in composition and overall texture, these are thought to be phases of the same intrusion. The weak foliation in the early phase possibly results from the forceful injection of the younger phase.

EXPERIMENTAL PROCEDURES

The experimental procedures used in this study were essentially the same as those described by de Laeter and others (1981). The value of $^{87}Sr/^{86}Sr$ for the NBS 987 standard measured during this project was 0·710 2 $\pm$ 0·000 1, normalized to a $^{88}Sr/^{86}Sr$ value of 8·375 2. The value of 1·42 x 10^{-11} yr $^{-1}$ was used for the decay constant of ^{87}Rb (Steiger and Jäger, 1977).

RESULTS

The measured Rb/Sr and $^{87}Sr/^{86}Sr$ ratios, as well as the calculated $^{87}Rb/^{86}Sr$ ratios are given in Table 1,. Errors accompanying the data are at the 95% confidence level. The Rb and Sr concentrations for all samples except those from the first group are also listed. However, these concentrations are only accurate to $\pm$ 7 per cent and the Rb/Sr ratios may not correspond exactly with the ratios which would be derived from the separate Rb and Sr values listed.

The data listed in Table 1 are plotted in Figure 2. Regression of the data has been carried out using the least-squares programme of McIntyre and others (1966) and the results are

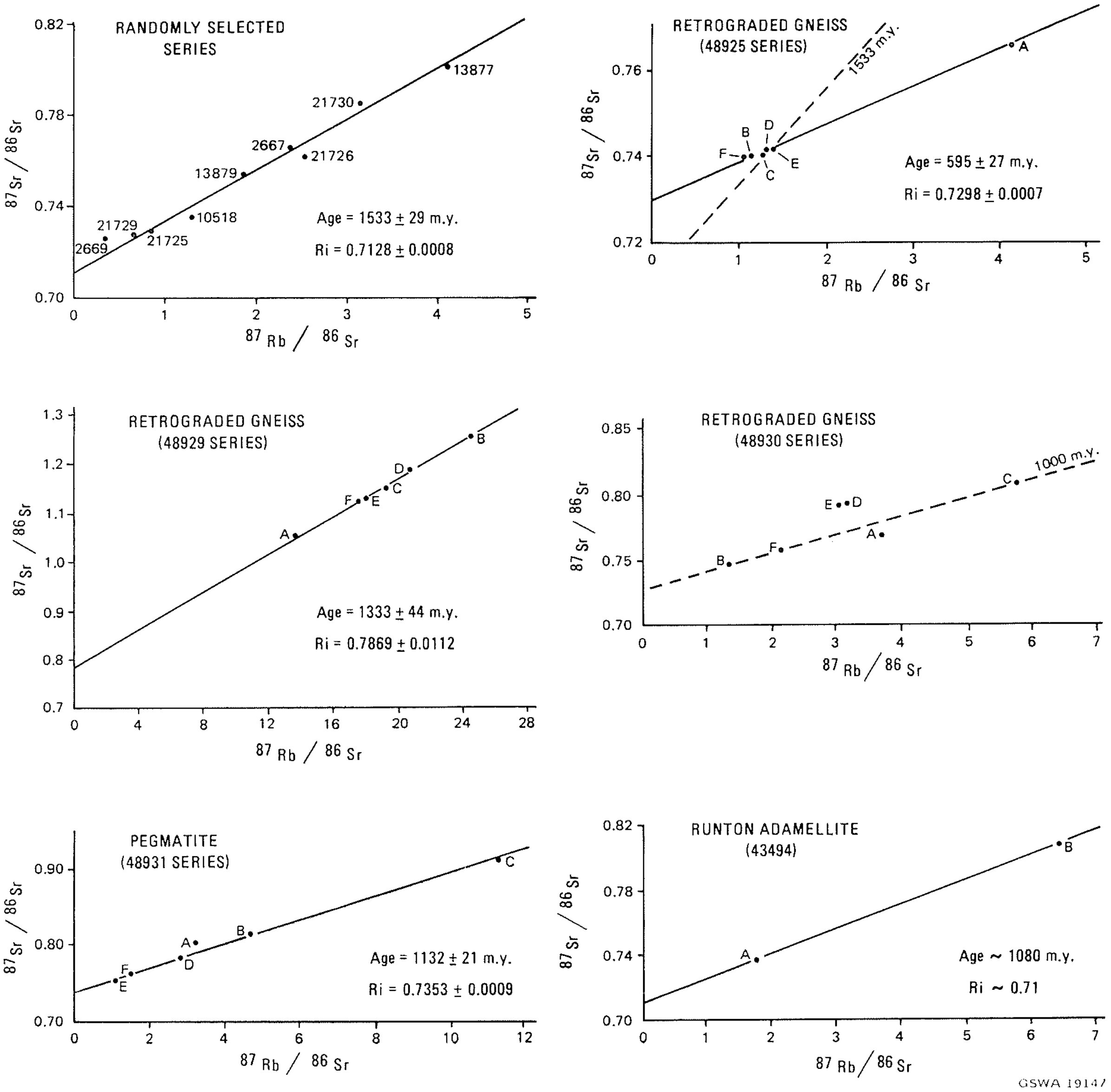


Figure 2 Rb-Sr isochron plots of sample series from the Rudall Metamorphic Complex.

summarized in Table 2. The regressed (Model 1) age (1 533 ± 29 m.y.) and initial ratio (0·712 8 ± 0·000 8) for the randomly selected series does not include samples 2669, 10518, 21726 as values for these points obviously do not form part of a well-defined isochron. The mean square of weighted deviates (MSWD) for this set of samples is 13·9. This indicates a scatter in the data which is probably due to a real variation in age.

The age of the 48925 series is 595 ± 27 m.y. with an initial ratio of 0·729 8 ± 0·000 7. The low MSWD suggests that this result can be classified as Model 1 (experimental error only). However, the reliability of this result is reduced by the fact that samples 48925B-F are concentrated over a small range and the age is consequently largely controlled by the sample 48925A. The age and initial ratio of the 48929 series is 1 333 ± 44 m.y. and 0·786 9 ± 0·011 2 and the data give a good fit. The 48930 series shows such a wide scatter of data that no computer regression was undertaken. The 48931 series give a poorly fitted isochron of 1 132 ± 21 m.y. and an initial ratio of 0·735 3 ± 0·000 9 (MSWD = 18·7). The Runton adamellite samples (43494A, B) generate a two-point isochron at about 1 080 m.y. and an initial ratio of about 0·71.

DISCUSSION

It is anticipated that the pervasive F_2 metamorphism, which has produced the metamorphic mica in the main foliation, would have the greatest control over the redistributon and homogenization of Sr isotopes. If homogenization was complete, the data will record a well-marked metamorphic date which lies between the age of the Bangemall Group and the age of the oldest known sedimentary basins which surround the Pilbara Block and from which the younger metasedimentary rocks of the Rudall Metamorphic Complex are likely to be derived. This indicates expected age limits between about 1 100 m.y. and 2 500 m.y. (Gee, 1980). High initial ratios in all series confirm prior crustal histories for the gneiss and granite prior to F_2 metamorphism but a definitive primary age for the gneiss could not be established from the results. However, the results are consistent with the older Archaean age for the gneiss that is suggested by geological considerations.

The rocks which show the least effects of alteration and metamorphism during later (F_3 and F_4) deformational events are the 48929 series which produce a good isochron at 1 333 ± 44 m.y. The high initial ratio of 0·786 9 ± 0·011 2 results from thorough metamorphic reworking of existing granitic rocks considerably enriched in Rb and ^{87}Sr relative to other samples analysed from the province. The data define a well-fitted isochron which indicates that there is sufficient homogenization of Sr isotopes over the area from which this series was selected. In view of the predominance of a single generation of metamorphic mica and corresponding metamorphic textures, the good isochron also suggests that the recorded age is that of the pervasive F_2 metamorphism at this locality.

The randomly selected series shows a high degree of scatter of data about the 1 533 m.y. isochron. Their petrology shows the predominance of the same style of F_2 metamorphic fabric as that of the 48929 series and also suggests that Sr isotope redistribution took place during this same event. The moderately high initial ratio (0·712 8 ± 0·000 8) indicates a crustal history prior to metamorphism. All samples used in the regression analysis were located in the headwaters of the

TABLE 1. ANALYTICAL DATA FOR WHOLE-ROCK SAMPLES FROM RUDALL METAMORPHIC COMPLEX

Sample	Rb (ppm)*	Sr (ppm)*	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
Randomly selected series:					
2669	....	....	0·120 5 ± 0·001	0·349 ± 0·003	0·726 9 ± 0·000 2
21729	....	....	0·237 ± 0·002	0·686 ± 0·007	0·728 1 ± 0·000 2
21725	....	....	0·306 ± 0·003	0·886 ± 0·009	0·731 8 ± 0·000 2
10518	....	....	0·461 ± 0·004	1·335 ± 0·01	0·735 5 ± 0·000 2
13879	....	....	0·650 ± 0·004	1·885 ± 0·01	0·754 2 ± 0·000 2
2667	....	....	0·825 ± 0·008	2·390 ± 0·02	0·765 2 ± 0·000 2
21726	....	....	0·875 ± 0·009	2·540 ± 0·03	0·762 9 ± 0·000 2
21730	....	....	1·080 ± 0·010	3·140 ± 0·03	0·784 6 ± 0·000 4
13877	....	....	1·416 ± 0·014	4·130 ± 0·03	0·801 2 ± 0·000 2
48925 series:					
48925F	90	244	0·370 ± 0·003	1·07 ± 0·01	0·739 34 ± 0·000 27
48925B	110	275	0·400 ± 0·004	1·16 ± 0·01	0·739 79 ± 0·000 26
48925C	128	288	0·445 ± 0·004	1·29 ± 0·01	0·740 34 ± 0·000 14
48925D	130	290	0·449 ± 0·004	1·30 ± 0·01	0·740 73 ± 0·000 28
48925E	134	285	0·468 ± 0·005	1·36 ± 0·01	0·741 20 ± 0·000 12
48925A	152	107	1·42 ± 0·01	4·12 ± 0·04	0·764 84 ± 0·000 20
48929 series:					
48929A	320	70	4·57 ± 0·10	13·63 ± 0·2	1·047 21 ± 0·000 23
48929F	355	61	5·83 ± 0·11	17·52 ± 0·2	1·124 17 ± 0·000 27
48929E	355	60	5·96 ± 0·12	17·91 ± 0·2	1·127 27 ± 0·000 19
48929C	380	60	6·37 ± 0·13	19·19 ± 0·3	1·152 60 ± 0·000 31
48929D	365	53	6·87 ± 0·14	20·75 ± 0·3	1·185 35 ± 0·000 25
48929B	400	50	8·03 ± 0·16	24·43 ± 0·3	1·252 76 ± 0·000 28
48930 series:					
48930B	125	280	0·45 ± 0·01	1·30 ± 0·02	0·748 46 ± 0·000 18
48930F	130	175	0·74 ± 0·02	2·15 ± 0·03	0·757 00 ± 0·000 21
48930E	135	130	1·05 ± 0·02	3·06 ± 0·04	0·790 52 ± 0·000 23
48930D	170	160	1·07 ± 0·02	3·11 ± 0·04	0·790 55 ± 0·000 20
48930A	200	160	1·26 ± 0·03	3·66 ± 0·05	0·768 03 ± 0·000 28
48930C	220	110	1·98 ± 0·04	5·77 ± 0·1	0·808 95 ± 0·000 24
48931 series:					
48931E	40	100	0·41 ± 0·01	1·19 ± 0·02	0·753 41 ± 0·000 18
48931F	45	80	0·54 ± 0·01	1·57 ± 0·03	0·760 56 ± 0·000 15
48931D	110	110	0·99 ± 0·02	2·88 ± 0·04	0·783 57 ± 0·000 31
48931A	110	100	1·12 ± 0·02	3·31 ± 0·08	0·799 28 ± 0·000 21
48931B	160	100	1·60 ± 0·03	4·67 ± 0·1	0·812 61 ± 0·000 25
48931C	300	85	3·50 ± 0·07	11·21 ± 0·2	0·913 08 ± 0·000 28
Runton adamellite:					
43494A	200	335	0·60 ± 0·01	1·74 ± 0·02	0·737 70 ± 0·000 18
43494B	290	130	2·19 ± 0·04	6·39 ± 0·02	0·809 37 ± 0·000 24

* Rb and Sr concentrations for randomly selected series were not determined.

Rudall River. Amongst the samples excluded were 10518 (10 km northeast of Karara Well) and 2669 whose location is not known. The scatter of points about the isochron possibly reflects lack of complete Sr isotope homogenization across the wider area of sampling in contrast to the apparent homogenization in the smaller area of collection of the 48929 series. Furthermore, slight disturbance of the isotopic system may be due to other events which are shown by the results of the other series discussed below.

From the uniform intensity and penetrative style of the F_2 metamorphism and deformation throughout the Rudall Metamorphic Complex, it can be inferred that the age of 1 333 m.y. from the controlled 48929 series is a single event. It is then likely that the isochron of the randomly selected series is a composite of an older age largely modified by the younger F_2 metamorphism. However, it cannot be altogether discounted that the closure of the Rb-Sr isotopic system occurred earlier (at 1 533 m.y.) in the northwestern part, and later (at 1 333 m.y.) in the central part, of the Rudall Metamorphic Complex.

Because the deposition of the Yeneena Group clearly postdates the F_2 metamorphic foliation, the 1 333 m.y. age is considered to be the oldest possible age so far identified for the Yeneena Group.

The 48925 series which produces a well-defined isochron at 595 ± 27 m.y. possesses F_2 metamorphic micas, but these rocks are affected by various degrees of sericitization and saussuritization of feldspar and chloritization of biotite. Most of the samples (B-F) form a cluster with an elongate distribution along the isochron. These points also cluster close to the isochron produced by the randomly selected series (see Fig. 2), and probably relate to that series.

There is no geological evidence for the event at about 600 m.y. recorded by the 48925 series in the Rudall River area. Alteration, which may be the result of an event of this age, cannot be easily distinguished from other post-F_2 metamorphic alteration. The 600 m.y. age is known from granite intrusion metamorphism in the Mount Crofton area in the northern part of the Paterson Province. Although granite intrusions which postdate the F_3 fabric are not known in the Rudall Metamorphic Complex, alteration of 600 m.y. age can reasonably be expected in the Rudall River area. Local crenulation and alteration by a later event (F_4), although not observed in retrograded gneiss, were observed in the general area and possibly provide another explanation for the scatter effects of the Rb–Sr isotopic equilibrium.

The 48930 series is located close to the Yeneena Group unconformity and consequently has been subject to significant deformation (F_3) which folds the Yeneena Group. The series has also possibly been subject to the 600 m.y. event recorded by the 48925 series. From the wide spread of the data, it is concluded that these later events resulted in some irregular distribution of the Sr isotopes. In particular, the F_3 metamorphism has initiated the growth of sericite and chlorite along the foliation but, due to the low grade of metamorphism, complete Sr homogenization was not accomplished.

Petrological observations of the 48930 series do not reveal any relationship between the degree of alteration of a sample and its position in the isotopic plot. In one instance, the most altered sample (48930E), which contains abundant carbonate sericite and epidote, plotted in almost the same position as the least altered sample (48930D) whose metamorphic biotite (generated during F_2 metamorphism) is free of alteration.

TABLE 2. WHOLE-ROCK AGES FROM RUDALL METAMORPHIC COMPLEX

Samples	No. of samples	MSWD*	Age (m.y.)	Initial ratio (R_i)	Model
Randomly selected series	6	13·9	1 533 ± 29	0·712 8 ± 0·000 8	1
			1 535 ± 91	0·712 7 ± 0·001 7	2
48925	6	1·06	595 ± 27	0·729 8 ± 0·000 7	1
48929	6	1·14	1 333 ± 44	0·786 9 ± 0·011 2	1
48930	6	N.D.	N.D.	N.D.	....
48931	6	18·7	1 132 ± 21	0·735 3 ± 0·009	1
43494	2	....	1 080	0·71	....

* Mean square of weighted deviates.
N.D. Not determined.

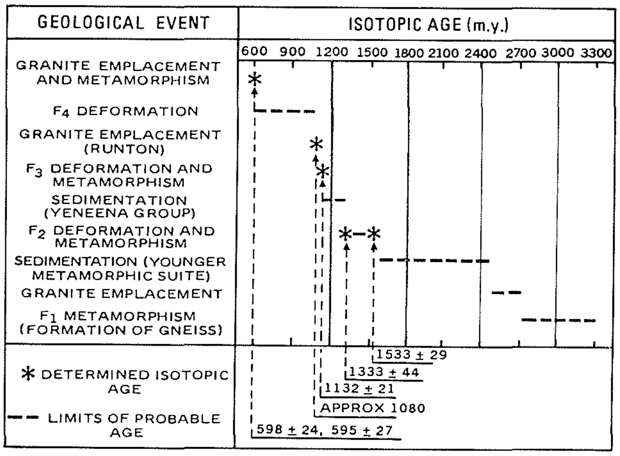
The pegmatite (48931 series) clearly was emplaced after the F_2 metamorphism had waned and if generated during that event would be expected to have an age around 1 300 m.y. It was probably subject to the same metamorphic and alteration conditions as the 48930 series, and recrystallization during the F_3 deformation may be responsible for redistribution of Sr and some scattering of points off the isochron (MSWD = 18·7). Thus the isochron may record the approximate date of the F_3 deformation in the Yeneena Group.

However, a second interpretation is that the pegmatite was generated within the Rudall Metamorphic Complex during the early part of the F_3 event but was not emplaced into the Yeneena Group. In this case 1 132 m.y. is possibly the primary age of the pegmatite. This interpretation leads to the same conclusion that this is also the approximate age for the F_3 deformation of the Yeneena Group.

The two-point isochron for the Runton adamellite samples (43494) is the first evidence obtained from the Paterson Province for granite activity along the zone of the Anketell Gravity Ridge. The age (about 1 080 m.y.) is consistent with the lack of foliation in the adamellite. The moderately high initial ratio (0·71) suggests that there is considerable crustal reworking prior to the adamellite emplacement.

CHRONOLOGICAL SUMMARY OF EVOLUTION OF THE PATERSON PROVINCE

From the geochronological results reported in this paper and the geological knowledge of the Paterson Province, the chronological sequence of events has now been established and is summarized in Figure 3.



GSWA 19148

Figure 3 Age of important geological events in the Paterson Province.

AGES OF POSSIBLY RELATED PROTEROZOIC PROVINCES

The Musgrave Block lies at the eastern end of the Anketell Gravity Ridge and, consequently, possibly comprises part of the same tectonic structure manifested by the gravity ridge. Even though the style and grade of metamorphism and deformation is different from that of the Rudall Metamorphic Complex, similar ages from gneisses and granites have been recorded.

A study of the ages of granulite metamorphism by Gray (1979) revealed an age of about 1 550 m.y. in the region north of a prominent fault (the Hinckley Fault) and 1 330 m.y. in the southern region. In the Rudall Metamorphic Complex the ages from the randomly selected series and the 48929 series correspond fairly closely to both ages in the Musgrave Block.

The ages of granitic intrusions within granulite of the Musgrave Block were determined by Arriens and Lambert (1969). Model 3 ages of 1 099 ± 27 m.y. are recommended for the isochron defined by all the granite samples and 1 098 ± 96 m.y. for the Ernabella Adamellite alone. The age is comparable to the Runton adamellite (43494) and possibly corresponds to the same tectonic activity along the Anketell Gravity Ridge. Initial ratios of about 0·71 are also comparable and may reflect a similar crustal history for both granites.

The Albany-Fraser Province, like the Paterson Province, borders an Archaean craton. In the northeastern part it contains a number of tectonic zones ranging in age between about 1 690 m.y. and 1 250 m.y. (Bunting and others, 1976). From the granulite zone in the Fraser Range, an age of 1 300 m.y. has been determined (Arriens and Lambert, 1969). Intrusions in other parts of the province have been dated at 1 077 ± 50 m.y. (initial ratio 0·712 ± 0·006) for the Albany Adamellite (Turek and Stephenson, 1966) and 1 057 ± 50 m.y. (initial ratio 0·715 ± 0·0006) from porphyritic granite at Balladonia Rock (Arriens, pers. comm., quoted by Doepel, 1975).

ACKNOWLEDGEMENTS

The authors are grateful to Mr D. J. Hosie of the Department of physics, Western Australian Institute of Technology for technical assistance during the project.

REFERENCES

Arriens, P. A., and Lambert, I. B., 1969, On the age and strontium isotopic geochemistry of granulite-facies rocks from the Fraser Range, Western Australia and the Musgrave Ranges, Central Australia: Geol. Soc. Aust. Spec. Pub. No. 2, p. 377–388.

Blockley, J. G., 1974, Notes on the Paterson Range gold prospects: West. Australia Geol. Survey Ann. Rept 1973, p. 71–73.

Blockley, J. G., and de la Hunty, L. E., 1975, Paterson Province, *in* Geology of Western Australia: West. Australia Geol. Survey Mem. 2, p. 114–119.

Bunting, J. A., Commander, D. P., and Gee, R. D., 1977, Preliminary synthesis of Lower Proterozoic stratigraphy and structure adjacent to the northern margin of the Yilgarn Block: West. Australia Geol. Survey Ann. Rept 1976, p. 43–48.

Bunting, J. A., de Laeter, J. R., and Libby, W. G., 1976, Tectonic subdivisions and geochronology of the northeastern part of the Albany-Fraser Province, Western Australia: West. Australia Geol. Survey Ann. Rept 1975, p. 117–126.

Chin, R. J., and Hickman, A. H., 1977, Proterozoic geology of the Paterson Range, W.A., 1:250 000 Sheet: West. Australia Geol. Survey Rec. 1977/11 (unpublished).

Chin, R. J., Williams, I. R., Williams, S. J., and Crowe, R. W. A., 1979, Explanatory notes on the Rudall 1:250 000 Geological Sheet, Western Australia: West. Australia Geol. Survey Rec. 1978/17.

Crowe, R. W. A., and Chin, R. J., 1978, Explanatory notes on the Runton, W.A., 1:250 000 Geological Sheet: West. Australia Geol. Survey Rec. 1977/17 (unpublished).

de Laeter, J. R., Hickman, A. H., Trendall, A. F., and Lewis, J. D., 1977, Geochronological data concerning the eastern extent of the Pilbara Block: West. Australia Geol. Survey Ann. Rept 1976, p. 56–62.

de Laeter, J. R., Williams, I. R., Rosman, K. J. R., and Libby, W. G., 1981, A definitive 3 350 m.y. age from banded gneiss, Mount Narryer area, Western Gneiss Terrain: West. Australia Geol. Survey Ann. Rept 1980, p. 94–98.

Doepel, J. J. G., 1975, Albany-Fraser Province, *in* Geology of Western Australia: West. Australia Geol. Survey Mem. 2, p. 94–102.

Fraser, A. R., 1974, Reconnaissance helicopter gravity survey of the Northwest of Western Australia, 1969: Australia Bur. Mineral Resources Rec. 1974/27.

Gee, R. D., 1979, Structure and tectonic style of the Western Australia Shield: Tectonophysics, v. 58, p. 327–369.

———— 1980, Summary of the Precambrian stratigraphy of Western Australia: West. Australia Geol. Survey Ann. Rept 1979, p. 85–90.

Gray, C. M., 1979, Geochronology of granulite-facies gneisses in the western Musgrave Block, Central Australia: Geol. Soc. Australia, Jour., v. 25, p. 403–414.

Maitland, A. G., 1919, A summary of the geology of Western Australia, *in* The Mining Handbook of Western Australia: West. Australia Geol. Survey Mem. 1, Ch. 1.

McIntyre, G. A., Brooks, C., Compston, W., and Turek, A., 1966, The statistical assessment of Rb–Sr isochrons: Jour. Geophys. Research, v. 71, p. 5459–5468.

Steiger, R. H., and Jäger, E., 1977, Subcommission on geochronology: Convention on use of decay constants in Geo- and Cosmochronology: Earth and Planetary Sci. Letters. v. 36, p. 359–362.

Talbot, H. W. B., 1910, Geological observations in the country between Wiluna, Hall's Creek, and Tanami: West. Australia Geol. Survey Bull. 39.

———— 1920, The geology and mineral resources of the Northwest, Central and Eastern Divisions between Long. 119° and 122°E and Lat. 22° and 28°S: West Australia Geol. Survey Bull. 83.

Traves, D. M., Casey, J. N., and Wells, A. T., 1956, The geology of the southwestern Canning Basin, Western Australia: Australian Bur. Mineral Resources Rept No. 29.

Trendall, A. F., 1974, The age of a granite near Mount Crofton, Paterson Range Sheet: West. Australia Geol. Survey Ann. Rept 1973, p. 92–96.

Turek, A., and Stephenson, N. C. N., 1966, The radiometric age of the Albany Granite and the Stirling Range Beds, southwest Australia: Geol. Soc. Australia Jour., v. 13, p. 449–456.

Wells, A. T., 1959, Paterson Range—4-mile geological series sheet: Australia Bur. Mineral Resources Explanatory Notes No. 17.

———— 1960, Tabletop—4-mile geological series sheet: Australia Bur. Mineral Resources Explanatory Notes No. 18.

Williams, I. R., Brakel, A. T., Chin, R. J., and Williams, S. J., 1976, The stratigraphy of the Eastern Bangemall Basin and Paterson Province: West. Australia Geol. Survey Ann. Rept 1975, p. 79–83.

Williams, I. R.. and Williams S. J., 1977, Explanatory notes on the Gunanya 1:250 000 Geological Sheet, W.A.: West. Australia Geol. Survey Rec. 1977/7 (unpublished).

Yeates, A., and Chin, R. J., 1979, Explanatory Notes Tabletop, W.A., 1:250 000 Geological Sheet: Australia Bur. Mineral Resources.

MERCURY IN SOME WESTERN AUSTRALIAN MINERALIZED ROCKS

by R. Davy, R. J. Marston and C. J. Dodd*

ABSTRACT

The mercury contents of some Western Australian mineralized rocks, together with concentrates prepared from these samples, have been determined, and show a wide range of variation. Mercury is preferentially concentrated in sphalerite where that phase is present. The stratabound copper-zinc deposits of volcanigenic origin commonly contain in excess of 1 ppm mercury. Vein deposits show a wide range of mercury (25 ppb–4·4 ppm), but magmatic nickel-copper deposits lack appreciable mercury (<200 ppb). Further research into mercury-halo prospecting in Western Australia should be directed towards the stratabound copper-zinc deposits.

INTRODUCTION

The use of Hg as a pathfinder element for base and precious metal deposits is now well documented (for example, Williston, 1964; Ozerova and others, 1975), and has been used for this purpose by various exploration organizations in Western Australia. Reference is made to its use by Cordwell (1965, at Kalgoorlie South) and by Smith (1980, at Mons Cupri), but no data pertinent to either its use in practice, or even to the presence or absence of Hg in different types of mineralization, have been published. This study is intended to provide some preliminary data on the Hg content of some mineralized rocks in Western Australia in the hope that it will stimulate more detailed studies.

An earlier study which showed that there were wide variations in the Hg content of 20 mineralized samples (Davy and Dodd, 1979) has been extended to include samples of copper mineralization collected as part of a statewide appraisal of copper occurrences (Marston, 1979). Additional samples were collected at Golden Grove and Teutonic Bore, by courtesy of Esso Exploration and Production Australia Inc. and Seltrust Mining Corporation Pty Ltd respectively.

The study has been based on that of Sears (1971). An attempt is made to classify qualitatively those types of mineralization which contain enough Hg for measurable dispersion away from the deposit. Considering the generally low content of Hg (<100 ppb†) in unmineralized rocks and soils (USGS, 1970; Jonasson, 1970; Jonasson and Boyle, 1972) and the extremely low detection limit of present-day analytical methods (about 5 ppb), deposits containing about 1 ppm Hg may be detectable at the surface by their Hg halo.

Jonasson and Sangster (1975) showed that Hg is preferentially collected in sphalerite rather than in chalcopyrite in those rocks where the two minerals occur together. In this study, therefore, the opportunity was taken to compare sphalerite and chalcopyrite concentrates and bulk ("head") sample analyses. In the case of non-cupriferous rocks, a single concentrate was obtained. In some instances this was monomineralic, but in others there was a mixture of various sulphides and heavy oxides. No attempt was made to separate pyrite and pyrrhotite concentrates from any sample. The Hg content of pyrite and pyrrhotite is generally thought to be of the same order as that of chalcopyrite (Jonasson and Boyle, 1972; Jonasson and Sangster, 1975).

*Western Australian Government Chemical Laboratories

†1 ppb = 1 x 10^{-9} g/g = 1 ng/g

PROCEDURES

SAMPLE PREPARATION

Each sample was crushed and lightly ground in a Rocklabs ring mill. A portion of the crushed material was retained for reference, and a further portion was analysed as a bulk sample. Fine-grained material less than 300 mesh BSS (53 μm aperture) was discarded.

An attempt was made to avoid contamination of the concentrates by minimizing their contact with laboratory reagents. Where possible, concentrates were obtained by separation from the less than 120 mesh and greater than 300 mesh fraction using a Frantz isodynamic magnetic separator. However, separation of concentrates from very fine-grained material or from interlocked compound-mineral grains was not possible in this way. Accordingly, separation had to be achieved using conventional tetrabromoethane and Clerici Solution heavy-liquid methods, in conjunction with the Frantz.

Clean separations of sphalerite were sometimes made but in many cases chalcopyrite concentrates contained up to 10% of other minerals, mainly pyrite or pyrrhotite. Care was taken to eliminate sphalerite from chalcopyrite concentrates. Tests on pyrite and pyrrhotite showed low values of Hg (<200 ppb) and further separation was not considered warranted because the diluent effects are contained within the limits of analytical error. The purity of the concentrates was checked at each stage by the preparation of polished sections.

All powdered samples and concentrates were refrigerated between preparation and analysis to minimize redistribution of the contained mercury.

ANALYTICAL METHOD

The method consisted of the dissolution of the sample by a concentrated nitric-hydrochloric acid mixture followed by concentrated sulphuric acid (Jonasson and others, 1973). Excess potassium permanganate ensured complete oxidation (Agemian and others, 1975), and ammonium metavanadate was used as catalyst (Dietz and others, 1973). The only residues were silica, and ferrites in nickel-bearing samples.

The contained Hg was reduced to the elemental state by stannous chloride and carried by air through a closed system to a quartz absorption cell in the optical path of a spectrometer (modified from Hatch and Ott, 1968). The absorbance of the Hg 253·7 nm line was measured and compared with several USGS standard rocks and with other prepared standards analysed by the same technique. The detection limit was 5 ppb. Statistical tests on 3 samples before commencement of routine analyses (Table 1) established the overall precision at approximately 20% (co-efficient of variation). Reliability was improved by routinely analysing samples and concentrates in duplicate.

RESULTS

The main results are given in Table 2. This provides not only the range of Hg values found but also a classification of the types of deposit, the inferred approximate temperature of formation of the mineralization, and the grade of metamorphic events affecting the deposit.

TABLE 1. STATISTICAL STUDY OF ANALYTICAL PRECISION

(Values in ppb)

GSWA No.	Deposit	Sample Type	Number of Determ-inations	Range	Mean $\bar{x}$	Standard Deviation σ	Coefficient of variation $100\sigma/\bar{x}$
59422	Golden Grove	Bulk	14	587–936	762	116	15·2
		Chalcopyrite	15	605–1 313	913	158	17·3
59425	Elverdton	Bulk	13	230–515	351	95	27·0
		Chalcopyrite	6	700–840	769	49	6·4
62929	Teutonic Bore	Bulk	8	3 265–4 022	3 561	263	7·4
		Sphalerite	6	4 495–5 915	5 047	495	9·8

HIDDEN SECRET MINE, KALGOORLIE

The apparent absence of any Hg in an Au-Te mineralized sample from the Hidden Secret Gold Mine, Kalgoorlie is notable. Conventional analysis suggested that no Hg was present, but attempts to recover Hg from a sample spiked with 100 nanograms of Hg were unsuccessful, the Hg being totally absorbed by the sample. This is probably due to the amalgamating effects of Au and particularly Te, and it is probable that the fresh rock contains several parts per million of Hg.

DISCUSSION

The Hg-halo prospecting technique is of most use in the search for blind metalliferous ore bodies. Where ore bodies, or their related caprocks, are exposed, it is considered that direct analysis for a wide range of metals of economic interest will be as cheap as, and more informative than, analysis for Hg. Though many of the deposits sampled in this study do crop out, subsequent discussion is directed towards blind ore bodies.

The results do not attempt to describe the overall Hg content of any particular mineralized body. Analyses for the deposits at Golden Grove and at Teutonic Bore, and results published for Woodlawn, NSW, and Broken Hill, NSW (Ryall, 1979a, 1979b) give some indication of the range of values expected. However, it is still possible to recognize in general terms those deposits where substantial Hg can be predicted. There is consistency between samples from deposits of the same type which suggests that the general conclusions are valid. It is recognized that a low value for a single sample from a deposit does not preclude high Hg values elsewhere in the deposit.

TYPE OF DEPOSIT AND TEMPERATURE OF FORMATION

Three main types of mineral deposit have been studied:

(a) Ni-Cu sulphide deposits associated with gabbroic and ultramafic rocks,

(b) stratabound Cu-Zn deposits, and

(c) vein deposits of various kinds.

A few deposits, such as those of the Ravensthorpe area, overlap the boundaries between vein and stratabound deposits. One sample has been taken from a metamorphosed greisen (Mount Mulgine) in mafic and ultramafic rocks, and another from a syngenetic disseminated Cu-pyrite deposit (Arrino).

The results (Table 2) indicate that the potential for using Hg to locate Ni-Cu deposits is minimal. No analysed sample contains more than 200 ppb Hg and there is little preferential concentration in the various concentrates.

The stratabound deposits are consistently high in Hg except for the Bunnawarra Cu-Zn deposit in the Murchison Province. However, the sample analysed came from the Cu-rich part of the deposit and contained no sphalerite. A Zn-rich zone (Marston, 1979, p. 129) was not tested.

The greatest variations in Hg values occur in the vein deposits. Bulk samples containing as much as 4·8 ppm (Moonlight mine, Wiluna) and as little as 25 ppb (Ridge Bros. mine, Evanston) were recorded.

The relationship between the Hg content and the type of mineralization is dependent, among other things, on:

(a) the absolute amount of Hg available,

(b) the availability of suitable minerals to retain Hg, and

(c) the temperature of formation of the deposit.

The data support the findings of Jonasson and Sangster (1975) in that sphalerite is shown to carry large amounts of Hg. Table 3 lists samples from which separate sphalerite and chalcopyrite concentrates could be obtained. In these samples, sphalerite contains up to 10 times the Hg content of the chalcopyrite. Where sphalerite and chalcopyrite co-exist the actual concentrations of Hg in the two phases is a function of the relative proportions of the minerals and a function of a partition law regulating the distribution of Hg.

Where chalcopyrite occurs separate from sphalerite there is a wide variation in Hg content, though the absolute amount is normally low. Chalcopyrite from Turtle Creek (Halls Creek Province) and from Whim Creek (Pilbara Block), which contains high Hg, also contains small inclusions of unidentified sulphides/sulphosalts, probably tetrahedrite or bournonite (Marston, 1979). These minerals are known as excellent collectors of Hg (Jonasson and Boyle, 1972) and probably contain most of the Hg.

Of the other sulphides studied, stibnite from the Moonlight mine, Wiluna, and a combined cobaltite and chalcopyrite concentrate from the Alice Mary mine, Kundip, contain 4·4 ppm and 3·2 ppm Hg, respectively. Arsenopyrite, pyrite, galena and molybdenite all contain low amounts of Hg (<700 ppb).

Many of the differences in the Hg content of the various deposits may be explicable in terms of the temperatures of formation. Suggested temperatures of formation for the mineralized deposits are given in Table 2, though in no case has geothermometry work been carried out. The estimates given are based on theoretical or actual examples from the literature; or, where deposits are considered to be of metamorphic origin, the temperature relates to the metamorphic grade given. The deposits containing most Hg are those formed between 100 and 400°C. It is unlikely that Hg, even if present in the original magma, would be retained in the high-temperature deposits. Experimental work by Reed and others (1972) and Watling and others (1973) suggests that Hg is released thermally from all sulphides at temperatures in excess of 625°C. It is unlikely that Hg would be retained in the lattice of sulphides formed above this temperature.

In the case of the low temperature sandstone hosted deposit like that of Arrino, the Cu is derived from ambient-temperature solutions which probably contained no Hg ions.

EFFECTS OF METAMORPHISM

The effects of metamorphism on Hg in mineral deposits is not fully understood. The works of Watling and others (1973), Reed and others (1972), and Ozerova and others (1975) indicate that Hg is likely to be lost during high-temperature metamorphism. However, Sears (1971), Jonasson and Sangster (1975) and Ryall (1979b) have all found high Hg levels in highly metamorphosed sulphide deposits.

The metamorphic grade of the samples studied is given in Table 2. Most deposits which contain appreciable Hg lie in greenschist facies rocks. Only in the Ravensthorpe area, at the Copper King, Last Venture and Alice Mary mines, is Hg present above 1 ppm when the metamorphic grade is amphibolite facies.

It may be significant that the Hg content of 3 veins (Ridge Bros mine, Evanston; Mistletoe mine, Day's Find; and Copper Queen mine, Mulline) from amphibolite facies terrains is quite low. Clearly more study is needed on the effects of metamorphism.

Veins which, subsequent to formation, have never been metamorphosed above greenschist facies conditions, and which contain little Hg, probably never contained any greater amount of Hg. Veins in rocks of the Ravensthorpe area are not of simple hydrothermal origin. Marston (1979, p. 135) argued that many of the Cu deposits, now in veins, are the product of metamorphic mobilisation of stratabound volcanigenic deposits. If the vein sulphides are identical in composition to the original stratabound sulphides, the original Hg content of deposits from the Ravensthorpe, Mount McMahon and Mount Desmond Groups of mines (represented here by samples from Elverdton, Ravensthorpe, Mount Benson and Mount Cattlin mines) was unusually low. However, these veins were subject to amphibolite facies metamorphism, the sulphide compositions may not be equivalent to those of the original sulphides, and Hg may have been lost from the system.

TABLE 2. MERCURY CONTENT OF ANALYSED SAMPLES CLASSIFIED BY DEPOSIT

Deposit (locality)	Mineralization	Temperature of formation (approx. °C)	No. of samples	Range of Hg Content: Bulk	Chalcopyrite	Sphalerite	Other (named)	Metamorphic grade
				parts per billion				
Nickel-Copper Deposits:								
Sally Malay (HC)	....	>1 000	3	60–150	140–300	....	....	G
Mount Sholl (P)	....	>1 000	1	110	....	....	....	LG
Carr Boyd (Y)	....	>1 000	2	40–80	30–55	....	....	LA
Mount Edwards (Y)	....	>1 000	2	60–80	110–170	....	....	MA
Mount Windarra (Y)	....	>1 000	1	110	110	....	....	MA
Nepean (Y)	....	>1 000	1	55	....	....	....	UA
Spargoville (Y)	....	>1 000	1	55	20	....	....	MA
Widgiemooltha (Y)	....	>1 000	1	100	210	....	....	MA
Stratabound Copper-Zinc Deposits				parts per million				
Yarraloola (G)	Cu-Pb-Zn	250–300	1	15	1·6	17	....	LG
Turtle Creek (HC)	Cu-Pb-Zn	250–300	2	28–38††	....	....	....	LG
			1	300††	400††	....	....	LG
Big Stubby (P)	Zn-Pb-Cu-Ba	250–300	1	16	2·7	....	....	?LG
Whim Creek (P)	Cu-Zn	250–300	1	0·54	....	....	....	}
			3	1·2–23	2·3–52	....	....	} ?LG
			1	160	....	340	....	}
Bunnawarra (M)	Cu-Zn	250–300	1	0·07	0·1	....	....	UG
Golden Grove (M)	Cu-Zn	250–300	1	0·90	1·5	16	....	}
			4	5·1–6·4	....	5·7–8·1	....	} G
			6	0·12–0·35	0·17–1·8	....	....	}
Nangaroo (Y)	Zn-Cu	250–300	1	3·7	....	....	....	}
			3	0·27–1·4	0·45–0·61	....	....	} LG
			1	2·0	....	2·4	....	}
Teutonic Bore (Y)	Zn-Cu	250–300	6	0·25–3·3	0·20–4·0	....	....	}
			6	2·7–7·1	....	3·3–11	....	} G
			2	0·65–1·0	0·85–0·86	3·1–3·5	....	}
Copper King (R)	Cu(-Zn)	?	1	0·42	1·2	4·5	....	A
Last Venture (R)	Cu-Zn	?	2	0·13–6·6	0·28–5·2	....	....	A
Vein Deposits:								
Ridge Bros, Evanston (Y)	Au	550	1	0·03	....	....	0·22 (Arsenopyrite)	HA
Mistletoe, Day's Find (Y)	Au	450–500	1	0·10	....	....	0·25 (Arsenopyrite*)	LA
Copper Queen, Mulline (Y)	Au-Cu	450–500	1	0·50	0·40	....	....	....
Gladiator, Laverton (Y)	Au	400	1	0·12	....	....	0·10 (Pyrite/ Magnetite)	G
Great Boulder (Y)	Au	400	1	0·21	....	....	0·70 (Pyrite†)	G
Hidden Secret, Kalgoorlie (Y)	Au-Te	400	1	‡	....	....	‡	G
Lilly Blanche, Roebourne (P)	Cu	400	1	2·4	2·5	....	....	?G
Q.E., Carlow Castle (P)	Cu-Au	400	1	3·7	1·3	4·5	....	?G
Moonlight, Wiluna (Y)	Au-Sb	300	1	4·8	....	....	4·4 (Stibnite)	LG
Nooka (N)	Pb-Zn	100–150	1	0·57	....	0·60	....	U
Wanernooka (N)	Cu-Pb	100–150	1	1·2	0·97	....	....	U
Mundijong (SW)	Pb	?	1	0·07	....	....	0·09 (Galena)	?
Alice Mary (R)	Au-Co	?	1	3·6	....	....	3·2 (Cobaltite + chalcopyrite)	A
Elverdton (R)	Cu-Au	?	2	0·12–0·22	0·16–0·22	....	....	A
Ravensthorpe (R)	Cu	?	1	0·14	0·08	....	....	A
Mount Benson (R)	Cu-Au	?	1	0·15	0·10**	....	....	A
Mount Cattlin (R)	Cu-Au	?	2	0·06–0·08	0·04–0·09	....	....	A

OTHER DEPOSITS				Bulk	Concentrates	
Greisen:						
Mount Mulgine (M)	Mo-W	500–700	1	0·13	0·31 (molybdenite) 0·18 (magnetite)	G
Sandstone-hosted:						
Arrino (PB)	Cu	>50	1	0·10	0·13 (Chalcopyrite)	U

KEY:
- * contains minor pyrite
- † contains minor arsenopyrite
- ‡ see discussion in text
- ** contains 10% pyrrhotite
- †† contains bournonite and tetrahedrite

LOCALITY (TECTONIC PROVINCE):
- HC Halls Creek Province
- P Pilbara Block
- Y Eastern Goldfields Province, Yilgarn Block
- G Gascoyne Province
- M Murchison Province, Yilgarn Block
- R Ravensthorpe area, S. Yilgarn Block
- SW Southwestern Yilgarn Block
- PB Perth Basin
- N Northampton Block

METAMORPHIC GRADE:
- G Greenschist Facies
- LG Lower Greenschist Facies
- UG Upper Greenschist Facies
- A Amphibolite Facies
- LA Lower Amphibolite Facies
- MA Middle Amphibolite Facies
- UA Upper Amphibolite Facies
- U Unmetamorphosed

COMPARISON OF FRESH CORE WITH PREVIOUSLY CRUSHED SAMPLES

It has been widely postulated that Hg is so mobile that only fresh samples should be analysed, and that Hg can be lost or gained through inadequate storage (e.g. Ryall, 1979c). This effect was tested on samples from Teutonic Bore. Results from samples of core were compared against equivalent samples taken by Seltrust Mining Corporation Pty Ltd, and crushed and analysed for base metals three years previously. The crushed remnants had been stored in calico bags in the open air at Boulder, Western Australia. Results are presented in Table 4. The Hg content of most of the crushed bulk samples is lower, and that of the chalcopyrite obtained from the crushed samples is much higher, than those of equivalent samples of the drill core. There is very little difference in the Hg content of the sphalerite, and it is considered that most of the variation in content between core and crushed samples is due to different proportions of sulphides in the bulk samples. However, the chalcopyrite concentrates taken from the crushed samples are consistently higher than those from fresh drill core and it is possible that there has been some migration of Hg into the chalcopyrite.

FUTURE DIRECTIONS IN Hg-HALO STUDIES IN WESTERN AUSTRALIA

This pilot study provides data which indicate that Hg is of potential use as a pathfinder element in prospecting. The study has shown that Hg in excess of 1 ppm can be expected in stratabound base-metal deposits of volcanigenic origin and also in hydrothermal veins containing Au, Sb, Zn, and possibly Co. Further research into Hg as a pathfinder element should be focused on these deposits.

Suggestions for additional work are as follows:

(i) investigation of other Western Australian base-metal and Au deposits, including other styles of mineralization;

(ii) systematic study of the distribution of Hg in individual deposits;

TABLE 3. MERCURY CONTENT OF CO-EXISTING CHALCOPYRITE AND SPHALERITE
(Values in ppb)

G.S.W.A. No.	Locality	Bulk	Chalcopyrite	Sphalerite
49048....	Copper King (Ravensthorpe)	420	1 165	4 500
59413....	Golden Grove	900	1 500	16 000
62921....	Teutonic Bore	650	860	3 500
62927....	Teutonic Bore	1 000	890	3 100
49145....	Yarraloola	15 000	1 600	16 800

TABLE 4. COMPARISON OF MERCURY IN DRILL CORE COMPARED WITH EQUIVALENT PULVERISED AND STORED MATERIAL
— Samples from Teutonic Bore
(Values in ppb)

G.S.W.A. No.	Drill Core			Pulverised samples		
	Bulk	Chalcopyrite	Sphalerite	Bulk	Chalcopyrite	Sphalerite
62921	650	860	3 500	370	2 580	3 200
62922	3 500	....	3 800	1 100	....	4 400
62923	220	200	....	150	810	....
62924	5 800	....	7 600	2 900	....	8 000
62925	1 700	1 500	....	2 900	2 750	....
62926	370	440	....	240	900	....
62927	1 000	890	3 100	910	5 100	3 300

(iii) investigation of the Hg content of surface rocks, including those in various stages of alteration and weathering, and investigation of the possible modes of transport between buried Hg-bearing mineralization and the surface;

(iv) investigation of the effects of metamorphism on the Hg content of mineralization, and of the relationships of Hg in association with mineralization by geographic province and by geologic time.

REFERENCES

Agemian, H., Aspila, K. I., and Chou, A. S. Y., 1975, A comparison of the extraction of mercury from sediments by using hydrochloric-nitric acid; sulphuric-nitric acid and hydrofluoric acid—aqua regia mixtures: Analyst, v. 100, p. 253–258.

Cordwell, K. S., 1965, Theoretical and technical aspects of rapid appraisal, *in* Lawrence, L. J., (ed.) Exploration and mining geology: Commonwealth Mining Metall. Australia and New Zealand Congress 8th Pub., v. 2, Aust. I.M.M. Melbourne, p. 61–71.

Davy, R., and Dodd, C. J., 1979, The mercury content of some Western Australian sulphide-bearing rocks: West. Australia Geol. Survey, Geochem. Rept. 16 (unpublished).

Dietz, F. D., Sell, J. L., and Bristol, D., 1973, Rapid sensitive method for the determination of mercury in a variety of biological samples: Assoc. Official Analytical Chemists Jour., v. 56, p. 378–382.

Hatch, W. R., and Ott, W. L., 1968, Determination of sub-microgram quantities of mercury by atomic absorption spectroscopy: Analyt. Chem., v. 40, p. 2 085–2 087.

Jonasson, I. R., 1970, Mercury in the natural environment: a review of recent work: Canada Geol. Survey, Pap. 70–57.

Jonasson, I. R., and Boyle, R. W., 1972, Geochemistry of mercury and origins of natural contamination of the environment: CIM Bull., p. 32–39.

Jonasson, R. I., Lynch, J. J., and Trip, W., 1973, Field and laboratory methods used in the Geological Survey of Canada in geochemical surveys. No. 12. Mercury in ores, rocks, soils, sediments and water: Canada Geol. Survey, Pap. 73–21, 22p.

Jonasson, R. I., and Sangster, D. F., 1975, Variations in the mercury content of sphalerite from some Canadian sulphide deposits, *in* Elliott, I. L., and Fletcher, W. K. (eds), Geochemical exploration 1974: Amsterdam, Elsevier, p. 313–332.

Marston, R. J., 1979, Copper mineralization in Western Australia: West. Australia Geol. Survey Mineral Resources Bull. 13.

Ozerova, N. A., Rusinov, V. L., and Ozerova, Y. K., 1975, The mercury in sulphide deposits emplaced in volcanic suites: Mineralium Deposita, v. 10, p. 228–233.

Reed, G. W., Jovanovic, S., and Tennissen, A. C., 1972, Concentrations and thermal release of Hg from iron and zinc sulphides: Earth Plan. Sci. Letters, v. 14, p. 28–30.

Ryall, W. R., 1979a, Mercury distribution in the Woodlawn massive sulphide deposit, New South Wales: Econ. Geol., v. 74, p. 1 471–1 484.

Ryall, W. R., 1979b, Mercury in the Broken Hill (NSW, Australia) lead-zinc-silver lodes: Jour. Geochem. Explor., v. 11, p. 175–194.

———— 1979c, Guidelines for the collection, preparation and storage of geochemical samples for mercury analysis: Australia C.S.I.R.O., Inst. Earth Resour., Tech. Comm. 67.

Sears, W. P., 1971, Mercury in base metal and gold ores of the Province of Quebec: CIM Special Volume 11, p. 384–390.

Smith, M. E., 1980, Mons Cupri Cu–Pb–Zn–Ag deposit, Pilbara Block, W.A.: Jour. Geochem. Explor., v. 12, p. 168–171.

United States Geological Survey, 1970, Mercury in the environment: U.S. Geol. Survey, Prof. Pap. 713.

Watling, R. J., Davis, G. R., and Meyer, W. T., 1973, Trace identification of mercury compounds as a guide to sulphide mineralization at Keel, Eire: *in* Jones, M. J. (ed.), Geochemical exploration 1972: London, Inst. Min. Metall., p. 59–70.

Williston, W. H., 1964, The mercury halo method of exploration: Engineering and Mining Jour., v. 165, p. 98–101.

SMALL CONICAL STROMATOLITES FROM THE ARCHAEAN NEAR KANOWNA, WESTERN AUSTRALIA

by K. Grey

ABSTRACT

Chert in an Archaean felsic volcanic sequence near Kanowna in the Yilgarn Block, Western Australia, contains well-preserved stromatolites, which consist of tabular sheets of small, laterally linked subcylindrical columns with conical tops. Poorly preserved filaments are present in some columns. The gross morphology of the columns invites comparison with similar forms occurring in a modern hot-spring environment in Yellowstone National Park, U.S.A. The chert is poorly exposed, but most probably occurs in an olistostrome at the base of a basinal slope. The stromatolites may have been constructed during hydrothermal activity in the surrounding volcaniclastic sequence from which the chert blocks were derived.

INTRODUCTION

Samples of chert collected in late 1979 from a complex Archaean mafic-felsic volcaniclastic sequence near Kanowna by R. D. Gee, A. H. Hickman and myself provided some well preserved columnar stromatolites.

The discovery is of significance because few stromatolite horizons have been recorded in the Archaean (Walter, 1978), and this is the first documentation of stromatolites in the Archaean of the Yilgarn Block. Furthermore, only a few of the known occurrences of Archaean stromatolites are of conical shape. The oldest well-established occurrence of stromatolites is a domal form in the 3·4 to 3·5 b.y. old Warrawoona Group of the eastern Pilbara Block (Walter and others, 1980). The oldest known conical stromatolites have also been reported from the Warrawoona Group, from a recrystallized evaporite, by Lowe (1980). Other conical forms of Archaean age occur in the Insuzi Group (Pongola Supergroup) South Africa; they are approximately 2·9 to 3·0 b.y. old, and probably formed in a tidally influenced environment associated with extensive volcanic activity (Mason and Von Brunn, 1977); yet others occur in the 2·5 to 3·0 b.y. old Belingwe Greenstone belt, Rhodesia, in a shallow-water sedimentary sequence associated with volcanic activity (Bickle and others, 1975; Martin and others, 1980). All known examples of Archaean conical stromatolites consist of small cones (usually with a relief of less than 10 cm); lack a well-defined, thickened crestal zone; are composed of fine laminae, which are laterally linked to form extensive sheets; and are found in sequences in which there is evidence of extensive volcanic activity. In all these features they resemble the conical stromatolites from Kanowna.

Although these previously described conical forms have usually been compared with *Conophyton* Maslov, a large conical stromatolite occurring in the Proterozoic, there are significant differences; the Archaean cones show a closer resemblance to stromatolites forming in hot springs in Yellowstone National Park, U.S.A. (Walter and others, 1976) and to forms of the Family Thyssagetaceae Vlasov from the Satka Formation (Lower Riphean) of the U.S.S.R. (Vlasov, 1977).

Conophyton is usually regarded as indicative of quiet water and subtidal conditions (probably below wave base). The previously described Archaean conical stromatolites have all been interpreted as occurring in shallow-water, intertidal to subtidal environments; these interpretations are based to some extent on comparisons with *Conophyton*. However, Archaean conical stromatolites need not necessarily be restricted to such environments, and a possible hot-spring origin within a shallow water sequence, either marine or non-marine, should not be ruled out.

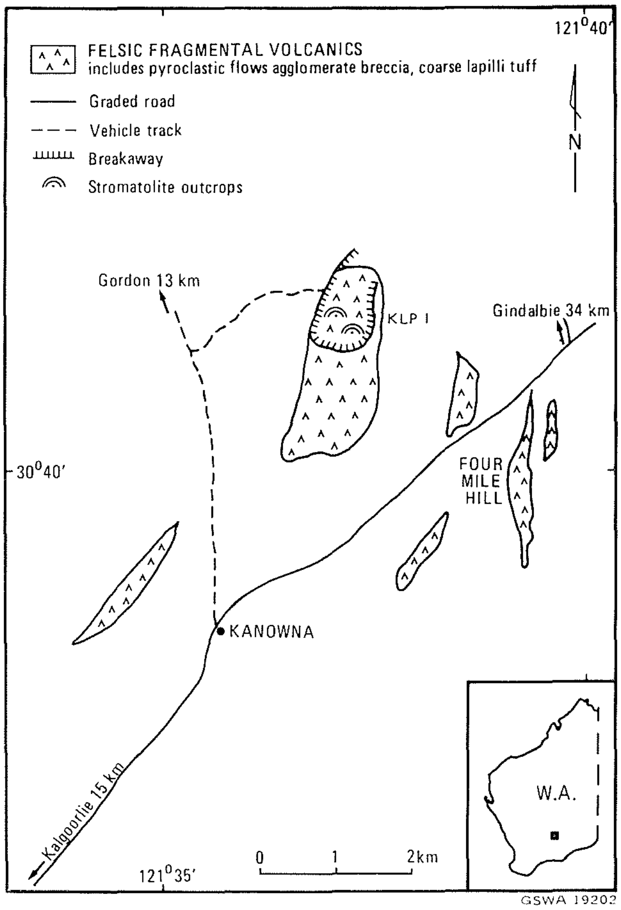


Figure I Sketch map showing stromatolite locality near Kanowna.

LOCALITY DETAILS

The stromatolites occur in two small chert outcrops at the base of a breakaway (locality KLP1) approximately 5 km north-northeast of Kanowna townsite (Fig. 1) on the western part of the Kurnalpi 1:250 000 geological sheet (121°37′E, 30°34′S). The locality is marked on the Kurnalpi geological map as an alunite deposit. It has been briefly described by Simpson (1948) and Groves and Gee (1980) who refer to it as the "alunite locality".

The Gindalbie Formation, in which the stromatolites occur, is the result of the widespread extrusion and intrusion of ultramafic and felsic igneous rocks, accompanied by the deposition of associated sediments on a platform shelf or a shallow basin-like surface (Williams, 1975). The locality at the alunite deposit has a deeply weathered, complex association of komatiitic rocks, pillowed basalts, and felsic volcaniclastics.

At both stromatolite outcrops, chert boulders protrude through a thin covering of colluvium and scree which has slipped down from the face of the breakaway. The relationship of the chert to the stratigraphically underlying and overlying units of the felsic complex is obscured by these later deposits. At one outcrop, approximately 1 m long, the chert boulders show an alignment parallel to the strike of bedding lamination, and recognizable bedding dips 70°. There is little doubt that, at this locality, the chert was largely undisturbed during the recent weathering cycle. At the second outcrop, the boulders are randomly orientated on a scree slope near the foot of the breakaway, and appear to have been disturbed by solifluction.

The cherts at both localities range from black to pale grey. In hand specimen, much of the black chert has a mottled texture and consists of finely laminated, stratiform stromatolites with

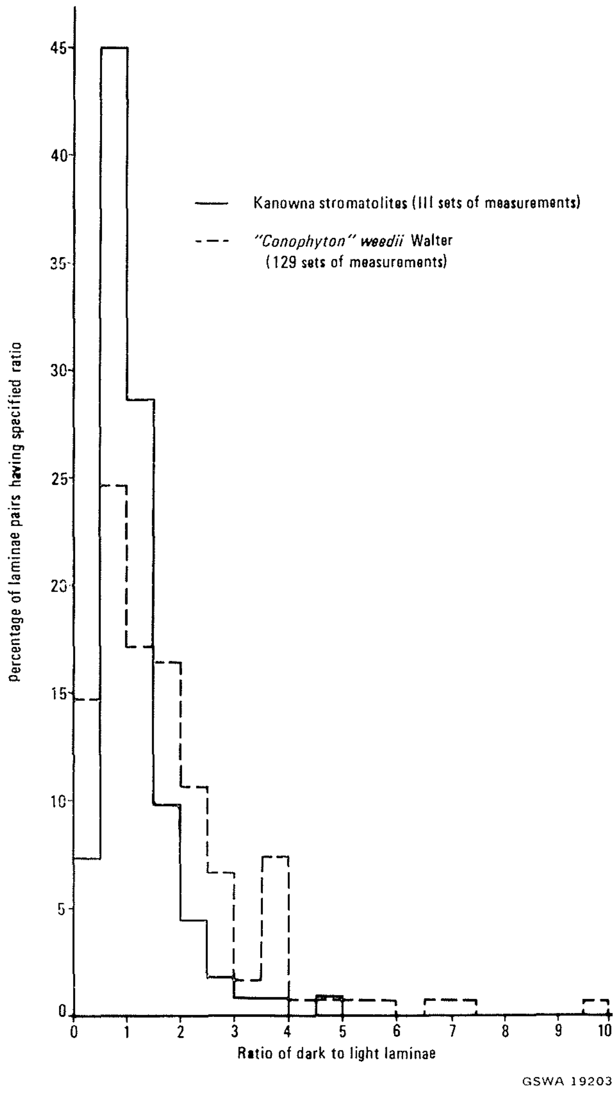


Figure 2 Frequency distribution of the ratios of dark to light laminae in the Kanowna stromatolites. A plot for the modern form "*Conophyton*" *weedii* is shown for comparison (after Walter and others, 1976 Fig. 32).

some small laterally linked columns up to 1 cm high and less than 5 mm wide. Fragments of this type of chert are less common than the dark-grey to almost white chert boulders in which the conical stromatolites occur. In hand specimen, the chert with conical stromatolites has a stripy texture with wavy laminations about 2 cm in both amplitude and wavelength. Stylolites emphasize the wavy markings, and the shape of the cones may be commonly observed on weathered surfaces.

Although the facing at one of the chert outcrops is consistent with facings in the felsic volcanics, the chert is probably not in its position of formation. Groves and Gee (1980 p. 57) quote a personal communication from T. Taylor, who interprets the complex association of rocks at the alunite deposit as having been deposited at the base of a slope in a moderately deep basin, with debris flows and olistostromes resulting from subaqueous slumping in a volcanic environment. The stromatolitic cherts are probably large olistoliths, which slipped down the basinal slope as large tabular blocks.

The Gindalbie Formation is older than 2·6 b.y. (Williams, 1975), the general age of granite intrusion; and Gee (1980) concluded that the greenstones of the Yilgarn Block are probably about 2·8 to 2·7 b.y. old.

DESCRIPTION OF STROMATOLITES

MODE OF OCCURRENCE

The stromatolites occur in sheets averaging 2 cm but ranging from a few millimetres to 3 cm or more thick. The upper and lower boundaries of a sheet are marked by a discontinuity of the columns (Fig. 3C) and by stylolites. The extent of the sheets cannot be determined because of the fragmented nature of the samples, but they may grade laterally into black cherts with small pillar-like columns and finely laminated stratiform stromatolites.

COLUMN SHAPE

Columns are subcylindrical and erect, and normally have conical tops (Figs 3A, B, C), although some have flattened tops. Transverse sections are subcircular to oval. Oval columns usually show a parallel elongation. Columns range from 0·6 to 3 cm in diameter, but the majority are about 1·5 cm wide. The columns can be 8 cm or more in height, but the height of an individual lamina above the substrate (the synoptic relief) is approximately 2·5 cm. The distance between the apices of the columns is variable, but is usually between 1 and 2 cm. Columns are usually contiguous.

Ridges and small spinose projections are commonly present; and on weathered surfaces or in vertical sections are marked by lines of darker chert approximately 1 mm wide which are formed by small superimposed peaks in successive laminae. The ridges have a radial orientation (Fig. 3B).

LAMINA SHAPE

Laminae are irregularly conical (Figs 3C, D) with sharp to blunt apices. The apical line is difficult to detect but is gently wavy. Laminae are mostly smooth, but some are wrinkled and wavy.

CRESTAL ZONE

The nature of the crestal zone is difficult to determine, because it is poorly defined and narrow, being rarely wider than 2 mm. The laminae appear to be at least twice as thick in the crestal zone as they are on the flanks.

MICROSTRUCTURE

The stromatolites have a streaky microstructure (one in which the laminae are moderately continuous, and the darker laminae are usually the more distinct). The laminae range between 3 and 176 μm thick. The thinnest laminae were probably formed by single filaments. Some of the thicker laminae have a linear fabric arranged perpendicular to the laminae (Fig. 3D) which may indicate the distribution of former microbial filaments. This radial fabric is best preserved in the black cherts associated with the conical stromatolites (Fig. 3E).

Dark laminae range in thickness from 4 to 176 μm (with a mean of 15 μm for 111 measurements) and light laminae from 3 to 107 μm (with a mean of 14 μm for 111 measurements). Both types of laminae have a texture in which the mineral grains are bounded by crystal faces (idiotopic), and are formed by quartz with average grain size of 10 μm. The dark laminae owe their colour to finely disseminated pigment, probably organic carbon. The pigment is often clustered as a diffuse sphere at the centre of each quartz grain (Fig. 3F) and may also be concentrated around grain boundaries.

SECONDARY ALTERATION

The stromatolites consist of coarse-grained chert, which has undergone some recrystallization (indicated by the redistribution of pigment along the grain boundaries), but which does not appear to be a replacement of carbonate. There has been little disturbance of the fabric of the conical stromatolites and the laminated black cherts; poorly preserved microbial filaments (Figs 3G, H) can be recognized and the redistribution of the pigment along the grain boundaries is only partial. No relict carbonate rhombs were recognized other than small siderite crystals.

DISCUSSION

The Kanowna stromatolites can be distinguished from conical forms of the group *Conophyton* Maslov by the presence of lateral linkage. They are also very small compared with most forms of *Conophyton* and do not have a well-developed thickened crestal zone. They resemble more closely some of the groups of the Family Thyssagetaceae recently erected by Vlasov (1977), and their closest resemblance is with the modern, linked, conical stromatolites described by Walter and others (1976, particularly figures 8, 11, 12) from the hot springs of Yellowstone National Park and named *Conophyton weedii* by Walter. Hofmann (1980) emphasised the fact that the original diagnosis of *Conophyton* includes only columnar, unlinked structures. The form *weedii* should not be classified in *Conophyton* but should be placed in Thyssagetaceae. Both "*Conophyton*" *weedii* and the Kanowna form have characteristics typical of the group *Thyssagetes*, but more detailed comparison is necessary before formally naming them.

The resemblance between "*Conophyton*" *weedii* and the Kanowna stromatolites extends to the presence of small spines and ridges (Figs 3B, C) the shape of the cones in cross-section (Fig. 3C) and the similarity of laminae thicknesses (Fig. 2). The main difference is in the nature of the crestal zone, which is wider and better developed in "*Conophyton*" *weedii*.

The poor preservation of microbial filaments in the Kanowna stromatolites prevents a detailed assessment of the nature of the stromatolite-building organisms. The filaments are best preserved in the laminated black cherts (Figs 3G, H). They were probably several tens of micrometres long and are approximately 5 μm thick. The vertical tube-like structures cross-cutting the laminae suggest that the organisms coped with burial by either growing (a phototropic response) or gliding (a photoactic response) towards a light source. Studies of Yellowstone conical stromatolites (Walter and others, 1976) indicate that their morphology is a result of the response of the constructing organisms to light in a quiet-water environment, and of cohesion of the filaments. Walter (1980) suggests that the Insuzi conical stromatolites may have been constructed by finely filamentous, phototactic micro-organisms. These may have been similar to the cyanobacterium *Phormidium*, which is the principal organism involved in the construction of the Yellowstone stromatolites. The Kanowna stromatolites were probably also constructed by finely filamentous, light-seeking organisms.

A shallow-water, subtidal to intertidal environment has been suggested for stromatolites from Warrawoona (Lowe, 1980), Insuzi (Mason and Von Brunn, 1977) and Belingwe (Bickle and others 1975; Martin and others, 1980). To some extent in each of these examples the evidence for a marine environment is based on an analogy between the conical

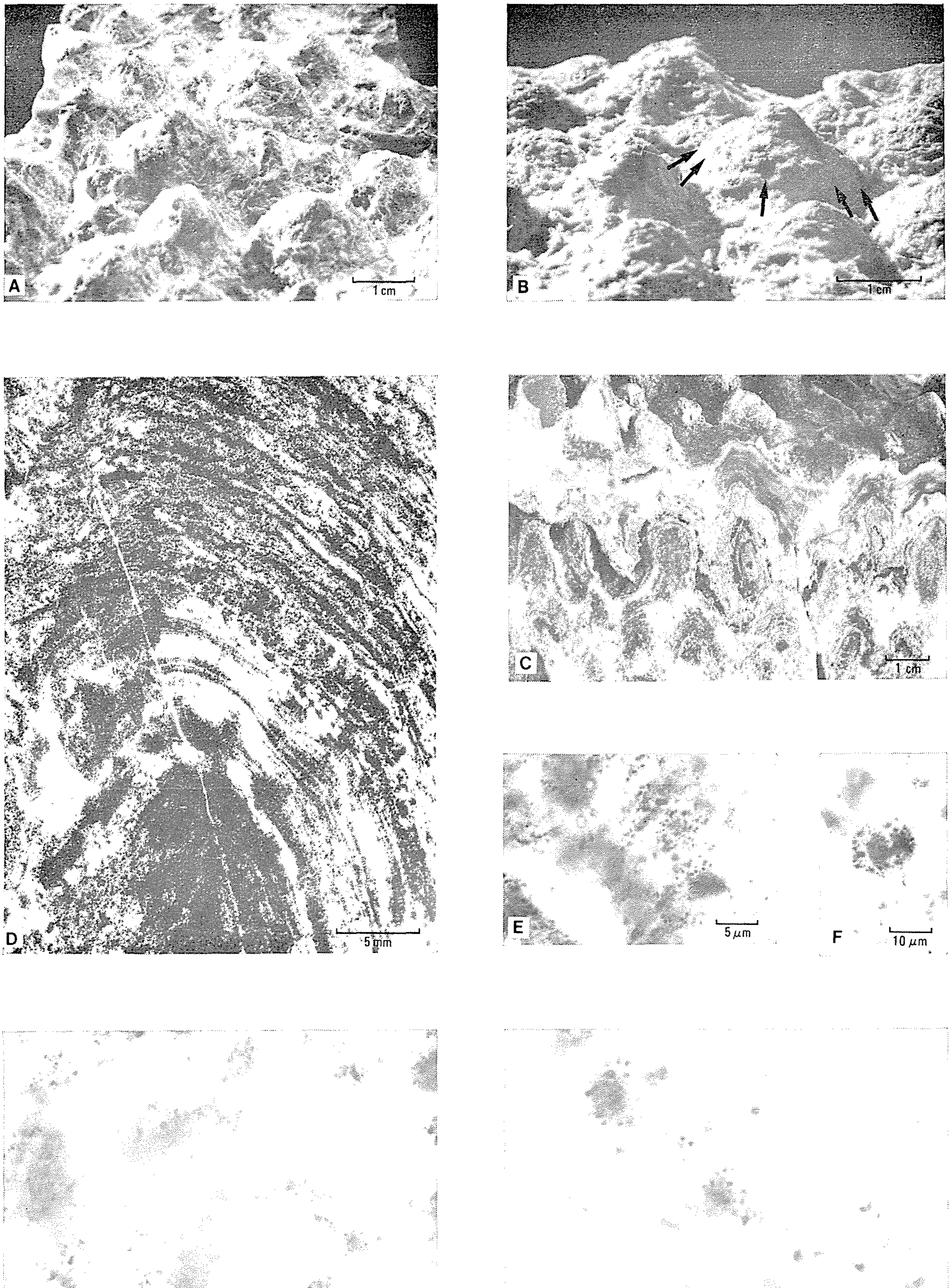
Figure 3 Conical stromatolites and black laminated cherts from Kanowna.

(A) and (B) (GSWA F11668) (A) Conical stromatolites on weathered surface. (B) Detail of cones showing ridges of darker chert (arrowed) radiating from tip of cone.

(C) (GSWA F11670)—Cut surface showing super-position of sheets of contiguous cones. Note the irregular lamina profile where small crests indicate the position of radiating ridges.

(D) (GSWA F11658)—Thin section of cone showing finely-banded laminae. Note the fine radiating structure cross-cutting dark laminae.

(E), (F), (G), and (H) (GSWA F11659) Microstructures from a black chert associated with the conical stromatolites. Coordinates are for Leitz Orthoplan microscope 834965. (E) Detail of radiating fabric showing possible filament tubes cross-cutting dark lamina. Coordinates 304, 1311. (F) Sphere of probable organic material at the centre of a quartz grain. Coordinates 294, 1266. (G) Poorly preserved filament cross-cutting a crystal boundary. Coordinates 554, 1107. (H) Poorly preserved filament. Coordinates 289, 1286.


A
1 cm
B
1 cm
D
5 mm
C
1 cm
E
5 μm
F
10 μm
G
10 μm
H
5 μm

stromatolites and the group *Conophyton*, for which Donaldson (1976) proposed a subtidal, quiet-water growth environment. In fact the small conical stromatolites are not *Conophyton*, and therefore cannot be regarded as unequivocally indicating a marine environment. In addition, *Conophyton* is rarely associated with the type of shallow-water and evaporitic structures described from sequences containing the small Archaean conical stromatolites. These small cones most probably occurred subaqueously, and most probably in quiet-water conditions, but not necessarily in a shallow-marine environment; lacustrine or hot-spring environments should also be considered.

The very close morphological similarity between the Kanowna and Yellowstone conical stromatolites suggests that sequences containing small conical stromatolites should be examined carefully for evidence of hydrothermal activity. If the stromatolites were constructed by an organism similar to the modern *Phormidium*, it is quite possible that they occupied a niche in the Archaean similar to that which they occupy at the present day. In this respect, it is interesting to note that the stromatolites from the Warrawoona and Isuzi Groups and from the Belingwe greenstone belt, as well as those from Kanowna, all occur within volcanic sequences.

Walter (1976) suggests that former alkaline hot springs can be recognised by the presence of volcanic rocks, the extensive hydrothermal alteration of host rocks, the presence of geyserite and other siliceous-sediment types, particularly siliceous stromatolites and diatomites, and by a limited areal extent. It is difficult to apply these criteria to the Kanowna stromatolites, which are present at a locality where deep weathering has obscured any trace of hydrothermal activity. The sequence in which the stromatolites now occur is considered by T. Taylor in a personal communication to Groves and Gee (1980, p. 57) ". . . to be the base of a slope in a moderately deep basin in which komatiitic volcanism was proceeding. Intermittent slumping on the subaqueous flanks of the basin produced conglomeratic debris flows and olistostromes", which probably included the stromatolitic cherts. Taylor mentions that the ". . . ultimate provenance of the felsic tuffwackes was presumably subaerial felsic volcanism", so that it is quite probable that the stromatolites grew in hot springs associated with this volcanism, rather than in a marine tidal to subtidal environment.

CONCLUSIONS

Stromatolites are often considered to be indicators of shallow-water, marine environments; but modern stromatolites occur in a wide variety of environments, including hot springs. The remarkable similarity between conical stromatolites from Kanowna and those from Yellowstone suggests that the possibility of a hot-spring environment should not be overlooked in interpreting these Archaean forms.

REFERENCES

Bickle, M. J., Martin, A., and Nisbet, E. G., 1975, Basaltic and peridotitic komatiites and stromatolites above a basal unconformity in the Belingwe greenstone belt, Rhodesia: Earth Planet, Sci. Lett. v. 27(2), p. 155–162.

Donaldson, J. A., 1976, Palaeoecology of Conophyton and associated stromatolites in the Precambrian Dismal Lakes and Rae Groups, Canada; *in* M. R. Walter (editor), Stromatolites: Elsevier, Amsterdam, p. 523–534.

Gee, R. D., 1980, Summary of the Precambrian stratigraphy of Western Australia: Geol. Survey West. Australia Ann. Rept 1979, p. 85–90.

Groves, D. I., and Gee, R. D., 1980, Regional Geology and mineral deposits of the Kalgoorlie-Norseman region: International Archaean Symposium, 2nd, Perth, 1980. Geol. Soc. Australia, Excursion Guide.

Hofmann, H. J., 1978, New stromatolites from the Aphebian Mistassini Group, Quebec: Canadian Journal Earth Sciences v. 16(4), p. 571–585.

Lowe, D. R., 1980, Stromatolites 3 400-Myr old from the Archaean of Western Australia: Nature v. 284, p. 441–443.

Martin, A., Nisbet, E. G., and Bickle, M. J., 1980, Archaean stromatolites of the Belingwe Greenstone Belt (Zimbabwe): Precambrian Research, v. 13, p. 337–362.

Mason, T. R., and Von Brunn, V., 1977, 3-Gyr-old stromatolites from South Africa: Nature v. 266, p. 47–49.

Simpson, E. S., 1948, Minerals of Western Australia, v. 1: Perth, Govt Printer.

Vlasov, F.Ya., 1977, Dokembriiskie stromatolity iz Satkinskoi svity Yuzhnogo Urala. [Precambrian stromatolites from the Satka Formation in the Southern Urals] Materialy po palaeontologii srednego paleozoya Urala i Sibiri. Sverdlovsk: Tr. Inst. Geol. Geokhim, 126 p. 101–128.

Walter, M. R., 1978, Recognition and significance of Archaean stromatolites, *in* Glover, J. E., and Groves, D. I., Archaean cherty metasediments, their sedimentology, micropalaeontology, biogeochemistry and significance to mineralization: University of Western Australia, Geology Department and Extension Service, Publication No. 2.

——— 1980, Palaeobiology of Archaean stromatolites: International Archaean Symposium, 2nd, Perth, 1980, Geol. Soc. Australia Extended Abstracts, p. 22–23.

Walter, M. R., Bauld, J., and Brock, T. D., 1976, Microbiology and morphogenesis of columnar stromatolites (*Conophyton*, *Vacerrilla*) from hot springs in Yellowstone National Park, *in* M. R. Walter (editor), Stromatolites: Amsterdam Elsevier, p. 273–310.

Walter, M. R., Buick, R., and Dunlop, J. S. R., 1980, Stromatolites 3 400–3 500-Myr old from the North Pole area, Western Australia: Nature v. 284, p. 433–445.

Williams, I. R., 1975, Eastern Goldfields Province, *in* Geology of Western Australia: West. Australia Geol. Survey Mem. 2, p. 33–54.

A DEFINITIVE 3 350 M.Y. AGE FROM BANDED GNEISS, MOUNT NARRYER AREA, WESTERN GNEISS TERRAIN

by J. R. de Laeter,* I. R. Williams, K. J. R. Rosman* and W. G. Libby

ABSTRACT

Thirteen whole-rock samples of banded gneiss from the east side of the Mount Narryer Metamorphic Belt at lat. 26°27′S, long. 116°24′30″E give a Rb-Sr age of 3 348 ± 43 m.y. with an initial $^{87}Sr/^{86}Sr$ ratio of 0·703 7 ± 0·000 5.

This date is substantially older than the 2 500 m.y. to 2 700 m.y. dates commonly reported from most of the Yilgarn Block, and confirms earlier suggestions that older Archaean rocks are involved in the Western Gneiss Terrain along the western margin of the Block.

INTRODUCTION

Regional mapping, undertaken between 1974 and 1978, on the Robinson Range (Elias and Williams, 1977), Glenburgh (Williams, Williams, and others, 1978) and Byro (Williams, Walker, and others, 1980) 1:250 000 sheets clearly delineated a high grade gneiss and migmatite belt that wrapped around the northwestern margin of the Archaean Yilgarn Block. This gneiss belt can be linked southwards to previously described gneiss terrains lying along the western margin of the Yilgarn Block (Baxter, 1974; Muhling and Low, 1977; Baxter and Lipple, 1979; Wilde and Low, 1978). It can also be traced northwards into the Gascoyne Province where reworked gneissic rocks are basement to the Proterozoic rocks of this Province (Williams, Williams, and others, 1978; and Williams, Williams and Hocking, 1980) (Fig. 1).

The extent and significance of these gneiss belts and the possible relationships with the greenstone belts of the Yilgarn Block were discussed by Gee (1979) where he referred to the West Yilgarn Gneiss Domain. In a later, expanded review, Gee and others (in press) placed the same rocks in the Western Gneiss Terrain of the Yilgarn Block.

Early Rb-Sr geochronological work by Arriens (1971) showed that dates older than 2 700 m.y. could be obtained from gneisses lying close to the western margin of the Yilgarn Block. Later, Williams, Elias and de Laeter (1978) interpreted similar gneisses along the northern margin of the Yilgarn Block on the Robinson Range 1:250 000 sheet to be older than 2 600 m.y. Similarly, to the south in the vicinity of Perth, Libby and de Laeter (1979) supported Arriens' work with isochron and model whole-rock ages older than 2 700 m.y.; more recently, Nieuwland and Compston (1980) have reported a zircon uranium-lead date from quartzite of 3 340 m.y., and from orthogneiss of 3 250 m.y.

*Department of Physics, Western Australian Institute of Technology.

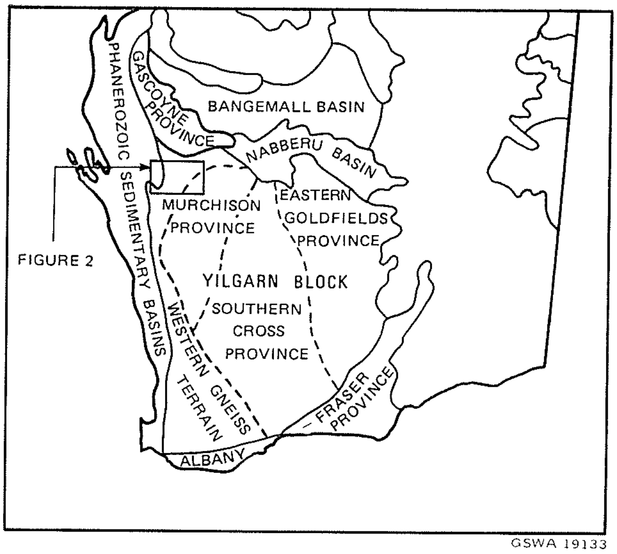


Figure 1 Regional distribution of tectonic units in the southwest of Western Australia, showing location of Mount Narryer area.

The need to obtain definitive geochronological data to back up the preliminary isotopic work and growing geological evidence that the gneiss belts were probably older than the granite-greenstone terrain of the Yilgarn Block (and perhaps therefore part of a pre-greenstone sialic basement) initiated the Older Gneiss Project in 1978.

Four localities, Goanna Bore (Glenburgh Sheet), Milly Milly, Ration Bore and Mount Narryer (all on the Byro Sheet) have, so far, been sampled. All these localities lie in the gneiss-migmatite belt between the northern limit of the Yilgarn intrusive granitoids, which have been dated at about 2 600 m.y. (see de Laeter and others, in press), and the Proterozoic Gascoyne Province.

This paper reports the first definitive early Archaean date from the Older Gneiss Project, which was obtained from the Mount Narryer area. The results and implications are briefly discussed.

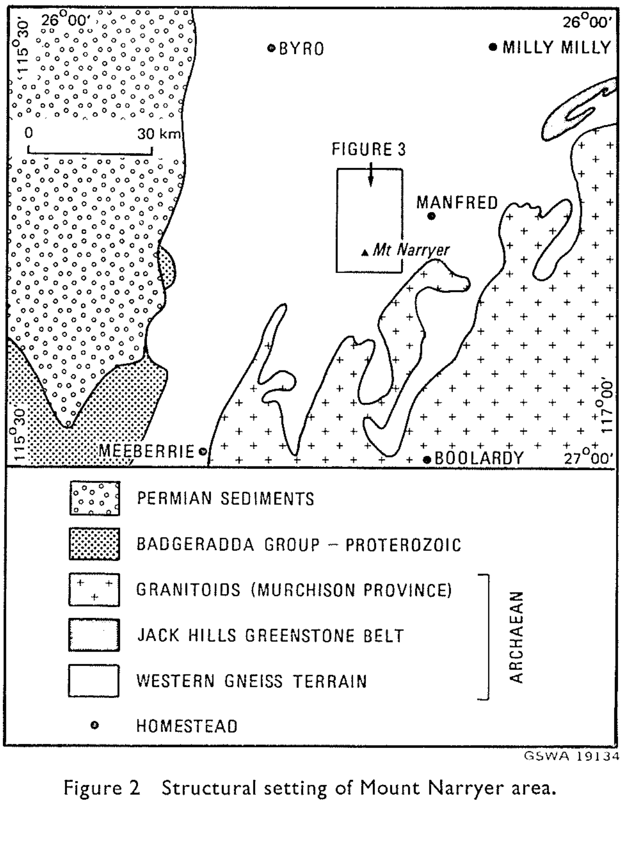


Figure 2 Structural setting of Mount Narryer area.

REGIONAL SETTING

The Mount Narryer area lies in the centre of the Byro 1:250 000 sheet, 240 km north-northeast of Mullewa. The geochronology sample sites lie 13·5 km due west of Manfred homestead and 8·5 km north-northeast of Mount Narryer trig point. Access to the sample localities can be gained along station tracks via Mindle Well from Manfred homestead, or via Warra Well from Mount Narryer homestead (Fig. 3).

Mount Narryer is the highest point in a range of rounded quartzite hills which rises 250 m above the Murchison River flood plain to the east, and the broad Murrum Creek drainage to the west. The range extends for 21 km north-northeast before being dissected by a major east-flowing drainage near Mount Dugel Well.

The Mount Narryer sequence lies near the eastern edge of the region designated the Mount Narryer Metamorphic Belt of the Western Gneiss Terrain (Gee and others, in press). Non-gneissic granitoids of the Yilgarn Block (about 2 600 m.y., belonging to the Murchison Province) crop out 10 km east of Mount Narryer. However, the Manfred Lineament, believed to be a major dislocation, lies between the granite and gneiss exposures (Williams, Walker, and others, 1980). Eroded fault scarps in colluvium, both east and west of Mount Narryer point to recent activity in this area of the Meeberrie Seismic Zone (Williams, 1979).

The Mount Narryer rocks are a high-grade (amphibolite-granulite transition facies) meta-sedimentary sequence. The large hills consist of garnet-sillimanite quartzite (some with fuchsite) interlayered with meta-conglomerate, cordierite-garnet-biotite-sillimanite gneiss and minor quartz-magnetite rock. These rocks are flanked, on both sides, by banded quartz-feldspar-biotite gneiss, with incipient migmatization, interlayered with minor quartz-magnetite rock and amphibolite. Minor ultramafic talc-serpentine-chlorite-amphibole bodies intrude the banded gneiss on the eastern side of the Mount Narryer quartzites. A small body of two-pyroxene mafic granulite (metamorphosed gabbro) lies 10 km north-northwest of Mount Narryer in the banded gneiss. Apart from a small orthogneiss component (non-banded adamellite or granodiorite gneiss) the Mount Narryer sequence appears to have been derived from sediments deposited in a shallow-water shelf environment.

The pressure and temperature of metamorphism of sillimanite-garnet-cordierite-biotite gneiss have been calculated at 510 MPa and 785°C (Blight and Barley, 1981) from co-existing cordierite-garnet pairs in association with sillimanite. The paragneiss providing the pressure and temperature information is interlayered in the quartzite unit at Mount Narryer, which is adjacent to the biotite gneiss unit which was dated.

Both the compositional banding in the gneiss and gneissic foliation have near vertical dips with a general northerly trend. However, the quartzites at Mount Narryer outline a vertical to steep south-plunging synformal structure which is gently bowed at the east (Fig. 3).

The geochronology samples were taken from banded gneiss lying on the eastern side of the quartzite ridge at Mount Narryer.

MATERIAL ANALYSED

Twenty-seven samples of banded gneiss were collected near Mount Narryer for the Older Gneiss Project. Twenty-five samples (numbers 60735 to 60738 and 69625 to 69645) came from fresh exposures lying northeast and southwest of the Manfred-Meeberrie Station boundary fence (lat. 26°27′S; long. 116°24′30″E). The samples were collected from an area of about 14·8 ha with distances between samples ranging from 1·5 m to 450 m. A map compiled with compass and tape, of the localities sampled (marked by steel pegs in the field) is given in Figure 4. All pegged samples within the mapped area are located on the map, though several have not been analyzed.

All samples are banded to nebulitically-banded quartz-feldspar-biotite gneiss, compositionally hovering between adamellite and granodiorite. Microcline is present in all samples, and plagioclase, where determined, is always oligoclase. Samples rich in quartz and microcline contain metamict allanite. All specimens show secondary deformation and recrystallization beyond the primary gneissiose structure. Alteration products include saussuritized plagioclase, powdery aggregates of epidote, and chlorite derived from recrystallization of biotite.

One group (samples 60738, 69627, and 69636 to 69645) lying southwest of the boundary fence have protomylonitic textures. The rock types are summarized in Table 1.

A single sample, 60734, came from an outcrop 2·1 km northeast of the main locality (lat. 26°26′00″S, long. 116°25′30″E). This rock is a banded biotite-amphibole-cummingtonite granodiorite gneiss.

A second sample, 60739, a plagioclase-quartz-epidote gneiss, comes from 350 m on a bearing of 295° from the main locality.

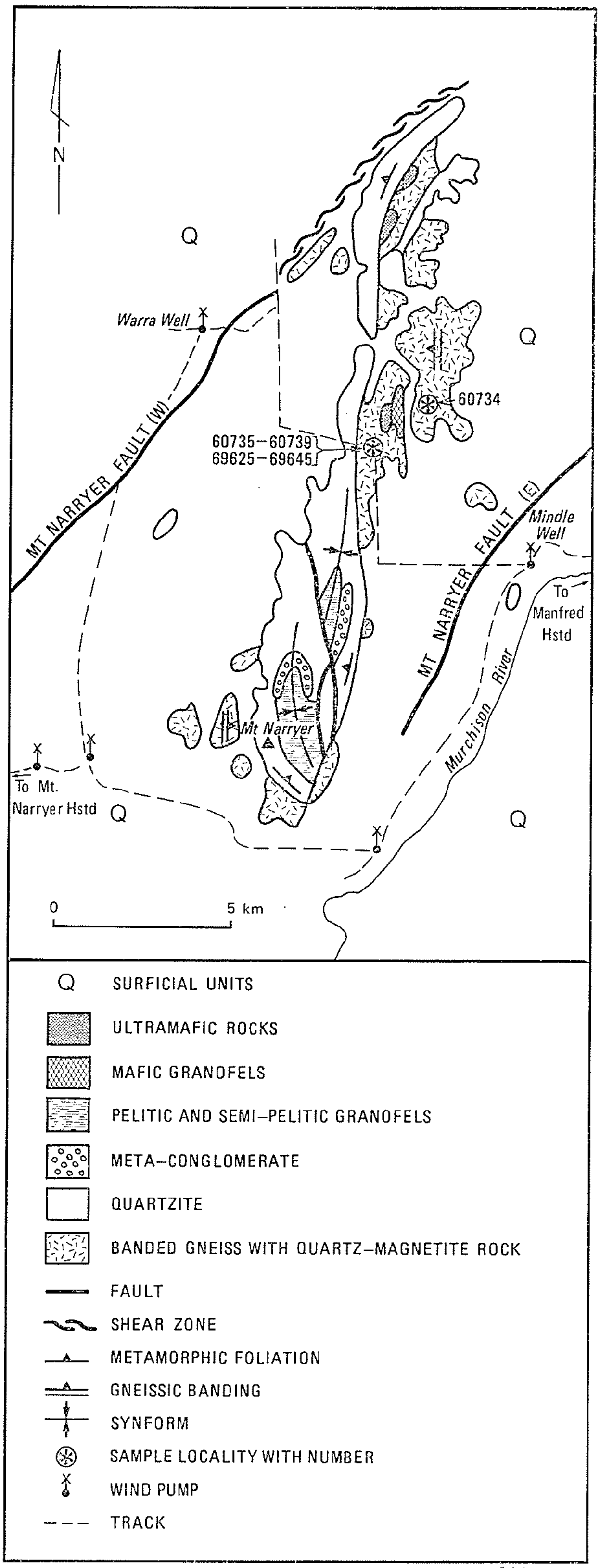


Figure 3 Simplified geological map of the Mount Narryer area.

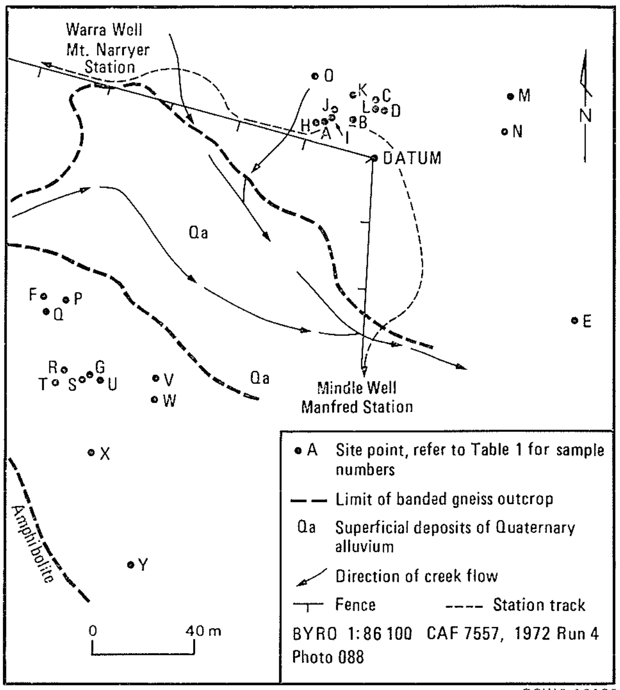


Figure 4 Detailed map of sampling localities, Mount Narryer area.

EXPERIMENTAL PROCEDURES

About 200 g of each sample was reduced to —200 mesh using a jaw crusher and a Tema-type mill. Approximately 0·4 g of each powdered sample was taken into solution using a HF-$HClO_4$ mixture. The solution was taken to dryness and the residue converted to the chloride form with 6M HCl. The concentration of the final solution was 1M HCl. After centrifuging, the supernate was transferred to a quartz ion-exchange column containing 2 g of BIORAD AG 50W-X8, 200–400 mesh cation exchange resin. Rubidium and strontium were eluted using conventional ion-exchange chemistry, and after being taken to dryness, mounted on a single zone-refined tantalum filament assembly ready for mass spectrometric analysis.

Blank determinations using the isotope dilution technique showed that the Rb and Sr contamination introduced by the chemical processing was less than 10^{-9} g and 10^{-8} g respectively. Full details of the isotope dilution technique used in this laboratory are given by de Laeter and Abercrombie (1970) and de Laeter (1976).

Isotope analyses were carried out in a 30·5 cm radius, 90° magnetic sector, solid-source mass spectrometer.

The Sr samples were loaded on to previously out-gassed tantalum filaments in dilute H_3PO_4. No evidence of Sr contamination from the ion source or filaments was observed. Microgram-sized samples produced an ion beam of approximately 10^{-11} amps for several hours. The resulting signals were amplified by an electron multiplier followed by a Model 401 Carey vibrating reed electrometer. After digitization using an integrating digital voltmeter, the signals were fed on-line to a mini-computer. Switching of the magnetic field was used to bring the centres of the isotopic ion beams to the collector. Switching was performed in a down-mass/up-mass sequence. Seven, one-second counts were taken on each peak with an eight-second delay after peak switching. Baseline measurements were taken on both the high-and low-mass sides of each peak. The non-linearity of the measuring system was established using a high accuracy potential divider, and a correction was made for this by the computer programme. During Sr analyses, mass 85 was monitored on a sensitive scale to ensure that no Rb was present.

Replicate analyses of the NBS 987 Sr standard were made, to give an average value of $^{87}Sr/^{86}Sr$ of 0·710 21 ± 0·000 08 normalized to a $^{88}Sr/^{86}Sr$ of 8·375 2. A decay constant for ^{87}Rb of $1·42 \times 10^{-11}$ yr^{-1} was used to calculate the age (Steiger and Jäger, 1977).

X-ray fluorescence was used to select rocks with favourable Rb/Sr ratios and Rb and Sr concentrations for mass spectrometric analysis, and also to determine the precise value of Rb-Sr for the selected samples. A Siemen's SRS 200 fluorescence spectrometer equipped with a molybdenum tube, a lithium

TABLE 1. DESCRIPTION OF ROCK TYPES

Site No. (shown on Figure 4)	G.S.W.A. Sample No.	Isochron	Rock type	Remarks
A	60737	X	Quartz biotite adamellite gneiss	Partly recrystallized, deformed
B	60736	X	Biotite granodiorite gneiss	Recrystallized, deformed
C	60735	X	Boitite adamellite gneiss	Slightly recrystallized, deformed
D	69626	X	Biotite adamellite gneiss	Seriate, partly recrystallized, deformed
E	69625	X	Biotite adamellite gneiss	Seriate, partly recrystallized, weak deformation
F	60738	X	Biotite adamellite gneiss	Seriate, partly recrystallized, protomylonitic fabric
G	69627	X	Biotite adamellite gneiss	Seriate, partly recrystallized, protomylonitic fabric
H	69628	....	Biotite granodiorite gneiss	Recrystallized, deformed
I	69629	....	Quartz-biotite granodiorite gneiss	Recrystallized, deformed
J	69630	....	Biotite granodiorite gneiss	Recrystallized, deformed
K	69631	....	Biotite granodiorite gneiss	Recrystallized, deformed
L	69632	....	Biotite granodiorite gneiss	Recrystallized, deformed
M	69633	....	Quartz-rich adamellite gneiss	Recrystallized, deformed
N	69634	X	Biotite granodiorite gneiss	Recrystallized, deformed
O	69635	....	Biotite granodiorite gneiss	Recrystallized, deformed
P	69636	X	Biotite adamellite gneiss	Recrystallized, protomylonitic fabric
Q	69637	X	Biotite adamellite gneiss	Seriate, recrystallized, protomylonitic fabric
R	69638	X	Biotite adamellite gneiss	Recrystallized, protomylonitic fabric
S	69639	....	Biotite granodiorite gneiss	Recrystallized, protomylonitic fabric
T	69640	....	Biotite granodiorite gneiss	Recrystallized, protomylonitic fabric
U	69641	....	Biotite adamellite gneiss	Recrystallized, protomylonitic fabric
V	69642	X	Biotite adamellite gneiss	Recrystallized, protomylonitic fabric
W	69643	....	Biotite adamellite gneiss	Recrystallized, protomylonitic fabric
X	69644	....	Biotite granodiorite gneiss	Recrystallized, protomylonitic fabric
Y	69645	....	Biotite granodiorite gneiss	Recrystallized, protomylonitic fabric
2·1 km NE*	60734	X	Biotite-amphibole-cummingtonite grano-diorite gneiss	Partly recrystallized
350 m WNW*	60739	....	Plagioclase-quartz-epidote gneiss	Intensely epidotized

* Not shown on Figure 4

TABLE 2. RUBIDIUM-STRONTIUM ANALYTICAL DATA, MOUNT NARRYER

Sample	Map Symbol	Rb	Sr	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
60739*	....	3	670	0·004 5 ± 0·000 1	0·013 ± 0·001	0·719 48 ± 0·000 09
60734	....	6·7	310	0·022 ± 0·000 2	0·064 ± 0·001	0·707 03 ± 0·000 12
60736	B	17	680	0·024 ± 0·000 2	0·069 ± 0·001	0·707 20 ± 0·000 07
60737	A	60	387	0·150 ± 0·002	0·433 ± 0·005	0·724 39 ± 0·000 12
69634	N	71	485	0·154 ± 0·002	0·445 ± 0·005	0·725 03 ± 0·000 11
69626	D	61	313	0·195 ± 0·002	0·564 ± 0·005	0·731 86 ± 0·000 15
60735	C	67	265	0·254 ± 0·003	0·736 ± 0·007	0·740 07 ± 0·000 08
69625	E	97	284	0·342 ± 0·003	0·991 ± 0·009	0·750 86 ± 0·000 14
69638	R	108	195	0·554 ± 0·005	1·61 ± 0·01	0·782 63 ± 0·000 05
60738	F	112	155	0·720 ± 0·007	2·10 ± 0·02	0·803 90 ± 0·000 11
69637	Q	138	153	0·905 ± 0·009	2·64 ± 0·02	0·832 25 ± 0·000 09
69636	P	134	139	0·959 ± 0·009	2·81 ± 0·02	0·842 61 ± 0·000 08
69627	G	123	123	1·00 ± 0·01	2·93 ± 0·03	0·846 02 ± 0·000 12
69642	V	139	134	1·05 ± 0·01	3·08 ± 0·03	0·854 82 ± 0·000 14

* Sample 60739 has been omitted from the regression because of petrographic evidence of intense epidotization which may indicate chemical mobility.

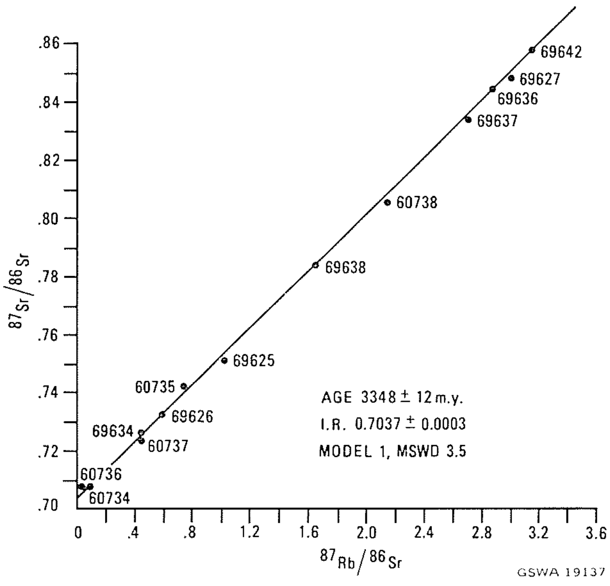


Figure 5 Rubidium-strontium isochron, Mount Narryer.

fluoride (200) crystal and a scintillation detec o was used. The spectrometer was calibrated against a set of geochemical reference samples whose Rb and Sr concentrations have been determined by isotope dilution (de Laeter and Abercrombie, 1970). Although the Rb/Sr ratios are accurate to better than 1 per cent, the individual Rb and Sr concentrations are only accurate to ± 7 per cent. Thus the Rb and Sr concentrations given in Table 2 do not necessarily correspond exactly to the stated Rb/Sr ratios. All errors are reported at the 95 per cent confidence level.

Regression analyses of the $^{87}Rb/^{86}Sr$ and $^{87}Sr/^{86}Sr$ ratios were carried out using the least squares programme of McIntyre and others (1966). If the mean square of the weighted deviates (MSWD) is <1, the regression fits within experimental error (a Model 1 isochron). An MSWD of greater than unity indicates a departure from the geological assumptions of homogenous initial $^{87}Sr/^{86}Sr$ ratios and subsequent chemical closure of all samples to Rb and Sr. The programme then tests the assumption that the geological variance, in excess of the assigned experimental errors, is proportional to the $^{87}Sr/^{86}Sr$ value for each sample. This implies that the samples have a real spread in ages (Model 2). The third model tests the assumption that the excess geological variation of $^{87}Sr/^{86}Sr$ is independent of $^{87}Rb/^{86}Sr$. This model is more appropriate for samples which have the same age but a difference in initial $^{87}Sr/^{86}Sr$ ratios. In some regressions neither Model 2 nor Model 3 is preferred, and the programme then distributes the excess geological variance as a compromise between Models 2 and 3 (Model 4).

RESULTS AND DISCUSSION

The Rb-Sr data for the Mount Narryer samples are listed in Table 2, and the rubidium-strontium isochron is shown in Figure 5.

A Model 1 regression of the analytical data yields an age of 3 348 ± 12 m.y. with an initial $^{87}Sr/^{86}Sr$ ratio of 0·703 83 ± 0·000 08 and MSWD of 10·8. Alternatively, a Model 4 date of 3 348 ± 43 m.y. with an initial ratio of 0·703 7 ± 0·000 5 m.y. is indicated.

The age and initial ratio of the data strongly supports earlier suggestions (Arriens, 1971; Gee, 1979; and Gee and others, in press) that the Western Gneiss Terrain is substantially older than the 2 500 to 2 700 m.y. dates normally recorded from elsewhere in the Yilgarn Block.

The substantial variation in dynamic metamorphism among samples seems not to have greatly disturbed the precission of the isochron. This suggests either that dynamic metamorphism is more pervasive than is apparent from petrography, almost totally resetting the isochron, or that the dynamic phase followed closely the principal phase of dynamothermal metamorphism.

Strontium evolution analysis (Libby and de Laeter, 1981) using the determined age (3 350 m.y.), the initial $^{87}Sr/^{86}Sr$ ratio (0·703 7) and the arithmetic mean of measured $^{87}Rb/^{86}Sr$ ratios (1·32) suggests a mantle evolution date of about 3 550 m.y., assuming a single-stage model. This is equivalent to a prior crustal residence time of approximately 200 m.y. Even using the highest $^{87}Sr/^{86}Sr$ value which was measured (3·08), the calculated crustal prehistory is still nearly 100 m.y.

This substantial crustal residence time is compatible with the multistage metamorphism suggested above, but is also consistent with simpler models of single stage metamorphism, of either igneous or sedimentary rocks with the indicated, or greater, crustal prehistory. The Mount Narryer rocks are interpreted, on field evidence, to be metasedimentary.

Further work is planned to document in more detail the sedimentological, metamorphic, structural and chronological history of these gneisses in the Narryer Metamorphic Belt.

ACKNOWLEDGEMENTS

The authors would like to thank Mr. D. J. Hosie of the Department of Physics, Western Australian Institute of Technology, for assistance with this project.

REFERENCES

Arriens, P. A., 1971, Archaean geochronology of Australia: International Archaean Symposium, First, Perth 1970, Geol. Soc. Australia Special Publication No. 3, p. 1–23.

Baxter, J. L., 1974, Murgoo, W.A.: West. Australia Geol. Survey 1:250 000 Geol. Series Explan. Notes.

Baxter, J. L., and Lipple, S. L., 1979, Explanatory notes on the Perenjori 1:250 000 Geological Sheet, Western Australia: West. Australia Geol. Survey Rec. 1978/16.

Blight, D. F., and Barley, M., 1981, Estimated pressure and temperature conditions from some Western Australian Precambrian metamorphic terrains: West. Australia Geol. Survey Ann. Rept 1980, p. 67–72.

de Laeter, J. R., 1976, Rb-Sr whole-rock and mineral ages from the Gascoyne Province: West. Australia Geol. Survey Ann. Rept 1975, p. 126–130.

de Laeter, J. R., and Abercrombie, I. D., 1970, Mass spectrometric isotope dilution analyses of rubidium and strontium in standard rocks: Earth and Planetary Sci. Letters v. 9, p. 327–330.

de Laeter, J. R., Libby, W. G., and Trendall, A. F., in press, The older Precambrian geochronology of Western Australia: International Archaean Symposium, Second, Perth 1980, Geol. Soc. Australia Special Publication No. 7.

Elias, M., and Williams, S. J., 1977, Explanatory notes on the Robinson Range 1:250 000 Geological Sheet, Western Australia: West. Australia Geol. Survey Rec. 1980/4.

Gee, R. D., 1979, Structure and tectonic style of the Western Australian Shield: Tectonophysics v. 58, p. 327–369.

Gee, R. D., Baxter, J. L., Wilde, S. A., and Williams, I. R., in press, Crustal development in the Archaean Yilgarn Block, Western Australia: International Archaean Symposium, Second, Perth 1980, Geol. Soc. Australia Special Publication 7.

Libby, W. G., and de Laeter, J. R., 1979, Biotite dates and cooling history at the western margin of the Yilgarn Block: West. Australia Geol. Survey Ann. Rept. 1978, p. 79–87.

Libby, W. G., and de Laeter, J. R., 1981, Rb-Sr geochronology of alkaline granitic rocks in the Eastern Goldfields Province: West. Australia Geol. Survey Ann. Rept. 1980, p. 98–103.

McIntyre, G. A., Brooks, C., Compston, W., and Turek, A., 1966, The statistical assessment of Rb-Sr isochrons: Jour. Geophys. Research v. 71, p. 5459–5468.

Muhling, P. C., and Low, G. H., 1977, Yalgoo, W.A.: West. Australia Geol. Survey 1:250 000 Geol. Series Explanatory Notes.

Nieuwland, D. A., and Compston, W., 1980, The geological history of part of the Jimperding Metamorphic Belt, west Yilgarn Block: International Archaean Symposium, Second, Perth 1980, Geol. Soc. Australia Extended Abstracts, p. 12–13.

Steiger, R. H., and Jäger, E., 1977, Subcommission on geochronology: Convention on use of decay constants in Geo- and Cosmochronology: Earth and Planetary Sci. Letters, v. 36, p. 359–362.

Wilde, S. A., and Low, G. H., 1978, Perth, W.A.: West. Australia Geol. Survey 1:250 000 Geol. Series Explan. Notes.

Williams, I. R., 1979, Recent fault scarps in the Mount Narryer area, Byro 1:250 000 Sheet: West. Australia Geol. Survey Ann. Rept 1978, p. 51–55.

Williams, S. J., Elias, M., and de Laeter, J. R., 1978, Geochronology and evolution of the Eastern Gascoyne Province and the adjacent Yilgarn Block: West. Australia Geol. Survey Ann. Rept 1977, p. 50–56.

Williams, S. J., Williams, I. R., Chin, R. J., Muhling, P. C., and Hocking, R. M., 1978, Explanatory notes on the Mount Phillips 1:250 000 Geological Sheet, Western Australia: West. Australia Geol. Survey Rec. 1978/13.

Williams, I. R., Walker, I. W., Hocking, R. M., and Williams, S. J., 1980, Explanatory notes on the Byro 1:250 000 Geological Sheet, Western Australia: West. Australia Geol. Survey Rec. 1980/5.

Williams, S. J., Williams, I. R., and Hocking, R. M., 1980, Explanatory notes on the Glenburgh 1:250 000 Geological Sheet, Western Australia: West. Australia Geol. Survey Rec. 1980/4.

Rb-Sr GEOCHRONOLOGY OF ALKALINE GRANITIC ROCKS IN THE EASTERN GOLDFIELDS PROVINCE

by W. G. Libby and J. R. de Laeter*

ABSTRACT

Isochrons from two alkaline granitic masses in the Eastern Goldfields Province of Western Australia give Rb-Sr whole-rock dates near 2 500 m.y. Rocks from Twelve Mile Well (lat. 29°55′S, long. 122°05′E) yield a model 1 date of 2 489 ± 82 m.y., with an initial $^{87}Sr/^{86}Sr$ ratio (Ri) of 0·701 2 ± 0·000 3, and a mean square of weighted deviates (MSWD) of 0·97. Samples from Woorana Well (lat. 27°30′S, long. 121°15′E), 270 km to the north, yield a model 1 date of 2 520 ± 113 m.y., with an Ri of 0·701 4 ± 0·001 7, and a MSWD of 0·70. All samples from both localities regressed together give a model 1 date of 2 512 m.y., with an Ri of 0·701 1, and a MSWD of 0·78.

Rubidium-strontium dating in general seems to be establishing alkaline plutonism as a distinctively late Archaean phenomenon in the Eastern Goldfields, and data from the present study do not support substantial crustal prehistory. Nevertheless, scattered results from other sources suggest that very mildly alkaline rocks may have been present in the area as early as 2 600 m.y. or even before 2 700 m.y.

*Department of Physics, Western Australian Institute of Technology.

INTRODUCTION

Mildly alkaline plutonic, hypabyssal and perhaps volcanic igneous bodies are scattered through the gneissic, granitoid and supracrustal rocks of the Eastern Goldfields Province. Most alkaline masses lie within a north-trending belt which is 70 km wide and nearly 700 km long. Compositions range from syenite and monzonite to alkali granite. Mildly sodic clinopyroxene is characteristic, and aegirine or aegirine-augite and arfvedsonitic amphibole are present at a few locations. Libby (1978) has summarized previous studies of these rocks and has explained the terminology that will be used in this report.

The present study indicates that the alkaline suite was emplaced late in the Archaean tectonic cycle. It also suggests that some members of the suite were derived from rocks of mantle composition late in the Archaean and have been little contaminated by older crustal rocks. However, other members appear to have been injected into the crust earlier in the Archaean, and were later reworked to give the late Archaean dates which they now show.

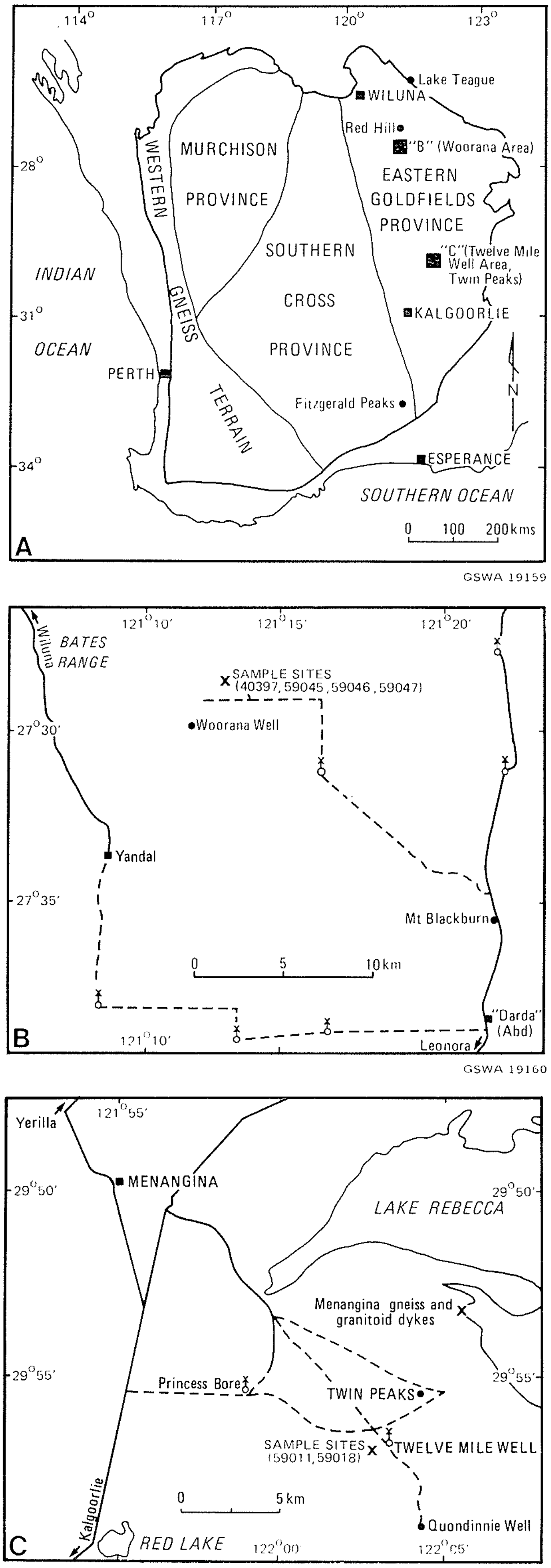


Figure 1 Index and location maps.
(A) Index map of the Yilgarn Block.
(B) Woorana Well area.
(C) Twelve Mile Well area.

New data presented here are based on two sets of samples, one from near Twelve Mile Well (lat. 29°55'S, long. 122°05'E) at the southern margin of the Edjudina 1:250 000 sheet; and the other from the vicinity of Woorana Well (lat. 27°30'S, long. 121°15'E) in the east-central part of the Sir Samuel 1:250 000 sheet. The localities are shown in Figure 1.

REGIONAL GEOLOGY

The Eastern Goldfields Province is a typical Archaean granite-greenstone terrain consisting of north-northwesterly trending belts of supracrustal rocks, separated by large masses of gneiss and granitoid plutons, and cut by smaller granitoid plutons. The regional geology has been summarized recently by Gee (1979) and Gee and others (in press), and in two guides to field excursions associated with the 1980 International Archaean Symposium in Perth (Groves and Gee, 1980; and Hallberg, 1980). The alkaline rocks have been described by Libby (1978) and by Lewis and Gower (1978). Stuckless and Bunting (written communication) have dated alkaline (2 760 m.y.) and subalkaline Mount Boreas type (2 371 m.y.) granitoids in the northern part of the Eastern Goldfields Province by Pb-Pb isochron techniques. Local geology has been mapped by Williams and others (1976) on the Edjudina sheet, and by Bunting and Williams (1979) on the Sir Samuel sheet. Further study of the chemistry of the alkaline plutonic rocks is in progress.

PETROGRAPHY

All samples are allotriomorphic seriate sodic syenite or quartz syenite, with the exception of 59011C which has similar minerals but is mafic. All samples contain albite, microcline, sphene, and variably green, mildly sodic clinopyroxene. Only three of the 13 samples have more than 10% normative quartz, and only one of these exceeds 20% normative quartz. Normative albite is low, exceeding 3% in only a single sample. Only sphene and, in rare cases, clinopyroxene achieve an approximation to crystal form. Where microcline insets are appreciably coarser than average grains, they are perthitic. Most samples have a weak preferred grain orientation.

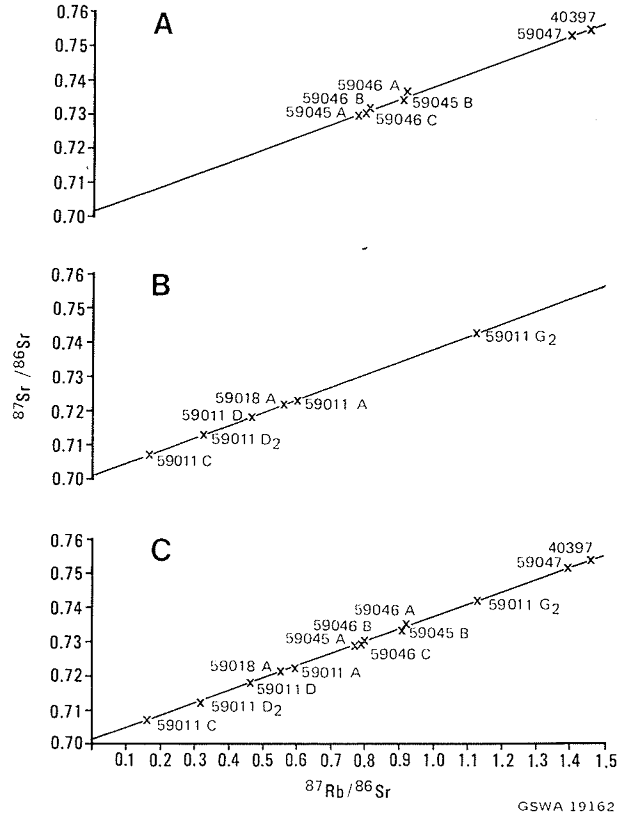


Figure 2 Isochrons
(A) Samples from Woorana Well, including 40397. Age 2520 ± 113, Ri 0.7014.
(B) Samples from Twelve Mile Well. Age 2489 ± 82, Ri 0.7012.
(C) Combined isochron of samples from Twelve Mile and Woorana Wells. Age 2512 ± 42, Ri 0.7011.

Note: For clarity in presentation the isochrons are arranged by replicating the $^{87}Sr/^{86}Sr$ axis, but all have initial ratios close to 0.701.

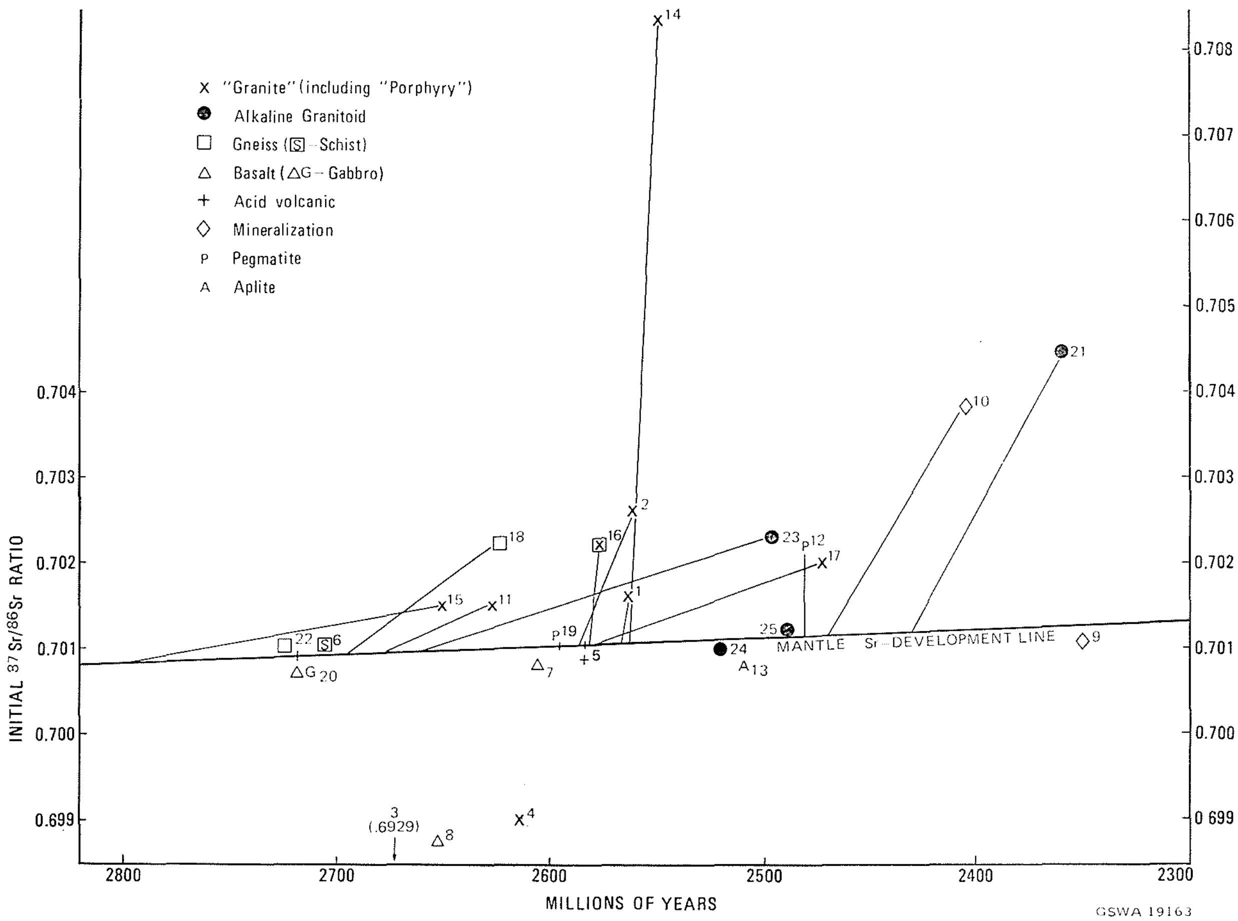


Figure 3 Strontium-evolution diagram of samples from the Eastern Goldfields Province. Parentheses indicate the point of projection on to the mantle Sr-evolution line of samples which plot beyond the limits of the graph. Samples more than 0·000 5 (Ri) below the mantle-evolution line are not projected on to the line.

A key to sources of data follows:

Sample	Author	Rock Unit
1.	Turek (1966)	Internal granites
2.	do.	External granites
3.	do.	Acid flows
4.	do.	Kalgoorlie Mine Porphyry
5.	do.	Norseman porphyritic rhyolite
6.	do.	Penneshaw acid schist
7.	do.	Paringa Basalt
8.	do.	Golden Mile Dolerite
9.	do.	Norseman quartz reefs
10.	do.	Kalgoorlie gold mineralization
11.	Roddick and others (1976)	Mount Keith Granodiorite
12.	do.	Mount Keith pegmatite
13.	do.	Aplite veins
14.	Worden and Compston (1973)	Mertondale granite
15.	Cooper and others (1978)	Lawlers tonalite
16.	do.	Lawlers Leucogranite
17.	do.	Lawlers Well Leucotonalite
18.	do.	Perseverance Gneiss
19.	do.	Perseverance pegmatite
20.	do.	Kathleen Valley Gabbro
21.	de Laeter and Lewis (1978)	Fitzgerald Peaks granitoids
22.	de Laeter and others (1978)	Menangina gneiss (Twin Peaks)
23.	do.	Menangina granite (Twin Peaks)
24.	This paper	Woorana Well
25.	do.	Twelve Mile Well

ANALYTICAL METHODS

The samples from Woorana and Twelve Mile Wells were prepared in the laboratory of the Geological Survey of Western Australia and analysed at the Department of Physics, Western Australian Institute of Technology. The methods of analysis are essentially as reported by de Laeter and others (1981). The value of $^{87}Sr/^{86}Sr$ for the NBS 987 standard measured during this project was 0·710 2 ± 0·000 1, normalized to a $^{88}Sr/^{86}Sr$ value of 8·375 2.

Measured Rb and Sr values and Rb/Sr ratios, determined by x-ray fluorescence spectrometry, are listed with mass spectrometric determinations of $^{87}Sr/^{86}Sr$ in Table 1. Errors accompanying the data are at the 95% confidence level. We believe the values of Rb and Sr are accurate to ± 7 per cent; however, the measured Rb/Sr ratios may not correspond precisely with ratios which would be derived from the separate Rb and Sr values listed.

RESULTS

Analytical results listed in Table 1 are plotted as isochrons on Figure 2. Sample 40397 is included in the results as it is from the Woorana Well locality, though analytical data are included in an earlier report (Bunting and others, 1980). The data for these samples have been regressed using the least squares programme of McIntyre and others (1966). The value $1{\cdot}42 \times 10^{-11} yr^{-1}$ was used for the decay constant of

TABLE 1. ANALYTICAL DATA FOR WHOLE-ROCK SAMPLES FROM TWELVE MILE AND WOORANA WELLS

Sample	Rb	Sr	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
Twelve Mile Well:					
59011 C	31	590	0·055 ± 0·001	0·160 ± 0·002	0·707 03 ± 0·000 20
59011 D_2	105	940	0·112 ± 0·001	0·324 ± 0·003	0·712 86 ± 0·000 13
59011 D	98	600	0·162 ± 0·002	0·468 ± 0·004	0·718 38 ± 0·000 28
59018 A	91	465	0·194 ± 0·002	0·561 ± 0·005	0·721 61 ± 0·000 14
59011 A	100	480	0·208 ± 0·002	0·601 ± 0·006	0·722 38 ± 0·000 07
59011 G_2	188	485	0·395 ± 0·003	1·14 ± 0·01	0·742 55 ± 0·000 34
Woorana Well:					
59045 A	160	590	0·273 ± 0·002	0·790 ± 0·008	0·729 95 ± 0·000 11
59046 C	137	490	0·281 ± 0·002	0·813 ± 0·008	0·730 15 ± 0·000 21
59046 B	173	615	0·282 ± 0·002	0·816 ± 0·008	0·730 33 ± 0·000 23
59045 B	202	640	0·316 ± 0·002	0·915 ± 0·008	0·724 38 ± 0·000 31
59046 A	175	555	0·319 ± 0·002	0·924 ± 0·009	0·735 07 ± 0·000 10
59047	180	370	0·488 ± 0 004	1·42 ± 0·02	0·752 67 ± 0·000 10
40397*	195	380	0·510 ± 0·005	1·48 ± 0·02	0·754 96 ± 0·000 21

* See Bunting and others (1980) for details.

^{87}Rb (Steiger and Jäger, 1977). To provide proper comparison, dates from sources using a different decay constant have been recalculated before inclusion in the present work.

All samples from the Woorana Well and Twelve Mile Well areas regressed together yield a model 1 date of 2 512 ± 42 m.y., with an initial $^{87}Sr/^{86}Sr$ ratio (Ri) of 0·701 1 ± 0·000 5, and a mean square of weighted deviates (MSWD) of 0·78. However, as the localities of the two suites are separated by 270 km, they are more reasonably considered separately. Thus samples, including 40397, from the locality near Woorana Well yield a model 1 age of 2 520 ± 113 m.y., with an Ri of 0·701 4 ± 0·001 7, and a MSWD of 0·70. The samples near Twelve Mile Well give a model 1 age of 2 489 ± 82 m.y. with an Ri of 0·701 2 ± 0·000 3 and a MSWD of 0·97.

The range of $^{87}Rb/^{86}Sr$ ratios among the samples from Twelve Mile Well is sufficiently great for this set to dominate the combined data from Twelve Mile Well and Woorana Well. The more clustered data from Woorana Well yield an age which is slightly older than that from Twelve Mile Well but well within the error limits of both data sets. Addition of the previously determined sample 40397 strengthened the Woorana Well isochron without appreciable effect on the date or initial ratio.

DISCUSSION

Geochronological data are now available from five suites of alkaline rocks from the Eastern Goldfields Province. At three localities, Woorana Well, Twelve Mile Well and Fitzgerald Peaks (de Laeter and Lewis, 1978), the isochron ages are unequivocal. Data from Lake Teague are difficult to interpret (Bunting and others, 1980). The fifth suite is a group of four granitoid samples collected from Twin Peaks, 3 km northeast of Twelve Mile Well, and recorded by de Laeter and others (1978). The rocks at Twin Peaks are reported to consist of alkaline granitoid (Williams and others, 1976; Libby, 1978) but the analysed samples are not avaialbe for direct verification of their alkalinity. Other samples from Twin Peaks do not seem greatly different from the analysed alkaline samples from Twelve Mile Well. Hence the isochron reported by de Laeter and others would seem to be from alkaline rock.

The low MSWD from the isochron on combined data from Twelve Mile and Woorana Wells suggests that both bodies were derived from materials of similar isotopic ratio at about the same time. The distance between the two localities would seem to preclude derivation from the same crustal source but is consistent with simultaneous derivation from homogenous mantle.

The alkaline rocks from all the localities have late Archaean radiometric dates, but strontium evolution anylsis and Pb-Pb isochron whole-rock studies suggest that the various bodies may have different histories.

Strontium evolution analysis is the study of the change with time of the ratio of ^{87}Sr to ^{86}Sr. The purpose of the study commonly is to date events which occurred prior to the isochron date of the rock. The $^{87}Sr/^{86}Sr$ ratio changes with time because the absolute amount of ^{87}Sr increases through radioactive decay of ^{87}Rb. Thus, the rate of change of $^{87}Sr/^{86}Sr$ depends on the $^{87}Rb/^{86}Sr$ ratio and the decay constant of ^{87}Rb.

Of particular interest is the rate of change of $^{87}Sr/^{86}Sr$ at the time given by the isochron date of the rock. The $^{87}Sr/^{86}Sr$ ratio at that time is given by the initial $^{87}Sr/^{86}Sr$ ratio read from the isochron, the decay rate of ^{87}Rb is a known constant, and the $^{87}Rb/^{86}Sr$ ratio can be approximated from the present ratio.

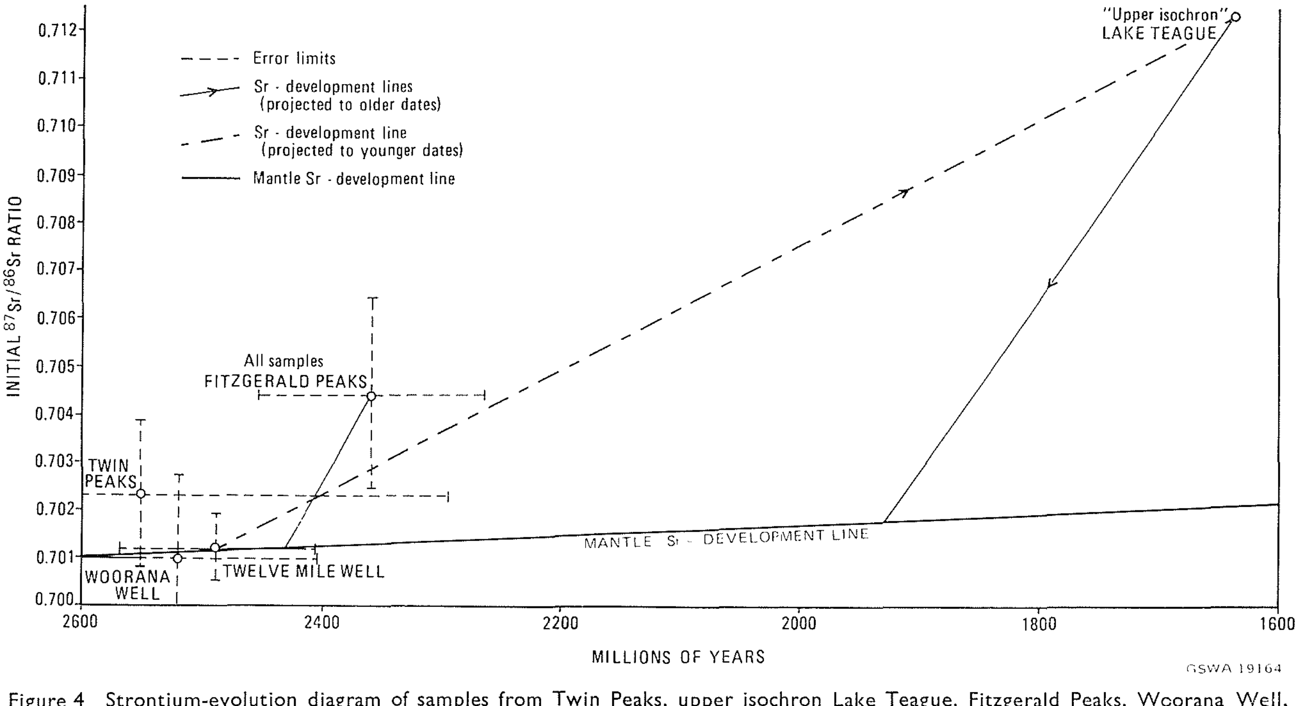


Figure 4 Strontium-evolution diagram of samples from Twin Peaks, upper isochron Lake Teague, Fitzgerald Peaks, Woorana Well, and Twelve Mile Well. Error bars are shown.

Knowing the rate of change of $^{87}Sr/^{86}Sr$ at a time in the past, the $^{87}Sr/^{86}Sr$ ratio can be projected farther backward. Thus the value of $^{87}Sr/^{86}Sr$ can be estimated for any time back to its original differentiation from materials of mantle composition, if the rock has not experienced a gross change in chemical composition (e.g. bulk metasomatism or further magmatic differentiation) which would change the $^{87}Rb/^{86}Sr$ ratio in the rock. A rock which meets this criterion is said to have experienced single-stage evolution. Metamorphism or melting would not disturb the system as long as bulk composition has remained unchanged.

The $^{87}Sr/^{86}Sr$ ratio in the mantle evolved similarly but more slowly than in crustal rocks because of a lower $^{87}Sr/^{86}Sr$ ratio than in the crust. Changes in mantle $^{87}Sr/^{86}Sr$ follow a development line which can be approximated by measuring the $^{87}Sr/^{86}Sr$ ratio in primitive rocks and again in modern, mantle-derived rocks (Faure and Powell, 1972). The intersection of the mantle development line and the backward projection of the $^{87}Sr/^{86}Sr$ ratio of a rock sample will give the date of differentiation of the sampled rock from material of mantle composition, assuming: that the rock is a product of single-stage evolution, that the mean of reported $^{87}Rb/^{86}Sr$ values is a close approximation to the bulk value of the rock body, that the mantle evolution line is correct, and that in each case the true ages and initial ratios of the samples are closely approximated by the isochron values.

The assumption of single-stage evolution is seldom capable of direct testing by the isotopic data, but even where this assumption cannot be accepted, the age of mantle evolution may sometimes be bracketed.

A multi-stage Sr-evolution line will consist of straight segments connecting points at which bulk composition has changed. The overall shape of the curve will be concave upward because young, evolved rocks will have a higher Rb/Sr ratio, and hence a higher $^{87}Rb/^{86}Sr$ ratio, than more primitive rocks. Consequently, the slope of the Sr evolution curve becomes steeper as age decreases.

From the upward concavity of the evolution curve, it follows that (1) straight-line projection to the mantle development line gives a minimum age for mantle evolution, (2) if the composition of the first stage is known, projection at the slope calculated from this composition will give the maximum age of mantle derivation.

Figure 3 summarizes whole-rock Rb-Sr analyses of a variety of granitoids, including the alkaline rocks, within the Eastern Goldfields Province on a Sr-evolution diagram. Six sources of data are utilized in addition to the present work; these are: Turek, 1966; de Laeter and others, 1978; Worden and Compston 1973; Roddick and others, 1976; Cooper and others, 1978; and de Laeter and Lewis, 1978. A further isotopic study, that of the syenitic rocks of the Teague Ring Structure (Bunting and others, 1980), which failed to establish a convincing isochron, is omitted from Figure 3, but some of these data are plotted in Figure 4.

All studies on Archaean metamorphic and igneous rocks of the Eastern Goldfields Province which include dates with error limits, initial $^{87}Sr/^{86}Sr$ ratios with error limits, and present-day $^{87}Rb/^{86}Sr$ ratios for individual samples are included in Figure 3. The mantle Sr-development curve was calculated assuming linear evolution from a $^{87}Sr/^{86}Sr$ ratio of 0·699 at 4 600 m.y. to 0·703 7 at the present (Faure and Powell, 1972, p. 130). The part of that line between 2 800 and 2 300 m.y. is plotted on Figure 3. A model Sr-development line for each sample is generated by the relationship:

$$S = (^{87}Rb/^{86}Sr)\ \lambda,$$

where S is the slope of the projection and λ is the ^{87}Rb decay constant ($1{\cdot}42 \times 10^{-11} yr^{-1}$). In this analysis the $^{87}Rb/^{86}Sr$ ratio which was used is the mean of the set of ratios reported for each locality; where determinations were replicated on an individual sample, the mean of replications was used as the value for that sample.

Initial ratios from three rocks, "Penneshaw acid schist" of Turek (1966), "Norseman porphyritic rhyolite" of Turek, and "Perseverance pegamtite" of Cooper and others (1978) fall outside the range of the graph. Consequently, these points are not plotted, but the intersections of Sr-evolution lines from these samples with the mantle Sr-development line are marked with ticks and labelled. "Acid flows", "Kalgoorlie Mine Porphyry", and "Golden Mile Dolerite" fall well below the mantle growth line and are not considered further.

Samples plotting within 0·000 5 (initial $^{87}Sr/^{86}Sr$ ratio) of the mantle development curve are assumed to be on it.

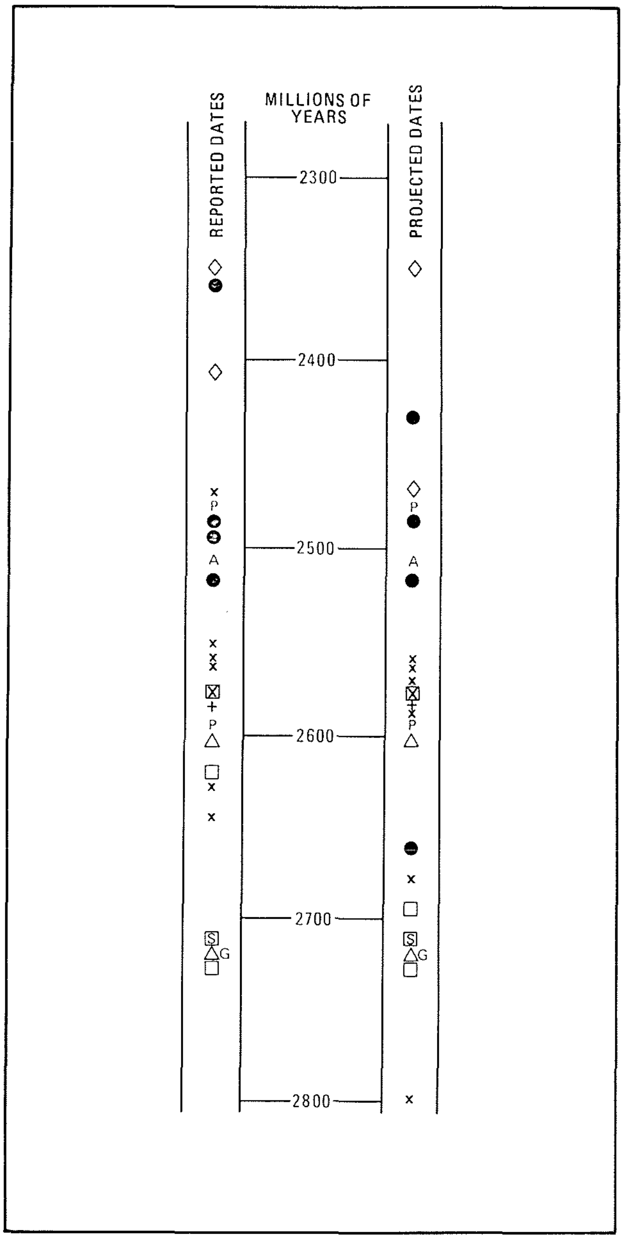
Figure 4 is a simplified version of Figure 3 in the time range of 2 600 to 1 600 m.y., and includes data from the Woorana Well, Twelve Mile Well, and Fitzgerald Peaks suites, as well as the younger age of the upper reference isochron from the Lake Teague suite.

Figure 5 shows that all ages are contained between 2 725 m.y. and 2 350 m.y., possibly in three groups: (1) gneiss and schist at an age slightly greater than 2 700 m.y., (2) the bulk of non-gneissic granitoids in an interval between 2 650 and 2 550 m.y., and (3) mainly alkaline and dyke rock together with gold mineralization at less than 2 550 m.y. Projection of dates along Sr-evolution lines to the mantle Sr-evolution line has little effect on the gross grouping, but in detail tightens the grouping in the younger age zone and loosens it in the older age area.

AGES OF THE ALKALINE ROCKS

The reported isochron ages of the alkaline rocks are among the youngest Archaean granitoid ages recorded from the Eastern Goldfields, all being 2 520 m.y. or younger (Fig. 5).

Most alkaline rocks also project to the mantle Sr-development line at relatively young Archaean ages (Figs. 3 and 5). Data from Twelve Mile Well and Woorana Well plot close to the mantle-development line, hence the projected dates are close to the isochron dates for these localities; and data from Fitzgerald Peaks project to the mantle-development line at 2 431 m.y. In contrast, data from Twin Peaks project to the mantle-development line at 2 660 m.y., a date considerably earlier than that of the other alkaline sets.



GSWA 19165

Figure 5 Bar graph showing the age of various rock types and their displacement upon projection to the mantle Sr—evolution line. Symbols are those in Figure 3.

The Woorana Well and Twelve Mile Well sample sets were, therefore, derived from rocks of mantle composition near the time of their isochron age, that is, about 2 500 m.y. ago. If the rocks at Fitzgerald Peaks were derived from the mantle in a single stage, Sr evolution suggests an age for this event which, at 2 431 m.y., is younger than the rocks from Woorana and Twelve Mile Wells; but if two-stage evolution is assumed, the data are compatible with derivation from rocks of the age and isotopic composition of Twelve Mile Well.

It might be noted in passing that the upper isochron of alkaline rocks from Lake Teague (Bunting and others, 1980), though post-Archaean (1 636 m.y.) and projecting to the mantle-development line at about 1 930 m.y., is also compatible with evolution from rocks of the same age and Rb-Sr composition as the Twelve Mile Well samples, if multiple-stage evolution is accepted.

The position of the Lake Teague sample on the projection of the Sr-evolution line for the Tewlve Mile Well samples suggests that the Lake Teague material may have been derived at 1 636 m.y. by differentiation from a pre-existing alkaline rock with the composition and age of the Twelve Mile Well rock (Fig. 4).

Thus two of the sets of alkaline rocks (Woorana and Twelve Mile Wells) seem to be derived from materials of mantle composition about 2 500 m.y. ago. A further two sets of data, from Fitzgerald Peaks and Lake Teague, are compatible with this date of mantle derivation, but data from Twin Peaks project to an earlier date (2 660 m.y.). This earlier date could be explained as an artifact of calculation of the average $^{87}Rb/^{86}Sr$ value from only four samples, which may not be representative of the rock as a whole; however, the possibility of the appearance of alkaline rocks in the Eastern Goldfields Province before 2 600 m.y. is supported by a Pb-Pb whole-rock isochron date (Stuckless and Bunting, written communication) of 2 760 m.y.

Most of the samples providing the Pb-Pb data were collected from the vicinity of Red Hill, 300 km north of Twin Peaks but only 35 km north of the Woorana Well Rb-Sr sampling site. None of the Pb-Pb sampling sites is more than 35 km from Woorana Well and one (sample 40397) is from the alkaline mass at Woorana Well. On petrographic evidence, neither the rocks from Red Hill nor from Twin Peaks are strongly alkaline but both sets of rocks conform to the criteria for inclusion in the alkaline suite used by Libby (1978), and no independent criterion for excluding them has been found.

Thus, as the Twelve Mile Well and Woorana Well samples seem fixed at a date of mantle derivation of about 2 500 m.y. by their position on the mantle Sr-evolution line and, as the Twin Peaks and Red Hill rocks seem considerably older than this date, alkaline rocks may have originated at more than one period in the Archaean.

An unresolved problem is the presence of sample 40397 both in the set of Rb-Sr samples from Woorana Well, providing apparently clear evidence of mantle derivation near 2 500 m.y., and in the set of Pb-Pb samples, providing an age of 2 760 m.y.

CONCLUSIONS

The new data establish a late Archaean date for differentiation of two bodies of alkaline rock from material of mantle composition, despite evidence that other alkaline bodies may have had longer prior crustal residence. Rb-Sr isochron dates continue to be late Archaean, establishing a pattern which is apparently characteristic of the alkaline suite in the Eastern Goldfields Province.

ACKNOWLEDGEMENTS

The authors would like to thank Mr. D. J. Hosie of the Department of Physics, Western Australian Institute of Technology, for his assistance in the project.

REFERENCES

Bunting, J. A., and Williams, S. J., 1979, Sir Samuel, W.A.: West. Australia Geol. Survey 1:250 000 Geol. Series Explan. Notes.

Bunting, J. A., de Laeter, J. R., and Libby, W. G., 1980, Evidence for the age and cryptoexplosive origin of the Teague Ring Structure: West. Australia Geol. Survey Ann. Rept 1979, pp. 81–85.

Cooper, J. A., Nesbitt, R. W., Platt, J. P., and Mortimer, G. E., 1978, Crustal development in the Agnew region, Western Australia, as shown by Rb/Sr isotopic and geochemical studies: Precambrian Research, v. 7, pp. 31–60.

de Laeter, J. R., Compston, W., and Chappell, B. W., 1978, An internal whole-rock age from an Archaean gneiss: West. Australian Inst. of Tech. Dept of Physics Report No. PD147/1978/EP18.

de Laeter, J. R., and Lewis, J. D., 1978, The age of the syenitic rocks of the Fitzgerald Peaks, near Norseman: West. Australia Geol. Survey Ann. Rept 1977, pp. 56–60.

de Laeter, J. R., Williams, I. R., Rosman, K. J. R., and Libby, W. G., 1981, A definitive 3 350 m.y. age from banded gneiss, Mount Narryer area, Western Gneiss Terrain: West. Australia Geol. Survey Ann. Rept 1980, p. 94–98.

Faure, G., and Powell, J. L., 1972, Strontium isotope geology: Berlin, Springer-Verlag, 188 pp.

Gee, R. D., 1979, Structure and tectonic style of the Western Australian Shield: Tectonophysics, v. 58, pp. 327–369.

Gee, R. D., Baxter, J. L., Wilde, S. A., and Williams, I. R., in press, Crustal development in the Yilgarn Block, Western Australia: Geol. Soc. Australia Special Publication.

Groves, D. I., and Gee, R. D., 1980, Regional geology and mineral deposits of the Kalgoorlie-Norseman region: Geol. Soc. Australia, W.A. Division, 2nd Int. Archaean Symposium, Perth, Excursion Guide, 112 pp.

Hallberg, J. A., 1980, Archaean Geology of the Leonora-Laverton area: Geol. Soc. Australia, W.A. Division, 2nd Int. Archaean Symposium, Perth, Excursion Guide, 37 pp.

Lewis, J. D., and Gower, C. F., 1978, Syenitic rocks of the Fitzgerald Peaks, near Norseman: *in* Contributions to the geology of the Eastern Goldfields Province of the Yilgarn Block: West. Australia Geol. Survey Report 9, pp. 139–161.

Libby, W. G., 1978, The felsic alkaline rocks: *in* Contributions to the geology of the Eastern Goldfields Province of the Yilgarn Block: West. Australia Geol. Survey Report 9, pp. 111–137.

McIntyre, G. A., Brooks, C., Compston, W., and Turek, A., 1966, The statistical assessment of Rb-Sr isochrons: Jour. Geophys, Research, v. 71, pp. 5459–5468.

Roddick, J. C., Compston, W., and Durney, D. W., 1976, The radiometric age of the Mount Keith Granodiorite, a maximum age estimate for an Archaean greenstone sequence in the Yilgarn Block, Western Australia: Precambrian Research, v. 3, pp. 55–78.

Steiger, R. H., and Jäger, E., 1977, Subcommission on geochronology: Convention on use of decay constants in Geo- and Cosmochronology: Earth and Planetary Sci. Letters, v. 36, pp. 359–362.

Turek, A., 1966, Rubidium-strontium isotopic studies in the Kalgoorlie-Norseman area, Western Australia: Australian National University, Ph.D. thesis (unpublished).

Williams, I. R., Gower, C. F., and Thom, R., 1976, Edjudina, Western Australia: West. Australia Geol. Survey 1:250 000 Geol. Series Explan. Notes.

Worden, J. M., and Compston, W., 1973, A Rb-Sr isotopic study of weathering in the Mertondale Granite, Western Australia: Geochim. Cosmochim. Acta, v. 37, pp. 2567–2576.

FELSIC DYKES OF THE MOUNT EDGAR BATHOLITH

by J. D. Lewis and R. Davy

ABSTRACT

A petrographic and chemical study has shown that a wide variety of felsic dykes, including andesitic, trachyandesitic, granophyric, and rhyolitic types, intrude the Mount Edgar batholith. The andesites are the oldest dykes and are possibly related to the Archaean Duffer Formation; they intrude only the alkali granite, which forms the oldest part of the batholith. The trachyandesite dykes are related to the Bridget Adamellite, of early Proterozoic age. Three types of rhyolite can be distinguished and most specimens are highly potassic, the dykes are confined to the batholith and probably related to it. The rhyolites and trachyandesites are intruded along the same fracture system as the widespread dolerite dyke swarm of the Pilbara and were intruded late in the Archaean and early in thr Proterozoic.

INTRODUCTION

The Mount Edgar batholith, which is located east of Marble Bar (lat. 21°10′S long. 119°45′E,), is roughly rhombic in outline, and has a maximum north-south dimension of 52 km and a

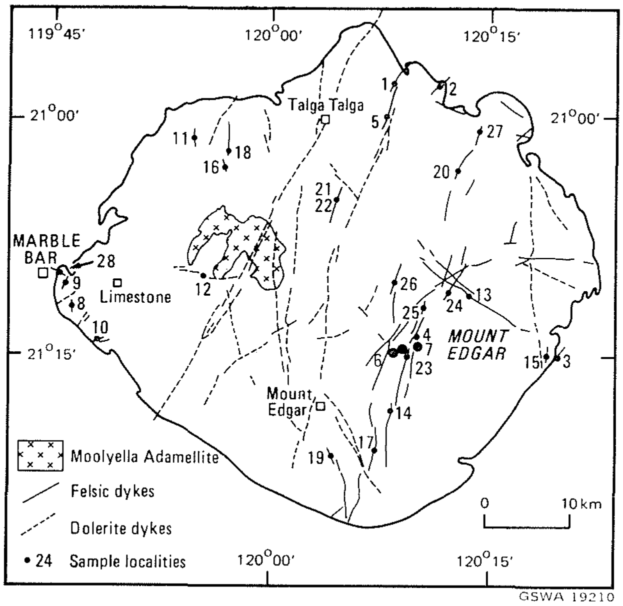


Figure 1 Dykes in the Mount Edgar Batholith.

maximum east-west dimension of 55 km. Its shape is structurally controlled along the southeast margin by a compressed and sheared greenstone belt, and along the southwest margin by a major lineament. Elsewhere the margin of the batholith shows cross-cutting intrusive relationships. The batholith consists of a large mass of granodiorite-tonalite into which are intruded a number of smaller granodioritic and adamellitic bodies. It is cut by large dolerite dykes belonging to the north-northeast trending Black Range dyke suite, which is prominent throughout the Pilbara Block, and by numerous felsic dykes which form the substance of this study. The regional geology of the Mount Edgar batholith has been described by Hickman (in press).

The felsic dykes follow two dominant trends; the principal set trends north-northeast, parallel to the dolerites of the Black Range suite, and a lesser set trends northwest. The dykes range in thickness from 5–20 m and are exposed over strike distances of up to 15 km. Dykes are found throughout the batholith, but the largest number are found in a belt centred on Mount Edgar in the eastern part of the batholith (Fig. 1). In addition, Mount Edgar itself and a number of small tors in the vicinity, are formed by small plugs of felsic material similar to the dyke rocks.

This study is concerned mainly with the petrography and geochemistry of the felsic dykes and arises out of a major geochemical study of the Mount Edgar batholith (Davy and Lewis, in prep. a).

METHODS OF STUDY

Twenty-four samples of felsic dykes, each of 2–3 kg, were collected, mostly in the vicinity of station tracks (Fig. 1). In addition, samples were collected from two small plugs of hornblende-bearing rock (thought to be related to some of the dykes) at Mount Edgar itself and, for comparative purposes, from two dolerite dykes.

Analyses for SiO_2, Al_2O_3, Fe_2O_3, CaO, TiO_2 and K_2O were carried out by X-ray fluorescence on fused discs using lithium tetraborate flux, and on Ba, Ce, La, Mn, Nb, Rb, Sr, Th, Sn, V, Y and Zr by X-ray fluorescence on pressed powder pellets. Determinations of MgO, Na_2O, Cu, P, Li, Ni and Zn were made by atomic absorption analysis after a perchloric-hydrofluoric acid digestion and extraction into 5% HCl. F was determined using a specific ion electrode. Analytical results are given in Tables 1, 2 and 3.

PETROGRAPHY

Visual inspection of the felsic dykes in outcrop and hand specimen reveals two major groupings depending on the phenocryst phase present. The largest group carries phenocrysts of quartz and feldspar, but a number of specimens contain hornblende phenocrysts. Samples from the Mount Edgar plugs appear similar to the hornblende porphyries, but there are a few dykes which cannot easily be assigned. As the groundmass in all the dyke rocks is fine grained, rock nomenclature is on the basis of major-element chemistry (Tables 1 and 2). On the outline classification of Cox and others (1979), based on silica and total alkali content, the quartz feldspar porphyries are rhyolites, while the hornblende-bearing varieties are trachyandesites and andesites.

HORNBLENDE PORPHYRIES

Trachyandesite

This group of major north-northeast trending dykes (Table 1, samples 1–5) in the eastern half of the batholith is characterized by a fine-grained feldspathic groundmass and small phenocrysts of hornblende up to 4 mm long.

The groundmass consists of small feldspar prisms and laths, often strongly sericitized. In some specimens, the laths were probably sanidine, and the rock has a sub-trachytic texture; in others, small prisms of calcic oligoclase are surrounded by low-relief potash feldspar. In all specimens, there

TABLE 1. CHEMICAL ANALYSES OF HORNBLENDE PORPHYRY, ANDESITE AND DOLERITE DYKES MOUNT EDGAR BATHOLITH

	1	2	3	4	5	6	7	8	9	10	11	12
SiO_2	52·7	54·2	56·0	58·3	58·3	54·1	61·6	59·9	62·5	63·5	47·9	54·5
Al_2O_3	14·3	14·1	14·9	14·8	16·0	13·8	15·5	15·9	14·7	15·8	13·6	15·7
Fe_2O_3	9·7	7·29	7·2	7·6	7·4	9·0	6·4	7·2	5·94	7·1	14·9	9·8
FeO	....	3·5	....	....	....	....	3·1	....	3·6	....	....	....
MgO	2·7	3·3	3·1	3·6	2·6	5·0	1·9	3·2	3·3	2·2	5·9	3·1
CaO	6·5	5·2	5·5	5·7	5·7	6·8	4·5	5·4	4·7	2·0	7·4	6·7
Na_2O	2·6	3·4	4·5	3·9	3·8	3·0	4·6	3·5	3·7	4·3	0·78	2·8
K_2O	3·6	3·6	1·1	3·1	3·1	3·3	3·2	1·5	1·8	0·7	0·89	1·8
TiO_2	0·75	0·65	0·46	0·64	0·74	0·67	0·69	0·66	0·56	1·06	2·78	1·03
P_2O_5	....	0·21	....	....	....	....	0·18	....	0·07	....	....	....
CO_2	....	3·80	....	....	....	....	0·02	....	0·14	....	....	....
$H_2O\pm$	....	1·89	....	....	....	....	0·35	....	1·16	....	....	....
$H_2O\pm$	....	0·09	....	....	....	....	0·03	....	0·03	....	....	....
LOI (*a*)	6·94	(5·43)	6·57	2·48	1·58	4·21	(0·09)	1·75	(0·97)	2·65	5·45	4·00
Total	99·79	101·23	99·53	100·02	98·88	99·88	102·07	99·01	102·2	99·31	99·60	99·33
Ba	2 000	1 200	1 000	1 000	1 200	900	1 000	400	500	240	1 000	1 200
Ce	80	80	40	60	80	80	100	60	<20	100	40	80
Cu	120	70	25	75	65	15	30	35	35	20	30	110
F	870	800	760	890	80	1 080	800	450	610	730	820	890
La	40	40	40	40	40	40	60	20	40	60	20	40
Pb	30	20	25	25	50	40	<10	<10	<10	<10	<10	20
Li	110	45	30	15	35	25	18	40	45	40	60	205
Mn	1 200	1 200	970	970	1 090	1 130	940	875	750	950	1 500	1 150
Ni	30	30	10	20	15	20	10	45	70	5	45	90
Nb	<5	<5	<5	<5	<5	<5	10	5	<5	10	10	5
Rb	130	140	65	110	85	150	120	90	90	20	40	95
Sr	500	480	400	800	900	750	750	320	260	150	180	420
Th	10	10	10	10	<10	<10	10	<10	<10	<10	<10	<10
Sn	<2	2	<2	<2	<2	<2	<2	2	2	6	<2	4
V	210	160	150	150	140	180	100	130	100	<10	320	170
Y	15	20	10	15	15	15	25	25	25	45	60	30
Zn	110	90	75	90	100	105	96	65	60	70	120	95
Zr	90	105	90	105	90	90	150	150	165	210	255	180

a) Bracketed L.O.I. are calculated; 1–5: Hornblende porphyry dykes; 6, 7: Hornblende porphyry plugs; 8–10: Andesite dykes; 11, 12: Dolerite dykes. For locations see Fig. 1.

TABLE 2. CHEMICAL ANALYSES OF QUARTZ-FELDSPAR PORPHYRY DYKES

	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
SiO_2	70·2	71·7	73·4	74·1	74·4	74·5	75·4	75·4	75·5	76·7	76·1	76·5	76·7	76·8	81·9	74·6
Al_2O_3	13·4	13·1	12·5	13·6	12·1	13·3	11·9	12·7	12·6	13·0	12·5	11·8	11·8	11·2	11·8	12·8
Fe_2O_3	4·1	3·6	1·4	1·8	2·1	2·0	2·3	2·2	2·2	1·6	1·9	1·7	1·6	1·8	1·2	2·7
FeO	....	....	....	....	1·3	....	1·3	....	....	....	....	....	....	1·2	....	....
MgO	0·69	0·53	0·27	0·50	0·30	0·33	0·33	0·33	0·22	0·05	0·39	0·16	0·38	0·12	0·32	0·27
CaO	2·4	1·4	2·4	0·65	0·52	1·3	0·37	0·89	0·18	0·14	0·60	0·53	0·33	0·52	0·21	1·1
Na_2O	1·6	3·7	7·1	3·9	2·8	1·6	2·7	1·0	3·3	3·6	2·7	1·6	2·6	3·3	0·05	4·5
K_2O	7·5	4·7	0·8	5·6	5·4	5·9	5·2	6·6	5·4	5·1	5·7	7·5	6·4	4·0	3·5	3·0
TiO_2	0·63	0·55	0·77	0·21	0·24	0·25	0·27	0·27	0·27	0·08	0·20	0·07	0·12	0·17	0·15	0·17
P_2O_5	....	....	....	....	0·02	....	0·03	....	....	....	....	....	....	0·01	....	....
CO_2	....	....	....	....	0·27	....	0·20	....	....	....	....	....	....	0·05	....	....
$H_2O\pm$	....	....	....	....	0·61	....	0·67	....	....	....	....	....	....	0·44	....	....
$H_2O\pm$	....	....	....	....	0·06	....	0·06	....	....	....	....	....	....	0·02	....	....
LOI (*a*)	1·45	1·50	2·37	0·69	(0·81)	2·01	(0·80)	1·54	0·90	0·66	0·57	0·93	0·83	(0·39)	1·75	1·65
Total	102·0	100·8	101·0	101·1	100·1	101·2	100·7	100·9	100·6	100·9	100·7	100·8	100·8	99·6	100·9	100·8
Ba	1 200	900	350	500	600	500	500	800	700	60	450	300	450	700	300	800
Ce	140	180	140	120	140	140	160	160	180	120	140	140	120	160	40	140
Cu	10	5	5	25	15	15	20	2·5	10	10	10	10	10	10	20	5
F	100	1 150	270	310	900	850	270	1 450	440	1 570	590	320	1 630	1 840	220	430
La	100	80	60	60	80	80	100	100	120	60	60	80	60	100	<20	80
Pb	<10	10	10	<10	10	10	<10	35	15	25	20	70	15	<10	20	<10
Li	20	15	10	15	11	40	9	10	15	70	10	15	20	11	15	10
Mn	400	445	135	180	220	240	220	240	185	115	220	205	160	150	60	190
Ni	<5	5	<5	10	<10	<5	10	<5	<5	<5	<5	<5	<5	<10	<5	<5
Nb	5	10	5	15	10	10	10	15	15	30	15	10	20	10	10	5
Rb	140	210	25	340	300	420	240	340	220	440	260	400	360	190	280	60
Sr	190	100	170	85	180	45	80	30	45	15	80	40	30	120	10	70
Th	20	30	20	50	30	50	50	40	30	50	50	50	50	30	50	20
Sn	<2	2	<2	2	4	2	4	2	4	8	4	40	6	4	2	2
V	30	20	40	10	20	10	<10	10	<10	<10	<10	<10	<10	<10	<10	10
Y	35	50	30	45	50	50	50	45	60	100	50	50	60	60	45	60
Zn	70	55	50	20	34	30	34	85	45	25	35	35	35	38	15	35
Zr	420	380	400	180	225	195	255	270	285	180	210	150	210	225	180	340

(*a*) Bracketed L.O.I. are calculated. 13–26: Quartz-feldspar porphyry dykes; 27: Silicified quartz-feldspar porphyry; 28: Granophyre dyke.

are prominent small euhedra of apatite and magnetite. Hornblende phenocrysts occur as euhedral prisms or acicular crystals up to 4 mm long, and more rarely as large anhedral grains and aggregates. Hornblende comprises about 15% of the rock and is often altered to an aggregate of chlorite and carbonate. Where fresh, the hornblende is rhythmically zoned, dark green and often has a narrow darker outer rim.

Most of the rocks contain sericite, chlorite, and carbonate. This alteration is related to the introduction of CO_2 rather than to weathering. Specimen 5, however, which contains rounded phenocrysts of oligoclase in addition to hornblende, has been epidotized rather than carbonated.

Trachyandesite plugs

The small intrusions (Table 1, samples 6 and 7) in the vicinity of Mount Edgar, have a similar chemical composition and show the same hornblende phenocrysts as the trachyandesite dykes described above. The two samples examined are from Mount Edgar itself (sample 7) and a smaller plug (sample 6) 2 km to the southwest.

Both specimens are similar to the dyke rocks and contain numerous small phenocrysts of dark green rhythmically zoned hornblende, but are distinctive in carrying minor amounts of strongly coloured sphene. Specimen 6 is a medium-grained, hypidiomorphic assemblage of euhedral prisms of andesine (An_{32}), rhythmically zoned to marginal albite, containing minor interstitial microperthite, quartz and calcite. In addition to approximately 15% of hornblende phenocrysts, there are a few flakes of brown biotite, prominent accessory apatite, and magnetite.

Specimen 7 is fine grained, and the groundmass to the hornblende phenocrysts consists of closely packed prisms of rhythmically zoned andesine (An_{32}), from 0·2–0·8 mm long, and minor interstitial potash feldspar and quartz. The rock contains a few larger phenocrysts (or xenocrysts) of altered plagioclase, a small amount of biotite, apatite and magnetite, and a little diopside. The pyroxene occurs in two forms, as ragged partially resorbed crystals up to 2 mm long, and as clots of small prisms. One such clot surrounds a distinctive patch of probably xenocrystic quartz.

Andesite

These dykes (Table 1, samples 8, 9 and 10) from the western margin of the batholith, probably belong to a different suite from the other hornblende-bearing dykes. Specimens 8 and 9 are similar and contain saussuritized phenocrysts of plagioclase, aggregates of pale-green hornblende, and green biotite in a fine-grained plagioclase-quartz-amphibole matrix. Both specimens are extensively altered and recrystallized, but specimen 9 preserves a sub-trachytic texture.

TABLE 3. ANALYSES OF SOME FELSIC ROCKS OF THE PILBARA REGION

	29	30	31	32	33	34	35	36	37	38
SiO_2	56·5	63·54	58·44	71·8	75·6	72·9	77·15	62·0	60·92	74·5
Al_2O_3	14·8	14·67	14·08	13·0	12·4	13·9	11·21	15·5	15·29	12·9
Fe_2O_3	8·6	3·67	3·44	3·0	2·3	2·2	0·55	7·9	1·71	2·3
FeO	....	2·53	4·72	....	....	....	0·30	....	3·40	....
MgO	3·17	2·35	4·41	0·50	0·28	0·37	0·42	2·9	2·74	0·23
CaO	5·7	4·19	6·11	2·07	0·55	1·6	0·68	4·0	4·55	0·50
Na_2O	3·7	3·51	3·02	4·13	2·6	4·0	0·81	3·8	4·50	4·5
K_2O	3·0	4·15	3·44	4·33	5·7	3·5	7·45	1·3	1·35	4·1
TiO_2	0·66	0·45	0·53	0·65	0·20	n.d.	0·05	0·76	0·59	0·14
LOI	4·10	0·67	1·06	1·77	0·99	0·90	1·62	2·08	4·44	0·92
Ba	1 200	900	970	815	500	985	90	380	460	536
Ce	75	....	....	150	140	76	58	60	47	127
Cu	55	26	100	7	12	32	1	30	30	12
F	770	....	....	500	925	196	....	600	....	487
La	40	....	....	80	80	50	25	40	23	69
Pb	25	....	....	8	20	10	16	<10	7	10
Li	40	....	....	15	20	14	7	40	8	5
Mn	1 070	1 300	1 200	330	195	209	300	850	1 100	154
Ni	20	....	....	3	<5	<5	2	40	35	<5
Nb	<5	....	....	7	15	<5	10	6	3	21
Rb	115	132	104	125	320	84	191	65	39	106
Sr	650	670	690	150	70	216	14	240	364	45
Th	10	....	....	23	40	17	31	<10	6	23
Sn	<2	....	....	<2	4	4	8	3	<2	<2
V	150	....	....	30	8	6	2	80	81	<10
Y	15	20	19	38	55	9	26	30	13	41
Zn	95	74	97	60	38	44	15	65	64	22
Zr	100	123	103	400	215	175	82	175	127	288

29: Average trachyandesite dykes (Table 1, 1–7); 30, 31: Bridget adamellite and satellite plug of hornblende porphyry (Barley, 1980); 32: Average Ca-rich rhyolite dyke (Table 2, 13–15); 33: Average rhyolite dyke (Table 2, 16–26); 34: Mount Edgar Batholith, Pluton J (Davy and Lewis, in press); 35: Average rhyolite of Wyman Fm (Hickman, in press); 36: Average andesite dyke (Table 1, 8–10); 37: Average Duffer Fm (Hickman, in press); 38: Average alkali granite, Marble Bar (Pluton F *in* Davy and Lewis, in press).

Specimen 10 is more dacitic and consists of patches of epidote and small subhedral phenocrysts of oligoclase in a fine-grained recrystallized matrix of oligoclase prisms. The phenocrysts are notable for showing Baveno and Manebach twinning.

Quartz-feldspar porphyries

The dykes in this suite are chemically all rhyolitic (Table 2). Specimen 27 has been strongly silicified, and specimen 28 is a granophyre not belonging to the porphyry suite; specimens 15, 16 and 18 are also texturally distinctive and will be considered later.

The main group of potash-rich rhyolites all contain phenocrysts of quartz, perthite and oligoclase in a fine-grained quartzo-feldspathic groundmass. The quartz phenocrysts are 1–6 mm across, subhedral to rounded, and usually show resorption features. Feldspar phenocrysts are similar in size, euhedral to rounded, and often occur as glomeroporphyritic aggregates. The proportion of phenocrysts ranges from 20% to 40% of the rock.

The only mafic mineral present is cholrite, which sometimes occurs as aggregates enclosing numerous grains of apatite and ilmenite.

The groundmass of the rock is an indeterminate, quartzo-feldspathic devitrified glass. Some specimens preserve original spherulitic textures, whereas others have developed a fine-grained, vermicular, granophyric texture. Alteration of groundmass and phenocrysts consists of sericitization of the feldspars and the introduction of minor carbonate; a few specimens contain minor epidote.

Specimens 16 and 18, from the western part of the batholith, are from adjacent dykes and are distinctive in carrying apparent phenocrysts of granophyric perthite. The rock consists of small prisms of oligoclase, perthite, small euhedra of quartz, and flakes of chlorite in a sparse matrix of devitrified quartzo-feldspathic material. In addition to a number of larger phenocrysts of quartz and feldspar, there are large subhedral grains of perthite showing a coarse, granophyric texture. These do not appear as xenocrysts but probably represent material picked up by passage of the magma through a still-hot granophyre.

Specimen 15 is distinctive in that it is low in potash. In thin section, it is similar to the potash rhyolites except that the rare perthite crystals show strong resorption and are probably xenocrysts.

Specimen 28 is a coarse leucocratic granophyre, in which phenocrysts of quartz and oligoclase form the nucleus of granophyric growth. The dyke probably represents a portion of the same magma as the alkali granite which it intrudes.

DOLERITE

Two specimens (Table 1, samples 11 and 12), collected for comparison purposes, are of saussuritized basalt and dolerite which nevertheless retain a relict igneous texture.

CHEMISTRY

MAJOR ELEMENTS

Analyses of the hornblende porphyry dykes and plugs of the eastern part of the batholith (Table 1) fit closely the average values for trachyandesites compiled by Le Maitre (1976), and are not greatly dissimilar from those of Le Maitre's andesites, except for the relatively high K_2O content. The Mount Edgar plug (sample 7) is relatively high in silica and low in MgO and CaO but is within the range of analyses of similar rocks reported by Barley (1980) east of the Mount Edgar batholith (Table 3, samples 30 and 31).

The trachyandesites differ chemically from the andesite dykes of the western part of the batholith principally by virtue of their higher K_2O content, but they also have a slightly lower silica content. Between the andesitic rocks and the rhyolitic quartz-feldspar porphyries there is a silica gap, the least siliceous rhyolite containing nearly 7% more SiO_2 than the most siliceous andesite. The andesitic and trachyandesitic rocks contain more Al_2O_3 and total Fe (as Fe_2O_3), and less total alkalis, than the rhyolitic dykes.

The rhyolitic rocks (Table 2) are more K_2O-rich than the average rhyolite of Le Maitre, and values reach 7·5% K_2O on a volatile-free basis. However, the mean values (Table 3 samples 32, 33) are well within two standard deviations of the published mean. Le Maitre has no classification to fit the soda-rich rock (sample 15—7·1% Na_2O) although it is closest to dacite.

The granophyre dykes (sample 28) are chemically similar to the rhyolites, and to the alkali granite which they intrude (Table 3, sample 38). Although the dykes contain less K_2O (3·0%) than the adamellite (mean of 4·1% in 7 samples) it is almost certainly a variant of the same magma.

TRACE ELEMENTS

There is no study of the trace elements of rock types comparable to Le Maitre's (1976) study of the major components; thus, no comparison can be made with average trace-element contents of rhyolites and trachyandesites.

Within the groups outlined by the chemistry of the major elements, trace-element contents are not always internally consistent. For example, one of three andesites contains no detectable Ce, another no detectable Ni or V, while the other samples are relatively high. Similarly, one of the trachyandesites contains an order of magnitude less F than the remainder; sample 5 contains only 80 ppm F while the next lowest, sample 3, contains 760 ppm. These anomalies notwithstanding, the andesites always contain more Sn, Y and Zr, and less Ba, Pb and Sr than the trachyandesites. In addition, the andesites generally contain more Li and Ni, and less Cu, F, Mn, Rb, Th, V and Zn than the trachyandesites. The trachyandesite plugs differ from their associated dykes in containing less Cu, but are comparable in other respects.

The rhyolitic dykes are distinctly different from the andesitic and trachyandesitic dykes, particularly in their Rb and Sr contents. The rhyolites are rich in Rb and poor in Sr compared with the andesitic rocks. In addition the rhyolites are generally richer in Ce, La, Nb, Th and Zr, and poorer in Cu, Mn, Ni and V than the andesites. Within the rhyolitic group, there are individual specimens with widely different trace-element contents; F, for example, varies between 100 ppm and 1840 ppm, while individual samples are poor in Ba and Rb and rich in Cu, Pb and Sn.

Compared with other dyke rocks of the group, the silicified rhyolite, sample 27, has lost Ce, F, La, Mn, Sr and Zn, but other potentially mobile components such as Li, Ba and Rb appear unaffected. These components are possibly retained in the remaining K-feldspar and secondary mica.

The trace-element chemistry identifies a separate subgroup within the rhyolite dykes. Not only are samples 13–15 the least siliceous, but they contain significantly less Rb and more CaO, TiO_2, MgO, V, Zn and Zr than the remainder of the rhyolites. The two potassic samples (13 and 14) are also relatively enriched in Mn. Petrographically only the ultrasodic sample 15 is distinctive, although in each sample, small euhedra of ilmenite are relatively more common than in the remainder of the rhyolites. Despite the lack of petrographic distinctions, these samples should probably be treated as a separate group within the rhyolites. Conversely, samples 16 and 18, which are petrographically distinctive in containing xenocrysts of granophyre, are indistinguishable chemically from the main group of rhyloites.

The trace-element chemistry of the granophyre dyke (sample 28) is very close to that of the rhyolites, except for lower content of Rb and Th.

INTERPRETIVE DIAGRAMS

The data have been subjected to graphical interpretation to attempt to highlight similarities and differences between the various groups of dyke rocks. The plots presented in Figures 2 to 5 are Rb versus Sr, principal component analysis, and triangular diagrams of normative Or-Ab-An, and AFM components.

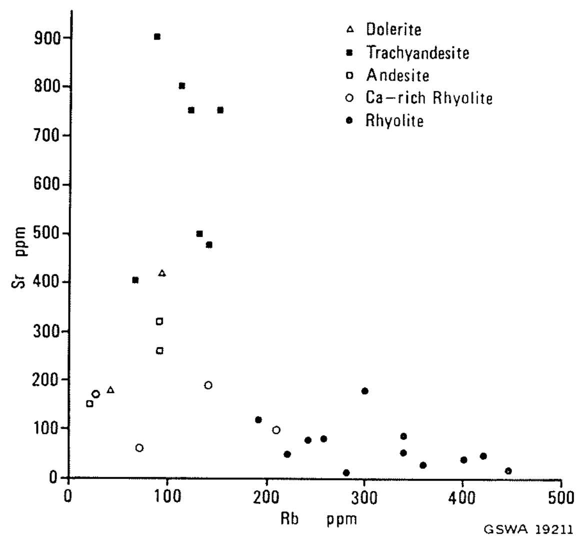
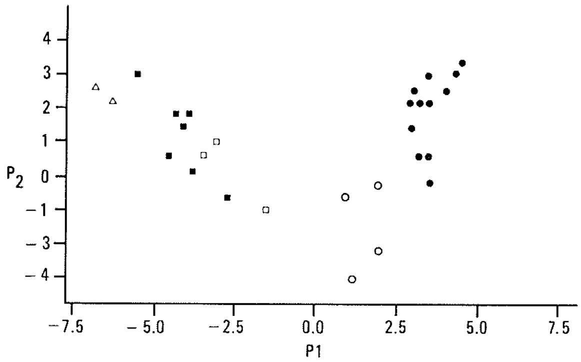


Figure 2 Rb versus Sr diagram for felsic dykes of the Mount Edgear Batholith.



Principal component loadings (standardized data) :

$$P_1 = 0.26\,SiO_2 + 0.19\,K_2O + 0.20\,Ce + 0.18\,La + 0.19\,Rb + 0.24\,Th + 0.16\,U + 0.19\,Y + 0.13\,Zr - 0.21\,Al_2O_3 - 0.26\,Fe_2O_3 - 0.27\,CaO - 0.25\,MgO - 0.19\,TiO_2 - 0.17\,Ba - 0.20\,Cu - 0.15\,Li - 0.26\,Mn - 0.19\,Ni - 0.21\,Sr - 0.25\,V - 0.24\,Zn$$

$$P_2 = 0.10 + 0.30\,K_2O + 0.14\,Cu + 0.20\,F + 0.19\,Li + 0.14\,Ni + 0.38\,Rb + 0.22\,Th + 0.32\,U + 0.13\,V + 0.10\,Y - 0.46\,Na_2O - 0.26\,B - 0.13\,Ca - 0.19\,La - 0.32\,Zr$$

Figure 3 Principal component analysis (symbols as in Figure 2).

The plot of Rb versus Sr (Fig. 2) clearly separates the Sr-rich trachyandesites from the Rb-rich rhyolite dykes. However, the dolerite, andesite and Ca-rich subgroup of the rhyolite dykes, all of which contain moderate amounts of Rb and Sr, are not clearly separated. Principal component analysis is intended to provide a multivariate comparison of samples using a wide range of chemical components. The resulting diagram (Fig. 3) demonstrates clearly two trends of groupings; the one includes the dolerites, trachyandesites and andesites, the other, the rhyolites. Except that they are distinct from the rhyolites, no clear subgroups appear within the more basic rocks, but within the rhyolites, the Ca-rich subgroup (samples 13–15) and the granophyre dyke form a distinct cluster separate from the bulk of the rhyolites.

The AFM diagram (Fig. 4) separates the trachyandesites and andesites from each other, but shows that both groups are within the field of Ringwood's (1974) calc-alkaline fractionation trends. The two dolerite samples, however, clearly follow a tholeiitic trend.

The normative plot of Q-Ab-An (Fig. 5) groups the rhyolites andesites and dolerites together, clearly separate from the trachyandesite dykes and plugs. The plot also indicates the possibility that a number of the rhyolites were near-eutectic melts although most must have been intruded at well above the eutectic temperature.

DISCUSSION

The limited data presented here show that there is far more diversity in the dyke rocks of the Mount Edgar batholith than might be expected, particularly when compared with the adjacent Corunna Downs batholith where only dolerite and microgranite dykes have been identified (Davy and Lewis, in prep. b). In the Mount Edgar batholith, geochemical and petrographic criteria suggest four groups of felsic dykes and two main types of intermediate dykes and plugs, as well as the dolerite dykes. There are, in addition, microgranite veins and dykes, quartz dykes, and pegamtites not discussed here (Davy and Lewis, in prep. a).

A major structural feature of the batholith is the presence of a well defined fracture pattern. The largest number and most clearly discernable fractures run in a north-northeast direction, parallel to the southeastern margin of the batholith. Landsat imagery indicates that this margin, together with the southeastern margin of the Corunna Downs batholith and the southeastern corner of the Shaw batholith, reflect a major deep-seated north-northeast-trending lineament. It is presumed, without direct evidence, that most of the fractures of the Mount Edgar batholith, now filled by dykes or quartz reefs, have been initiated by, or are related to this boundary lineament.

The north-northeast-trending fractures are accompanied by a lesser number of northwest trending fractures. From the offset of north-northeast-trending dykes, particularly the dolerites, there is evidence that some of these fractures may be younger than the main set of fractures. Both sets of fractures display an *en echelon* pattern.

The fractures are filled with dyke rocks of all types, but the distribution of felsic dykes is largely separate from the dolerite dykes. The western and eastern parts of the fracture pattern are predominantly filled by dolerite dykes while the central part contains rhyolite and trachyandesite dykes. The Mount Edgar plugs, of trachyandesite, lie close to north-northeast-trending fractures in the densest part of the felsic dyke swarm. Northeast of Talga Talga homestead both dolerite and trachyandesite dykes occupy *en echelon* portions of the same fracture (Fig. 1).

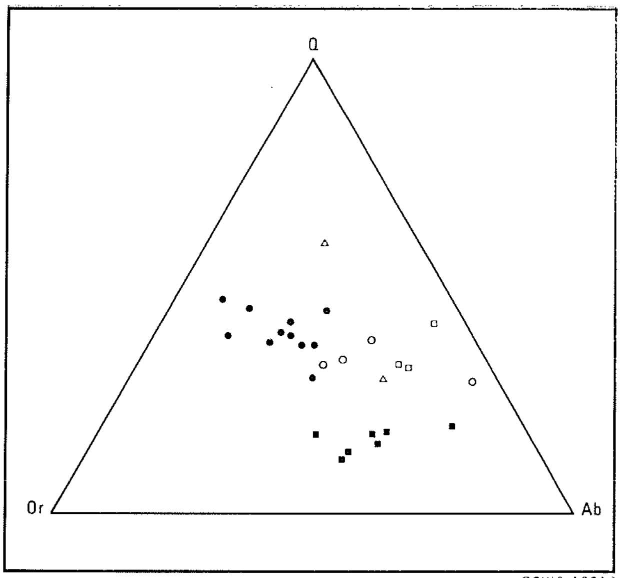


Figure 4 Normative Q-Or-Ab diagram (symbols as in Figure 2).

As far as is known, the rhyolitic dykes are restricted to the batholith proper. With their generally high K_2O/Na_2O ratio and high Rb and Rb/Sr, the presence of detectable Sn and moderate to high F content, it seems likely that the dykes are the last stage of the development of the granitoid rocks—the intrusion of residual magma along fractures. However, the high K_2O content of the dykes precludes the possibility of finding exact equivalents among the Mount Edgar granitoids. The high Ce and La of the dykes suggests that the only possible related granitoid is the granodiorite pluton located 5 km north of Mount Edgar (Table 3, sample 34). This pluton is geographically close to the main trend line of the dyke swarm but it seems an unlikely source as this would require severe fractionation to reverse the Rb/Sr ratio from 84/216 in the pluton to 319/68 in the dykes. The only other potassic rocks in the vicinity are the lavas of the Wyman Formation (Table 3, sample 35) but these form part of the Archaean layered succession into which the batholith is intruded and have an entirely distinct trace-element signature; there is no reason to suppose the dykes are related to this formation.

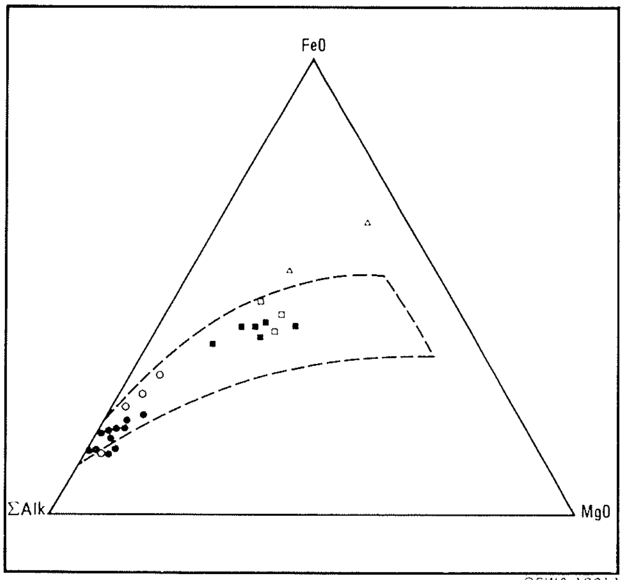


Figure 5 AFM diagram. The dashed line encloses calc-alkaline trends (Ringwood, 1974) (Symbols as in Figure 2).

Two of the Ca-rich rhyolite dykes (samples 13 and 14) occur with the main group of Ca-poor dykes. The rock appears to be a variant of the main rhyolite dyke magmas; the high CaO and TiO_2, and distinctive trace-element content may indicate a lesser degree of fractionation or perhaps minor contamination of the magma by basic material. The ultrasodic dyke (sample 15) may be derived from the same magma source as some of the aplites, as these also contain highly sodic varieties (Davy and Lewis, in prep. b). The petrographically distinctive rhyolites containing xenocrysts of granophyre (samples 16 and 18) occur in the west of the batholith and have no known affinities.

The trachyandesite dykes and plugs occur in the same swarm as the rhyolites but are chemically and petrographically distinct from them. None of the granitoids of the Mount Edgar batholith are comparable with the trachyandesites, but similar dykes are known to occur southeast of the batholith associated with the Bridget Adamellite. The Bridget Adamellite is the largest of a number of small stocks which intrude the Mosquito Creek Formation; the composition of the stocks varies from adamellite to quartz monzonite (Table 3, samples 30, 31) and both stocks and dykes are characterized by prominent green euhedral hornblende. From the major-element chemistry, it is possible that the trachyandesites were formed by the contamination of doleritic magma with granitic material, but the trace element content of the rocks does not support this hypothesis.

The dolerite dykes are widespread throughout the region, rocks of similar type and composition occupy north-northeast-trending fractures cutting across many batholiths and greenstone belts.

No evidence has been found in this study for providing even a relative age for the dyke suites that intrude the Mount Edgar batholith, but there are a number of lines of evidence from other areas which suggest that, apart from the andesites in the eastern part of the batholith, the rhyolites are oldest, followed by the dolerites and trachyandesites. In the Shaw batholith, southwest of Mount Edgar, rhyolite dykes similar to those described here are cut by dolerites of the Black Range suite (Hickman, in press). Trachyandesite dykes associated with the Bridget Adamellite intrude Proterozoic lavas of the Fortescue Group (Hickman, 1978; Barley, 1980) for which the Black Range dyke swarm probably acted as feeders (Lewis and others, 1975). The absolute age of the dykes is also problematic: a lower limit is set by the age of the Moolyella Adamellite which is intruded both by dolerite and rhyolite dykes, and this pluton has been dated by the Rb-Sr method at 2 670 $\pm$ 95 m.y. by de Laeter and Blockley (1972). An upper age limit for the trachyandesite dykes is possibly provided by the Spinaway Porphyry, a dacite sill which intrudes the Hardey Sandstone, which was dated by Trendall (1975) at 2 124 $\pm$ 195 m.y. The Black Range Dolerite has been dated by Lewis and others (1975) at 2 329 $\pm$ 89 m.y., but the significance of this age is not certain as there is the possibility that the Hardey Sandstone, which unconformably overlies a dyke of the Black Range suite, is as old as 2 600 m.y. (Hickman and de Laeter, 1977). At all events, the three main dyke suites were intruded at the end of Archaean and in earliest Proterozoic times; in the Mount Edgar batholith they were intruded along a single fracture system and the time interval over which they were intruded may be relatively short. The availability of three distinctly different magmas over a single geographic area within a short space of time, remains a problem.

The last group of felsic dykes to be considered are the andesite which are restricted to a small area southeast of Marble Bar (Fig. 1). Though their dominant trend is northeast, the fractures are localized and do not appear to form part of the major fracture pattern occupied by dykes in the eastern part of the batholith. The fractures are confined to the alkali granite, which occupies the margin of the batholith, and there is some suggestion of a radial distribution with a centre close to the nearby 'Big Stubby' and 'Halley's Comet' lead-zinc mineralization. Hickman and Lipple (1978) and Hickman (in press) suggest that the alkali granite may be older than the Mount Edgar batholith and a magma source for the Duffer Formation. Xenoliths of this granitoid are present within the migmatite complex which is believed to be in the order of 3 280 $\pm$ 20 m.y. old (Pidgeon, 1978b), whereas the Duffer Formation itself is 3 452 $\pm$ 16 m.y. old (Pidgeon, 1978a); both ages were obtained by the U-Pb method on zircons.

A comparison of the chemistry of the andesite (samples 8–10) with that of felsic rocks within the Duffer Formation (Table 3, sample 37) indicates their overall similarity. The main differences are in SiO_2, Fe_2O_3 (total), MgO, and Li, but even here the differences are not great. While the similarities do not prove that the andesite dykes and the Duffer Formation are co-magmatic they are suggestive. That the andesite dykes are older than the other felsic dykes of the Mount Edgar batholith is also suggested by the fact that, unlike the rhyolites and trachyandesites, the andesite dykes have been metamorphosed and recrystallized.

In conclusion, this study has shown that there is a wide variety of felsic dykes intruding the Mount Edgar batholith and that their petrography and chemistry pose significant problems concerned with the availability of a variety of magmas over a wide area during a relatively short time interval. In the past little attention has been paid to dyke rocks in the Pilbara region, and it is suggested that a wider study is needed to solve the problems.

In particular the problems raised are:

(1) The relationship of the andesite dykes and alkali granite near Marble Bar to the Duffer Formation and the Mount Edgar batholith.

(2) The nature of the photolineament which marks the eastern margin of the Mount Edgar, Corunna Downs and Shaw batholiths and its relation to the fractures now filled by rhyolitic, trachyandesitic and doleritic dykes.

(3) The time-relationships and origin of the magmas which formed the dyke rocks.

REFERENCES

Barley, M. E., 1980, Evolution of Archaean calc-alkaline volcanics: University of Western Australia Ph.D. thesis (unpublished).

Cox, K. G., Bell, J. D., and Pankhurst, R. J., 1979, The Interpretation of igneous rocks: London, George Allen and Unwin.

Davy, R., and Lewis, J. D., in press, The geochemistry of the Mount Edgar batholith, Pilbara area, Western Australia: International Archaean Conference, 2nd, Perth, 1980, Geological Soc. Australia Spec. Publ.

Davy, R., and Lewis, J. D., in prep. a, The geochemistry and petrography of the Mount Edgar batholith, Pilbara region: West. Australia Geol. Surv.

Davy, R., and Lewis, J. D., in prep. b, The geochemistry and petrography of the Corunna Downs batholith, Pilbara region: West. Australia Geol. Surv.

de Laeter, J. R., and Blockley, J. G., 1972, Granite ages within the Archaean Pilbara Block, Western Australia: Geol. Soc. Australia, Jour. v. 19, p. 363–370.

Hickman, A. H., 1978, Nullagine, Western Australia: West. Australia Geol. Surv., 1:250 000 Geol. Series Explanatory Notes.

Hickman, A. H., in press, Geology of the Pilbara Block and its environs: West Australia Geol. Surv. Bulletin 127.

Hickman, A. H., and de Laeter, J. R., 1977, The depositional environment and age of a shale within the Hardey Sandstone of the Fortescue Group: West. Australia Geol. Surv. Ann. Rept 1976, p. 62–68.

Hickman, A. H., and Lipple, S. L., 1978, Marble Bar, Western Australia: West. Australia Geol. Surv., 1:250 000 Geol. Series Explanatory Notes.

Le Maitre, R. W., 1976, The chemical variability of some common igneous rocks: Jour. Petrology v. 17, p. 589–637.

Lewis, J. D., Rosman, K. J. R., and de Laeter, J. R., 1975, The age and metamorphic effects of the Black Range Dolerite dykes: West. Australia Geol. Surv. Ann. Rept 1974, p. 80–88.

Pidgeon, R. T., 1978a, 3 450 m.y.-old volcanics in the Archaean layered greenstone succession of the Pilbara Block, Western Australia: Earth and Planetary Sci. Letters, v. 37, p. 421–428.

——— 1978b, Geochronological investigations of granite batholiths of the Archaean granite-greenstone terrain of the Pilbara Block, Western Australia: Archaean Geochemistry Conference, Toronto, 1978, Proc. p. 361–362.

Ringwood, A. G., 1974, The petrological evolution in island arc systems: Geol. Soc. London, Jour. v. 130, p. 183–204.

Trendall, A. F., 1975, Preliminary geochronological results from two Pilbara porphyry bodies: West. Australia Geol. Surv. Ann. Rept 1974, p. 103–106.

Rb-Sr DATING OF TECTONIC EVENTS IN THE PROTEROZOIC MOUNT BARREN GROUP NEAR HOPETOUN

by R. Thom, J. R. de Laeter* and W. G. Libby

ABSTRACT

Samples of mica schist from the Mount Barren Group at Barrens Beach and West Beach, respectively about 9 km and 12 km west of Hopetoun, Western Australia, were sampled for Rb-Sr geochronology. Whole-rock samples from Barrens Beach provide a model 4 isochron at 1 077 $\pm$ 22 m.y. with an initial $^{87}Sr/^{86}Sr$ ratio of 0·790 3 $\pm$ 0·007 1. A single biotite sample has a radiometric age of 1 087 m.y., assuming an initial ratio of 0·79. The data from West Beach failed to define an isochron, but suggest older ages and a lower initial ratio. The 1087 m.y. date is believed to be associated with the latest folding in the area, as this folding is pervasive at Barrens Beach but only locally developed at West Beach. Muscovite—whole-rock pairs from the erratic data at West Beach may indicate an event between 1 200 and 1 300 m.y. Similarly, a low-precision isochron through whole-rock and biotite data at West Beach may reflect an event at about 1 790 m.y.

INTRODUCTION

The Mount Barren Group is a succession of arenaceous and shaley rocks forming an elongate outlier of Proterozoic metasediment in older gneiss, encompassing the peaks, East Mount Barren, Mid Mount Barren, and West Mount Barren, on the south coast of Western Australia (Fig. 1). The outlier straddles the boundary between the Yilgarn Block and the Albany-Fraser Province, and has undergone metamorphism and deformation, thought to be the effects of overprinting during development of the Albany-Fraser Province, a complex Proterozoic mobile belt. The intensity of metamorphism and deformation within the outlier decreases with distance from the mobile belt, northwestward toward the Yilgarn Block. This metamorphic gradient was first recognized by Sofoulis (1956), and has been described in more detail by Thom (1977).

The main aim of this study was to obtain a firm metamorphic age from the schist on the coast near East Mount Barren which would represent a reliable minimum age of deposition of the Mount Barren Group. A secondary aim was to examine whether interpretable differences in ages could be identified from metasediments of different structural history, and, therefore, elucidate the nature of the polyphase tectonic events in this area.

The Mount Barren Group has long been assigned to the Proterozoic on various lines of evidence:

(i) it is a stable-shelf sequence unconformably overlying, at a high angle, Archaean volcanic and sedimentary rocks of the Ravensthorpe Range;

(ii) it is younger than three dyke suites cutting the Ravensthorpe Quartz Diorite which has intruded the Archaean volcanics. An east-northeasterly trending mafic dyke suite is correlated with mafic dykes of the same trend in the Phillips River west of Ravensthorpe, dated at 2 447 $\pm$ 50 m.y. (Giddings, 1976);

(iii) where the effects of Proterozoic metamorphism and deformation are minimal, the Mount Barren Group is seen to post-date the main Archaean metamorphism and deformation;

(iv) stromatolites, but no other fossils, have been recognized within the succession (Thom and others, 1977);

(v) the Stirling Range Formation, 150 km to the west, with which the Mount Barren Group has long been correlated (Roe, 1852; Maitland, 1901; and Blatchford, 1919) has a metamorphic age of 1 126 $\pm$ 40 m.y. and an interpreted depositional age of 1 312 m.y. (Turek and Stephenson, 1966);

(vi) the metamorphic gradient within the Mount Barren Group has been attributed to overprinting during a tectonothermal event of 1 400–1 200 m.y. age within the Albany-Fraser mobile belt (Thom, 1980).

STRUCTURE OF THE MOUNT BARREN GROUP

The two locations (Fig. 1) which were sampled for geochronology represent different situations in the structural sequence, so that it is appropriate to summarize the structure of the repeatedly deformed Mount Barren Group.

*Department of Physics, Western Australian Institute of Technology.

On the basis of consistent structural relationships it is possible to recognize four generations of folds (F_1, F_2, F_3, and F_4), all with axial planar foliations (S_1, S_2, S_3, and S_4), which are assigned to four deformational events (D_1, D_2, D_3 and D_4). These relationships are summarized below:

D_1 The Fitzgerald Syncline, which is the major fold structure of the Mount Barren Group, is assigned to F_1. It is identified regionally (Fig. 1) by the distribution of younging directions of the various rock types within the outlier. Few associated mesoscopic structures are known (Thom and Chin, in press).

D_2 Thrusting was an important event in D_2, and recumbent F_2 folds were formed during this period. These folds are transected by a later cleavage, S_3, which is not axial planar to the F_2 folds.

D_3 Mesoscopic F_3 folds are ubiquitous throughout the Mount Barren Group, but the folded surface is commonly rendered indistinct by the strongly developed axial-planar foliation, S_3. This foliation is the most prominent planar surface in the metasediments of the Mount Barren Group.

D_4 F_4 folds are widespread and commonly have S_3 as the folded surface. F_4 folds have only poorly developed axial-planar foliation and are, therefore, the most conspicuous of the different generations of folds in the Mount Barren Group.

Folding is summarized schematically in Figure 2.

The Mount Barren Group is most strongly deformed and metamorphosed between Barrens Beach and West Beach. Quartz arenite has been metamorphosed to quartzite, and pelitic rocks have been metamorphosed to muscovite-biotite-kyanite-staurolite-garnet schist. A macroscopic F_4 fold train is clearly visible on aerial photographs and is mappable on the ground from varying younging directions in quartzite. These folds decrease in amplitude westward from several hundred metres near East Mount Barren to a few metres near Mylies Beach. This decrease in intensity of D_4 is reflected in the mesoscopic structures at the two sample locations, as described below:

(a) At West Beach, the most prominent feature is the foliation, S_3, which is planar and imparts a fissility or flagginess to the schists. This foliation is axial-planar to mesoscopic F_3 folds, and is so intense that F_3 folds are nearly obliterated, although evidence for them can always be found. F_3 folds are best preserved by quartz veins whose injection pre-dated the D_3 event. F_4 folds, which deform the S_3 foliation, are confined to discrete linear zones. The accompanying foliation (S_4, a crenulation cleavage) is widespread but is everywhere weaker than S_3. The samples were collected from a zone in which planar S_3 foliation is the dominant structure and F_4 folds are absent.

(b) At Barrens Beach, S_3 foliation is again the most prominent foliation, but here it is deformed into innumerable F_4 folds. These folds have an axial-planar crenulation cleavage (S_4) which is strongly developed and partially transposes the earlier foliation (S_3). Wide compositional bands, in which coarsely crystallized biotite alternates with bands of finer grained muscovite schist, have been deformed into F_3 folds, several metres in wavelength, and have been subsequently refolded in D_4. All samples from this locality contain recognizable F_4 folds. Except for the coarse-grained biotite schist, all of the samples contain abundant mesoscopic F_4 folds, usually with distinct axial-planar crenulation cleavage (S_4).

PETROGRAPHY

The Barrens Beach samples (55249A–F) are little-altered kyanite-biotite-muscovite-quartz schist with rutile and tourmaline, and, except for 55249E and F, opaque minerals and staurolite. Chlorite is present in all samples but is clearly secondary in at least some samples. Accessory apatite and zircon are present in most samples.

Biotite in sample 55249E ranges from fine to very coarse grained. Fine flakes of biotite tend to have a common orientation parallel to muscovite, whereas coarse, poikiloblastic grains have little systematic orientation and have grown post-kinematically to D_4. In this sample, chloride is interleaved

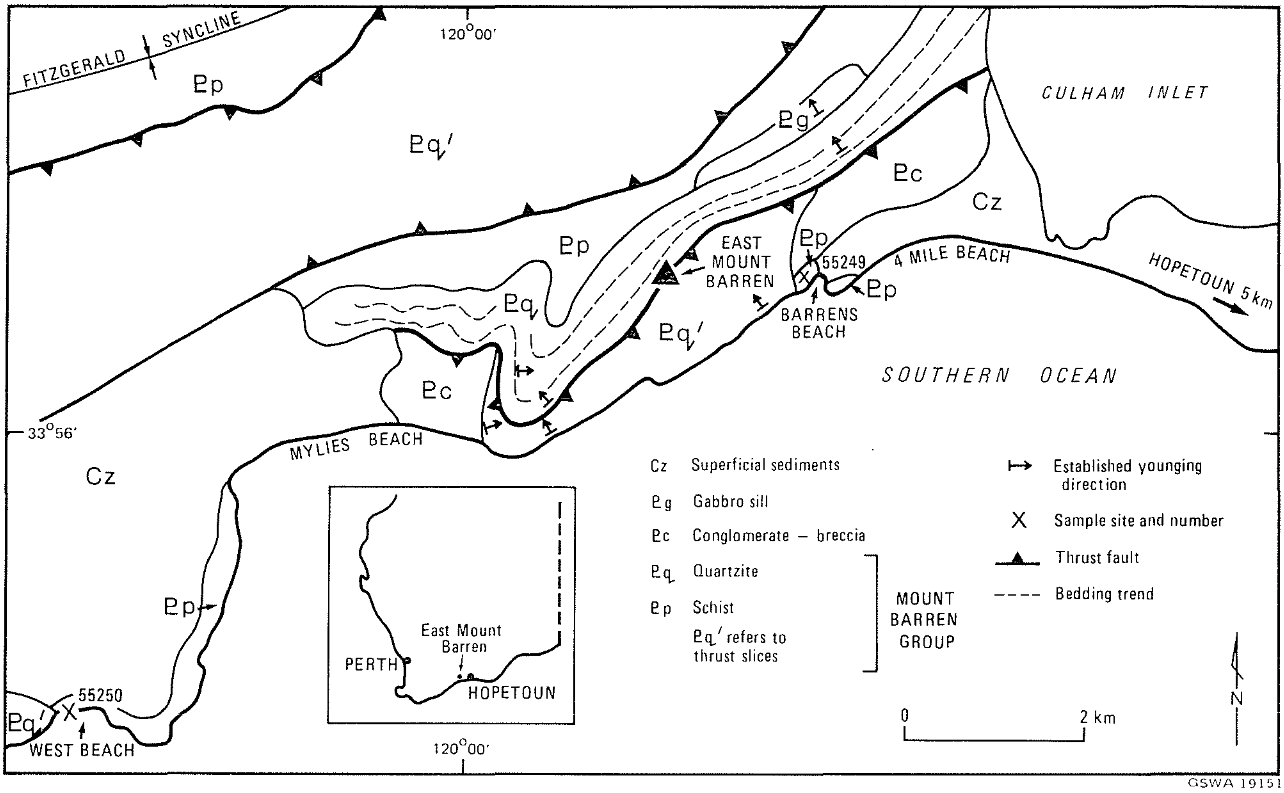


Figure 1 Structural and geological setting of the geochronology sample sites.

with biotite. Thus, as many as three stages of crystallization (synkinematic biotite, post-kinematic biotite and chloritization of biotite) are suggested by the sample.

Samples from West Beach (55250A–H) are fresh pelitic schists containing quartz, biotite, muscovite, tourmaline, and an opaque mineral which is probably graphite. Staurolite is present in five samples (55250A, B, C, F and G), of which three (55250A, B and F) contain kyanite. In contrast, garnet is present in samples 55250D, E and H, which are free of kyanite and staurolite. Iron oxide is present in some samples.

ANALYTICAL PROCEDURE

Geochronological samples were prepared mechanically in the laboratory of the Geological Survey of Western Australia and analyzed at the Department of Physics, Western Australian Institute of Technology.

Whole-rock samples were crushed and split, where appropriate, into subsamples for whole-rock and for mica analysis. Samples for whole-rock analysis were reduced to —200 mesh in a Tema-style mill.

Biotite and muscovite splits were further ground and the individual micas separated by a variety of techniques, primarily using the Frantz magnetic separator, then reduced to —200 mesh in an agate mortar.

The procedure for Rb-Sr analysis is essentially as described by de Laeter and others (1981). The value of $^{87}Sr/^{86}Sr$ for the NBS 987 standard measured during this project was 0·710 2 ± 0·000 1, normalized to a $^{88}Sr/^{86}Sr$ value of 8·375 2.

RESULTS

Measured Rb and Sr values and Rb/Sr ratios, determined by x-ray fluorescence, are listed with mass-spectrometric determinations of $^{87}Sr/^{86}Sr$ in Table 1. We believe the measured values of Rb and Sr are accurate to within ± 7%; however, the measured Rb/Sr ratios may not correspond precisely with ratios which would be derived from the separate Rb and Sr values listed. Errors are reported at the 95% confidence level. The data listed in Table 1 have been regressed using the least-squares programme of McIntyre and others (1966). All dates reported have been calculated using an ^{87}Rb decay constant (λ) of $1{\cdot}42 \times 10^{-11}$ yr^{-1}(Steiger and Jäger, 1977). Dates

TABLE 1. ANALYTICAL DATA FOR BARRENS BEACH AND WEST BEACH

Sample	Rb	Sr	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
Barrens Beach:					
$55249B_1$*	207	161	1·29 ± 0·02	3·78 ± 0·04	0·849 37 ± 0·000 30
55249A	143	57	2·51 ± 0·03	7·38 ± 0·07	0·897 00 ± 0·000 23
55249F	171	43	4·0 ± 0·04	11·9 ± 0·01	0·974 91 ± 0·000 41
55249E	198	36	5·50 ± 0·05	16·4 ± 0·02	1·051 19 ± 0·000 33
55249C	228	26·6	8·59 ± 0·08	26·0 ± 0·3	1·192 8 ± 0·000 51
55249D	177	7·9	22·4 ± 0·2	72·1 ± 0·8	1·888 03 ± 0·000 10
55249B	260	8·3	31·4 ± 0·3	105 ± 1·0	2·396 11 ± 0·000 4
$55249B_2$†	395	6·3	62·2 ± 0·6	250 ± 3	4·680 21 ± 0·000 70
West Beach:					
$55250C_1$*	345	170	2·03	5·95 ± 0·06	0·863 89 ± 0·000 5
55250F	187	84	2·23	6·54 ± 0·07	0·866 10 ± 0·000 35
55250A	222	89	2·50	7·35 ± 0·07	0·888 55 ± 0·000 34
55250B	230	91	2·53	7·43 ± 0·07	0·880 93 ± 0·000 32
55250G	187	72	2·60	7·65 ± 0·08	0·907 96 ± 0·000 49
55250C	216	81	2·66	7·82 ± 0·08	0·895 68 ± 0·000 30
$55250E_2$*	283	99	2·86	8·46 ± 0·09	0·962 78 ± 0·000 11
$55250E_1$*	247	84	2·94	8·70 ± 0·09	0·961 59 ± 0·000 30
55250D	180	45	4·04	12·0 ± 0·1	1·018 36 ± 0·000 09
55250H	181	43	4·21	12·5 ± 0·1	1·015 38 ± 0·000 48
55250E	235	46	5·08	15·2 ± 0·1	1·086 37 ± 0·000 46

* Separated muscovite
† Separated biotite

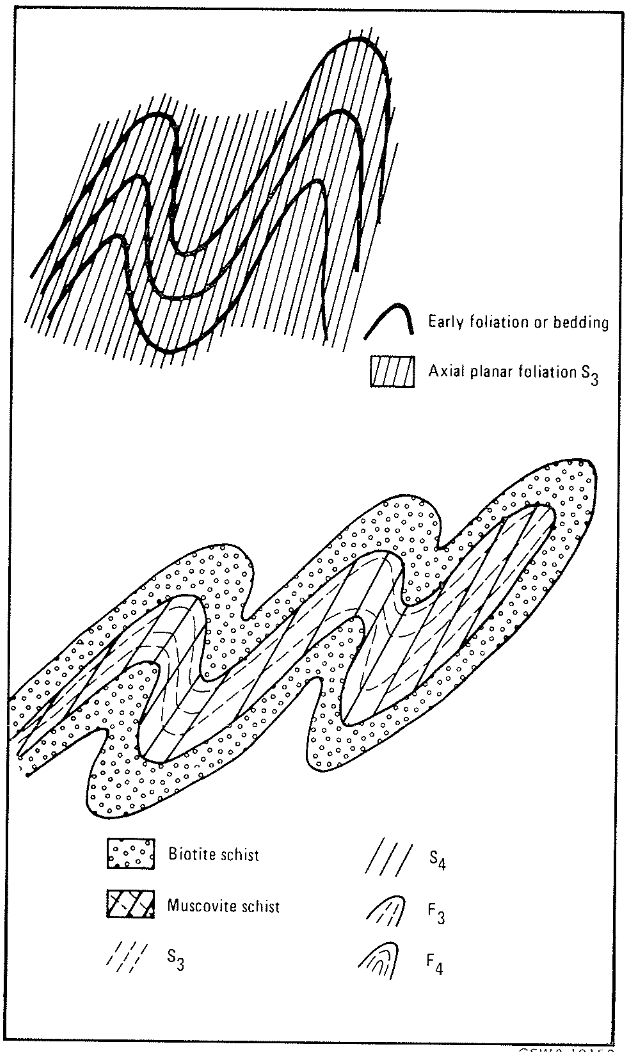


Figure 2 Schematic line drawing of fold types:—
(a) F_3 folds with strongly developed axial-planar foliation, S_3.
(b) F_4 folds in muscovite schist (with strongly developed S_3 and weaker S_4) and coarsely recrystallized biotite schist (no perceptible cleavages).

referred to here, from sources which used a different decay constant, have been recalculated before inclusion in the present work.

The six whole-rock samples plus one sample of separated muscovite and one sample of separated biotite from Barrens Beach provide a good model 4 isochron of 1 077 ± 22 m.y. with an initial $^{87}Sr/^{86}Sr$ ratio of 0·790 3 and a mean square of weighted deviates (MSWD) of 27·6. The isochron for these samples is plotted on Figure 3. Removing either biotite or both biotite and muscovite from the isochron changes the date slightly, but the deviation is well within the quoted error limits. The single biotite sample, 55249B$_2$, provides a slightly older model date of 1 087 m.y., assuming an initial $^{87}Sr/^{86}Sr$ ratio of 0·79.

Samples from West Beach, plotted on Figure 4, failed to generate an intelligible isochron. There is, however, some order in the data which encourages an effort to extract some information.

The scatter of points can be reduced somewhat by deleting data based on separated muscovite (samples 55250C$_1$, E$_1$ and E$_2$). A least-squares regression line on the remaining points corresponds to a model 4 age of 1 791 ± 184 m.y. with an initial ratio of 0·699 ± 0·024. This unrealistically low initial ratio may be attributable to the scatter in the data. A reference isochron drawn from an initial ratio of 0·702 to the mean of $^{87}Rb/^{86}Sr$ and $^{87}Sr/^{86}Sr$ values for whole-rock samples from the locality yields an age of 1 767 m.y., probably a better estimate than 1 791 m.y., and still well within the quoted error limits.

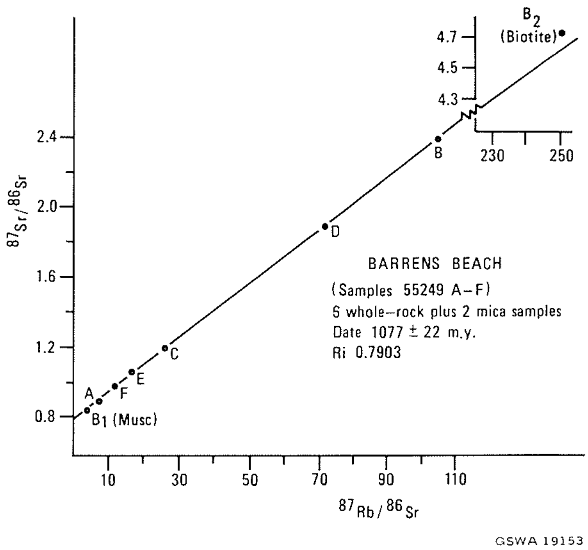


Figure 3 Rubidium-strontium whole-rock and mineral isochron from Barrens Beach.

If the scatter in points is due to partial re-equilibration of isotopes, separated minerals may be expected to be more completely reset than whole-rock samples, which were collected as much as 60 m apart. Two whole-rock samples with associated separated muscovite are available to test this possibility. Samples 55250E$_1$ and E$_2$ are muscovite concentrates separated from whole-rock sample 55250E; sample 55250C$_1$ is muscovite separated from 55250C. In both sets of samples the muscovite concentrate has a lower $^{87}Rb/^{86}Sr$ ratio than the whole-rock sample, implying that muscovite has retained or gained more radiogenic Sr than the other minerals in the rock, most notably biotite. Sample 55250E with its separated muscovite suggests an age of 1 307 m.y.; sample 55250C and separated muscovite indicates an age of 1 187 m.y. These dates may record an event at about 1 250 m.y.

DISCUSSION

Field mapping has established that the tectonic history of the area is complex, but has not indicated whether this complexity was concentrated in a single, polyphase orogenic event or was developed by a series of discrete unrelated events spread over substantial geological time. As a result of the tectonic complexity, the geochronological results are also

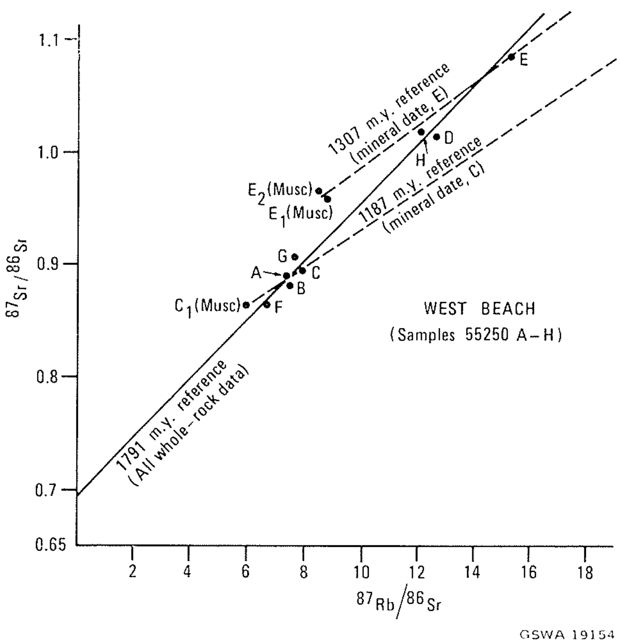


Figure 4 A plot of rubidium-strontium whole-rock and mineral data from West Beach, with reference isochrons.

largely ill defined. However, a single event seems well established at 1 077 m.y. at Barrens Beach, and discrete events extending back for several hundred million years before this date are suggested by the data from West Beach.

The 1 077 m.y. isochron at Barrens Beach probably is associated with the latest deformation (D_4) of the Mount Barren Group, as the substantial development of D_4 deformation is the only recognized geological difference between the rocks at Barrens Beach and at West Beach where no isochron is defined. The 1 077 m.y. date is similar to the metamorphic date of 1 126 $\pm$ 40 m.y. ($\lambda = 1{\cdot}42 \times 10^{-11}yr^{-1}$) obtained from the Stirling Range Formation by Turek and Stephenson (1966).

The less reliable dates of 1 187 and 1 307 m.y. calculated by joining muscovite data to whole-rock data cannot be confidently tied to specific events, but may be associated with the earlier events, F_2 or F_3, for which there is field evidence. The 1 767 m.y. whole-rock date is even more difficult to interpret. Candidates for the event generating this date are: (1) igneous or metamorphic activity in the provenance prior to sedimentation, (2) sedimentation of the unit, and (3) one of the metamorphic-tectonic events subsequent to deposition. Survival of provenance and sedimentary ages through medium-grade metamorphism seems unlikely, hence an early metamorphism of the Mount Barren Group in its present site probably has been dated.

If the low-precision isochron at 1 767 m.y. on whole-rock data from West Beach approximates the date of a real post-depositional event, and if the 1 077 m.y. date from Barrens Beach represents F_4, metamorphic and tectonic activity affecting the Mount Barren Group was spaced over 700 million years, probably as discrete periods of activity within that interval.

The 700 m.y. history of deformation of the Mount Barren Group includes the date of the Woodline Beds, measured by Turek (1966) at 1 586 $\pm$ 100 m.y. ($\lambda = 1{\cdot}42 \times 10^{-11}yr^{-1}$) which was interpreted as the time of deposition.

The dates of the Woodline Beds and the Mount Barren Group should be the same, within the limits of accuracy, if the two units are contemporaneous and both dates are depositional. However, 1 586 m.y. is not within the limits of the 1 791 m.y. date of the Mount Barren Group. Furthermore, a line through the midpoint of the data from the Mount Barren Group at a slope consistent with the date of the Woodline Beds clearly fails to fit the Mount Barren Group data.

These observations suggest either (1) 1 767 m.y. is not an adequate estimate of the age of either deposition or metamorphism within the Mount Barren Group, (2) the Mount Barren Group is older than the dated portion of the Woodline Beds, or (3) the 1 586 m.y. isochron from the Woodline Beds dates a post-depositional period of metamorphism rather than sedimentary deposition.

If the 1 767 m.y. date is accepted as an approximation to the age of a post-depositional event, and the Mount Barren Group correlates stratigraphically with the Stirling Range Formation, deposition of both groups was substantially earlier than the 1 312 m.y. ($\lambda = 1{\cdot}42 \times 10^{-11}yr^{-1}$) minimum depositional age suggested by Turek and Stephenson (1966) for the Stirling Range Formation.

This discussion serves to highlight the fact that at present, very little is known of the depositional age of the Proterozoic rocks that are scattered around the periphery of the Yilgarn Block.

CONCLUSIONS

The Mount Barren Group was substantially and penetratively deformed at about 1 077 m.y. providing a minimum depositional age of 1 077 m.y. Interpretation of imprecise and scattered data from West Beach suggests a tectonic event between 1 700 and 1 800 m.y., and again at about 1 250 m.y. These dates suggest that the Mount Barren Group, deposited 1 800 million years ago, was deformed in several discrete stages spanning several hundred million years.

Further work could explore the relation between the depositional ages of the Stirling Range Formation and Mount Barren Group. The results of the present study suggest that firm dates on the earlier tectonic events affecting these rocks could be obtained by careful selection of sampling localities on the basis of degree of development of each phase of deformation.

ACKNOWLEDGEMENTS

The authors acknowledge the technical assistance of Mr. D. J. Hosie of the Department of Physics, Western Australian Institute of Technology during the project.

REFERENCES

Blatchford, T., 1919, The country between Hopetoun and the Fitzgerald River: West. Australia Geol. Survey Ann. Progress Rept 1918, p. 11–12.

de Laeter, J. R., Williams, I. R., Rosman, K. J. R., and Libby, W. G., 1981, A definitive 3 350 m.y. age from banded gneiss, Mount Narryer area, Western Gneiss Terrain: West. Australia Geol. Survey Ann. Rept 1980, p. 94–98.

Giddings, J. W., 1976, Precambrian palaeomagnetism in Australia I: Basic dykes and volcanics from the Yilgarn Block: Tectonophysics, v. 30, p. 91–108.

Maitland, A. G., 1901, Phillips River Goldfield: West. Australia Geol. Survey Ann. Progress Rept 1900, p. 9–11.

McIntyre, G. A., Brooks, C., Compston, W., and Turek, A. 1966, The statistical assessment of Rb-Sr isochrons: Jour. Geophys. Research, v. 71, p. 5459–5468.

Roe, J. S., 1852, Report of an expedition to the south-eastward of Perth, Western Australia: Royal Geog. Soc. Jour., v. 22.

Sofoulis, J., 1956, Report on the broad geological structure of the Phillips River Goldfield, W.A.: West. Australia Geol. Survey Ann. Rept 1953, p. 28–32.

Steiger, R. H., and Jäger, E., 1977, Subcommission on geochronology: Convention on the use of decay constants in Geo- and Cosmochronology: Earth and Planetary Sci. Letters, v. 36, p. 359–362.

Thom, R., 1977, The evolution of Proterozoic rocks near the Fraser Front at Ravensthorpe, Western Australia: Univ. London Ph.D. thesis (unpublished).

——— 1980, Clastic dykes near the south coast of Western Australia: West. Australia Geol. Survey Ann. Rept 1979, p. 78–81.

Thom, R., and Chin, R. J., in press, Explanatory notes on the Bremer Bay 1:250 000 geological sheet, Western Australia: West. Australia Geol. Survey Record.

Thom, R., Lipple, S. L., and Sanders, C. C., 1977, Ravensthorpe, Western Australia: West. Australia Geol. Survey 1:250 000 Geol. Series explan. notes.

Turek, A., 1966, Rubidium-strontium isotopic studies in the Kalgoorlie-Norseman area, Western Australia: Australian National University Ph.D. thesis (unpublished).

Turek, A., and Stephenson, N. C. N., 1966, the radiometric age of the Albany Granite and the Stirling Range Beds, southwest Australia: Geol. Soc. Australia Jour., v. 13, p. 449–456.

INDEX

Albany-Fraser Province 120
alkaline granitic rocks 150
andesite 157
Antarctica 120, 122
Ascot Beds 94, 96

Barrow Island 102
Bassendean Sand 82, 84
Bonaparte Gulf Basin 99
Bunbury Basalt 81
Bunnawarra Cu-Zn deposit 140
Browse Basin 99

Canning Basin 100
Carnarvon Basin 100, 114
coal 57
Cockleshell Gully Formation 81, 85
Conophyton 143
Cooljarloo heavy mineral sand prospect 96
Corunna Downs Batholith 159

Darling Scarp 124
Devonian 114
diamond 57
Dongara Gas Field 104

Eastern Goldfields Province 150
Eucla Basin 104
eurypterid tracks 108, 111
Exmouth Plateau 102

felsic dykes 155
foraminifers 98
Fortescue Plain 87
Frasnian (Upper Devonian) 119

Gascoyne Province 120
geochronology 125, 128, 131, 132, 133, 149, 150, 163
Gindalbie Formation 143
gold 57
Golden Grove 139
gravity surveys 104
groundwater 64, 79
groundwater temperature 86
Guildford Formation 82, 85

Harvey 124
Hg-halo 140
Hidden Secret mine 140
Hopetoun 161
hydrogeology 71

Kangiangi Clay 92
Kanowna 143
Kumina Conglomerate 92

laterite 82

Leederville Formation 67, 72, 76, 81, 85
Lesueur Sandstone 81
Logue Brook Granite 124

magnetic Surveys 77
mercury 133
Merlinleigh Sandstone 96
metamorphism 119
Millstream Dolomite 91
molluscs 96
Mount Barren Group 161
Mount Edgar Batholith 155
Mount Narryer 146
Munabia Sandstone 114
Murchison River 105

Northampton Block 120

Officer Basin 104
Osborne Formation 71, 72, 74

palaeocurrents 106
Paterson Province 132
Perth Basin 64, 102
petroleum exploration 99, 101
phosphate 94

quartz-feldspar porphyries 158
Quindalup boreholes 79

Robe Pisolite 89
Rudall Metamorphic Complex 132

Safety Bay Sand 82, 84
seismic surveys 104
Silurian 105
Skolithos 108, 111, 113
stratabound Cu-Zn deposits 140
stromatolites 142
Sue Coal Measures 80, 85
superficial deposits; Fortescue Plain 93
"superficial formations" 69, 71, 73
Swan Valley 64

uranium 57

vein deposits 140

Weelumurra Beds 91
Western Gneiss Terrain 120, 121
Willaraddie Formation 114
Woorana 152

Tamala Limestone 82, 84
tectonics 162
Teutonic Bore 139
trachyandesite 156
Tumblagooda Sandstone 105
Twelve Mile Well 152

Yarragadee Formation 81, 85
Yarraloola Conglomerate 89
Yeneena Group 133
Yilgarn Block 119, 120, 124
Yoganup Formation 94

DIVISION V

Report of the Director of The Petroleum Branch for the Year 1980

CONTENTS

	Page
TENEMENTS	169
Status at 31st December, 1980	169
Activity Offshore	169
Activity Onshore	180
EXPLORATION	180
APPRAISAL AND DEVELOPMENT	181
Barrow Island Field (PL-1H & PL-2H) Dongara, Mondarra and Yardarino Fields (PL-1 & PL-2)	181
North Rankin, Angel and Goodwyn Fields (WA-1-L to WA-6L)	181
PRODUCTION	186
Barrow Island Field (PL-1H)	186
Dongara, Mondarra and Yardarino Fields (PL-1 & PL-2	186
RESERVES	187
ENGINEERING	187
Construction	187
Operations and Safety	187
Pipelines	189
STAFF	189

LIST OF TABLES

1. Tenements held under the Petroleum (Submerged Lands) Act, 1967 169
2. Tenements held under the Petroleum Act, 1936 171
3. Tenements held under the Petroleum Act, 1967 171
4. Tenements held under the Petroleum Pipelines Act, 1969 172
5. Tenement Applications Pending under the Petroleum (Submerged Lands) Act, 1967 174
6. Tenement Applications Pending under the Petroleum Act, 1967 174
7. Dealings under the Petroleum (Submerged Lands) Act, 1967 during 1980 175
8. Dealings under the Petroleum Act, 1967 during 1980 177
9. Summary Comparison of Exploration Permit Dealings for 1979 and 1980 180
10. Barrow Island Field, Well Completion Status by Reservoirs at 31st December, 1980 181
11. Barrow Island Field, Petroleum Production during 1980 186
12. Dongara, Mondarra and Yardarino Fields, Petroleum Production during 1980. 187
13. Summary of Petroleum Production to 31st December, 1980 188
14. Summary of Identified Recoverable Petroleum Reserves at 31st December, 1980 188
15. Accident Statistics relating to Petroleum Exploration, Production and Pipeline Industries during 1980 189

LIST OF FIGURES

1. Petroleum Tenements Held at 31st December, 1980 168
2. Petroleum Tenement Applications Pending at 31st December 1980 173
3. Petroleum Tenement Dealings During 1980 176
4. Comparison of Exploration Activity Levels 182
   - A. Rig Months 182
   - B. Meters Drilled 182
   - C. Wells Drilled 182
   - D. Seismic Surveys 182
   - E. Expenditures 182
5. Barrow Island Field—Wells Drilled during 1980 status 31/12/1980 183
6. Dongara, Mondarra and Yardarino Fields—Status of Petroleum Tenements and Wells at 31st December 1980 184
7. North Rankin, Angel and Goodwyn Fields 185
8. Barrow Island Field—Annual Production of Crude Oil to 31st December 1980 186
9. Barrow Island Field—Windalia Sand Reservoir, Cumulative Production of Crude Oil and Water and Cumulative Water injected to 31st December 1980 187
10. Northern Perth Basin. Yearly production of gas between 1971 and 31st December, 1980 187
11. Frequency and severity rate of serious injuries in the petroleum exploration, development, production and pipeline industries during 1979 and 1980 188

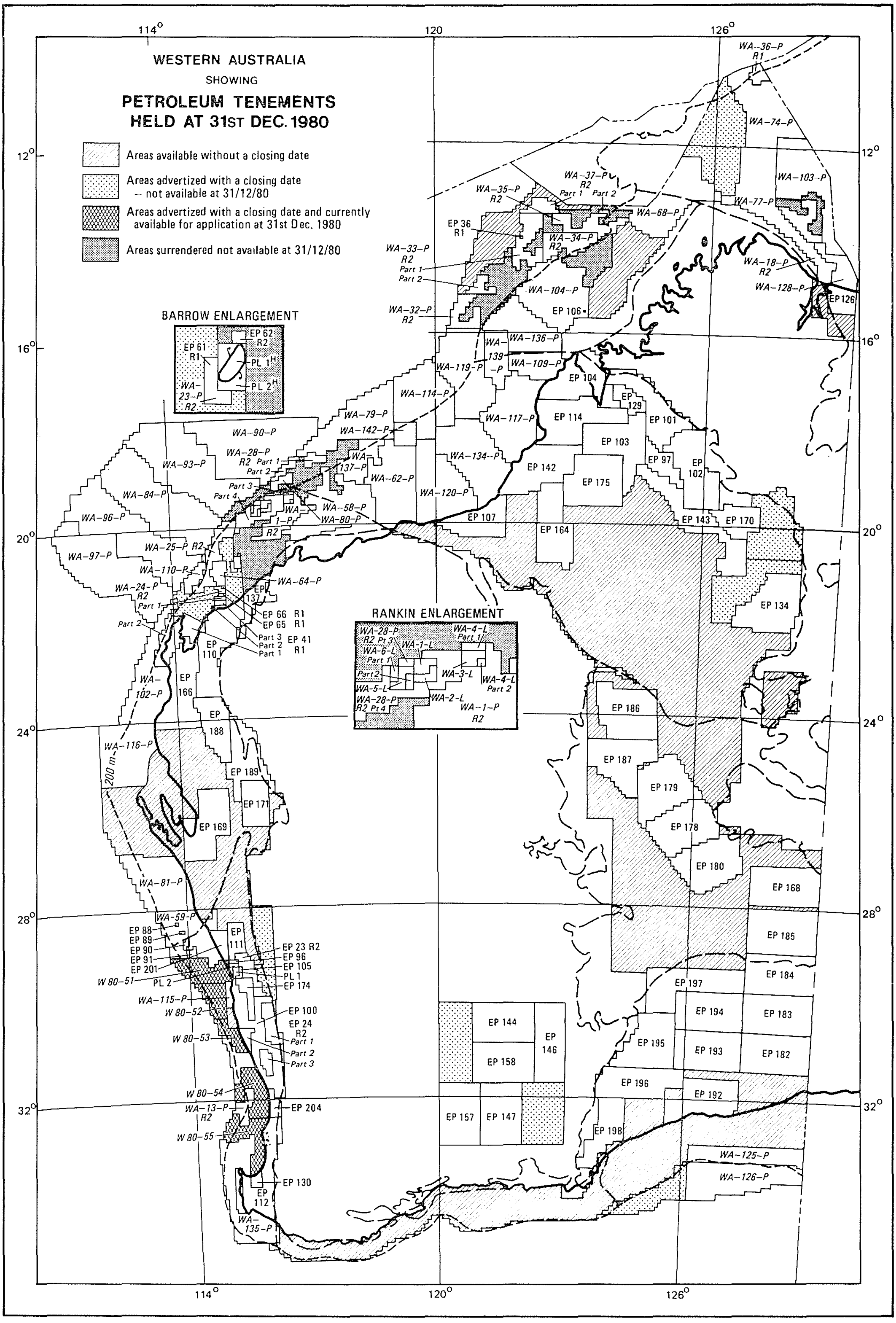


Figure 1 Petroleum Tenements on 31st December, 1980.

UNDER SECRETARY FOR MINES:

I herewith present my report on the activities of the Petroleum Branch and the petroleum exploration, development, production industry activities in Western Australia for 1980.

A. J. SHARP B.Sc. Hons
DIRECTOR,
PETROLEUM BRANCH.

TENEMENTS

Status at 31st December 1980

At the end of 1980, there were 49 offshore and 66 on shore current permits to explore for petroleum in Western Australia.

These permits cover areas of 665 265 square kilometres and 633 460 square kilometres respectively and are shown graphically in Figure 1 and are tabulated in Tables 1 to 3. The number of exploration permits is at an all-time high and reflects a high level of petroleum exploration activity.

At the year's end a total of 41 applications for exploration permits (19 offshore and 22 onshore) were being processed. These applications are shown in Figure 2 and are listed in Tables 5 and 6.

The area available for application for petroleum exploration is shown in Figure 2 and totals about 750 000 square kilometres including both offshore and onshore areas.

Activity offshore

During 1980, 9 offshore areas were made available for application with a closing date (Table 7A). Four of these areas had a closing date for applications within 1980 and attracted 16 applications—one area alone attracted 8 applications. These areas had been made available as the results of the second round of relinquishments required under the Petroleum (Submerged Lands) Act, 1967.

One area which was made available for application without a closing date attracted an application and an exploration permit was granted over the area.

Of the 22 applications made during the year and the 6 applications outstanding at the beginning of the year, 4 permits covering 30 515 square kilometres were granted, 5 applications were refused and 19 applications were being dealt with at the year's end. Dealings during the year are shown in Figure 3 and are listed in Table 7A–D and applications outstanding at year's end are listed in Table 5.

At the end of the year there were 49 current offshore exploration permits covering 665 265 square kilometres (Figure 1 and Table 1).

TABLE 1

TENEMENTS HELD UNDER THE PETROLEUM (SUBMERGED LANDS) ACT 1967

A. EXPLORATION PERMITS

Permit Number	Registered Holder	Number Blocks	Area (km²)	Expiry Date
WA–1–P–R2	Woodside Oil Ltd, Woodside Petroleum Development Pty Ltd, Mid-Eastern Oil Ltd, Shell Development (Australia) Pty Ltd, BP Petroleum Development Australia Pty Ltd, California Asiatic Oil Company, Hematite Petroleum Pty Ltd	75	6 750	14/11/84
WA–13–P–R2	West Australian Petroleum Pty Limited	35	2 585	29/8/84
WA–18–P–R2	Australian Aquitane Petroleum Pty Ltd	52	4 320	16/4/85
WA–23–P–R2	West Australian Petroleum Pty Limited	4	320	3/10/84
WA–24–P–R2	West Australian Petroleum Pty Limited	16 (Part 1) 36 (Part 2)	4 125	17/10/84
WA–25–P–R2	West Australian Petroleum Pty Limited	64	5 125	16/10/84
WA–28–P–R2	Woodside Oil Ltd, Woodside Petroleum Development Pty Ltd, Mid-Eastern Oil Ltd, Shell Development (Australia) Pty Ltd, BP Petroleum Development Australia Pty Ltd, California Asiatic Oil Company, Hematite Petroleum Pty Ltd	16 (Part 1) 16 (Part 2) 2 (Part 3) 46 (Part 4)	6 455	24/3/85
WA–32–P–R2	Woodside Oil Ltd, Woodside Development Pty Ltd, Mid-Eastern Oil Ltd, Shell Development (Australia) Pty Ltd, BP Petroleum Development Australia Pty Ltd, California Asiatic Oil Company, Hematite Petroleum Pty Ltd	50	4 120	2/7/85
WA–33–P–R2	Woodside Oil Ltd, Woodside Petroleum Development Pty Ltd, Mid-Eastern Oil Ltd, Shell Development (Australia) Pty Ltd, BP Petroleum Development Australia Pty Ltd, California Asiatic Oil Company Hematite Petroleum Pty Ltd	74 (Part 1) 23 (Part 2)	8 040	18/5/85
WA–34–P–R2	Woodside Oil Ltd, Woodside Petroleum Development Pty Ltd, Mid-Eastern Oil Ltd, Shell Development (Australia) Pty Ltd, California Asiatic Oil Company, Hematite Petroleum Pty Ltd	74	6 135	2/7/85
WA–35–P–R2	Woodside Oil Ltd, Woodside Petroleum Development Pty Ltd, Mid-Eastern Oil Ltd, Shell Development (Australia) Pty Ltd, Hematite Petroleum Pty Ltd	62	5 150	2/7/85
WA–36–P–R1	Woodside Oil Ltd, Woodside Petroleum Development Pty Ltd, Mid-Eastern Oil Ltd, BP Petroleum Development Australia Pty Ltd, Hematite Petroleum Pty Ltd	18	1 520	18/5/80
WA–37–P–R2	Woodside Oil Ltd, Woodside Petroleum Development Pty Ltd, Mid-Eastern Oil Ltd, Shell Development (Australia) Pty Ltd, BP Petroleum Development Australia Pty Ltd, Hematite Petroleum Pty Ltd	27 (Part 1) 3 (Part 2)	2 495	2/6/85
WA–58–P	Western Energy Pty Ltd, Stirling Petroleum N.L.	222	17 890	11/7/82
WA–59–P	Esso Exploration and Production Australia Inc., Western Mining Corporation Limited	190	14 320	18/6/82
WA–62–P	Oxoco International Inc., Peyto Exploration Inc., Voyager Petroleums Ltd, Australian Oil and Gas Corporation Ltd, Bridge Oil Limited, Endeavour Resources Ltd, AAR Ltd, Offshore Oil N.L., BP Petroleum Development Australia Pty Ltd	226	18 265	7/3/83
WA–64–P	Offshore Oil N.L., Southern Cross Exploration N.L., Hallmark, Minerals N.L.	22	1 760	28/2/83
WA–68–P	Oxoco International Inc., Peyto Exploration Inc., Voyager Petroleums Ltd, Bridge Oil Ltd	249	20 730	7/3/83
WA–74–P	Pelsart Oil N.L.....	253	21 270	24/6/83
WA–77–P	Magnet Metals Ltd, Jeerinah Mining Pty Ltd, Sundance Resources (Cayman) Limited, Crux (International) Limited, Scorpio Petroleum Ltd, Pluto Petroleum Ltd	254	21 270	1/8/83
WA–79–P	Hematite Petroleum Pty Ltd, Conoco Australia Limited	235	19 155	1/8/83

TABLE 1—*continued*

TENEMENTS HELD UNDER THE PETROLEUM (SUBMERGED LANDS) ACT 1967—*continued*

A. EXPLORATION PERMITS—*continued*

Permit Number	Registered Holder	Number Blocks	Area (km²)	Expiry Date
WA-80-P	Otter Exploration N.L., Target Minerals (W.A.) Pty Ltd, Endeavour Resources Ltd, Timor Oil Ltd, Spargos Exploration N.L., Alkane Exploration (Terrigal) N.L.	16	1 300	6/10/83
WA-81-P	Conoco Australia Limited, General Crude Oil Company International Ltd.	249	19 010	13/10/83
WA-84-P	Mobil Oil Australia Ltd, Phillips Australian Oil Co., Australian Gulf Oil Company, M.I.M. Investments Pty Ltd, B.P. Petroleum Development Australia Pty Ltd	400	32 330	18/11/83
WA-90-P	Woodside Petroleum Development Pty Ltd, Woodside Oil Ltd, Mid-Eastern Oil Ltd, B.P. Petroleum Development Australia Pty Ltd, California Asiatic Oil Company, The Shell Company of Australia Ltd, Hematite Petroleum Pty Ltd	400	32 470	18/11/83
WA-93-P	Hudbay Oil (Australia) Ltd, Canadian Superior Oil International Ltd, Pan Canadian Petroleum Limited, Australian Oil & Gas Corporation Limited	400	32 740	18/11/83
WA-96-P	Esso Exploration and Production Australia Inc., Hematite Petroleum Pty Ltd	400	32 180	18/11/83
WA-97-P	Esso Exploration and Production Australia Inc., Hematite Petroleum Pty Ltd	400	30 080	18/11/83
WA-102-P	CNW Oil (Australia) Pty Ltd, Star Oil and Gas Ltd, Oakwood International Petroleum N.L. Cultus Pacific N.L.	234	18 140	15/3/84
WA-103-P	Natomas of West Australia Inc., Wainoco International Inc., Bonaparte Petroleum Limited, Petro Energy Limited, Lennard Oil N.L., White Pine Mining Pty Ltd	247	20 610	29/12/83
WA-104-P	Oberon Oil Pty Ltd	242	19 970	7/3/84
WA-109-P	Esso Exploration and Production Australia Inc., Oil Company of Australia N.L., Santos Ltd.	75	6 150	4/7/84
WA-110-P	Cultus Pacific N.L., CNW Oil (Australia) Pty Ltd, Oakwood International Petroleum N.L., Star Oil & Gas Ltd	25	2 000	24/7/84
WA-113-P	Haoma Gold Mines N.L.	44	3 240	22/9/84
WA-114-P	Era South Pacific Pty Ltd, E.S.P. Exploration Pty Ltd, Carr Boyd Minerals Ltd, Hill Minerals N.L., Monarch Petroleum N.L., Attock Petroleum Ltd.	239	19 500	4/1/85
WA-115-P	Geometals Oil Exploration Pty Ltd	14	1 040	9/11/84
WA-116-P	Geometals Oil Exploration Pty Ltd	250	19 450	9/11/84
WA-117-P	Pursuit Exploration Pty Ltd	248	20 200	15/11/84
WA-119-P	Weaver Oil & Gas Corporation Australia	227	18 500	28/5/85
WA-120-P	Weaver Oil & Gas Corporation Australia	250	20 205	28/5/85
WA-125-P	Esso Exploration and Production Australia Inc., Hematite Petroleum Pty Ltd	162	11 655	8/8/85
WA-126-P	Esso Exploration and Production Australia Inc., Hematite Petroleum Pty Ltd	230	16 350	8/8/85
WA-128-P	Cultus Oil & Gas Pty Ltd, York Resources N.L., Archean Investments Limited, CNW Oil (Australia) Pty Ltd	54	3 730	7/8/85
WA-134-P	Chapman Oil of Australia Inc., Wainoco International Inc.	247	20 205	13/11/85
WA-135-P	Chapman Oil of Australia Inc., Wainoco International Inc.	231	16 440	13/11/85
WA-136-P	Conex Oil Exploration Pty Ltd, Geometals Oil Exploration Pty Ltd	173	14 220	4/1/86
WA-137-P	BP Petroleum Development Australia Pty Ltd, AAR Limited, Australian Oil & Gas Corporation Limited, Bridge Oil Ltd, Endeavour Resources Ltd, Offshore Oil N.L., Oil Company of Australia N.L., Pelsart Oil N.L., Oxoco International Inc., Peyto Exploration Inc., Voyager Petroleums Ltd, Stirling Petroleum N.L., Western Energy Pty Ltd	84	6 810	24/3/86
WA-139-P	Oil & Minerals Quest N.L., Terrex Resources N.L., Mincorp Ltd, Mid-East Minerals N.L.	80	6 560	30/12/86
WA-142-P	BP Petroleum Development Australia Pty Ltd, AAR Limited, Australian Oil & Gas Corporation Limited, Bridge Oil Ltd, Endeavour Resources Ltd, Offshore Oil N.L., Oil Company of Australia N.L., Pelsart Oil N.L., Oxoco International Inc., Peyto Exploration Inc., Voyager Petroleums Ltd, Stirling Petroleum N.L., Western Energy Pty Ltd	36	2 925	18/11/86

TABLE 1

TENEMENTS HELD UNDER THE PETROLEUM (SUBMERGED LANDS) ACT 1967

B. PRODUCTION LICENSES

Permit Number Number	Registered Holder	No. Blocks	Area (km²)	Expiry Date
WA-1-L	Woodside Oil, Woodside Petroleum Development Pty Ltd, Mid-Eastern Oil Ltd, Shell Development (Australia) Pty Ltd, BP Petroleum Development Australia Pty Ltd, California Asiatic Oil Company, Hematite Petroleum Pty Ltd	5	....	29/9/2001
WA-2-L		4	....	29/9/2001
WA-3-L		5	....	29/9/2001
WA-4-L		4	....	29/9/2001
WA-5-L		5	....	29/9/2001
WA-6-L		4	....	29/9/2001

TABLE 2

TENEMENTS HELD UNDER THE PETROLEUM ACT 1936

PETROLEUM LEASES

Leases Number	Registered Holder	No. Blocks	Area (km^2)	Expiry
PL–1H	West Australian Petroleum	N/A	259	9/2/88
PL–2H	Pty Limited	N/A	259	9/2/88

TABLE 3

TENEMENTS HELD UNDER THE PETROLEUM ACT, 1967

A. EXPLORATION PERMITS

Permit Number	Registered Holder	No. Blocks	Area (km^2)	Expiry Date
EP–23–R2	West Australian Petroleum Pty Limited	33	2 465	6/8/85
EP–24–R2	West Australian Petroleum Pty Limited	39 (Part 1) 24 (Part 2) 22 (Part 3)	6 265	6/8/85
EP–36–R1	Woodside Oil Ltd, Woodside Petroleum Development Pty Ltd, Mid-Eastern Oil Ltd, Shell Development (Australia) Pty Ltd, BP Petroleum Development Australia Pty Ltd, California Asiatic Oil Company, Hematite Petroleum Pty Ltd	1	85	15/4/81
EP–41–R1	West Australian Petroleum Pty Limited	102 (Part 1) 1 (Part 2) 2 (Part 3)	8 400	18/7/81
EP–61–R1	West Australian Petroleum Pty Limited	4	320	19/9/81
EP–62–R1	West Australian Petroleum Pty Limited	2	160	19/8/81
EP–65–R1	West Australian Petroleum Pty Limited	2	160	19/9/81
EP–66–R1	West Australian Petroleum Pty Limited	1	80	19/9/81
EP–88	Esso Exploration and Production Australia Inc., Western Mining Corporation Limited	1	75	18/6/81
EP–89	Esso Exploration and Production Australia Inc., Western Mining Corporation Limited	2	150	18/6/81
EP–90	Esso Exploration and Production Australia Inc., Western Mining Corporation Limited	4	300	18/6/81
EP–91	Esso Exploration and Production Australia Inc., Western Mining Corporation Limited	7	530	18/6/81
EP–96	XLX N.L.	3	225	3/11/81
EP–97	Whitestone Petroleum Australia Ltd, Amax Iron Ore Corporation, International Energy Development Corporation of Australia Pty Ltd, Australian Consolidated Minerals Ltd, YOM Oil Ltd	64	5 185	16/9/81
EP–100	D. A. Hughes, D. J. Hughes, Strata Oil N.L., Landshare Investment Pty Ltd, J. M. Goldberg, Wise Nominees Pty Ltd, Cladium Mining Pty Ltd, A. R. Burns, V. W. Burns, D. R. Gascoine, J. Gascoine, B. C. Forster, Haoma Petroleum Pty Ltd	163	12 000	3/10/82
EP–101	Whitestone Petroleum Australia Ltd, Amax Iron Ore Corporation, International Energy Development Corporation of Australia Pty Ltd, Australian Consolidated Minerals Ltd, Australian Occidental Petroleum Inc. Vamgas Ltd, YOM Oil Ltd	172	14 040	24/6/82
EP–102	Whitestone Petroleum Australia Ltd, Amax Iron Ore Corporation, International Energy Development Corporation of Australia Pty Ltd, Australian Consolidated Minerals Ltd, YOM Oil Ltd	200	16 180	24/6/82
EP–103	Whitestone Petroleum Australia Ltd, YOM Oil Ltd, International Energy Development Corporation of Australia Pty Ltd	184	14 950	22/8/82
EP–104	Esso Exploration and Production Australia Inc., Oil Company of Australia N.L., Santos Ltd	199	16 280	31/8/82
EP–105	Colgas Inc., Mesa Australia Limited	4	300	29/11/82
EP–106	Oberon Oil Pty Ltd	1	80	7/3/83
EP–107	Era South Pacific Pty Ltd, Era West Australia Inc., E.S.P. Explorations Pty Ltd, Cambridge Royalty Co., Cambridge Petroleum Royalties Ltd, North West Mining N.L.	146	11 740	30/6/83
EP–110	Samantha Mines Pty Ltd, Otter Exploration N.L., Onslow Oil & Gas Exploration Pty Ltd	200	15 830	3/8/83
EP–111	Jervois Sulphates (N.T.) Ltd	42	3 155	21/10/83
EP–112	Weaver Oil & Gas Corporation Australia	135	9 600	29/4/84
EP–114	Swan Resources Ltd, Eagle Corporation Ltd	196	15 970	22/7/84
EP–126	Australian Acquitaine Petroleum Pty Ltd, Alliance Petroleum International Ltd, Vamgas Ltd, Western Mining Corporation Ltd	47	3 880	17/8/84
EP–129	Home Oil Australia Ltd, Occidental Exploration & Production Company, Alberta Eastern Gas (1978) Ltd, Vamgas Ltd	43	3 510	7/8/84
EP–130	Mesa Australia Ltd, Western Mining Corporation Ltd, Offshore Oil N.L., Monarch Petroleum N.L., Whicher Oil N.L.	18	1 285	22/8/84
EP–134	Mobil Oil Australia Ltd	200	15 935	22/7/84
EP–137	J. O. Clough & Son Pty Ltd, Avon Engineering Pty Ltd	72	5 730	22/7/84
EP–142	Chapman Oil of Australia Inc. Wainoco International Inc.	200	16 190	10/10/84
EP–143	Western Mining Corporation Ltd	198	15 930	20/9/84

TABLE 3—*continued*

TENEMENTS HELD UNDER THE PETROLEUM ACT, 1967—*continued*

A. EXPLORATION PERMITS—*continued*

Permit Number	Registered Holder	No. Blocks	Area (km²)	Expiry Date
EP–146	Openpit Mining & Exploration Pty Ltd	180	13 270	8/2/85
EP–147	Dampier Mining Co	192	13 930	8/2/85
EP–144	Magnum Minerals Pty Ltd	180	13 270	8/2/85
EP–157	Swan Resources Ltd	192	13 930	8/2/85
EP–158	C.S.R. Ltd	180	13 270	8/2/85
EP–164	Medcon Petroleum Ltd, Brunswick Oil N.L. Pontella Nominees Pty Ltd, Willara Petroleum Pty Ltd, Royal Resources Exploration Inc, Meridian Oil N.L., Delta Petroleum Pty Ltd.	172	15 700	17/6/85
EP–166	Winthorp Investments Ltd, Monarch Petroleum N.L. Meda Petroleum N.L., Geotechnics Australia Pty Ltd	200	15 620	8/1/85
EP–168	Terrex Resources, N.L., Oil and Minerals Quest N.L., Zanex Ltd, Capital Oil Corporation Ltd, Mincorp Ltd	200	15 200	16/4/85
EP–169	Eagle Corporation Ltd, Pan Continental Mining Ltd, Elvert Exploration Pty Ltd, Mergul Holdings Pty Ltd	182	14 000	6/6/85
EP–170	Oil Company of Australia N.L., Offshore Oil N.L., E.S.P. Interior Pty Ltd, Pan Pacific Petroleum N.L., Strata Petroleum Pty Ltd	83	6 650	13/7/85
EP–171	Eagle Corporation Ltd	96	7 400	20/4/85
EP–174	Australian Aquitaine Petroleum Pty Ltd, Alcoa of Australia Ltd, Alliance Minerals Australia N.L.	32	2 380	16/4/85
EP–175	Getty Oil Development Co Ltd, Union Texas Aust. Inc, Alliance Petroleum International Ltd	193	15 620	23/1/85
EP–178	The Shell Company of Australia Ltd	200	15 375	30/4/85
EP–179	The Shell Company of Australia Ltd	200	15 480	30/4/85
EP–180	The Shell Company of Australia Ltd	200	15 260	30/4/85
EP–182	} C.R.A. Exploration Pty Ltd, Eagle Corporation Ltd, Swan Resources Ltd	200	14 700	28/4/85
EP–183		200	14 850	28/5/85
EP–184		200	14 960	28/5/85
EP–185		200	15 070	28/5/8ς
EP–186	} News Corporation Ltd, Eagle Corporation Ltd, Swan Resources Ltd	200	15 650	22/7/85
EP–187		200	15 530	22/7/85
EP–188	Esso Exploration and Production Australia Inc.	118	9 230	22/7/85
EP–189	Esso Exploration and Production Australia Inc.	144	11 180	22/7/85
EP–192	Carr Boyd Minerals Ltd, Hill Minerals N.L. Monarch Petroleum N.L.	191	13 900	28/7/85
EP–193	} Western Mining Corporation Ltd	200	14 700	25/8/85
EP–194		200	14 850	25/8/85
EP–195		199	14 670	25/8/85
EP–196		194	14 150	25/8/85
EP–197		199	14 810	25/8/85
EP–198		143	10 320	25/8/85
EP–201	Lassoc Pty Ltd	31	2 330	4/12/85
EP–204	Phoenix Oil & Gas N.L., Girvan Oil & Gas Pty Ltd, Eastmet Ltd, Oilmin N.L., Transoil N.L., Petromin N.L., Basin Oil N.L., Reef Oil N.L., Pan-Continental Petroleum Ltd, Mid-Eastern Minerals N.L., Petro Energy Ltd	32	2 330	30/12/85

TABLE 3

TENEMENTS HELD UNDER THE PETROLEUM ACT 1967

B. PRODUCTION LICENSES

Number	No. of Graticular Sections	Expiry Date	Registered Holder or Application
PL 1	5	24/10/92	West Australian Petroleum Pty Limited
PL 2	4	24/10/92	

TABLE 4

PETROLEUM TENEMENTS UNDER THE PETROLEUM PIPELINES ACT 1969

A. PIPELINE LICENSES (ONSHORE)

Number	Expiry Date	Registered Holder
1	1/12/91	California Asiatic Oil Co., Texaco Overseas Petroleum Co., Shell Development (Australia) Pty Ltd, Ampol Exploration Ltd.
2	1/12/91	
3	1/12/91	
4	1/12/91	
5	1/12/91	

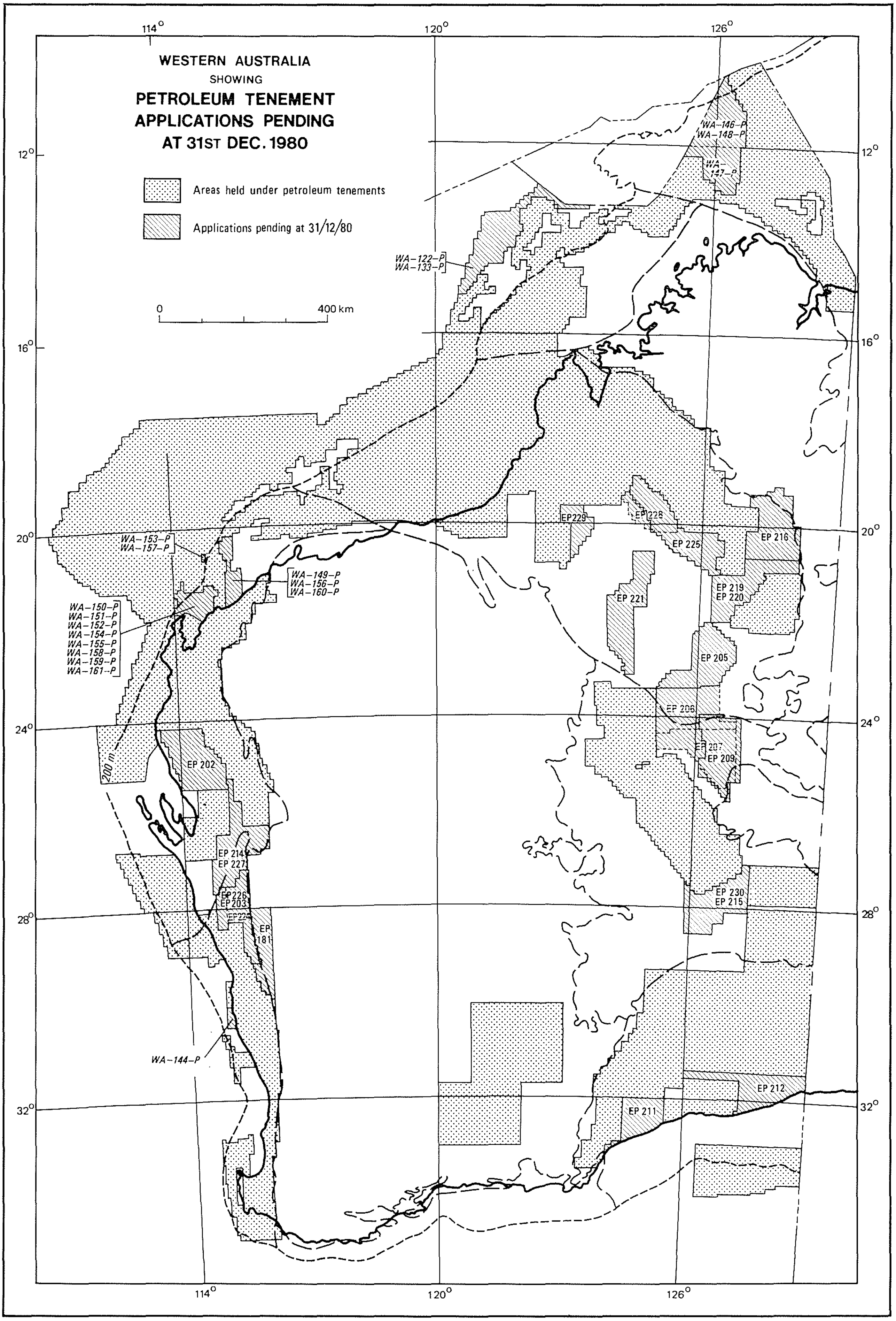


Figure 2 Petroleum Tenement Applications Pending at 31 December, 1980

B. PIPE LICENSES (OFFSHORE)

Number	No. of Graticular Sections	Expiry Date	Registered Holder Application
WA-1-PL	....	Appln.....	Woodside Petroleum Development Pty Ltd, Woodside Oil Ltd, Mid-Eastern Oil Ltd, Shell Development (Australia) Pty Ltd, Hematite Petroleum Pty Ltd, B.P. Petroleum Development Australia Pty Ltd, California Asiatic Oil Company

TABLE 5

TENEMENT APPLICATIONS PENDING UNDER THE PETROLEUM (SUBMERGED LANDS) ACT 1967

Number	Registered Applicant	No. of Graticular Sections	Area	
WA-122-P	Oil & Minerals Quest N.L. Consolidated Gold Mining Areas N.L., Seleka Mining and Investments Ltd, Oklahoma Crude Pty Ltd, Coldstream Crude Oil & Gas Pty Ltd	202	16 760	Appln.
WA-133-P	Otter Exploration N.L., Pegasus Oil & Gas N.L., Eyre Petroleum Pty Ltd, Laredef Pty Ltd	202	16 760	Appln.
WA-144-P	Mesa Australia Ltd, Monarch Petroleum N.L., Geometals Oil Exploration Pty Ltd, Conex Oil Exploration Pty Ltd	15	1 110	Appln.
WA-146-P	Weeks Petroleum (Australia) Pty Ltd, Alliance Petroleum International Ltd, Ogli Petroleum Inc., Metals & Energy Minerals N.L., Charterhall Oil Australia Pty Ltd.	291	24 360	Appln.
WA-147-P	Mesa Australia Ltd, Bridge Oil Ltd, Oxoco International Inc., Peyto Exploration Inc., Voyager Petroleums Ltd, Cluff Oil (Australia) N.L.	128	10 765	Appln.
WA-148-P	Stirling Petroleum N.L. Monarch Petroleum N.L., Lennard Oil N.L., Magnet Metals Ltd, Geometals Oil Exploration N.L., Lenistone Oil & Gas Pty Ltd.	291	24 360	Appln.
WA-149-P	Mesa Australia Ltd, Western Mining Corporation Ltd, Offshore Oil N.L., Pancontinental Petroleum Ltd, Sydney Oil Co. Ltd, Petro Energy Ltd, Golden West Hydrocarbons Pty Ltd, Pan Pacific Petroleum N.L.	62	4 950	Appln.
WA-150-P	Mesa Australia Ltd, Offshore Oil N.L., Pancontinental Petroleum Ltd, Sydney Oil Co. Ltd., Tricentrol Oil Corp. Ltd, Northern Michigan Exploration Co., Petro Energy Ltd, Golden West Hydrocarbons Pty Ltd, Pan Pacific Petroleum N.L.	75	5 730	Appln.
WA-151-P	Getty Oil Development Co. Ltd., Australian Occidental Petroleum Inc., Australian Aquitane Pty Ltd, Alliance Petroleum International Ltd, Cluff Oil (Australia) N.L., Pelsart Oil N.L.	75	5 730	Appln.
WA-152-P	Phillips Australian Oil Co., BP Petroleum Development Australia Pty Ltd	75	8 730	Appln.
WA-153-P	Phillips Australian Oil Co., Australian Gulf Oil Co., BP Petroleum Developments Australia Pty Ltd, MIM Investments Pty Ltd, Mobil Oil Australia Ltd	2	160	Appln.
WA-154-P	L.L. and E. Australia Inc., Ampol Exploration Ltd, Oil Company of Australia N.L. Fernsbury Pty Ltd	75	5 730	Appln.
WA-155-P	Esso Exploration and Production Australia Ltd, Hematite Petroleum Pty Ltd	75	5 730	Appln.
WA-156-P	Esso Exploration and Production Australia Ltd, Hematite Petroleum Pty Ltd	62	4 950	Appln.
WA-157-P	Canada Northwest Australian Oil N.L., Cultus Pacific N.L., Star Oil & Gas Ltd, Oakwood International Petroleum N.L.	2	160	Appln.
WA-158-P	Australian Gulf Oil Co., Australian Oil & Gas Corporation Ltd, Santos Ltd	75	5 730	Appln.
WA-159-P	Stirling Petroleum N.L. Magnet Metals Ltd, Lennard Oil N.L., Monarch Petroleum N.L., Forsayth Oil & Gas N.L., Metramar Minerals Ltd, Hampton Trust Ltd, Balmoral Resources N.L., Amad Oil & Gas N.L. Siberia Oil & Gas N.L.	75	5 730	Appln.
WA-160-P	Oil & Minerals Quest N.L. Winterbottom Oil & Gas Pty Ltd, South Eastern Resources Ltd, Zanex Ltd, Cue Mineral N.L., Capital Oil Corp. Ltd, Petro Quest Pty Ltd, Trivest Corp. Ltd, Estates Holdings Ltd, Australis Mining Finance Ltd, Theseus Investments Ltd	62	4 950	Appln.
WA-161-P	Sion Resources Australia Ltd	75	5 730	Appln.

TABLE 6

TENEMENT APPLICATIONS PENDING UNDER THE PETROLEUM ACT, 1967

Number	Registered Applicant	No. of Graticular Sections	Area	Status
EP-181	C.R.A. Exploration Pty. Ltd	109	8 170	Appln.
EP-202	C.R.A. Exploration Pty Ltd	200	14 520	Appln.
EP-203	North Broken Hill Ltd, Numbat Pty Ltd	168	12 720	Appln.

TABLE 6

TENEMENT APPLICATIONS PENDING UNDER THE PETROLEUM ACT, 1967—*continued*

Number	Registered Applicant	No. of Graticular Sections	Area	Status
EP-205 }	Whim Creek Consolidated N.L. Swan Resources Ltd, Eagle Corporation Ltd	200	15 770	Appln.
EP-206 }		200	15 650	Appln.
EP-207 }		200	15 590	Appln.
EP-209	Banner Resources Pty Ltd, Forsayth Mineral Exploration N.L., Era Petroleum N.L., Siberia Oil & Gas N.L., Girvan Oil & Gas Pty Ltd	200	15 600	Appln.
EP-211 }	The Mintaro Slate & Flagstone Co. Ltd, Acer Pty Ltd	192	14 720	Appln.
EP-212 }		199	14 520	Appln.
EP-214 }		192	14 720	Appln.
EP-215	The Mintaro Slate & Flagstone Co., Ltd, Cissus Pty Ltd	200	15 200	Appln.
EP-216	Ranger Oil Australia Pty Ltd, Pontoon Oil & Minerals N.L., Pioneer Concrete Services Ltd	199	16 000	Appln.
EP-219	Mobil Oil Australia Ltd	185	14 760	Appln.
EP-220	Meridian Oil N.L., Valiant Consolidated Ltd, Southern Basins Petroleum N.L., Energy Exploration Pty Ltd	185	14 760	Appln.
EP-221		200	15 880	Appln.
EP-224	Siberia Oil & Gas N.L., Girvan Oil & Gas Pty Ltd, Scomeld Pty Ltd	105	12 720	Appln.
EP-225	Western Mining Corporation Limited	200	16 100	Appln.
EP-226 }	Minwest Fidelity Finance Ltd, Trans Ocean Offshore Pty Ltd, Coho Australia Ltd	168	12 720	Appln.
EP-227 }		189	14 590	Appln.
EP-228 }	Anjolij Pty Ltd	119	9 605	Appln.
EP-229 }		62	4 985	Appln.
EP-230	Mintaro Slate & Flagstone Co. Ltd, Cissus Pty Ltd	200	15 145	Appln.

TABLE 7

DEALINGS UNDER THE PETROLEUM (SUBMERGED LANDS) ACT, 1967 DURING 1980

(A) ADVERTISEMENTS (SECTION 20)

Area Number	Basin	Date Gazetted	Closing Date	No. of Blocks	Area (km²)
"Closing Date" Section 20(1)					
W80-47	Bonaparte Gulf	13/6/80	10/10/80	291	24 360
W80-48	Carnarvon	4/7/80	31/10/80	75	5 730
W80-49	Carnarvon	4/7/80	31/10/80	2	160
W80-50	Carnarvon	4/7/80	31/10/80	62	4 950
W80-51	Perth	26/9/80	27/1/81	88	6 580 }
W80-52	Perth	26/9/80	27/1/81	56	4 160 }
W80-53	Perth	26/9/80	27/1/81	42	3 100 } 27 440
W80-54	Perth	26/9/80	27/1/81	87	6 330 }
W80-55	Perth	26/9/80	27/1/81	101	7 270 }
"No Closing Date" Section 20(3)					
W79-46	Canning	13/6/80	....	36	2 980

(B) ACCESS AUTHORITIES AND CONSENTS (SECTION 112)

Number	Applicant	Basin or Area of Survey	Permit or Area requiring Access Authority
AA80SL	Woodside	Carnarvon	WA-1-P, 28-P, 90-P
AA81SL	WAPET	Carnarvon	WA-24-P, 25-P
AA82SL	WAPET	Carnarvon	WA-25-P
AA83SL	Otter Exploration	Carnarvon	WA-28-P, 90-P
AA84SL	Era South Pacific	Canning	WA-114-P
AA85SL	Hudbay Oil	Exmouth Plateau	WA-93-P
AA86SL	Hudbay Oil	Carnarvon	WA-58-P
AA88SL	BP Petroleum Development Aust. Pty Ltd	Canning	WA-58-P, 62-P
AA89SL	CNW Oil	Carnarvon	WA-102-P
AA91SL	CNW Oil	Carnarvon	WA-110-P
AA92SL	Magnet Metals Ltd	Bonaparte Gulf	WA-77-P
AA93SL	CNW Oil	Bonaparte Gulf	WA-128-P
AA94SL	Esso	Exmouth Plateau	WA-96-P, 97-P
AA95SL	Esso	Exmouth Plateau	WA-96-P
AA96SL	Conoco	Carnarvon	WA-81-P
AA97SL	Weaver	Canning	WA-119-P
AA98SL	Weaver	Canning	WA-120-P
AA99SL	Geometals Oil	Perth	WA-115-P
AA100SL	Aust. Aquitaine	Bonaparte Gulf	WA-18-P
AA101SL	Esso	Exmouth Plateau	WA-96-P, 97-P
AA103SL	Geometals Oil	Perth	WA-115-P
AA104SL	CNW Oil	Carnarvon	WA-110-P
AA105SL	Woodside	Browse	WA-28, 32, 33, 34, 35 37-P
AA106SL	BP	Canning	WA-142-P
AA107SL	CNW Oil	Bonaparte Gulf	WA-128-P

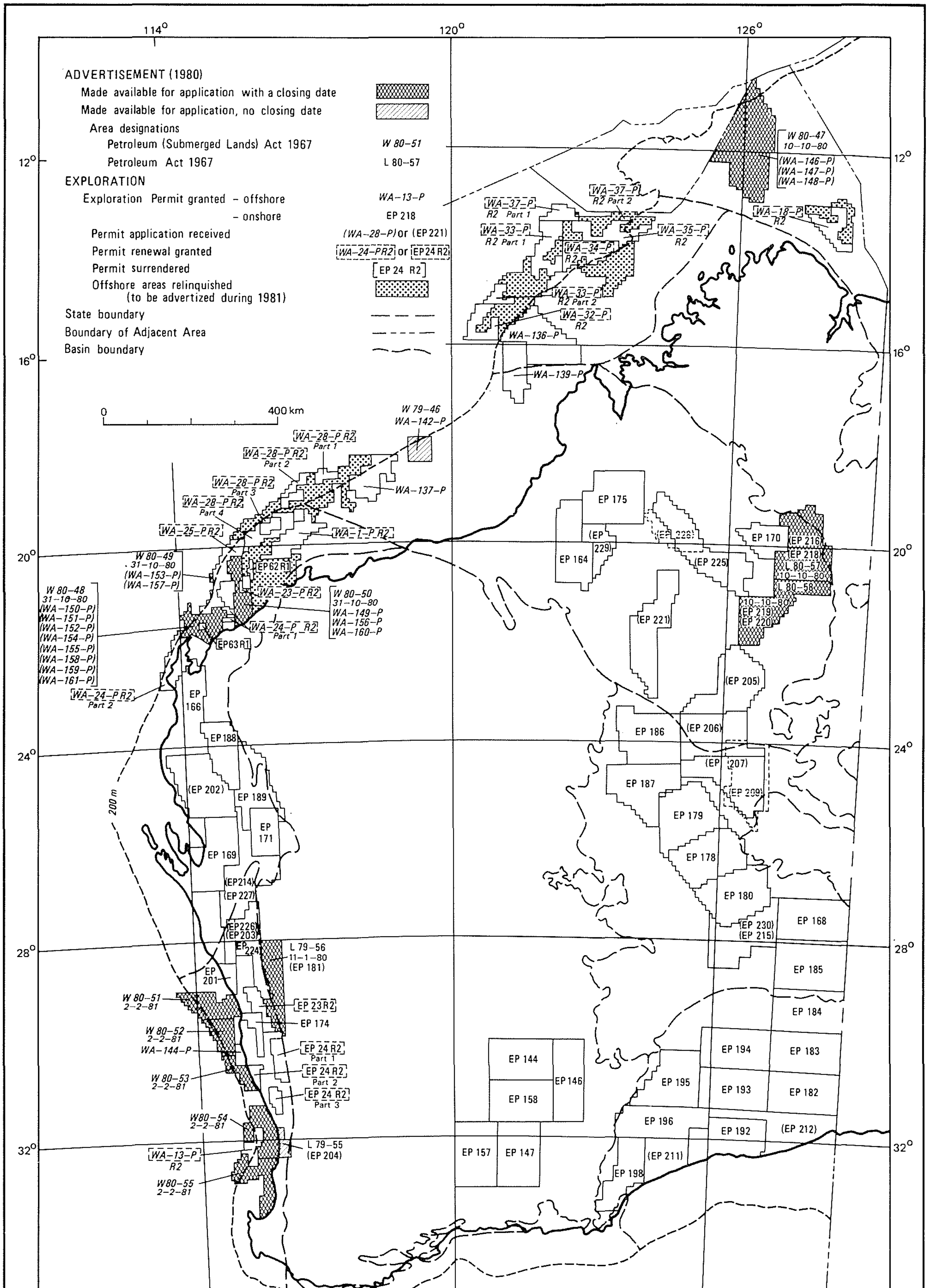


Figure 3 Petroleum Tenement Dealings during 1980.

TABLE 7—*continued*

DEALINGS UNDER THE PETROLEUM (SUBMERGED LANDS) ACT, 1967 DURING 1980—*continued*

(C) EXPLORATION PERMIT RENEWALS (SECTION 30)

Permit Number	Basin	Permittee	No. of Blocks	Second Term Expiry Date	Status	No. of Blocks Renewed	Area
WA–1–P R1	Carnarvon	Woodside *et al*	178	4/11/79	Renewed	84	6 750
WA–13–P R1	Perth	Wapet	194	29/8/79	Renewed	35	2 545
WA–23–P R1	Carnarvon	Wapet	199	3/10/79	Renewed	4	320
WA–24–P R1	Carnarvon	Wapet	104	17/10/79	Renewed	52	4 125
WA–25–P R1	Carnarvon	Wapet	128	16/10/79	Renewed	64	5 125
WA–18–P R1	Bonaparte	Australian Aquitaine	105	16/4/80	Renewed	52	4 320
WA–34–P R1	Browse	Woodside *et al*	149	2/7/80	Renewed	74	6 135
WA–35–P R1	Browse	Woodside *et al*	123	2/7/80	Renewed	62	5 150
WA–37–P R1	Browse	Woodside *et al*	59	2/6/80	Renewed	30	2 495
WA–28–P R1	Carnarvon	Woodside *et al*	178	24/3/80	Renewed	80	6 455
WA–32–P R1	Browse	Woodside *et al*	100	2/7/80	Renewed	50	4 120
WA–33–P R1	Browse	Woodside *et al*	194	18/5/80	Renewed	97	8 040

(D) EXPLORATION PERMIT APPLICATIONS AND GRANTS (SECTIONS 21 AND 22)

Application or Permit Number	Area Number	Application	Date Received	Basin	No. of Blocks	Area (km²)	Status	Operating Date
WA–136–P	W76–17 (part)	Conex Oil Exploration *et al*	8/5/79	Browse	173	14 220	Granted	5/1/80
WA–137–P	W79–45	BP Petroleum Development *et al*	22/11/79	Canning	84	6 810	Granted	25/3/80
WA–138–P	W79–45	Cultus Pacific N.L. *et al*	22/11/79	Canning	84	6 810	Refused	7/3/80
WA–139–P	W78–44	Oil and Minerals Quest *et al*	18/12/79	Canning-Browse	80	6 560	Granted	21/12/80
WA–140–P	W78–44	Mesozoic Resources	27/2/80	Canning-Browse	80	6 565	Refused	8/12/80
WA–141–P	W77–40	Brunswick Oil *et al*	19/6/80	Perth	15	1 110	Refused	30/11/80
WA–142–P	W79–46	BP Petroleum Development *et al*	7/7/80	Canning	36	2 925	Granted	14/10/80
WA–143–P	W77–40	WAPET	9/7/80	Perth	15	1 110	Refused	30/12/80
WA–144–P	W77–40	Mesa *et al*	1/8/80	Perth	15	1 110	Pending	....
WA–145–P	W77–40	Brunswick Oil N.L. *et al*	13/8/80	Perth	15	1 110	Refused	30/12/80
WA–146–P	W80–47	Weeks Petroleum *et al*	10/10/80	Bonaparte Gulf	291	24 360	Pending	....
WA–147–P	W80–47	Mesa *et al*	10/10/80	Bonaparte Gulf	291	24 360	Pending	....
WA–148–P	W80–47	Stirling Petroleum *et al*	10/10/80	Bonaparte Gulf	291	24 360	Pending	....
WA–149–P	W80–50	Mesa *et al*	30/10/80	Carnarvon Basin	75	4 950	Pending	....
WA–150–P	W80–48	Mesa *et al*	30/10/80	Carnarvon Basin	75	5 730	Pending	....
WA–151–P	W80–48	Getty *et al*	31/10/80	Carnarvon Basin	75	5 730	Pending	....
WA–152–P	W80–48	Phillips *et al*	31/10/80	Carnarvon Basin	75	5 730	Pending	....
WA–153–P	W80–49	Phillips *et al*	31/10/80	Carnarvon Basin	2	160	Pending	....
WA–154–P	W80–48	L.L. and E. Australia Inc. *et al*	31/10/80	Carnarvon Basin	75	5 730	Pending	....
WA–155–P	W80–48	Esso *et al*	31/10/80	Carnarvon Basin	75	5 730	Pending	....
WA–156–P	W80–50	Esso *et al*	31/10/80	Carnarvon Basin	62	4 950	Pending	....
WA–157–P	W80–49	CNW *et al*	31/10/80	Carnarvon Basin	2	160	Pending	....
WA–158–P	W80–48	Australian Gulf Oil Co. *et al*	31/10/80	Carnarvon Basin	75	5 730	Pending	....
WA–159–P	W80–48	Stirling Petroleum *et al*	31/10/80	Carnarvon Basin	75	5 730	Pending	....
WA–160–P	W80–50 (part)	Oil and Minerals Quest N.L.	31/10/80	Carnarvon Basin	60	4 950	Pending	....
WA–161–P	W80–48	Sion Resources Aust. Ltd	31/10/80	Carnarvon Basin	75	5 730	Pending	....

Note: For full title of Registered Holders or Applicants, refer Table 1, 3, 5, 6.

TABLE 8

DEALINGS UNDER THE PETROLEUM ACT, 1967, DURING 1980

(A) ADVERTISEMENTS (SECTION 30)

Area Number	Basin	Date Gazetted	Closing Date	No. of Blocks	Area (km²)
"Closing date" (Section 30(1))					
L80–57	Canning	13/6/80	10/10/80	199	16 000
L80–58	Canning	13/6/80	10/10/80	185	14 760
"No closing date" (Section 30(3))					
L79–55	Perth	13/6/80	....	32	2 330

TABLE 8—*continued*

DEALINGS UNDER THE PETROLEUM ACT 1967, DURING 1980—*continued*

(B) ACCESS AUTHORITIES (SECTION 106)

Number	Applicant	Basin or Area of Survey	Permit or Area requiring Access Authority
AA 10	Getty Oil Development Co. Ltd	Canning	EP 175
AA 11	Weaver Oil & Gas	Perth	EP 112
AA 12	Australian Aquitaine	Bonaparte Gulf	EP 126
AA 13	Home Oil	Canning	EP 129
AA 14	Australian Aquitaine	Perth	EP 174
AA 15	Pancontinental Petroleum Ltd	Perth	EP 111
AA 16	Home Oil	Canning	EP 129
AA 17	Mesa *et al*	Perth	EP 130
AA 18	Pancontinental Petroleum Ltd	Perth	EP 111
AA 19	Otter Exploration	Carnarvon	EP 110
AA 20	Swan Resources	Officer	EP 186

(C) EXPLORATION PERMIT SURRENDERS (SECTION 98)

Permit Number	Basin	Permittee	Date Surrender (Gazetted)	No. of Blocks		Area (km^2)
				Original	Surrendered	
EP 62 R1....	Carnarvon	Wapet	11/1/80	8	6	480
EP 63 R1....	Carnarvon	Wapet	11/1/80	4	4	320

(D) SECOND RENEWALS

Permit Number	Basin	Permittee	Blocks	First Term Expiry Date	Status	Blocks Renewed	Area	Second Term Expiry Date
EP 23 R1	Perth	Wapet	33	6/8/80	Renewed	33	2 465	6/8/85
EP 24 R1	Perth	Wapet	85	6/8/80	Renewed	85	6 265	6/8/85

(E) EXPLORATION PERMIT APPLICATIONS, GRANTS AND WITHDRAWALS (SECTIONS 31 AND 32)

Application for Permit Number	Area Number	Applicant	Date Application	Basin	No. of Blocks	Area (km^2)	Status	Operative Date
EP 163	L79–48	Ferrovanadium Corp. N.L. *et al*	27/7/79	Eastern Goldfields	180	13 270	Refused	24/1/80
EP 164	L75–13	Willara Petroleum Pty Ltd N.L.	23/8/79	Canning	172	13 840	Granted	18/6/80
EP 166	L76–52	Monarch Petroleum *et al*	21/9/79	Carnarvon	200	15 700	Granted	18/1/80
EP 167	Unlisted	Terrex Resources N.L. *et al*	10/10/79	Officer	197	15 370	Refused	24/3/80
EP 168	Unlisted	Terrex Resources N.L. *et al*	10/10/79	Officer	200	15 200	Granted	17/4/80
EP 169	Unlisted	Eagle Corp. *et al*	19/10/79	Carnarvon	182	14 000	Granted	7/6/80
EP 170	L76–30 (part)	Oil Co. of Australia *et al*	24/10/79	Canning	83	6 650	Granted	14/7/80
EP 171	L75–5 (part) plus	Eagle Corp.	21/11/79	Carnarvon	96	7 400	Granted	21/4/80
EP 172	L79–54	Getty *et al*	21/11/79	Perth	32	2 380	Refused	17/4/80
EP 173	L79–54	Leighton *et al*	22/11/79	Perth	32	2 380	Refused	17/4/80
EP 174	L79–54	Australian Aquitaine *et al*	23/11/79	Perth	32	2 380	Granted	17/4/80
EP 175	L79–53	Getty *et al*	23/11/79	Canning	193	15 620	Granted	24/1/80
EP 176	L79–54	Strata Oil N.L. *et al*	23/11/79	Perth	32	2 380	Refused	17/4/80
EP 177	L79–54	Magnet *et al*	23/11/79	Perth	32	2 380	Refused	17/4/80
EP 178	Unlisted	Shell Company of Australia	6/12/79	Officer	200	15 375	Granted	1/5/80

TABLE 8—*continued*

DEALINGS UNDER THE PETROLEUM ACT 1967, DURING 1980—*continued*

(E) EXPLORATION PERMIT APPLICATIONS, GRANTS AND WITHDRAWALS (SECTIONS 31 AND 32)—*continued*

Application for Permit Number	Area Number	Applicant	Date Application	Basin	No. of Blocks	Area (km^2)	Status	Operative Date
EP 179	Unlisted	Shell Company of Australia	6/12/79	Officer	200	15 480	Granted	1/5/80
EP 180	Unlisted	Shell Company of Australia	6/12/79	Officer	200	15 260	Granted	1/5/80
EP 181	L79–56	CRA Exploration Pty Ltd	11/1/80	Perth	109	8 170	Pending	....
EP 182	Unlisted	CRA *et al*	14/1/80	Eucla	200	14 700	Granted	28/5/80
EP 183	Unlisted	CRA *et al*	14/1/80	Eucla	200	14 850	Granted	28/5/80
EP 184	Unlisted	CRA *et al*	14/1/80	Officer	200	14 960	Granted	28/5/80
EP 185	Unlisted	CRA *et al*	14/1/80	Officer	200	15 070	Granted	28/5/80
EP 186	Unlisted	Eagle Corp *et al*	5/2/80	Officer	200	15 650	Granted	23/7/80
EP 187	Unlisted	Eagle Corp *et al*	5/2/80	Officer	200	15 530	Granted	23/7/80
EP 188	L78–44 (part)	Esso	14/2/80	Carnarvon	118	9 230	Granted	23/7/80
EP 189	L78–5 (part)	Esso	14/2/80	Carnarvon	144	11 180	Granted	23/7/80
EP 190	L78–44, L78–5, L78–8	Perthshire Petroleum	21/2/80	Carnarvon	200	15 590	Refused	16/7/80
EP 191	L76–30	Ranger Oil (Aust.) Ltd	28/2/80	Canning	83	6 680	Refused	3/7/80
EP 192	L76–20	Monarch	4/3/80	Eucla	191	13 900	Granted	29/7/80
EP 193	Unlisted	Western Mining	20/3/80	Eucla	200	14 700	Granted	26/8/80
EP 194	Unlisted	Western Mining	20/3/80	Eucla	200	14 850	Granted	26/8/80
EP 195	Unlisted	Western Mining	20/3/80	Eucla	199	14 670	Granted	26/8/80
EP 196	Unlisted	Western Mining	20/3/80	Eucla	194	14 150	Granted	26/8/80
EP 197	Unlisted	Western Mining	20/3/80	Eucla	199	14 810	Granted	26/8/80
EP 198	Unlisted	Western Mining	20/3/80	Eucla	143	10 320	Granted	26/8/80
EP 199	Unlisted	Strata Oil	9/6/80	Officer/Eucla	200	14 965	Refused	26/8/80
EP 200	Unlisted	Strata Oil	9/6/80	Officer	131	9 895	Refused	26/8/80
EP 201	Unlisted	Lassoc Pty Ltd	30/6/80	Perth	31	2 330	Granted	5/12/80
EP 202	L75–8 part area	CRA	30/6/80	Carnarvon	187	14 520	Pending	....
EP 203	L76–21 plus unlisted	North Broken Hill *et al*	30/6/80	Perth	168	12 720	Pending	....
EP 204	L79–55	Siberia Oil & Gas N.L.	17/7/80	Perth	32	2 330	Granted	30/12/80
EP 205	L75–17, L78–41 L78–39, L78–42	Whim Creek Cons *et al*	18/7/80	Canning	200	15 770	Pending	....
EP 206	L75–17, L78–42	Whim Creek Cons *et al*	18/7/80	Canning	200	15 650	Pending	....
EP 207	Unlisted	Whim Creek Cons *et al*	18/7/80	Officer	200	15 590	Pending	....
EP 208	L79–55	Meridian Oil N.L.	21/7/80	Perth	32	2 330	Refused	23/12/80
EP 209	L78–42 (part)	Banner Resources *et al*	25/7/80	Officer	200	15 600	Pending	....
EP 210	L79–55	Alcoa of Aust Ltd *et al*	7/8/80	Perth	32	2 330	Refused	8/12/80
EP 211	Unlisted	The Mintaro Slate & Flagstone Co. Ltd	5/8/80	Eucla	131	9 506	Pending	....
EP 212	Unlisted	The Mintaro Slate & Flagstone Co. Ltd	5/8/80	Eucla	199	14 520	Pending	....
EP 213	L75–12	Southern Goldfields	7/8/80	Canning	138	11 100	Lapsed	14/12/80
EP 214	Unlisted	The Mintaro Slate & Flagstone Co. Ltd	12/8/80	Canning	192	14 730	Pending	....
EP 215	Unlisted	The Mintaro Slate & Flagstone Co. Ltd	17/9/80	Officer	200	15 200	Pending	....
EP 216	L80–57	Ranger *et al*	7/10/80	Canning	199	16 000	Pending	....
EP 217	L79–55	Abrolhos	9/10/80	Perth	32	2 330	Refused	23/12/80
EP 218	L80–57	Mobil Oil Australia Ltd	10/10/80	Canning	199	16 000	Refused	23/12/80
EP 219	L80–58	Mobil Oil Australia Ltd	10/10/80	Canning	185	14 760	Pending	....
EP 220	L80–58	Meridian Oil N.L. *et al*	10/10/80	Canning	185	14 760	Pending	....
EP 221	L75–16	Meridian Oil N.L. *et al*	10/10/80	Canning	200	15 880	Pending	....
EP 222	L80–57	Forsayth Oil & Gas N.L. *et al*	10/10/80	Canning	199	16 000	Refused	30/11/80
EP 223	L80–58	Forsayth Oil & Gas N.L. *et al*	10/10/80	Canning	185	14 760	Refused	15/12/80
EP 224	L76–21	Siberia Oil *et al*	4/11/80	Perth	105	12 720	Pending	....
EP 225	L76–29, L78–37, L75–14	WMC	2/12/80	Canning	200	16 100	Pending	....
EP 226	L76–21	Minwest Fidelity *et al*	3/12/80	Perth	170	12 720	Pending	....
EP 227	Unlisted	Minwest Fidelity *et al*	3/12/80	Canning	189	14 590	Pending	....
EP 228	L76–29 (part)	Anjolij Pty Ltd	30/11/80	Canning	119	9 605	Pending	....
EP 229	L75–10	Anjolij Pty Ltd	30/11/80	Canning	62	4 985	Pending	....
EP 230	Unlisted	Mintaro Slate & Flagstone *et al*	31/12/80	Canning	200	15 145	Pending	....

TABLE 9

SUMMARY COMPARISON OF EXPLORATION PERMIT DEALINGS

(1979–1980)

	1979		1980	
	No.	Area (km²)	No.	Area (km²)
Areas Advertised—				
Onshore	17	199 440	3	33 090
Offshore	3	16 300	10	65 570
Totals	20	215 740	13	98 660
Permits Granted—				
Onshore	9	88 030	33	417 805
Offshore	8	126 430	4	30 515
Totals	17	214 460	37	448 320
Permit Applications (pending at year end)—				
Onshore	35	204 575	23	184 895
Offshore	6	44 350	19	53 070
Totals	41	248 925	42	237 965
Permits Held				
Onshore	35	217 870	66	633 460
Offshore	45	691 845	49	665 265
Totals	80	909 715	115	1 298 725
Permits Surrendered				
Onshore	7	44 440	2	800
Offshore	3	34 135	Nil	....
Totals	10	78 575	2	800
Second Renewals				
Onshore	Nil	....	2	8 730
Offshore	5	18 865	12	55 585*
Totals	5	18 865	14	64 315
Permits Expired—				
Onshore	Nil	....	Nil	....
Offshore	1	14 460	Nil	....
Totals	1	14 460	Nil	....

*Area Surrendered : 32 435 km²

Onshore Activity

Onshore tenement activity increased during 1980 as a result of the large number of areas made available in 1979. There were 50 applications for available areas during the year, many of the applications were competing.

From the 50 applications made, plus 17 not yet dealt with from the previous year, 6 applications were refused, one lapsed and 28 were granted making a total of 66 current onshore exploration permits covering 633 460 km².

Onshore dealings during the year are shown in Figure 3 and are listed in Table 8. Applications outstanding at year's end are listed in Table 6.

The feature of the year's tenement activities was firstly the interest in potential oil shale areas and secondly the upsurge in interest in areas which although available for a long time, had attracted little interest from petroleum explorers.

EXPLORATION

Exploration activity increased markedly during 1980. Figure 4E shows that committed expenditure for 1980 was in excess of $80 million. The actual expenditure is likely to be well in excess of that figure for the year.

Drilling activity is shown in Figure 4C. Drilling was completed on 32 wells during the year with 6 further wells still being drilled at the end of the year. 6 offshore and 7 onshore drilling rigs operated. Operations were at a lower level than anticipated due to a shortage of offshore rigs. The dynamically positioned drillships "Sedco 445" and "Sedco 472" left Western Australian waters during the second half of 1980 and the Australian-built semi-submersible "Ocean Digger" drilled only one well during the first half of the year before leaving Australian waters for a foreign contract.

During the year 4 cyclones resulted in the loss of 55 rig-days.

COMPARISON OF EXPLORATION ACTIVITY LEVELS

The exploration highlights of the year were the discovery of gas at the Woodada No. 1 well in EP–100 on the onshore Perth Basin and the hydrocarbon shows in the offshore Phoenix No. 1 well in WA–58–P. Significant small gas and oil discoveries were made in wells drilled on Barrow Island in PL–1H. Oil was recovered from wells drilled in the Mt. Horner area of the Perth Basin where production was previously thought to be non-commercial at prices of about $2/bbl. The potential of the area still has to be evaluated.

Seismic surveys in terms of line kilometres decreased in 1980 compared with 1979, but there was a considerable increase in the expensive onshore seismic coverage due to increased activity in the Perth and Canning Basins. Magnetic and gravity surveys were also carried out in conjunction with the seismic surveys. A summary of drilling and seismic activity is shown on Figures 4A to 4D.

TABLE 10

BARROW ISLAND FIELD

WELL COMPLETION STATUS BY RESERVOIRS ON 31st DECEMBER, 1980

Horizon/Pools	On Production	On Injection	Shut In			Abandoned §	Total
			Producers †	Injectors	Mis-cellaneous ‡		
Tertiary—Carbonates *	....	8	1	....	....	....	9
Lower Cretaceous—							
Gearle	3	....	7	....	1	....	11
Windalia Radiolarite	....	....	1	....	....	....	1
Windalia Sand	283	122	44	72	6	4	531
Muderong	9	....	4	....	....	....	13
Flacourt (Water Source)	4	....	6	....	....	1	11
5 500 ft to 6 200 ft Sands	1	....	2	....	1	....	4
Upper Jurassic—Dupuy	3	....	4	....	....	....	7
Middle Jurassic—High Pressure Gas Sands	1	....	2	....	....	....	3
Other Jurassic	....	....	....	....	....	1	1
Totals	304	130	71	72	8	6	591

* Includes salt water disposal.
† Shut-in producers includes wells where attempts to obtain commercial production have been unsuccessful.
‡ Miscellaneous includes wells cased but not currently perforated plus wells completed in the water leg for observation.
§ Abandoned wells are fully plugged and abandoned.
General: Recompleted wells are included in horizon/pool of current completion.

APPRAISAL AND DEVELOPMENT

Barrow Island Field

(Operator—Western Australian Petroleum Pty Limited)

West Australian Petroleum Pty Limited continued a programme of infill, development and exploration drilling on Barrow Island with the T–32 rig during 1980. A total of 18 wells were drilled (Figure 5); 12 of these wells were drilled to the main Windalia Sand reservoir. These wells included B–16B which completed phase 2 of the infill programme on the southern five-shot area of the main field. Barrow Numbers L–14, J–78 and J–88 were all 16 hectares regular development wells. Two further wells were drilled to follow up the small new oil discovery at F–72, but these wells (F–48 and F–64) came in lower than predicted and were water wet.

In the north-western J and R blocks, 4 extension wells (R–28, R36, R–38 and J–46) were completed as Windalia producers. Well R–38 was drilled with dual Windalia/Muderong objectives, but was unsuccessful in the Muderong and was eventually completed as a producer in the Windalia reservoir.

In the northern T-block, wells T–12 and T–24 established gas production in the Windalia Sand some distance north of the known limits of the main Windalia reservoir.

Four Muderong wells were drilled during 1980. Two of these resulted in new pool discoveries at Y–24M and L–45M. Well Q–46M resulted in a successful oil production for the first time on Barrow Island from the Flacourt Sandstone immediately below the Muderong Shale. The production is from a very thin oil column and the extent of the oil accumulation is unknown at present. On the eastern side of the field, a Muderong test well E–31M was being prepared for testing from the Greensand unit at the end of the year.

Water source well WSW–8A at location L–63 was drilled to the Flacourt Sandstone for source water for the waterflood programme.

Two Ideco workover rigs were fully occupied during the year on routine well servicing, well repairs and some stimulation. Casing failure investigations which commenced in 1979 indicate a lessening in the rate of failures. A pilot study of cathodic protection indicates that further casing corrosion may be substantially arrested.

The Gearle L–32G well was recompleted within the Lower Gearle Siltstone and after acid stimulation produced oil at an initial rate of up to 160 kl/day.

Computer modelling of the Windalia reservoir in the G-block was completed in 1980. Prediction runs indicate that ultimate recovery of oil may be significantly improved through the infill drilling programmes. The large amount of incoming additional data has necessitated ongoing geological reviews of Barrow Island.

The status of the 591 wells on Barrow Island to the end of 1980 is shown in Table 10. All but 60 of these wells are completed in the Windalia Sand Member which is the principal reservoir of the Barrow Island Field.

Dongara, Mondarra and Yardarino Fields

(Operator—West Australian Petroleum Pty Limited)

Three additional wells were drilled by the operators during 1980. Dongara No. 21 in PL–2 was completed in the Irwin River Coal Measures as the principal reservoir (Dongara Sandstone) was missing. The well was intended as an infill well to increase deliverability. Dongara No. 22, also in PL–2 was located between Wells Nos. 2 and 4 but encountered the Dongara Sandstone reservoir below the field hydrocarbon-water contact The well was plugged and abandoned with the hole left such that it could be used as a future water disposal well. A third well in the field, No. 23 reached total depth just before year's end and was being prepared for testing. (Figure 6).

Mondarra No. 2 was placed on production during May 1980 and was still producing at year's end.

During the year Dongara Nos. 17 and 19 were placed on production as oil wells and produced intermittently throughout the year. Dongara No. 10 continued to produce as a high gas/oil ratio oil well.

The average daily production of oil from the Dongara Field (including Yardarino No. 1) was 49·54 m^3 compared to 41·38m^3 for 1979.

North Rankin, Angel and Goodwyn Fields

(Operator—Woodside Petroleum Development Pty. Ltd.)

The decision to proceed with the North West Shelf Natural Gas Development Project was announced on 30th September 1980. On the same date Production Licences WA–1–L to WA–6–L were granted to the partners in the North West Shelf Joint Venture. The production licences covered both primary and secondary licences for the North Rankin (WA–1–L and WA–2–L), Angel (WA–3–L and WA–4–L) and Goodwyn Fields

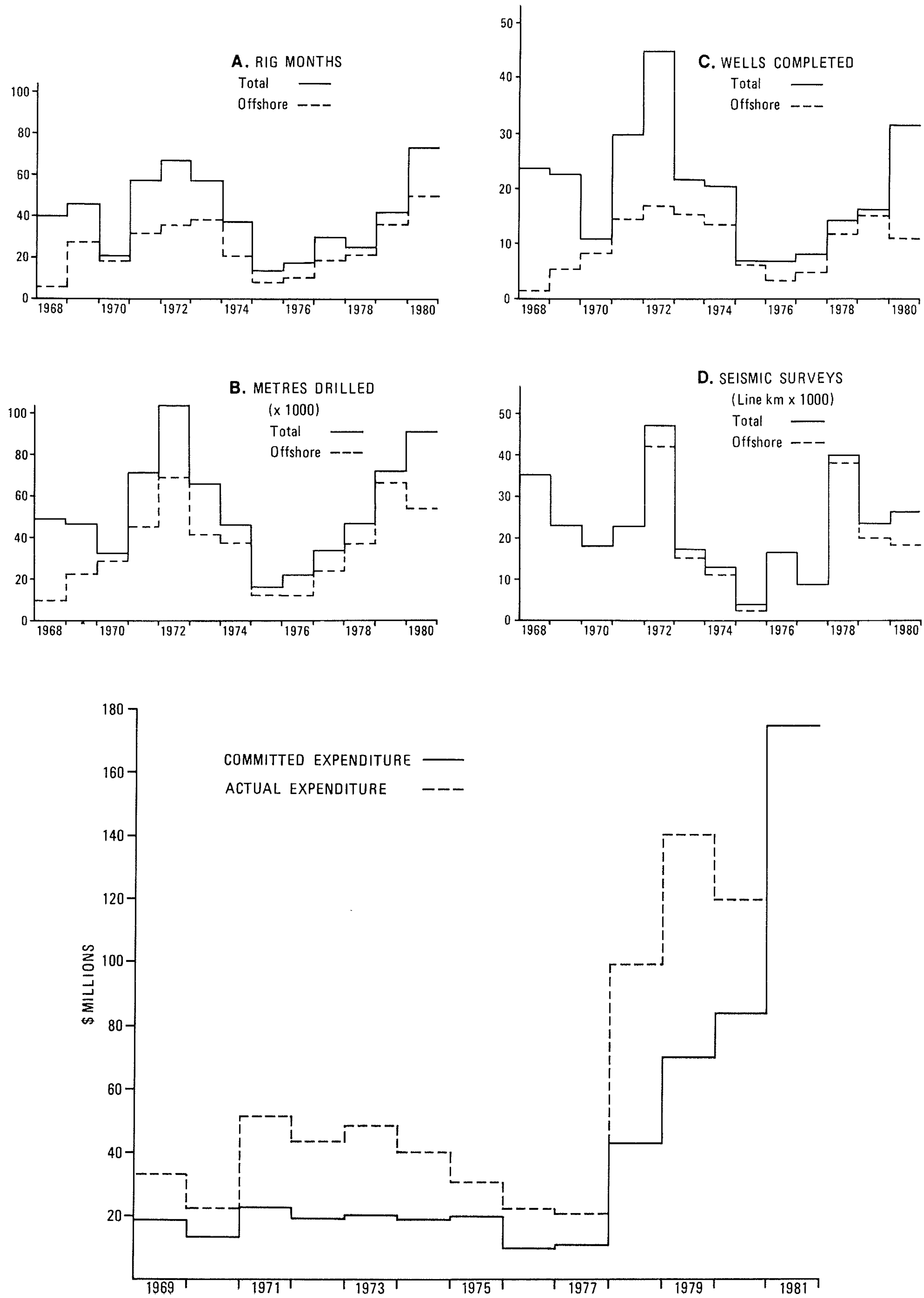


Figure 4 Comparison of Exploration Levels

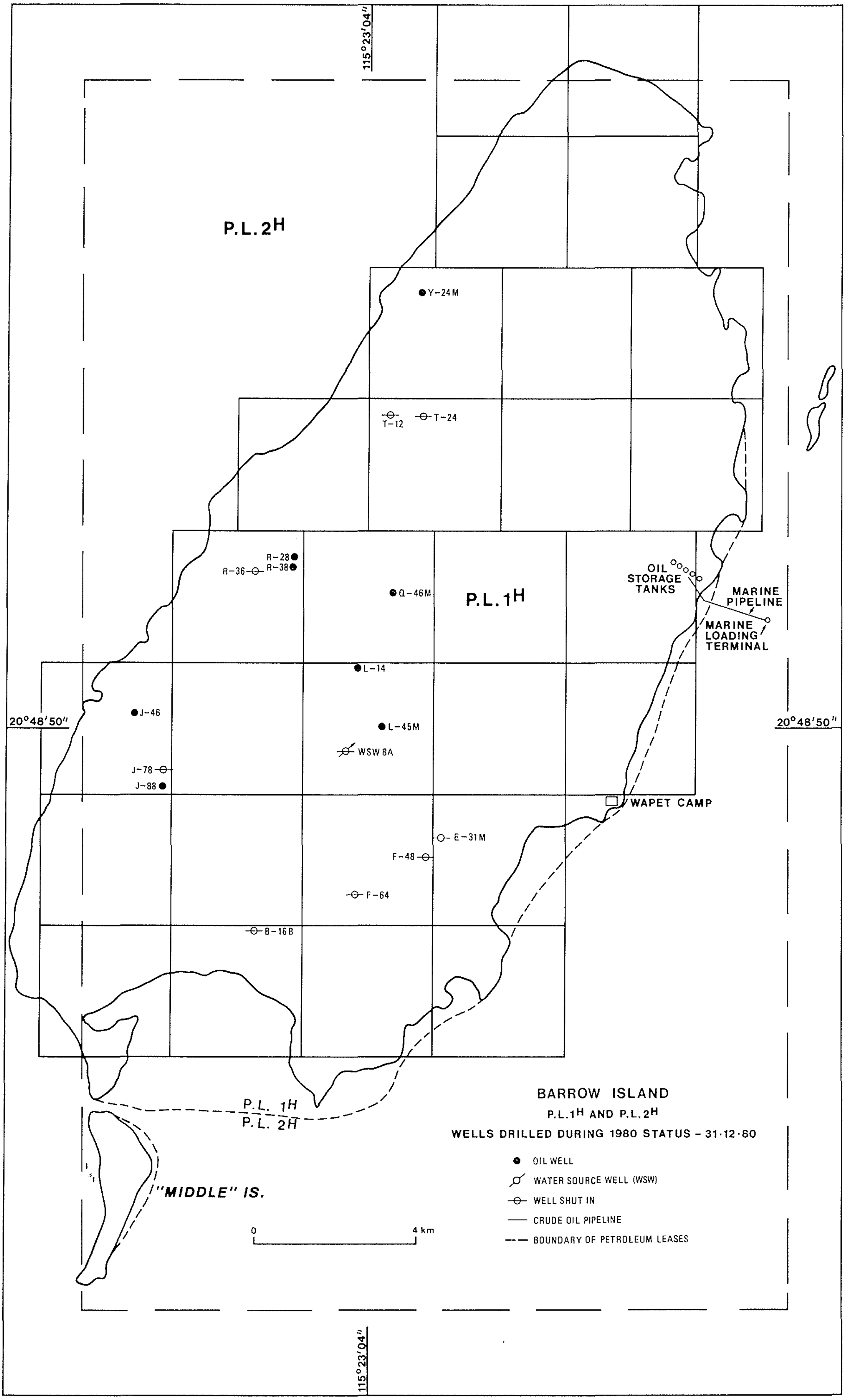


Figure 5 Wells Drilled during 1980. Status 31/12/80

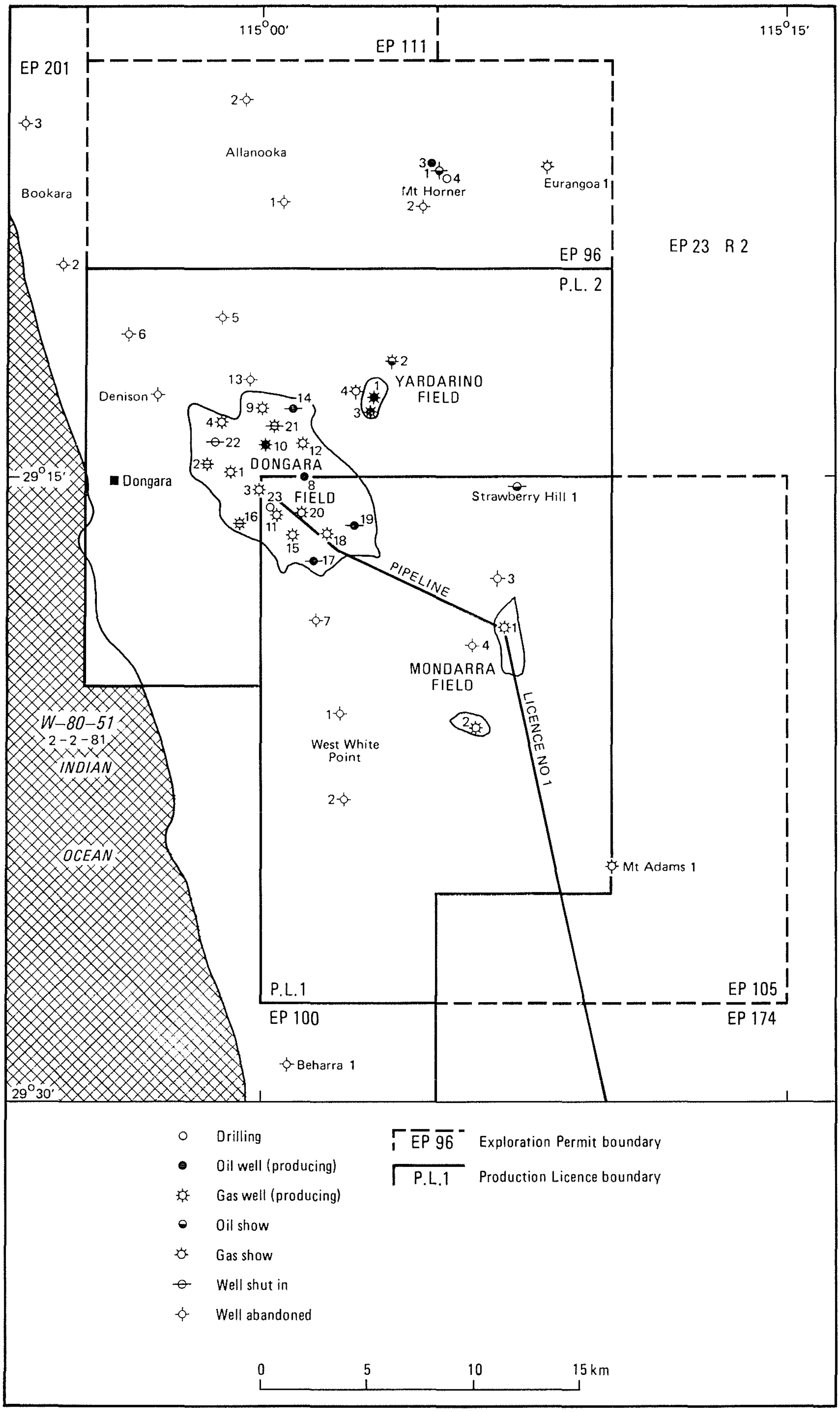


Figure 6 Dongara, Mondarra and Yardarino fields status of Petroleum Tenements and Wells at 31st December, 1980

(WA-5-L and WA-6-L). Application has been lodged for an offshore pipeline licence from the North Rankin Field to a landfall at Withnell Bay.

The project, for financing purposes, is divided into two phases. The first phase ("Gas Phase I") will comprise the construction and erection of an offshore production platform on the North Rankin Field, 12 production wells, a submarine pipeline to carry gas and liquids ashore, an onshore gas treatment plant and associated infrastructure. Phase 1 gas will be sold under long term contracts to the State Energy Commission of Western Australia. LPG and condensate are to be sold to markets in Australia and, to the extent that local markets cannot be found overseas.

Gas Phase II will produce LNG for export under contract to Japan and further quantities of LPG and condensate. The additional facilities required for this will include two further production platforms, an LNG plant within the onshore gas treatment complex, and further product storage and shipping facilities.

The announcement on 30th September coincided with the completion of individual gas sales contracts between the Joint Venturers and the State Energy Commission of Western Australia for the sale of 414 million MJ of gas per day (10·9 million cubic metres per day). Agreement was also reached concurrently between the Joint Venturers on the terms which will govern the mutual commercial/operating relationship between them for the duration of the project.

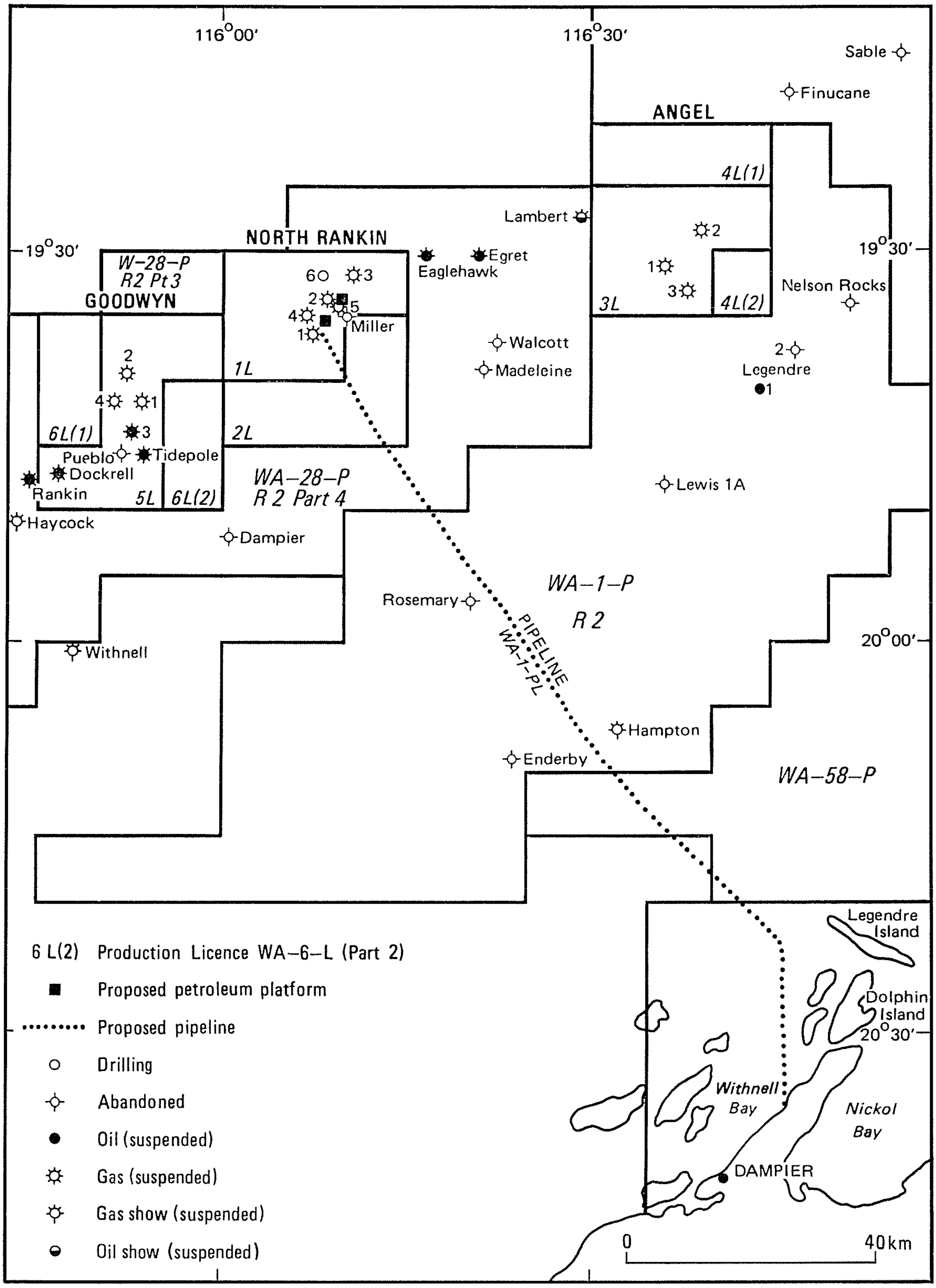


Figure 7 North Rankin, Angel and Goodwyn Fields

During 1980, initial construction of the North Rankin A Platform and the 135 km submarine pipeline to the mainland commenced. Contracts had also been awarded for all topside facilities of the platform. These included drilling, wellhead, production and accommodation modules and the helicopter deck. The contract for the flare tower had also been awarded. Other contracts let were for the manufacture of pipe and the coating and laying of the undersea pipeline to the mainland. Preliminary site work was also underway for onshore support facilities.

Appraisal well, North Rankin No. 6 was spudded on 23rd December and was drilling at 460 metres at year's end. No other drilling was carried out.

PRODUCTION

Barrow Island Field

The total production of crude oil from the Barrow Island Field during 1980 was 1 618 491 kilolitres. In addition small amounts of natural gasoline and liquefied petroleum gas (LPG) were extracted from associated gas through a low temperature separation plant. Associated gas produced with the crude oil has no direct market outlet at Barrow Island. About 10% of associated gas is used as field fuel and the remainder is processed through the low temperature separation plant to extract natural gasoline and LPG. The natural gasoline is blended with the crude oil for sale and the LPG is sold to markets in the north-west of the State as LPG or is blended with the crude oil for sale to refineries. A small amount (377 kilolitres) is used as vehicle fuel on Barrow Island.

During 1980, the development and in-fill programme which commenced in 1978 contributed about 207 000 kilolitres of crude oil or about 13% of the Barrow Island production for the year. Total production of crude oil increased in 1980 by 11% compared with 1979 due primarily to increased availability of tankers to transport crude oil, but was still about 8% below that of 1978.

A breakdown of annual and cumulative production for the reservoirs of the Barrow Island Field is shown in Table 11. Annual production of crude oil since production commenced in 1967 is shown in Figure 8 and cumulative production of liquids and water injected is shown in Figure 9. It should be noted that in Figure 9 the volume of water injected exceeds the volume of crude oil and water produced; the difference is due largely to the volume of gas produced from the Windalia Reservoir.

Total royalty paid on Barrow Island crude oil sales during 1980 was $5 715 333, an increase of $2 093 695 or 58% over 1979. When the difference in production between 1979 and 1980 is taken into account, the increase is not so spectacular. Royalty per kilolitre of sales has risen from $2·58 in 1979 to $3.56 in 1980, or an increase of 38%. Increased royalty reflects the increased price of Barrow Island crude oil which has risen from $118·53 per kilolitre for the latter half of 1979 to $175·12 per kilolitre at the end of 1980.

Dongara, Mondarra and Yardarino Fields

Annual production from the northern Perth Basin fields during 1980 and cumulative production is shown in Table 12. Cumulative production of natural gas from fields currently in production amounts to 7·3 109m³ since October 1971 when commercial production commenced

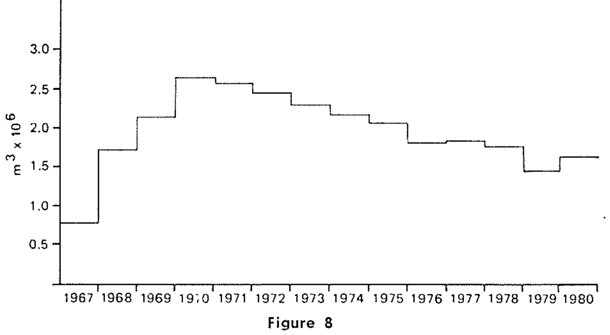


Figure 8

TABLE 11
BARROW ISLAND FIELD, PETROLEUM PRODUCTION DURING 1980
(Kilolitres)

Reservoir	Production for year 1979					Cumulative Production				
	Oil and Condensate (kl)	Natural Gasoline (kl)	Liquefied Petroleum Gasoline (kl)	Gas (10^3m^3)	Water (kl)	Oil and Condensate (kl)	Natural Gasoline (kl)	Liquefied Petroleum Gas (kl)	Gas (10^3m^3)	Water (kl)
Gearle	11 911	....	....	4 647	3 448	65 880	....	....	13 943	6 236
Windalia	1 583 326	5 878	5 638	107 293	891 398	26 677 442	36 981	35 978	2 239 346	8 380 470
Muderong	10 430	....	....	2 714	7 217	246 137	....	....	40 161	93 420
Lower Cretaceous	2 573	....	....	254	7 004	16 625	....	....	96 048	44 092
Upper Jurassic	9 577	....	....	2 653	48 039	324 709	....	....	155 758	339 720
Middle Jurassic	674	....	....	26 543	155	1 896	....	....	60 324	616
Total....	1 618 491	5 878	5 638	144 104	957 261	27 332 689	36 981	35 978	2 605 580	8 864 554

Oil and Gas Disposal 1980—
Oil—1 606 631 kl
Gas—15 022 10^3m^3—field fuel
LPG—2 022 kl sold as LPG; 3 162 kl blended with crude; 377 kl used as vehicle fuel.
Natural gasoline—5 878 m³ kl blended with crude oil.

Water injected during 1980 —2 535 165 kl
Cumulative water injected—58 734 452 kl

Royalty paid—$5 715 333

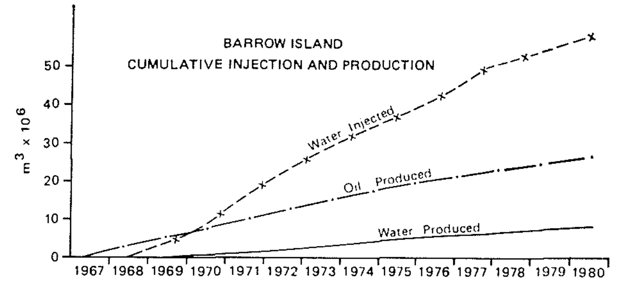


Figure 9

Gas production averaged 2 410 10^3m^3 per day during 1980 from the Dongara, Mondarra and Yardarino Fields. Annual production since 1971 is shown in Figure 10 and it is estimated that about 56% of the reserves of the northern Perth Basin gas field has been produced. Oil production averaged about 50 kilolitres per day during 1980.

Royalty paid on petroleum production from the northern Perth Basin fields during 1980 was $1 440 967, an increase of $392 592 or 37% over 1979.

RESERVES

The total recoverable petroleum reserves of the State at the end of 1980 are estimated with a probability greater than 75% to be at least 14·3 10^6m^3 of crude oil, 54·6 10^6m^3 of condensate, 29·4 10^6m^3 of LPG and 434·6 10^9m^3 of natural gas. There have been a number of small revisions to reserves during 1980 as a result of production and production history in existing fields.

During 1980 a gas discovery was made at Woodada in the Perth Basin. The discovery was confirmed by a step-out well, but requires further evaluation before it can be regarded as economic reserves. At the end of 1980 there were promising indications of a gas discovery at Wapet's Gorgon No. 1 in WA–25–P.

A breakdown of petroleum production to the end of 1980 is presented in Table 13 and the details of identified remaining recoverable reserves as at 31st December 1980 are set out in Table 14.

ENGINEERING

Construction

During the year a petroleum engineering (construction) section was formed and a Level 4 construction engineer appointed to the Branch.

The technical function of this section is to verify and ensure that structures used in petroleum production are designed, constructed and maintained safely in accordance with good engineering practice and appropriate standards.

During 1980, this section was engaged in the design appraisal and safety aspects of the construction proposals submitted by Woodside Petroleum Development Pty Limited on behalf of the Joint Venturers for the North West Shelf Development Project.

Contracts awarded by Woodside during 1980 included the pre-fabrication of the North Rankin "A" offshore platform, the flare tower structure, drilling and production facilities, living accommodation and helideck, the submarine pipeline manufacture, coating and laying.

The value of these contracts was in excess of $600 million. The offshore construction associated with the North Rankin Field will commence in 1982.

OPERATIONS AND SAFETY

The number of accidents in the petroleum industry increased dramatically during 1980. This was due to increased activity in petroleum exploration.

Unfortunately there was a fatality near Dongara during the year. At present an inquiry is being made into how the circumstances surrounding this accident occurred and how to avoid their recurrence.

Officers of the Department stress the need for companies to despatch regular reports even though the previous month may have been accident-free.

Figures relating to accident statistics in the petroleum exploration and production industry are shown in Figure 11 and Table 15.

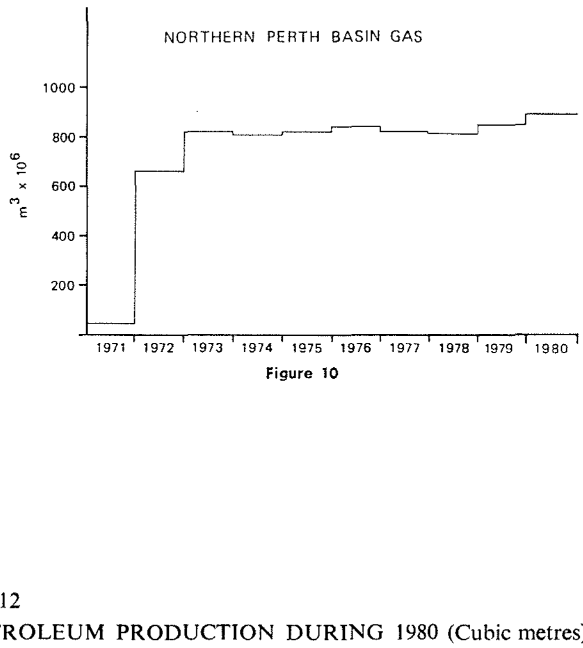


Figure 10

TABLE 12

DONGARA, MONDARRA AND YARDARINO FIELDS, PETROLEUM PRODUCTION DURING 1980 (Cubic metres)

Field	Number of producing wells at 31/12/1980	Production for year 1980				Cumulative production			
		Gas (10^3m^3)	Condensate (kl)	Oil (kl)	Water (kl)	Gas (10^3m^3)	Condensate (kl)	Oil (kl)	Water (kl)
Dongara	13	790 549	2 405	17 376	11 906	6 741 535	29 372	70 130	52 660
Mondarra	2	45 115	756	....	558	489 725	6 819	....	4 276
Yardarino	1	46 214	....	754	1 926	72 156	....	1 612	2 836
Total	16	881 878	3 161	18 130	14 390	7 303 416	36 191	71 742	59 772

Total gas sold in 1980 = 859 688 10^3m^3
Total condensate sold 1980 = 3 124 kl
Total oil sold in 1980 = 18 115 kl

Royalties: Gas	$	1 307 186
Oil	$	117 096
Condensate	$	16 665
Total royalties paid	$	1 440 947

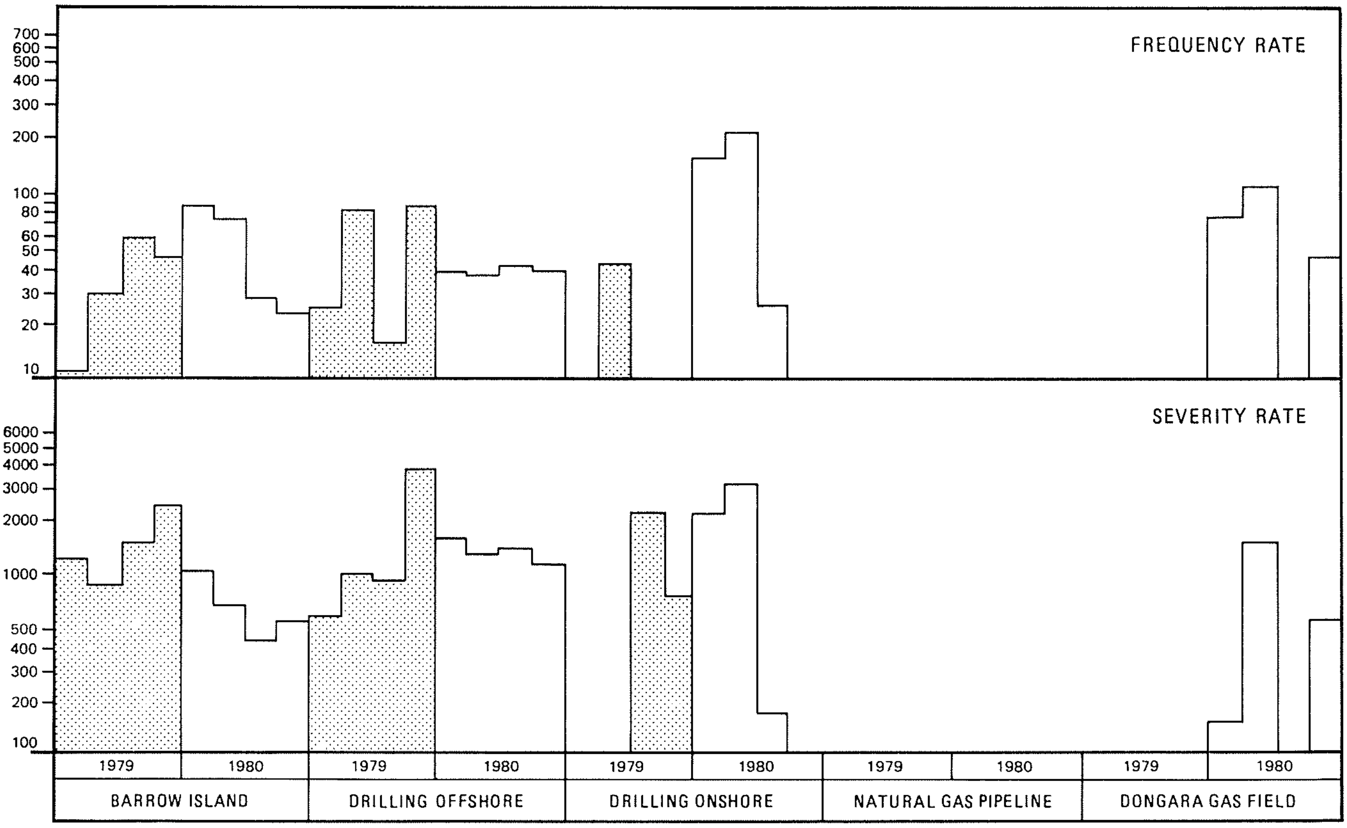
TABLE 13
SUMMARY OF PRODUCTION TO 31st DECEMBER 1980

	OIL (10^6m^3)		GAS $C_1 + C_2$ (10^9m^3)		LPG $C_3 + C_4$ (10^6m^3)		CONDENSATE C_5 + (gas fields) (10^6m^3)	
	1980	Cumulative	1980	Cumulative	1980	Cumulative	1980	Cumulative
Carnarvon Basin—								
Barrow Island	1·618	27·319	0·117	2·450	0·006	0·036	0·006	0·037
Other	....	0·011	0·027	0·158	....	....	0·001	0·004
Perth Basin—								
Dongara	0·017	0·070	0·791	6·742	....	....	0·002	0·029
Mondarra	....	....	0·045	0·490	....	....	0·001	0·007
Yardarino	0·001	0·002	0·046	0·072	....	....	....	....
Other	....	....	....	0·062	....	....	....	0·003
Total	1·636	27·402	1·026	9·974	0·006	0·036	0·010	0·081

TABLE 14
SUMMARY OF IDENTIFIED RECOVERABLE PETROLEUM RESERVES AT 31st DECEMBER, 1980

	OIL (10^6m^3)		GAS $C_1 + C_2$ (10^9m^3)		LPG $C_3 + C_4$ (10^6m^3)		CONDENSATE C_5 + (gas fields) (10^6m^3)	
	P1	P2	P1	P2	P1	P2	P1	P2
PRODUCING FIELDS—								
Carnarvon Basin—								
Barrow Island	12·51	12·64	0·46	0·50	0·09	0·09	0·06	0·06
Perth Basin—								
Dongara	0·26	0·26	4·53	4·53	....	....	0·02	0·02
Mondarra	....	....	0·09	1·08	....	....	neg	0·01
Yardarino	neg	neg	0·04	0·04	....	....	....	....
Total	....	12·91	....	6·15	....	0·09	....	0·09
UNDEVELOPED FIELDS—								
Carnarvon Basin—								
Angel	....	....	10·56	40·35	....	....	2·48	9·47
Goodwyn	0·17	0·17	62·00	79·00	8·70	11·10	12·20	15·80
North Rankin	....	....	200·00	233·00	15·80	18·20	19·30	22·30
Tidepole	0·97	1·18	13·03	17·21	....	....	2·66	2·99
West Tryal Rocks*	....	....	8·25	58·94	....	....	0·55	3·94
Total	....	1·35	....	428·50	....	29·30	....	54·50
Total Reserves	....	14·26	....	434·65	....	29·39	....	54·59

P1 Probability > 75% *Excludes inerts
P2 Probability > 25%



Frequency and Severity rate of serious injuries 1979-1980.

TABLE 15

ACCIDENT STATISTICS RELATING TO THE PETROLEUM EXPLORATION, PRODUCTION AND PIPELINE INDUSTRY DURING 1980

PETROLEUM INDUSTRY CATEGORIES

Nature of Injury	Drilling Activities		Barrow Island Oil Field	Dongara Gas Field	Total
	Onshore	Offshore			
Head	....	34	6	....	40
Eye	....	20	4	1	25
Trunk	9	54	17	2	82
Arm	1	27	1	1	30
Hand	6	67	19	1	93
Leg	3	29	9	1	42
Foot	1	23	9	1	35
Occupational	....	....	....	....	....
Other	....	....	....	....	....
Agency of Injury—					
Machinery in operation	2	34	6	....	42
Vehicles	....	1	....	....	1
Tools—hand	1	12	9	1	23
Tools—power	....	3	4	....	7
Manual Handling	7	38	18	 1	64
Harmful Contacts	3	16	6	1	26
Persons falling or striking	1	72	8	3	84
Objects flying or falling	5	56	12	1	74
Other	1	22	2	....	25
Magnitude of Injury—					
Minor	5	158	44	2	209
Serious	15	96	21	5	137
Fatal	....	....	....	1	1
Time Factor—					
Manhours Exposure	181 634	2 524 462	400 890	61 788	3 168 774
Manhours Lost	2 650	40 188	3 202	720	46 760

PIPELINES

Dongara to Pinjarra Natural Gas Pipeline.

A total of 262 work proposals from Government Departments, Instrumentalities and other parties were processed during 1980 compared with 276 in 1979 (revised figure).

There were no encroachments on the pipeline during the year.

STAFF

The staff of the Petroleum Branch at 31st December 1980 was:

Director (Level 8)—A. J. Sharp

Senior Petroleum Engineer (Level 5)—A. H. Pippet

Petroleum Engineer (Operations) (Level 4)—P.H.J. Hammett

Petroleum Engineer (Construction) (Level 4)—D. L. Schonhut

Production Geologist (Level 4)—D. N. Smith

Reservoir Engineer (Level 4)—S. P. Willmott

Petroleum Engineer (Offshore Construction) (Level 3)—Vacant

Petroleum Technologist (G–II–13)—Vacant

Technical Assistant (G–VII–1)—M. Vojkovic

Technical Assistant (G–VII–1)—Vacant

Secretary/Stenographer (C–III–2)—F. Kleinman

DIVISION VI

Report of the Superintendent Surveys and Mapping for the Year 1980

Under Secretary for Mines

For the information of the Hon. Minister, I submit my report of the activities of the Surveys and Mapping Division for the year ended December 31st, 1980.

STAFF

During the year, 4 Level 1 Draftsmen resigned to go into other types of work and 1 Drafting Assistant resigned to go overseas. All these positions were filled and only one vacancy remained resulting from the retirement of the Plan Printer. Mr D. T. Pearce, formerly Chief Cartographer was appointed as Assistant Superintendent of Mapping and Mr G. R. Sharp, formerly Draftsman in Charge, Metropolitan Water Board, was appointed Chief Cartographer. Two temporary clerks were appointed to assist with work at the counter and two trainee draftsmen were also appointed.

	Occupied	Vacant	Temporary	Total
Professional	71	....	....	71
General	28	....	....	28
Technical	6	1	....	7
Clerical	11	....	2	13
Trainee	5	....	....	5
				124

All staff in the Branch were called upon to maintain an extra effort to cope with the pressure arising from increased mining activity. Overtime programmes had to be introduced and staff moved from section to section to deal with urgent priorities.

Counter staff were particularly busy. The introduction of new maps related to gold and mineral production, although providing much new information, added to the work load because of their popularity. Sales of maps and plans in both quantity and value greatly exceeded all previous records.

A provisional sub-section was created to handle the increased interest in Temporary Reserves.

The Mapping Branch also had increased activity with more requests for base maps and the need to provide increased services to Geological Survey. The Reprographic Branch was heavily pressed to meet the demands of printing and processing. Mapping Branch staff assisted in the Public Plans Branch.

The Survey Branch was required to maintain the issue of survey instructions and all sections had arrears. Survey Branch staff also assisted in the Public Plans Branch and the Computer Services Section assisted with investigations into a tenement information system for the Department.

A more detailed report of each Branch follows:—

SURVEYS BRANCH

Surveys of mining tenements during 1980 were carried out by 26 Licensed Surveyors attached to 18 practices.

Survey work completed is summarised as follows:—

	1980 Average Area (57·78 ha)	1979 Average Area (64·92 ha)
No of Tenements surveyed	1 163	742
Cost per Tenement	$406·75	$405
No of field books lodged	145	167
Total boundary line run	1 834 km	1 329 km
Traverse line run	167 km	162 km
Total area delineated by survey	67 200 ha	47 747 ha
Distance travelled in positioning	76 207 km	74 611 km
Total value cadastral surveys	$473 052	$300 423
Total value geodetic surveys	$ 42 467	$103 182
Total value special surveys	$ 43 496	$ 5 542
Total expenditure:	$559 015	$409 147

Also 231 photogrammetric surveys were finalised by completion of some cadastral marking. The cost of these was met by special survey costs in 1979 and not included in the above averaging.

The work performed by individual practitioners is itemised as follows:—

Company	Surveyor(s)	No. of Surveys
D. F. V. Wilson & Associates	D. Wilson	165
J. Zuideveld & Associates	J. Zuideveld	68
P. D. Heyhoe	P. D. Heyhoe	113
Ranieri, Bateman & Ingram Pty. Ltd.	J. S. Ranieri .... G. G. Bateman	90
Fisher, Lewis	M. M. Fisher .... E. J. Still .... N. G. Harrison	159
F. R. Rodda	F. R. Rodda	61
K. R. Maguire	K. R. Maguire	30
R. G. Agnew	R. G. Agnew	97
K. F. Paterson & Associates	K. F. Paterson	59
Markey Campbell & Thomson Pty. Ltd.	T. L. Markey .... A. G. Quinn .... M. J. Webber	65*
Warren F. Johnson (W.A.) Pty. Ltd.	K. D. Bartlett	51
A. R. Williams	R. G. Beardman .... A. R. Williams	46
McKimmie Jamieson & Partners	G. S. Chignall .... H. Karl	51
K. M. Edwards & Associates	K. M. Edwards	39
Hille & Thompson	M. W. Hatch	35
Associated Surveys Pty Ltd.	R. A. Holland .... G. M. Sloman	14
McGay Surveys	D. J. McGay	7
I. M. Gordon	I. M. Gordon	13
18	26	1 163 + 231 = 1 394

*+ 231 Photo grammetric

Considerable difficulty was experienced with completion of outlying surveys in the Autumn due to widespread unseasonable rains stopping all parties in the field.

The average size of tenements has decreased from 64·92 hectares in 1979 to 57·78 hectares in 1980 reflecting continued increase in the pegging of gold mining leases.

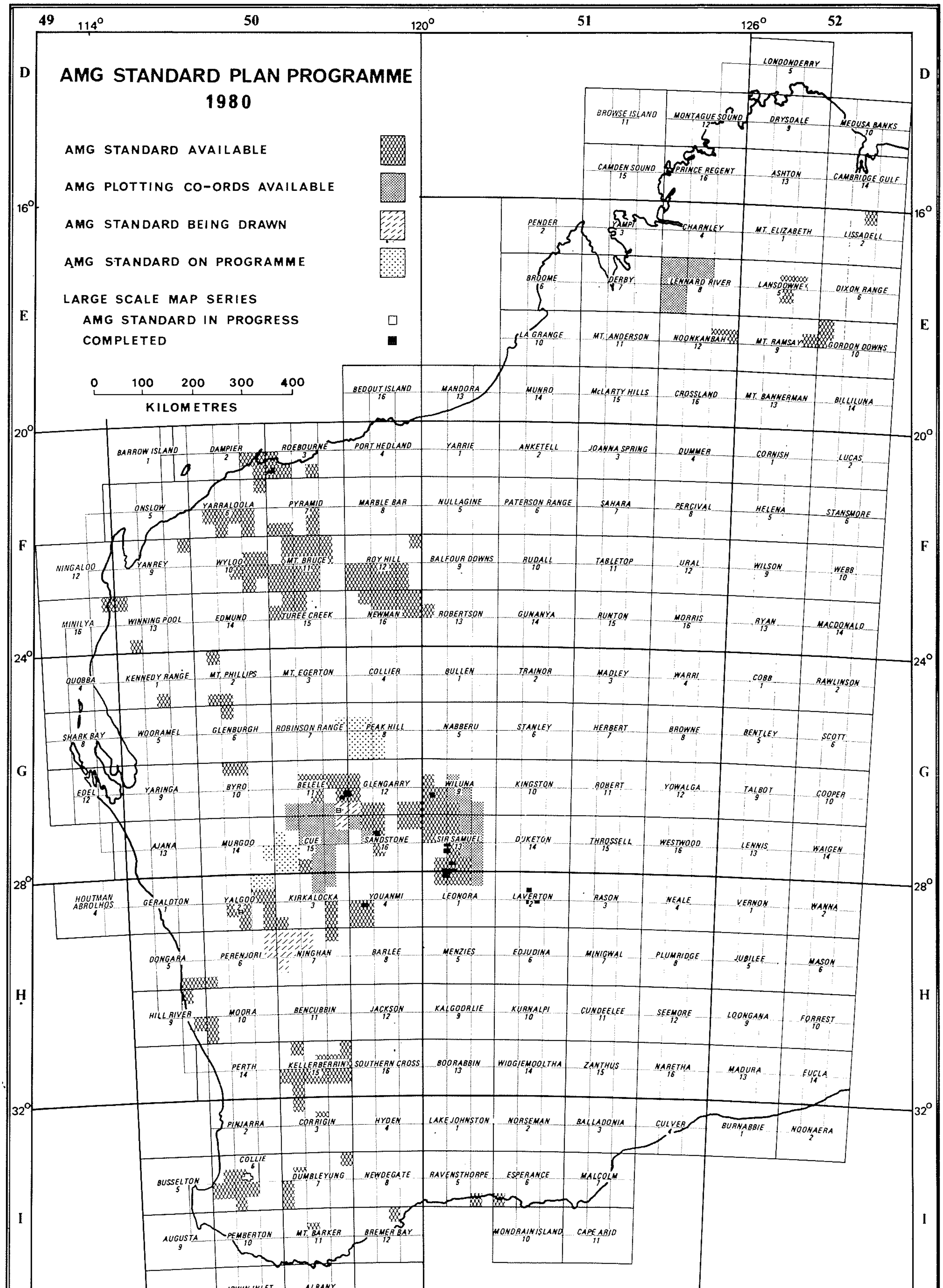

AMG STANDARD PLAN PROGRAMME
1980
AMG STANDARD AVAILABLE
AMG PLOTTING CO-ORDS AVAILABLE
AMG STANDARD BEING DRAWN
AMG STANDARD ON PROGRAMME
LARGE SCALE MAP SERIES
AMG STANDARD IN PROGRESS
COMPLETED
0 100 200 300 400
KILOMETRES
49
50
51
52
114°
120°
126°
16°
20°
24°
28°
32°
D
E
F
G
H
I
LONDONDERRY 5
BROWSE ISLAND 11
MONTAGUE SOUND 12
DRYSDALE 9
MEDUSA BANKS 10
CAMDEN SOUND 15
PRINCE REGENT 16
ASHTON 13
CAMBRIDGE GULF 14
PENDER 2
YAMPI 3
CHARNLEY 4
MT. ELIZABETH 1
LISSADELL 2
BROOME 6
DERBY 7
LENNARD RIVER 8
LANSDOWNE 5
DIXON RANGE 6
LA GRANGE 10
MT. ANDERSON 11
NOONKANBAH 12
MT. RAMSAY 9
GORDON DOWNS 10
BEDOUT ISLAND 16
MANDORA 13
MUNRO 14
McLARTY HILLS 15
CROSSLAND 16
MT. BANNERMAN 13
BILLILUNA 14
BARROW ISLAND 1
DAMPIER 2
ROEBOURNE 3
PORT HEDLAND 4
YARRIE 1
ANKETELL 2
JOANNA SPRING 3
DUMMER 4
CORNISH 1
LUCAS 2
ONSLOW 5
YARRALOOLA 6
PYRAMID 7
MARBLE BAR 8
NULLAGINE 5
PATERSON RANGE 6
SAHARA 7
PERCIVAL 8
HELENA 5
STANSMORE 6
NINGALOO 12
YANREY 9
WYLOO 10
MT. BRUCE 11
ROY HILL 12
BALFOUR DOWNS 9
RUDALL 10
TABLETOP 11
URAL 12
WILSON 9
WEBB 10
MINILYA 16
WINNING POOL 13
EDMUND 14
TUREE CREEK 15
NEWMAN 16
ROBERTSON 13
GUNANYA 14
RUNTON 15
MORRIS 16
RYAN 13
MACDONALD 14
QUOBBA 4
KENNEDY RANGE 1
MT. PHILLIPS 2
MT. EGERTON 3
COLLIER 4
BULLEN 1
TRAINOR 2
MADLEY 3
WARRI 4
COBB 1
RAWLINSON 2
SHARK BAY 8
WOORAMEL 5
GLENBURGH 6
ROBINSON RANGE 7
PEAK HILL 8
NABBERU 5
STANLEY 6
HERBERT 7
BROWNE 8
BENTLEY 5
SCOTT 6
EDEL 12
YARINGA 9
BYRO 10
BELELE 11
GLENGARRY 12
WILUNA 9
KINGSTON 10
ROBERT 11
YOWALGA 12
TALBOT 9
COOPER 10
AJANA 13
MURGOO 14
CUE 15
SANDSTONE 16
SIR SAMUEL 13
DUKETON 14
THROSSELL 15
WESTWOOD 16
LENNIS 13
WAIGEN 14
HOUTMAN ABROLHOS 4
GERALDTON 1
YALGOO 2
KIRKALOCKA 3
YOUANMI 4
LEONORA 1
LAVERTON 2
RASON 3
NEALE 4
VERNON 1
WANNA 2
DONGARA 5
PERENJORI 6
NINGHAN 7
BARLEE 8
MENZIES 5
EDJUDINA 6
MINIGWAL 7
PLUMRIDGE 8
JUBILEE 5
MASON 6
HILL RIVER 9
MOORA 10
BENCUBBIN 11
JACKSON 12
KALGOORLIE 9
KURNALPI 10
CUNDEELEE 11
SEEMORE 12
LOONGANA 9
FORREST 10
PERTH 14
KELLERBERRIN 15
SOUTHERN CROSS 16
BOORABBIN 13
WIDGIEMOOLTHA 14
ZANTHUS 15
NARETHA 16
MADURA 13
EUCLA 14
PINJARRA 2
CORRIGIN 3
HYDEN 4
LAKE JOHNSTON 1
NORSEMAN 2
BALLADONIA 3
CULVER 4
BURNABBIE 1
NOONAERA 2
COLLIE 6
BUSSELTON 5
DUMBLEYUNG 7
NEWDEGATE 8
RAVENSTHORPE 5
ESPERANCE 6
MALCOLM 7
AUGUSTA 9
PEMBERTON 10
MT. BARKER 11
BREMER BAY 12
MONDRAIN ISLAND 10
CAPE ARID 11
IRWIN INLET 14
ALBANY 15

Figure 2

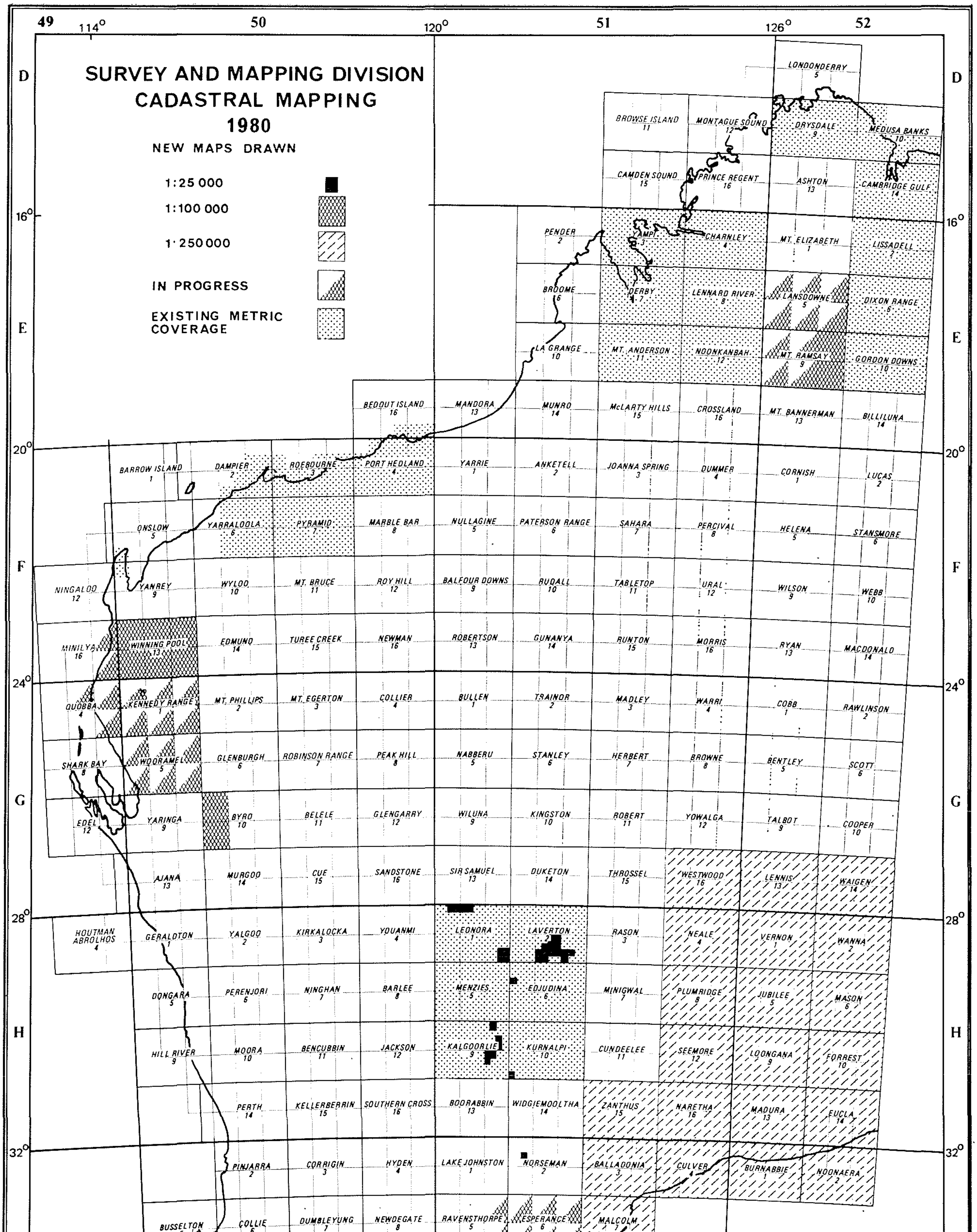

SURVEY AND MAPPING DIVISION
CADASTRAL MAPPING
1980
NEW MAPS DRAWN
1:25 000
1:100 000
1:250 000
IN PROGRESS
EXISTING METRIC COVERAGE
49
50
51
52
114°
120°
126°
D
E
F
G
H
I
16°
20°
24°
28°
32°
LONDONDERRY 5
BROWSE ISLAND 11
MONTAGUE SOUND 12
DRYSDALE 9
MEDUSA BANKS 10
CAMDEN SOUND 15
PRINCE REGENT 16
ASHTON 13
CAMBRIDGE GULF 14
PENDER 2
YAMPI 3
CHARNLEY 4
MT. ELIZABETH 1
LISSADELL 2
BROOME 6
DERBY 7
LENNARD RIVER 8
LANSDOWNE 5
DIXON RANGE 6
LA GRANGE 10
MT. ANDERSON 11
NOONKANBAH 12
MT. RAMSAY 9
GORDON DOWNS 10
BEDOUT ISLAND 16
MANDORA 13
MUNRO 14
McLARTY HILLS 15
CROSSLAND 16
MT. BANNERMAN 13
BILLILUNA 14
BARROW ISLAND 1
DAMPIER 2
ROEBOURNE 3
PORT HEDLAND 4
YARRIE 1
ANKETELL 2
JOANNA SPRING 3
DUMMER 4
CORNISH 1
LUCAS 2
ONSLOW 5
YARRALOOLA 6
PYRAMID 7
MARBLE BAR 8
NULLAGINE 5
PATERSON RANGE 6
SAHARA 7
PERCIVAL 8
HELENA 5
STANSMORE 6
NINGALOO 12
YANREY 9
WYLOO 10
MT. BRUCE 11
ROY HILL 12
BALFOUR DOWNS 9
RUDALL 10
TABLETOP 11
URAL 12
WILSON 9
WEBB 10
MINILYA 16
WINNING POOL 13
EDMUND 14
TUREE CREEK 15
NEWMAN 16
ROBERTSON 13
GUNANYA 14
RUNTON 15
MORRIS 16
RYAN 13
MACDONALD 14
QUOBBA 4
KENNEDY RANGE 1
MT. PHILLIPS 2
MT. EGERTON 3
COLLIER 4
BULLEN 1
TRAINOR 2
MADLEY 3
WARRI 4
COBB 1
RAWLINSON 2
SHARK BAY 8
WOORAMEL 5
GLENBURGH 6
ROBINSON RANGE 7
PEAK HILL 8
NABBERU 5
STANLEY 6
HERBERT 7
BROWNE 8
BENTLEY 5
SCOTT 6
EDEL 12
YARINGA 9
BYRO 10
BELELE 11
GLENGARRY 12
WILUNA 9
KINGSTON 10
ROBERT 11
YOWALGA 12
TALBOT 9
COOPER 10
AJANA 13
MURGOO 14
CUE 15
SANDSTONE 16
SIR SAMUEL 13
DUKETON 14
THROSSEL 15
WESTWOOD 16
LENNIS 13
WAIGEN 14
HOUTMAN ABROLHOS 4
GERALDTON 1
YALGOO 2
KIRKALOCKA 3
YOUANMI 4
LEONORA 1
LAVERTON 2
RASON 3
NEALE 4
VERNON 1
WANNA 2
DONGARA 5
PERENJORI 6
NINGHAN 7
BARLEE 8
MENZIES 5
EDJUDINA 6
MINIGWAL 7
PLUMRIDGE 8
JUBILEE 5
MASON 6
HILL RIVER 9
MOORA 10
BENCUBBIN 11
JACKSON 12
KALGOORLIE 9
KURNALPI 10
CUNDEELEE 11
SEEMORE 12
LOONGANA 9
FORREST 10
PERTH 14
KELLERBERRIN 15
SOUTHERN CROSS 16
BOORABBIN 13
WIDGIEMOOLTHA 14
ZANTHUS 15
NARETHA 16
MADURA 13
EUCLA 14
PINJARRA 2
CORRIGIN 3
HYDEN 4
LAKE JOHNSTON 1
NORSEMAN 2
BALLADONIA 3
CULVER 4
BURNABBIE 1
NOONAERA 2
BUSSELTON 5
COLLIE 6
DUMBLEYUNG 7
NEWDEGATE 8
RAVENSTHORPE 5
ESPERANCE 6
MALCOLM 7
AUGUSTA 9
PEMBERTON 10
MT. BARKER 11
BREMER BAY 12
MONDRAIN ISLAND 10
CAPE ARID 11
IRWIN INLET 14
ALBANY 15

Figure 3

1: 250 000 SHEET NAME	MAPPING COMPLETED			IN PROGRESS	
	FIRST EDITION		PRELIMINARY EDITION	FIRST EDITION	PRELIMINARY EDITION
	PRINTED	AWAITING PRINTING			
AJANA			■		
BARLEE					■
BELELE			■		
BENCUBBIN					■
BREMER BAY			■		
BULLEN	■				
BYRO			■		
COLLIE				■	
COLLIER		■			
GLENBURGH			■		
GLENGARRY		■			
GUNANYA	■				
JACKSON					■
KINGSTON	■				
KIRKALOCKA			■		
MOORA				■	
MT PHILLIPS			■		
NABBERU				■	
NEWDEGATE					■
NINGHAN			■		
NULLAGINE	2nd Edition				
ONSLOW				■	
PEMBERTON–IRWIN INLET					■
PERENJORI			■		
PINJARRA		■			
QUOBBA				■	
ROBINSON RANGE		■			
RUDALL		■			
SHARK BAY–EDEL			■		
SOUTHERN CROSS		■			
STANLEY				■	
TRAINOR	■				
WILUNA		■			
WINNING POOL–MINILYA					■
YANREY–NINGALOO		■			
YARINGA			■		

Figure 4

ACCOMMODATION

The relocation of survey staff currently on the 1st Floor to an area within or closer to the main group on the 7th Floor is an urgent requirement.

The accommodation for staff of the Computer Services Section and their equipment is unsuitable.

IN GENERAL

Although the very high interest in mining tenement applications continued into 1980, the emotional feel of the 1969/71 nickel boom is not evident.

At the end of 1980 there were 43 811 tenements which could require survey so no reduction in survey activities is foreseen in the immediate future.

MAPPING BRANCH

CADASTRAL MAPPING

Intensive pegging of Gold Mining Leases resulted in the demand for larger scale plans over areas which were previously adequately mapped in order to more clearly record tenement boundaries in areas of congestion.

As a result priority was given to the production of maps at a scale of 1:25 000 in the Eastern Goldfields and during this year 31 maps were produced.

Another area of priority mapping was the replacement of old imperial maps by new maps at a scale of 1:100 000 in the Dundas and Phillips River Goldfield areas. These were required to assist in the recording of Coal Mining Leases. Nine of these new series maps are in the final stages of production.

In addition, 1:100 000 mapping is progressing in the East Kimberley area of Mt Ramsay (2 sheets completed, 4 sheets near completion), Landsdowne and Mt Elizabeth and also in the Ashburton-Gascoyne areas of Kennedy Range, Quobba, Wooramel and Minilya.

Twenty-two 1:250 000 maps were produced during the year to replace old imperial sheets in the south-eastern part of the State.

The programme for the revision of existing maps was suspended as there was insufficient staff to cope with both the priority mapping and the revision programme.

See fig. 3.

GEOLOGICAL MAPPING

1:250 000 *Series*

A combination of increased expertise and sustained effort resulted in a rewarding output of completed regional maps.

The previous years heavy programme was intensified resulting in an increase from 27 to a total of 36 sheets in various stages of production.

Of these, 6 full colour editions were printed. Seven full colour first editions are awaiting printing by contract and 10 preliminary editions were produced.

See fig. 4.

1:50 000 *Urban Geology Series*

Six coloured editions were produced during the year as follows:—

Nickol Bay	Baynton
Point Samson	Dampier
Karratha	Roebourne

One further sheet, Picard de Witt, has been received and is ready for drawing.

PROJECT MAPPING

Printed copies of coloured maps of the Meckering Bulletin, Copper Bulletin, Tin Bulletin and Pilbara Bulletin were received, whilst work proceeded with the drawing of the coloured maps of the Bangemall Basin and Nickel Bulletins.

GEOLOGICAL PUBLICATIONS

This area of work embraces a large variety of drafting ranging from diagrams required for publication in Bulletins, Reports, Records, Explanatory Notes, Pamphlets, colour slides and artwork for display purposes.

A total of 756 diagrams were produced which represents an increase of approximately 250 on last year's figures.

Another area of increasing activity is the preparation of visual aids to support lectures. This year 179 x 35 mm slides and 135 overhead projection transparencies were produced.

The figures for both the Cadoux Earthquake Report and the revised edition of the Nickel Pamphlet were completed.

STATE MAPS

The revised State Map at 1:2 500 000 with gazetteer was published and work is progressing on the preparation of a new Mineral Deposits Map of Western Australia at a scale of 1:2 500 000.

THEMATIC MAPPING

A new series of maps at a scale of 1:5 000 000 was produced, depicting various map indexes and mineral resources themes. They are designed to impart to the Public, in a simple graphical way, information which has previously been difficult to access or has only been recorded in statistical form.

Maps produced are as follows:—

- Western Australia showing a 1:100 000 map sheet index.
- Western Australia showing a 1:50 000 map sheet index.
- Western Australia showing administrative divisions, principal mines and operators.
- Mineral Production in W.A. showing tonnages, value and number of workers involved in the production of various minerals.
- Gold in W.A., portraying gold prospecting activity.

The production of a new series was commenced, at a scale of 1:1 000 000 showing in colour areas held under gold mining leases. Four sheets, Perth, Kalgoorlie, Wiluna and Meekatharra were produced during the year. There was a great public response to these maps and numerous reprintings were required to satisfy the demand.

There has been a big public acceptance of both of these new map series and it is a type of mapping which should be encouraged and actively developed.

REPROGRAPHIC SECTION

This section worked under difficulties; limited space and poorly appointed dark-rooms aggravate what is already a sensitive area that operates under continual pressure of work. Demands are made upon the staff from all areas of the Department. Additional space, better designed access to dark rooms and more modern equipment is required to enable this section to cope with the continually increasing work load.

During this year, 2 585 items of work were processed on the vacuum frame and 1 697 items were prepared on the process camera. Four thousand six hundred and ninety-six prints and slides were processed for many branches of the Department. The demand for colour photography continued to increase, there being almost twice the number of colour requests than there were for black and white. Another specialised area of work is the colour proofing of geological maps.

The demands placed upon the plan printing section continued to increase, so much so that the output from this section increased by 50 per cent on the previous year's figures. Sixty-four thousand and twenty-two plans were printed, 3 574 plans were mounted and 395 booklets were bound giving an overall total of 67 991 items from this section.

PUBLIC PLANS BRANCH

The attached graphs and tables reflect the tremendous increase in the work of this Branch as a result of increased mining activity. All sections found difficulty in maintaining essential services and arrears developed with most sections of work. Assistance had to be obtained from other Branches and programmes of overtime were introduced to cut back these arrears. The counter staff were particularly busy as large crowds regularly waited for service. The introduction of new maps and plans while providing additional information, also increased the demand at the counter. The number of public plans and other associated survey documents registered and in use with the Department are listed below.

Public Plans	Current	Archived
1:1 000 000 index series	14	96
1:1 000 000 temporary reserve series	14	47
1:1 000 000 petroleum series	34	35
1:250 000 public plans	106	370
1:100 000 public plans	86	82
1:50 000 & 1:25 000 public plans	1 183	2 542
Large Scale Series	9	17
Lands Old Series (Imperial)	176	836
Mines Old Series (Miscellaneous)	20	477
Lands Old Series (TM)	14	182
Old Index Sheets (10 mile)	....	137
Petroleum Map (M175)	1	70
	1 657	4 891

Standard Plans	Current	Archived
Index: 1:1 000 000	14	33
Old Projection (20 chains)	550	117
Transverse Mercator	211	10
Australian Map Grid—		
1:100 000	1	....
1:50 000	206	21
1:25 000	29	5
1:10 000	38	....
Provisional (All scales)	371	28
	1 420	214

Field Books	
Cadastral Surveys	6 194

Survey Plans	
Diagrams (Imperial)	49 880
Diagrams (Metric)	8 134
Original Plans:—	
(Imperial)	286
(Metric)	587
	58 887

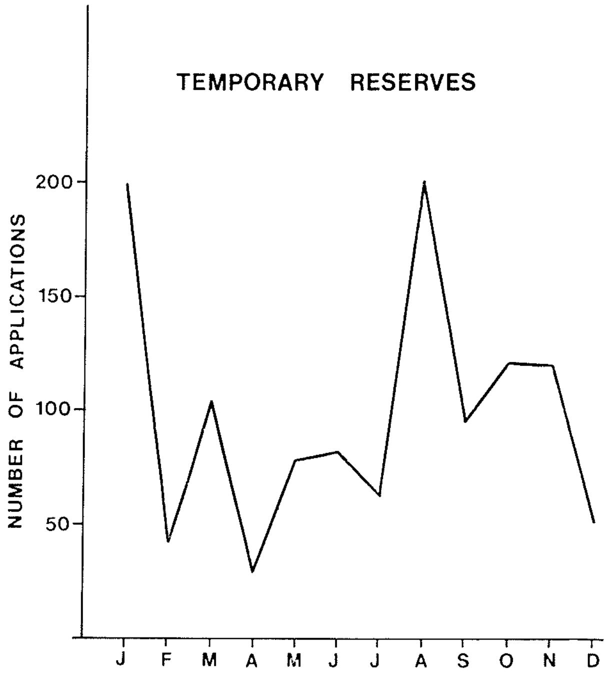


Figure 6

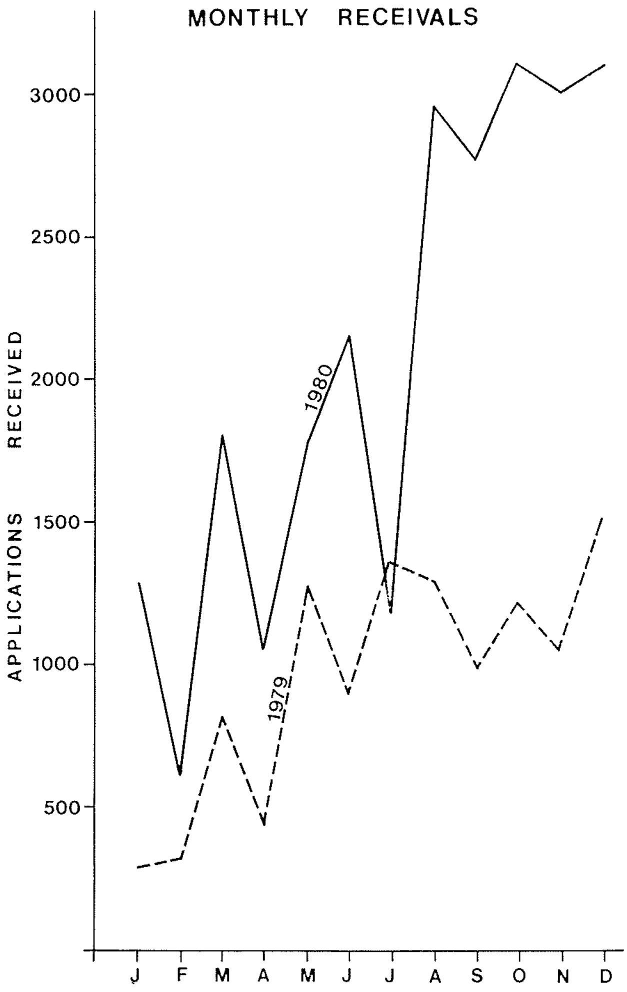


Figure 5

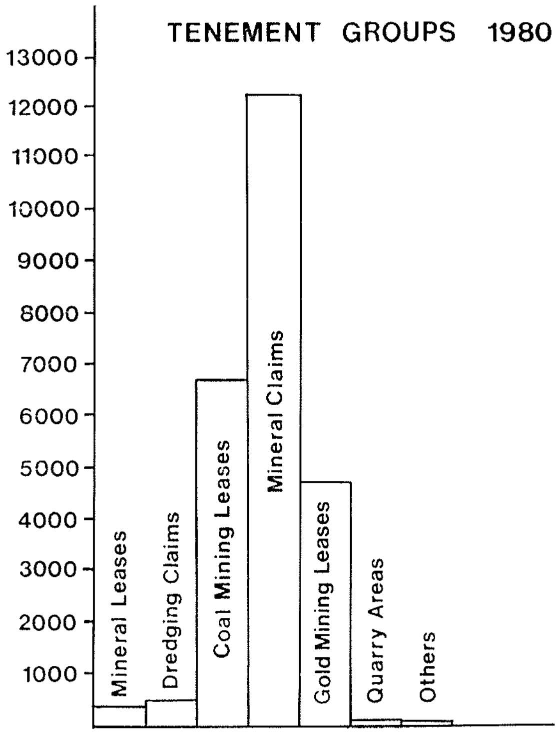


Figure 7

SURVEYS AND MAPPING BRANCH
COUNTER SECTION
SALES

Photocopies General	9921
Transparencies	690
Ammonia Prints – Plans	34028
Gold Bearing Areas Map (STATE)	274
Gold Area Map 1: 1000,000	2116
Canning Stock Route Maps	200
State Maps Petroleum	1400
State Maps Mineral Occurrence	90
State Maps Index	1292
Gazetteers	976
T.R. Tenements Iron	66
T.R. Tenements Minerals	82
Total No. Items	51135

Figure 8

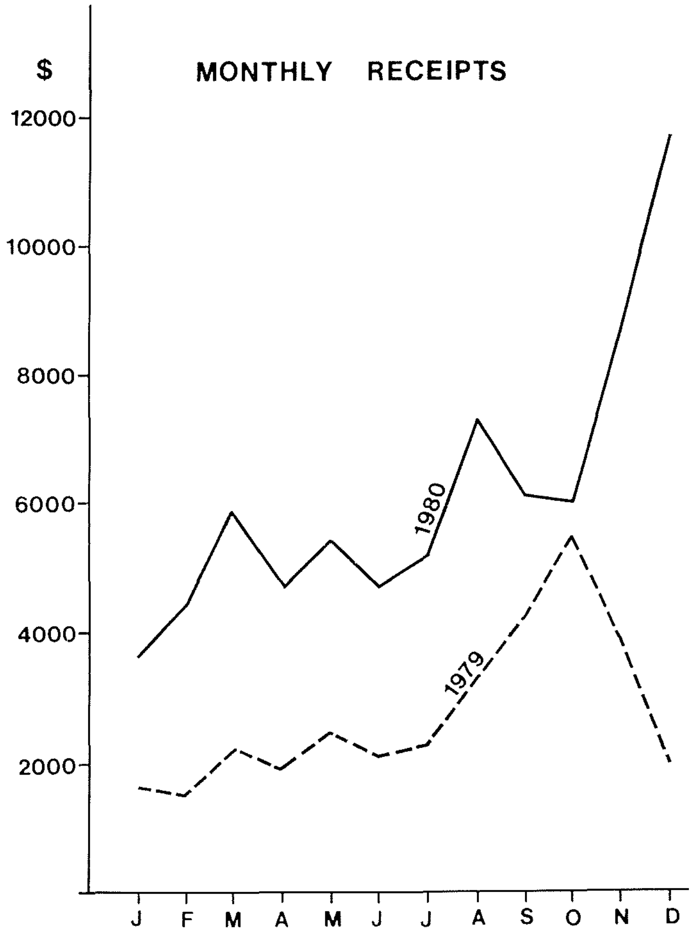


Figure 9

W. R. MOORE,
Superintendent, Surveys and Mapping.

CONTENTS

	Page
Administration and General Report	201
Reports of Division	
Agricultural Chemistry	203
Engineering Chemistry	206
Food and Industrial Hygiene	209
Forensic Chemistry	212
Industrial Chemistry	215
Kalgoorlie Metallurgical Laboratory	217
Mineral	218
Water	223
Tables showing Source and Nature of Samples	
General Table 1	202
Agricultural Chemistry Division Table 2	203
Food and Industrial Hygiene Division Table 3	210
Forensic Chemistry Division Table 4	212
Mineral Division Table 12	218
Water Division Table 13	223

Government Chemical Laboratories Annual Report—1980

UNDER SECRETARY FOR MINES

I submit the Annual Report on the activities of the Government Chemical Laboratories for the calendar year 1980.

ADMINISTRATION

The Laboratories continued to function during the year with the Administration and six Divisions, Agricultural Chemistry, Food and Industrial Hygiene, Forensic Chemistry, Industrial Chemistry, Mineral and Water Divisions on the Plain Street site, the Engineering Chemistry Division at Catherine Street, Bentley and the Kalgoorlie Metallurgical Laboratory at MacDonald Street, Kalgoorlie.

STAFF

No increases in staff were obtained during the year. Restriction of staff growth combined with limited funding is our major problem, in coping with the compounding increase in growth and complexity of work, on which there are no growth restrictions.

Because of the ages of most of the senior staff there is going to be a major change in all senior positions in the next five to ten years. The severe limitation on staff increases over the past 10 or more years has meant there has been, inevitably a high level of in-breeding within the Laboratories. To overcome the effects of this as far as possible programmes in staff training have been instituted. These have involved in-service courses in instrumentation, computing, administration and management, attendance at conferences and seminars, encouragement to participate in scientific societies, and to undertake additional studies.

In June Mr. Goodheart, Chief Engineering Chemistry Division, visited China as a member of a trade mission lead by the Minister for Resources Development. This trade mission concentrated on metallurgical processing with the intent of developing mutual trade in the area. Subsequently because of staff level problems, resulting from reorganisation of the previous Department of Industrial Development and because of Mr. Goodheart's experience and knowledge in mineral processing, he was seconded to the Department of Resources Development from November for a period of about one year. This has consequently had a restricting effect on some efforts in the Engineering Chemistry Division.

Staff members served during the year on thirty-three different statutory, inter-departmental or ad hoc committees. The Director served on eleven of these committees and other officers represented the Laboratories on the other twenty-two. The contribution by staff to these committees is an important professional advisory and consultancy role of the Laboratories.

The establishment of the Laboratories including three long term temporary officers in the Water Division consists as in 1979 of the following officers:

Professional Division	83
General Division	49
Clerical Division	12
Wages staff	2
Total	146

Again it is necessary to express thanks and appreciation for the efforts and dedication of staff in making a special effort in trying to cope with the increased volume of work received and at the same time making significant professional contributions.

During the year and continuing into 1981 the Deputy Director and Acting Deputy Director acted in turn as convenor of the Mines Department Computer Co-ordinating Committee. This involved a considerable amount of their time in planning for future development of computing facilities within the Department. A survey of the computing needs of the Department was commissioned through consultants and their recommendations are now being implemented. As a result of the consultants' survey our own PDP 11/40 computer will be retained primarily for our own use for direct links with automated. instrumentation. Other requirements by the Department will gradually be transferred to bureau facilities.

ACCOMMODATION

Major internal alterations in the Agricultural Chemistry Division commenced during the year, were not completed because of delays in design and construction of new fume cupboards. Early completion of this work in 1981 is necessary so that the planned reorganisation of the Division for further automation does not further delay their enormous back-log of work.

Stage one of the air-conditioning of the Laboratories was not completed for the summer of 1980, it is at an advanced stage and will be operating for the summer of 1981–82. Approval for reconstruction of the Kalgoorlie Metallurgical Laboratory was given in the 1980–81 budget. Construction will start in 1981 on the Egan Street frontage, as an integral part of the School of Mines metallurgical building, which will be built at the same time. This new building is a very necessary requirement and the close co-operation in functions with the School of Mines through the design of the building will be beneficial to both organisations.

On the Plain Street site there is an urgent need for further laboratory space for the increased work of the Agricultural Chemistry and Forensic Chemistry Divisions as well as for storage and library space. In addition there is serious over crowding in the pesticide residue laboratory of the Food and

Industrial Hygiene Division. More importantly there is no laboratory space that can be suitably fitted up for permanent use in this area with all the necessary safety requirements for dealing with hazardous and highly toxic chemicals such as dioxins and aflatoxins. The safety and health of staff and the reliability of results at levels of down to parts per billion requires an early solution to these accommodation problems. Expansion of the Laboratories by construction of a three storey building on the Hay Street frontage now requires an urgent decision and an early start.

EQUIPMENT

The only major equipment obtained by funding through the Equipment Purchase and Replacement Committee was a dual unit high performance liquid chromatograph. This instrument is already in great use in forensic, agricultural, food and environmental work.

The low level of funding for equipment is the major single item that is affecting our efficiency, productivity and staff morale. The considerable inflationary increase in minor equipment costing less than around $200, has been assessed at around 18–20 per cent a year. This has meant that expenditure on these necessary items, virtually consumables, has left a very meagre budget for purchase or replacement of equipment in the medium cost range of $200–$5 000.

A major infusion of funds for replacing old, obsolete and unrepairable equipment, for providing us with the facilities for further automation of instrumentation and with the equipment to use new techniques now unavailable to us, is essential if the Laboratories are to continue as a useful and efficient service to Government Departments and the community. We have estimated just to replace current equipment, which is either obsolete or will become unfunctional in the next five years, will require three quarters of a million dollars. This is without providing us with any additional new equipment to be up to date with current instrumental quantitative sensitivities and qualitative specificities. Replacement of the X-ray fluorescence equipment for which spare parts are getting more difficult to obtain because of its age, is of the order of $200 000 alone, on current prices.

One major item of equipment needed in the near future is an inductively coupled plasma atomic emission spectrometer. One private laboratory in the State has been able to invest over $200 000 in such equipment and AMDEL in South Australia have invested over $300 000. The wide range of elemental analyses at low sensitivities and with great speed makes such instrumentation a necessity, as a way of handling work loads without increasing staff levels.

GENERAL

Again this year there has been an appreciable increase in sample receivals, up over 11 per cent on 1979. The 53 000 samples received represents over $2\frac{1}{2}$ times more samples than in 1970 with a staff increase of about 1/5th for the same period.

Major increases have been in agricultural samples from the Department of Agriculture, forensic work for the Police Department and in doping control in sport samples. This is the first full year which we have done doping control work for all three of the Turf Club, Trotting Association and the Greyhound Control Board, resulting in over 2 000 samples from this source alone, 1 200 more than last year. The source and allocation of all work received in 1980 is shown in Table 1.

With our instrumentation it is possible to readily detect down to parts per billion levels i.e. one part in 10^9, with high resolution mass spectrometry parts per trillion i.e. one part in 10^{12} is possible. At these low levels of detection some Departments have been sceptical about the reliability and meaning of such results. An example of this is our reporting several years ago of low levels of dieldrin in samples of waters, soils, etc. from the Ord River Irrigation Area. Several Departments have doubted the presence of dieldrin, since it was claimed dieldrin had never been used at the Ord River. This was despite confirmation by two gas chromatography techniques and specific confirmation by gas chromatography/mass spectrometry. It was therefore gratifying to learn during a study by us on dieldrin use undertaken this year, that it was found that dieldrin had been used quite extensively on the Ord, though there were no official departmental records of its having been used.

The study of the use of dieldrin in W.A. referred to above was undertaken for the Pesticides Advisory Committee because of publicity given to levels of dieldrin in human breast milk. The survey which will be completed in 1981 was made into all approved uses, levels and quantities of use as well as the very large amount of analytical data available on residues in water, soil, milk, various other foods, tobacco and in the environment. Evidence found to date shows an appreciable decrease in the number of uses of dieldrin, decreasing levels in the environment and the overall impression that current restrictions on its use are effective in reducing levels of residues. The source of the levels of dieldrin in breast milk which are comparable with those from other countries, has not been elucidated.

In the 1979 report I referred to a review of our functions, inter-departmental relationships, building and site requirements, staffing and funding which was being undertaken by a group under the Public Service Board. A detailed submission by the Director plus individual submissions by each Chief of Division was made to this group. There has been a preliminary inspection by some members of this group and more lengthy interviews with staff by one academic member of this group.

TABLE 1

SOURCE AND ALLOCATION OF WORK 1980

Source	Agricultural Chemistry Division	Engineering Chemistry Division	Food and Industrial Hygiene Division	Forensic Chemistry Division	Industrial Chemistry Division	Kalgoorlie Metallurgical Laboratory	Mineral Division	Water Division	Total
STATE—									
Agriculture Department	25 039	....	1 584	12	....	....	42	22	26 699
Conservation and Environment Department	....	....	209	....	....	....	13	65	287
Consumer Affairs Bureau	....	....	6	....	24	....	2	9	41
Corrections Department	....	....	....	86	....	....	....	1	87
Education Department	13	....	....	....	5	....	....	....	18
Fisheries and Wildlife Department	....	....	141	....	2	....	....	38	181
Geological Survey	....	1	....	....	....	....	566	368	935
Government Chemical Laboratories	27	104	28	32	1	....	166	41	399
Harbour and Light Department	....	....	....	3	8	....	....	....	11
Hospitals	....	....	60	....	....	....	1	....	61
Labour and Industry Department	....	....	120	....	5	....	42	....	167
Leschenault Inlet Management Authority	....	....	8	....	....	....	....	96	104
Main Roads Department	2	4	....	....	4	....	25	39	74
Metropolitan Water Board	....	....	237	....	19	....	22	1 140	1 418
Mines Department	....	....	129	4	....	21	475	2	631
Peel Inlet Management Authority	....	....	....	....	....	....	....	73	73
Police Department	1	....	1	3 703	10	23	21	....	3 759
Public Health Department	21	....	2 279	5	60	....	1 836	116	4 317
Public Works Department	8	....	139	....	62	2	104	5 674	5 989
Regional Administration and the North West	1	4	4	....	3	....	11	....	23
Road Traffic Authority	....	....	....	1 125	....	....	....	....	1 125
State Housing Commission	....	....	6	....	7	....	....	6	19
Swan River Management Authority	....	....	....	....	....	....	....	258	258
Tender Board	....	....	....	....	111	....	....	....	111
Waterways Commission	....	....	38	....	....	....	....	....	38
Other Authorities (10)	....	....	1	8	4	....	14	8	35
PUBLIC—									
Free	....	....	....	....	....	15	23	....	38
Pay	1 511	91	33	2 137	55	1 236	747	468	6 278
Total	26 623	204	5 023	7 115	380	1 297	4 110	8 424	53 176

However to date no finality has been reached. Until some conclusions and recommendations are made by this group, satisfactory longer term planning of the future of the Laboratories is not possible. It is hoped there will be early in 1981 some resolution by this group and that their conclusions will be supported by Treasury and the Public Service Board.

The summarised reports of the various individual Divisions which follow again emphasise the range of work and functions of the Laboratories. They show that no matter what area of development within the State whether it be social, industrial, agricultural, environmental, consumerism or health all have an impact on the increasing work of the Laboratories and in return show the contribution made by the Laboratories to the advancement of the State.

R. C. GORMAN,
Director, Government Chemical Laboratories.

AGRICULTURAL CHEMISTRY DIVISION

GENERAL

Since the separation in December 1969 of the then Agriculture and Water Supply Division into two Divisions, the Agricultural Chemistry Division has completed a decade of operations which have been devoted almost exclusively to the application of the science of chemistry to the State's agricultural services and research. At least 95 per cent of our work derives from the Department of Agriculture and work carried out on a private basis for primary producers provides the remainder.

The Division is organised so that work is dealt with by three main groups, namely Plant Section, Soil Section and Trace Environment Section. This arrangement facilitates the processing of routine type service work and also encourages a degree of specialisation in research activities for senior staff.

Some of the more interesting work during the year is described later. It reflects an active expansion of the Division's activities in agricultural chemistry.

CONFERENCES AND WORKSHOPS

The Laboratories were represented at the 12th Australian Spectroscopy Conference in Sydney by Mrs. L. A. Plues-Foster.

Messrs S. C. Baseden and B.J. Codling were delegates to the National Soils Conference, Sydney.

Messrs Z. E. Spadek and P. Gentelli attended, at their own expense, the 13th Biennial Conference of the Australian Society of Animal Production in Perth.

A one day Symposium on Laboratory Automation, Data Acquisition and Computerisation arranged by the Royal Australian Chemical Institute, W.A. Branch, was attended by several staff members.

The Division assisted with the organisation of two workshops; a four day course in High Performance Liquid Chromatography presented by Waters Associates and a Marine Pollution Pilot Monitoring Programme arranged by the Australian Department of Science and the Environment and sponsored by the Inter Governmental Oceanographic Commission for training of eight technical staff from countries in the Indian Ocean region. Instruction was given in a method of measuring petroleum pollution in marine samples.

MEETINGS

The Chief of Division attended meetings of the Lupinseed Technology Committee in connection with developments in Australia in the use of lupinseed as a food for humans.

He also participated in a study of computing requirements of other Branches of the Mines Department and chaired meetings of a nine weeks preliminary study of Departmental requirements conducted by Access Computing Consultants.

EQUIPMENT

The following items were received: Waters Associates High Performance Liquid Chromatograph, Prototype Autosampler, Hook & Tucker Superspenser S4313 and Grant Waterbath—Shaker.

Attempts to obtain other badly needed equipment by applying for grants from industry research funding bodies were unsuccessful. It appears that we are to continue in the completely unsatisfactory situation of having to compete on a low priority with other Departments for purchase of equipment. The result is frustrating and morale destroying in that we are forced to be up to five years behind the times in the use of certain instrumental techniques required to provide an efficient chemical service and in the study of modern analytical methods.

COMPUTER

The PDP 11/40 is housed in the Division which contributes substantial man hours to its management. A new ADK analogue to digital converter was installed but was not in use because of delays in upgrading the RSX 11M operating system received earlier in the year.

Interfacing of an autoanalyser used for determination of phosphorus in extracts of soil samples was almost completed. This will allow direct print out of reports of soil tests carried out for farmers, which should result in a faster service and less tedium for staff.

A number of power fluctuations were recorded by the computer during the year. The cost of installing voltage stabilizing facilities was investigated but no conclusion was reached. However it would appear to be preferable, for a number of reasons, to use small portable stabilizers for individual instruments rather than a reticulated power supply.

ACCOMMODATION

Alterations to the older part of the Divison were commenced early in the year but were not completed due to delays in finishing the design of new fume cupboards. The cupboards incorporate features which make them suitable for special operations such as perchloric acid digestion of samples as well as general laboratory use. A prototype is under test to aid in optimising the exhaust system. The final product is expected to solve a problem, common to many laboratories, of being unable to obtain a good general purpose cupboard which can be adapted to a range of laboratory requirements.

NATURE OF WORK

The Division deals with almost half of the total number of samples received by the Laboratories each year. Detail of the source and nature of the samples is given in Table 2.

The total number of receivals is 11 per cent higher than 1979 and is two and a half times greater than for 1970.

Plants Section received 13 746 samples, 40 per cent more than last year. Soils Section received 11 611 samples, five per cent

Plants Section received 13 746 samples, 40 per cent more than last year. Soils Section received 11 611 samples, five per cent less than last year. Trace and Environmental Section received 1 266 samples.

Apart from the increased quantity of work over this period there have been changes in the type of chemical work carried out. These are due both to the expanding and changing emphasis of the Department of Agriculture's research programmes and to the questionable policy of some Departments in establishing their independent laboratories.

The sample output for the year and work in hand at 31 December with a comparison with previous years is given below.

TABLE 2

AGRICULTURAL CHEMISTRY DIVISION

	Department of Agriculture	Government Chemical Laboratories	Education Department	Public Health Department	Other Department	Public Pay	Total
Animal Tissue	87	....	....	....	....	....	87
Cereal	8 184	....	....	....	....	36	8 220
Fertilizer	130	....	....	....	1	11	142
Horticulture	2 471	....	....	....	1	....	2 472
Miscellaneous	1 375	26	....	....	1	28	1 430
Pasture and Stockfood	2 554	....	13	20	...	70	2 657
Soil	10 238	1	....	....	10	1 366	11 615
Total	25 039	27	13	20	13	1 511	26 623

Year	1970	1976	1977	1978	1979	1980
Sample Receivals	7 438	13 803	16 765	19 122	23 979	26 623
Samples in hand 31 December	1 535	7 281	8 158	5 005	7 352	10 742
Sample Output	8 221	11 835	15 888	22 275	21 632	23 233

The three-fold rise in annual turnover of work since 1970 has been achieved while additions to the Division's staff establishment were limited to three, a 12 per cent increase over 11 years, or only one per cent per annum and is due to continuing investigation, improvement of methodology and a diligent staff.

Output for the year was seven per cent greater than last year. All staff can be very satisfied with this work effort in the face of disruptions due to building alterations and inconveniences caused by staff vacancies. In particular the members of the Sample Preparation Section have efficiently handled the rise in sample numbers and proposed further streamlining of their methods.

A great deal of the Division's resources is expended on servicing field and glasshouse experiments conducted by the Department of Agriculture's Plant Research Division. The results of experiments for which supporting chemical data are provided on a routine basis are now published in Annual Reports of the various Divisions of that Department. Work which falls into this category, and which involves large numbers of plants and soils samples, includes long term trials on cereals, pastures, legumes, vegetables and oilseeds as listed below:—

Phosphorus fertilizers—residual values on crops and pastures and effectiveness of different sources of P.

Nitrogen fertilizers—comparison of sources of N, finding a soil or tissue test for N status and effects on soil pH.

Potassium fertilizers—leaching and residual effects of K sources including slow release forms.

Sulphur fertilizers—leaching of S fertilizers, residual values for pasture nutrition and seeking a soil or tissue test for prediction of S requirements.

Copper and Zinc—residual values for crops.

Legumes—evaluation of high protein species as alternatives to lupins.

Pasture regeneration—effects of lime on sand plain soils.

Rotation trials—effects on soil fertility.

Horticulture—monitoring of nutrient levels in leaf samples of fruit trees, grape vines and vegetable crops.

Rangelands—evaluation of feed quality of native and introduced pastures.

Ord River—evaluation of fertilizer uptake by plants and residual soil values for sugar-cane, rice, peanuts, sorghum, sunflower and maize.

Soil Structure—measurement of changes in structure under rotation trials.

Analyses included all or individual elements concerned with plant nutrition, but most analyses were for calcium, copper, magnesium, manganese, nitrogen, phosphorus, potassium and zinc. However considerable effort was spent on boron, chloride, cobalt and molybdenum analyses.

Work in which chemists were closely involved included the following:

PLANT SECTION

Lupinseed

Our method for determining total crude alkaloid content in sweet lupin products by a potentiometric titration of extracted material was refined. The method is too slow and therefore work was commenced on a gas chromatography procedure. The need for a rapid method is all the more imperative because of the need to quickly confirm, on a routine basis, the low levels of alkaloids in W.A. narrow-leafed sweet lupinseed. This need is urgent because of the current use of sweet lupinseed as a valuable protein-rich stockfood and the expected future use of lupin products as human food which is dependent on the very low alkaloid content of the W.A. cultivars. Athough seeds of the bitter varieties are easily identifiable by colour and taste, future marketing of the sweet varieties may require certification of content and identity of alkaloids. The alkaloid content of lupinseed hulls was shown to be lower than in kernels. Advice and standard samples were provided for laboratories in the Eastern States wishing to conduct their own assays of lupin products.

A survey of the alkaloid content of seeds of selected varieties from the main lupin-growing regions in W.A. involved the analysis of 39 samples for total alkaloid and qualitative identification of the individual alkaloids by thin layer and gas chromatography. Total crude alkaloid content ranged between 0·01 and 0·08 per cent as received.

Nitrogen tissue tests for cereals

A selective ion electrode method was modified for use in determination of nitrate levels in wheat tops and young leaves. The method is based on that of Milham *et al* (Analyst 95, 751, 1970) with alterations to the buffer extractant and inclusion of a filtration step. The electrode method agreed well with slower colorimetric methods. Results obtained for the wheat tissues analysed gave good correlations with grain yield and response to N fertilizer. Prediction of N requirements for optimum economic grain yield and detection of N deficiency at an early growth stage to allow corrective applications of fertilizer appear possible using this test.

Feeding Stuffs

Silage samples were analysed for volatile fatty acids and volatile nitrogen to allow correction of results for dry matter content obtained by oven drying. It was shown that, for the samples concerned, there was a significant correlation between dry matter determined by oven drying and by toluene distillation, which gives a better estimate of dry matter. However the distillation method is tedious and slow, and it has been proposed to use oven drying with a correction for loss of volatiles. This requires determination of volatile nitrogen and volatile fatty acids which is also time consuming. The use of the relationship between distillation and oven drying results for estimating true dry matter saves a considerable amount of effort.

Vitamin A estimation in pig and poultry feeds by liquid chromatography was investigated, using the high performance liquid chromatograph (HPLC) received late in the year. Preliminary tests using a published method showed promise.

Sugar beet grown for stockfood was higher in crude protein and carbohydrate content than mangels. These crops are of interest as a raw material for production of ethanol as an alternative motor fuel. Comparison of the potential for ethanol production (based on crop yield and the carbohydrate available for fermentation) showed that, for these samples, sugar beet and mangels had about ten times the potential of wheat grain as an ethanol source.

Aluminium, calcium and fluoride content of sixty nine batches of mixed pig rations from a trial studying effects of supplementation with Christmas Island rock phosphate, showed wide variation of these additives. It appears that even mixing is difficult to achieve, as efforts have been made to rectify poor distribution of additives following previous occurrences.

Turf Management

Five hundred and fifty samples of couch grass clippings from a large trial at the new turf centre at Woodlands were examined to define fertilizer requirements for couch grass establishment. Contents of nitrogen (1·0 to 6·1 per cent), phosphorus (0·12 to 0·64 per cent) and potassium (0·5 to 2·9 per cent), varied markedly with time of cut and rate of fertilizer applied.

Pollen

The export pollen industry (value $3 million per annum) is being assisted by provision of chemical data used for marketing and evaluation as health foods. There is very little reliable chemical data for pollens, and none have been reported previously for W.A. material. Crude protein content was very dependent on the source of the pollen, ranging from 19 per cent for Capeweed to 36 per cent for Patterson's Curse. Marri pollen contained 28 per cent while Jarrah contained 20 per cent. The amino acid composition of the pollens was found to be affected by commercial drying at elevated temperature, lysine, histidine and proline each being less in dried samples. An increase in valine concentration in dried pollen suggested that degradation may occur. Each of the 20 pollens examined contained a balanced supply of amino acids essential for bee nutrition. The mean concentrations of cystine, methionine, histidine and proline were higher than mean values reported in a survey of Italian pollens.

Fertilizers Act

Arrangements finalised with the Department of Agriculture are designed to improve the administration of the Act in respect of non-compliance with guaranteed chemical composition of a product. Results of analyses of samples submitted by the Inspector of Fertilizers are made available as quickly as possible to allow time for legal procedures to be completed in time for prosecution of offending vendors.

Ninety-nine samples were examined, of which 18 were deficient in one or more constituents. The position is simailr to last year when 19 per cent of samples analysed were below standard. However this is a vast improvement on previous years. Samples below guarantee were mainly compound fertilizers in which mixing appears to be a problem, for when one of the three main ingredients N, P or K is deficient, one or both of the others may be well above the guaranteed content.

Some of the samples were seaweed products containing relatively low contents of the plant nutrients and it is questionable whether registration as a fertilizer is warranted in these cases.

Fertilizers used in field trials were checked for S and P contents and samples of calcined rock phosphate were analysed to aid in identification of the source of the material. Advice was given to the City of Canning on the physical properties, chemical composition and sampling of fertilizers and in the selection of products submitted under tender.

Other Work

Manganese estimation in some types of plant samples by atomic absorption spectroscopy is known to give slightly low results in an air-acetylene flame when compared to results obtained with nitrous oxide. Attempts to identify the interferences responsible were inconclusive. Ionisation was shown to be partly responsible for variable results obtained in iron determinations using a nitrous oxide flame.

Advice was given to laboratories at the Department of Agriculture on analytical methods and accuracy of results of check plant and soil analyses.

The Australian Feeds Information Centre was supplied with data for inclusion in its records of the nutritional and feeding value of plants and plant products throughout Australia.

SOIL SECTION

Soil Testing

The demand by farmers for tests of extractable phosphorus, potassium and copper increased by 23 per cent over last year. In addition there is a trend among research workers to request these measurements either to assist in selecting responsive sites for field trials, to ensure that these elements are not a limiting factor in other trials, or as a diagnostic aid for field advisers in solving problems.

Extractable phosphorus in soils from Esperance measured by two laboratories (this Division and a private laboratory) gave very reassuring results from the sampling and analytical point of view, but indicated that the Residual Value Function (RVF) of the Decide model for Esperance sandplain soils may need revision, in that the integrated current phosphate value from past dressings predicted by Decide was about double the soil test values.

A survey of sandy soils in the Kulin area showed a wide variation of extractable potassium (3 to 400 ppm) which may explain a response to potassium fertilizer on wheat in the district.

Bowling greens, tennis courts and playing fields were again surveyed for extractable phosphorus and potassium. Farms on light land in the Northam district were checked for pH (in relation to molybdenum status) and for extractable copper. Phosphorus and potassium were estimated to be at adequate levels between 20 to 50 ppm in the top (10 cm) soil, while 50 to 100 ppm indicated that fertilizer addition could be reduced slightly.

Copper

Extractable copper (0·2M ammonium oxalate), in soils from a pot trial studying effects of incubation on copper uptake by wheat plants, was not related to time or temperature of incubation and did not reflect copper availability as measured by plant uptake.

DTPA (diethylenetriaminepentaacetic acid) 0·005M was used to extract copper from samples which had previously been analysed by 0·2M ammonium oxalate extraction. There was a good relationship between the results obtained by the two methods ($r=0{\cdot}91$) with DTPA extracting about one third of the copper extracted by ammonium oxalate.

Soil Acidity

A three year study of the chemistry of acidic soils was commenced. There are large areas in the wheatbelt where soil acidity is believed to be the cause of poor crop and clover production. A large amount of data were generated this year including measurements of pH, extractable aluminium and lime requirement. Each of these parameters was measured by more than one analytical method with the object of selecting procedures most suitable to W.A. soils. A number of the methods were rejected because they were imprecise or too tedious.

The method adopted for determination of lime requirement is based on FAO Soils Bulletin No. 10, 1970 which allows calculation of the lime requirement in milliequivalents per 100 g for adjustment of the soil to a selected pH. For conversion to tonnes per hectare the bulk density of the soil and the depth to which the lime is to be incorporated can be taken into account, the values depending on the local conditions. Plant sampling from early stages of the project showed good correlation between yield and soil pH and extractable aluminium determined by each of three methods tested.

At Kununurra a disease of groundnuts appeared to be associated with areas of ash from burnt logs. Samples of soil from the affected area showed some increases in electrical conductivity, pH and extractable calcium and magnesium which may have been sufficient to stress the plants.

Organic Matter as Nitrogen Source

An aerobic incubation procedure for measuring mineralisable nitrogen in soils (Dolmat *et al* Soil Science 129, 229, 1980) was compared with our current anaerobic procedure based on that of Waring and Bremner, Nature 201, 951, 1964. Both methods gave better precision and higher results when the soil sample was finely ground before incubation. The aerobic method gave good correlations with dry matter yield of wheat plants in field and pot trials. The method will be used to study the contribution of nitrogen from coarse organic matter, which will necessitate grinding of the material to allow uniform incorporation with soil samples before incubation.

Because of the current renewed interest in nitrogen in soils, and in particular the availabliity of non-fertilizer nitrogen, an improved automated method for nitrate, based on the method of Best, Queensland J. Agr. and An Sci 33, 161, 1976, was introduced early in the year.

Unusually high nitrate and ammonia values in some Kununurra samples were attributed to the practice of forwarding moist soils which undoubtedly undergo incubation during transit. It was recommended that samples be dried before despatch and that an incubation technique, such as that described above, be tried as a measure of soil nitrogen status.

Sulphate Adsorption

The automated turbidimetric procedure in routine use for sulphur in soils and plants was modified to allow a study of adsorption properties of soils in the South-west. Useful data in the low concentration range, one to five ppm sulphur in soil are being collected and should aid in classifying soils with respect to sulphur fertilizer needs.

Other Work

Iraqi soils were analysed to aid in planning a programme of farming development of 10 000 ha in the Jezirah region of northern Iraq.

Deterioration of the bitumen catchment of the Ravensthorpe Town Water Supply led to chemical evaluation, for Public Works Department, of basecourse material used in construction.

Soils from Eneabba and Shark Bay were checked for suitability for establishment of jojoba.

Comprehensive analysis was made of problem soils, including samples from Salmon Gums where trials with water-repellant soils commenced, and from an extensive survey of potato soils at Manjimup.

Red mud waste from alumina refining had high pH and phosphate adsorption capacity but a surprisingly low cation exchange capacity. Incorporation of the waste in sandy soil may improve fertility by raising moisture and nutrient retention.

Peat which is excavated during highway construction in the northern suburbs is frequently submitted for analysis to check suitability for horticultural purposes. Samples from Hutton Street area were high in organic matter, having loss on ignition of 70 to 85 per cent. W.A. "peats" have generally less than 50 per cent organic matter.

Analytical work servicing trials throughout the State continued with priority being given to Ord River work. At the same time efforts are directed towards updating and automating methods for future use. These include the use of a Leco furnace for determining total sulphur and a comparison of methods for more rapid determination of organic carbon. Preliminary results were encouraging.

TRACE AND ENVIRONMENT SECTION

The Section has developed valuable experience and techniques for analysis of elements at the trace and ultra-trace levels. The aim has been to determine as many elements as possible in samples of limited size. It also deals with diagnostic samples from trace element deficiency problems and is responsible for evaluation of the quality of oilseeds.

It participated in two international surveys of methods for determining trace elements in marine tissue with very satisfactory results.

Human Tissue

Tissues from a survey of cot deaths were analysed for cadmium, calcium, copper, iron, lead, magnesium, manganese and zinc. There were no unusual results which might suggest a metal imbalance as a cause or result of the cot death syndrome, and there were no relationships to age or sex of the cases involved. The results do, however, contribute to an important field of research in which such data are very limited.

Trace Elements in Porcine Tissues

As an adjunct to a study of the effects of feeding high levels of rock phosphate to pigs, the concentrations of eight elements in five types of tissue were determined using the analytical technique devised for human tissues.

Examination of the results in relation to feed treatments and time showed that none of the elements cadmium, calcium, copper, iron, lead, magnesium, manganese, zinc accumulated in the muscle tissues during the period of the trial. This was generally true for the other tissues examined namely kidney, liver, spleen and testes. It was concluded that no complications from the effects of the elements examined would be expected in the trial but the following observations are of interest:

- Cadmium levels in kidneys increased for the first weeks of feeding the rock phosphate supplemented diet and then remained constant.
- Copper was higher and iron was lower in the livers of animals fed the control diet containing meatmeal compared to those on rock phosphate supplement.
- Iron levels in spleen were variable, probably due to residual blood in the tissues.
- Lead in kidneys varied 20 fold between animals and was low in spleen samples. Magnesium and zinc increased in testes as time of feeding the rock phosphate supplemented diet increased.

Fluoride in Porcine Bones

As reported last year, laboratory tests were conducted to compare the complexing of fluoride ions with aluminium in the form of either a soluble salt or alumina powder. This year the investigation was extended to a trial with pigs in which aluminium was added to diets as commercial grade alumina powder produced at Kwinana, with the aim of restricting uptake of fluoride from either sodium fluoride or rock phosphate additives. Analysis of fluoride in metacarpal bones at the end of the trial showed that alumina was ineffective in suppressing fluoride uptake, but calcium (as limestone) caused significant decreases in fluoride uptake.

Copper in wheat leaves

Estimation of copper at very low levels in young wheat leaves can be carried out using electrothermal atomisation in a graphite furnace attached to an atomic absorption spectrophotometer. In the absence of such instrumentation an alternative method was investigated based on gas chromatography of metal chelates. Preliminary investigations were sufficiently encouraging to continue this approach which depends on using suitable chelates.

Oilseeds

Oil content of a large number of sunflower seed samples was estimated using NMR (nuclear magnetic resonance) on an instrument located at the Department of Agriculture. The time saved by using NMR instead of conventional solvent extraction of oil was approximately 4 man-weeks for 100 samples. The exercise provides a good example of the advantages of modern instrumentation which are denied us by financial restrictions.

A linoleic acid content of 62 per cent in sunflower oil is classed as top quality for margarine manufacture and attracts higher prices. Samples were examined for the Grain Pool of W.A. to establish what concentrations of linoleic acid could be expected in seed from the Ord River area and to assist with marketing.

Oil content and the ratios of linoleic and oleic acids in the oil were determined for evaluation of field trials with sunflowers in the Albany district comparing eight varieties and time of sowing. Oil content was unaffected by time of sowing. At one site, linoleic acid content was higher for the late (December) sowing. Varieties Hysun 11 and Sunace had highest (62·4 per cent) linoleic acid content. The ratio linoleic: oleic acids was about 3:1 for all samples and they comprised about 80 per cent of the total fatty acids in the oil.

Comparison of four sunflower varieties at Kununurra showed little difference in linoleic acid content between varieties but there was a large effect of sowing time, values ranging from 26 to 58 per cent.

Rapeseed erucic acid content showed that samples of Wesway variety received late in the season contained near to the 1·5 per cent of erucic acid set as the upper limit for seed examined under the Department of Agriculture's Seed Certification Scheme.

Environmental

Fluoride level in oat plant tops was too low to explain a poor crop. Oats are relatively tolerant to fluoride. On the other hand damage to grape vines was again reported from Swan Valley vineyards and as a result monitoring of fluoride in vine leaves was re-introduced. Results are to be used for comparison with measurements of fluoride in air taken at the sampling site by the Department of Public Health and Medical Services.

Fluoride emissions from aluminium smelters proposed for the South-west region are expected to introduce environmental issues. Samples of vegetation taken near the Picton Junction superphosphate works which also emits fluoride to the atmosphere were examined for fluoride content and compared with surveys carried out in 1971–73 for use as baseline data for the area.

Sodium content of local produce comprising part of the diet of the metropolitan population was estimated for comparison of the contributions from food and drinking water to total dietary sodium.

Other Work

A sample of emu fat was of interest. It had iodine value, saponification equivalent and fatty acid composition similar to neatsfoot oil. It could have commercial value and was used for leather dressing and for preserving timber by our early settlers.

Fluoride concentration in guinea pig feed was checked in new batches of feed received by hospital animal houses. Results were low and generally less than 20 ppm fluoride. No outbreaks of fluorosis were reported to us during the year and it appears that the problem is being held in check.

The detection limit for determination of molybdenum was improved three-fold by using a micro cell in place of the standard 40 mm spectrophotometer cell. Better knowledge of the trace element nutrition of irrigated pastures required analysis for molybdenum of samples from a survey conducted in the Wokalup district.

Copper analyses at low levels in wheat plant parts showed that residual copper fertilizer applied 12 years previously was still available.

Cobalt levels as low as 0·02 ppm in livers and feed indicate that the concern of the Department of Agriculture that steep increases in the cost of cobalt fertilizers may result in reduced usage of this essential element, are well founded.

Linoleic acid content of hulled oats was more than twice that of wheat grain. Hulled oats is a cheaper source of linoleic acid which is important in controlling egg size in poultry.

J. JAGO
Chief Agricultural Chemistry Division

ENGINEERING CHEMISTRY DIVISION

GENERAL

The pattern of activities set in recent years continued throughout 1980. The Division is meeting the needs of a sector of the mining industry for access to research and development facilities and ancillary consultative services. This activity is common to the Kalgoorlie Metallurgical Laboratory which is now under the supervision of the Chief of this Division. However, as separately reported, the Kalgoorlie laboratory had a difficult year because of staff shortages and was unable to accept all requests for work and attend to its own programme of developmental research.

As well as company oriented testwork, the Division continued the departmental directed project into the use of stabilised north-west soils for construction and was able to conduct its own innovative investigations. These are reported below but aspects of confidentiality restrict the review of work done for companies.

In June, the Chief of Division, Mr. B. A. Goodheart, was a member of the trade mission taken to the People's Republic of China by the Hon. Minister for Resources Development Mr. P. V. Jones. This was the first official delegation from the State to China and was concentrated on metallurgical aspects of common interest. In November Mr. Goodheart was seconded to the Department of Resources Development for a year. Both of these movements reflect the necessity for technical expertise in administering the development of the State's mineral resources.

In June Mr. H. Dyall attended a two week Workshop Course in "Mineral/Commodity Economics" at the Australian Mineral Foundation in Adelaide. In August Mr. R. Marshall attended the Electro-chemistry Conference held at the University of Western Australia. In September he attended the chemical engineering conference, Chemeca 80, held at Monash University. As well he visited two CSIRO Divisions in Victoria and AMDEL (Australian Mineral Development Laboratories) in Adelaide. In November Mr. L. Brennan visited the Kalgoorlie Metallurgical Laboratory and attended the November Conference of the Kalgoorlie School of Mines. Mr. Goodheart also visited the Kalgoorlie Metallurgical Laboratory and examined various mining and processing ventures in the eastern goldfields area.

In March the Division was visited by a group drawn from South African and Asian countries and sponsored in Australia by the Australian Development Assistance Bureau. They were undertaking a Study Tour at the Western Australian Institute of Technology (WAIT) and were professionally qualified geologists, scientists and mining engineers with a special interest in heavy mineral sands.

BUILDINGS

During 1980 construction was begun of the long awaited extensions to the pilot plant building. The building shell and most of the fittings have been completed but work on the installation of a grinding circuit and dust collection equipment was not quite complete at the close of the year.

The extensions cover 162 m^2 of floor space and provide several much needed specialised work areas. The Division's grinding equipment used in sample preparation is now housed in one enclosed area where each unit has its own dust extraction hood connected to a common exhaust system. As well there is provision for wet and dry screening. A solvent storage room has been constructed to standard specifications.

A second area houses a grinding-classification circuit which was initially installed in the Industrial Chemistry Division. This area has some open working space and adjustable exhaust hoods which will allow the Division's mobile processing units to be set up as required.

The third area is intended for wet processing operations and has a mezzanine floor for permanent installation of the Wilfley table and the Denver flotation cells in two banks of six cells. The grinding-classification circuit referred to above is designed to prepare the feed to the flotation cells.

The extensions will ease the previous overcrowding in the pilot plant and storage areas and will allow some operations to be performed without interruption under cover instead of in the open subject to weather conditions. The permanent nature of the installations will obviate the previous need for improvisation in setting up temporary circuits.

Plans for the re-establishment of the Kalgoorlie Metallurgical Laboratory on another part of the School of Mines site were drawn up and reviewed during the year. The schedule provides for construction to begin in 1981 and be completed in 1982. The historical association of the Laboratory with the Kalgoorlie School of Mines will be continued and even re-inforced. The Laboratory will share a common architecture with the extensions to the School of Mines and, although autonomous and self-contained, will be physically part of the campus.

The review of the Division's objectives which was initiated at the close of 1979 was suspended pending the outcome of the more widespread review of the whole Laboratories referred to in the 1979 Annual Report. This matter is not yet resolved. During the year the Government announced its intention to form the Western Australian Mining and Petroleum Research Institute (WAMPRI). This Division has established a liaison with WAMPRI in the expectation that Divisional research programmes will be considered for the allocation of funds controlled by the Institute.

CONTRACT INVESTIGATIONS

Diatomite

It is always gratifying to see research and development culminate in practical application. Several years ago the Division began an examination of local diatomite deposits to ascertain their potential for beneficiation to filter grade products which are now imported, mainly from the United States of America. The expertise developed in this innovative programme enabled the Division to undertake work for a company interested in exploiting one of the many deposits of diatomite found on the coastal plain between Jandakot and Geraldton.

Laboratory and pilot scale trials involving flux calcination trials in the Division's rotary kiln and processing in a pneumatic classification circuit produced encouraging results. Overseas consultants engaged by the company reviewed our reports and visited the Division for an inspection of facilities and discussions on technical aspects of processing local diatomite. The company has publicly announced its intention to proceed to commercial development of the project.

Another company requested further work on processing diatomite for use in a patent insecticide. Sufficient material was processed for use in large scale trials aimed at evaluating the effectiveness of the preparation in protecting stored grain from weevil infestation. The insecticide has a dehydrating action so that it is a non-toxic pesticide and as such could be used repeatedly without the risk of organisms developing immunity to the insecticide.

Attapulgite

The testwork referred to in the 1979 Annual Report continued during the year. Attapulgite (palygorskite) can be listed under the general heading of Fuller's Earth and is an alumino-magnesium silicate clay with a structure composed of fibrous crystals. Individual aggregates of crystals can lie skew to each other to produce a "bundle of straw" effect. The spaces between individual agglomerates become empty pores when the mineral is dried giving rise to the mineral's ability to absorb liquids. Thus the mineral's major applications are as absorbative granules for use as insecticide carriers, industrial oil or general spillage absorbents and the pet litter market. Australia's consumption of absorbent clay is estimated at 5–7 thousand tonnes per year.

In a different application advantage can be taken of the absorbing power of attapulgite. In the refining of animal fats and edible vegetable oils it is necessary to remove selectively the large organic molecules that cause undesirable colour in the products. Natural attapulgite can be activated by physical and chemical methods to become an efficient bleaching clay for this industry. Australia currently imports four to five thousand tonnes per year of such decolouring agents costing $250–$350 per tonne. The world market for bleaching clays exceeds 300 000 tonnes per year with about 25 per cent being used in the South East Asian area.

Earths which are more acidic appear to be more effective bleaching agents but they also tend to hydrolyse the oil and increase its fatty acid content which is undesirable. The level of addition of clay needed to accomplish bleaching is important in terms of the cost of the clay and the amount of valuable oil it retains. Other parameters investigated have been specific surface area, bulk density and chemical and mineralogical composition.

Laboratory scale investigations into the activation of a Western Australian attapulgite have produced a range of clays with similar bleaching efficiencies to three commercially available earths for certain animal fats and vegetable oils. These results were sufficiently encouraging to warrant the preparation of larger bulk quantities for testing by commercial interests. At year's end the company concerned was studying the feasibility of commercial application of the activation process and it seemed probable that the company would commission further testwork in the Division.

Beach Sands

Several small scale investigations relative to beneficiation of beach sands were carried out. Although none of them was sufficiently important to warrant separate comment at this time, it is probable that one item will assume more significance during 1981. The competitive nature of the industry makes confidentiality of research themes a key issue so that only guarded references to the work can be made.

Western Australian firms are major competitors on the international market in the heavy minerals produced from beach sands. In many cases the "beach sands" referred to are concentrations of heavy minerals accumulated on ancient (but geologically recent) beaches which may now be many kilometres inland from current shore lines. The heavy minerals present are ilmenite, zircon, rutile and leucoxene as major components and kyanite, monazite and xenotime as minor components.

The market for these minerals is subject to considerable vagaries so that the mining and processing companies are continually seeking to upgrade their products to match market specifications. Colour, size, reactivity, chemical composition and level of impurities are characteristics which influence market penetration. In recent years the Division has been engaged in testwork on these themes as indicated in previous Annual Reports. Some Divisional work on the beneficiation of zircon is discussed in a later section of this report.

Utilisation of Forest Waste

South African researchers have developed a method for producing soil-less nursery blocks suitable for the propagation of plants. Termed WRIBLOKS, they are composed of waste materials of the timber industry bonded with small quantities of repulped newspaper (papier maché).

A waste material of the Western Australian timber industry is currently used as a mulch and soil conditioner. As this usage accounts for only a modest percentage of the annual waste production, its incorporation into a nursery block would enhance overall waste usage and produce a saleable object.

Two separate batches of papier maché/mulch mix yielded blocks for assessment. These blocks displayed acceptable physical properties but market acceptance of the product will depend on such factors as root penetration, seed propagation and seedling growth, which will be assessed in nursery trials. So that these trials can be pursued, twenty dried blocks of each mix have been delivered to the company.

Sawdust

Samples of sawdust and woodchips were submitted for size analysis. The technical input from this Division was minimal in terms of the overall issue which was to find a fuel to replace oil. Interest in this issue is commonplace now and several queries were dealt with during the year particularly in relation to replacing oil with coal.

In domestic circumstances wood as fuel has regained some of the popularity it lost in recent years. However present circumstances have changed wood from a cheap readily available fuel to a dearer scarcer fuel although the cost per unit of heat may still favour wood. Green mill ends (40 per cent water) costing $15 per tonne and used at only 20 per cent efficiency will yield a kilowatt hour of energy for 2·2 cents. The same quantity of electrical energy costs 5·42 cents. However the wood has to be stored, chopped and carried and the ashes must be disposed of so that inconvenience is a hidden cost. Firewood suppliers state that woodchipping operations have reduced supplies and increased the cost of wood fuel. In the United States of America domestic and industrial consumers in some areas are turning back to wood. Perhaps here in Western Australia future generations will enjoy again in winter the pleasure of a log fire that many people remember nostalgically.

PROJECTS FOR OTHER DEPARTMENTS

Soil Stabilisation for Brick Making

The Pindan project in conjunction with the Office of Regional Administration and the North West and the State Housing Commission continued in 1980 along the lines indicated in last year's Annual Report. The nature of the investigation is such that no sudden breakthrough or discovery is anticipated—soil stabilisation is an ancient technique. However it is necessary to establish criteria relative to the circumstances which prevail in the northwest of our State with particular attention to soil types, climatic conditions and ruling economic factors. As well there are sociological factors of acceptance of the product as construction material in accord with aesthetic appeal and building regulations.

A further sum of money has been made available by the State Housing Commission and the continuing research programme will be formulated. A report has been prepared and is expected to be released at the beginning of 1981 as Report of Investigations No. 23. The majority of the soils that have been examined are of similar composition to Pindan and are generally responsive to stabilisation. Variations in response can be attributed to differences in physical and chemical properties. Research is continuing with an emphasis on stabilising with cement which is preferred to lime as the stabilising agent.

The soils from Broome, Derby, Fitzroy Crossing and Pandanus Park had similar mineralogical contents. They were predominantly quartz sand (70–85 per cent), silt (5–13 per cent) and kaolinitic clay (10–26 per cent). The quartz grains, although superficially covered with silt and clay, were discrete, transparent and partly water worn. In effect, the minerals represented were ultimate products of weathering of former host rock and primary minerals. The sub-rounded nature of the quartz grains suggested a relatively high degree of transportation of the soils to their present sites. The principal difference between these soils was in the level of clay content and the particle size distribution of the sands fractions. The Broome and Derby samples had a sands particle size distribution disposed towards that of fine sand (0·06–0·2 millimetre) whereas the sands fractions of the Fitzroy Crossing soils were mainly coarser (0·2–0·6 millimetre).

In contrast, the samples of Wyndham soils and one of the Kununurra soils contained sands fractions which were composed principally of composite, angular grains. These contained partly weathered feldspar, mica and ferro-magnesian minerals in addition to quartz. The Wyndham soils wree essentially alluviums containing 65–86 per cent combined silt and clay. The composition and angularity of the grains suggested a granitic origin and a low degree of transportation from their source. These and the similar Kununurra soil were in a firmly agglomerated condition and could not be dispersed by screening, stirring or wetting. Only by treatment in a pulveriser could they be successfully blended with stabiliser. Another Kununurra soil sample was similar physically and chemically to Broome sands except that it was finer.

A sample of termite mound from Fitzroy Crossing was examined. A large proportion of particles had a black organic coating and this was detrimental to stabilisation with lime and cement.

Localised production of bricks in the sparsely populated north-west would support a decentralisation policy, create employment and utilise indigenous soils. Government has a particular desire to involve the aboriginal population of the region in work activites to aid their assimilation into the community. Maintenance costs of non-brick houses in the north-west are high and it is probable that stabilised earth construction would be more durable and more easily repaired. Stabilised earth construction could be more suited to the extreme climatic, cyclonic and monsoonal conditions that prevail in the north-west.

In recent years in this State some small scale stabilised earth construction has proceeded. The W.A. Government has been involved in housing developments at Broome and Pandanus Park. Private interests have completed a cement stabilised winery at Margaret River in the south-west of W.A. In the Northern Territory, homes in Darwin have been made from stabilised soil.

Geochronology

Arising out of work done in 1979 to assist the Geological Survey in determining the age of rock formations, some further work was done on two samples for the Geology Department of the University of Western Australia. Ore dressing techniques were used to produce two samples of zircon concentrates from granite and gneiss respectively.

Bitumen Tanker Hazard

The hard grades of bitumen used for road making must be heated to fluidity to allow the charging and discharging of tankers and the application of the bitumen. There is a safe working code of practice designed to limit the degree of hazard associated with heating a flammable material.

When the bitumen is heated in the tanker it is oxidised to some extent at the liquid-air interface and the chemical and physical properties of the oxidised bitumen are different from those of the bitumen. Some analysis of the oxidised bitumen was requested to assist in assigning a cause to accidental fires in tankers. The analyses have not shown the oxidised bitumen to be more flammable than the original bitumen. The organisation had already begun changing the configuration of the heating tubes to an inherently less hazardous pattern so that strict adherence to the bitumen safety code should substantially eliminate the incidence of fires.

INTRA-DIVISION PROJECTS

Char Briquettes

A sample of char briquettes produced in Japan from Collie coal char was made available for examination. The briquettes were strong, only slightly dusty to touch and resisted weathering to a satisfactory degree. They ignited easily and burned almost completely away in a static bed situation. The briquettes would appear to be a suitable fuel for pot bellied stoves and similar domestic space heating units and perhaps for domestic barbecues and slow combustion stoves.

The current demand for fuel for such units is met, at least in part, by bringing in brown coal briquettes from Victoria This reflects the adverse effect of the "economy of scale" factor in setting up a local facility to briquette Collie coal. Only a small plant would be needed to carbonise and briquette enough Collie coal to satisfy the local market. However the combined capital and operating costs would necessitate an unreasonable selling price to yield a fair return on investment. Victorian lignite can be dried and briquetted relatively simply to yield a fuel which can bear the addition of transport costs and still be sold in Western Australia.

Gold Recovery

A patent method for recovering gold by electrolysis in the presence of a particular synthetic resin was investigated. The claims of the patent were not confirmed.

Energy from Waste

Arising out of interest shown in briquetting straw for use in a gas producer, attention has been directed at the conversion of waste biomass into energy via a gas producer. Through the good offices of the well known enthusiast, Mr. C. V. Pederick, a producer unit was made available for preliminary testing. Although a range of fuels is to be tested some familiarisation with the unit has been gained using dried pig manure provided by the Food Technology Branch of the Department of Agriculture.

By invitation the Division provided a working exhibit at the Open Day held by the Department of Agriculture in November. Producer gas made from dried pig manure was used to replace part of the oil fuel feeding a diesel generator. The engine performance was noticeably quieter when gas was fed to the engine and the rate of oil consumpion was significantly decreased. The exhibit was well received by the large number of people who visited the Open Day.

Premium Grade Zircon

The Divisional investigation of the processing of zircon to premium grade was completed. Methods of removing surface iron, reducing total iron content and improving the appearance of the zircon were examined. The methods paralleled those on which confidential work had been done for companies and one of those is successfully marketing premium grade zircon.

Chemical and physical treatment brings the zircon to within the specifications set by the market. The treated zircon can be more efficiently separated by magnetic and electrostatic means from remnant grains of other minerals, e.g. ilmenite and rutile, which detract from the value of the zircon. Although zircons from the various producing areas may differ to some extent, the Division believes that Western Australian zircons can be beneficiated to increase their share of the market. Certainly the market influences the vigour with which companies pursue this topic.

Flux Losses From Pellets

During a sponsored investigation requiring the fluxing, pelletising and roasting of magnetite it was found that the residual sodium content was less than would be expected from the amount of sodium carbonate added as flux. The deficiency ranged between 6 and 16 per cent and a programme of testwork was undertaken to define the cause of the apparent loss of flux.

The investigation showed that the fluxing-pelletising circuit used produced pellets in which the flux level was not constant at the desired level (as added) but the average flux level was close to the level of addition. The causes of the variation appeared to be the particle size of the flux and segregation of flux and magnetite in a vibratory feeder. The variations between pellets will be minimised in future by finer grinding of the flux and by using a non-vibrating method of moving the feed onto the pelletising disc.

The green pellets from the disc were oven dried prior to storage and eventual feeding to the rotary kiln for roasting. During the drying stage the pellets aggregated and flux migrated to the surface of the pellets so that they assumed a whitish appearance. The manual handling associated with the movement of pellets into and out of storage and into the kiln caused mechanical abrasion of the surface with a consequent disproportionate loss of flux. The necessity to operate on a batch rather than a continuous basis in this phase of our pilot scale testwork aggravated the loss of flux. It should be of less consequence in commercial practice where continuous processing would be normal.

Oxidised Copper Ores

The Report of Investigations (No. 22) titled "Potential for Exploitation of the Oxidised Copper Ores in Western Australia" was released in March. This publication examined the major known oxidised copper deposits in Western Australia in terms of past development, mineralogy and amenability to beneficiation. Established and novel copper extraction methods were reviewed and some assessed for potential application.

For ores containing a low level of acid consuming gangue (the Whim Creek deposit is of this type) sulphuric acid leaching followed by cementation or solvent extraction/electrowinning to recover the copper appears the best prospect for a return on investment. The presence of a high level of acid consuming gangue minerals (Thaduna deposit is typical) can be nullified by leaching in basic media.

Economic assessments of the agitation leach process, utilising ethylenediamine tetra-acetic acid (EDTA) as the copper complexing agent, showed that, while marginally economic at copper prices above $A1 700 (1979 prices), the process still suffered from two significant disadvantages:

(a) the use of a highly priced reagent
(b) the need to prove the process beyond the bench scale.

The high price of the reagent can be partially offset by recirculating the leaching medium It has been demonstrated that an agitation leach-filtration-copper recovery-releach process can be completed ten times without appreciable EDTA loss.

However, agitation leaching requires concentrated solutions (70-150 kg per m^3 depending on level of copper in the ore) with violent agitation, at temperatures of the order of 80°C for an acceptable copper recovery in under eight hours.

Solutions containing a high concentration of an expensive reagent represent a high inventory cost. Hence liquor losses (via entrainment in solids, spillage or pump seal leakage etc) become important operating cost items in a commercial plant.

If heap or dump leaching using EDTA as the copper solubilising agent can be shown to be as effective as agitation leaching then considerable savings, both in cost and energy, can be effected. Such a technique eliminates fine grinding, the need for agitation leach vessels, solid-liquid separation (i.e. filtration) and a tailings dam. The simpler system can be operated at ambient temperature by a smaller and less skilled workforce. The lower number of processing stages reduces the risk of spillages and leaks and by employing lower strength solutions (20 kg per m^3 EDTA) any liquor loss that may occur would be less costly.

In one 1 m high percolation column a copper extraction in excess of 75 per cent was achieved from an ore containing 1·37 per cent copper. Although no attempt was made to physically recover the EDTA from the leach liquors, analysis showed that little EDTA had been lost from the circuit and was thus available to leach further ore. Extension of the work is planned to investigate the potential of the method for the extraction of metals other than copper.

Economic Studies

The examination of the economic aspects of mineral processing is an integral part of the feasibility study of a proposal. The appointment of a Research Officer for this function was noted in last year's Annual Report and satisfactory progress is being made in developing the potential of the position.

The economics of the leaching of oxidised copper ores with EDTA were examined. The examination suggested that, for an ore containing 2·5 per cent copper, the process was marginally viable when the price of copper was $1 800 per tonne. The copper price exceeded $2 000 per tonne during 1980 but at year's end was about $1 600 per tonne. However when the costing of similar hydrometallurgical treatment of tungsten was examined it appeared that there was scope for the process. Some laboratory testwork on such leaching will be undertaken in 1981.

Some other divisional projects for which economic reviews have been made are diatomite processing, Pindan soil, zircon cleaning, alunite, Banded Iron Formation and gas producers operating on biomass waste.

L. J. BRENNAN,
Acting Chief, Engineering Chemistry Division.

FOOD AND INDUSTRIAL HYGIENE DIVISION

GENERAL

The Division has continued to receive a wide range of samples calling for complex and sophisticated analyses. The acquisition by the Laboratories of a high performance liquid chromatograph has assisted the Division to analyse environmental samples for polynuclear aromatic hydrocarbons (PAH's).

TABLE 3

FOOD AND INDUSTRIAL HYGIENE DIVISION

	Department of Agriculture	Department of Conservation and Environment	Government Chemical Laboratories	Fisheries and Wildlife Department	Hospitals	Lechanault Inlet Management Authority	Metropolitan Water Board	Mines Department	Public Health Department	Public Works Department	Waterways Commission	Other Departments	Public Pay	Total
FOOD—														
Apples	37	....	....	....	....	....	....	....	7	....	....	....	....	44
Alcoholic Liquors	....	....	....	....	....	....	....	....	51	....	....	....	....	51
Breast Milk	....	....	....	....	1	....	....	....	20	....	....	....	....	21
Canned Fish	....	....	....	....	....	....	....	....	18	....	....	....	....	18
Coconut	....	....	....	....	....	....	....	....	168	....	....	....	....	168
Crabmeat	....	....	....	....	....	....	....	....	16	....	....	....	....	16
Fish	....	....	....	53	....	....	....	....	661	....	....	....	....	714
Fruit Juice	2	....	....	....	....	....	....	....	35	....	....	....	....	37
Milk	165	....	....	....	....	....	....	....	....	....	....	....	....	165
Mussels	....	6	....	....	....	....	19	....	32	....	....	....	....	57
Oysters	....	....	....	....	....	....	....	....	46	....	....	....	....	46
Peanuts	62	....	4	....	....	....	....	....	1	....	....	3	....	70
Sausages	....	....	....	....	....	....	....	....	13	....	....	....	....	13
Squid	....	....	....	....	....	....	....	....	39	....	....	....	....	39
Tripe	....	....	....	....	....	....	....	....	38	....	....	....	....	38
Vegetables	2	....	....	....	....	....	....	....	18	....	....	....	....	20
Various	12	....	....	....	1	....	....	....	66	....	....	....	....	79
INDUSTRIAL HYGIENE—														
Air	32	....	....	....	6	....	....	12	85	....	....	14	....	149
Blood	....	....	....	....	1	....	....	....	198	....	....	....	3	202
Dust	....	....	....	....	....	....	....	....	103	....	....	....	....	103
Filters	....	....	....	....	....	....	....	....	38	....	....	....	....	38
Inspections	....	....	....	....	2	....	....	....	8	....	....	4	....	14
Transformer Oil	....	....	....	....	....	....	....	....	26	....	....	....	....	26
Urine	....	....	....	....	....	....	31	112	99	12	....	102	8	364
Various	....	....	....	....	1	....	....	....	33	....	....	....	....	34
MISCELLANEOUS—														
Air	330	....	....	....	....	....	....	....	....	....	....	....	....	330
Animal and Fish Tissue	72	....	....	84	....	....	....	....	14	....	....	....	....	170
Animal toxicology	17	....	....	4	....	....	....	....	....	....	....	....	....	21
Beads (Wooden)	....	....	....	....	....	....	....	....	14	....	....	....	....	14
Bovine fat	25	....	....	....	....	....	....	....	....	....	....	....	....	25
Dips	39	....	....	....	....	....	....	....	....	....	....	....	....	39
Dust	....	....	....	....	....	....	....	....	48	....	....	....	....	48
Maritime Sediment	....	54	....	....	....	....	....	....	....	....	....	....	....	54
Medicinals	....	....	....	....	....	....	....	....	49	....	....	....	....	49
Pesticides	18	....	5	....	1	....	1	....	25	....	....	6	5	61
Seawater	....	52	....	....	....	....	....	....	....	....	....	....	....	52
Sediment	....	76	....	....	....	....	....	....	....	....	....	....	....	76
Silts	....	....	....	....	....	....	....	....	....	17	....	....	....	17
Soil	226	....	....	....	....	....	....	....	122	....	....	....	....	348
Specimen from Patients	....	....	....	....	47	....	....	....	68	....	....	1	11	127
Tallow	12	....	....	....	....	....	....	....	....	....	....	....	....	12
Water	21	17	6	....	....	8	186	....	30	110	38	....	4	420
Wheat	4	....	12	....	....	....	....	....	1	....	....	....	....	17
Wool	486	....	....	....	....	....	....	....	....	....	....	....	....	486
Various	22	4	1	....	....	....	....	5	89	....	....	8	2	131
Total	1 584	209	28	141	60	8	237	129	2 279	139	38	138	33	5 023

Because of the increased demand for pesticide residue analysis and our lack of staff, laboratory space and equipment there have been long delays in reporting some of these samples.

There has been an increase in the number of samples received by this Division of nearly 21 per cent when compared with the previous year. Food samples have increased by 5 per cent, industrial hygiene samples by 29 per cent and miscellaneous samples by 31 per cent.

The Division has handled numerous enquiries for technical information and advice from Government Departments, Instrumentalities and the Public during the year.

The source and type of samples received are given in Table 3.

CONFERENCES AND WORKSHOPS

Mr. G. A. Taylor attended the Annual Conference of Scientific Officers and Engineers engaged in Occupational Health held in Melbourne in June.

Mr. F. E. Uren attended the first meeting of the reformed Food Analysis sub-committee of the National Health and Medical Research Council held in Canberra in August.

Several members of the staff attended sessions of the Workshops on High Performance Liquid Chromatography conducted by Waters and Associates.

Mr. G. F. Ebell addressed an inter Department Seminar on The Use of Pesticides and Herbicides in Forestry and Agriculture held in Bunbury in June.

Mr. Taylor gave a talk to a meeting of Factory Inspectors from the Department of Labour and Industry on Chemical Hazards in the Work Environment held at these Laboratories in August.

PUBLICATIONS

Two papers have been published by scientific journals of work by members of the staff.

"Determination of 2,4– and 2,6– diisocyanato-toluene (TDI) and 3,3'– dichloro-4,4'-diaminodiphenylmethane (MOCA) in Air" by G. F. Ebell, D. E. Fleming, J. H. Genovese and G. A. Taylor, in the "Annals of Occupational Hygiene 23, (2), 1980".

"Determination of Alkylmercury in Fish by Steam distillation and Cold-Vapour Atomic Absorption Spectrophotometry" by D. L. N. Collett, D. E. Fleming and G. A. Taylor in the "Analyst. 105, (9), 1980".

FOODS

Officers of the Division have again co-operated with Officers of the Fruit Section of the Horticultural Division, Department of Agriculture on problems associated with the storage of apples. Further work is to be carried out at Murdoch University next year on the fate of applied calcium; which will conclude the research programme. In all cases of bitter pit and superficial storage scald that were investigated this year, it was found that the standard instructions for treatment by dipping in a correct strength solution of calcium salts and diphenylamine had not been carried out correctly by the growers.

A new plant in the South West to produce apple juice from fresh apples resulted in a large quantity of apple pomace residue being available. The pomace was tried as a stock feed but because of its rapid fermentation it was not attractive to the animals. A series of experiments were undertaken to find a suitable preservative which could be added to the pomace. It was found that 500 mg/kg of sulphur dioxide when added to the pomace prevented fermentation and the growth of moulds for one month and also prevented browning of the pomace.

This year saw the first commercial production of peanuts in the Ord Irrigation Area. The Division was called upon to determine if aflatoxins were present in the commercial samples. No aflatoxins were found.

A complaint was received from a Middle East Country that live sheep exported from Western Australia arrived suffering from the effects of aflatoxin poisoning. Samples of the feedstuffs supplied to the ship and a sample of surplus feed from the ship were examined for aflatoxins with negative result.

A consignment of fish fillets were received which had small black spots just on and below the surface of the fillets. When examined by the scanning electron microscope these spots were found to be the result of a bacterial growth.

An outbreak of food poisoning resulted in a number of blown cans of fish being examined for the nature of the gas to assist in typing the bacteria present. In all cases the major gas present was carbon dioxide. It was noted that the ratio of nitrogen to oxygen in the gas was in most cases greatly in excess of that of air further suggesting that the bacteria were aerobic. In samples where hydrogen was found corrosion of the edge of the seam of the lacquered cans was noted.

Cans of wine stacked in a warehouse were examined because there was extensive leakage of wine. It was at first thought that the cans were leaking due to internal corrosion or pressure build up. Examination of the cans showed that they were well lacquered and the only corrosion had occurred at the points of external contact with other cans. The acidic wine had leaked from one can and this leaking wine corroded externally other cans until these leaked, which in turn leaked on to other cans thus compounding the problem.

Two samples of alcoholic beverage described as "Low Alcoholic Riesling Style" and "Low Alcoholic Moselle Style" were examined. Both of the beverages had an alcohol content slightly in excess of eight per cent volume/volume, the minimum standard for wine. The label infers that the lower than normal alcohol content had been achieved by the addition of grape juice. As the sugar content of the beverages was low the reduction in alcohol content could not have been achieved by the addition of grape juice as suggested on the labels.

Samples of orange juice from an Eastern States supplier were consistently low in orange juice content. The firm was squeezing fresh oranges and then pasteurizing the juice before shipment to this state. It was ascertained that the pasteurization was carried out using live steam which condensed in the orange juice causing the dilution. When a closed system was used for pasteurization no problems with diluted juice was experienced.

Again this year a large proportion of the samples of coconut from the Philippines were found to contain non permitted residues of sulphur dioxide which had been used as a bleaching agent. Samples taken from shipments of coconut from Malaysia were free of sulphur dioxide. Residues of methyl bromide the standard fumigant for coconut were not detected in any of the samples.

INDUSTRIAL HYGIENE

In March this year Mr. F. E. Uren accompanied by Mr. R. A. C. Williams of the Ventilation Section, State Mining Engineer visited six mine sites in the Pilbara. The purpose of the visit was to survey the use of chemicals by the mining companies and point out where hazards and dangerous practices existed. Mr. Taylor accompanied by Mr. E. F. Shenton made a similar visit to mine sites in the Midlands in October. These visits not only acquainted the Division with the problems of using and handling hazardous chemicals in the mining industry but onsite practical advice was given on several of these problems.

Early this year the Occupational Health Division, Department of Health and Medical Services changed its policy for monitoring persons exposed to lead from using urine samples to blood samples. This policy was applied only to personnel within the Metropolitan area and has greatly reduced the number of urine samples submitted by the Department of Labour and Industry.

This year over 360 samples of biological specimens were examined from workers to monitor their industrial exposure. These specimens included the following analyses: arsenic, cadmium, chromium, fluorine, lead, manganese, mercury, molybdenum, P.C.B's, pesticides, thallium, uranium and vanadium. These specimens included a large number of samples for P.C.B's. These came mainly from electrical workers on sites where transformers and/or capacitors contained P.C.B's as a dielectric medium. A number of transformer oils have also been examined for P.C.B's, where the P.C.B's have been substituted for non P.C.B. oils.

A commercial waste disposal venture to dispose of P.C.B's by controlled incineration has been investigated by officers of Clean Air, Department of Health and Medical Services and this Division. Samples of exhaust gases from the discharge stack under various operating conditions were taken and analysed. The maximum quantity of P.C.B. which could be safely burnt in this furnace was found to be 20 litres per hour. This investigation is continuing.

A survey was conducted for the Occupational Health Branch of several engineering workshops where oils are used on various machines, to determine the extent of the oil mist. In all the situations examined the oil mist content in the operators breathing zone was well below the Threshold Limit Value (T.L.V.).

A continuous monitoring of air for ethylene oxide was carried out in a hospital sterilising unit. Small polymer bags of surgical equipment are packed into larger polymer bags. Before the larger bags are sealed one or two ampoules of ethylene oxide used as a sterilant are placed in the bags. The ampoules are broken and the bags allowed to stand in lidded polymer boxes. After 12 hours the large bags are opened and the smaller bags allowed to stand for 24 hours. On opening the large bags the level of ethylene oxide in this area rose rapidly to about 350 μL/L and then declined within an hour to below the T.L.V. These levels would account for the symptoms of throat irritation experienced by the staff. Alternate procedures to reduce this concentration have been suggested.

Checks for purity of piped gases have been carried out within the following hospitals: Princess Margaret operating theatre, Wanneroo operating theatre and wards and renovated wards at Royal Perth. Hydrocarbons were detected in one of the gas lines tested but after further flushing, the line was found to be free of hydrocarbon contamination.

Visits were made to several factories where plastic foams and mouldings are produced. The breathing zone of the workers was tested for various organic isocyanates and/or MOCA. In one factory the level of M.D.I. exceeded the T.L.V. and recommendations for increased ventilation were made. The spray painting facilities at a technical college were inspected and tests for hexamethylene diisocyanate in the air conducted. The levels of the diisocyanate were satisfactory.

Several photographic film processing laboratories were visited to check on the safe use of chemicals and solvents. In all cases a good standard of industrial hygiene was being maintained.

SPECIMENS FROM PATIENTS

These samples submitted by medical practitioners and hospitals are taken to assist in the patients' diagnosis.

Arsenic determinations followed by lead, mercury and thallium were the most frequently requested metals.

A sample from a child patient in which a small amount of arsenic was found was further investigated. It appears that this child was being treated with homaeopathic medicines containing small quantities of arsenic. These medicinals were examined for arsenic but only traces of arsenic were found.

PESTICIDES

Formulation

There has been a continuation of the monitoring of the dioxin content of 2,4,5–T herbicide. Twenty three samples of formulations or raw materials were examined for 2,3,7,8 tetrachlorodibenzo-p-dioxin. All complied with Australian Standard 1175–1976.

This Division has been examining pesticide emulsions and soils in connection with soil treatment of buildings against subterranean termites for a number of years. Knowing the amount and strength of the pesticide emulsion applied, the field capacity and bulk density of the soil, the expected amount of pesticide in the soil can be calculated. A demonstration treatment of a sand pad was carried out by a pesticide operator and samples of emulsion and soil sampled to a depth of 75 mm were taken by a building surveyor. Taking into account the strength of the pesticide emulsion and the amount applied to the known area when compared with that found by analysis, a 95 per cent recovery of pesticide was achieved. This supports our frequent comment in cases where low amounts of pesticide are found in treated soils that the soil was not treated in accordance with Australian Standard 2057–1977. This standard only gives the concentration of the pesticide and rate of application per area, only by calculation from the various parameters referred to above is it possible by analysis of the treated soil to show compliance or not with the standard.

It has also come to our attention that in many cases of insufficient treatment of soils the amount quoted by the operator would not cover the cost of the chemicals if the area had been treated correctly.

Residues

Further work in conjunction with the Department of Agriculture has been carried out in the Geraldton area this year in connection with the alleged hormone damage to tomato plants. Our reporting of 2,4–D in air samples this year was at a level of 0·001 $\mu g/m^3$ compared with 0·01 $\mu g/m^3$ the previous year. A trial spraying of a property at Mullewa using the iso propyl ester of 2,4–D was carried out to determine spray drift. The iso propyl ester was used because it has similar physical properties to the most commonly used ethyl ester. Because there is no commercial availability of the iso propyl ester it was readily distinguished in the samples used to measure spray drift. Spray drift was found 10 km from the target area. Results indicated that vapour loss from the field was still occurring 24 hours after spraying.

The Division has been involved in the following projects with various sections of the Department of Agriculture: The control of soil potato weevils with chlorpyrifos, dieldrin, heptachlor and phoxim. The control of attack on peanuts by termites with aldrin, chlorpyrifos, chlorpyrifos-methyl, fensulphothion, heptachlor, propoxur and terbufos. The use of DDT for control of insect attack on the seed in minimum tillage for grain crops. The control of blowfly and lice on sheep with diazinon and vetrazin.

An outbreak of cattle tick in the South of the State resulted in an intensified dipping programme, with coumaphos, for cattle being transported from the North to abattoirs in the South West. Weekly batches of samples of fat taken from cattle slaughtered were monitored for coumaphos. Only four samples had a coumaphos level greater than the maximum residue level (MRL) of 1 mg/kg, three of these were only slightly in excess. In the fourth case insufficient withholding time between dipping and slaughter was the cause of the elevated level; such level would be below the MRL in a further 2–3 days.

ANIMAL TOXICOLOGY

A sample of pheasant liver was submitted because of the sudden death of pheasants. A high level of dieldrin was found in the liver. It was ascertained that the sheds that house the pheasants had been treated with aldrin to combat an infestation of termites. Eggs from the birds, litter and wood shavings from the shed's frame all contained high levels of aldrin and/or its metabolite dieldrin. This case is being further investigated.

The death of some calves illustrates that vessels used for mixing pesticides must not be used for mixing feedstuffs. A farmer used a bucket for mixing a dieldrin emulsion to treat a white ant infestation. The bucket was insufficiently rinsed and used for mixing feed for the calves. A number of the calves soon died and high levels of dieldrin were found in the abomasal and rumen contents of the dead calves. The only source of the pesticide would have been the residues left in the bucket from the termite treatment.

A large number of water samples from the Metropolitan Water Board, Public Works Department, Department of Conservation and Environment and the Waterways Commission have been monitored for residue during the year. These samples have been to survey possible pesticide residue level in existing water supplies and to monitor the effects of the limited treatments within catchments and the establishment of base environmental levels for future reference. The levels of pesticides found in waters for human consumption were all below the recommended maximum residue levels. In most cases the samples met the more stringent recommended environmental criteria.

The reporting of elevated levels of dieldrin in breast milk led to an investigation of the pesticide content of cigarettes. For a woman smoking 20 cigarettes a day, if all the dieldrin present was absorbed from these locally manufactured cigarettes about 25 per cent of the acceptable daily intake for dieldrin would come from this source alone. However smoking trials confirmed literature reports that only a small percentage of the dieldrin in cigarettes enters the inhaled smoke. Hence it is unlikely that smoking contributes significantly to levels of dieldrin in breast milk.

A survey of bulk milk tankers and tallow from South West abattoirs was carried out this year. No abnormal levels of organochlorine residues were found.

MISCELLANEOUS

Oil from the hydraulic system of a car was the subject of an investigation for the Consumer Affairs Bureau. This hydraulic system uses a mineral oil and after its failure it was thought that brake fluid had been used to top up the system instead of mineral oil. On examination it was found that the oil in the system was only mineral oil. By comparison a sample of hydraulic fluid from the same make of car which was known to have been contaminated with brake fluid was also examined. This known contaminated sample when examined chemically and physically in no way resembled the suspect sample.

A sample of a spray on cleaner for magnesium alloy wheels was examined and found to contain both phosphoric and hydrofluoric acids. The label of the package did not give any warning of the dangers associated with hydrofluoric acid as required by the Poisons Act Regulation.

A series of samples were taken from a water catchment. Portion of the catchment is part developed and the remainder is uninhabited. The purpose of the exercise was to establish if there were any marked differences between the two types of catchment with respect to P.A.H.'s, hydrocarbons, pesticide residues and trihalomethanes after chlorination. In samples from both types of catchment no P.A.H.'s or hydrocarbons were detected down to a levels of 0·02 and 2 $\mu g/L$ respectively. Dieldrin was detected in the samples taken from the part developed catchment at levels well below the recommended MRL. The trihalomethanes after chlorination were higher in the uninhabited catchment. This is due to greater content of forest debris increasing the organic content of the run off water.

F. E. UREN,
Chief, Food and Industrial Hygiene Division.

FORENSIC CHEMISTRY DIVISION

A steady increase in criminal activity within the community together with a greater appreciation by the Police of the contribution which science can make to the investigation of crime

TABLE 4

FORENSIC CHEMISTRY DIVISION

	Agriculture Department	Government Chemical Laboratories	Department of Corrections	Greyhound Racing Control Board	Police Department	Road Traffic Authority	Other Departments	Western Australian Trotting Association	Western Australian Turf Club	Public Pay	Total
Blood and Urine Alcohol—											
Sobriety	....	....	....	....	....	847	....	....	....	....	847
Traffic Deaths	....	....	....	....	170	270	....	....	....	....	440
Criminal Investigation	....	....	....	....	577	2	3	....	....	....	582
Doping Control in Sport—											
Greyhounds....	....	....	....	277	....	....	....	....	....	....	277
Horses	....	....	....	....	....	....	....	710	1 135	10	1 855
Drugs	1	7	1	....	1 869	6	8	....	....	....	1 892
Miscellaneous—											
Maritime Pollution	....	....	....	....	52	....	3	....	....	....	55
Specimens from prisoners or patients	....	....	85	....	....	....	3	....	....	....	88
Various	3	3	....	....	4	....	3	1	....	3	17
Projects	....	22	....	....	....	....	....	....	....	....	22
Toxicology—											
Animal	8	....	....	....	5	....	....	....	....	1	14
Human	....	....	....	....	1 026	....	....	....	....	....	1 026
Total	12	32	86	277	3 703	1 125	20	711	1 135	14	7 115

and to court evidence saw demands on the Forensic Chemistry Division rise in 1980 to an unprecedented level. Contributing also to the 48 per cent increase in workload was the acceptance, for the first full year, of the doping control work from the Western Australian Turf Club.

A laboratory technician was appointed in late 1979 to assist with the expected increase in doping control work. To accommodate the additional Police work received extensive investigations into analytical procedures were undertaken and some time saving modifications were introduced. To this end the acquisition of High Performance Liquid Chromatography equipment late in 1980 was of assistance.

One unwelcome but necessary time saving feature introduced in 1980 was the general tendency to be more discriminating in the scope and depth of some investigations carried out in some case work. For example in certain cases of sudden death where a cause of death is seemingly apparent the range of drugs and poisons screened for has been restricted. This may be seen as a deterioration in the standard of service available to the Police but in the current staffing situation no other alternative presents itself other than limiting the amount of work which is accepted.

Table 4 shows the type and source of samples received in 1980.

TOXICOLOGY

The most significant development in the year was the acquisition of a High Performance Liquid Chromatograph (HPLC) and the subsequent application of the instrument to general analytical problems. Analytical conditions for over forty drugs of toxicological and forensic significance have been established and the instrument has been shown to possess potential for drug screening and identification.

In many instances the HPLC has enabled analyses for specific drugs to be carried out more quickly and with a greater degree of accuracy than existing methods. This factor was highlighted in a recent case involving a death caused by a combined overdose of amitriptyline, oxazepam and phenobarbitone.

Analyses for these drugs which are of three distinctly different chemical classes would previously have required separate extraction, purification and quantitation steps for each drug. The HPLC enabled the analysis for the three drugs and nortriptyline (the major metabolite of amitriptyline) to be completed with a simple extraction and single quantitation step, no purification step being required.

Table 5 lists the details of the drugs and poisons involved in the 334 cases of sudden death which were the subject of Police investigation. The concentrations of drugs detected in some cases made their toxicological significances uncertain.

TABLE 5
DRUG AND POISON CASES

Drug or Poison	No. of Positive Identifications
Carbon monoxide	36
Amitriptyline	9
Propoxyphene	9
Amylobarbitone	7
Pentobarbitone	7
Paracetamol	6
Phenobarbitone	6
Trichloroethanol	6
Methadone	5
Salicylic acid	5
Imipramine	4
Morphine	4
Oxazepam	4
Various*	62

* Desipramine, benztropine, haloperidol, thioridazine, propranolol, diazepam, quinalbarbitone (3 each). Trimethoprim, demoxepam, toluene, codeine, carbamzepine, pheniramine, lignocaine, orphenadrine, petrol (2 each). Fenthion, trimipramine, valproate, ethylene, dibromide, theophylline, chlordiazepoxide, lorazepam, fluphenazine, chlormethiazole, dextromoramide, metasytox, xylene, oxprenolol, doxylamine, sulphamethiazole, phenyltoloxamine, carbromal, pentazocine, diazinon, acetone, pethidine, trichlorfon, nitrazepam (1 each).

ALCOHOL, DRUGS AND DRIVING

The Division continued to handle blood alcohol analysis arising from drink driving offences. Of the 448 blood samples analysed 87 per cent had alcohol levels in excess of 0·08 per cent while 58 per cent were greater than 0·15 per cent when calculated to the time of offence.

Approximately 20 of these blood samples were analysed for the presence of drugs and of these 12 were found to contain one or more drugs. Oxazepam (SEREPAX) was by far the most common, occurring on seven occasions either alone or with other drugs. Although the number of bloods in which drugs were found represents only 1·4 per cent of the total, the percentage of drivers affected by drugs must certainly be far greater than this because:

1. Only about 2 per cent of the bloods submitted could be screened for drugs
2. Drugs are looked for only where there is evidence that they have been used
3. Urine as well as blood needs to be submitted to obtain comprehensive detection of drug usage
4. A complete drug screen was not carried out. For example cannabis which could be expected to be prevalent was not screened for because the nature of the drug is such that it requires additional specialised equipment and staff
5. When a person submits a breath test which gives a low result there is no provision for taking a blood sample. The number of persons preferring to have a Breathalyzer test is about twelve times the number who have blood samples taken.

A list of the drugs detected in blood samples submitted in connection with driving offences is shown in Table 6.

TABLE 6
DRINK DRIVING OFFENCE BLOOD SAMPLES
DRUGS DETECTED

Drugs Detected	No. of Cases
Methadone	1
Pentobarbitone	2
Oxazepan + Alcohol	4
Diazepam + Alcohol	1
Methadone + Oxazepam	1
Phenytoin + Carbamazepine	1
Oxazepam + Quinalbarbitone + Amylobarbitone	1
Oxazepam + Chlorbutol + Salicylamide	1

TRAFFIC DEATHS

Table 7 shows the distribution of alcohol in the bloods of drivers, passengers, pedestrians and motor cyclists killed in traffic accidents. The figures show little variation from the trend of recent years in that 48 per cent of motor vehicle drivers involved in fatal accidents had greater than 0·08 per cent alcohol in their bloods whilst 32 per cent were in excess of 0·15 per cent.

TABLE 7
TRAFFIC DEATHS—BLOOD ALCOHOL LEVELS

Alcohol per cent	Motor Vehicle Drivers	Passengers	Pedestrians	Motor Cycle Riders
Not detected	63	20	14	13
Less than 0·05	1	1	....	1
0·050–0·079	2	4	1	....
0·080–0·099	6	1	1	2
0·100–0·149	13	2	2	4
0·150–0·199	11	5	4	4
0·200–0·249	15	6	1	3
0·250–0·299	9	....	2	....
More than 0·299	7	....	4	1
Total	127	39	29	28

DOPING CONTROL IN SPORT

Owing to the large increase in the number of equine samples received mainly from the Western Australian Turf Club, it became necessary to consider alternative procedures which would be more economical in terms of manpower and chemicals After considerable investigation a suitable method incorporating these criteria whilst maintaining sensitivity, and widening the spectrum of drugs detected, was successfully instituted in the middle of the year. It is anticipated that future modifications of this method will be the addition of modern automated instrumentation which will achieve greater sensitivity and less human involvement. Research has enabled our normal screening procedures to be extended to certain low dosage drugs where these are indicated.

Table 8 lists the drugs detected in 1980.

TABLE 8
DOPING CONTROL IN SPORT—DRUGS DETECTED

Drugs Detected	Horse racing	Trotting	Greyhounds	Total
Caffeine	5	1	....	6
Theobromine	2	....	....	2
Phenylbutazone	1	....	....	1
Etamiphylline	1	....	....	1
Hydrocortisone	....	1	....	1
Total	9	2	....	11

DRUGS

Two cases involving a total of 18 grams of amphetamine sulphate are of interest, firstly, because it is a number of years since a substantial quantity of amphetamine has been examined and secondly because of the constituents of the seizure. The preparation, as received, had been diluted with glucose and on analysis was found to contain a significant proportion of benzylphenethylamine and a trace quantity of methylphenylpyrimidone. The former compound is an indicator that the starting material for the synthesis of the amphetamine was illicity manufactured phenyl acetone and the methylphenyl-pyrimidone indicates that the Leukhart synthetic route was followed.

A similar attempt to identify route specific impurities in a seizure of methylamphetamine gave a negative result, indicating that either that the manufacturers of the drug used a sophisticated technique or (as is more likely) that the drug was diverted from a legitimate source.

In a fourth case involving possession of cocaine, benzoyl ecgonine and cinnamoyl cocaine impurities common to the illicitly manufactured form of the drug were identified. The source of the drug was thus shown to be by importation rather than by diversion from a legitimate source.

Table 9 lists the number and types of drug cases received. The total number of drug exhibits handled during the year (1879) was more than double the 1979 figure.

TABLE 9
DRUGS—POLICE DRUG SQUAD

Type of Drug	No. of positive identifications
Cannabis and/or products	171
Heroin	22
Cocaine	6
Morphine	5
Methadone	5
Bromo-dimethoxyamphetamine	4
Pethidine	3
Amphetamine	2
Methylamphetamine	2
Scheduled drugs (various)	11

CRIMINAL INVESTIGATION

Techniques designed to expedite or improve analysis were examined and introduced during the year. These techniques related to arson investigation, fibre identification, glass analysis and polymer analysis. In addition, a number of approaches were used to solve "one off" miscellaneous cases.

Arson Investigation

The use of capillary column gas chromatography has improved considerably the sensitivity and recognition of evaporated fire accelerants. In this work, any hydrocarbon residue is separated from the fire debris by steam distillation, extracted into n-pentane and chromatographed on a 30 metre SE 30 S.C.O.T. column, temperature programmed to 300°C. Cases which yield gas chromatography traces indicative of petrol are confirmed by gas chromatography with electron capture detection of ethylene dibromide, a specific petrol additive.

Fibre Identification

(i) An X-ray diffraction technique for fibre identification was developed and X-ray photographs for a considerable number of fibres have been collected. This collection is continuing as samples and time become available. The technique enables the non-destructive identification of a single fibre and is parttticularly useful when the sample is limited or when microscopic features are obscured by dye or wear. This preliminary identification greatly assists the selection of additional more discriminating treatments.

(ii) The use of mass spectrometry for fibres as reported by Hughes, Wheals and Whitehouse (Analyst 1978, 103 482) has been tested and found very useful in casework, especially for the discrimination of nylons and is now routinely used if doubt exists.

(iii) Scanning electron microscopy (S.E.M.) is a third technique which has improved fibre comparisons and is illustrated by a case involving an alleged rape. Black wool fibres alleged to be from the rapists clothing were found at the site of the attack. A black wool jumper worn by a suspect was also submitted for comparison. Energy dispersive X-ray analysis in the S.E.M. showed that fibres from the jumper contained chromium (from a chrome dyeing process) while fibres from the site contained no chromium, indicating a different dyeing process. The scanning electron microscope also enables very high quality photographs to be taken which make good and easily understood court evidence.

Glass Analysis

Glass analysis is an area which the Division has been seeking to expand since the number of cases submitted, compared to the number of incidents which actually occur and might yield glass evidence, is rather low. Improvements to glass analysis have largely been aimed at handling smaller samples.

The techniques are currently being developed in a joint project with the W.A.I.T. Physics Department and sponsored by a research grant from the Australian Institute of Criminology. This research is proceeding in three aspects:

(1) Glass museum and data acquisition
(2) Electron induced X-ray fluorescence in the S.E.M.
(3) X-ray photon induced X-ray fluorescence in the S.E.M.

Polymer Analysis

Polymer analysis forms a considerable part of the work of this section—e.g. paints, rubbers, plastics, adhesives etc. Analyses and comparison are largely carried out using Pyroysis Gas Chromatography. Improvements in this area have been with the use of non-polar stationary phases which have been found to give much greater discrimination.

The volume in particular and the variety of work submitted by the Police in connection with criminal investigation showed a marked increase during 1980 which reflects greater dependency by the Police on the use of scientific assistance as well as a general increase in the crime rate. Tables 10 and 11 summarise the range of exhibits received and the matters which gave rise to their submission.

TABLE 10
CRIMINAL CASES 1980

Type of Exhibit	No. of Cases
Flammable liquids (including fire debris)	64
Blood and urine	39
Paint and paint flakes	34
Clothing and fibres	9
Body tissues	6
Explosive and incendiary residues	6
Oil	4
Glass	4
Inks	4
Gunshot residues	3
Miscellaneous	40

TABLE 11
CATEGORY OF OFFENCE OR INCIDENT

Type of Exhibit	No of Cases
Arson and fires	64
Sex offences	30
Hit run traffic	19
Murder	17
Stealing and holdup	14
Wilful damage	14
Sudden deaths other than murder	7
Assaults and woundings	7
Conspiracy to defraud	3
Drugs	2
Unclassified	15

MARITIME POLLUTION BY OIL

Methods of "finger-printing" oil have been improved by the use of capillary gas chromatography so that greater discrimination between oils of the same type can now be obtained. As well as determining the n-alkane distribution it is now possible to compare isoprenoid type compound distributions and distributions of other minor constituents of oils. Such improvements were applied to the ten cases of marine oil spillage during the year. In six cases oil from the spill matched the oil from suspected vessel. Both light and heavy fuel oils were involved.

CONFERENCES—LECTURES

N. T. Campbell attended the Annual Conference of Forensic Toxicologists and the Annual Conference on Illicit Drugs both held in Hobart.

B. F. Lynch attended the Second Government Forensic Chemists Conference at Marysville, Victoria.

The following lectures were given by staff of the Division.

N. T. Campbell "Forensic Chemistry" to Chemistry Students Association W.A.I.T.

J. M. Challinor "Forensic Examination of Paint" to Oil and Colour Chemists Association.

J. M. Challinor "Analysis of Oils in Maritime Pollution" to a seminar on Oil in Marine Pollution monitoring conducted by UNESCO.

V. J. McLinden "Drugs, Medication and The Analyst" to a seminar on Drugs, Feeding and Training. Muresk Agricultural College.

V. J. McLinden "Drugs, Medication and The Analyst" to a seminar conducted by Greyhound Breeders, Owners and Trainers Association.

V. J. McLinden "Forensic Science in W.A." to the Australian Institute of Metals.

COURT APPEARANCES

During the year staff of the Division Attended 64 metropolitan court hearings, 3 in the country and 3 in Brisbane.

GAS CHROMATOGRAPH—MASS SPECTROMETER

The Division has compiled an "in house" library by mass spectral data of drugs and other compounds of forensic and environmental interest. The compilation had become necessary because of the deficiencies in, and difficulty of effectively searching existing commercially available mass spectral data banks.

The library totals approximately one thousand compounds and includes the mass spectral data of trifluoroacetyl derivatives of drugs and drug metabolites that have a hydroxy or primary or secondary amine functionality. The data on the trifluoroacetyl derivatives was generated in the Forensic Chemistry Division, initially, to improve the chromatographic properties of the drugs and equally importantly to improve the discriminating power of the GC–MS for the identification of primary and secondary amines.

Procedures for the analysis of four volatile poisons namely, carbon monoxide, ethylene dibromide, toluene and xylene based on GC–MS with Selected Ion Monitoring were developed during the year to enable the analysis of specific cases.

V. J. McLINDEN,
Chief, Forensic Chemistry Division.

INDUSTRIAL CHEMISTRY DIVISION

The function of the Industrial Chemistry Division is to provide technical information, advice and investigational facilities on industrial and chemical products to Government Departments and industry. Areas of particular interest are building materials, floor coverings, plastics, paints, chemical specialities, textiles and adhesives. The Division during the year continued to receive enquiries and to carry out work in the areas outlined above.

Dr. Smith and Mr. Kippo both delivered lectures to the Know Your Plastics series organised by the Plastics Institute of Australia.

Dr. Smith attended a meeting of the Government Paint Committee in Melbourne and also attended the Annual Convention of the Oil and Colour Chemists Association Australia held in South Australia.

MATERIALS TESTING

Paint

Work was completed on the paint tender and results reported to the Tender Board. This year all paints requiring it were tested for dry hiding power by the contrast ratio method.

Some years ago we briefly reported a short investigation of emulsion paint peeling from the ceilings of Carnarvon Hospital. The reason given at the time was the powdery surface of the plaster. Peeling has continued to occur and Public Works Department, Architectural Division, requested a further investigation. The hospital was visited, the peeling areas examined and further samples taken. The plaster surface from which paint had peeled was examined under the electron microscope and found to exhibit considerable efflorescence identified as calcium sulphate. The plaster was shown to be very porous and little or no penetration of the plaster by the paint had occurred. The application of a sealer as recommended in 1976 gave good penetration of the plaster and good adhesion.

A sample of plaster from a plaster works was also examined.

This was found to be much harder and denser than the original ceiling plaster, little penetration of sealer occurred and adhesion was poor. This investigation has been reported in some detail since adhesion failures of emulsion paint coatings to plaster ceilings have become relatively common in recent years. The particular cause in this case is considered to be the powdery surface produced by the calcium sulphate efflorescence, but another cause is shown in the final test on the fibrous plaster sheet from a modelling works. Dense, nonporous plaster can also cause problems even with a sealer. Such hard, nonporous plaster also occurs at joints between sheets and many complaints investigated showed that peeling had started at the joints.

Another cause of concern sometimes expressed is the compatibility of pink wood primer, white undercoat and enamel topcoat if each individual product is supplied by a different paint manufacturer. In reply to a request for guidance from Sir Charles Gairdner Hospital, our report showed that there should be no incompatibility if all paints concerned are of top quality and manufactured to Government Paint Committee specifications.

The painting of roofs of cement tiles is another area where poor adhesion problems can occur. In this case the cause is almost invariably inadequate cleaning of the tiles for removal of dirt, lichen, algae, etc., and this was shown to be the case in a complaint submitted by the Bureau of Consumer Affairs.

Good paint adhesion depends very largely on good surface preparation, as was shown by a request from Department of Health and Medical Services. Samples of previously painted ceiling and wall panels from Derby Hospital were prepared by normal surface preparation methods as recommended by paint manufacturers, particularly thorough sanding, washing down and drying. Good adhesion was obtained on recoating the samples.

Brand new painted aluminium road signs had been stored for periods up to several months at several Main Roads Department country depots. On unpacking many signs were found to have a central discoloured and blistered area where paint adhesion was very poor. After suitable surface preparation, a coating system of etch primer, epoxy undercoat and two polyurethane top coats had been applied. Soon after completion the signs were packed two to a crate face to face with the faces separated by a sheet of polystyrene foam. The cause of the problem was considered to be collection of water within the pack in contact with the paint and producing what was in fact a situation of complete water immersion over the affected areas. Etch primers are not suitable under such conditions and cause adhesion failures.

An investigation of a paint failure on the roof of the nocturnal house at the Zoo was investigated for Public Works Department, Architectural Division. Both horizontal and vertical surfaces had been affected. The paint had been applied to a galvanised steel surface and there was a considerable amount of white rust present caused by corrosion of the zinc. Examination of the paint film showed it to be extremely porous. It was considered that water had penetrated the film to reach the zinc surface forming white rust which lifted the paint film from the surface.

Two enamels, one white and the other deep yellow, and a latex exterior gloss were submitted by State Housing Commission. Both enamels were claimed to sag after application and the deep yellow had poor hiding power. The latex was claimed to produce a poor finish. The sagging of the enamels was confirmed, but the poor hiding power of the deep yellow enamel is probably inherent in the particular combination of a deep tint colour in a deep tint base. This is a known problem with some deep colours which, however, is not usually noted on manufacturers' colour cards. The latex paint was found to be so thixotropic that it did not level properly after application and brush marks were clearly visible.

Another paint problem on rendered walls at Collie Hospital was investigated. It consisted of two parts, one of blistering and in other areas of poor adhesion of the sealer. The blisters, which were very small, were found to be another example of efflorescence, on this occasion sodium sulphate. The poor adhesion problem could probably be overcome by acid etching the smooth, hard steel trowelled render surface.

Building Materials

A number of samples of carpet were submitted by Bureau of Consumer Affairs during the year as the result of consumer complaints. These included the following: confirmation that a carpet was 100 per cent wool and that a silicone-based stain repellent treatment had been applied; a 100 per cent nylon carpet with a damaged area also showing apparent bleaching—some evidence of chemical attack was found; an acrylic carpet claimed to be showing excessive wear particularly on stairs was shown to have poor abrasion resistance; in another sample carpet was disintegrating and the area was found to have an alkaline pH harmful to jute; an installed carpet was claimed to be inferior to the original shop sample and determination of several properties indicated that the installed sample was a little inferior to the shop sample. As a final example, a carpet was examined which was claimed to be showing pile pulling out in long runs. The nylon pile was found to be constructed by weaving continuous lengths of nylon yarn through the scrim to produce the loop pile. A run could easily be started at the edge by pulling an end horizontally. Much more effort was needed to pull a loop vertically from the body of the carpet The carpet was not considered to be faulty since this method of loop pile construction is being widely used.

Other work for the Bureau of Consumer Affairs covered different types of flooring. In one complaint of stretching and wrinkling of vinyl tiles, it was found that an underlayer of bituminous felt had been fully bonded to the vinyl tiles but only randomly spot bonded to the sub-floor, thus allowing stretching to occur. In two other cases ceramic tiles were involved. One involved abrasion resistance of tiles with an embossed design. Such tiles usually wear comparatively quickly at the high points of the embossing and this seemed to be the reason in this case. Another case involved a complaint of crazing of ceramic tiles. Samples were tested for resistance to crazing by the method of BS 1281:1974, Appendix D and two of five tiles tested failed the test.

Another set of flooring samples examined for the Department of Health and Medical Services were locally produced experimental ceramic tiles with grains of rutile embedded at various depths for improved abrasion and skid resistance. The most effective tiles had the rutile grains embedded to about half their depth in the surface glaze.

As part of a continuing project on the use of various types of flooring in hospitals and public buildings, 26 samples of floorings including vinyl tiles or sheet, various carpets or carpet tiles and a ceramic tile were examined. A range of tests were applied, where applicable, including stain resistance, dimensional stability, resistance to UV light, slip resistance, abrasion resistance, residual indentation, etc. Recommendations were made as to the most suitable materials.

A report was provided on the control of mildew in houses and describing methods for carrying out comparative trials with anti-mould treatments.

The sagging of a number of ceiling tiles in new extensions to Harvey High School was investigated. The tiles were made in Japan and it was known that some tiles used did not comply with the Japanese manufacturer's specification. The tiles were of plaster reinforced with slag wool. It was confirmed that the sagged tiles were under specification, being well below the minimum specified density, contained less slag wool and in addition 9 per cent of cellulose fibres not present in other samples. The manufacturer's installation instructions were very specific requiring reverse cycle air conditioning during installation and subsequently and with good roof space ventilation. The school is not air conditioned and roof space ventilation is inadequate. It is therefore quite possible that even tiles meeting the specification could sag in time.

Plastics and Rubber

A number of plastic tumblers and one jug were submitted for identification. They were to be used in hotels and for other catering purposes. The tumblers were all found to be 100 per cent acrylic (polymethyl methacrylate) and the jug polycarbonate. They should be suitable for the proposed use.

A number of samples of tyre buffings for determination of proportions of natural and synthetic rubber and various samples of tap washers, joint rings and gaskets for identification of the materials used were examined.

Urea-formaldehyde plastic foams have been used very widely for many years for building insulation. It has one potential problem and that is a smell of formaldehyde which generally only lingers and is a problem for a few days after application. With proper ventilation there is usually no particular discomfort to the occupiers of the house. Sometimes, however, free formaldehyde lingers for a longer time and causes irritation to the nose, eyes and throat, particularly if the house is closed up all day. As there have been such complaints, a number of samples of foam have been analysed for free formaldehyde and found to be present in varying amounts, although generally at not very high levels. A study of free formaldehyde levels in UF foam to determine the initial levels of formaldehyde in freshly produced foam and its rate of disappearance with time has been started.

A considerable amount of work was carried out on the testing of PVC pipe adhesives. The standard method required the use of full joints in 50 mm rigid PVC vent pipe, but this gave joints that were generally too strong for the capacity of the Division's tensile tester. Most tests were carried out by a method developed by the Melbourne and Metropolitan Board of Works called the "dowel in the hole" method. This involved the use of 10 mm rigid PVC conduit bonded into a clearance hole in a piece of flat rigid PVC sheet. One of the W.A. extruders of rigid PVC pipe gave considerable help in developing the method, which finally gave reproducible results.

A constant cause of concern to the Department of Health and Medical Services is the stuffing used in dolls, teddy bears, etc. Two samples submitted were found to be flammable, one being flexible polyurethane foam scrap and the other polystyrene foam beads. Neither is considered to be safe as toy filling because of the fire hazard.

Two samples of impure toluylene diisocyanate (TDI) were examined to determine whether they could be purified for re-use. The material is one of the major raw materials for flexible polyurethane foam production. One sample was off-specification material probably contaminated by moisture and this was found to be easily purified by one distillation. The other sample contained a solvent used for cleaning out the TDI lines, etc., of the foam production equipment. This solvent decomposed during distillation and pure TDI could not be produced from the mixture. As the quantities available of both materials were small, it was considered hardly worthwhile bothering to recover any TDI, particularly as it is a relatively cheap chemical. It was recommended that the wastes be disposed of safely by readily available means.

A sample of a polysulphide rubber joint sealant taken from the Strelley water tank near Port Hedland was examined. After several years of service a tacky surface layer about 0·5 mm thick had developed indicating deterioration of the material. It was reported that the rubber had been subjected to rain soon after placement. Tests showed that the rubber was undercured. It is known that the rate of cure is affected by temperature and humidity and that the presence of water adversely affects the curing cycle.

Miscellaneous

Several complaints were investigated for the Bureau of Consumer Affairs. One involved the creasing of an embossed velvet fabric covering a lounge suite seat. The fabric was satisfactory but the cover was rather loose, allowing folding to occur. Another complaint concerned the performance of an outboard motor. A sample of the fuel used was found to contain the correct proportion of oil and it should not have caused any trouble.

Two samples of engine oil used in a launch were examined for the Department of Fisheries and Wildlife. One sample was of reclaimed oil and the other of unused brand name oil. When changing to the reclaimed oil a fall in oil pressure was noted. The viscosities of both samples were determined and found to comply with the appropriate specification. However, the brand name oil viscosity was at the high end of the range and the reclaimed oil at the low end. This difference probably explains the fall in pressure noted.

Samples of fruit of the tung tree were examined for the Office of Regional Administration and the North West for preparation of tung oil. The trees grow well in the North West and could be established in plantations as aboriginal group projects. No oil could be obtained by expression from untreated kernels but a satisfactory yield was obtained after the kernels had been steamed under pressure at 105°C.

An investigation of a swimming pool (fibreglass reinforced plastic) was carried out for the Small Claims Tribunal. Earlier work by Water Division had shown that the pool water had a pH of 2·5 after acid treatment to remove black spot and had apparently stayed in that condition for at least 4 months. A pH of about 4·5 is sufficient for black spot removal and thus too much acid had been added. No attempt appeared to have been made to neutralise the acidity until after corrosion of metal fittings had occurred.

A sample of yellowish waxy deposit taken from the shower recess of a State Housing Commission house at Karratha was identified as a mixture of calcium and magnesium stearates. This would have been formed from toilet soap and the hardness in the Karratha water. The problem is quite a normal one, but the tiles should be cleaned, e.g. with a proprietary bathroom tile cleaner, sufficiently frequently to prevent an excessive build-up occurring.

ASSISTANCE TO INDUSTRY

Fire tests were carried out for a company on some samples of work clothing fabric. Two standard methods were used: AS 1176:1976, Part 1 "Combustion Characterisation of Textile Materials" and BS 2963:1958 Method A—Vertical Strip Test. One sample appeared to be made of fire retardant cotton. Both the other samples were flammable, one being cotton and the other a synthetic fibre/cotton blend.

Several samples of fibreglass reinforced plastic were tested for loss on ignition and resin/glass ratio for a group building a large prototype surveillance craft. In addition many problems were discussed in some detail and considerable information provided on resin injection methods for use in place of spray-up or hand lay-up methods and replacing the polyester resins with phenol-formaldehyde resins because of their substantially better fire resistance.

Jute bags were supplied by a shipping company for comparative tests on tensile strength. Breaking loads and elongation at break were determined. One sample came from Bangladesh and the other from Thailand. The Bangladesh material was found to be significantly stronger than the Thai material in the warp direction but weaker in the weft direction. It was also slightly more extensible.

Two samples of bentonite were tested for dry and green compressive strength and dry and green shear strength for a local mineral processing company. Blends with sand were prepared and the tests carried out in accordance with the methods of the American Foundrymen's Association. Dry strength properties were similar for both, but one material was significantly higher in green strength.

Ninety-eight litres of tannin solution were spray dried to provide about 3 kg of tannin powder. The solutions were prepared as part of a project being carried out at the W.A. Institute of Technology for a timber company. In addition a further quantity of 36 litres of another plant extract was also spray dried. This was part of an investigation into Jarrah die back also being carried out at the Institute. The spray drying was performed in the pilot spray drying equipment available in the Division and which is the only one of its kind in the State.

Because of failure of adhesion of polysulphide sealant in joints in concrete water tanks the problem was investigated for a local construction company. The sealant itself appeared to be satisfactory, as was the primer solution used. There was also no evidence of form oil which, if present, could interfere with adhesion. The primer material from the tank was found to be oxidised (weathered) indicating that some time had elapsed between application of the primer and application of the sealant. There was also some indication that insufficient primer had been used. A combination of these two findings could have been the cause of the adhesion failure.

A film processing laboratory submitted samples of developed 16 mm colour movie film which showed random black spots disfiguring the emulsion. Examination showed that the black spots were within the emulsion layer but were overlaid by pieces of clear plastic film. A source of this foreign film was found on the staples used to connect lengths of film together. The strips of staples were bonded together by application of a clear lacquer coating in excessive amount. Small pieces of the lacquer film were found in the equipment and when photographic film was deliberately contaminated with it and processed, black spots showed up.

Two samples of polyester resin, both isophthalic resins from different manufacturers, were submitted by an engineering construction company. They are contractors to the Metropolitan Water Board for the design and construction of the Bibra Lake sewer tunnel which is to be lined with a fibreglass reinforced plastic liner of total length about 1 900 m and diameter 2 250 mm. It is in fact the single biggest FRP project in terms of quantity of resin used and in cost undertaken to date in Australia. The two samples were submitted to chemical resistance tests to caustic soda and hydrochloric acid developed by the Sydney Water Board. One resin was found to be superior and was recommended for use in the project.

In addition to the above tests lengthy and frequent discussions were held with the engineer in charge and the chief design engineer, Metropolitan Water Board, on the technology of fibreglass reinforced plastics and on quality control to enable them to interpret and assess the tenders. In addition considerable background information was provided.

Work was done on the evaluation of micaceous iron oxide from a W.A. deposit as a paint pigment in comparison with material presently imported from Austria. Typical long oil alkyd primer compositions were prepared and applied to steel panels which were then exposed in the salt spray cabinet. The results showed that the W.A. material was slightly inferior to the imported material, but this may have been caused by differences in grinding. The product was certainly good enough for further evaluation. Subsequently, primers prepared by a local paint company were tested in a similar way. In this case the imported material was found to be slightly inferior, reversing the previous finding.

The Department of Defence-Navy has two exposure sites at HMAS Stirling on Garden Island. One is a marine atmospheric exposure rack and the other is a salt water immersion raft. It is the Department's intention to make the sites available to industry, both paint manufacturers and users, for the evaluation of surface coatings. It has been agreed that this Division will act as agent for the Department in arrangements made with industry, in assessing results and issuing reports. It is expected that both sites will be approved by the National Association of Testing Authorities early in 1981.

INVESTIGATIONAL

Much by-product gypsum is available from phosphoric acid manufacture in the fertilizer industry. A literature survey was prepared on the utilisation of this phosphogypsum. In countries such as Australia with adequate supplies of natural gypsum it is usually uneconomic to utilise the phosphogypsum in any way.

A survey has been made of the availability of waste solvents from the paint and printing ink manufacturers. If sufficient quantities are available it could be worthwhile for a waste solvent recovery industry to be established. A report is in preparation.

CONSULTATIVE

As usual a very wide range of enquiries was received from all sections of the community, Government Departments and Instrumentalities, industry, commerce and the general public.

E. B. J. SMITH,
Chief Industrial Chemistry Division.

KALGOORLIE METALLURGICAL LABORATORY

GENERAL

The buoyant gold mining industry was responsible for a busy year experienced by the staff of this section. A high number of sponsored metallurgical investigations was again undertaken this year as many small operating syndicates examined the feasibility of individual gold recovery prospects and some proceeded to establish treatment plants.

During the year two commercial fire assaying facilities were established in Kalgoorlie and assaying demands on this laboratory decreased, leading to a slight reduction in sample receivals over 1979.

During 1980 the laboratory issued 501 certificates of which 87 were associated with metallurgical investigations and 15 on the request of government departments.

The allocation of funds for the re-building of the Kalgoorlie Metallurgical Laboratory was received this year. Throughout the year considerable time was spent providing layout and fitting details in association with the project architects.

METALLURGICAL INVESTIGATIONS

Contract confidential reports were mainly associated with the recovery of gold from ores and tailings. An increasing number of existing treatment plants requested investigations to determine and improve metallurgical recoveries. Testwork associated with the carbon in pulp technology was significant in demand.

Custom Milling Plant

The laboratory continued to provide services to North Kalgurli Mines Limited for the purpose of establishing the gold recoveries for individual clients using the Custom Plant.

This independent service is a crucial part of the client's payment and therefore is very beneficial to the gold prospecting industry as a whole.

This testwork requires a high standard of accuracy which has been achieved to the credit of the existing staff.

During 1980 some 180 ore parcels were tested on a simulated treatment circuit and the potential gold recovery established.

Tailing Retreatment

The demand for investigations into the feasibility of tailing retreatment was very high and 32 reports were issued.

There was a sharp increase in the demand for agitation cyanidation tests, most of which were requested with a carbon in pulp treatment plant in mind.

The demand for percolation tests to simulate trickle leaching of tailings in plastic, steel or concrete vats continued and 13 reports were issued.

Trends in testwork indicated that large high grade deposits were scarce and recoveries in general were poorer due mainly to locking of gold in the coarse fraction of the deposit. It has become more clearly evident that large capacity treatment plants with possible regrinding facilities would be required to make the treatment of many deposits viable.

Ore Beneficiations

New gold ore bodies of varying grade and size were submitted to establish the best treatment approach. In many cases follow-up testwork was recommended. Some 13 reports were issued in this section. Most of the ores were free-milling but had variable recoveries by gravity and amalgamation.

The present high costs associated with equipment, labour and security make it difficult to justify a gravity/amalgamation circuit unless the gold is very coarse or high gravity recoveries are indicated.

There has been a renewed trend to the use of flotation as a primary concentration stage on gold ores and tailings. Results from tailing investigations have been less successful. If successful, large capital cost benefits, through reduced plant equipment requirements, can be achieved. This approach is successfully used by Kalgoorlie Mining Associates at the Oroya Plant when treating the Mt. Charlotte gold ore.

A number of coarse ore leaching investigations were conducted. This approach by-passes the costly grinding process, usually requiring only a crushing stage. The capital cost benefits are very large and this operation is particularly suitable to remote and low water availability areas. To be amendable to this process the gold has to be very fine in size and the rock porous to allow complete penetration of the cyanide solution.

Other Investigations

Size and gold distribution, activated charcoal stripping potential and mine water suitability tests were carried out on request.

A limestone deposit was examined to determine degree of upgrading by trommel washing and sizing.

ANALYTICAL SERVICES

In spite of a drop in public demand, assaying requirements associated from investigations maintained a high work-load for most of 1980.

The laboratory became more selective in acceptance of large quantities of samples for assay purposes only and gave priority to umpire and interlaboratory check requests.

As in past years, assaying of gold bullions and battery treatment sands were given high priority. This year 98 gold bullions were analysed.

Estimation of gold content in gold specimens was again in demand although not to the degree experienced in the previous year. During 1980, 36 specimens were estimated.

Assay of cyanide solutions for gold by atomic absorption provides a method that is much faster and cheaper than the conventional fire assay approach. The laboratory has refined the atomic absorption method to a satisfactory accuracy and currently all cyanide solutions are assayed by this technique. Comparative data between this method and fire assaying is being compiled.

The analysis of nickel in ores and concentrates was a common request. This element was usually assayed to umpire standards.

Chalcopyrite and Sphalerite Concentration by Flotation

The Geological Survey of W.A. is carrying out an investigation of the mercury content of West Australian base metal sulphides. This laboratory undertook to produce clean concentrates of sphalerite and chalcopyrite from 10 drill core samples using flotation techniques.

Carbon in Pulp Technology

The carbon in pulp method for recovery of gold from cyanide solutions has come into significant prominence this year. Its main advantage is that it by-passes the conventional solid/liquid separation stage necessary for zinc precipitation. Solid/liquid separation is normally carried out by filters and thickeners, both high capital cost items. With oxidised ore bodies the efficiency of liquid separation by these units declines, making this a very costly process step.

The laboratory has been carrying out an intensive study of current literature, conducting process plant visits and holding discussions with academic, commercial and industry representatives. The aim has been to achieve a basic understanding of the process and problems experienced in the use of this technology in the State.

This programme will continue in 1981 with development of testing equipment and methods, to study the chemical behaviour associated with local problems and possible remedies.

Consultative and Advisory

Advisory services to Government Departments, Public and Mining Company representatives were in frequent demand. During the second half of 1980 some 120 enquiries were handled.

The laboratory also provided a consultative service to many small gold treatment plant operations with advice on process problems through metallurgical investigations, plant appraisal reports and general technical explanations.

A. MYKYTUIK,
Officer in Charge.

MINERAL DIVISION

GENERAL

The major areas in which the Division worked this year are indicated by the titles of the following sections.

In general the trend was for the proportion of work related to atmospheric contaminants to increase. The work related to rock analyses again fully occupied the equipment available while submissions reflected the fluctuations which occur from year to year depending on the stage reached in particular projects by the Geological Survey field staff.

Participation in the movement of the Department toward computerisation was considerable, and constant consideration was given to replacement of equipment approaching its expected effective lifespan.

Chemical and mineralogical support was provided for 18 Government Departments and Instrumentalities as well as the public.

Details of submissions are in Table 12.

ATMOSPHERIC CONTAMINANTS

The trend which was evident in earlier years, of an increased emphasis on work relating to atmospheric contaminants has been continued. This work was undertaken by mineralogists where identification and assessment is best achieved by optical microscopy and X-ray diffraction methods and also by chemists using XRF spectrometry and wet chemistry.

The greater part of this work was associated with monitoring the environment under the provisions of the Clean Air Act, with requirements of the Mines Regulation Act, the Factories and Shops Act, and with occupational health requirements.

A change occurred in the source of occupational health samples in that Department of Labour inspectors commenced some sampling which was previously done by the Department

TABLE 12

MINERAL DIVISION

	Agriculture Department	Geological Survey	Government Chemical Laboratories	Main Roads Department	Metropolitan Water Board	Mines Department	Police Department	Public Health Department	Public Works Department	Labour and Industry Department	Other Departments	Public: Pay	Public: Concession	Public: Free	Total
Building Materials	....	....	2	11	....	....	....	....	24	....	1	9	....	....	47
Cement and Concrete	....	....	...	3	....	....	....	....	60	....	....	4	....	....	67
Dusts	....	....	6	....	....	423	....	1 765	....	35	....	53	....	....	2 282
Forensic Examinations	....	....	....	....	....	....	21	....	....	....	....	....	....	....	21
Geochemistry	....	164	....	....	....	....	....	....	....	....	....	....	....	....	164
Metals and Alloys	....	....	....	....	....	....	....	6	5	....	1	12	....	....	24
Mineral Identification	....	8	69	....	4	6	....	15	....	5	....	67	48	7	229
Miscellaneous	....	181	26	....	18	6	....	49	2	....	22	18	....	....	322
Ores and Minerals—															
Clay	....	....	....	11	....	....	....	....	13	....	4	2	....	....	30
Gold Assays	....	2	2	....	....	5	....	....	....	....	....	165	82	....	256
Gold Specimens	....	....	2	....	....	....	....	....	....	....	....	213	....	16	231
Iron	....	5	47	....	....	....	....	....	....	....	....	34	....	....	86
Lead	....	....	....	....	....	10	....	....	....	2	....	1	3	....	16
Silicate Rocks	....	196	10	....	....	....	....	....	....	....	....	....	....	....	206
Soils	42	....	1	....	....	....	....	1	....	....	4	6	....	....	54
Various	....	10	....	....	....	25	....	....	....	....	9	30	1	....	75
Total	42	566	165	25	22	475	21	1 836	104	42	41	614	134	23	4 110

of Health and Medical Services. To assist this transition, Mr. R. M. Clarke spoke at a Seminar arranged to instruct the Department of Labour inspectors in relation to the significance of the condition of the samples submitted for assessment.

Considerable consultation also took place with Mines Ventilation inspectors regarding the factors involved in assessing the various components of mines dusts.

The methods used in assessing the concentration of a contaminant vary with the nature of the sample and the significant form relative to an authoritative threshold limit value (TLV).

Assessment by total elemental concentration by chemical means was used where the essential form of the contaminant was known and the relationship to the accepted TLV could be calculated.

Contaminants measured in this way included lead from the sampling of city streets, iron ore in townsite dusts from the Pilbara region, alumina from production plants, nickel and cobalt from the smelter, chromium from various industrial plants, sodium and vanadium from a newly operative plant and from the associated townsite. Phosphorus and sulphur from monitoring in the Kwinana Industrial Area were assessed by direct X-ray fluorescence examination of filters.

Monitoring of contaminants which were not able to be assessed by elemental analysis were handled by methods specific to their characteristics. Thus the contribution of rock dust from a mine at Kalgoorlie to indigenous dust which has the same mineral composition was assessed on the basis of the freshness and angularity of newly contributed particles. A regular check was made of current dust output at the source.

From another area material which could be described as, of cement works origin, consisted of alite (from cement clinker) calcium hydroxide, calcium oxide and some calcite. These components were mixed with indigenous calcite, carbon, fibres, quartz and other minerals. In another area a different range of components accompanied the "cement works" materials.

Optical microscopy was used to assess the contribution of such contaminants as talc, flyash, and mica as well as for identification of numerous unknown dusts.

The determination of the free silica content of mine and quarry dusts was by X-ray diffractometry in the accepted manner. In order to obtain the optimum concentration on the filter presented to the X-ray beam, and also to remove absorption interference in the case of iron areas, the sample taken is redispersed on to 13 mm filters after low temperature ignition. Apparent losses of even quite inert mineral samples indicates that sampling is collecting volatile components such as moisture and oil mist along with the mineral dust.

At the request of the W.A. Chamber of Mines a group of Environment and Safety Officers from mines in the Eastern Goldfields area attended the Laboratories to see a demonstration of the measurement technique and to discuss interpretation of results.

In relation to the same problem of quartz in respirable dust, the atmospheres associated with a number of sand blasting operations were monitored and a review undertaken of possible alternative abrasive substitutes.

Sand Blasting

The materials examined consisted of a variety of heavy mineral sands and mixtures used in other States and countries as well as W.A. An assessment was made on such factors as cost, initial size distribution, durability in terms of size distribution following a controlled impaction test, specific gravity and the presence of hazardous or corrosion inducing materials.

Several of the materials were equal to or superior to quartz in one or more of the factors, the most promising being copper slag from Mt. Lyell or Port Kembla, and nickel slag from Kalgoorlie.

Garnet sand, although considerably more costly than quartz sand has been used in the industry in some cases.

Asbestos Fibre

Concern regarding the hazard of asbestos fibre inhalation continued with an increased demand for assessment of atmospheric concentration and identification of a range of insulating materials. Several large institutions have taken the action of stripping the insulation from buildings and vehicles. The procedures involved were monitored and atmospheric concentrations, at various stages of the process, were determined.

To assist this process officers of one institution were assisted, late last year, to acquire the instrumentation and technique to do their own monitoring. This year cross checks of samples have taken place. Assistance to another institution resulted in a mineralogist from the Division spending several days at the US Navy base at Exmouth advising on asbestos fibre assessment.

The advisability of stripping insulation which is sound, has been questioned in the literature. There is some evidence that the practice, in fact, adds to the atmospheric concentration of fibres for some time after stripping and overall may represent a greater hazard than originally existed. There are many situations, such as when the bond between asbestos and substrate is good, in which it may be more satisfactory to leave the insulation undisturbed and seal the surface to prevent release of fibres.

The procedure for estimation of asbestos fibre concentration in air is one which has received the support of the National Health and Medical Research Council and defines the particles which, for medical reasons, should be included in the concentration assessment. This procedure was however initially designed to handle the situation where, as in a well kept asbestos handling factory, the dust in the air consists of extremely few fibres with virtually no other materials. In this situation sample slides having an unduly heavy load and obscuring mineral components are rejected for assessment. When mining or demolition operations are in progress the situation is substantially different. Submissions were made to the Asbestos Occupational Hygiene Committee (AOHC) which is currently reviewing the method recommended by the National Health and Medical Research Council. It is hoped that the method or methods developed as a result of AOHC deliberations will include an assessment of standard deviations to be expected from competent operators at various levels. Another long needed project being handled by the AOHC is to compare results of fibre concentration assessments of standard samples by laboratories throughout Australia. Similar projects in other countries have shown a tremendous lack of reproducibility between and within laboratories, due to lack of standardisation of methods. In this Division selection of operators enabled a stable level of counting efficiency to be maintained.

An opportunity occurred this year for comparison with the results being obtained by a central assessment laboratory in NSW, of a local asbestos handling factory. Parallel sampling was undertaken by Government and company officers and slides from both samplings were assessed in each laboratory.

Allowing for the very low concentration of fibres in the air sampled, and different methods of assessing effective filter area at each laboratory, the results were in very close agreement. Only two results in thirty six were sufficiently divergent from the rest to be classed as outliers. However the exercise involved elements of variation due to sampling as well as counting and provided little information regarding variation which might take place at concentrations around the critical level.

Although evidence to date does not indicate that asbestos fibres ingested in food and drink represents a significant hazard some further examinations have been made to determine the concentration of fibres which occur in some bottled beverages from the filtration media in manufacture. An individual sample was also examined from the reticulated water supply in a country area where Commonwealth officers are engaged.

The significance of these assessments is also dependent on the method used in the examinations, and choice of method depends on a medical definition of which fibres are important. As indicated by the literature there is no universal acceptance of any particular method or fibre characteristics.

An earlier investigation of the yield of fibres from a specified area of asbestos roofing sheet was continued, after exposure of the sheet to urban atmosphere for eighteen months. In both investigations the sheet was subjected to spraying of water equivalent to a 6 mm rainfall on separate occasions.

The earlier experiment, conducted on a new sheet, had indicated a concentration of 7 600 fibres/mL in the trapped water initially, dropping in an hyperbolic type curve to 130 fibres/mL after 8 washings. After the weathering the initial yield was 20 100 fibres/mL dropping in a similar curve to 390 fibres/mL after 5 washings. The release of an increased number of fibres after weathering suggests roofing as a possible source of airborne asbestos.

ROCK ANALYSES

Rock analyses in connection with granitoids in the Pilbara were associated with variations within the Mt. Edgar and Corunna Downs batholiths and with associated dykes and pegmatites. Assessments of economic potential (e.g. tin) were made by way of trace element analyses.

This study was reasonably typical of rock analyses generally. X-ray spectrometry was used as widely as possible to determine the major elements by the Norrish-Hutton method (Geochimica et Cosmochimica Acta. 1969, Vol. 33). Samples were prepared by fusion with a flux of lithium carbonate tetraborate plus lanthanum oxide. The fused samples were hot quenched and pressed to give a glass disc.

Counts were obtained for the various analytes on both samples and background discs and concentrations derived from comparison with spiked internal standards and selected standard USGS rocks where available.

Trace element determinations by XRF were made on samples prepared by mixing the crushed (–200 BSS) material with a binder in a Tema mill and pressing 5 gram briquettes with boric acid backing, in an hydraulic press.

Line and background readings were obtained for each element and the ratio of peak/background counts were compared with known standards to obtain the concentrations.

Elements determined by other than X-ray techniques were boron, beryllium, molybdenum, fluorine, uranium, sodium, magnesium, lithium, copper, lead, nickel and zinc, ferrous oxide, moisture and total water. The precision of each analysis was established by repetitive determinations of control samples.

This work was published by authors R. Davy and J. D. Lewis at the Second International Archean Symposium, Perth, 1980.

Analyses for detailed comparison of similar rocks were provided for correlation of the Ravensthorpe quartz-dolerite with the quartz-dolerite granulite of the Albany-Fraser province, for determining the variability of granite types on the Newdegate 1:250 000 sheet, for differentiating syntechtonic and post-techtonic members of the Yilgarn granites, for determining the dolerite magma type in the Bangemall Basin, and for detailed comparison of granitoids in the Minnie Creek batholith with a meta-sedimentary anatectic suite and with archean gneissic basement rocks.

A requirement for determination of aluminium in various positions in the Mt. McRae Shales presented an analytical problem because the alumina content varied from less than 0·1 to 22 per cent, and the carbon content also varied between wide limits.

Preparation of the maps and explanatory notes for the titles yet to be published in the 1:250 000 geological series required analyses of numerous rocks of non-silicate as well as silicate type, for such purposes as establishing potential for mineralisation, identification of gossans, identification of the particular mineral bearing metal values, and for relating the characteristics of sedimentary rocks. Analyses were made in support of an investigation of kimberlites from Ellendale in the West Kimberley and the Barrubiddy pipes in the Carnarvon Basin.

MERCURY AS AN INDICATOR

Following previous work on trace mercury levels as an indicator for halo exploration a further study was made of the mercury content of individual sulphide minerals in ores from 20 different deposits. The object of the investigation was to determine whether a relationship exists between the mercury content of the minerals and the temperature of formation of the deposits. It was hoped also that an indication could be obtained of the mineral most useful for the purpose. The sulphide samples were intergrowths and overall contained pyrite, pyrrhotite, pentlandite, chalcopyrite, sphalerite and magnetite.

The separation of sufficiently pure fractions of individual sulphides from the samples chosen proved to be difficult due, in most cases, to very fine intergrowths and in the end, analyses were confined to fractions of chalcopyrite and sphalerite.

As a check on the separation, the mercury content of the head sample was determined at the same time as the individual sulphide.

In general the sphalerite concentrates showed higher mercury than the head sample, but the chalcopyrite concentrates were often lower than or equivalent to the head sample.

Typical analyses with an indication of reproducibility are as follows.

Sulphide	Fraction	Mercury Hg ppB	Coeff. of Variation per cent
Nepean chalcopyrite	a head	170	40
	b concentrate	no sample	....
Golden Grove chalcopyrite	a head	760	15
	b concentrate	910	17
Elverton chalcopyrite	a head	350	27
	b concentrate	770	6
Teutonic bore sphalerite	a head	3 550	7
	b concentrate	5 050	10

ORE MINERALS

Assessments of economic potential were made relating to a Ministerial Reserve over iron deposits, to an application for a claim for manganese in the area of a National Park, and to a gold mining lease which had excited interest on the stock exchange.

Analyses of lead and zinc, and, in a separate series tungstic oxide, of fractions obtained by an upgrading treatment at a State Battery, provided a balance showing movement of the minerals.

FORENSIC EXAMINATIONS

Although the Forensic Division now handles all other investigations relating to police work, those cases in which evidence of a mineralogical nature can be helpful are still handled by the Mineral Division. This work consisted almost entirely of comparison of materials to establish whether a common source was possible.

Because of natural variation of soils the evidence which could be presented was of a corroborative nature and resulted generally in a statement to the effect that the observed facts were or were not consistent with a certain contention.

In the comparison of sands, factors which were used included size grading, the proportion of major mineral species and organic matter, the contribution of minor species, physical characteristics of the grains and the identification of exotic materials. These parameters were used in the following cases.

Soil obtained from bags of potatoes and from a number of potato paddocks were examined in connection with a possible case of illegal potato dealing.

The soils were found to be loamy sands but with significant variation in colour and in quartz, clay minerals, and gibbsite content. Comparison of the properties of the soils in the various paddocks and on the potatoes indicated the probable source of the potatoes.

Soil from a lawn area at the scene of an alleged attack was compared optically and by X-ray diffraction with soil from the rear seat of a car and it was found that both were quartzose sands with a small content of calcareous shell fragments.

Exhibits in connection with an alleged sex offence, consisted of soil from the scene and others of soil from items of clothing. These were compared. Soil from boots of the suspect proved to be closely similar to that from the scene, being wet red-brown sandy loams containing kaolinite and montmorillonoid clay.

A sand and a sandy silt from the scene of an alleged rape offence were compared with mineral matter recovered from the complainant's skirt. The latter was found to match very closely the colour, grain size and mineral composition of the sandy silt.

A range of exhibits consisting of soils from pots in which cannabis had been growing, and of various materials found in a house, were compared. The materials from the house included two types of coastal plain sand, a peaty swamp soil, processed vermiculite, and an organic-rich mixture. These materials were represented in each of the soils containing the cannabis, indicating that the materials were consistent with having been used to fabricate the soils.

CEMENT AND CONCRETE

The advent of blended and masonry cements on the market in Western Australia has increased the possibility of cements unsuitable for particular purposes, being used. Supervising architects and engineers have shown concern to know that specified materials were used and the possiblity of assessing the composition of mixtures was explored on behalf of a manufacturing company.

Mixtures of portland cement with blast furnace slag (BFS) or pulverised fly ash (PFA) were prepared with thorough mixing, and a heavy liquid gravity technique was used to separate the constituents. The separation of blast furnace slag was not satisfactory because of a range of specific gravity of BFS particles which straddled the medium used. In the case of pulverised fly ash admixture, the separation was more satisfactory and a mean value of 14 per cent was obtained for a mixture 85:15 portland cement : PFA, with a coefficient of variation of 3·7 per cent.

While physical separation of BFS was not particularly satisfactory its recognition in mixtures has been comparatively simple because of its differences from portland cement constituents in optical properties, morphology and composition, as shown by scanning electron microscope. It is a fortunate fact that only a single source of BFS is being used in Western Australia.

The mentioned properties of BFS were used to determine its presence or absence in dry cement powder and also in freshly prepared mixes. In the case of fresh concrete slurries rapid treatment is necessary. When the aggregate of dimensions greater than 75 micrometres has been removed by wet sieving the resultant material is dried by acetone washing before reaction of the alite has proceeded to a significant degree. In the resultant condition, as a loose powder, the individual particles of portland cement (alite) and BFS are readily recogisable.

In the search for an explanation of excessive creep associated with one of two test cylinders of concrete, the possiblity of a blended cement having been used, was explored. The absence of blending materials from the set concrete was indicated by optical examination, supported by a manganese content normal for portland cement and considerably lower than that of supplied BFS. Also there was no evidence of hydrogen sulphide being liberated by acid digestion as is the case with the BFS. In fact the water cement ratio calculated from bulk density, capillary porosity, and degree of carbonation, differed in the test pieces by an amount which was significant in terms of concrete creep.

The problem of bowing of end supported concrete panels in some public buildings is still under investigation. The panels in each instance are composed of a white imported portland cement with a gap-graded milky quartz aggregate. It is apparent that bowing is due to contained lateral expansion.

While earlier mortar-bar tests with the constituents had indicated a contraction after 3 months the latest measurement was greater than those preceeding. For this reason extended testing is now in hand including detailed mineralogical examination of the cement paste.

Examination was made of the concrete linings of the smoke chambers of some cement kilns which were damaged by deep cracks necessitating relining. Constituents found in the damaged concrete and not in comparable sound concrete were halite, NaCl, sylvite KC1 and ettringite $Ca_6Al_2(SO_4)_3(OH)_{12}\cdot 26H_2O$. Since the age of the concrete was such that ettringite would not be a normal constituent, its occurrence in the fabric and on the surface of the concrete was ascribed to crystallisation accompanied by expansion.

Since masonry blocks are a major building material in many country areas the occurrence of an efflorescence on blocks is of concern. Therefore a series of blocks from producers in several towns were examined for their potential to produce efflorescence. Most showed nil or slight efflorescence with an occasional "moderate" result. The descriptive scale adopted was that of Australian Standard AS 1226·3 for efflorescence testing of burnt clay and shale building bricks.

That is:

slight—not more than 10 per cent of the surface covered with a thin deposit of salts.

moderate—a heavier deposit than slight and covering up to 50 per cent of the surface but unaccompanied by powdering or flaking.

The most common cause of the calcite efflorescence is an interruption of the hydration of the cement before completion. While well constructed plants with steam curing can control humidity and hence ensure completion of hydration, vagaries due to summer temperatures and lack of humidity do occur. The potential to effloresce is very much a function of the individual history of the block as well as of the properties of the constituents.

OTHER BUILDING MATERIALS

A local marble for which there was a potential overseas market was examined for flaws and tested for several physical properties. No specifications were available from the potential buyer and therefore its suitablilty for the market could not be assessed.

The firing properties of a series of clays, suggested to be the basis of a potential Regional development in the form of a brick works in a country town, were examined. Although one was seriously lacking in clay content others were suitable for making a satisfactory clay brick.

The failure of paint on a plaster surface by blistering, was shown to be associated with the formation of a series of concentric rings of crystalline sodium sulphate. This structure which is typical of the evaporation of droplets of a salt bearing water indicated that such droplets were present when the paint was applied. The probable mechanism of the disruption is that water droplets beneath the paint contracted as they dried out, to volumes at which they became super saturated with respect to sodium sulphate. The rings represent temporary pauses in the shrinkage of the droplets, probably due to diurnal humidity variations.

INDUSTRIAL DEPOSITS

In many situations deposits were found which were foreign to the surfaces on which they occurred, and to the normal functioning of the materials. These were either outfall from other sources or corrosion of the material itself.

A first approach in deciding the origin of the deposit was to determine its composition and nature. The deposits examined were numerous and varied.

There are many occurrences in which failure of the material through corrosion is suspected, but the cause is found elsewhere. An example was an aluminium mullion capping with a surface coloured with a cobalt compound and protected by an anodised oxide layer. A white discolouration suspected of being an efflorescent corrosion product was shown to be due to crazing and powdering of the protective layer due to abrasion.

In another case a Zincalume roofing sheet had minute brown spots which were suspected of being due to pin-hole failure of the protective coat. Examination showed the coating to be intact and the spots due to swarf from drilling of the sheets in emplacement.

Another instance of an erroneous suspicion regarding the cause of a deposit was where corrosion occurred on vehicles which had been shipped by sea in wooden crates. Routine fumigation of the crates to destroy insect stowaways was suspected to have caused the corrosion. Examination of the deposits did not support this contention.

Excessive corrosion of steel objects in a store adjacent to a galvanising works was suspected of being due in some way to outfall from the galvanising process. The corrosion product, though of normal type for the steel, contained considerably more zinc than could be accounted for by oxidation of that metal. Outfall in the area was then collected over a period of 72 hours, in bubblers and on test surfaces. The size of sample collected in that time was too small for a decision as to the source of the zinc.

A very common source of complaint is the sulphuric smuts which fall from boiler stacks, and efforts have been made to overcome this in at least one instance, by introduction of ammonia gas into the stack. The effectiveness of this operation was demonstrated by analyses of the iron content of washings from a stainless steel probe inserted into the stack gases.

The combustion areas of boilers are collecting places for deposits which can represent a hazard to those involved in their clean up. In one instance vanadium oxide was a major component of the deposit.

Other deposits in motors were often considered to have caused damage by abrasion where there was evidence of a mechanism by which filters had been by-passed. Coarse mineral dust in the air duct of one engine showed a range of abrasive minerals which are common in Western Australia. It was not possible however to meet the client's request for a decision as to whether they may have originated in WA or Canada. From another vehicle a deposit on a fuel filter consisted in part of magnetite flakes up to 2 mm in size. These were obviously of artificial origin.

Another type of deposit which attracted regular attention was that relating to electrical switch gear. These generally followed overheating and, in some instances, fire. In one instance a deposit covering contacts of a circuit breaker which had failed to operate proved to be the product of break down of a plasticiser in the insulation. Whether this material reached the contacts as a result of electrical overheating of the insulation or resulted from the heat of the subsequent fire could not be determined. In another case failure of the refrigeration system of an air conditioning plant produced a deposit which clearly indicated a source in the electrical motor.

PRECIOUS METALS

Although the price of gold receded during 1980 from its peak at the commencement of the year, confidence in gold mining and precious metals generally had its effect on the Division. A great demand existed in the State for gold assays and, although work for the public was generally directed to private laboratories, technical advice and assays in some limited circumstances were provided for prospectors. Officers of the Division were also involved in consultations and demonstrations to assist parties interested in setting up public or company fire assay facilities.

Concern regarding accuracy of assay results was reflected in a number of submissions of samples from firms wishing to check previously obtained assays.

It was apparent that sampling procedures adopted were not always such as would give a reasonable comparison of assay results. In some instances the "prepared" sample submitted consisted of only a few grams representing the remnant of a sample from which previous analytical portions had been taken. In addition, particles of free gold were present of dimensions far greater than permissible for accurate assay.

The effect of market prices was also evident from enquiries for the identity of metals in unserviceable scientific equipment. Assistance by way of demonstration and detailed instructions for recovery was given to a charitable institution which had access to electrical scrap containing gold plated contacts. The value of silver was also the cause of an assessment made for a Government Department, of the amount of silver in various brands of X-ray film.

Evidence of continued interest in gold prospecting by the use of metal detectors was the submission of 230 gold nuggets for assessment of metal content. These ranged in mass from a few grams to the equivalent of 416 troy ounces in the "Yellow Rose of Texas" nugget.

In order to provide an historical record, plaster casts of a number of the larger nuggets were made.

The Division also participated in a round-robin check by an exploration firm on reproducibility statistics comparing fire assay results with those of various extraction techniques.

An extended investigation of several aspects of the occurrence of secondary gold by Professor Wilson of University of Queensland, was assisted by provision of a great deal of material from the Laboratory's collection.

SOILS IN ENGINEERING SITUATIONS

Both mineralogy and soil chemistry were involved in determining the engineering characteristics of soils. Examinations have in the past included evaluation of dam wall fill and footings, building foundations and road construction materials. A development in the latter area was close consultation established with a geologist appointed, by the Main Roads Department, to specialise in this field.

Following failure of the surface of a bituminised water catchment area extensive examinations were made to determine the cause, before resealing operations could commence. A feature of the failure was that it was worse in an area in which the substrate had reputedly been stabilised with lime. Considerable difficulty was experienced in establishing the origin of borrow material used in preparation of the substrate and the nature of the lime treatment used, and comparison of many factors were involved.

While illite and nontronite were present to a minor degree in the failed areas the most significant difference from the sound areas was the presence of calcite in varying amounts. Since this was not present in the borrow material its presence was attributed to the lime added for stabilisation.

Later information indicated that the lime addition had been by way of dry quick lime powder, CaO, and that the soil at the time was extremely dry and very little water had been available for the treatment. Mixing had been by way of rotary hoe and bulldozer blade.

These factors together with the composition found in sound and failed areas indicate that there was no effective reaction of the lime with clays to cause stabilisation because of lack of intimate mixing, and also uneven mixing. The apparent reaction was hydration of the lime in the soil probably after sealing, followed by carbonisation to calcite.

The swelling and lubrication action which accompanied the hydration after compaction are probable factors in the failure.

Implication of the mixing procedure in the failure was indicated by the form of the failures which was by way of uplifted ridges occurring in parallel lines.

MINERALOGY

Participation of the mineralogical staff in monitoring environmental and occupational health dust hazards, and forensic examinations, have restricted the capacity of the Division for mineralogical investigations. A source of new material for mineralogical examination by way of submissions from the prospecting public has now largely dissappeared due to such factors as the setting up of mineralogical services within prospecting companies and the charging of fees by the Laboratories for mineral identifications. Wherever possible identifications were made by visual inspection and free of charge, but where professional experience indicated that further examination involving laboratory time was necessary, then a fee was applied.

As a result of the decline in submitted material, collecting excursions have become more necessary.

A project on the mineralogy of the National Parks of WA continued with a visit of the investigating officer to several new collecting sites in the Cape Leeuwin area, and a report is being prepared.

A beginning has been made to a joint project with the Geological Survey to determine the characteristics of Western Australian kimberlite deposits for comparison with other known deposits.

Detailed examinations were made of concentrates supplied by the lease holders from kimberlite pipes. The range of indicator minerals, and variety within species, was recorded. Similar examinations were made of rotary pan concentrates from gravels from the surface expression of several kimberlite pipes in another temporary reserve.

Examination of material held in the Laboratories has continued and during the year sufficient detail was lodged with the New Minerals and New Mineral Names Commission of the International Mineralogical Association, for recognition to be given to two new species from Western Australia. Articles will be prepared for the mineralogical literature.

The first new species is a monoclinic potassium barium iron titanate for which the name Jeppeite was proposed to mark the fact that it was found by Dr. J. F. B. Jeppe of Nedlands. The mineral occurs as shiny, black, submetallic crystals in the scree of a weathered lamproite at Walgidie Hills, Kimberley Division, Western Australia.

The second mineral is an unusual hydrated copper oxalate with an analysis which corresponds to a formula $CuC_2O_4.O \cdot 44H_2O$. It is turquoise green in colour and occurs as micro-botryoidal crusts and earthy coatings in cracks and cavities in a surface quartz vein intruding Pre Cambrian schist on Mooloo Downs Station, Gascoyne Province, Western Australia. The name Moolooite is proposed.

Other mineralogically interesting specimens included allanite from two new localities in the Leeuwin area; cassiterite from Lamboo Station; cassiterite and yttrotantalite from Nunyerry; and donated specimens from the Capricorn Range which contained well crystallised pyromorphite, crystals of which were attached to acicular malachite. This material also included well formed chrysocolla pseudo-morphs after acicular malachite. The mineral dufrenite was recorded from Permian sandstone at Watermelon Creek in the Kennedy Range. This is the first recorded occurrence in non-cretaceous beds. A notable feature of this occurrence is the wide range of refractive index observed and the anomalous absorption i.e. X=light sulphate green—sulphate green=1·70—1·75; Z=deep colonial buff=1·75—1·80. This may indicate unusually high FeO and/or Al_2O_3.

Mineral Collection

The holding of the Mineral Division collection was increased to 11 307 specimens during the year. These additions included bixbyite, partridgeite and todorokite and a suite of kimberlites from South Africa.

A specimen from the Mt. Wideerin Cave at Skipton in Victoria which was held at the Smithsonian Institute as dittmarite was borrowed and reidentified as newberyite after stuverite with monetite.

Specimens from the collection were also loaned to researchers for scientific work.

A donation of considerable value was made to the collection by an ex member of the staff P. J. Bridge. This consisted of a suite of gold nuggets showing crystal structure and other features of individual occurrence.

During the year the Laboratories mineral collection was recognised by the Commissioner of Taxation as a collection to which donations are accepted as gifts under Section 78 of the Income Tax Act. A proviso of this recognition is that viewing of the specimens should be available to members of the public.

New Mineral Occurrences

Listed below are localities from which the specific minerals were recorded in the Division for the first time this year.

Greater detail of localities may be available on application depending on the source of the material.

Kimberley		
	Cassiterite	Lamboo Station
	Cerussite	Mt. Dockrell
North West		
	Cassiterite	Nunyerry
	Yttrotantalite	Nunyerry
	Covellite	Capricorn Range
	Tetrahedrite	Capricorn Range
	Pyrite	Capricorn Range
	Malachite	Capricorn Range
	Pyromorphite	Capricorn Range
	Chrysocolla	Capricorn Range
	Dufrenite	Watermelon Creek
Murchison		
	Paragonite	Windimurra Station
South West		
	Chrysoprase	Cairn Hill
Central		
	Chrysoprase	Sandstone
	Cuprite	Doolgunna
	Elbaite	Londonderry
	Jarosite	Malcolm

CHEMICAL TESTING

The importance of reliable analytical results has always been a highly significant factor in commercial contracts and has been a concern of these Laboratories as well as such bodies as the Standards Association of Australia which, through voluntary expertise, devise, check and publish standard methods of analyses, and the National Association of Testing Authorities which, again with voluntary expertise, assesses the ability of laboratories to carry out the analyses.

The work of both these organisations was strongly supported by the Laboratories during the year.

Staff members have acted as assessors of laboratories throughout the State and have also participated in technical sub-committees of the Standards Association dealing with iron ores. bauxite and heavy mineral sands. Support for the work on heavy mineral sands was at the request of the Chamber of Mines, and an officer of the Division participated in the work of a technical committee of that body.

The Department's representative on the Standards Association committee to determine the direction of activity regarding Mineral Standards is the Chief of the Mineral Division.

COMPUTING SERVICES

Acceptance by the Department of a report prepared by a firm of computer consultants, relating to future computing developments in the Department involved Division staff in implementation of the report, as well as with administration of the computer systems. As in the past, the lack of trained computer staff throughout the Department necessitated time being spent by experienced personnel from the Division in servicing the computer related needs of other Divisions and Branches. Various computer committees and the Departmental users group were supported.

Preparations were made to continue the in-service computer training of the Laboratories staff by means of the internal introductory course introduced by Divisional staff in 1979. The next course will take place in February 1981.

Concurrent with these activities the work of developing instrumental data capture systems and associated data processing operations for the X-ray spectrometer continued.

D. BURNS,
Chief, Mineral Division.

WATER DIVISION

GENERAL

1980 was a busy and demanding year.

The effectiveness of the Division, when measured solely on total samples receival and publication output, was slightly less than that of 1979. The interfacing between automatic analytical equipment and the computer did not arrive until late in the year and hence did not contribute any improvement during the year.

In the consultative and advisory area, activity increased during 1980, particularly in the water treatment field, for domestic, irrigation and swimming pool supply. This increased activity was a natural result of general water shortage throughout the State.

Activity associated with the various committees in which the Division is involved, did not lessen during the year. These committees included Laporte Effluent Disposal Environmental and Hydrogeological Sub-Committees, Waste Disposal Technical Committee, Effluent Licensing Panel under the Rights in Water and Irrigation Act and Swan River Management Authority Industrial and Biological Committees.

Sample Source

During the year sample receivals decreased from 1979, by 3·9 per cent. This is the first year since the Division was established as a separate entity in 1970, that there has been a decrease in the annual total of samples received.

Of these samples approximately 2 000 were handled in the Environmental Section, approximately 1 500 in the Automated Network Section and approximately 5 000 in the Water and Treatment Section. The allocation of the samples to the various Divisional Sections was similar to that of 1979.

Table 13 shows the source of the samples received during the year and the domination by the Public Works Department remains similar to that of the past few years. Table 17 of the 1979 Annual Report showed that the Public Works Department during the past decade had contributed an increasing proportion of the samples received, varying from 36 per cent in 1970 to 62 per cent in 1979. The percentage for 1980 was 67.

Papers and Publications

Collection of material for topics for five publications was completed during 1980, but three of these will not be printed till 1981.

Those printed in 1980 were—

1. An information bulletin on "Hygiene and Algal Control for Home Swimming Pools".
2. A report on the groundwater contamination associated with effluent discharge from an industrial plating factory.

Those for which material has been gathered and for which the reports are at various stages of completion are—

3. A heavy metal survey of the Swan and Canning Rivers and inputs from the drains and other tributaries.
4. Physical and chemical conditions in the Swan River during the development period of algal blooms in May 1980.
5. A survey of chemical and hydrological factors associated with the occurrence of acid waters in the Bayswater/Bassendean area.

Conference and Seminar Attendence

Apart from several part day or up to two day seminars attended in Perth, the full conferences of approximately one week duration attended during 1980 were—

The 4th Australian Water and Wastewater Association Summer School in Adelaide.

The 5th Electrochemistry Conference in Perth.

The 20th Australasian Corrosion Association Conference in Adelaide

Equipment

No funds were available for acquisition of major instrumentation during 1980. Minor equipment received during the year included a vacuum pump, a drying oven, a dialyser unit for the autoanalyser, a block digester, a dissolved oxygen meter and interfacing for the automated equipment and the computer.

TABLE 13

WATER DIVISION

	Agriculture Department	Dept. of Conservation and Environment	Bureau of Consumer Affairs	Dept of Fisheries and Wildlife	Geological Survey of W.A.	Leschenault Inlet Management Authority	Main Roads Department	Metropolitan Water Board	Dept of Health and Medical Services	Peel Inlet Management Authority	Public Works Department	Swan River Management Authority	Other Departments	Public Pay	Total
Corrosion and Deposits	....	....	....	....	....	....	1	14	2	....	20	....	1	11	49
Effluents	....	....	....	....	....	....	....	....	6	....	336	17	....	24	383
Environmental Monitoring	....	....	....	....	....	96	....	....	....	72	....	209	....	....	377
Miscellaneous	....	10	....	....	....	....	....	1	5	1	4	....	1	2	24
Soils	....	....	....	....	....	....	....	....	....	....	....	....	....	11	11
Waters—															
Fluoridated	....	....	....	....	....	....	....	660	....	....	956	....	....	....	1 616
Network Survey	....	....	....	....	....	....	....	....	....	....	1 372	....	....	....	1 372
General	22	55	9	38	368	....	38	465	103	....	2 986	32	56	420	4 592
Total	22	65	9	38	368	96	39	1 140	116	73	5 674	258	58	468	8 424

WATER AND TREATMENT

Fluoridated Water Supplies

During 1980 fluoridation of the Exmouth town supply commenced, bringing to a total of ten the number of supply systems being fluoridated. A list of the average fluoride levels for 1980 for fluoridated water supplies throughout the State is given in Table 14, together with the intended level. With the exception of the Manjimup supply, which was lower than that intended, all other fluoridated supplies had mean fluoride levels within the range intended.

TABLE 14
FLUORIDATED TOWN SUPPLIES

Supply	No. of samples	Fluoride (F) mg/L mean	intended
Perth/Metropolitan	688	0·83	0·8 ± 0·1
Mundaring/Goldfields	82	0·79	0·8 ± 0·1
Wellington/Comprehensive	89	0·71	0·8 ± 0·1
Albany	179	0·87	0·9 ± 0·1
Broome	98	0·68	0·7 ± 0·1
Collie	140	0·74	0·8 ± 0·1
Esperance	101	0·81	0·9 ± 0·1
Exmouth	50	0·64	0·7 ± 0·1
Geraldton	99	0·83	0·8 ± 0·1
Manjimup	56	0·72	0·9 ± 0·1

PERTH METROPOLITAN SUPPLY

Production bores and treatment plants—samples from the production bores servicing the treatment plants at Mirrabooka, Gwelup, Wanneroo and Jandakot are being regularly monitored. These bores are analysed annually for approximately 20 components and once every three years for thirty five components. The results continued to show that the levels of any potentially harmful components are always below the recommended maximums for a drinking supply. Undesirable naturally occurring components, which require some chemical treatment to bring them within the acceptable standards for a drinking supply, include pH, colour, turbidity, odour, iron and manganese. Analysis of the various sludges from these upflow clarifier treatment plants during 1980 showed that the levels of potentially toxic ingredients were similar to natural levels in soils and hence their disposal would not present any hazard.

Tastes and odours—On several occasions, assistance was given to the Metropolitan Water Board Laboratory to resolve odour/taste complaints. A number of these resulted from the use of certain plastic washers in taps which released traces of phenolic compounds which subsequently reacted with the chlorine of the reticulated supply to form chlorphenols. These chlorphenols are capable of producing objectionable tastes at levels as low as 0·001 mg/L. Causes of other non specific types of odours and tastes were not positively identified, but were probably due to the presence of organic growths in the reticulation. These complaints were of moderate severity with taste thresholds as high as two or three and were considered to be natural products of metabolism or decay of these organic growths or reaction products with chlorine. Water reserves were inadequate for a sustained flushing programme and maintenance of desirable free chlorine levels to the consumer's tap would have in the short term caused increased consumer complaints.

Deposits—An exercise involving analyses of a number of deposits from the Canning tunnel achieved little other than to confirm what was predicted in 1979, namely that the predominantly manganese deposit was bacterial in origin and the extent of the deposit could be accounted for by the manganese content of Canning Dam water flowing through it. An unexpected result from the analyses of these deposits was the absence of organic carbon, the level being generally only 0·1 per cent of the dried deposit.

Salinity of Hills Catchment Dams

During 1980 the testing for salinity for those Hills Catchment dams under Metropolitan Water Board control was undertaken by their own Laboratory. These dams under M.W.B. control have not shown the variation between minimum and maximum salinity values over the past decade as have the two dams for the Public Works Department comprehensive supplies, namely Mundaring and Wellington. For a year where the recorded rainfall at Perth was 847 mm compared to the average of 881 mm it was perhaps a little unexpected that the average chloride value for 1980 in Mundaring increased from 215 to 240 mg/L and that for Wellington dam from 430 to 535 mg/L. Wellington dam is more saline than it has ever been.

Table 15 lists the average annual chlorinity values for Mundaring Weir and Wellington Dam over the past 20 years.

TABLE 15
MUNDARING WEIR AND WELLINGTON DAM
ANNUAL AVERAGE CHLORINITY

Year	Rainfall (Perth) mm	Chloride, Cl mg/L Mundaring	Wellington
1960	717	145	205
1961	820	165	180
1962	731	175	165
1963	995	130	125
1964	976	75	85
1965	1 042	95	120
1966	774	135	190
1967	1 038	160	195
1968	931	160	180
1969	574	200	240
1970	909	235	275
1971	799	245	265
1972	611	270	285
1973	974	265	295
1974	938	180	205
1975	682	150	180
1976	713	190	295
1977	608	220	400
1978	923	220	455
1979	560	215	430
1980	847	240	535

Conversion factor for Cl to total dissolved solids (by evaporation at 180°C) 2·0 for Mundaring, 1·8 for Wellington.

Country Water Supplies

Samples from these sources are being more frequently monitored for an increased number of components to comply with the recommendations of the National Health and Medical Research Council. For those country town supplies not being serviced by either Mundaring or Wellington, there are a wide variety of raw waters, either surface or underground, which require treatment. A number of these to which additional attention in relation to a particular problem was directed during the year included:

Boyanup—Laboratory tests showed that the aeration/filtration plant for iron removal, which was producing a product water with 0·3 mg/L of iron, could be improved to produce a product water with less than 0·1 mg/L of iron, with either alkali or chlorine addition. Modification of the plant to cope with increased demands will include this new dosage feature.

Dandaragan—The raw supply is aerated and filtered to effect removal of iron. Raising of the pH to produce a better quality water was carried out by field officers without the supporting evidence of laboratory tests. It did not achieve the desired effect. Raising of the pH beyond a certain level, after aeration, although increasing the theorectial rate for iron hydroxide insolubilisation, had an adverse effect because of the fine (colloidal) nature of the insoluble material. The recommendation was to raise the pH no higher than 7.

Gingin—A decision based on the results of 1969 to use an upflow clarifier without sand filtration in preference to aeration/sand filtration for removal of iron was reassessed during 1980. Field trials in 1969 had indicated less than 50 per cent removal of the several mg/L of iron present by the aeration/filtration process. Since the installation of the upflow clarifier, iron levels in the reticulation have frequently been in excess of 0·3 mg/L. The results of laboratory tests in 1980 showed that with time delays between aeration and filtration of 1 to 5 minutes and filter rates up to 2 mm/sec, a product water with 0·2 mg/L of iron could be obtained. Increased flow rates gave an unsatisfactory product. The failure of the aeration/filtration field tests in 1969 were attributed mainly to poorer aeration efficiency of 50 per cent in 1969 compared to the present aeration efficiency of 75 per cent.

Moora—The raw supply for Moora contains both iron and manganese, the manganese not being readily removed by coprecipitation with the iron. Although the manganese, present at 0·18 mg/L, can be partly deposited by bacterial growths in the lengthy mains from Kolburn to Moora, this could accentuate rather than diminish dirty water occurrences. Field trials by P.W.D. officers showed that raising of the pH to encourage coprecipitation of manganese, frequently yielded an iron colloid which was not adequately removed in the sand filter. The field trials were inconsistent, but appeared to indicate that soda ash was superior to caustic soda or hydrolime. Laboratory trials are scheduled for 1981 to resolve the problem.

Northampton—Most of the raw water supplies to the town contain between 0·1 and 1·2 mg/L of manganese, this is the cause of the black deposits occurring in the reticulation. Chlorine dosage to prevent these bacterial growths is not the answer in this case as it causes colloidal oxides of manganese to separate from solution and give the water an apparent colour. Control by flushing, also is not a solution to this problem; manganese removal would be the only satisfactory solution for this water.

Walpole—Treatment to remove the colour from the Walpole River to make it suitable for the town supply, involved the dosing of filter alum and soda ash in an upflow clarifier treatment plant. This treatment reduced the colour from 300 to 15 units with upflow rates of 50 mm/minute. This upflow rate could be doubled with the use of coagulant aids such as sodium alginate.

Yarloop—Problems with poor sand filter performance at Yarloop were assessed by measuring the suspended solids content of the inlet, product and backwash water to the filters during a period of several weeks in October 1980. The suspended solids content of the raw, product and backwash water averaged over the period 3–4, 1 and 40 mg/L respectively. These results indicate a raw water that really does not need filtration and a backwash which constitutes a reasonably acceptable 6 per cent of the throughput.

Iron Bacteria

An inspection of the bore site at the Mullaloo Wildlife Sanctuary and subsequent examination of the production water after chlorination of the borehole equipment *in situ*, highlighted the current and potential role for iron bacteria in creating problems.

Iron bacteria are frequently of nuisance value where they cause iron to be deposited from solution in bore screens or pipes and hence cause a drastic reduction in the quantity of water supplied. The usual remedy is to kill the bacteria in the screen, pump and pipes by allowing a 100 mg/L solution of chlorine to remain in contact for about 24 hours.

The current trend in W.A. is to keep the down hole equipment free of iron bacteria and to remove or complex the iron at the surface so that staining does not occur in the domestic or irrigational uses which follow. Although it has been recommended to a number of clients without them adopting the recommendation, the idea of injecting aerated "iron free" water into the aquifer through a cluster of satellite bores around the production bore is an acceptable alternative. This would raise the redox potential in the vicinity of the production bore and allows the proliferation of the iron bacteria to remove the iron from solution *in situ* in the aquifer and allow an iron free product water from the main bore.

ENVIRONMENTAL

Rights in Water and Irrigation Act

During 1980 the responsibility for administering this Act in the Metropolitan area was transferred to the Metropolitan Water Board, who will analyse most of the samples associated with this administration at their waste water laboratory. The exception to this will be only where they do not have the expertise or equipment to carry out the full range of tests. Prior to 1980 the involvement in the metropolitan area by the Public Works Department, who were solely responsible for policing the Act, was limited. Any diminution in samples received by the Water Division from the metropolitan area has been compensated for by increased activity in other areas of the State.

Several obvious conclusions to date from the various effluent disposal means practiced are—

1. Impervious evaporative lagoons are rarely so.
2. Effluents containing high levels of nutrients, unless irrigated with scientific control, rarely reduce the nutrient load to the underground aquifer or the adjacent surface drainage by more than 50 per cent.
3. Particular underground water movement is frequently not in the same direction as the general movement for an area; and this makes it difficult to locate the plume of contaminated water.

There are at least two incidents in a specific industry in the metropolitan area where contamination of the shallow underground aquifer by the on site soakage/evaporative ponds have led to appreciable contamination of the ground water outside the boundary of the factory sites.

With limited funding for policing this Act, and the high costs associated with measuring the extent and intensity of contamination of underground aquifers, it will be a lengthy period before before all sources of contamination are eliminated. This situation is exacerbated by the lack of alternative sites for controlled industrial liquid waste disposal.

There are also a number of sites in the metropolitan area where natural processes are considered responsible for some of the acidic waters encountered and this does not help to clearly resolve some of these industrial contamination problems. This is referred to later in the section on natural acidic waters.

Lower Helena Catchment Study

Four sites in the Lower Helena, two representing undeveloped catchment and two representing developed catchment have been monitored since June 1980. The waters are tested at weekly intervals for basic components, and at monthly intervals for 20 components including heavy metals, pesticides, surfactants and organics which include polycyclic aromatic hydrocarbons and trihalomethanes after chlorinating the water at 2 mg/L greater than that required for breakpoint chlorination.

Most of the components tested for were at insignificant levels but those which were exerting an influence on the water quality, were—

1. Nutrients—Ammonia and phosphorus levels at all sites were at pristine levels. The nitrate nitrogen level at the undeveloped sites was also at the expected pristine level but was several mg/L at both developed sites.
2. Salinity—Clearing and development usually initially produce a more saline water, but after attainment of equilibrium a fresher water would be anticipated. In these four cases the two developed sites as a group generally gave less saline water than the undeveloped.

Laporte Effluent Disposal

Regular quarterly monitoring of samples from approximately 200 boreholes in the Laporte effluent sand dune disposal area, continued during 1980. The results of this monitoring predicted the entry into the Leschenault Inlet via the shallow aquifer of a small volume of incompletely neutralised effluent containing iron in excess of 100 mg/L. This proved capable of producing noticeable brown staining over a limited period and area on the western side of Leschenault Inlet. Disposal at these lagoons, which were sited closer to the Inlet than to the Indian Ocean has been discontinued.

It is predicted that the life of the present dune site beyond 5 years without staining in the Inlet, can only be achieved by allowing significant quantities of iron to seep into the ocean. With extension of the present sand dune disposal area and with significant utilisation of the neutralising capacity of the deep limestone aquifer it would be possible to appreciably increase the life of the dune system.

The much debated but unknown process of iron fixation within the dune system may be resolved if an experiment currently being carried out at Murdoch University achieves the success it initially indicated. Water Division staff are involved in the planning and interpretation of the results obtained. A clearer understanding of the fixation mechanism should lead to better utilisation of the resources available in the disposal area.

A management procedure has been recommended and this allows only completely neutralised effluent (ie. less than 100 mg/L of iron) to reach the boundary of the Inlet via the shallow aquifer. This should prevent any staining of the Inlet.

Estuarine Monitoring

General—It is difficult to equate the eutrophic state of the three estuarine systems being monitored, namely the Swan/Canning, the Peel/Harvey and the Leschenault Inlet, in terms of nutrient and chlorophyll–a levels. In terms of nutrients the total phosphorus level is almost always above that considered limiting for eutrophication, while the inorganic nitrogen would rarely, if ever, reach the limiting level of 0·3 mg/L in the non winter period ie. eutrophication should not be a problem in the main water bodies of the three estuarine systems. Nevertheless chlorophyll–a levels in both the Swan/Canning and Peel/Harvey systems have frequently been ten times higher than that considered to be indicative of eutrophication. Although chlorophyll–a levels have not been assessed to date in the Leschenault Inlet, the lack of reports by the public would indicate that blooms are not as severe as in the other two estuarine systems.

The Swan River—The quarterly monitoring surveys in 1980 were amended to include Kjeldahl N and inorganic phosphorus. Although the Swan River Management Authority desired more frequent monitoring this was not possible with the present commitments and resources of the Division.

A study of the heavy metals in the river has been completed and the report is almost ready for publication. The concentration of zinc in the Swan and Canning Rivers was occasionally equal to or greater than the Californian Environmental Quality Act (CEQA) chronic toxicity value and the copper value occasionally exceeded the water quality objective of C.E.Q.A. Calculation of the Causeway and Riverton Bridge copper and zinc values from upstream inputs gave values which in general agreed well with the observed values and such agreement indicates that sedimentation is not a major fate of the inputs. Continued monitoring for heavy metals will continue for 11 river and 11 drain sites.

A study of chlorophyll–a levels, algae identification and physical and chemical parameters leading up to and through two separate algal blooms in April/May 1980 near the Causeway has been completed and a report should be available in early 1981. The algal blooms were moderate, the dominant species being the dinoflagellate Gymnodinium, Chrysochromulina and Prorocentrum with chlorophyll–a levels reaching as high as 0·45 mg/L. A subsequent bloom is October had a chlorophyll–a level of 2·3 mg/L with the green Chlamydomonas being the dominant species.

Although the average total phosphorus and inorganic nitrogen levels in the middle and upper reaches of the Swan and Canning Rivers are both much higher (1·5 to 2 fold) than those of the Harvey Estuary, the Swan River does not experience the prolonged algal blooms that can last for several months over vast areas in the Harvey Estuary. This could be because higher levels of inorganic nitrogen are known to suppress the activity of the nitrogen fixing blue green algae, which are dominant in the Harvey estuary.

A short term investigation of the input of nutrients originating from the drainage system of the Wungong/Southern River system into the Canning River was commenced in December 1980 and is intended to be continued through till the winter rains. It has shown for December that the nutrients, inorganic nitrogen and total phosphorus, originating from the drainage from Westfield comprise more than 75 per cent of the total input to the Canning River immediately after its confluence with the Southern River. The final levels in the Canning River at this point for inorganic nitrogen and total phosphorus were 0·72 and 0·30 mg/L respectively. These nutrient levels are in excess of those considered limiting for eutrophication. The phosphorus levels at regular monitoring sites in the Canning River immediately downstream of the confluence with the Southern River have shown several fold increases in phosphorus levels over the past few years as far downstream as the Riverton Bridge.

Peel Inlet/Harvey Estuary—Until late October the quality of the water in this system appeared normal, but then a blue green algae bloom of Nodularia Spumagena developed and persisted as an intense bloom well into January 1981. On 7/1/81 at Point Meelup in the Harvey Estuary the chlorophyll–a level was slightly in excess of 1 mg/L while that at Point Herron Ford and the Mandurah Bridge were 0·16 and 0·04 mg/L respectively. That at the Mandurah Bridge was considered high enough to represent a mild bloom. Table 16 lists nutrient, chloride and chlorophyll–a levels at some of the sites in the system. By averaging surface and depth results and taking due consideration of chloride values, it can be shown that the phosphorus level in January 1981 could not have originated from other than bottom growths or sediments.

Waste Disposal

Solids—The Hertha Road and Jones Street disposal site monitoring will continue at regular intervals despite the recent closure of the Hertha Road site. The water aquifers at the new site at Yirrigan for deposition of baled rubbish has already had samples submitted for analysis from one of its monitoring bores.

The contamination at the surrounds of the Brockway site is being investigated as a joint venture by officers of the Metropolitan Water Board and the Geological Survey of W.A. to quantify the extent (if any) of contamination by seepage from the waste water plant.

Liquids—The two liquid waste disposal sites at the Gnangara pine plantation and at Warton Road Jandakot are in relatively close proximity to production bores from the Wanneroo and Jandakot treatment plants respectively. They are both now being regularly monitored. There is contamination of the monitoring bores close to the disposal sites, but possibly because of little or no production from the nearest production bore, there is no evidence of significant contamination at distances of several hundred metres from the disposal sites.

Natural Acid Waters in the Metropolitan Area

Acid waters occur naturally in many areas of the State, probably the most extensive being that associated with the Collie coal field. In the metropolitan area there are at least two instances where acid waters are due to industrial contamination. There are however a large number of sites where acid waters are considered to be the result of natural causes. These areas include West Perth (near the Mitchell Freeway), Balcatta, Cloverdale, Gwelup, Stirling, Mandogalup and Osborne Park but probably the most extensive is in the Bayswater/Bassendean area.

A joint exercise with the Geological Survey of W.A. over an area of several square kilometres in the Bayswater area where approximately 50 bores were surveyed and the water from them analysed, showed that the contamination does not result from any present industry and that there are pockets of more intense acidification within the affected area. Needless to say these acid waters are associated with high iron and sulphate levels. A report on these findings is intended for publication in 1981.

MISCELLANEOUS

Allanooka-Geraldton Mains

Due to the relatively high free carbon dioxide content of the bores from the Allanooka borefield of approximately 80 mg/L, this water has been found to be particularly aggressive towards cement and concrete. Previous analyses and a report in 1975 indicated that losses of calcium per annum from the 55 km

TABLE 16

NUTRIENTS AND ALGAE

MAIN WATER BODY SITES—OCTOBER 80/JANUARY 81

	Middle of Peel Inlet		Pt. Grey midstream		Pt. Mealup midstream		Mandurah Bridge		Pt. Heron Ford
Depth (m)	0·0	2·0	0·0	2·0	0·0	2·0	0·0	5·0	0·0
Sampled 15/10/80 mg/L									
Nitrogen N—									
kjeldahl	N.D....	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
ammonia	<0·02	0·04	0·02	0·05	0·02	0·03	0·02	0·02	0·03
nitrate	<0·02	<0·02	<0·02	<0·02	<0·02	<0·02	<0·02	0·06	<0·02
Phosphorus P—									
inorganic	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
total	0·04	0·04	0·05	0·07	0·11	0·10	0·15	0·08	0·25
Chlorophyll-a	0·009	....	0·011	....	0·015	....	0·002	....	0·005
Chloride Cl	8 860	15 300	8 250	8 490	3 880	3 880	18 000	19 400	3 120
Sampled 7/1/81 mg/L									
Nitrogen N—									
kjeldahl	1·8	....	3·0	....	6·3	....	1·6	....	5·2
ammonia	0·24	0·25	0·38	0·69	0·05	1·6	0·14	0·21	0·19
nitrate	0·11	0·06	0·09	0·06	0·03	0·03	0·17	0·04	0·02
Phosphorus P—									
inorganic	<0·01	0·01	<0·01	<0·01	0·01	0·01	<0·01	0·01	<0·01
total	0·12	0·12	0·18	0·14	0·49	0·17	0·15	0·08	0·25
Chlorophyll-a	0·023	....	0·038	....	1·04	....	0·040	....	0·16
Chloride Cl	18 700	19 400	17 200	18 700	15 800	15 800	19 700	19 700	13 300

cement lined mains for the years 1969, 1973 and 1975 were 70, 18 and 5 tonnes respectively. Follow up tests in 1980 indicated that 13 tonnes of calcium were leached from the mains during the year and this indicated a loss per annum equivalent to 0·4 mm of cement.

This relatively high rate of leaching is not unexpected and currently consideration is being given to aeration and caustic soda or hydrolime dosing to reduce the free carbon dioxide levels to less than 1 mg/L. This is expected to be achieved by dosing of hydrolime at about 15 mg/L and would be equivalent to approximately 30 tonnes per annum of calcium i.e. several-fold the current leaching rate.

The attack by this same water on concrete tanks was confirmed as being equivalent to 2 mm per year.

Asbestos Cement Pipes for Metropolitan Area

Unfortunately types of asbestos cement (A.C.) pipes made before the current autoclaved "Mazza" piping whose production commenced in W.A. in the early 1950's, did not give good performance and this has understandably prejudiced their current use. Because of economic advantages associated with purchase price, transport costs and laying costs the Metropolitan Water Board wishes to use more A.C. pipes in its reticulation system, provided the life expectancy is similar to that of other types being used, namely cement lined or reinforced concrete.

A review of past experiences and chemical testing in these Laboratories reveal that there is inadequate information to make such a confident assessment. Leaching tests have been carried out on numerous A.C. pipes that have been in service in the metropolitan area for periods of 15 years, but tests on pipes that have been exposed for lesser periods include only one of 5 years and one of 10 years. Based on the results of these tests it could be predicted that leaching of calcium has almost stopped after 15 years but further tests on samples after 5 and 10 years are required to substantiate this.

An unexpected result is that despite leaching of up to 25 per cent of the calcium content after 15 years original physical crushing and tensile stress properties are retained.

Based on visual evidence and experience in other areas of the State with more aggressive waters it could be confidently predicted that an average life expectancy would be in excess of 50 years.

It is even more difficult to make accurate assessments from leaching tests on concrete pipes but tests to date indicate that they are equal to or superior to asbestos cement pipes in the metropolitan area.

Corrosion of Submersible Pump

The cause for the premature failure of a multi stage submersible pump at Duncraig High School was not resolved. The impellors were of bronze and the bowls of protectively coated cast iron. The water being pumped contained no dissolved oxygen or hydrogen sulphide and its free carbon dioxide level was less than 20 mg/L. The bowl had corroded (or eroded) to a depth of 1·5 mm. If the failure was not due to erosion caused by air or soil ingress then this is the first case from hundreds of predictions where life expectancy based on free carbon dioxide levels has been a failure.

Swimming Pools

Because of the disturbing and often misleading advertisements and recommendations made by promoters of chemicals or equipment for swimming pools an information bulletin Hygiene and Algae Control For Home Swimming Pools was published in 1980. Its main thrust was in the use of chlorine compounds, both with and without stabiliser. Recommended levels of chlorine for control of amoebic meningitis were twice that for hygiene and algal control.

Malfunction of one of the electrodes for chlorine generation by electrolysis in a pool water containing 7 000 mg/L of sodium chloride was attributed to the high calcium level. During electrolysis one of the electrodes produces sodium hydroxide and raises the pH in the immediate vicinity to such an extent that excessive quantities of calcium carbonate are deposited thereby reducing the area of the electrode and the quantity of chlorine generated Although no guidelines are given for maximum calcium levels in this situation, it is expected to be somewhere approaching 150 mg/L.

In two separate instances swimming pools had been accidentally dosed with several hundred mg/L of copper sulphate and zinc sulphate respectively leaving undesirable levels of copper and zinc in the pool water, some of it as an insoluble sludge. In both instances it was recommended to raise the pH to 8·5 to reduce the soluble metallic ions to a minimum, filter off the precipitated material, and then to lower the pH to the recommended pool value of $7 \cdot 5 \pm 0 \cdot 1$.

N. PLATELL,
Chief, Water Division.

DIVISION VIII

Annual Report of the Chief Inspector of Explosives and Dangerous Goods, for the Year 1980

In accordance with Section 10 of the Explosives and Dangerous Goods Act, 1961–1978, I submit for the information of the Hon. Minister for Mines the following report on the administration of the Act for the year ended December 31, 1980.

LEGISLATION

The Third Schedule to the Act was amended to:

Alter the sub-classification of Class 2 Dangerous Goods to align them with current United Nations classifications.

Clarify the definition of Class 3 Dangerous Goods.

Amendments to the Explosives Regulations and the Flammable Liquids Regulations were promulgated to:

Increase the penalties for breach of the regulations to $2 000 and $200 per day for a continuing offence;

Effect the first increase in licence fees since 1972.

Since Cabinet's decision late in 1978, to require legislation be drafted to control the transport of dangerous goods, considerable effort has been directed towards that end. This culminated with the forwarding to Cabinet of the final draft of the Regulations for the Transport of Dangerous Goods by Road. In parallel with this, a list of dangerous goods was submitted to Parliamentary Counsel for drafting into a form suitable for gazettal as dangerous goods in accordance with the provision of Section 42(2)(b) of the Act. It is believed that the draft is now at a stage where it could be gazetted into Law during 1981.

The proposed regulations are based on and maintain uniformity with the recommendations of the National Advisory Committee on the Transport of Dangerous Goods which were endorsed by the Ministers at the July 4, 1980 meeting of the Australian Transport Advisory Council. The proposals have been drafted in consultation with industry and organizations throughout the nation associated with the transport of dangerous goods and are the results of some 450 constructive comments received over 2 years on the formative drafts.

The main features of the proposed regulations are the sensible and realistic safety requirements made to control the transport of all internationally recognized dangerous goods whether in bulk or in packages. These features include requirements for:

Labelling and identification of packages
The placarding of vehicles conveying more than a prescribed quantity of dangerous goods.
The certification, examination and licensing of vehicles used for the conveyance of large quantities of dangerous goods.
The design and construction of containers and tanks for dangerous goods.
The provision of not less than $500 000 accident indemnity.
Periodic medical examination of drivers for all tanker vehicles conveying dangerous goods.
Stowage compatibility and segregation of all hazardous items.
Emergency procedures, forming the basis of a proposed Western Australian Transport Emergency Assistance Scheme (TEAS).

There were several additions to the list of authorised explosives throughout the year.

Authorised Explosives:

Class 1.1B:

(0030) Du Pont Acudet Mark V Detonators (z)
(0029) Nonel Primadets (z)
(0029) Nonel Primadet Connectors (z)
(0029) Anoline Delay Detonators (z)
(0029) Cordline Delay Detonators (z)

Class 1.1C: (0160) Propellant AR 2051 (zz)

Class 1.1D: (0065) Trunkcord (zz)

Class 1.4S: (0323) T + Couplings (x)

STAFF

Mr H. R. Powell was appointed as Inspector of Explosives following the premature retirement of Mr J. Best. Mr Best was an Inspector with the Branch for nearly 10 years and his retirement was on medical grounds.

At December 31, the staff of the Explosives and Dangerous Goods Branch totalled 22 and consisted of:

Inspectorate—8
Clerical—6
Reserve Security—8

An era in the development of the Explosives and Dangerous Goods Branch ended during 1980 with the death of Mr G. A. Greaves who was Chief Inspector from 1968–1974. Arthur Greaves saw the Branch through the drafting and incorporation into Law of the Flammable Liquids Regulations, 1967 and was largely responsible for the same action with the Explosives Regulations, 1963. He was one of the true gentlemen of the explosives industry and he had the respect and admiration of all who knew and worked with him.

MANUFACTURE OF EXPLOSIVES

Inspections were made of the main explosives manufacturing plants throughout the year at Collie, Goldsworthy, Kalgoorlie, Newman, Pannawonica, Paraburdoo, Shay Gap and Tom Price. Ammonium nitrate prill trans-shipment facilities and road train operations were observed at Dalwallinu, Kalgoorlie, Meekatharra and Narngulu.

The manufacture of nitrate based explosives at licensed plants throughout the State showed a minor decrease when compared with figures for 1979.

	1979 (tonnes)	1980 (tonnes)
ANFO	59 071	57 363
Water Gel	2 309	2 921
Total	61 380	60 284

The development of improved blasting techniques in the iron ore industry continued to affect the quantity of nitrate based explosives manufactured. Iron ore production in 1980 was approximately 6 per cent higher than 1979 and ANFO production decreased by 3 per cent over the same period.

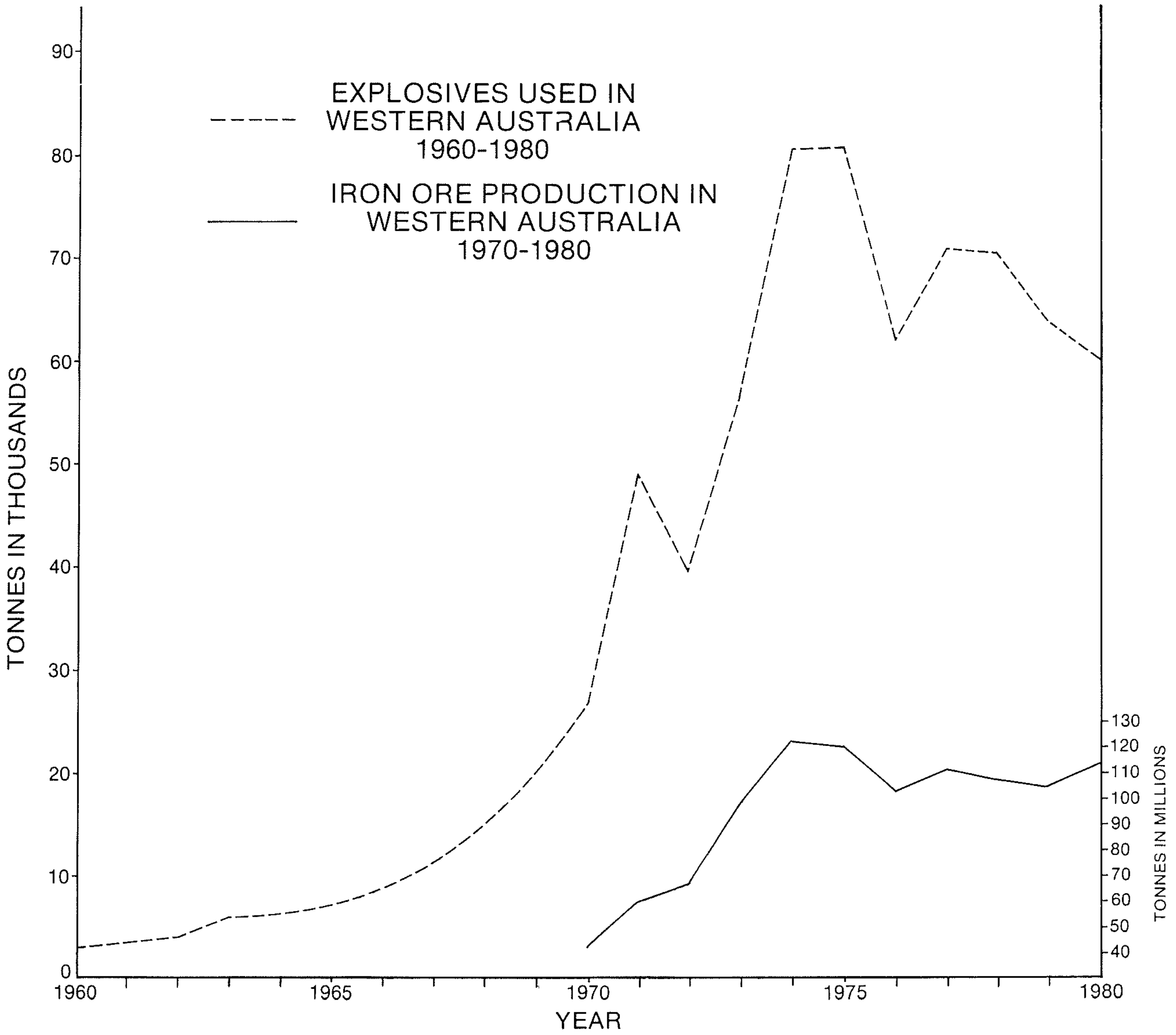


FIG. 1

IMPORTATION AND USAGE OF EXPLOSIVES

The importation and use of small diameter cartridged nitrate based explosives increased by about 19 per cent over the previous year and the quantity of nitroglycerine based explosives decreased by some 43 per cent over the same period. Despite these relative movements in favour of the less sensitive water gels, nitroglycerine based explosives continue to dominate this area of the market. The predictions of the mid-70's that nitroglycerine based explosives would be completely phased out in favour of water gels by 1980 have not proven accurate and it is now apparent that they will continue to be in use for some considerable time yet.

The graph (Fig. 1) of the annual consumption of explosives since 1960 illustrates the increase in the use of explosives which, up to 1978, paralleled the production of iron ore from mines in Western Australia. Unless another major technological breakthrough is made in this field, the two curves should again follow parallel courses from 1980 or 1981.

Eight agencies now hold a licence to import explosives into Western Australia. The majority of imported explosives came into the State by rail from Victoria and were imported to replenish the magazine stocks as they were used during the year. Minor quantities of explosives for specialised use were imported under authority of an Entry Permit. In all, some 26 consignments of explosives were imported in this manner, and, after examination, were issued certificates of release.

The Inspectorate continued to maintain a close observation in the usage and sale of explosives. Similarly the use of fireworks was closely checked and control was exercised by the issue of permits, totalling 37 during the year, to authorise the use of fireworks for public display.

EXPLOSIVES LICENCES AND PERMITS

The increase in the number of licences issued for explosives was of the order of 9 per cent over the previous year. Once again significant increases occurred in the number of Shotfirers Permits issued.

A comparison of the number of licences and permits issued for explosives during the past 2 years is shown below.

Licences	1979	1980
Import	7	8
Explosives Manufacture	7	6
Blasting Agent Manufacture	402	401
Storage—Mode A	36	35
Storage—Mode B	11	7
Magazine Type One (1 000 kg)	116	122
Magazine Type Two (5 000 kg)	45	45
Magazine Type Three (greater than 5 000 kg)	88	77
Sell	35	31
Convey	50	65
Total Licences	797	797
Permits		
Shotfirers	1 231	1 442
Fireworks Display	43	37
Entry Permit for Explosives	37	26
Total Licences and Permits	2 108	2 302

Training and examination of shotfirers continued but at a lower level than 1979. Of the 210 people involved, 147 candidates passed the examination, 29 failed and 34 withdrew from Training Courses. Four Departmental Courses were held; at Albany, Geraldton and Perth. The Inspector and Research Officer lectured at 2 evening courses conducted in Perth under the auspices of the Technical Education Department and a third, similar course was supervised by an employee of Alcoa at Pinjarra. The Pinjarra course was principally, but not solely, for the benefit of Alcoa personnel. Of the 147 successful candidates 106 attended courses and 41 studied privately.

In addition to regular Shotfirer Training Courses one-day training sessions for farmers continued in a similar vein to 1979. A total of 70 farmers were given safety training at 3 sessions held at Harvey and Manjimup.

EXPLOSIVES RESERVES

Woodman Point Explosives Reserve

Once again the distribution of explosives by road and rail proved to be the main function of the Reserve with some 4 800 tonnes of explosives and 306 tonnes of prilled ammonium nitrate dispatched to various locations in the south western part of the State. As in previous years, all vehicles leaving the Reserve with explosives (more than 4 000) were checked by the Reserve Staff.

A high standard of security continued at the Woodman Point Explosives Reserve with only one recorded instance of illegal entry on to the Reserve. This most satisfactory situ ation must be attributed to the presence of an alert and diligent watching staff within the Reserve.

The jetty facilities were used once only during the year for the trans-shipment of a small quantity of explosives intended for local use.

The main function of the Reserve continued to be as a storage and dispatch area for explosives used in the South West Division and the Departmental staff again played an active part in ensuring compliance with all aspects of the regulations relating to explosives manufacture, storage and conveyance.

OTHER EXPLOSIVES RESERVES

With mining and development work in the area continuing to increase, activities at the Kalgoorlie Explosives Reserve are at a high level. The fire protection for the manufacturing plant was upgraded during the year.

A new explosives reserve was gazetted at Collie, and approval given for a 50-tonne magazine and manufacturing plant to be constructed there.

A new magazine location was approved near Karratha in anticipation of the greatly increased usage of explosives in the development work on the Burrup Peninsula.

Relocation of Woodman Point Explosives Reserve

According to schedule, a feasibility study conducted by an independent group of consultant engineers confirmed the suitability of the proposed explosives area at Baldivis. Within the guildelines set by the Explosives Branch staff, the consultants drew up preliminary site plans and estimated construction costs. Plans for the relocation are proceeding steadily.

INSPECTORAL ACTIVITIES

Explosives Security

Approximately 113 kilograms of explosives and 1 000 detonators were collected by the Inspectorate from 26 locations. The explosives fit for transport were delivered to Woodman Point Explosives Reserve for destruction by the Magazine Keeper and the balance destroyed by the collecting Inspector in a safe place near the point of collection. Approximately 1 000 kilograms of explosives and 20 600 detonators which were damaged or otherwise unsuitable for sale were destroyed by the manufacturer under the supervision of the Magazine staff.

Eight instances of theft involving explosives were reported during 1980, 3 of which occurred at isolated small mines in the Eastern Goldfields. In these cases, the matter was referred to the local branch of the Mines Inspectorate for appropriate action.

Thieves entered the Woodman Point Explosives Reserve after cutting several barbed wire stringers on the security fence. It is believed they started a small bushfire in the area to distract the watching staff while they broke and entered a magazine. No explosives were stolen but almost $700 worth of blasting accessories were taken. The bushfire was extinguished by the watching staff at the Reserve.

A locked box containing a small quantity of detonators and blasting accessories was stolen from a locked vehicle at the home of an explosives inspector. The box was subsequently recovered intact but the offenders were not apprehended.

A man was successfully charged by the Police for stealing explosives and possessing explosives with intent to endanger the lives of others following a theft from a working party magazine to which the offender had had legal access. The Senior Inspector of Explosives assisted in the collection and disposal of the explosives involved.

Detonators and safety fuse were stolen from a licensed magazine on a mine in the Pilbara. The offenders were not apprehended but steps have been taken to upgrade the standard of security on the mine.

A small quantity of detonators was stolen from an unlicensed and unapproved location in a shed at a general storage depot in the Perth metropolitan area. The detonators had been stored at the site by a shotfirer who had subsequently died and their existence and location was forgotten until a piece of paper that had been with the detonators was found on the floor. It is believed that the forced entry and theft was the work of children but the offenders were not apprehended.

Explosives Storage, Use and Conveyance

Two hundred and ninety-one magazines and licensed stores were inspected and some licensees were required to modify storage units to improve security and other conditions. The policy of upgrading magazine construction to the new Australian Standard continued.

Some requirements of the appropriate Australian Standard are also being applied to vehicles intended for use to convey explosives.

A man was prosecuted for the illegal conveyance of explosives after a watchman at a mine site reported that he had loaded some 1 250 kilograms of ANFO onto an unlicensed vehicle.

Analysis and Testing

Chemical analysis of porous prill ammonium nitrate continued through the year with no measurable deterioration in quality or safety standards.

The examination of new equipment designed for the explosives industry continued without any sign of reduced activity. One hundred and ninety Asahi photo-electric circuit meters were approved for use in mining work. Provisional approval of ICI's multi-channel exploder was extended for a further year thereby enabling the industry to assess the performance of the machine. Similar provisional approval was given to Du Pont for three new electronic exploders:

The REO BM-125-10 Sequential blasting machine.
The REO BM-125-10 CD 600 blasting machine.
The REO 5 000 Sequential blasting machine.

Preliminary reports indicate that the machines are performing quite satisfactorily.

General approval was given to Du Pont for the use of the Model 200 Blasting Ohm meter and the Model 101 Multi-meter.

The delay times of "Acudets", "Nonel Primadets" and "Nonel Primadet Connectors" were compared with the manufacturers specified delay times and found to be quite satisfactory. All were subsequently authorised.

"Trunkcord", a low explosive content detonating cord was tested to ensure it was of adequate sensitivity and strength to initiate boosters and normal detonating cord. The tests proved satisfactory and the explosive was authorised.

Tests on "T+ Coupling" showed it presented no significant hazard and it was approved for authorisation. This equipment enables a T connection to be made into an operating pipeline up to 25 mm I.D. with no necessity to interrupt the flow along the line.

A new watergel, "Aquapour 100" was tested, found to be satisfactory and authorisation is now proceeding.

A series of tests are proceeding on detonators to assess their explosibility when packaged in various ways. The tests were prompted by a proposal that detonators with 3·6 metre leadwires could be packaged so they would not mass explode when initiated and hence could be safely off-loaded at general cargo handling berths.

Heat tests were conducted on 603 samples of nitroglycerine type explosives and all were found to be in safe condition. Similarly, 69 batches of imported safety fuse were satisfactorily tested for burning characteristics.

Flammable Liquids and Gases Inspections

A total of 5 375 premises and vehicles were inspected through 1980 and 5 095 licences were issued for premises to store flammable liquids throughout the State.

The number of licences issued in 1980 is 100 less than 1979, the decrease being attributable to the "rationalisation" occurring in the petroleum industry. In this case, "rationalisation" means the closing of many service stations and other fuel outlets. This trend became evident in 1979 and is likely to continue at least through 1981.

Self service outlets continued to increase in numbers and received a deservedly disproportionate amount of inspectoral attention in relation to their numbers. There are now 113 self service outlets in the Perth metropolitan area and 1980 saw their introduction into several country towns. Unsupervised dispensing, the use of plastic containers and dispensing by underage persons were the most common problems encountered.

The storage of swimming pool chemicals at service stations continued to be a minor but persistent problem. Their potential to cause a major accident prompted consideration to banning their storage on licensed premises, but it was decided to advise the industry of the problem at senior management level in the hope that some degree of self regulation could improve the situation. The results so far have been encouraging.

Numerous complaints were received from several sources about the retailing of petrol from bulk fuel depots. Three prosecutions are pending following the discovery of self service operations in 3 bulk depots in Geraldton.

The examination of tanker vehicle designs is becoming increasingly technical and is straining the limited expertise in this field of the existing Branch staff. However, a corresponding increase in professionalism occurring in the industry is resulting in an overall improvement in public safety.

Although the Branch continued to take an active role in the redrafting of the Standards Association of Australia's LP Gas Code, field inspections of LPG installations have ceased at all, but those premises which are licensed to store flammable liquids. It was found that the existing staff, which was generally less than full strength for most of the year could not cope with this work which is not yet subject to statutory control. Increasing activity involving the regulation of the transport of dangerous goods further exacerbated the situation.

Miscellaneous Dangerous Goods

Over several years, dangerous goods other than explosives and flammable liquids have involved increasing amounts of the Inspectorate's time. The release of drafts of the Regulations for the Transport of Dangerous Goods by Road, for comment from industry has resulted in an increasing awareness by industry of the existence of this source of expertise and a corresponding increase in enquiries. The Act and Regulations empower the Chief Inspector to set conditions for the storage of hazardous materials where they are stored on premises licensed to store flammable liquids. However, in other cases advice from the Branch has no legal authority and may be rejected. It is an indication of the professional and realistic approach taken by the Inspectorate that, to date, this has not happened.

A brief summary of some of the areas in which the Branch was involved follows:

The Metropolitan Water Board was advised on the route of a pipeline intended for use to carry dilute chlorine solution. Further advice was given on the conditions for safe storage of liquid chlorine and concentrated (50 per cent) hydrogen peroxide.

Advice was given to the City of Fremantle on the current statutes and recommended storage conditions which apply to liquified chlorine.

The Road Traffic Patrol was advised on the conditions applying to the conveyance of calcium oxide.

Several engineering firms with licensed flammable liquids storages were required to upgrade their liquid oxygen storage and handling facilities to ensure compliance with the appropriate Australian Standard.

A major brick manufacturing company was advised on the conditions which would apply to the transportation of pulverised coal as stated in the Draft Regulations for the Transport of Dangerous Goods by Road.

Several companies and Government authorities were advised on the applicable safe working procedures and and other conditions which would apply to the receival and application of a proposed shipload of anhydrous ammonia intended for use as a fertiliser in a pastoral area in the Kimberleys.

- An active part was also taken in formulating the safety procedures applying to the transport, storage and handling of anhydrous hydrofluoric acid at two quite diverse locations in Western Australia. It is expected that the importation and use of this substance will substantially increase in the near future.
- Advice was given on the safety procedures which applied to the generation and storage of methane intended to be used to generate electricity. The methane was to be generated from animal wastes and it was estimated that enough could be generated to make the farm self sufficient in electricity.
- Five-and-a-half kilograms of sundry dangerous chemicals consisting mostly of flammable liquids or alkali metals were disposed of at the Woodman Point Explosives Reserve.

Summary of General Duties Inspections

Although the number of inspections carried out through 1980 fell, the rate of inspections continued at the 1979 level. As previously indicated, one inspector's position was vacant for more than 6 months and this alone resulted in a 10 per cent decrease in the number of inspector-weeks available.

	1979	1980
Explosives—		
magazines, etc.	351	291
vehicles	24	30
use	20	29
destruction	22	29
Licence to Manufacture Blasting Agent	78	76
Flammable Liquids—		
licensed and exempt premises	5 462	4 517
advice	224	214
vehicles	313	644
Total	6 494	5 830

ACCIDENTS AND OUTRAGES

Explosives

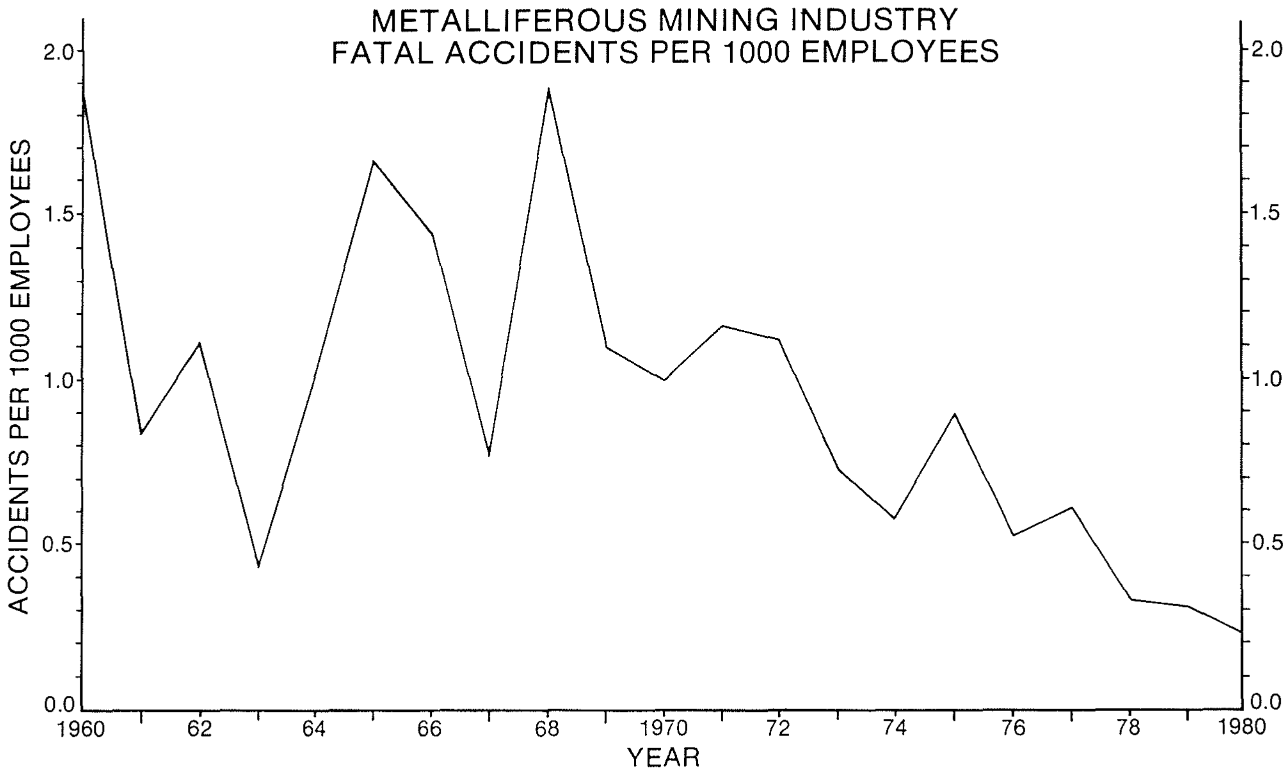
Five accidents involving explosives were investigated by the Branch in 1980. This is a marked decrease from the 8 investigated in 1979 and the severity of the accidents was also much less. In keeping with previous policy, where criminal activity is suspected (such as occurred in the destruction by explosives of a restaurant early in the year) the investigation is carried out by the Police and this Branch attends only when requested.

- A man was hospitalised after a packet of detonators prematurely exploded and peppered him with fragments of metal. As he lit the fuse to destroy the detonators, the match head fragmented and a burning particle flew in to the open end of a detonator causing it, and the rest of the packet, to explode.
- Legal proceedings were instituted against a man whose unlicensed vehicle overturned on a country road while carrying 600 kilograms of ammonium nitrate and 50 kilograms of gelignite.
- A Police lecturer gave a rather more graphic demonstration of the hazards of gun powder than he originally intended when a small pile of powder prematurely ignited and burned him on the face and hands. The lecturer was in the process of lighting a fuse to the powder when the match head fragmented and a burning particle dropped onto the pile of powder.
- Three railway fog signals exploded while being conveyed in their original cartons inside a metal cannister on the back of a utility vehicle in the Pilbara. The explosion was confined to the cannister. Enquiries made of the manufacturer indicated that no such premature explosion had previously been recorded in Australia. The roughness of the road is believed to be the major contributing factor in this accident and the recommendation has been made that the signals are carried on their sides in future.
- An 8 year old boy was hospitalised after a detonator exploded and threw sand into his eyes. After finding the detonator the boy threw it into a small scrub fire he lit for that purpose. Fortunately the injuries were not serious and no permanent eye damage was sustained. An extensive search of the area revealed no further detonators and it was not possible to determine how the detonator came to be at that location.

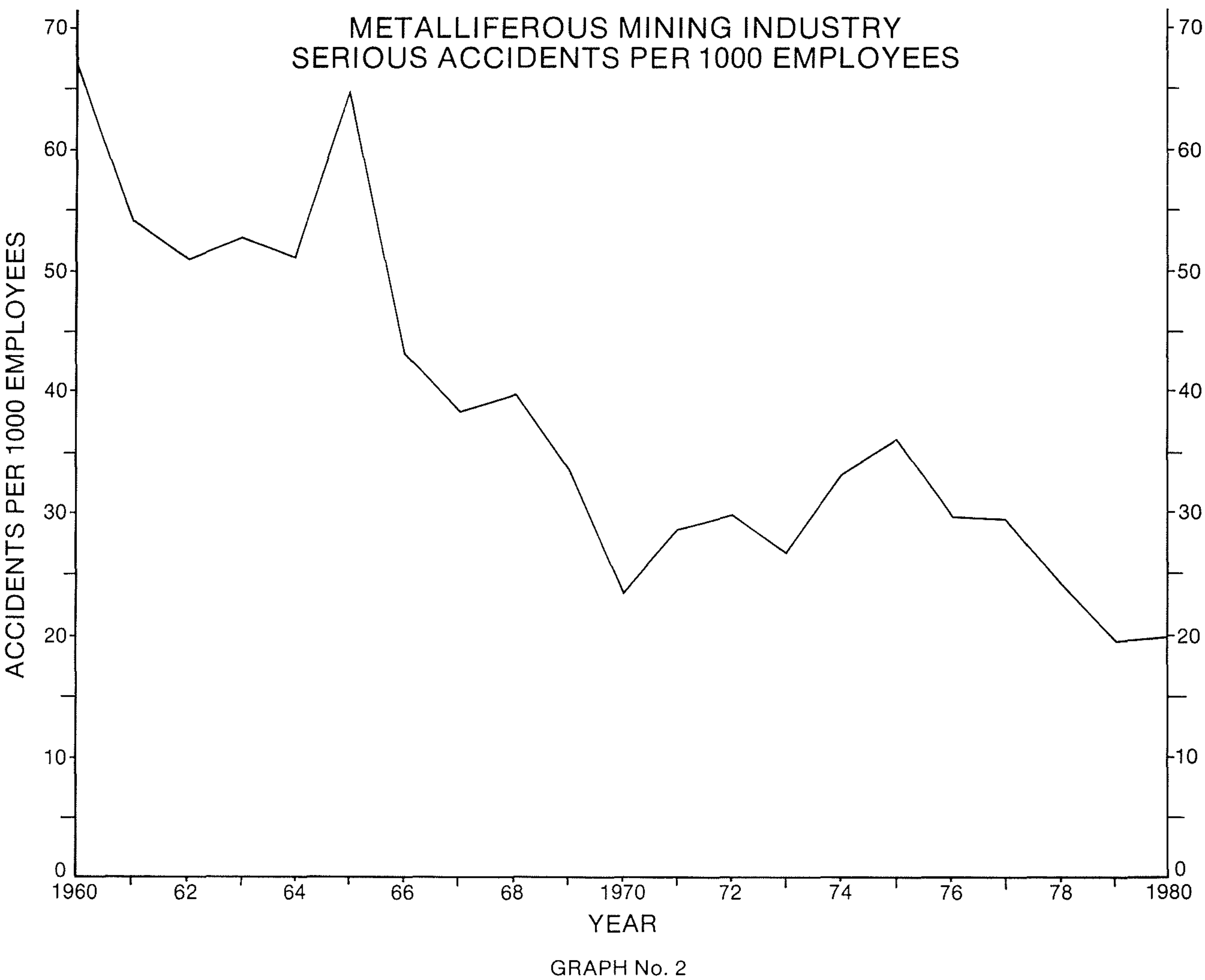
Flammable Liquids

Twelve incidents involving flammable liquids were reported during the year and of these 6 were investigated by the Inspectorate. The remainder were of a relatively minor nature and were adequately reported by the Police or the licensee. As is usually the case, most accidents were the result of ignorance of the properties of flammable liquids rather than wilful disregard of safety standards.

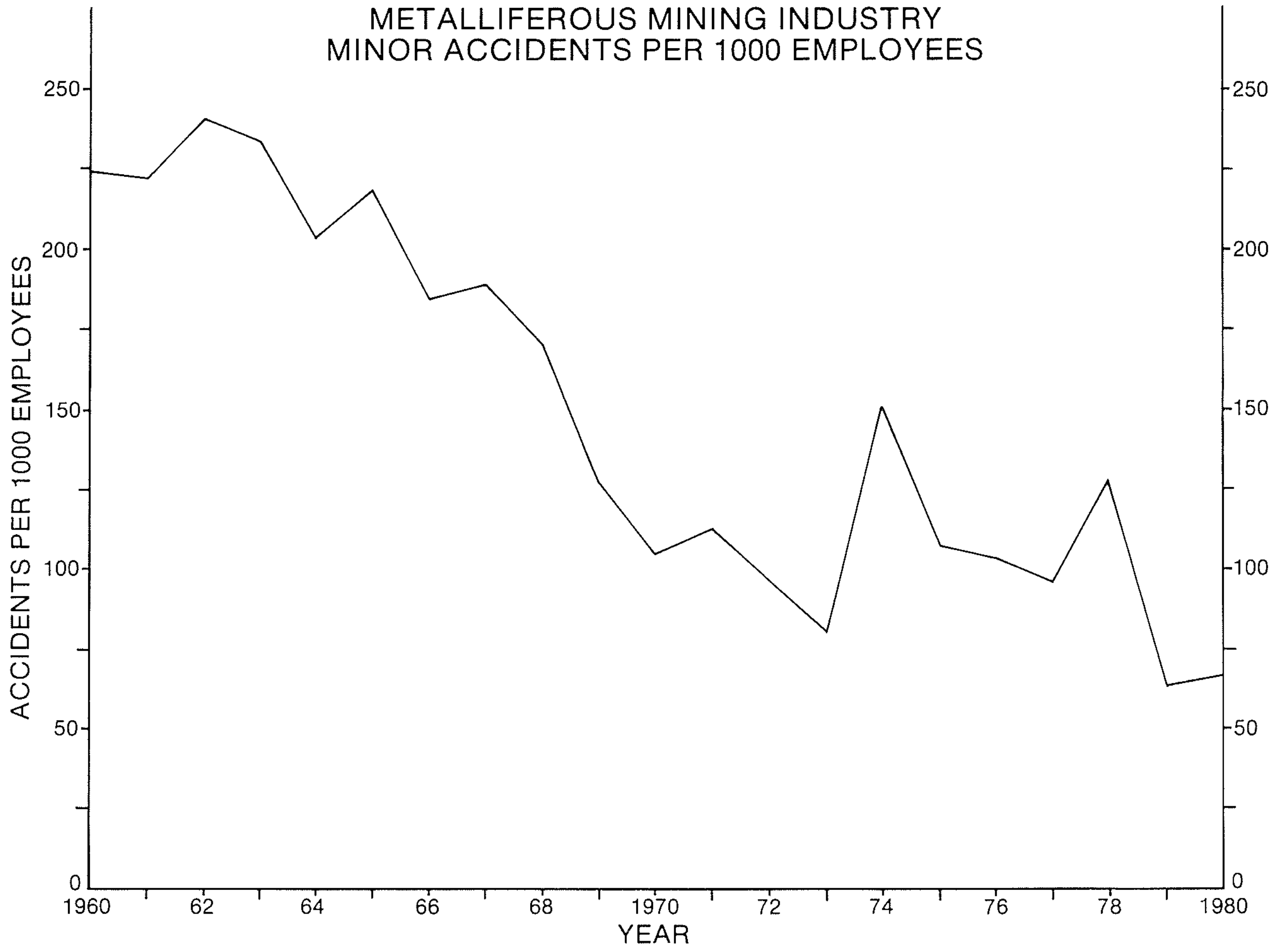
- In 2 separate incidents 2 pleasure boats exploded and burned when electrical equipment was switched on after the boats were refuelled.



GRAPH No. 1



GRAPH No. 2



GRAPH No. 3

- During a period of very hot weather, a hot water system caught fire and damaged the dwelling in which it was situated. The fuel for the heater was as recommended by the manufacturer and there was no breach of the Flammable Liquids Regulations.
- A spillage of some 38 000 litres of diesel fuel occurred when a ferry refuelling operation was left unattended and then forgotten. Pumping continued unnoticed, overnight and emptied the associated storage tanks resulting in the contamination of several square kilometres of river.
- A small fire in a Perth metropolitan service station was contained by use of the extinguishers on site pending the arrival of the local Fire Brigade which extinguished the blaze. The fire was started on an extremely hot day by a nearby welding operation while the floor of the lubricating area was being cleaned with a mixture of kerosine and degreasing oil.
- Three separate drum explosions which resulted in 4 injuries were reported. Two farmers were burned when welding operations ignited a drum of diesel fuel. A young boy was struck by the end of a drum which exploded soon after a cutting disc was applied to the side of the drum. Another young boy was partially scalped when a drum exploded, probably after a spark fell into it and ignited the contents. The boy is known to have been playing with fire near the drums.
- A semi-trailer loaded with fuel was destroyed by fire after it overturned while pulling another semi-trailer out of a bog on an isolated country road.
- A truck-trailer combination loaded with bulk and drummed fuel overturned and went on fire on a country road following a tyre failure. The driver was seriously burned and hospitalised for several months. Although the method of conveyance was contrary to the requirements of the Flammable Liquids Regulations, legal action was considered inappropriate because the driver and owner were the only persons to suffer inconvenience or injury from the incident and both were responsible for the breach of the regulations.
- A man was found dead inside his house which had been extensively damaged by fire. Investigations indicated that the fire had been deliberately started by the deceased with the intention of ending his life.
- A camper van was destroyed in a fire at a Perth metropolitan service station. Investigations established that the engine of the van was running during the refuelling operation and petrol fumes were ignited as the engine was restarted after stalling. The service station building was also extensively damaged in the fire.

Other Dangerous Goods

- A series of explosions which occurred in the Northam area were reported by the Police who had ascertained that the offender was using swimming pool chemical to make an explosive mixture. The offender, who was 15 years old, was severely warned by the Police in the presence of his father and no legal action was taken.
- A school gardener and a student were injured when a jar containing pool chemicals exploded. The student had prepared a mixture of chemicals in the jar with the intention of causing an explosion and the unsuspecting gardener had seen the youth throw the jar away. Understandably the student was reluctant to retrieve the jar when instructed to do so by the gardener, but he did so and the jar exploded in the vicinity of both people. Fortunately the injuries sustained were not serious. The youth was reprimanded and no legal action was taken.
- Following a minor accident, a Main Roads Department out-station was advised on safety precautions and ventilation requirements for a storage of formaldehyde based cleaning agents.

LECTURES, PUBLICATIONS AND COMMITTEES

The Inspectorate continued to take an active role in the working of several committees, some of which necessitated interstate travel.

Meetings of 2 Standards Association of Australia committees were attended:

- AU/17 (Road Tankers for the Conveyance of Flammable Liquids and Gases) and,
- ME/17 Flammable and Combustible Liquids.

The Chief Inspector attended meetings of the Association of Australian Port and Marine Authorities Dangerous Goods Committee and the A.T.A.C. Advisory Committee on the Transport of Dangerous Goods. The Chief Inspector also attended a National Seminar on the Transport of Dangerous Goods in Australia which was held in Canberra.

The Deputy Chief Inspector and the Inspector and Research Officer attended a seminar held in Perth by the Standards Association of Australia on the use of LP Gas in Motor Vehicles.

The Chief Inspector spoke on the ABC's Country Hour programme about the application of the Flammable Liquids Regulations to the storage of fuel on farms.

The Inspector and Research Officer and Inspector W. Gildare separately addressed meetings of the St John Ambulance Association at Kalgoorlie and Pinjarra on possible hazards to their personnel attending at an accident site where explosives or flammable liquids may be present.

The Senior Inspector addressed a meeting of oil company area managers on the Flammable Liquids Regulations as they affected vehicles—particularly at country depots.

Inspector K. Douglas delivered a lecture at a Main Roads Department training course on the safe handling and conveyance of flammable liquids and explosives.

While in South East Asia on private business the Deputy Chief Inspector took the opportunity to examine various aspects of the storage and conveyance of dangerous goods in Malaysia and Singapore. Points of particular interest were:

- The complete absence of any normal safety precautions at LP gas cylinder storage areas. These were typically located in a converted shop in the central business district of towns throughout Malaysia.
- The similarity between service stations in Malaysia and Singapore and those in Western Australia. Vents, tank locations, fire extinguishers, security on site were almost identical in format to their counterparts in Western Australia. Warning signs were also provided and these were multi-lingual.
- The location of a bulk fuel depot on an arterial route into Kuala Lumpur in the centre of a very densely populated market/residential area.
- Tanker vehicles also appeared similar to those in Australia with respect to exhaust locations, fire extinguisher types and quantities, rollover protection, and placarding.

CONCLUSION

The staff of the Explosives and Dangerous Goods Branch continued to serve the public and maintain the provisions of the Explosives and Dangerous Goods Act and associated Regulations in a most competent and professional manner. The year 1980 was a very demanding one in which considerable time was expended in the preparation of the Draft Regulations for the Transport of Dangerous Goods by Road. This was required in addition to the more routine activities of the Branch and pressures on the Inspectorate were increased with the extended absence of one Inspector previously referred to. I express my thanks to the staff for their excellent response to these demands.

The Branch is most grateful for the excellent co-operation it continues to receive from all other Branches, Departments and Authorities with which it has a working association.

K. R. PRICE.
Acting Chief Inspector of
Explosives and Dangerous Goods.

DIVISION IX

Report of Superintendent, Mine Workers' Relief Act, and Chairman, Miners' Phthisis Board 1980

Under Secretary for Mines

Annual Report 1980—Mine Workers' Relief Act 1932 and Miners' Phthisis Act 1922

1. This Report is submitted for the information of the Honourable Minister for Mines, on the above Acts for the year ended 31st December, 1980.

2. *General*

The State Public Health Department, under arrangements made with this Department, continued the periodical examination of mine workers throughout the year, and the following mine sites were visited by the Mobile X-ray Unit—

Byford, Cue, Dampier, Goldsworthy, Gosnells, Herne Hill, Maddington, Marble Bar, Meekatharra, Mount Magnet, Newman, Pannawonica, Paraburdoo, Payne's Find, Port Hedland, Shay Gap, Tom Price, Wickham, Wittenoom.

3. *Mine Workers' Relief Act*

3.1 The Mine Workers' Relief Act is in the process of wind-down. Legislation was in December, 1980 before Parliament to allow lump sum payments in lieu of the present fortnightly payment scheme. It is expected that 90% of existing beneficiaries will be paid out in the 1981 calendar year. Examinations under this Act will cease at the end of 1983 and from that date Mines Regulation Act will cover any remaining persons.

3.2 TOTAL EXAMINATIONS

The examinations made under the Mine Workers' Relief Act during the year totalled 4 927 and compared with 3 712 for the previous year; an increase of 1 215. The results of examinations are as follows:—

Normal	4 775
Silicosis early, previously normal	1
Silicosis early, previously silicosis early	144
Silicosis advanced, previously normal	....
Silicosis advanced, previously silicosis early	2
Silicosis advanced, previously silicosis advanced	1
Silico-tuberculosis, previously normal	....
Silico-tuberculosis, previously silicosis early	....
Silico-tuberculosis, previously silicosis advanced	....
Silico-tuberculosis, previously tuberculosis	....
Tuberculosis, previously normal	....
Asbestosis early, previously normal	....
Asbestosis early, previously asbestosis early	....
Asbestosis advanced, previously normal	....
Asbestosis advanced, previously asbestosis early	....
Silico-asbestosis early, previously normal	....
Silico-asbestosis early, previously asbestosis early	4
Silico-asbestosis early, previously silicosis early	....
Silico-asbestosis early, previously silico-asbestosis early	....
Silico-asbestosis advanced, previously silicosis early	....
Silico-asbestosis plus tuberculosis, previously normal	....
Silico-asbestosis advanced plus tuberculosis, previously silico-asbestosis early	....
Total	4 927

The 1980 figures, together with figures for previous years, are shown on the table annexed hereto. Graphs are also attached illustrating the trend of examinations since 1940.

3.3 ANALYSES OF EXAMINATIONS

In explanation of the examination figures, I desire to make the following comments:—

3.3.1 NORMAL, etc.

These numbered 4 775 or 96.92% of the men examined and include men having first class lives or suffering from fibrosis only. The figures for the previous year being 3 517 or 94·61% of the men examined.

3.3.2 EARLY SILICOSIS

These numbered 145 of which 1 was a new case and 144 had previously been reported; the figures for 1979 being 171 and 10 respectively. Early silicotics represent 0·94% of the men examined, the percentage for the previous year was 4·88%.

3.3.3 ADVANCED SILICOSIS

There were 3 cases reported, one of which had been previously reported as Advanced Silicosis. Advanced silicotics represent 0·6% of the men examined, the percentage for the previous year being 0·16%.

3.3.4 SILICOSIS-ASBESTOSIS

Four (4) cases of Early Silicosis-Asbestosis were reported during the year. This category represents 0·08% of the men examined.

4. *Mines Regulation Act*

4.1 TOTAL EXAMINATIONS

Examinations under the Mines Regulation Act totalled 4 524. There was an increase of 361 under this Act in 1980, as compared with 1979.

4.2 ANALYSES OF EXAMINATIONS

Particulars of examinations are as follows:—

4.2.1. NEW APPLICANTS

Normal	4 030
Silicosis early	....
Silicosis early with tuberculosis	....
Tuberculosis	....
Other conditions	....
Total	4 030

4.2.2. RE-EXAMINEES

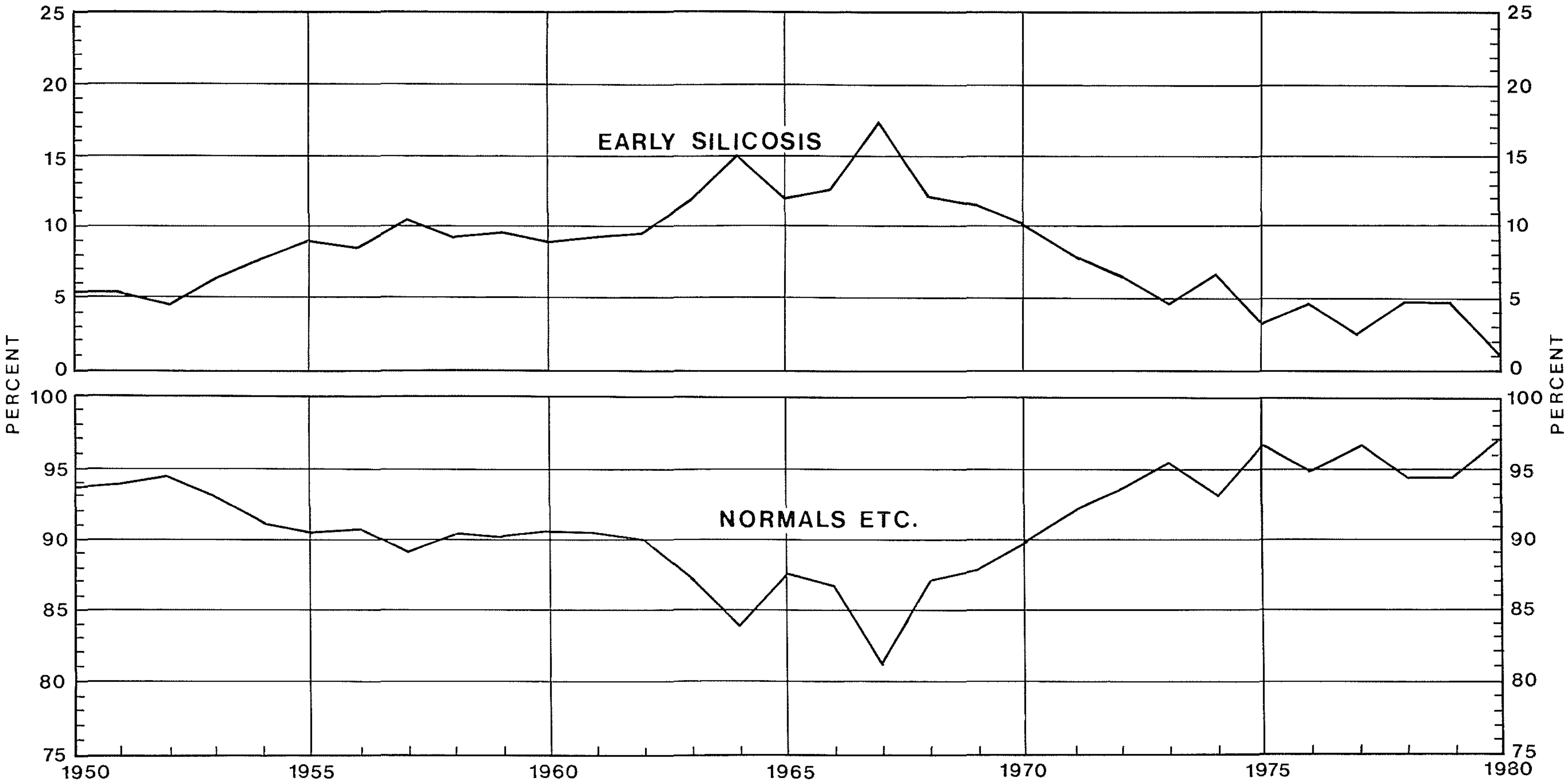
Normal	494
Silicosis early	....
Silicosis early with tuberculosis	....
Tuberculosis	....
Other conditions	....
Total	494

These men had previously been examined and some were in the industry prior to this examination.

PERIODICAL EXAMINATION OF MINE WORKERS

GRAPH Nº 1

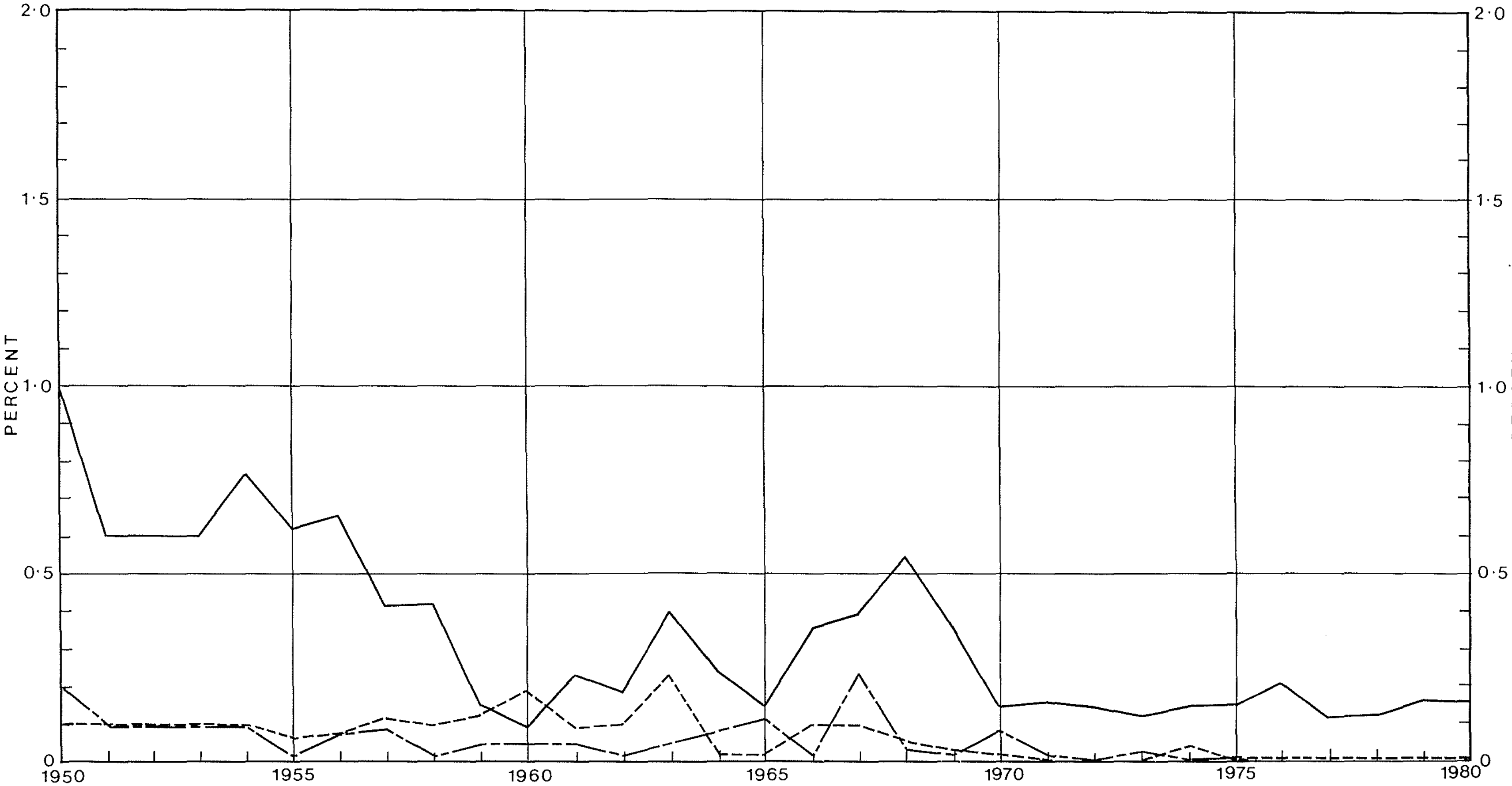
SHOWING PERCENTAGES OF NORMALS AND EARLY SILICOTICS FROM 1950 ONWARDS



PERIODICAL EXAMINATION OF MINE WORKERS

GRAPH Nº 2

SHOWING PERCENTAGES OF SILICOSIS ADVANCED, SILICOSIS PLUS TUBERCULOSIS AND TUBERCULOSIS ONLY, FROM 1950 ONWARDS



SILICOSIS ADVANCED ——— SILICOSIS PLUS TUBERCULOSIS - - - - - - TUBERCULOSIS ONLY —·—·—

TABLE SHOWING RESULTS OF PERIODICAL EXAMINATION OF MINE WORKERS FROM INCEPTION OF EXAMINATIONS (1925)

Year	Normal		Silicosis Early				Silicosis Advanced					Silicosis plus Tuberculosis					Tuberculosis Only		Asbestosis									Total
	Total	Per Cent.	Previously reported as normal etc.	Previously reported as Silicosis early	Total	Per Cent.	Previously reported as normal etc.	Previously reported as Silicosis early	Previously reported as Silicosis advanced	Total	Per Cent.	Previously reported as normal etc.	Previously reported as Silicosis early	Previously reported as Silicosis advanced	Total	Per Cent.	Total	Per Cent.	Asbestosis early previously normal	Asbestosis early previously asbestosis early	Asbestosis advanced previously normal	Asbestosis advanced previously asbestosis early	Asbestosis advanced previously asbestosis advanced	Asbestosis plus tuberculosis previously normal	Asbestosis plus tuberculosis previously asbestosis	Total	Per Cent.	
1925 } 1926 }	3 239	80·5	....	....	459	11·4	....	....	....	183	4·5	....	....	....	131	3·3	11	0·3	....	....	....	....	....	....	....	....	....	4 023
1927	3 116	83·6	33	348	381	10·2	8	...	85	93	2·5	39	27	62	128	3·4	10	0·3	....	....	....	....	....	....	....	....	....	3 728
1928	2 977	85·5	59	303	362	10·4	3	16	79	98	2·8	18	14	10	42	1·2	4	0·1	....	....	....	....	....	....	....	....	....	3 483
1929	2 120	81·9	102	224	326	12·6	....	34	60	94	3·6	8	14	19	41	1·6	7	0·3	....	....	....	....	....	....	....	....	....	2 588
1930	2 785	81·9	136	247	383	11·3	2	22	43	67	2·0	8	60	46	114	3·3	50	1·5	....	....	....	....	....	....	....	....	....	3 399
1931	2 530	84·0	94	252	346	11·5	....	18	35	53	1·8	4	35	19	58	1·9	25	·8	....	....	....	....	....	....	....	....	....	3 012
1932	3 835	89·5	35	338	373	8·7	....	6	47	53	1·2	3	9	4	16	·4	8	·2	....	....	....	....	....	....	....	....	....	4 285
1933	2 920	86·5	57	322	379	11·2	1	15	44	60	1·8	2	9	4	15	·4	3	·1	....	....	....	....	....	....	....	....	....	3 377
1934	5 140	92·4	54	315	369	6·6	1	24	12	37	·7	6	6	....	12	·2	5	·1	....	....	....	....	....	....	....	....	....	5 563
1935	4 437	92·3	35	303	338	7·0	....	24	2	26	·6	....	5	....	5	·1	2	·0	....	....	....	....	....	....	....	....	....	4 808
1936	6 972	94·7	29	323	352	4·8	1	15	4	20	·3	3	8	....	11	·1	8	·1	....	....	....	....	....	....	....	....	....	7 363
1937	7 487	95·4	15	319	334	4·3	....	14	4	18	·2	1	10	....	11	·1	2	·0	....	....	....	....	....	....	....	....	....	7 852
1938	6 833	95·7	13	266	279	3·9	....	15	2	17	·2	1	8	....	9	·1	3	·0	....	....	....	....	....	....	....	....	....	7 141
1939	6 670	95·6	18	264	282	4·0	....	7	3	10	·1	1	9	1	11	·2	2	·0	....	....	....	....	....	....	....	....	....	6 975
1940	7 023	96·2	12	245	257	3·5	....	10	1	11	·2	....	4	....	4	·0	4	·0	....	....	....	....	....	....	....	....	....	7 299
1941	6 840	95·8	32	248	280	3·9	....	11	3	14	·2	....	....	....	....	....	7	·1	....	....	....	....	....	....	....	....	....	7 141
1942	5 469	93·9	61	264	325	5·6	....	20	5	25	·4	....	2	....	2	·0	3	·1	....	....	....	....	....	....	....	....	....	5 824
1943	3 932	91·5	63	262	325	7·6	....	25	7	32	·7	....	5	....	5	·1	4	·1	....	....	....	....	....	....	....	....	....	4 298
1944	4 079	91·5	70	270	340	7·5	....	21	14	35	·8	1	7	....	8	·2	6	·1	....	....	....	....	....	....	....	....	....	4 468
1945	3 071	92·1	54	166	220	6·6	....	26	10	36	1·1	3	2	....	5	·2	2	·1	....	....	....	....	....	....	....	....	....	3 334
1946	5 294	94·4	89	172	261	4·7	1	36	2	39	·7	3	1	2	6	·1	6	·1	....	....	....	....	....	....	....	....	....	5 606
1947	6 021	93·3	101	237	338	5·2	....	49	9	58	1·0	13	11	1	25	·3	8	·1	....	....	....	....	....	....	....	....	....	6 450
1948	4 827	94·0	24	239	263	5·1	....	18	17	35	·7	1	3	....	4	·1	5	·1	....	....	....	....	....	....	....	....	....	5 134
1949	5 162	94·0	24	239	263	4·8	....	20	31	51	1·0	3	2	1	6	·1	7	·1	....	....	....	....	....	....	....	....	....	5 489
1950	5 077	93·6	14	269	283	5·2	....	14	41	55	1·0	....	1	2	3	·1	8	·2	....	....	....	....	....	....	....	....	....	5 426
1951	4 642	93·9	13	248	261	5·3	....	9	20	29	·6	....	4	2	6	·1	4	·1	....	....	....	....	....	....	....	....	....	4 942
1952	5 073	94·6	8	234	242	4·5	....	4	31	35	·6	....	2	....	2	·1	7	·1	....	....	....	....	....	....	....	....	....	5 359
1953	4 474	93·03	74	225	299	6·22	....	8	24	32	·6	....	2	...	2	·1	2	·1	....	....	....	....	....	....	....	....	....	4 809
1954	5 142	91·33	154	275	429	7·62	....	22	21	43	·76	1	6	2	9	·1	7	·1	....	....	....	....	....	....	....	....	....	5 630
1955	4 559	90·40	63	286	449	8·90	....	9	22	31	·62	1	1	1	3	·06	1	·02	Segregation of asbestosis diagnoses commenced in 1959									5 043
1956	4 600	90·78	25	401	426	8·41	....	8	25	33	·65	1	3	....	4	·08	4	·08	....	....	....	....	....	....	....	....	....	5 067
1957	3 925	89·08	30	424	454	10·30	....	8	10	18	·41	1	4	....	5	·12	4	·09	....	....	....	....	....	....	....	....	....	4 406
1958	5 154	90·20	46	483	529	9·26	....	15	9	24	·42	....	6	...	6	·10	1	·02	....	....	....	....	....	....	.	....	....	5 714
1959	5 242	90·10	66	485	551	9·47	....	9	....	....	·15	1	5	1	7	·12	3	·05	6	....	....	....	....	....	....	6	....	5 818
1960	5 214	90·54	50	473	523	9·08	....	5	....	5	·09	2	9	....	11	·19	3	·05	2	....	....	....	....	1	....	3	....	5 759
1961	5 188	90·18	54	479	533	9·26	....	13	....	13	·23	2	3	....	5	·09	3	·05	5	5	....	1	....	....	....	11	·19	5 753
1962	5 183	89·98	50	499	549	9·53	1	10	....	11	·19	1	5	....	6	·10	1	·02	2	7	....	1	....	....	....	10	·18	5 760
1963	4 795	87·21	188	451	639	11·62	....	22	....	22	·40	7	6	....	13	·24	3	·05	10	11	....	4	....	1	....	26	·47	5 498
1964	3 484	83·85	64	561	625	15·04	....	9	1	10	·24	....	1	....	1	·02	2	·05	13	17	....	2	....	....	1	33	·80	4 155
1965	3 770	87·39	53	459	512	11·87	....	6	....	6	·14	....	1	....	1	·02	5	·12	5	15	....	....	....	....	....	20	·46	4 314
1966	3 411	86·56	26	469	495	12·56	....	14	...	14	·36	3	1	....	4	·10	1	·02	4	12	....	....	....	....	....	16	·40	3 941
1967	1 644	81·03	19	332	351	17·30	....	7	1	8	·39	....	2	....	2	·10	5	·24	8	6	....	5	....	....	....	19	·94	2 029
1968	3 364	86·93	39	431	470	12·14	....	18	3	21	·54	....	1	1	2	·05	1	·03	5	4	....	3	....	....	....	12	·31	3 870
1969	3 406	87·77	36	412	448	11·55	....	13	1	14	·36	....	1	....	1	·03	1	·01	2	7	....	2	....	....	....	11	·28	3 881
1970	3 841	89·73	30	400	430	10·04	....	6	...	6	·14	....	1	....	1	·02	3	·07	....	....	....	....	....	....	....	....	....	4 281
1971	3 915	91·80	15	327	342	8·02	....	5	2	7	·16	....	....	....	....	....	1	·02	....	....	....	....	....	....	....	....	....	4 265
1972	4 647	93·30	20	308	328	6·55	....	5	2	7	·15	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	4 982
1973	5 078	95·27	27	215	242	4·54	....	4	3	7	·13	....	....	....	....	....	2	·04	....	1	....	....	....	....	....	1	·02	5 330
1974	4 803	93·02	31	310	341	6·60	....	4	4	8	·15	....	2	....	2	·04	....	....	3	7	....	....	....	....	....	10	·19	5 164
1975	8 394	96·53	33	242	275	3·16	....	11	3	14	·16	....	....	....	....	....	1	·01	4	7	1	....	....	....	....	12	·14	8 696
1976	5 495	94·94	20	250	270	4·67	....	7	5	12	·21	....	....	....	....	....	....	....	1	9	....	....	....	....	....	10	·18	5 788
1977	7 172	96·74	18	212	230	3·10	....	1	7	8	·11	....	....	....	....	....	....	....	....	3	....	1	....	....	..	4	·05	7 414
1978	6 719	97·05	17	174	191	2·75	....	....	5	5	·07	....	....	....	....	....	....	....	2	6	....	...	....	....	....	8	·08	6 923
1979	3 517	94·61	10	171	181	4·88	....	....	6	6	·21	....	....	....	....	....	....	....	...	7	....	1	....	....	....	8	·11	3 712
1980	4 775	96·92	1	144	145	0·94	....	2	1	3	·16	....	....	....	....	....	....	....	....	4	....	....	....	....	....	4	·08	4 912

4.2.3. HEALTH CERTIFICATES ISSUED TO NEW APPLICANTS AND RE-EXAMINEES

The following health certificates were issued under the Mines Regulation Act:—

Initial Certificates (Form 2)	4 524
Temporary Rejection Certificates (Form 3)	....
Rejection Certificates (Form 4)	....
Re-Admission Certificates (Form 5)	....
Special Certificates (Form 9)	....
Total	4 524

5. *Miners' Phthisis Act*

The amount of compensation paid during the year was $3 717.80, compared with $4 087.40 for the previous year.

The number of beneficiaries under the Act as on 31/12/1980 was 14, being 2 ex-miners and 12 widows.

R. S. THOMPSON,
Superintendent, Mine Workers' Relief Act
and
Chairman, Miners' Phthisis Board.

MINING STATISTICS
to 31st December, 1980

•

Table of Contents

	Page
Table I.—Tonnes of Ore Treated and Yield of Gold and Silver, in kilograms reported to the Mines Department, from operating mines during 1980, and Total Production recorded to 31st December, 1980, from those mines	244
Table II.—Total Alluvial, Dollied and Specimen Gold, Tonnes of Ore Treated, Yield of Gold and Silver therefrom, reported to Mines Department from each respective Goldfield and District during 1980	254
Table III.—Total Production of Alluvial, Dollied and Specimen Gold, Tonnes of Ore Treated, Yield of Gold and Silver therefrom, since inception to 31st December, 1980	255
Table IV.—Total Output of Gold Bullion, Concentrates, etc., entered for Export, and received at the Perth Mint from 1st January, 1886	256
MINERALS OTHER THAN GOLD	
Table V.—Quantity and Value of Minerals, other than Gold, as reported to the Mines Department during 1980	256
Table VI.—Total Mineral output of Western Australia, showing for each mineral, the progressive quantity produced and value thereof as reported to the Mines Department to 31st December, 1980	261
Table VII.—Showing average number of Men Employed above and underground in the larger mining companies operating in Western Australia during the Years 1979 and 1980	263

TABLE I

PRODUCTION OF GOLD AND SILVER AS REPORTED TO THE MINES DEPARTMENT DURING 1980

(For details concerning Mines and Centres not listed see Annual Report for 1966 or previous Reports.)

(*Note*—Lease numbers in brackets indicate that the holding was *voided* during the year.)

(*Note*—*Denotes mainly derived from treatment of tailings. † Denotes mainly derived from lead ore. ‡ Denotes mainly derived from copper ore. ° Concentrates)

Kimberley Goldfield

Mining Centre	Number of Lease	Registered Name of Company or Lease	Total for 1980					Total Production				
			Alluvial	Dollied and Specimens	Ore treated	Gold therefrom	Silver	Alluvial	Dollied and Specimens	Ore treated	Gold therefrom	Silver
			kg	kg	Tonnes	kg	kg	kg	kg	Tonnes	kg	kg
Halls Creek	G.M.L. 80/154	Argonaut	·091	....	....	....	·006	·091	....	....	....	·006
	153	Golden Fleece	·035	....	....	....	....	·035	....	....	....	....
	164	Lucky Four	·735	....	....	....	....	·735	....	....	....	....
	152	Nameless	·009	....	....	....	....	·009	....	....	....	....
		Deposited at Mint—Crown Land generally	·412	2·005	....	....	....	·412	2·005	....	....	....

Pilbara Goldfield

MARBLE BAR DISTRICT

Mining Centre	Number of Lease	Registered Name of Company or Lease	Alluvial (1980) kg	Dollied and Specimens (1980) kg	Ore treated (1980) Tonnes	Gold therefrom (1980) kg	Silver (1980) kg	Alluvial (Total) kg	Dollied and Specimens (Total) kg	Ore treated (Total) Tonnes	Gold therefrom (Total) kg	Silver (Total) kg
Bamboo Creek	G.M.L. 45/1118	Kitchener	....	....	186·00	·312	....	....	....	3 632·22	95·119	·110
Marble Bar	1487	Charger	....	....	294·00	·594	....	·292	....	2 024·00	4·497	....
	1536	Charlie	....	....	338·00	9·028	....	....	....	346·00	9·278	....
	1529	Halleys Comet	....	....	....	12·346	1·536	....	....	6 462·06	331·826	36·494
	1183	Mickie South Extended	....	....	250·00	·769	....	....	....	250·00	·769	....
	1616	Miracle	....	....	99·00	·569	....	....	....	99·00	·569	....
	1390	Nick	....	....	6·00	·025	....	....	....	48·00	·316	....
	1632	Old Timer Two	....	....	304·00	·246	....	....	....	304·00	·246	....
	1651	Two Tickets	....	....	140·00	·078	....	....	....	140·00	·078	....
	D.C. 45/1222	Adamson, B. J.	....	·384	....	....	....	....	·384	....	....	....
	1306	Dorrington, A.	....	·029	....	....	....	....	·029	....	....	....
		Sundry Claims	·190	·568	....	....	....	2·430	9·120	23 017·39	407·946	·341
Telfer	G.M.L. 45/1430 etc	Newmont Proprietary Limited	....	....	478 200·00	4 280·069	169·102	....	....	1 646 409·00	21 005·457	310·878
Western Shaw	1570	Flossies Gift	·231	....	....	....	....	·231	....	....	....	....
		Deposited at Mint—Crown land generally	·263	·690	....	....	....	·263	·690	....	....	....
		Banks and gold dealers	·161	....	....	....	....	455·783	14·221	....	·479	69·204

NULLAGINE DISTRICT

Mining Centre	Number of Lease	Registered Name of Company or Lease	Alluvial (1980) kg	Dollied and Specimens (1980) kg	Ore treated (1980) Tonnes	Gold therefrom (1980) kg	Silver (1980) kg	Alluvial (Total) kg	Dollied and Specimens (Total) kg	Ore treated (Total) Tonnes	Gold therefrom (Total) kg	Silver (Total) kg
Nullagine	G.M.L. 46/461	Golden Dawn	....	....	60·00	·103	....	....	....	60·00	·103	....
	411	Little Linden	....	1·123	....	....	·056	....	1·123	....	....	·056
	401	Lucky Star	....	....	11·00	·363	....	....	....	47·00	·967	....
		Sundry Claims	....	·038	....	....	....	....	....	....	....	....
		Deposited at Mint—Crown land generally	2·286	2·112	....	....	....	2·286	2·112	....	....	....

West Pilbara Goldfield

Mining Centre	Number of Lease	Registered Name of Company or Lease	Alluvial (1980) kg	Dollied and Specimens (1980) kg	Ore treated (1980) Tonnes	Gold therefrom (1980) kg	Silver (1980) kg	Alluvial (Total) kg	Dollied and Specimens (Total) kg	Ore treated (Total) Tonnes	Gold therefrom (Total) kg	Silver (Total) kg
Friendly Creek	M.C. 47/3135	Futuris Corporation	....	....	....	38·849	2·399	....	....	....	38·849	2·399
		Deposited at Mint—Crown land generally	·928	·321	....	....	....	·928	·321	....	....	....

Gascoyne Goldfield

Marangaroon	G.M.L. 9/71	Popeye	....	·030	....	....	....	....	·030	....	....	....
	46	Star of Marangaroon	....	2·027	140·00	2·500	....	....	5·318	3 906·99	176·351	....

Peak Hill Goldfield

Horseshoe	G.M.L. 52/679	Kristi	·570	....	....	....	·073	·570	....	....	....	·073
Peak Hill	664	Hit and Miss	....	....	30·00	·065	....	....	....	30·00	·065	....
	653	McWilliams Submarine	....	....	444·00	·580	....	....	....	757·00	1·817	....
	609	Morning Star	·520	1·894	....	....	....	·770	5·833	....	·038	6·641
	610	North Star	1·617	....	....	....	....	1·877	4·744	2 072·00	1·745	....
		Deposited at Mint—Crown land generally	·156	·922	....	....	....	·156	·922	....	....	....

East Murchison Goldfield

LAWLERS DISTRICT

Kathleen Valley	G.M.L. 36/1473	Penocon	....	....	273·00	·305	....	....	....	273·00	·305	....
Lawlers	1518	Little Well	·056	....	....	....	....	·056	....	....	....	....
		Sundry Claims	·090	1·378	30·00	·100	....	12·584	15·425	18 147·71	305·027	8·566
Wildara Station	1407	Double A	....	....	92·00	·153	....	....	....	92·00	·153	....

WILUNA DISTRICT

		Deposited at Mint—Crown land generally	....	·143	....	....	....	....	·143	....	....	....

BLACK RANGE DISTRICT

Barrambie	G.M.L. 57/1293	Gold Hill	....	....	30·00	·015	....	....	....	30·00	·015	....
	1117	Scheelite Leases	....	....	17·00	·249	....	....	....	2 059·77	38·177	·610
Birrigrin	1296	Kelly	....	....	177·00	·581	....	....	....	177·00	·581	....
Montague	1270	Montague Boulder	....	....	100·00	·228	....	....	....	100·00	·228	....
Nungarra	1386	Two Mile	....	....	100·00	·100	....	....	....	100·00	·100	....
Sandstone	1278	Connemara	....	....	344·00	3·009	....	....	....	344·00	3·009	....
		Sundry Claims	....	....	202·00	·448	....	1·464	44·200	17 075·16	216·964	....
		L.T.T. 57/64 (2623H) Youanmi Tailings	....	....	....	*18·513	*1·505	....	....	....	*18·513	*1·505
		Deposited at Mint—Crown land generally	1·079	·674	....	....	....	1·079	·674	....	....	....

Murchison Goldfield

CUE DISTRICT

Cue	G.M.L.(20/2413)	White Hope	....	....	20·00	·100	....	....	....	20·00	·100	....
		Sundry Claims	·240	1·627	....	....	....	8·107	30·246	48 540·00	640·913	·178
Tuckanarra		Sundry Claims	....	....	76·00	·203	....	3·584	24·817	10 444·45	320·998	·004
		Deposited at Mint—Crown land generally	5·842	4·666	....	....	....	5·842	4·666	....	....	....

Table I.—*Production of Gold and Silver from all sources, etc.*—continued.

Murchison Goldfield—cont.

MEEKATHARRA DISTRICT

Mining Centre	Number of Lease	Registered Name of Company or Lease	Total for 1980 Alluvial	Total for 1980 Dollied and Specimens	Total for 1980 Ore treated	Total for 1980 Gold therefrom	Total for 1980 Silver	Total Production Alluvial	Total Production Dollied and Specimens	Total Production Ore treated	Total Production Gold therefrom	Total Production Silver
			kg	kg	Tonnes	kg	kg	kg	kg	Tonnes	kg	kg
Chesterfield		Sundry Claims	·132	....	....	....	....	·132	1·379	1 193·90	25·695	·038
Gabanintha	G.M.L. 51/2012	New Brew	....	....	300·00	·276	....	....	....	300·00	·276	....
	2022	New Brew East	....	....	600·00	·940	....	....	....	600·00	·940	....
	2021	New Brew South	....	....	540·00	1·003	....	....	....	540·00	1·003	....
		Sundry Claims	....	·242	....	....	....	·696	5·189	5 478·02	93·932	·114
Meekatharra	2313	Blue Horse	....	1·494	....	....	....	....	1·494	....	....	....
	2016	Commodore	....	....	58·00	·338	....	....	....	141·17	1·382	....
	2247	Fishers	....	....	300·00	·360	....	....	....	890·00	1·319	....
	2244	Gloria Jean	....	....	270·00	1·477	....	....	....	957·00	5·640	....
	2068	Halcyon	....	....	300·00	·580	....	....	·051	4 781·20	9·429	....
	2008 } 2015 }	Mines Administration	....	....	91 246·00	11·453	·023	....	....	91 246·00	11·453	·023
	2139	Ingliston	....	....	1 974·00	37·353	....	....	....	4 908·00	128·491	....
	2349	Phar Lap West	....	1·664	....	....	....	....	1·664	....	....	....
	2013	Prohibition	....	....	653·00	·776	....	....	....	1 215·13	1·829	....
		Sundry Claims	....	1·119	....	....	....	8·704	44·896	33 388·41	368·850	·407
Nannine	2433	John's Gordon	·058	....	....	....	....	·058	....	....	....	....
	2230	Nannine	....	....	365·00	2·230	....	....	....	365·00	2·230	....
Quins		Sundry Claims	·522	....	....	....	....	·991	40·112	3 903·00	84·549	....
Yaloginda	2050	Bluebird	....	·519	....	2·343	....	....	·519	1 236·49	3·134	....
	2387	Romsey Gold	....	....	....	·171	·005	....	....	....	·171	·005
		Ball Mill—Meekatharra	....	....	....	·041	·001	....	....	....	·041	·001
		State Battery Meekatharra	....	....	....	*4·638	*·128	....	....	196·10	*921·845	*·910
		L.T.T. 51/51 (2792H) Schmidt, L. G.	....	....	....	*·154	....	....	·076	....	*·736	....
		Deposited at Mint—Crown land generally	4·419	4·429	....	....	....	4·419	4·429	....	....	....

MOUNT MAGNET DISTRICT

Mining Centre	Number of Lease	Registered Name of Company or Lease	Total for 1980 Alluvial	Total for 1980 Dollied and Specimens	Total for 1980 Ore treated	Total for 1980 Gold therefrom	Total for 1980 Silver	Total Production Alluvial	Total Production Dollied and Specimens	Total Production Ore treated	Total Production Gold therefrom	Total Production Silver
			kg	kg	Tonnes	kg	kg	kg	kg	Tonnes	kg	kg
Lennonville	G.M.L. 58/1793	Ard Patrick	....	·031	....	....	....	....	·031	345·00	·439	....
	(1885)	Contura D.	....	....	97·00	·060	....	....	....	181·00	·122	....
	1882	Contura North	....	....	300·00	·420	....	....	....	300·00	·420	....
Mt Magnet	1689	Bigita	....	....	50·00	·060	....	....	....	50·00	·060	....
	1903	Chris	....	....	60·00	·050	....	....	....	60·00	·050	....
	1708	Gay Parisian	....	·471	320·00	·431	....	....	·471	1 227·00	1·842	....
	2050	Lady Zena	....	....	50·00	·030	....	....	....	50·00	·030	....
	1798	Edith	....	....	284·00	2·882	....	....	....	284·00	2·882	....
	1703	Leisa	....	....	406·00	·909	....	....	....	406·00	·909	....
	1788	Pamela	·888	....	....	....	....	·888	....	....	....	....
	1916	Sams Oak	....	....	10·00	·009	....	....	....	10·00	·009	....
		Sundry Claims	6·334	·760	329·00	·147	·012	11·437	86·845	65 060·70	944·657	·930
		Deposited at Mint—Crown land generally	1·621	1·088	....	....	....	1·621	1·088	....	....	....

Yalgoo Goldfield

Mining Centre	Number of Lease	Registered Name of Company or Lease	Total for 1980 Alluvial	Total for 1980 Dollied and Specimens	Total for 1980 Ore treated	Total for 1980 Gold therefrom	Total for 1980 Silver	Total Production Alluvial	Total Production Dollied and Specimens	Total Production Ore treated	Total Production Gold therefrom	Total Production Silver
			kg	kg	Tonnes	kg	kg	kg	kg	Tonnes	kg	kg
Goodingnow	G.M.L. 59/1357	Ark	....	·300	56·00	·737	....	....	·688	4 286·41	119·417	....
	1242	Carnation	....	....	95·00	·580	....	....	....	1 184·78	9·897	....
	1378	Horse Hole	....	....	112·00	·220	....	....	....	112·00	·220	....
	1356	Scorpio	....	....	120·00	1·648	....	....	....	120·00	1·648	....
	1349	Two by Two	....	....	87·00	·070	....	....	....	154·00	·145	....
Yalgoo	1345	Old Emerald	....	....	26·00	·681	....	....	....	26·00	·681	....
	1522	Telstar Mine	....	....	100·00	·200	....	....	....	100·00	·200	....
		Sundry Claims	....	....	62·00	·120	....	....	·733	2 726·84	31·535	....
		L.T.T. 59/31 (3174H) M. & S. Mining	....	....	....	*4·345	*·644	....	....	....	*8·956	*·644
		Deposited at Mint—Crown Land generally	·358	·175	....	....	....	·358	·175	....	....	....

Mt. Margaret Goldfield

MOUNT MORGANS DISTRICT

Linden	G.M.L. 39/724 etc.	Good Hope Mine	....	....	168·00	·032	....	....	....	168·00	·032	....
	744	Harlech Castle	·091	....	....	....	·011	·091	....	....	....	·011
	706	Mess Fury	....	....	310·00	·787	....	....	....	310·00	·787	....
Mt. Morgans	802	Bobby's Find	....	·042	....	....	....	....	·042	....	....	....
	870	Sellina	....	....	208·00	·457	....	....	....	208·00	·457	....
	786	Utnapishtin	....	....	47·00	·050	....	....	....	47·00	·050	....
Murrin	812	Nelson	·803	....	....	....	·076	·803	....	....	....	·076
	762	Shirlie's Find	....	....	100·00	·282	....	....	....	100·00	·282	....
Redcastle	689	Lady Susan	....	....	12·00	·105	....	....	....	1 660·00	4·001	....
	710	Lady Susan West	....	·038	686·00	·933	....	....	·038	686·00	·933	....

MOUNT MALCOLM DISTRICT

Diorite	G.M.L. 37/1974	Puzzle	....	·155	899·00	6·183	....	....	·155	1 261·88	8·974	....
	2102	Tiny Bit	....	·106	....	....	·013	....	·106	....	....	·013
Lake Darlot	2061	Monte Christo	....	....	97·00	·299	....	....	....	97·00	·299	....
Leonora	2184	Crookies	....	....	304·00	·358	....	....	....	304·00	·358	....
	2185	Doddsy's Star	....	·019	39·00	·345	....	....	·019	39·00	·345	....
	2107	Fine Time	....	·154	....	....	....	....	·154	....	....	....
	2077	Garden	....	....	40·00	·280	....	....	....	95·00	·556	....
	2045	Gray Lode	....	....	200·00	·363	....	....	....	630·00	·774	....
	2084	Harbour Lights	....	....	512·00	1·078	....	....	....	1 126·00	2·046	....
	1888	Healeys Hope	....	....	404·00	1·588	....	....	....	1 041·83	8·201	....
	2083	Heartbreak	....	....	60·00	·377	....	....	....	243·00	1·513	....
	2150	Helens Lode	....	....	130·00	·295	....	....	....	130·00	·295	....
	2015	Island	....	·155	110·00	·837	....	....	·155	2 092·72	16·436	....
	2100	Leeta	....	....	24·00	·037	....	....	....	24·00	·037	....
	2186	Lucky Burrow	·099	....	....	....	·006	·099	....	....	....	·006
	2218	Malcolm Perseverance	....	....	40·00	·061	....	....	....	40·00	·061	....
	2103	Picnic	....	....	331·00	·842	....	....	....	1 373·00	2·584	....
	2163	Ross's Lease	....	·029	....	....	....	....	·029	....	....	....
	(1762)	Sons of Gwalia	....	....	109·00	2·654	....	....	·718	10 519·07	28·445	....
	2114	Super Dog	....	....	94·00	1·153	....	....	....	94·00	1·153	....
	1860	Tower Hill	....	....	8 269·00	40·328	·015	....	....	15 129·61	56·300	·015
	1859	Tower Hill South	....	....	359·00	1·043	....	....	....	359·00	1·043	....
	1906	Two Glads	....	·677	1 465·00	19·199	·078	....	·677	10 463·28	79·159	·078
		Sundry Claims	5·740	1·033	188·00	2·458	·125	7·355	13·455	26 695·52	424·389	·994
Malcolm	2217	Alice	·012	....	....	....	·014	·012	....	....	....	·014
		State Battery—Lake Darlot	....	....	....	*1·021	*·088	....	....	18·29	*135·763	*·243
		State Battery—Leonora	....	....	....	*8·048	*·679	....	....	92·46	*125·738	*4·928
		Deposited at Mint—Crown land generally	1·192	1·516	....	....	....	1·192	1·516	....	....	....

MOUNT MARGARET DISTRICT

Burtville	G.M.L. 38/2828	Burtville Omicron	....	....	235·00	·533	....	....	....	235·00	·533	....
	2802	Burtville Zeta	....	....	305·00	·145	·001	....	....	305·00	·145	·001
Erlistoun	(2838)	J.J.	....	....	268·00	·476	....	....	....	268·00	·476	....
	2824	No mistake	....	....	804·00	3·321	....	....	....	804·00	3·321	....
	2854	Jerringa	....	·341	....	....	....	....	·341	14·00	·045	....
Laverton	2679	Bulldog	....	....	41·00	·100	....	....	....	1 634·67	1·591	....
	2818	Craggiemore South	....	....	888·00	1·744	....	....	....	2 799·00	4·965	....
	2985	Dockie Time	....	·682	....	....	....	....	·682	....	....	....
	2899	Ives End (North)	·192	....	250·00	·234	....	·192	....	250·00	·234	....
	2844	Her Mistake	....	....	190·00	·623	....	....	....	190·00	·623	....
	2799	Ida H. North End	....	....	133·00	·078	....	....	....	433·00	·316	....
	2867	North	....	....	60·00	·007	....	....	....	250·00	·402	....
	2900	Ives End (South)	....	....	212·00	·510	....	....	....	212·00	·510	....
	2968	Tricias Find	·767	....	....	....	....	·767	....	....	....	....
	2784 etc.	Whim Creek Cons.	....	....	256·00	1·297	....	....	....	256·00	1·297	....
		Sundry Claims	....	·842	....	·340	....	6·705	47·601	18 321·38	290·411	....
		L.T.T. 38/78 (2964H) Tucker, L	....	....	....	*·055	....	....	....	....	*·055	....
		L.T.T. 38/69 (2709H) Hopkins & Crocker	....	....	....	*16·107	....	....	....	....	*16·201	....
		L.T.T. 38/74 (2903H) Strong, A. P.	....	....	....	*·278	....	....	....	....	*·278	....
		Deposited at Mint—Crown land generally	·472	·779	....	....	....	·472	·779	....	....	....
		Banks and Gold Dealers	·105	....	....	....	....	80·517	3·362	....	·907	....

Table I.—*Production of Gold and Silver from all sources, etc.*—continued.

North Coolgardie Goldfield

MENZIES DISTRICT

Mining Centre	Number of Lease	Registered Name of Company or Lease	Total for 1980 Alluvial kg	Total for 1980 Dollied and Specimens kg	Total for 1980 Ore treated Tonnes	Total for 1980 Gold therefrom kg	Total for 1980 Silver kg	Total Production Alluvial kg	Total Production Dollied and Specimens kg	Total Production Ore treated Tonnes	Total Production Gold therefrom kg	Total Production Silver kg
Goongarrie	G.M.L. 29/6095	Joy Margaret	....	....	80·00	·279	....	....	....	80·00	·279	....
	6026	Long Wait	....	·041	....	....	....	....	·041	31·00	·568	....
	M.L. 29/24	Higgs, W.	....	....	539·00	·837	....	....	....	626·00	1·099	....
Menzies	G.M.L. 29/5971	Alfia	....	....	34·00	·289	....	....	....	117·00	3·991	....
	5815	Espacia	....	....	1 053·00	10·735	....	....	....	5 618·00	32·427	....
	5780	Good Enough	....	....	865·00	2·926	....	....	....	5 136·41	35·707	·048
	6049	Little Buffy	....	....	265·00	·609	....	....	....	265·00	·609	....
	5814	Lucky Five	....	....	80·00	·238	....	....	....	146·00	·337	....
		Sundry Claims	....	....	91·00	·645	....	1·769	19·490	44 136·69	829·598	25·311
Mt Ida	6000	Corida	....	....	583·00	4·489	....	....	....	742·00	5·915	....
	6103	Madhatter	....	·263	....	·139	....	....	·263	....	·139	....
	6037	Pianto Find	....	....	93·00	·317	....	....	....	93·00	·317	....
		Sundry Claims	....	....	9·00	1·542	....	1·497	13·773	16 463·99	259·213	·004
		State Battery—Menzies	....	....	....	*1·540	*·266	....	*·237	20·32	*139·759	*35·910
		L.T.T. 29/56 (2824H) Woosnam, G.	....	....	....	*1·129	....	....	....	....	*1·332	....
		L.T.T. 29/63 (2139H) Yundaga Mining	....	*17·018	....	*5·854	*·187	....	*24·550	....	*12·684	*·187

ULARRING DISTRICT

Mining Centre	Number of Lease	Registered Name of Company or Lease	Total for 1980 Alluvial kg	Total for 1980 Dollied and Specimens kg	Total for 1980 Ore treated Tonnes	Total for 1980 Gold therefrom kg	Total for 1980 Silver kg	Total Production Alluvial kg	Total Production Dollied and Specimens kg	Total Production Ore treated Tonnes	Total Production Gold therefrom kg	Total Production Silver kg
Davyhurst	G.M.L. 30/1333	Makai	....	....	31·00	·254	....	....	....	86·00	·487	....
Morleys	(1094)	First Hit	....	....	43·00	·360	....	....	....	43·00	·360	....
Mulline	1334	Good Chance	....	....	42·00	·248	....	....	....	42·00	·248	....
	1173	Riverina	....	....	601·00	1·338	....	....	·214	2 240·14	7·673	....
		L.T.T. 30/46 (2821H) Jones Mining N.L.	....	....	....	*10·435	....	....	....	....	*10·435	....
		L.T.T. 30/108 (3204H) Jones Mining N.L.	....	....	....	*·416	....	....	....	....	*·416	....

NIAGARA DISTRICT

Mining Centre	Number of Lease	Registered Name of Company or Lease	Total for 1980 Alluvial kg	Total for 1980 Dollied and Specimens kg	Total for 1980 Ore treated Tonnes	Total for 1980 Gold therefrom kg	Total for 1980 Silver kg	Total Production Alluvial kg	Total Production Dollied and Specimens kg	Total Production Ore treated Tonnes	Total Production Gold therefrom kg	Total Production Silver kg
Kookynie	G.M.L. 40/992	Twice	....	....	47·00	·456	....	....	....	47·00	·456	....
Niagara	1053	Give It A Go	....	....	62·00	·719	....	....	....	62·00	·719	....

YERILLA DISTRICT

Mining Centre	Number of Lease	Registered Name of Company or Lease	Total for 1980 Alluvial kg	Total for 1980 Dollied and Specimens kg	Total for 1980 Ore treated Tonnes	Total for 1980 Gold therefrom kg	Total for 1980 Silver kg	Total Production Alluvial kg	Total Production Dollied and Specimens kg	Total Production Ore treated Tonnes	Total Production Gold therefrom kg	Total Production Silver kg
Edjudina	G.M.L. 31/1460	Golden Tameira	....	....	160·00	·374	....	....	....	160·00	·374	....
Pinjin	1458	Anglo Saxon	....	....	48·00	·163	....	....	....	48·00	·163	....
Yarri	1464	Black Rooster	....	....	796·00	1·560	....	....	....	1 224·00	2·470	....
	1474	Cindy	....	....	263·00	·619	....	....	....	566·00	1·404	....
	1320	Margaret	....	....	608·00	1·765	....	....	....	6 428·15	45·704	·010
	1543	Silver	....	....	473·00	1·816	....	....	....	473·00	1·816	....
		Sundry Claims	·019	·341	....	....	....	·046	·581	19 308·94	201·323	·043
Yerilla	1514	Temple Bar R.R.	....	....	....	·287	....	....	....	....	·287	....
Yilgangie	1467	Johns Find	....	....	42·00	·032	....	....	....	42·00	·032	....
	1209 etc.	Yilgangie Queen	....	....	109·00	·515	·088	....	....	460·55	5·278	·088
		Deposited at Mint—Crown land generally	....	·097	....	....	....	....	·097	....	....	....

Broad Arrow Goldfield

Bardoc	G.M.L. 24/2521	Bardoc Consuls	....	....	530·00	·984	....	....	....	530·00	·984	....
	2501	Bardoc Extended South	....	....	96·00	·100	....	....	....	96·00	·100	....
	2680	Lady Jean....	....	....	21·00	·048	....	....	....	21·00	·048	....
	2511	Near Miss	....	....	286·00	·560	....	....	....	286·00	·560	....
	2490	Three and One	....	....	9·00	·148	....	....	....	9·00	·148	....
		Sundry Claims	....	·228	111·00	·147	....	1·709	38·115	20 251·17	268·480	....
Black Flag	2679	Dasher	....	....	1 345·00	5·201	....	....	....	1 345·00	5·201	....
	2563	Marbill	....	....	389·00	1·430	....	....	....	389·00	1·430	....
	2486	Natal	....	....	624·00	2·273	....	....	....	624·00	2·273	....
Broad Arrow	2741	Gloria	....	....	231·00	·565	....	....	....	231·00	·565	....
	2561	Madam Kelly	....	....	278·00	·284	....	....	....	278·00	·284	....
	2528	Toni's Luck	....	....	18·00	·065	....	....	....	18·00	·065	....
	2348	Wentworth	....	....	140·00	1·139	....	....	....	622·62	5·502	....
		Sundry Claims	3·820	·092	381·00	·322	....	35·190	98·924	42 715·87	556·219	·044
Cashmans	2487	Lorraine	....	....	137·00	·220	....	....	....	137·00	·220	....
Christmas Reef	2509	Fare Adelaide	....	....	465·00	·486	....	....	....	465·00	·486	....
Fenbark	2523	Wendy Gully	....	....	345·00	·537	....	....	....	345·00	·537	....
Grants Patch	2311	Bent Tree	....	....	81·00	·260	....	....	....	2 154·76	7·828	....
Ora Banda	2290 2270 }	Gimlet South Leases	....	....	824·00	1·971	....	....	....	80 095·56	225·46	5·120
	2522	Happy Hours	....	....	208·00	·196	....	....	....	208·00	·196	....
	2351	Sand King	....	·155	....	....	....	....	·155	28·46	1·669	....
	2516	Six Boys	....	....	110·00	·215	....	....	....	110·00	·215	....
	2463	Three Boys	....	....	56·00	·045	....	....	....	132·00	·134	....
Paddington	2594	Fireside	....	....	117·00	·194	....	....	....	117·00	·194	....
	2329	Shirley Lorna	....	....	358·00	·895	....	....	....	455·00	1·096	....
Siberia	2405	Pride of Erin	....	....	218·00	·405	....	....	....	365·00	·574	....
		State Battery—Ora Banda	....	*·270	....	....	....	....	*·270	130·10	*892·098	*3·976
		L.T.T. 24/68 (3278H) 24/69 (3279H) Bodenham and Kean	....	....	....	*·386	....	....	....	....	*·386	....
		L.T.T. 24/50 (1872H) Harford, Savage and Stewart	....	*·446	....	*19·037	*2·734	....	*79·307	....	*21·124	*3·071
		L.T.T. 24/65 (3236H) Jones Mining N.L.	....	....	....	*1·603	....	....	....	....	*1·603	....
		Deposited at Mint—Crown land generally	·432	·016	....	....	....	·432	·016	....	....	....

North-East Coolgardie Goldfield

KANOWNA DISTRICT

Gindalbie	G.M.L. 27/1738	Four Dudes	....	....	....	170·00	·071	....	....	....	170·00	·071	....
Gordon	1719	Gordon	....	·271	....	....	....	....	·271	....	....	....	....
Kanowna	1586	Kanowna Red Hill	....	....	·076	608·00	2·695	....	....	·076	11 119·68	50·331	·060
		Sundry Claims	....	1·199	·475	....	....	·021	5·097	67·940	29 666·40	384·987	·074

KURNALPI DISTRICT

Karonie	G.M.L. 28/492	Rowes Find	....	....	....	157·00	·815	....	....	....	282·00	1·466	....
Kurnalpi	503	Tuppence	....	....	....	97·00	·160	....	....	....	356·00	·980	....
Mulgabbie	507	Casurina	....	....	....	80·00	·528	....	....	....	184·00	1·070	....

East Coolgardie Goldfield

EAST COOLGARDIE DISTRICT

Binduli	G.M.L. 26/7040	Rising Son	....	....	·885	88·00	2·748	....	....	2·256	186·00	6·474	....
	7136	Royal Standard	....	....	....	226·00	·114	....	....	....	226·00	·114	....
	7262	Royal Standard South	....	....	....	100·00	·120	....	....	....	100·00	·120	....
Boorara	6658	Waterfall	....	....	....	55·00	·186	....	....	·088	639·34	6·763	....
Boulder	5345 etc.	Kalgoorlie Lake View Pty Ltd	....	....	....	23 210·00	102·392	23·334	....	....	1 131 234·40	6 618·468	2 396·469
		Prior to transfer to present holders	....	....	....	....	....	....	....	26·700	62 162 730·32	732 838·733	106 492·417
	6663	Kalgoorlie Lake View Pty Ltd	....	....	....	1 886·00	16·387	....	....	....	4 733·00	34·001	....
	6837	Kalgoorlie Lake View Pty Ltd	....	....	....	1 451·00	1·822	....	....	....	1 451·00	1·822	....
	7124	Kalgoorlie Lake View Pty Ltd	....	....	....	679·00	2·075	....	....	·367	3 153·00	10·262	....

Table I—*Production of Gold and Silver from all sources, etc.*—continued

East Coolgardie Goldfield—cont.

EAST COOLGARDIE DISTRICT—cont.

Mining Centre	Number of Lease	Registered Name of Company or Lease	Total for 1980					Total Production				
			Alluvial	Dollied and Specimens	Ore treated	Gold therefrom	Silver	Alluvial	Dollied and Specimens	Ore treated	Gold therefrom	Silver
			kg	kg	Tonnes	kg	kg	kg	kg	Tonnes	kg	kg
Boulder—*continued*	7120	Kalgoorlie Lake View Pty Ltd	....	·037	....	....	....	....	·037	....	....	....
	6897	Kalgoorlie Lake View Pty Ltd	....	....	688·00	3·954	....	....	....	8 022·00	34·008	....
	6593	Kalgoorlie Lake View Pty Ltd	....	....	957·00	3·526	....	....	....	5 357·00	29·967	....
	6665	North Kalgurli Gold Mines	....	....	7 319·00	23·593	....	....	....	9 230·00	35·616	....
	6869	North Kalgurli Gold Mines	....	....	7 282·00	21·574	....	....	....	9 263·00	25·920	....
	7007	North Kalgurli Gold Mines	....	....	5 817·00	11·317	....	....	....	9 450·00	16·637	....
Feysville	6791	Butterfly	....	....	39·00	·181	....	....	....	63·10	·274	....
		Sundry Claims	8·320	....	100·00	·139	....	8·320	6·189	1 927·00	23·174	....
Hampton Plains	S.L. 53	Dellaca, Amadio and Divitini	....	....	244·00	·233	....	....	....	244·00	·233	....
	S.L. 1	Hampton Areas Aust. Pty Ltd	....	....	5 207·00	8·489	....	....	....	15 392·00	16·105	....
	P.P.L. 488 Loc. 48	Lethlean, L.	....	....	20·00	·072	....	....	....	54·59	1·593	....
	S.L. 20	Procak, R.	....	....	101·00	·244	....	....	....	101·00	·244	....
Kalgoorlie	G.M.L. 26/6997	Acrobat	....	....	443·00	·513	....	....	....	443·00	·513	....
	7135	Cygnet	....	....	300·00	·407	....	....	....	300·00	·407	....
	6678	Domeyer	....	....	68·00	·036	....	....	....	120·07	·409	....
	6692	Golden Pennies	....	....	318·00	·317	....	....	4·271	2 031·48	4·838	....
	6630	Golden Star	....	....	810·00	1·082	....	....	....	2 975·37	5·233	....
	(6702)	Hillside	....	....	577·00	·420	....	....	....	577·00	·420	....
	6563 etc.	Kalgoorlie Lake View Pty Ltd (Mt Charlotte)	....	....	859 669·00	3 188·746	655·565	....	....	5 060 352·38	21 036·982	2 918·518
		Prior to transfer to present holders	....	....	....	....	....	....	·178	4 947 601·36	21 751·229	5·336
	6485	Maritana Hill	....	....	654·00	·989	....	....	....	10 790·95	32·081	....
	7172	Missing Link	....	....	302·00	·233	....	....	....	302·00	·233	....
	6991	Taroya	....	....	294·00	·621	....	....	....	3 197·00	4·441	....
	7153	Trafalgar	....	....	176·00	·182	....	....	....	176·00	·182	....
	7038	Venezia	....	·281	....	....	....	....	·281	....	....	....
Wombola	7165	Big Mouth	....	....	461·00	·342	....	....	....	461·00	·342	....
	7223	Caledonian	....	....	3 874·00	12·451	....	....	....	3 874·00	12·451	....
	6844	Daisy Gold Mine	....	....	1 143·00	15·037	....	....	1·756	31 788·50	889·088	27·519
	7259	December Mine	....	....	81·00	·086	....	....	....	81·00	·086	....
	7015	Fifty Grand	....	....	344·00	·137	....	....	....	344·00	·137	....
	7148	Hammer and Tap	....	....	75·00	·297	....	....	....	136·00	·521	....
	7174	Inverness Again	....	....	426·00	2·207	....	....	....	426·00	2·207	....
	7013	Jimberella	....	....	2 269·00	7·466	....	....	....	2 499·00	7·769	....
	6877	Lurgan	....	·984	59·00	·581	....	....	1·326	805·00	6·356	....
	7187	Mader's Mine	....	....	40·00	·196	....	....	....	40·00	·196	....
	7309	Margie	....	....	13·00	·024	....	....	....	13·00	·024	....
	7176	Marise	....	....	133·00	·140	....	....	....	153·00	·225	....
	6781	Promise	....	·174	....	....	....	....	·174	12·19	·094	....
	6676	Rosemary	....	·277	27·00	·644	....	....	·277	1 072·00	12·491	....
	6888	Spinifex	....	....	190·00	·685	....	....	....	190·00	·685	....
		Sundry Claims	....	....	79·00	·862	....	....	22·459	30 716·31	492·135	·006
		State Battery—Kalgoorlie	....	....	....	*15·645	*1·894	....	....	396·97	1 352·953	*28·912
		L.T.T. 26/207 (3431H) L. A. Mills	....	....	....	*2·114	....	....	....	....	*2·114	....
		L.T.T. 26/206 (3430H) Jones Mining N.L.	....	....	....	*6·381	....	....	....	....	*6·381	....
		L.T.T. 26/56 (2065H) R. L. Smith	....	*·939	....	....	....	....	*·939	....	....	....
		Deposited at Mint—Crown land generally	1·272	3·021	....	....	....	1·272	3·021	....	....	....

BULONG DISTRICT

Mining Centre	Number of Lease	Registered Name of Company or Lease	Alluvial (1980)	Dollied and Specimens (1980)	Ore treated (1980)	Gold therefrom (1980)	Silver (1980)	Alluvial (Total)	Dollied and Specimens (Total)	Ore treated (Total)	Gold therefrom (Total)	Silver (Total)
Bulong	G.M.L. 25/1393	Judith	....	·083	....	....	....	....	·719	37·00	·221	....
	1418	Three Boys	....	....	183·00	·218	....	....	....	183·00	·218	....
Morelands	1343	Old Timer	....	....	27·00	·251	....	....	....	27·00	·251	....
		L.T.T. 25/22 (3522H) Jones Mining N.L.	....	....	....	*·202	....	....	....	....	*·202	....

Coolgardie Goldfield.

COOLGARDIE DISTRICT

Bonnievale	G.M.L. 15/6729	Ada Ann	....	....	60·00	·075	....	....	....	60·00	·075	....
	6389	Daisy	....	....	116·00	·112	....	....	....	116·00	·112	....
	6465	Mystery	....	....	251·00	1·137	....	....	....	317·00	1·386	....
	5890	Rayjax	....	....	34·00	·570	....	....	1·416	2 100·09	61·910	·159
		Sundry Claims	....	....	48·00	·082	....	....	12·075	12 265·69	183·164	·034
Bulla Bulling	6278	Pool Mans Wealth	....	....	92·00	·416	....	....	....	326·00	1·523	....
	6424	The Golden Soak	....	....	334·00	·878	....	....	....	334·00	·878	....
Burbanks	6602	Belgium Queen Extended	....	....	300·00	·750	....	....	....	300·00	·750	....
	6591	Blue Bell	....	....	23·00	·106	....	....	....	23·00	·106	....
	6267	Grosmont	....	....	531·00	1·928	....	....	....	4 501·00	10·214	....
	6217	Lady Robinson	....	....	322·00	·982	....	....	....	700·41	1·601	....
	6069	New Lord Bobs	....	....	300·00	·565	....	....	....	821·97	2·551	....
	5757	Susan	....	....	1 859·00	3·872	....	....	....	1 859·00	3·872	....
	6375	Unknown	....	....	....	·291	....	....	....	....	·291	....
		Sundry Claims	·038	....	10·00	·032	....	1·750	15·475	20 140·74	299·281	·030
Cave Rocks	6137	Gold Coin	....	....	147·00	·148	....	....	....	147·00	·148	....
	6528	Three Sisters	....	....	69·00	·101	....	....	....	69·00	·101	....
Coolgardie	6462	Amandas Meed	....	....	720·00	1·165	....	....	....	720·00	1·165	....
	6317	Big Blow East	....	....	255·00	·350	....	....	....	255·00	·350	....
	6026	Cyanide North	....	....	883·00	2·615	....	....	....	1 169·83	3·071	....
	6362	De Profundis	....	5·626	....	....	....	....	6·962	....	....	....
	6282	Doreen Rose	....	....	259·00	·727	....	....	....	1 623·26	3·346	....
	422	Dorothys	....	....	45·00	·165	....	....	....	190·00	·340	....
	6701	Erics Dream	....	....	50·00	·290	....	....	....	50·00	·290	....
	6199	Fly Flat	....	....	470·00	·529	....	....	·559	470·00	·968	....
	6425	Heather Bell	....	....	280·00	·685	....	....	....	808·00	1·388	....
	6350	Hennessy	....	....	128·00	·032	....	....	....	297·00	·237	....
	6517	Last Chance	....	....	18·00	·173	....	....	....	18·00	·173	....
	6265	Lindsay's Patch	....	....	50·00	·050	....	....	....	50·00	·050	....
	5884	Lone Hand	....	....	305·00	·208	....	....	·617	956·71	2·970	....
	6460	Marjohn	....	·002	....	....	....	....	·002	....	....	....
	6154	Monkani	....	....	....	2·373	....	....	....	15 909·92	24·071	....
	6457	My Hope	....	....	20·00	·145	....	....	....	20·00	·145	....
	6680	Peters Wish	....	....	50·00	·180	....	....	....	50·00	·180	....
	6481	Que Sera Sera	....	....	12·00	·111	....	....	....	12·00	·111	....
	6383	Tamali	....	....	4·00	·028	....	....	....	4·00	·028	....
	6184	Three Mile Extended	·171	·077	40·00	·251	·012	·171	·355	109·00	·372	·012
	6363	Twenty Grand	....	....	107·00	1·100	....	....	....	107·00	1·100	....
	6346	Worked Out	....	....	106·00	·670	....	....	....	317·00	2·037	....
	6653	Zenith Jane	....	....	62·00	·100	....	....	....	62·00	·100	....
		Sundry Claims	....	·163	392·00	·897	....	7·375	95·943	95 296·12	948·984	·059
Eundynie	....	Sundry Claims	....	....	110·00	·410	....	·275	7·143	819·32	16·621	....
Gibraltar	6341	Reform	2·851	....	214·00	·691	·348	2·851	....	977·00	1·891	·348
Gnarlbine	6447	Gold Demon	....	....	193·00	·526	....	....	....	193·00	·516	....
Hampton Plains	P.P.L. 484 Loc. 59	McIlree, G.	....	....	300·00	·785	....	....	....	2 761·63	6·796	....
	S.L. 48	Francis, K.	....	....	33·00	·106	....	....	....	33·00	·106	....
	S.L. 42	Anderson and Rupe	....	....	13·00	·018	....	....		13·00	·018	....
	S.L. 48	Grainger, E.	....	....	43·00	·040	....	....	....	43·00	·040	....
	S.L. 252	Marmarac, C.	....	....	109·00	·613	....	....	....	109·00	·613	....
	S.L. 288	Peterkin, N.	....	....	50·00	·200	....	....	....	50·00	·200	....
	S.L. 288	Warren, J.	....	....	123·00	·184	....	....	....	123·00	·184	....
	S.L. 35	Waters, L.	....	....	101·00	·312	·012	....	....	101·00	·312	·012
Higginsville	G.M.L. 15/5647	Fair Play Gold Mine	....	....	639·00	1·314	....	·137	1·950	43 006·04	121·369	·001
	6061	Two Boys	....	....	511·00	1·232	....	....	9·074	4 873·64	37·960	....
		Sundry Claims	....	....	102·00	·441	....	....	5·824	4 272·34	63·525	....
Kambalda	6161	Elizabeth Ellis	....	....	330·00	·772	....	....	....	355·00	·852	....
	6426	St Barbara	....	....	230·00	·917	....	....	....	349·00	1·406	....
	M.L. 163 etc.	Western Mining Corporation	....	32·349	87 147·00	78·111	6·345	....	32·349	87 147·00	78·111	6·345
	M.L. 152 etc.	Western Mining Corporation	....	....	....	308·431	335·735	....	22·003	32·00	882·420	1 985·952
		Sundry Claims	....	....	132·00	·262	....	....	....	1 038·50	3·273	....
Larkinville	G.M.L. 15/6384	Newlark	....	....	50·00	·158	....	....	....	50·00	·158	....
		Sundry Claims	....	·064	9·00	·124	....	....	4·642	565·90	35·126	....
Logan's Find	....	Sundry Claims	....	....	14·00	·123	....	·214	17·157	3 648·64	113·935	1·409
Widgiemooltha	6344	Host Group	....	....	2 398·00	17·748	....	....	·995	4 827·89	41·149	....
	6468	The Fox	....	....	381·00	·748	....	....	....	381·00	·748	....
		Sundry Claims	....	·025	32·00	·010	....	1·446	14·645	16 798·21	215·460	·002
		State Battery—Coolgardie	....	....	....	*1·249	*·085	....	....	783·38	*1 354·465	*1·194
		Deposited at Mint—Crown land generally	·645	·171	....	....	....	·645	·171	....	....	....

Table I—*Production of Gold and Silver from all sources, etc.*—continued

Coolgardie Goldfield—cont.

KUNANALLING DISTRICT

Mining Centre	Number of Lease	Registered Name of Company or Lease	Total for 1980 Alluvial kg	Total for 1980 Dollied and Specimens kg	Total for 1980 Ore treated Tonnes	Total for 1980 Gold therefrom kg	Total for 1980 Silver kg	Total Production Alluvial kg	Total Production Dollied and Specimens kg	Total Production Ore treated Tonnes	Total Production Gold therefrom kg	Total Production Silver kg
Carbine	G.M.L. 16/1082	Hawkin's Find	....	....	922·00	·889	....	....	·270	5 771·00	10·623	·065
	1164	Rising Sun	....	....	63·00	·228	....	....	....	63·00	·228	....
Chadwin	1200	Magdalla	....	....	432·00	·593	....	....	....	432·00	·593	....
Dunnsville	1128	Min Min Revisited	....	·218	....	....	....	....	1·643	4·00	·234	....
	1126	Wealth of Nations	....	·230	164·00	1·406	....	....	·230	476·00	2·448	....
	1232	You and Me	....	....	124·00	·297	....	....	....	124·00	·297	....
Jourdie Hills	1224	Jourdie Star	....	·100	13·00	·180	....	....	·100	13·00	·180	....
	1197	Pride of Jourdie Hills	....	....	67·00	·570	....	....	....	67·00	·570	....
Kunanalling	1137	Barbara	....	....	142·00	·179	....	....	....	142·00	·179	....
	1052	Catherwood	....	....	516·00	·975	....	....	....	3 166·30	4·052	....
	1253	Destiny	·128	....	....	....	....	·128	....	....	....	....
	1111	Goldfarmer	....	....	105·00	·224	....	....	....	1 228·00	1·435	....
	1159	Goodyear	....	....	516·00	·975	....	....	....	516·00	·975	....
	1135	Kiora	....	....	110·00	·300	....	....	....	183·00	·544	....
		Sundry Claims	....	....	109·00	·303	....	6·735	30·928	18 661·66	324·451	·674
Kundana	1235	Pride of Kelly	....	....	185·00	·737	....	....	....	185·00	·737	....

Yilgarn Goldfield.

Mining Centre	Number of Lease	Registered Name of Company or Lease	Total for 1980 Alluvial kg	Total for 1980 Dollied and Specimens kg	Total for 1980 Ore treated Tonnes	Total for 1980 Gold therefrom kg	Total for 1980 Silver kg	Total Production Alluvial kg	Total Production Dollied and Specimens kg	Total Production Ore treated Tonnes	Total Production Gold therefrom kg	Total Production Silver kg
Bullfinch	G.M.L. 77/4535	Casas	....	....	1 199·00	2·416	·351	....	....	2 790·43	11·947	·420
	4560	Uranus	....	....	5 563·00	4·106	·444	....	....	5 563·00	4·106	·444
	5804	Karalee	....	....	89·00	·087	....	....	....	89·00	·087	....
	4607	Open Cut	....	....	133·00	·501	....	....	·400	1 023·49	2·967	....
		Sundry Claims	....	....	45·00	·114	....	·263	1·745	8 437·48	135·784	·755
Corinthian	4826	Corinthian South	....	....	15 098·00	16·150	3·090	....	....	15 703·00	18·295	3·090
Eenuin		Sundry Claims	....	....	195·00	·224	....	·098	2·829	3 183·39	64·860	·167
Golden Valley	4986	Elbi Extension	....	·048	....	....	....	....	·048	....	....	....
Greenmount	4823, 4524	Boomalli Ltd	....	....	1 233·00	4·634	....	....	....	1 233·00	4·634	....
	4829	Electrum	....	....	124·00	·047	....	....	....	467·00	1·497	....
	4888	Greenmount	....	....	489·00	·639	....	....	....	592·00	·795	....
Hopes Hill	4801	Hopes Hill	....	....	204·00	·483	....	....	....	256·00	·559	....
	4576	Irene Betty	....	·454	63·00	·120	....	....	·454	68·08	·167	·001
Kennyville	4802	Dorothy Leslie	....	....	352·00	·766	....	....	....	929·00	1·457	....
	4852	Victoria	....	....	207·00	·288	....	....	1·129	5 752·58	37·809	·066
		Sundry Claims	....	....	30·00	·027	....	....	·157	9 111·67	73·809	·017
Marvel Loch	4814	Frances Firness	....	....	3 474·00	12·227	1·237	....	21·998	39 739·43	423·715	14·136
	4646	Jacoletti South	....	....	202·00	·240	....	....	....	791·00	1·111	....
	4590	Koomarlin	....	....	112·00	·290	....	....	....	142·99	·450	·031
	5082	Lucky Lenneburg	....	....	1 395·00	2·654	·946	....	....	1 395·00	2·654	·946
	4631	Marvel Loch	....	....	4 003·00	17·041	17·036	....	....	5 385·00	40·127	17·036
	4796	Rhys	....	....	129·00	·038	....	....	....	129·00	·038	....
	4855	Treasury	....	....	101·00	·092	....	....	....	101·00	·092	....
	4035	Undaunted	....	....	209·00	11·181	....	....	....	1 581·17	18·026	·012
Mt Palmer	4632	North Palmer	....	....	478·00	2·211	....	....	....	478·00	2·211	....
	4250	Palmerston	....	....	248·00	·715	....	·063	·052	2 502·26	11·791	·059
Parkers Range	4570	Banker	....	....	123·00	·074	....	....	....	123·00	·074	....
	4508	Buffalo	....	....	421·00	·824	....	....	·322	2 470·50	9·703	·175
	4717	Centipede	....	·093	1 143·00	4·455	....	....	·093	1 352·00	4·957	....
	4512	Constance Una	....	....	204·00	·349	....	....	....	9 499·81	195·502	2·628
	4621	Dollar	....	....	94·00	·203	....	....	·114	422·18	2·408	....
	4905	Mopoke	....	....	258·00	1·791	....	....	....	258·00	1·791	....
	4765	Ripper	....	....	130·00	·253	....	....	....	451·00	2·330	....

	4818	Snowdrop	....	....	31·00	·216	....	....	....	31·00	·216	....
	4626	The Australia	....	....	6·00	·820	·278	....	·781	248·00	1·979	·313
	4821	White Horseshoe....	....	....	188·00	·480	....	....	....	318·00	·566	....
		Sundry Claims	....	....	74·00	·117	....	·205	9·453	15 107·83	179·386	·101
Southern Cross	4871	New Find	....	....	99·00	·160	....	....	....	174·00	·252	....
	4510	Three Boys	....	....	....	·306	·028	....	....	·51	2·635	·215
Westonia	4744	Pius Sheila	....	15·569	....	....	....	....	48·197	....	....	....
		State Battery—Marvel Loch	....	....	....	*5·793	*1·248	....	....	149·36	*202·644	*97·567
		L.T.T. 77/172 (2853H) J. Emmett	....	....	....	*1·168	*·030	....	....	....	*1·168	*·030
		L.T.T. 77/288 (2599H) Retreatment Enterprises	....	....	....	*1·618	*·351	....	....	....	*1·618	*·351
		Deposited at Mint—Crown land generally	·164	·235	....	....	....	·165	·235	....	....	....

Dundas Goldfield

Buldania	G.M.L. 63/2434	Queen of Sheba	....	....	98·00	·575	....	....	....	98·00	·575	....
Dundas	2506	Deep Leads	....	·092	....	....	....	....	·092	....	....	....
Norseman	1936 etc.	Central Norseman Gold Corporation....	....	....	192 526·00	2 337·339	717·995	....	....	6 370 615·18	89 482·618	56 270·193
	2373 etc.	Crabb Corporation	....	....	200·00	·139	....	....	....	200·00	·139	....
	2407	Ivy Bushes	....	....	221·00	·194	....	....	....	221·00	·194	....
	2364	Narweena	....	....	1 306·00	2·699	....	....	....	1 347·00	2·790	....
	2248	The Emperor	....	....	397·00	1·155	....	....	....	397·00	1·155	....
	2278	The Prince Alfred	....	....	508·00	·446	....	....	....	508·00	·446	....
		Sundry Claims	....	·242	98·00	·131	....	32·729	112·895	51 203·01	705·626	7·623
Peninsula	2319	Peninsula	....	....	485·00	7·658	....	....	·251	1 239·00	13·117	....
		State Battery—Norseman	....	·108	....	*3·243	*·180	....	·108	434·76	*839·894	*37·273
		L.T.T. 63/56 (2733H) Crabb Corporation	....	....	....	*3·707	*·828	....	....	....	*3·707	*·828
		Deposited at Mint—Crown land generally	....	·070	....	....	....	....	·070	....	....	....

Phillips River Goldfield

Hatters Hill	G.M.L. 74/284	Ric's Rocks	....	....	78·00	·297	....	....	....	78·00	·297	....
Kundip	277	Western Gem	....	....	199·00	2·518	....	....	....	1 191·33	15·971	·001
Ravensthorpe		Sundry Claims	....	....	....	·197	....	5·100	·239	7 384·44	99·665	1·279

State Generally

		Deposited at Mint—Crown land generally	11·496	15·527	....	....	....	11·496	15·527	....	....	....

TABLE II

Production of Gold and Silver from all Sources, showing in kilograms the output as reported to the Mines Department during the year 1980.

Goldfield	District	District: Alluvial	District: Dollied and Specimens	District: Ore Treated	District: Gold Therefrom	District: Total Gold	District: Silver	Goldfield: Alluvial	Goldfield: Dollied and Specimens	Goldfield: Ore Treated	Goldfield: Gold Therefrom	Goldfield: Total Gold	Goldfield: Silver
		kg	kg	Tonnes	kg	kg	kg	kg	kg	Tonnes	kg	kg	kg
West Kimberley	....	....	....	....	....	....	....	....	....	....	....	....	....
Kimberley	....	....	....	....	....	....	....	1·282	2·005	....	....	3·287	·006
Pilbara	Marble Bar	·845	1·671	479 817·00	4 304·036	4 306·552	170·638	3·131	4·944	479 888 ·00	4 304·502	4 312·577	170·694
	Nullagine	2·286	3·273	71·00	·466	6·025	·056						
West Pilbara	....	....	....	....	....	....	....	·928	·321	....	38·849	40·098	2·399
Ashburton	....	....	....	....	....	....	....	....	....	....	....	....	....
Gascoyne	....	....	....	....	....	....	....	....	2·057	140·00	2·500	4·557	....
Peak Hill	....	....	....	....	....	....	....	2·863	2·816	474·00	·645	6·324	·073
East Murchison	Lawlers	·146	1·378	395·00	·558	2·082	....	1·225	2·195	1 365·00	23·701	27·121	1·505
	Wiluna	....	·143	....	....	·143	....						
	Black Range	1·079	·674	970·00	23·143	24·896	1·505						
Murchison	Cue	6·082	6·293	96·00	·303	12·678	....	20·056	18·110	98 608·00	69·434	107·600	·169
	Meekatharra	5·131	9·467	96 606·00	64·133	78·731	·157						
	Day Dawn	....	....	....	....	....	....						
	Mt. Magnet	8·843	2·350	1 906·00	4·998	16·191	·012						
Yalgoo	....	....	....	....	....	....	....	·358	·475	658·00	8·601	9·434	·644
Mt. Margaret	Mt. Morgans	·894	·080	1 531·00	2·646	3·620	·087	9·473	6·568	18 847 ·00	117·341	133·382	1·106
	Mt. Malcolm	7·043	3·844	13 674·00	88·847	99·734	1·018						
	Mt. Margaret	1·536	2·644	3 642·00	25·848	30·028	·001						
North Coolgardie	Menzies	....	17·322	3 692·00	31·568	48·890	·453	·019	17·760	7 017·00	52·925	70·704	·541
	Ularring	....	....	717·00	13·051	13·051	....						
	Niagara	....	....	109·00	1·175	1·175	....						
	Yerilla	·019	·438	2 499·00	7·131	7·588	·088						
Broad Arrow	....	....	....	....	....	....	....	4·252	1·207	7 378·00	39·716	45·175	2·734
North East Coolgardie	Kanowna	1·470	·551	778·00	2·766	4·787	·021	1·470	·551	1 112·00	4·269	6·290	·021
	Kurnalpi	....	....	334·00	1·503	1·503	....						
East Coolgardie	East Coolgardie	9·592	6·598	928 294·00	3 458·007	3 474·197	680·793	9·592	6·681	928 504·00	3 458·678	3 474·951	680·793
	Bulong	....	·083	210·00	·671	·754	....						
Coolgardie	Coolgardie	3·705	38·477	102 016·00	440·415	482·597	342·537	3·833	39·025	105 484·00	448·271	491·129	342·537
	Kunanalling	·128	·548	3 468·00	7·856	8·532	....						
Yilgarn	....	....	....	....	....	....	....	·164	16·399	38 146·00	95·918	112·481	25·039
Dundas	....	....	....	....	....	....	....	....	·512	195 839·00	2 357·286	2 357·798	719·003
Phillips River	....	....	....	....	....	....	....	....	....	277·00	3·012	3·012	....
South West Mineral Field	....	....	....	....	....	....	....	....	....	....	....	....	....
Northampton Mineral Field	....	....	....	....	....	....	....	....	....	....	....	....	....
State Generally	....	....	....	....	....	....	....	11·496	15·527	....	....	27·023	....
Outside Proclaimed Goldfield	....	....	....	....	....	....	....	....	....	....	....	....	....
Total	....	....	....	....	....	....	....	70·142	137·153	1 883 737·00	11 025·648	11 232·943	1 947·264

TABLE III

Return showing total production reported to the Mines Department to 31st December, 1980.

Goldfield	District	District: Alluvial	District: Dollied and Specimens	District: Ore Treated	District: Gold Therefrom	District: Total Gold	District: Silver	Goldfield: Alluvial	Goldfield: Dollied and Specimens	Goldfield: Ore Treated	Goldfield: Gold Therefrom	Goldfield: Total Gold	Goldfield: Silver
		kg	kg	Tonnes	kg	kg	kg	kg	kg	Tonnes	kg	kg	kg
West Kimberley	....	....	....	....	....	....	....	·040	·768	1·02	·077	·885	1 160·705
Kimberley	....	....	....	....	....	....	....	283·896	96·417	23 312·89	537·869	918·182	4·011
Pilbara	Marble Bar	488·964	144·912	2 018 662·97	31 751·056	32 384·932	1 370·562	818·321	238·883	2 218 907·92	36 691·589	37 748·793	1 404·238
	Nullagine	329·357	93·971	200 244·95	4 940·533	5 363·861	33·676						
West Pilbara	....	....	....	....	....	....	....	202·799	11·976	25 300·54	798·569	1 013·344	61·831
Ashburton	....	....	....	....	....	....	....	288·283	15·006	6 916·33	90·617	393·906	1 305·455
Gascoyne	....	....	....	....	....	....	....	21·725	9·013	4 411·21	204·231	234·969	3·973
Peak Hill	....	....	....	....	....	....	....	108·745	183·516	799 756·12	10 046·565	10 338·826	118·082
East Murchison	Lawlers	221·690	75·201	2 055 637·12	25 750·696	26 047·587	848·153	282·164	693·860	12 835 281·81	113 761·102	114 737·126	1 877·841
	Wiluna	7·355	39·150	9 016 082·65	58 236·403	58 282·908	321·060						
	Black Range	53·119	579·509	1 763 562·04	29 774·003	30 406·631	708·628						
Murchison	Cue	166·118	291·390	6 926 725·34	43 662·736	44 120·244	8 548·605	822·583	1 882·852	15 900 642·67	189 055·889	191 761·324	16 343·909
	Meekatharra	462·732	593·588	2 492 505·85	41 023·394	42 079·714	164·348						
	Day Dawn	102·381	353·886	2 070 709·73	42 792·490	43 248·757	5 270·404						
	Mt. Magnet	91·352	643·988	4 410 701·75	61 577·269	62 312·609	2 360·552						
Yalgoo	....	....	....	....	....	....	....	56·835	102·630	456 719·04	8 303·655	8 463·120	48·016
Mt. Margaret	Mt. Morgans	112·085	292·523	1 242 638·67	22 342·484	22 747·092	181·461	376·644	1 111·539	11 764 651·70	154 924·536	156 412·719	8 179·759
	Mt. Malcolm	134·003	525·093	7 941 900·88	96 025·419	96 684·515	5 939·536						
	Mt. Margaret	130·556	293·923	2 580 112·15	36 556·633	36 981·112	2 058·762						
North Coolgardie	Menzies	52·773	244·093	1 997 735·83	44 716·050	45 012·916	1 222·601	151·940	648·540	3 826 353·17	80 734·426	81 534·906	2 260·710
	Ularring	4·831	227·341	554 060·43	13 968·512	14 200·684	693·202						
	Niagara	53·451	57·745	961 179·06	16 447·962	16 559·158	177·793						
	Yerilla	40·885	119·361	313 377·85	5 601·902	5 762·148	167·114						
Broad Arrow	....	....	....	....	....	....	....	688·619	967·594	1 496 499·55	23 695·260	25 351·473	189·476
North East Coolgardie	Kanowna	3 315·522	425·343	1 059 620·73	19 659·409	23 400·274	94·924	3 714·812	684·264	1 076 188·10	20 263·344	24 662·420	95·319
	Kurnalpi	399·290	258·921	16 567·37	603·935	1 262·146	·395						
East Coolgardie	East Coolgardie	1 059·119	1 311·990	109 232 108·18	1 243 680·148	1 246 051·257	210 436·659	1 911·526	1 812·541	109 428 059·69	1 247 851·084	1 251 575·151	210 439·776
	Bulong	852·407	500·551	195 951·51	4 170·936	5 523·894	3·117						
Coolgardie	Coolgardie	549·819	763·277	3 240 149·37	49 421·720	50 734·816	3 687·438	597·283	956·437	3 634 629·35	57 385·633	58 939·353	3 711·559
	Kunanalling	47·464	193·160	394 479·98	7 963·913	8 204·537	24·121						
Yilgarn	....	....	....	....	....	....	....	69·512	456·924	8 522 320·37	76 795·680	77 322·116	6 776·591
Dundas	....	....	....	....	....	....	....	70·176	520·646	8 455 931·26	119 791·362	120 382·184	69 274·511
Phillips River	....	....	....	....	....	....	....	18·883	25·608	134 052·68	3 925·275	3 969·766	2 520·036
South West Mineral Field	....	....	....	....	....	....	....	9·738	1·513	5 068·38	78·493	89·744	·472
Northampton Mineral Field	....	....	....	....	....	....	....	....	....	....	....	....	164·423
State Generally	....	....	....	....	....	....	....	48·847	53·974	27·43	321·902	424·723	1 015·922
Outside Proclaimed Goldfield	....	....	....	....	....	....	....	....	....	....	....	....	39·177
Total	....	....	....	....	....	....	....	10 543·371	10 474·501	180 615 031·23	2 145 257·158	2 166 275·030	326 995·792

TABLE IV

Total output of Gold Bullion, Concentrates, etc., entered for export and received at the Perth Mint from 1st January, 1886.

Year	Export	Mint	Total	Estimated Value
	kg	kg	kg	$A
From 1886 to 1960 (inclusive)	360 147·861	1 556 923·314	1 917 071·175	887 344 248
1961	91·524	27 025·885	27 117·409	27 413 780
1962	141·179	26 588·160	26 729·339	26 871 460
1963	145·109	24 744·257	24 889·366	25 035 372
1964	95·516	22 076·504	22 172·020	22 299 886
1965	93·204	20 417·579	20 510·783	20 722 164
1966	45·475	19 511·667	19 557·142	19 765 287
1967	85·325	17 830·932	17 916·257	18 071 924
1968	28·580	15 887·164	15 915·744	16 785 723
1969	43·951	14 431·968	14 475·919	17 707 219
1970	49·089	10 576·110	10 625·199	11 069 049
1971	29·183	10 795·117	10 824·300	11 921 570
1972	....	10 850·502	10 850·502	16 042 688
1973	6·098	7 934·406	7 940·504	18 326 747
1974	60·504	6 570·454	6 630·958	22 324 330
1975	39·341	6 950·413	6 989·754	28 887 180
1976	71·589	7 194·549	7 266·138	25 570 928
1977	105·448	9 721·736	9 827·184	42 572 837
1978	63·665	13 380·475	13 440·140	73 719 472
1979	136·583	11 520·938	11 657·521	109 124 526
1980	308·431	10 492·735	10 801·166	179 314 357
	361 787·655	1 851 424·865	2 213 212·520	1 620 890 747

	1979	1980
	$A	$A
Estimated Mint value of above production	1 172 052 737	1 187 327 671
Overseas Gold Sales Premium distributed by Gold Producers Association, 1920–1924	5 179 204	5 179 204
Overseas Gold Sales Premium distributed by Gold Producers Association from 1952	264 344 449	428 383 872
Estimated Total	$A1 441 576 390	$A1 620 890 747
Bonus paid by Commonwealth Government under Commonwealth Bounty Act, 1930	322 896	322 896
Subsidy paid by Commonwealth Government under Mining Industry Assistance Act, 1954, from 1955	29 200 611	29 200 611
Gross estimated value of gold won	$A1 471 099 897	$A1 650 414 254

For individual figures from 1886 to 1960 see 1976 Annual Report.

TABLE V

Quantity and Value of Minerals, other than Gold, Reported during the year 1980

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonne	Metallic Content	Value $A
		ALUMINA			
M.L. 70/1SA	.... South West	.... Alcoa of Australia Ltd	2 189 618	....	260 564 542
M.L. 70/1SA	.... South West	.... Alcoa of Australia Ltd	1 474 371	....	175 450 149
			3 663 989	....	(1) 436 014 691
		BARYTES			
M.L. 45/1522	.... Pilbara	.... Dresser Minerals International Inc.	26 602	....	(b) 650 042
		BUILDING STONE			
		Quartz			
M.C. 70/1921	.... South West	.... Cutts, J. E.	315	....	338
M.C. 70/2110	.... South West	.... Snowstone Pty. Ltd.	2 133	....	94 635
			2 448	....	(a) (c) 94 973
		Quartzite			
M.C. 70/1158–9	.... South West	.... House R. P.	1 535	....	(a) (c) 19 230
		Spongolite			
M.C. 70/726	.... South West	.... Universal Milling Co. Pty. Ltd.	260	....	(a) (c) 3 887
		CLAYS			
		Cement Clay			
M.C. 70/788	.... South West	.... Bell Bros. Pty. Ltd.	25 328	....	(a) (c) 63 319

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonne	Metallic Content	Value $A
		Fire Clay			
M.C. 70/436–7	South West	Midland Brick Co. Pty. Ltd.	262 947	....	39 442
M.C. 70/304 etc.	South West	Clackline Refractories Ltd.	5 887	....	11 774
M.C. 70/522–3	South West	Bridge, J. S.	95 774	....	95 774
			364 608	....	(a) (c) 146 990
		White Clay—Ball Clay			
M.C. 70/109	South West	Bristile Ltd.	1 131	....	(a) (c) 11 094
		Kaolin			
M.C. 70/247, 605	South West	Universal Milling Pty. Ltd.	163	....	(a) (c) 978
		Attapulgite (Fullers Earth)			
M.C. 70/16369	South West	Malina Holdings Ltd.	11 407	....	(a) (c) 204 325
		COAL			
C.M.L. 12/448 etc.	Collie	Griffin Coal Mining Co. Ltd.	1 737 288	....	35 565 595
C.M.L. 12/437 etc.	Collie	Western Collieries Ltd.	1 414 182	....	25 151 746
			3 151 470	....	(e) 60 717 341
		COBALT (Metallic by-product of Nickel Mining)			
				Cobalt Tonne	
M.L. 15/152 etc.	Coolgardie	Western Mining Corporation	....	900·670	10 290 116
M.L. 38/255 SA	Mt. Margaret	Agnew Mining Co. Pty. Ltd.		81·980	2 733 026
			....	982·650	13 023 142
		COPPER (Metallic by-product of Nickel Mining)			
				Copper Tonne	
M.L. 15/152 etc.	Coolgardie	Western Mining Corporation	....	2 549·494	3 878 038
M.L. 38/255 SA	Mt. Margaret	Agnew Mining Co. Pty. Ltd.	....	582·905	873 612
			....	3 132·399	4 751 650
		EMERALDS			
				Carats	
M.L. 20/116	Murchison	Bellairs, R. D.	....	13 000	78 000
		FELSPAR			
M.C. 70/2110	South West	Snowstone Pty. Ltd.	2 240	....	112 000
M.C. 59/5800, 5987	Yalgoo	Chandilla Exploration and Investments Pty. Ltd.	328	....	4 932
			2 568	....	(a) 116 932
		GLASS SAND			
M.C. 70/417–8 etc.	South West	Australian Glass Manufacturers	28 019	....	37 823
M.C. 70/1076	South West	Ready Mix Group (W.A.)	99 888	....	N.A.
M.C. 70/6056	South West	Zaninovich L. V.	1 460	....	1 460
			129 367	....	(c) 39 283
		GYPSUM			
M.C. 77/50 etc.	Yilgarn	H. B. Brady Pty. Ltd.	22 232	....	54 947
M.C. 77/9 etc.	Yilgarn	W.A. Plaster Mills	33 386	....	113 799
M.C. 70/15466 etc.	South West	Swan Portland Cement Ltd.	13 826	....	209 805
M.C. 70/611, 616 etc.	South West	Gypsum Industries of Aust. Pty. Ltd.	11 606	....	24 264
M.C. 70/1115–6	South West	McAndrew, R. W.	5 108	....	10 176
M.C. 9/43, 49, 50	Gascoyne	Agnew Clough Ltd.	207 112	....	713 638
			293 370	....	(a) 1 126 629
			Plaster of Paris reported as manufactured during the year—37 290 tonnes from 53 144 tonnes by Two (2) Companies		
		GARNET SANDS			
M.C. 70/11563	South West	Target Minerals N.L.	76	....	(b) 7 540

TABLE V.—*Quantity and Value of Minerals, other than Gold, Reported during the Year 1980—continued*

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonne	Metallic Content	Value $A
		IRON ORE			
		Pig Iron	Ore Treated Tonne	Pig Iron Recovered Tonne	
M.L. 77/2 SA	Yilgarn	Wundowie Iron & Steel Industry	61 327	38 988	(c) 4 241 104
		Ore Railed to Kwinana		Av. Assay Fe%	
M.L. 77/2 SA	Yilgarn	Dampier Mining Co. Ltd.	*1 657 610	63·00	(n) 12 229 942
		Ore Shipped Interstate			
M.L. 4/10 etc.	West Kimberley	Dampier Mining Co. Ltd.	57 510	69·23	(b) 395 666
M.L. 52/244 SA	Peak Hill	Mt. Newman Mining Co. Ltd.	6 486 977	64·00	(b) 71 628 071
		Ore Exported Overseas			
M.L. 4/10 etc.	West Kimberley	Dampier Mining Co. Ltd.	542 831	68·92	(b) 7 073 169
M.L. 4/50 etc.	West Kimberley	Dampier Mining Co. Ltd.	1 493 928	66·72	(b) 22 644 353
M.L. 52/244 SA	Peak Hill	Mt. Newman Mining Co. Ltd.	20 808 445	63·00	(b) 296 841 023
M.L. 47/4 SA	West Pilbara	Hamersley Iron Pty. Ltd.	36 396 815	63·54	(b) 536 758 500
T.R. 2401H	West Pilbara	Cliffs W.A. Mining Co. Pty. Ltd.	12 138 214	56·91	(b) 130 718 291
M.L. 45/235 SA	Pilbara	Goldsworthy Mining Ltd.	5 370 359	62·56	(b) 79 709 666
			84 952 689	....	1 157 998 681
		*Includes 862 715 tonnes shipped interstate			
		PELLETS (Exported Overseas)			
M.L. 47/4SA	West Pilbara	Hamersley Iron Pty. Ltd.	18 940	63·54	(b) 388 102
		* LIMESTONE (For Building, Burning and Agricultural Purposes)			
M.C. 70/1662	South West	Bell Bros. Pty. Ltd.	17 425	....	15 332
M.C. 70/684, 728	South West	Bell Bros. Pty. Ltd.	4 272	....	4 272
M.C. 70/1290	South West	Bellombra V.	9 766	....	29 301
M.C. 70/1755	South West	Cockburn Cement Ltd.	149 000	....	149 000
M.C. 70/713	South West	General Bulldozing Co. Pty. Ltd.	5 741	....	5 741
M.C. 70/1093	South West	Piper Walker Pty. Ltd.	114	....	114
M.C. 70/709	South West	Snader, R.	6 033	....	3 017
M.C. 70/2734–5	South West	Swan Portland Cement Ltd.	59 280	....	271 288
M.C. 70/1660	South West	Swan Portland Cement Ltd.	305 272	....	1 203 011
M.C. 70/17966	South West	Twilight Nominees	550	....	550
M.C. 70/989	South West	W.A. Limestone Co. Pty. Ltd.	38 300	....	95 750
M.C. 70/17025	South West	Wolfe, S. H.	700	....	3 500
M.L. 47/513	West Pilbara	Specified Services Pty. Ltd.	8 359	....	8 359
	South West	†Unspecified Producers	3 000	....	3 000
			607 812	....	(c) 1 792 235

* Incomplete. † From Private Property not held under the Mining Act.

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonne	Metallic Content	Value $A
		MANGANESE (Metallurgical Grade)		Av. Assay Mn%	
T.L. 52/14	Peak Hill	Universal Milling Co. Pty. Ltd.	1 481	47·5	31 444
M.L. 52/65	Peak Hill	Dampier Mining Co. Pty. Ltd.	212	47·0	5 294
			1 693	....	(b) 36 738
		MICA			
M.C. 45/7145, 8416	Pilbara	Pilbara Mica Corporation Ltd.	352	....	(b) 79 225
		MINERAL BEACH SANDS			
		Ilmenite (g)		Av. Assay TiO2%	
M.C. 70/619 etc.	South West	Westralian Sands Ltd.	165 062	55·00	
M.C. 70/746 etc.	South West	Cable Sands Pty. Ltd.	132 491	55·59	
M.C. 70/389	South West	Western Mineral Sands Pty. Ltd.	138 664	54·00	
M.C. 70/516	South West	Western Titanium Ltd.	350 908	54·53	
M.C. 70/7002	South West	Western Titanium Ltd.	103 802	59·44	
M.C. 70/7556	South West	Jennings Mining Ltd.	24 885	60·00	
M.C. 70/7062	South West	Allied Eneabba Pty. Ltd.	291 916	60·26	
			1 207 728		(b) 30 084 556
		Upgraded Ilmenite (*g*)			
M.C. 70/516	South West	Western Titanium Ltd.	48 992	91·69	

TABLE V.—*Quantity and Value of Minerals, other than Gold, Reported during the Year 1980—continued*

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonne	Metallic Content	Value $A
		Rutile (*g*) (*h*)		TiO2 Tonnes	
M.C. 70/7556	South West	Jennings Mining Pty. Ltd.	3 500	3 325	1 072 000
M.C. 70/7062	South West	Allied Eneabba Pty. Ltd.	43 537	41 773	12 003 661
M.C. 70/7002	South West	Western Titanium Ltd.	44 630	42 800	10 217 169
			91 667	87 898	(b) 23 292 830
		Leucoxene (*g*) (*h*)		TiO2 Tonnes	
M.C. 70/619 etc.	South West	Westralian Sands Ltd.	16 432	14 919	3 492 750
M.C. 70/516	South West	Western Titanium Ltd.	3 281	2 874	678 750
M.C. 70/746	South West	Cable Sands Pty. Ltd.	7 198	6 309	1 373 874
			26 911	24 102	(b) 5 545 374
		Monazite (*g*) (*h*)		ThO2 Units	
M.C. 70/516	South West	Western Titanium Ltd.	2 311	13 185	688 549
M.C. 70/619 etc.	South West	Westralian Sands Ltd.	1 152	7 477	303 754
M.C. 70/746 etc.	South West	Cable Sands Pty Ltd.	756	4 751	265 860
M.C. 70/7062	South West	Allied Eneabba Pty. Ltd.	6 759	44 007	2 426 089
			10 978	69 420	(b) 3 684 252
		Zircon (*g*) (*h*)		ZrO2 Tonnes	
M.C. 70/619 etc.	South West	Westralian Sands Ltd.	35 039	22 236	2 274 715
M.C. 70/746 etc.	South West	Cable Sands Pty. Ltd.	11 386	7 458	687 308
M.C. 70/516	South West	Western Titanium Ltd.	38 469	25 458	2 239 738
M.C. 70/7062	South West	Allied Eneabba Pty. Ltd.	135 170	89 454	8 826 170
M.C. 70/7556	South West	Jennings Mining Ltd.	2 696	1 752	134 820
M.C. 70/7002	South West	Western Titanium Ltd.	103 932	69 159	5 979 715
			326 692	215 517	(b) 20 142 466
		Xenotime (*g*) (*h*)		Y203 kg	
M.C. 70/516	South West	Western Titanium Ltd.	21	6 416	(b) 32 192
		NICKEL CONCENTRATES		Av. Assay Ni %	
M.L. 15/152 etc.	Coolgardie	Western Mining Corporation	285 462	12·61	235 513 421
M.L. 38/255 SA	Mt. Margaret	Agnew Mining Co. Pty. Ltd.	94 852	10·39	52 669 423
M.L. 15/336	Coolgardie	Selcast Exploration Ltd.	16 220	16·50	15 568 753
			396 534	....	(o) 303 751 597
		NICKEL ORE		Av. Assay Ni %	
M.C. 15/1288 M.L. 15/248	Coolgardie	Metals Exploration N.L.	86 565	3·62	(c) 18 544 973
		PALLADIUM (*h*) (Metallic by-product of Nickel Mining)		kg	
M.L. 15/152 etc.	Coolgardie	Western Mining Corporation	....	328·241	1 834 614
		PLATINUM (*h*) (Metallic by-product of Nickel Mining)			
M.L. 15/152 etc.	Coolgardie	Western Mining Corporation	....	63·609	954 184
		OCHRE			
M.C. 20/26, 29	Murchison	Universal Milling Co. Pty. Ltd.	53	....	(a) 897
		PETROLEUM Crude Oil	Kilolitres		
1H	Ashburton	West Australian Petroleum Pty. Ltd.	1 606 631	....	(m) 266 422 558
Lic. 1	South West	West Australian Petroleum Pty. Ltd.	18 117	....	(q) 2 359 634
			1 624 748	....	268 782 192
		Natural Gas	$M^3 10^3$		
Lic. 1	South West	West Australian Petroleum Pty. Ltd.	859 688	....	(p) 25 494 035
		Condensate	Tonne		
Lic. 1	South West	West Australian Petroleum Pty. Ltd.	2 435	....	N.A.

TABLE V.—*Quantity and Value of Minerals, other than Gold, Reported during the Year 1980—continued*

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonne	Metallic Content	Value $A
		SALT			
		State Total Reported to Mines Dept.	3 680 844	....	(b) 37 553 115
		SEMI PRECIOUS STONES			
		Amethyst	kg		
M.C. 9/444, 256	Gascoyne	Soklich, F.	1 269	....	6 247
		Moss Opal			
M.C. 63/60	Dundas	Soklich, F.	1 116	....	572
		Chalcedony			
M.C. 9/498, 884	Gascoyne	Soklich, F.	12	....	13
		Serpentinite			
M.C. 45/99	Pilbara	Stubbs S. H.	615	....	2 150
					8 982
		TALC			
M.L.70/433	South West	Three Springs Talc Pty. Ltd.	91 205	....	N.A.
M.L. 52/190	Peak Hill	Westside Mines N.L.	22 006	....	N.A.
			113 211	....	....
		SILVER	kg		
		By-Product of Gold Mining	1 699·150	....	767 895
		By-Product of Nickel Mining	350·659	....	127 356
			2 049·809	....	895 251
		TANTO-COLUMBITE ORES AND CONCENTRATES (*g*) (*h*)			
				TA205 Units	
M.L. 1/657 etc.	Greenbushes	Greenbushes Tin N.L.	97·800	4 248	8 256 170
M.C. 45/920, D.C. 45/755	Pilbara	Pilgan Mining Pty. Ltd.	33·880	1 173	1 645 975
M.C. 45/107 etc., D.C. 45/553	Pilbara	Goldrim Mining Australia Ltd.	13·167	690	1 494 154
M.C. 45/668 etc.	Pilbara	Endeavour Resources Ltd.	8·326	265	464 557
M.C. 09/2651-2	Gascoyne	Jays Exploration Pty. Ltd.	3·007	56	60 710
M.C. 59/5052	Yalgoo	Bowen M. J.	2·865	269	311 550
			159·045	6 701	(b) 12 233 116
		TIN CONCENTRATES		Sn Tonnes	
M.L. 1/657 etc.	Greenbushes	Greenbushes Tin N.L.	420·000	300·000	5 339 040
M.C. 45/668 etc.	Pilbara	Endeavour Resources Ltd.	108·070	76·180	1 105 070
M.C. 45/107 etc. D.C. 45/553	Pilbara	Goldrim Mining Australia Ltd.	8·501	6·203	101 323
M.C. 45/672, 700	Pilbara	Hart, D. N. & L. E.	3·320	2·180	28 612
M.C. 47/305	West Pilbara	Friendly Creek Mining Pty. Ltd.	18·243	11·186	147 830
			558·134	395·749	(b) 6 721 875
		VERMICULITE			
M.C. 74/1567	Phillips River	Vermiculite Industries Pty. Ltd.	159	....	(a) 1 590

REFERENCES

N.A. Not available for publication.
(a) Estimated F.O.R. Value.
(b) Estimated F.O.B. Value.
(c) Value at Works.
(d) Value of Mineral Recovered.
(e) Value at Pit Head.
(f) Estimated Value based on current price published.
(g) Only results of sales realised during the period under review.
(h) Metallic content calculated on assay basis.
(i) Concentrates.
(j) By-Products of Gold Mining.
(k) By-Products of Tin Mining.
(l) Value based on the Average Australian Value of Alumina as published by the Bureau of Mineral Resources in the Australian Mineral Industry Review.
(m) Value based on the price per barrel as assessed by the Commonwealth Government for Barrow Island Crude Oil at Kwinana.
(n) Nominal Price.
(o) Estimated F.O.B. Value based on the current price for Nickel Cathodes.
(p) Nominal Price at Well Head.
(q) Net Well Head Value.

TABLE VI

Total Mineral Output of Western Australia

Recorded mineral production of the State to 31st December, 1980, showing for each mineral the progressive quantity produced and value thereof, as reported to the Department of Mines; including Gold (Mint and Export) as from 1886, and Other Minerals as from commencement of such records in 1899.

Mineral		Quantity	Value $A
Abrasive Silica Stone	tonne	2	18
Alumina (from Bauxite)	"	25 517 415	2 422 962 046
Alunite (Crude Potash)	"	9 219	431 729
Antimony Concentrates (*a*)	"	11 132	1 863 882
Arsenic (*a*)	"	39 295	1 494 410
Asbestos—			
Anthophyllite	"	518	13 547
Chrysotile	"	11 420	989 397
Crocidolite	"	154 913	33 496 645
Tremolite	"	1	50
Barytes	"	90 295	2 690 857
Bauxite (Crude Ore) (*g*)	"	37 331	187 070
Beryl	"	4 099	1 029 757
Bismuth	kg	7 375	14 496
Building Stone (*g*)—			
Chrysotile-Serpentine	tonne	5	106
Granite (Facing Stone)	"	1 059	38 904
Lepidolite	"	84	713
Prase	"	10	275
Quartz (Deadwhite)	"	1 618	33 914
Quartz Crystal	"	1 830	24 967
Quartz	"	46 973	938 066
Quartzite	"	15 681	110 510
Sandstone	"	681	4 020
Sandstone (Donnybrook)	"	84	3 486
Slate	"	239	2 115
Spongolite	"	4 605	53 102
Tripolite	"	268	264
Calcite	"	5	50
Chromite	"	14 650	416 593
Clays—			
Bentonite	"	15 484	117 282
Brick, Pipe and Tile Clays	"	1 373 449	1 888 074
Cement Clays	"	726 030	1 479 044
Fireclay	"	3 289 694	2 397 926
Fullers Earth	"	21 941	389 352
White Clay—Ball Clay	"	34 436	252 771
Kaolin	"	10 695	53 687
Coal	"	60 997 330	352 328 323
Cobalt (Metallic By-Product Nickel Mining)	"	3 008	21 968 147
Copper (Metallic By-Product Nickel Mining)	"	16 415	17 364 485
Copper (Metallic By-Product) (*a*)	"	195	65 375
Copper Ore and Concentrates	"	319 599	11 701 660
Corundum	"	64	1 310
Cupreous Ore and Concentrates (Fertilizer)	"	88 519	3 311 561
Diamonds	(e)	....	48
Diatomaceous Earth (Calcined)	tonne	548	16 491
Dolomite	"	3 681	29 628
Emeralds (Cut and Rough)	carats	48 165	109 570
Emeralds	grams	1 407	11 149
Emery	tonne	21	750
Felspar	"	81 529	844 292
Fergusonite	kg	300	783
Gadolinite	tonne	1	224
Garnet Sands	"	761	56 974
Glass Sand	"	2 077 498	1 708 076
Glauconite (*h*)	"	6 571	300 679
Gold (Mint and Export)	kg	2 213 212	1 620 890 747
Graphite	tonne	156	2 608
Gypsum	"	2 917 884	8 203 256
Iron Ore—			
Pig Iron Recovered	tonne	1 296 263	76 999 512
Ore Exported	"	802 892 431	7 214 436 003
Pellets Exported	"	50 823 118	747 819 924
Locally Used Ore	"	36 059 783	289 345 160
For Flux	"	58 996	74 096
Jarosite	"	10	75
Kyanite	"	4 283	43 562
Lead Ores and Concentrates	"	489 720	10 636 394
Limestone	"	15 153 489	19 272 893
Lithium Ores—			
Petalite	"	8 042	124 123
Spodumene	"	108	3 627
Magnesite	"	60 376	1 075 116
Manganese—			
Metallurgical Grade	"	1 933 359	41 514 513

TABLE VI.—Total Mineral Output of Western Australia—*continued*

Mineral		Quantity	Value $A
Manganese—*continued*			
Battery Grade	tonne	2 254	90 860
Low Grade	,,	5 135	81 538
Mica	,,	2 648	162 003
Mineral Beach Sands—			
Ilmenite Concentrates	,,	13 279 841	210 198 878
Monazite Concentrates	,,	78 734	14 822 327
Rutile	,,	537 069	108 751 359
Leucoxene	,,	178 695	20 721 196
Zircon	,,	1 704 177	99 272 004
Xenotime	,,	328	343 931
Crude Concentrates	,,	158	1 553
Molybdenite	,,	79	1 730
Nickel Concentrates	,,	4 109 967	1 838 854 785
Nickel Ore	,,	782 698	70 699 625
Ochre—			
Red	,,	13 930	274 345
Yellow	,,	455	5 956
Peat	,,	4 052	62 633
Petroleum (Crude Oil)	kl	27 285 996	879 157 349
(Natural Gas)	$m^3 10^3$	7 324 642	104 169 646
(Condensate)	tonne	30 130	N.A.
Palladium (By-Product Nickel Mining)	kg	1 622	4 426 647
Platinum (By-Product Nickel Mining)	,,	626	3 918 687
Phosphatic Guano	tonne	12 047	145 421
Pyrites Ore and Concentrates (For Sulphur) (*b*)	,,	1 347 984	16 309 423
Quartz Grit	,,	843	1 401
Ruthenium (By-Product Nickel Mining)	kg	32	51 640
Salt	tonne	36 487 053	204 916 758
Semi Precious Stones—			
Amethyst	kg	29 990	36 495
Beryl (Coloured)	,,	91	100
Chalcedony	,,	89 135	39 514
Chrysoprase	,,	123 552	125 642
Dravite	,,	8 640	15 594
Green Beryl	,,	50	629
Magnesite	,,	5 073	2 780
Moss Opal	,,	118 117	50 606
Moss Agate	,,	16 257	4 800
Opal	,,	4	16 994
Opaline	,,	11	8
Opalite	,,	1 020	400
Prase	,,	3 955	730
Quartz	,,	33 484	13 545
Serpentinite	,,	1 422	5 378
Tiger Eye Opal	,,	20 447	14 412
Topaz (Blue)	,,	3	4
Tourmaline	,,	1 035	2 124
Sillimanite	tonne	2	26
Silver (*c*)	kg	433 365	10 842 404
Soapstone	tonne	574	3 856
Talc	,,	869 126	(g) 4 719 452
Tanto/Columbite Ores and Concentrates	,,	3 007	31 954 756
Tin	,,	36 564	60 618 898
Tungsten Ore and Concentrates—			
Scheelite	,,	172	144 532
Wolfram	,,	310	125 810
Vermiculite	,,	4 640	48 921
Zinc (Metallic By-Product) (*d*)	,,	2 934	(j)
Zinc Ore (Fertiliser)	,,	20	200
Total Value to 31st December, 1980	....		$A16 599 870 474

(a) By-Product from Gold Mining.
(b) Part By-Product from Gold Mining.
(c) By-Product from Gold, Copper and Lead Mining.
(d) By-Product from Lead Mining.
(e) Quantity not recorded.
(f) Value of mineral or concentrate recovered.
(g) Incomplete.
(h) Mineral Recovered.
(i) Assayed Metallic Content.
(j) Value included in Lead value.
(k) Based on the price assessed by the Commonwealth Government for Barrow Island Crude Oil at Kwinana.
(l) Nominal well-head value.

Footnote.—Comprehensive Mineral production records maintained in the Royalty and Statistics Branch of the Department of Mines show locality, producers, period, quantity, assayed or metallic content, and value of the various minerals listed above.

TABLE VII

Showing average number of men employed above and below ground in the larger mining companies operating in Western Australia during 1980.

Company	Above	Under	Total
GOLD—			
Central Norseman Gold Corporation N.L.	198	117	315
Kalgoorlie Lake View Pty. Ltd. (Mt. Charlotte)	22	177	199
Kalgoorlie Lake View Pty. Ltd. (Boulder)	13	111	124
Newmont Pty. Ltd. (Telfer Project)	99	....	99
All Other Operators	571	172	743
State Average	903	577	1 480
ALUMINA (from Bauxite)—			
Alcoa of Australia Ltd.	3 176	....	3 176
COAL—			
Griffin Coal Mining Co. Ltd.	298	....	298
Western Collieries Ltd.	299	321	620
IRON ORE—			
Cliffs Western Australia Mining Co. Pty. Ltd.	1 408	....	1 408
Dampier Mining Co. Ltd.	685	....	685
Goldsworthy Mining Ltd.	1 208	....	1 208
Hamersley Iron Pty. Ltd.	4 135	....	4 135
Mt. Newman Mining Co. Pty. Ltd.	3 919	....	3 919
Wundowie Iron & Steel	10	....	10
MINERAL BEACH SANDS—			
Allied Eneabba Pty. Ltd.	184	....	184
Cable Sands Pty. Ltd.	69	....	69
W.S.L. Group	127	....	127
Western Titanium Ltd.	255	....	255
NICKEL—			
Agnew Mining Co. Pty. Ltd.	189	68	257
Metals Exploration N.L.	81	104	185
Western Mining Corporation	699	719	1 418
PETROLEUM CRUDE OIL—			
West Australian Petroleum Pty. Ltd.	122	....	122
SALT—			
Dampier Salt Ltd.	202	....	202
Lefroy Salt Co.	5	....	5
Leslie Salt Co.	47	....	47
All Other Minerals	441	....	441
	17 559	1 212	18 771

13629/7/81—720

WILLIAM BENBOW, Acting Government Printer, Western Australia