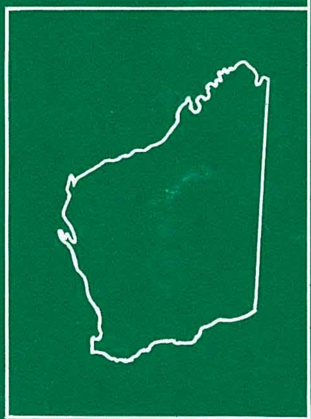
DEPARTMENT OF MINES ANNUAL REPORT 1979



DEPARTMENT OF MINES WESTERN AUSTRALIA ANNUAL REPORT 1979

"Helicopters on contract to CRA Exploration – Ashton Project near the Argyle diamond prospect, Kimberley, W.A."

"Geologists examining reconnaissance samples for diamonds from Smoke Creek, Kimberley, W.A."

REPORT OF THE DEPARTMENT *of* MINES WESTERN AUSTRALIA FOR THE YEAR 1979

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 1979, *together with the reports from the officers controlling Sub-Departments, and Comparative Tables furnishing statistics relative to the Mining Industry.*

B. M. ROGERS,
Under Secretary for Mines.

Perth, 1980.

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DIVISION I

PART 1—GENERAL REMARKS

I have the honour to submit for your information a report on the Mining Industry for 1979.

The estimated value of the mineral output of Western Australia (including gold, coal and petroleum) was $2 134·735 million an increase of $413·145 million or 24 per cent over the previous year and an all time record. This increase was due mainly to much higher values of gold, petroleum, alumina, iron ore and nickel.

ROYALTIES

The royalty revenue for the year amounted to $58 million which is $3·97 million above the figure for 1978. Iron ore royalties accounted for 81·2 per cent of that total. Full details are contained in Table 2 of Part 2 of this report.

IRON ORE

The quantity of iron ore for export and local use increased from 82·5 million tonnes in 1978 to 85·1 million tonnes in 1979. The value increased from $957 million to $1 039·6 million.

ALUMINA

Production of alumina by Alcoa of Australia (W.A.) Ltd from bauxite mined at Jarrahdale and Del Park increased by ·5 million tonnes to 3·9 million tonnes the value of which was estimated at $422·16 million.

NICKEL

The total value of nickel in concentrates, briquettes and powder was estimated at $227·3 million an increase of $41·2 million. Nickel concentrates and nickel ore produced during the year amounted to 413 101 and 66 018 tonnes, respectively. Early in the year the International Nickel Co. Ltd., the worlds largest producer and market leader, announced the reinstatement of its published nickel prices thereby signalling the end of a costly price discounting war which affected nickel producers during 1977 and 1978.

PETROLEUM
(Crude Oil and Natural Gas)

Sales of crude oil produced from Barrow Island during 1979 totalled 1·4 million kilolitres valued at $140·16 million compared with 1·8 million kilolitres valued at $77·5 million in 1978.

As in 1978 this large increase in value is a direct result of the Commonwealth Government policy of pricing all indigenous crude oil production on a full import parity basis.

The Dongara, Mondarra and Yardarino Gas fields supplied a total of 836·1 million cubic metres of natural gas valued at $19·9 million to sales outlets in the Perth, Fremantle, Kwinana and Pinjarra areas.

As at the 31st December, 1979 petroleum tenements covered 217 870 square kilometres on-shore and 691 845 square kilometres off-shore.

GOLD

The estimated value of gold received at the Perth Mint during 1979 was $109 124 526 an increase of $35 405 054 over the 1978 value. The quantity of gold received was 11 657 kilograms which was 1 787 kilograms less than the 1978 figure.

The weighted average price obtained for Western Australian gold as recorded by the Department of Mines for 1979 computed to $291·90 per fine ounce (troy) compared to $170·55 in 1978. During 1979 the world gold price increased from an average of $199·80 in January to an average of $419·35 in December and this dramatic increase is reflected in the values quoted above.

The Telfer mine operated by Newmont Proprietary Limited was again the States major producer contributing 5 292 kilograms of the above total of 11 657 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 1 370 878 tonnes compared to 1 280 532 tonnes in 1978 and the average number of persons engaged in gold mining increased from 960 in 1978 to 996 in 1979.

COAL

Coal production from the Collie Coal Field during the year showed an increase of 331 727 tonnes over that for 1978.

Figures for the last three years were:—

	1977	1978	1979
Tonnes	2 358 006	2 403 503	2 735 230
Total Value	$23 172 093	$28 642 245	$44 407 880
Average value per tonne	$9·826 9	$11·916 9	$16·235 5
Average effective workers	862	870	896
Proportion of deep mined coal	22·82%	23·04%	21·64%

OTHER MINERALS

Other minerals to realise over a million dollars for the year were: Salt $27 million, Ilmenite $27·7 million, Zircon $17·9 million, Rutile $19·9 million, Monazite $4 million, Leucoxene $3·9 million, Tin $7·5 million, Tanto/Columbite $7·4 million, Cobalt (by-product of nickel mining) $2·6 million, Copper (by-product of nickel mining) $2·2 million, Limestone $1·5 million. Pig iron valued at $4·7 million was produced by the Wundowie Iron and Steel Industry.

OUTLOOK

The mining industry in Western Australia continued to expand during 1979, recording a 24 per cent growth rate, the highest for a number of years.

The spectacular rise in the world gold price is leading to expansion of existing operating mines and the re-opening of many former gold mining areas while generally improved metal prices have resulted in intense activity in the search for base metals.

With this growing interest in re-development and exploration, particularly for diamonds, uranium and gold, approaching boom conditions the State's mining industry seems assured of continued growth and prosperity.

PART 2—COMPARATIVE STATISTICS

TABLE 1

SUMMARY

Mineral Production: Quantity, Value, Persons Engaged

	1978	1979		Variation
IRON ORE—				
Tonnes	82 498 589	**85 171 982**	+	2 673 393
Value ($A)	$956 965 039	**$1 039 594 173**	+	$82 629 134
Persons Engaged	5 151	**5 435**	+	284
ALUMINA—				
Tonnes	3 470 380	**3 945 445**	+	475 065
Value ($A)	*$277 630 400	**‡$422 162 615**	+	$144 532 215
Persons Engaged	2 804	**2 947**	+	143
NICKEL—				
Tonnes (Ore and Concentrates)	468 941	**479 119**	+	10 178
Value ($A)	$186 088 405	**$227 304 194**	+	$41 215 789
Persons Engaged	1 748	**1 731**	—	17
PETROLEUM—CRUDE OIL—				
Kilolitres	1 820 146	**1 420 730**	—	399 416
†Value ($A)	$77 907 370	**$140 987 361**	+	$63 079 991
Persons Engaged	102	**106**	+	4
GOLD—				
Reported to Department (Mine Production)—				
Ore Treated (Tonnes)	1 280 532	**1 370 878**	+	90 346
Gold (Kilograms)	13 332	**11 582**	—	1 750
Average Grade (grams per tonne)	10·40	**8·45**	—	1·95
Persons Engaged	960	**996**	+	36
Mint and Export (Realised Production)—				
Gold (Kilograms)	13 444	**11 658**	—	1 786
Estimated Value ($A) (including Overseas Gold Sales Premium)	$73 719 472	**$109 124 526**	+	$35 405 054
COAL—				
Tonnes	2 403 503	**2 735 230**	+	331 727
Value ($A)	$28 642 245	**$44 407 880**	+	$15 765 635
Persons Engaged	870	**896**	+	26
MINERAL BEACH SANDS—				
Tonnes	1 329 014	**1 621 426**	+	292 412
Value ($A)	$58 358 767	**$73 514 046**	+	$15 155 279
Persons Engaged	736	**692**	—	44
OTHER MINERALS—				
Value ($A)	$62 279 559	**$77 640 210**	+	$15 360 651
Persons Engaged	695	**597**	—	98
TOTAL ALL MINERALS—				
Value ($A)	$1 721 591 257	**$2 134 735 005**	+	$413 143 748
Persons Engaged	13 066	**13 400**	+	334

* Value computed by Department of Mines based on the price for alumina f.o.b. Jamaica.

† 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 1978 *and* 1979
Western Australia

Mineral	1978		1979		Increase or Decrease for Year Compared with 1978	
	Quantity	Value	Quantity	Value	Quantity	Value
	Tonnes	$	Tonnes	$	Tonnes	$
Alumina (from Bauxite)	3 470 380	277 630 400	3 945 445	422 162 615	+ 475 065	+ 144 532 215
Barytes	....	....	34 658	482 235	+ 34 658	+ 482 235
Building Stone (Quartzite)	615	7 466	1 135	13 775	+ 520	+ 6 309
(Quartz)	3 516	103 088	1 674	46 994	— 1 842	— 56 094
(Spongolite)	225	3 350	152	2 268	— 73	— 1 082
Clays (Cement Clay)	22 927	57 317	21 348	53 369	— 1 579	— 3 948
(Fire Clay)	266 703	135 451	386 968	171 659	+ 120 265	+ 36 208
(White Clay—Ball Clay)	519	6 228	619	7 428	+ 100	+ 1 200
(Kaolin)	408	3 314	827	4 960	+ 419	+ 1 646
(Fullers Earth)	....	....	10 067	181 206	+ 10 067	+ 181 206
Coal	2 403 503	28 642 245	2 735 230	44 407 880	+ 331 727	+ 15 765 635
Cobalt (By-product of Nickel Mining)	172	854 689	216	2 660 628	+ 44	+ 1 805 939
Copper (By-product of Nickel Mining)	1 501	1 330 712	1 741	2 256 476	+ 240	+ 925 764
Dolomite	....	....	585	3 510	+ 585	+ 3 510
	Carats		Carats		Carats	
Emeralds (cut)	7	875	1 205	7 230	+ 1 198	+ 6 355
	Grams		Grams		Grams	
Emeralds (rough, uncut)	668	5 346	....	....	— 668	— 5 346
	Tonnes		Tonnes		Tonnes	
Feldspar	889	29 278	1 929	82 999	+ 1 040	+ 53 721
Garnet Sands	479	33 474	42	3 480	— 437	— 29 994
Glass Sand	104 697	36 505	278 091	425 288	+ 173 394	+ 388 783
Gypsum	159 537	588 660	243 210	966 783	+ 83 673	+ 378 123
Iron Ore (Pig Iron Recovered)	42 691	3 760 667	54 181	4 767 928	+ 11 490	+ 1 007 261
(Exported and locally used)	76 119 045	830 516 035	78 941 664	916 075 194	+ 2 822 619	+ 85 559 159
(Pellets)	6 379 544	126 449 004	6 230 318	123 518 979	— 149 226	— 2 930 025
Limestone	715 490	1 373 387	679 596	1 560 229	— 35 894	+ 186 842
Manganese (Metallurgical Grade)	922	16 140	1 395	24 427	+ 473	+ 8 287
Mica	....	....	310	65 773	+ 310	+ 65 773
Mineral Beach Sands (Ilmenite)	1 030 331	23 687 589	1 143 286	27 699 090	+ 112 955	+ 4 011 501
(Monazite)	10 457	1 848 767	17 352	4 033 271	+ 6 895	+ 2 184 504
(Rutile)	114 643	22 422 136	94 351	19 887 292	— 20 292	— 2 534 844
(Leucoxene)	13 273	1 773 702	29 196	3 919 851	+ 15 923	+ 2 146 149
(Zircon)	151 297	8 614 435	337 197	17 920 552	+ 185 900	+ 9 306 117
(Xenotime)	13	12 138	44	53 990	+ 31	+ 41 852
Nickel Concentrates	404 528	179 630 243	413 101	218 281 967	+ 8 573	+ 38 651 724
Nickel Ore	64 413	6 458 162	66 018	9 022 227	+ 1 605	+ 2 564 065
Ochre	281	4 776	222	3 772	— 59	— 1 004
	kg		kg		kg	
Palladium (By-product of Nickel Mining)	230	418 136	214	625 772	— 16	+ 207 636
Platinum (By-product of Nickel Mining)	92	557 698	86	862 865	— 6	+ 305 167
	kl		kl		kl	
Petroleum—Crude Oil	1 820 146	77 907 370	1 420 730	140 987 361	— 399 416	+ 63 079 991
	$m^3 10^3$		$m^3 10^3$		$m^3 10^3$	
Natural Gas ($m^3 10^3$)	806 865	17 232 225	836 175	19 953 906	+ 29 310	+ 2 721 681
	Tonnes		Tonnes		Tonnes	
Condensate	2 368	N.A.	2 368	N.A.	....	....
Salt	3 888 065	27 410 412	3 731 854	27 024 382	— 156 211	— 386 030
	kg		kg		kg	
Semi-precious Stones	11 523	10 575	4 973	9 600	— 6 500	— 975
	Tonnes		Tonnes		Tonnes	
Talc	120 352	N.A.	110 359	N.A.	— 10 164	N.A.
Tanto/Columbite Ores and Concentrates	139	2 751 264	172	7 454 069	+ 33	+ 4 702 805
Tin Concentrates	692	5 341 725	695	7 542 231	+ 3	+ 2 200 506
Tungsten Ores and Concentrates (Scheelite)	140	1 108	....	....	— 140	— 1 108
Vermiculite	244	2 440	....	....	— 244	— 2 440
		1 647 668 532		2 025 235 511		+ 377 566 979

TABLE 1 (*b*)

Quantity and Value of Gold and Silver received at the Perth Mint during the years 1978 *and* 1979

Mineral	1978		**1979**		Increase or Decrease for Year Compared with 1978	
	Quantity	Value	**Quantity**	**Value**	Quantity	Value
	kg	$	kg	$	kg	$
Gold	*13 444·140	†73 719 472	***11 657·521**	**†109 124 526**	— 1 786·619	+ 35 405 054
Silver	*2 178·107	203 253	***1 856·650**	**374 968**	321·457	+ 171 715
Total		73 922 725		**109 499 494**		+ 35 576 769
Grand Total		1 721 591 257		**2 134 735 005**		+ 413 143 748

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

TABLE 2

ROYALTIES

Mineral	Royalty Collected 1978	Royalty Collected **1979**	Increase or Decrease Compared with 1978
	$	$	$
Alumina	1 720 808.47	**2 498 926.32**	+ 778 117.85
Amethyst	.53	**31.83**	+ 31.30
Antimony	30.24	....	— 30.24
Barytes	....	**1 605.46**	+ 1 605.46
Building Stone	345.09	**384.94**	+ 39.85
Chalcedony	16.77	**8.10**	— 8.67
Chrysoprase	....	**10.00**	+ 10.00
Clay	15 897.69	**24 310.33**	+ 8 412.64
Coal	64 334.73	**59 437.81**	— 4 896.92
Cobalt	6 322.22	**16 964.15**	+ 10 641.93
Dolomite	....	**29.25**	+ 29.25
Emeralds	....	**65.80**	+ 65.80
Felspar	36.61	**97.45**	+ 60.84
Glass Sand	4 450.31	**14 716.27**	+ 10 265.96
Gold	9.00	....	— 9.00
Gypsum	6 808.37	**11 078.61**	+ 4 270.24
Heavy Mineral Sands concentrate	....	**825.00**	+ 825.00
Ilmenite	325 529.84	**355 468.20**	+ 29 938.36
Iron Ore	45 006 521.75	**47 124 898.18**	+ 2 118 376.43
Leucoxene	21 407.44	**63 495.98**	+ 42 088.54
Limestone	23 858.47	**26 181.51**	+ 2 323.04
Manganese	138.34	**179.82**	+ 41.48
Mica	....	**238.87**	+ 238.87
Monazite	29 598.52	**75 031.89**	+ 45 433.37
Moss Opal	8.94	**10.93**	+ 1.99
Natural Gas	777 685.90	**973 278.19**	+ 195 592.29
Natural Gas-Condensate	4 571.48	**7 323.13**	+ 2 751.65
Nickel	1 836 545.82	**2 118 367.27**	+ 281 821.45
Ochre	7.32	**17.65**	+ 10.33
Oil (Crude)	3 170 681.67	**3 586 455.13**	+ 415 773.46
Palladium	2 337.89	**4 926.50**	+ 2 588.61
Platinum	2 353.10	**1 819.84**	— 533.26
Rutile	563 783.36	**336 734.27**	— 227 049.09
Salt	212 859.61	**242 185.52**	+ 29 325.91
Scheelite	5.00	....	— 5.00
Serpentenite	9.20	....	— 9.20
Talc	11 547.69	**11 330.58**	— 217.11
Tanto-Columbite	12 566.40	**20 810.56**	+ 8 244.16
Tiger Iron	37.72	....	— 37.72
Tin	672.67	**95.22**	— 577.45
Vermiculite	12.20	....	— 12.20
Xenotime	242.77	....	— 242.77
Zircon	210 249.58	**428 334.12**	+ 218 084.54
Total	54 032 292.71	**58 005 674.68**	+ 3 973 381.97

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	
	1978	**1979**	1978	**1979**	1978	**1979**
	kg	**kg**	Per cent.	**Per cent.**	grams	**grams**
Kimberley	....	**·028**	....	....	....	**2·1**
West Kimberley	....	....	....	....	....	....
Pilbara	7 070·873	**5 310·123**	53·23	**45·85**	16·2	**12·06**
West Pilbara	....	....	....	....	....	....
Ashburton	....	....	....	....	....	....
Gascoyne	....	....	....	....	....	....
Peak Hill	1·745	**8·731**	0·01	**·08**	·8	**·4**
East Murchison	·363	**·753**	....	**·01**	4·2	**3·1**
Murchison	43·952	**41·981**	·33	**·36**	8·4	**6·5**
Yalgoo	2·194	**8·050**	·02	**·07**	5·9	**23·5**
Mount Margaret	41·010	**43·015**	·31	**·37**	5·0	**4·7**
North Coolgardie	18·629	**34·926**	·15	**·30**	6·1	**5·6**
Broad Arrow	12·994	**34·413**	·10	**·30**	2·5	**3·3**
North-East Coolgardie	·547	**2·522**	....	**·02**	2·9	**2·8**
East Coolgardie	3 243·304	**3 479·699**	24·41	**30·04**	5·0	**4·7**
Coolgardie	99·737	**268·929**	·75	**2·32**	8·0	**18·9**
Yilgarn	37·478	**72·471**	·28	**·63**	12·6	**3·7**
Dundas	2 711·291	**2 272·397**	20·41	**19·62**	18·0	**16·5**
Phillips River	....	**3·950**	....	**·03**	....	**22·0**
South West Mineral Field	....	....	....	....	....	....
State Generally	....	....	....	....	....	....
	13 284·117	**11 581·988**	100·00	**100·00**	10·4	**8·4**

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

TABLE 4

Total Coal Output from Collie River Mineral Field, 1978 *and* 1979, *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
1978	553 849	10 025 567	116	319	....	....	1 736	1 273
1979	591 950	12 288 410	108	320	....	....	....	....
Open Cut Mining—								
1978	1 849 654	18 616 678	....	....	435	4 252	....	....
1979	2 143 280	32 119 470	....	....	468	....	....	....
Totals—								In All Mines
1978	2 403 503	28 642 245	116	319	435	....	....	2 763
1979	2 735 230	44 407 880	108	320	468	....	....	3 053

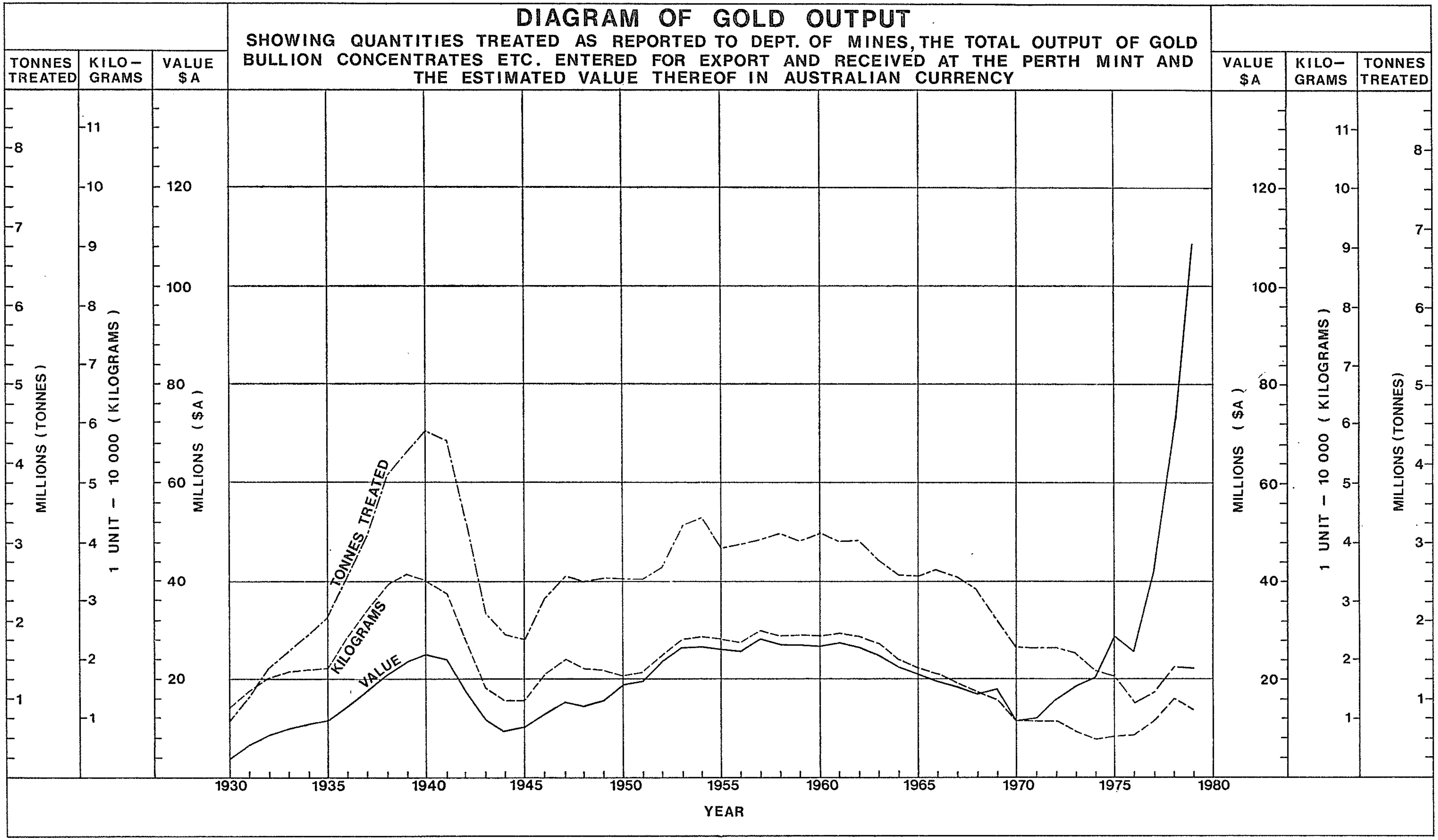
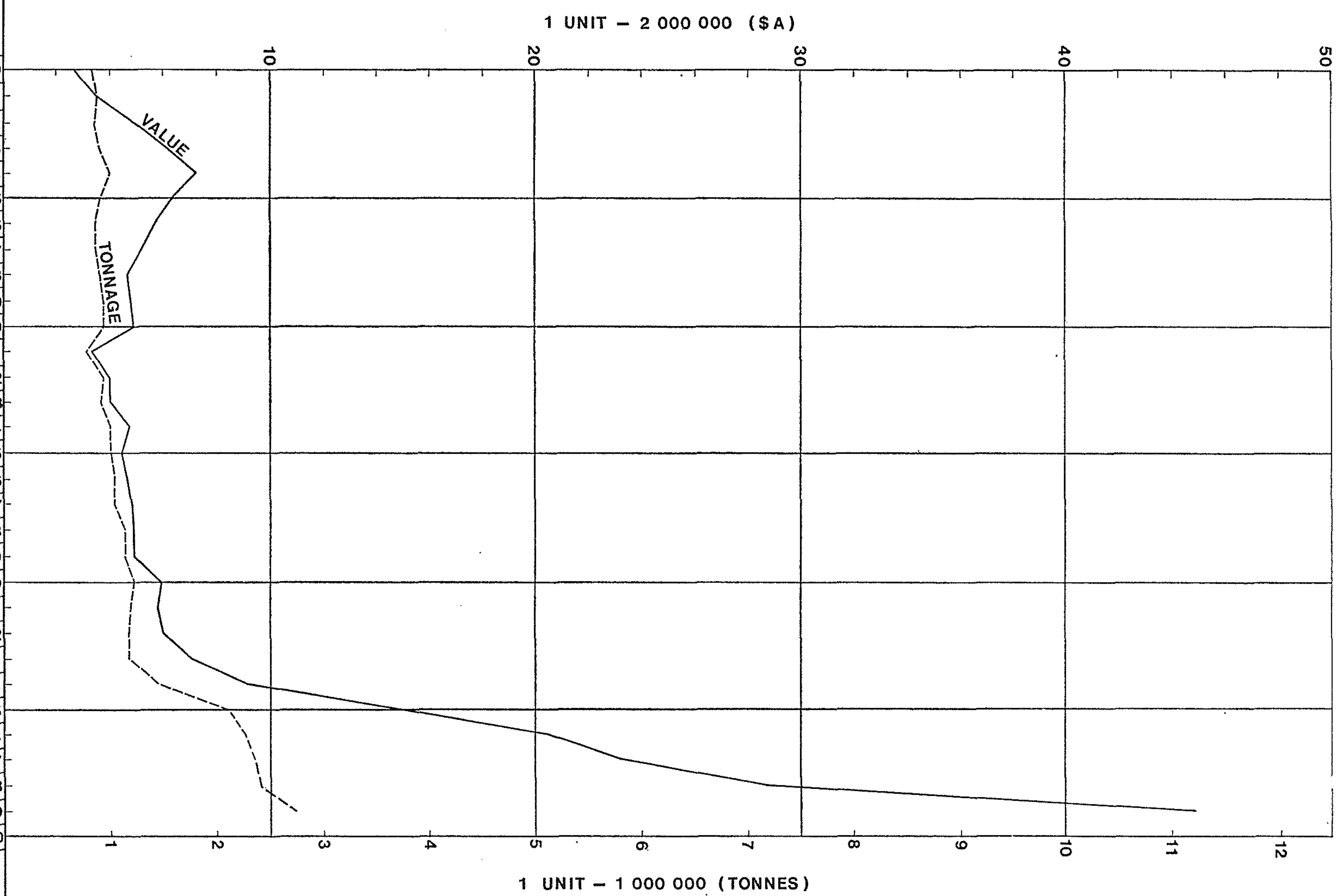


DIAGRAM OF GOLD OUTPUT
SHOWING QUANTITIES TREATED AS REPORTED TO DEPT. OF MINES, THE TOTAL OUTPUT OF GOLD BULLION CONCENTRATES ETC. ENTERED FOR EXPORT AND RECEIVED AT THE PERTH MINT AND THE ESTIMATED VALUE THEREOF IN AUSTRALIAN CURRENCY
TONNES TREATED
KILO-GRAMS
VALUE $A
MILLIONS (TONNES)
1 UNIT - 10 000 (KILOGRAMS)
MILLIONS ($A)
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

TONNES	VALUE $A	YEAR
827,421	2,575,498	1950
862,093	3,433,576	1951
843,790	4,914,592	1952
900,405	6,146,146	1953
1,034,687	7,177,636	1954
918,298	6,264,148	1955
843,330	5,595,012	1956
852,120	5,105,310	1957
884,860	4,560,398	1958
932,159	4,713,064	1959
937,197	4,878,390	1960
778,030	3,260,518	1961
933,864	3,961,556	1962
916,980	3,970,120	1963
1,003,268	4,678,934	1964
1,009,691	4,409,972	1965
1,078,126	4,562,087	1966
1,079,199	4,765,503	1967
1,104,831	4,816,725	1968
1,108,033	4,804,089	1969
1,216,957	5,827,291	1970
1,190,429	5,734,353	1971
1,167,544	5,907,162	1972
1,171,069	7,048,726	1973
1,446,048	9,144,982	1974
2,113,979	15,073,668	1975
2,268,728	20,468,874	1976
2,358,006	23,172,093	1977
2,403,503	28,642,245	1978
2,735,230	44,407,880	1979
		1980
TONNES	VALUE $A	YEAR



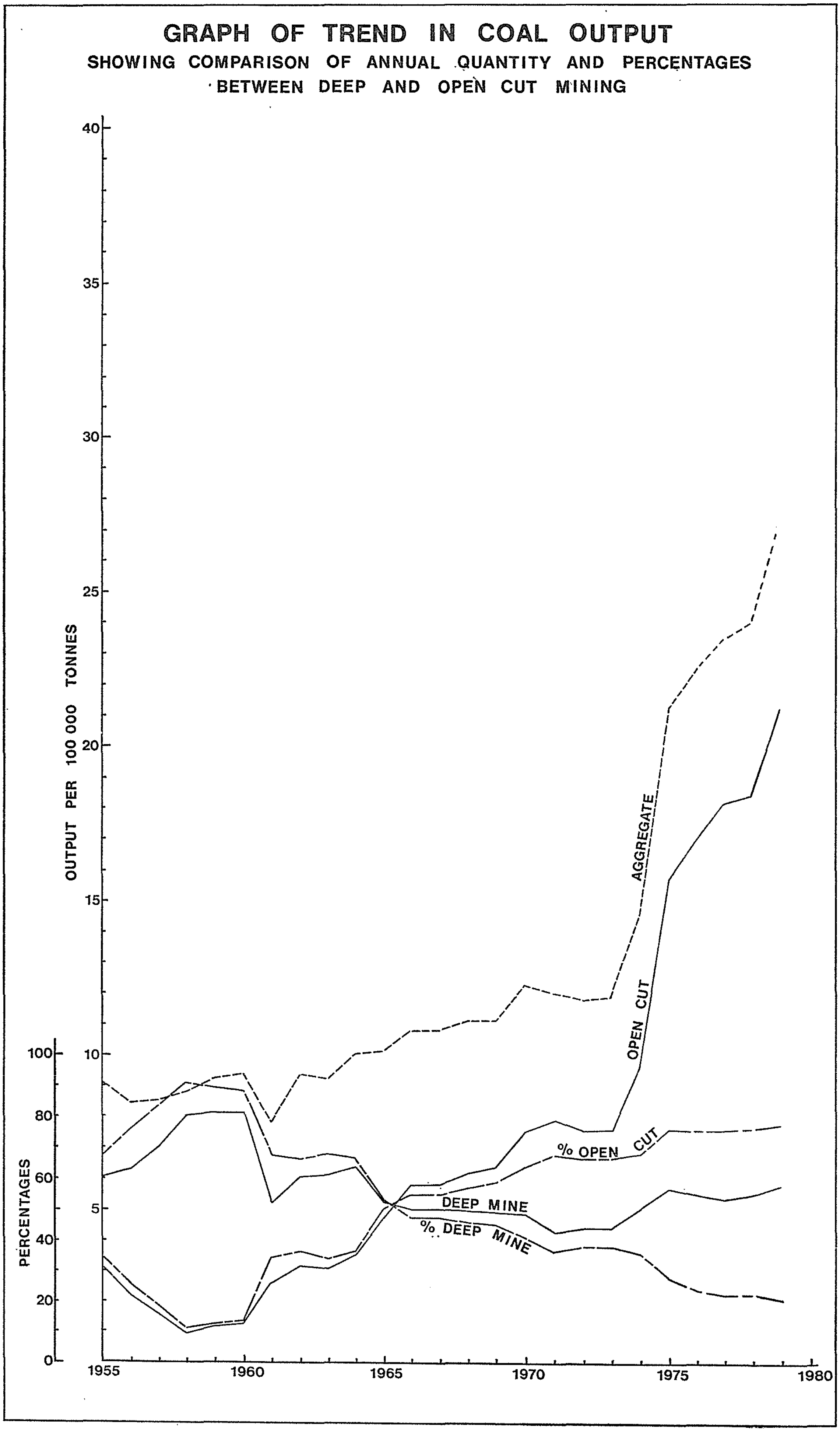

GRAPH OF TREND IN COAL OUTPUT
SHOWING COMPARISON OF ANNUAL QUANTITY AND PERCENTAGES BETWEEN DEEP AND OPEN CUT MINING
OUTPUT PER 100 000 TONNES
PERCENTAGES
40
35
30
25
20
15
10
5
100
80
60
40
20
0
AGGREGATE
OPEN CUT
% OPEN CUT
DEEP MINE
% DEEP MINE
1955
1960
1965
1970
1975
1980

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 1979 *and in force as at* 31*st December*, 1979 (*compared with* 1978)

	Applied for				In Force			
	1978		**1979**		1978		**1979**	
	No.	Hectares	No.	Hectares	No.	Hectares	No.	Hectares
Gold—								
Gold Mining Leases	701	5 979	**1 510**	**12 778**	2 309	18 556	**2 719**	**22 022**
Dredging Claims	75	2 810	**56**	**4 036**	16	159	**20**	**554**
Prospecting Areas	361	2 820	**610**	**5 051**	281	2 171	**481**	**4 004**
Temporary Reserves	32	3 751	**20**	**2 379**	52	6 080	**71**	**8 252**
Totals	1 169	15 360	**2 196**	**24 244**	2 658	26 966	**3 291**	**34 832**
Coal—								
Coal Mining Leases	129	15 051	**749**	**89 758**	121	13 579	**161**	**16 118**
Prospecting Areas	2	1 197	**10**	**8 727**	4	5 445	**3**	**645**
Temporary Reserves	3	58 500	**156**	**2 408 227**	11	171 508	**117**	**1 664 599**
Totals	134	74 748	**915**	**2 506 712**	136	190 532	**281**	**1 681 362**
Other Minerals—								
Mineral Leases	22	22 390	**9**	**73**	770	72 980	**930**	**90 994**
Dredging Claims	186	20 196	**705**	**75 905**	260	13 736	**284**	**14 422**
Mineral Claims	9 234	1 056 078	**8 808**	**987 179**	11 804	1 225 039	**13 952**	**1 427 543**
Prospecting Areas	20	173	**9**	**87**	16	127	**14**	**118**
Temporary Reserves	230	3 769 934	**366**	**5 653 251**	465	9 082 769	**630**	**9 683 213**
Totals	9 692	4 868 771	**9 897**	**6 716 495**	13 315	10 394 651	**15 810**	**11 216 290**
Other Holdings—								
Miners' Homestead Leases	2	284	**2**	**192**	314	12 810	**314**	**12 810**
Miscellaneous Leases	5	24	**9**	**73**	102	750	**79**	**756**
Residential Areas	1	1	**....**	**....**	45	16	**45**	**16**
Business Areas	....	....	**....**	**....**	16	7	**16**	**7**
Machinery Areas	1	2	**3**	**5**	24	34	**22**	**30**
Tailings Areas	4	36	**1**	**2**	19	28	**24**	**60**
Garden Areas	5	10	**18**	**24**	81	126	**79**	**124**
Quarrying Areas	78	685	**54**	**485**	247	1 990	**272**	**2 423**
Water Rights	11	33	**4**	**8**	95	5 802	**84**	**241**
Licenses to Treat Tailings	123	....	**440**	**....**	70	....	**157**	**....**
Totals	230	1 075	**531**	**789**	1 013	21 563	**1 092**	**16 467**
Grand Totals	11 225	4 959 954	**13 539**	**9 248 240**	17 122	10 633 712	**20 474**	**12 948 951**

TABLE 5 (*a*)

SPECIAL ACTS

Leases applied for during 1979 *and in force as at* 31*st December*, 1979 (*Compared with* 1978)

	Applied for				In Force			
	1978		**1979**		1978		**1979**	
	No.	Hectares	No.	Hectares	No.	Hectares	No.	Hectares
Bauxite	....	....	**....**	**....**	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	1 709·38	**1**	**871·14**	1	966·20	**4**	**222 671·54**
Totals	1	1 709·38	**1**	**871·14**	23	1 893 411·16	**26**	**2 115 116·50**

TABLE 5 (*b*)

PETROLEUM ACTS

Permits, Licenses and Leases applied for during 1979 *and in force as at* 31*st December*, 1979 (*Compared with* 1978)

Holding	Applied for				In Force			
	1978		**1979**		1978		**1979**	
	No.	Blocks	No.	Blocks	No.	Blocks	No.	Blocks
Onshore—								
Petroleum Act, 1967—								
Exploration Permits	2	242	**69**	**9 052**	31	2 187	**35**	**2 816**
Production Licenses	....	....	....	....	2	9	**2**	**9**
Petroleum Leases (Barrow Island)	....	....	....	....	1	8	**1**	**8**
Totals	2	242	**69**	**9 052**	34	2 204	**38**	**2 833**
Offshore—								
Petroleum (Submerged Lands) Act 1967—								
Exploration Permits	10	1 320	**21**	**3 629**	41	7 633	**45**	**8 106**
Production Licenses	....	....	....	....	....	....	....	....
Petroleum Leases (Barrow Marine)	....	....	....	....	1	12	**1**	**12**
Totals	10	1 320	**21**	**3 629**	42	7 645	**46**	**8 118**
Grand Totals	12	1 562	**90**	**12 681**	76	9 849	**84**	**10 951**

(A block contains between approximately 75 km² to 85 km² and the numbers given above include part blocks)

Holding	Applied for				In Force			
	1978		**1979**		1978		**1979**	
	No.	Km	No.	Km	No.	Km	No.	Km
Onshore—								
Petroleum Pipelines Act, 1969—								
Pipeline Licenses	....	....	....	....	5	444·87	**5**	**444·87**
Totals	....	....	....	....	5	444·87	**5**	**444·87**

TABLE 5 (*c*)

MINING ACT, 1904

Leases in Force as at 31*st December*, 1979 *in each Goldfield, Mineral Field or District*

Goldfield, Mineral Field, or District	Gold Mining Leases		Mineral Leases		Miner's Homestead Leases		Miscellaneous Leases	
	No.	Hectares	No.	Hectares	No.	Hectares	No.	Hectares
Ashburton	5	48·40	13	1 466·51	....	....	....	....
Black Range	23	185·43	5	566·27	....	....	....	....
Broad Arrow	66	486·50	30	3 215·94	....	....	....	....
Bulong	35	296·39	....	....	....	....	....	....
Collie	....	....	65	7 518·00	....	....	....	....
(Private Property)	....	....	2	210·43	....	....	....	....
Coolgardie	170	1 262·64	371	41 550·95	22	752·30	1	9·78
Cue	84	755·57	1	41·17	3	446·29	....	....
Day Dawn	30	263·35	....	....	1	8·09	....	....
Dundas	486	4 321·12	....	....	15	341·06	....	....
East Coolgardie	399	2 922·80	5	448·52	59	1 305·99	52	431·67
Gascoyne	7	57·39	....	....	....	....	....	....
Greenbushes	....	....	73	3 958·80	6	168·14	....	....
(Private Property)	....	....	3	18·22	....	....	....	....
Kanowna	58	462·70	....	....	12	284·03	....	....
Kimberley	2	17·00	....	....	....	....	....	....
Kunanalling	35	320·17	....	....	2	211·45	1	0·25
Kurnalpi	12	115·52	....	....	5	449·13	....	....
Lawlers	67	527·00	....	....	....	....	....	....
Marble Bar	199	1 660·58	61	6 728·84	....	....	2	64·21
Meekatharra	143	1 164·67	....	....	9	512·03	1	0·40
Menzies	73	592·36	1	28·73	7	299·43	....	....
Mount Magnet	187	1 487·29	....	....	1	4·04	....	....
Mount Malcolm	62	468·66	....	....	9	311·90	1	0·30
Mount Margaret	57	527·59	59	6 011·61	6	14·93	....	....
Mount Morgans	41	335·05	....	....	....	....	....	....
Niagara	35	303·17	....	....	1	8·07	....	....
Northampton	....	....	12	1 110·67	....	....	....	....
(Private Property)	....	....	....	....	....	....	....	....
Nullagine	28	204·24	....	....	....	8·89	1	9·71
Peak Hill	24	169·04	5	270·31	4	99·94	....	....
Phillips River	4	21·36	24	1 297·39	105	5 661·72	1	2·42
(Private Property)	....	....	9	1 087·04	....	....	....	....
South West	2	6·34	37	281·46	....	....	1	2·00
(Private Property)	2	18·00	44	4 398·76	....	....	....	....
Ularring	34	269·79	....	....	....	....	....	....
West Kimberley	....	....	30	5 066·71	....	....	....	....
West Pilbara	16	143·50	37	1 471·50	2	4·44	7	44·48
Wiluna	38	347·74	23	2 657·66	17	1 538·42	2	1·20
Yalgoo	43	312·97	5	421·96	1	9·00	....	....
Yerilla	61	487·02	....	....	1	4·04	....	....
Yilgarn	176	1 325·79	10	940·11	24	366·51	....	....
(Private Property)	15	134·45	....	....	....	....	....	....
Outside Proclaimed	....	....	....	....	....	....	....	....
Totals	2 719	22 022·00	930	90 994·00	314	12 810·00	77	566·00

	No.	Hectares
Gold Mining Leases on Crown Land	2 702	21 869·55
Gold Mining Leases on Private Property	17	152·45
Mineral Leases on Crown Land	872	85 279·25
Mineral Leases on Private Property	58	5 714·75
Miner's Homestead Leases on Crown Land	314	12 810·00
Other Leases on Crown Land	77	566·00
Other Leases on Private Property	....	....

TABLE 5 (*d*)

MINING ACT, 1904

Claims and Authorised Holdings in Force at 31st December, 1979 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 Areas		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	....	....	....	....	289	30 600.87	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Black Range	8	61·36	....	....	168	17 905·96	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Broad Arrow	62	509·97	....	....	63	10 495·87	1	0·4	....	....	....	....	....	....	....	....	....	....	5	5·06
Bulong	9	87·37	....	....	16	3 927·00	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Collie	....	....	....	....	....	....	....	....	....	....	1	2·00	....	....	....	....	1	4·21	....	....
(Private Property)	....	....	....	....	....	....	....	....	....	....	1	2·02	....	....	....	....	....	....	....	....
Coolgardie	98	748·05	....	....	242	24 289·97	3	1·20	....	....	....	....	....	....	7	11·73	32	268·77	5	34·58
Cue	20	173·77	....	....	239	24 905·65	1	0·1	....	....	1	2·02	....	....	....	....	1	9·71	....	....
Day Dawn	10	84·17	....	....	25	2 562·67	....	....	....	....	....	....	....	....	4	8·08	....	....	....	....
Dundas	21	770·90	....	....	120	7 004·75	....	....	....	....	....	....	1	2·02	....	....	2	19·36	2	4·85
East Coolgardie	26	218·56	....	....	115	12 189·52	28	11·20	....	....	1	1·21	10	18·57	12	21·80	15	111·11	12	13·29
Gascoyne	....	....	....	242·80	483	48 088·44	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Greenbushes	....	....	....	....	2	12·13	....	....	....	....	....	....	....	....	8	13·59	....	....	2	13·50
Kanowna	18	167·02	....	....	146	16 345·61	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Kimberley	....	....	....	....	1 516	174 038·14	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Kunanalling	18	154·23	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Kurnalpi	8	69·82	....	....	52	6 077·20	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Lawlers	7	67·95	....	....	587	67 916·50	....	....	....	....	....	....	....	....	....	....	9	87·30	....	....
Marble Bar	21	191·52	271	11 706·62	1 067	103 720·37	1	0·20	2	0·44	8	12·21	1	2·02	16	26·83	68	603·89	22	140·00
Meekatharra	20	156·30	4	394·76	266	31 177·80	....	....	....	....	....	....	....	....	....	....	....	....	3	2·84
Menzies	15	128·22	....	....	154	15 723·04	....	....	....	....	....	....	....	....	1	0·4	....	....	....	....
Mount Magnet	35	295·44	....	....	117	13 615·60	....	....	....	....	....	....	....	....	7	3·6	....	....	3	2·00
Mount Malcolm	11	94·46	....	....	494	54 146·59	....	....	....	....	....	....	1	2·00	8	13·71	1	2·02	2	0·80
Mount Margaret	5	46·95	....	....	330	37 762·49	....	....	....	....	....	....	....	....	2	2·82	3	29·13	1	0·40
Mount Morgans	4	27·21	....	....	233	26 656·58	....	....	....	....	....	....	....	....	....	....	....	....	1	0·40
Niagara	2	15·71	....	....	25	2 814·55	....	....	....	....	1	1·00	....	....	....	....	....	....	3	2·40
Northampton	1	7·00	....	....	50	2 599·05	....	....	....	....	....	....	3	28·06	....	....	....	....	....	....
(Private Property)	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Nullagine	3	23·95	12	1 441·40	353	24 061·01	....	....	....	....	1	0·40	3	1·60	1	0·02	....	....	5	3·20
Peak Hill	7	60·30	....	....	708	28 649·83	....	....	2	0·80	3	5·02	2	3·30	3	5·24	7	67·90	2	8·53
Phillips River	....	....	....	....	105	7 832·57	....	....	....	....	1	0·80	1	0·80	....	....	1	2·02	....	....
(Private Property)	....	....	....	....	32	615·99	....	....	....	....	....	....	....	....	....	....	....	....	....	....
South West	1	45·00	12	1 054·32	406	28 090·62	....	....	....	....	....	....	....	....	....	....	3	22·40	1	0·40
(Private Property)	1	....	....	....	811	66 614·25	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Ularring	7	63·11	....	....	24	2 453·74	....	....	....	....	1	0·4	2	1·61	....	....	....	....	3	1·6
West Kimberley	1	9·70	1	121·40	3 112	361 824·97	....	....	....	....	1	1·00	....	....	3	6·02	23	137·53	....	....
West Pilbara	3	29·00	2	15·37	357	33 044·09	4	1·6	6	2·4	....	....	....	....	4	7·67	102	891·15	....	....
Wiluna	1	9·70	....	....	409	4 745·44	....	....	....	....	....	....	....	....	....	....	2	11·73	1	0·4
Yalgoo	13	119·65	....	....	401	41 632·09	....	....	6	2·4	....	....	....	....	....	....	....	....	....	....
Yerilla	4	28·84	....	....	211	24 304·10	....	....	....	....	....	....	....	....	....	....	....	....	5	4·82
Yilgarn	36	291·99	....	....	161	15 346·57	7	0·76	....	....	2	2·01	....	....	3	2·59	1	9·71	1	1·66
(Private Property)	....	....	....	....	3	275·00	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Outside Proclaimed	....	....	....	....	21	2 786·48	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Totals	498	4 767·09	304	14 976·00	13 952	1 427 543·00	45	15·46	16	6·04	22	30·09	24	59·98	79	124·10	272	2 423·39	84	240·73

TABLE 6

MEN EMPLOYED

Average number of Men employed in Mining during 1978 *and* 1979

Goldfield	District	Gold 1978	Gold 1979	Other Minerals 1978	Other Minerals 1979	Total 1978	Total 1979
Kimberley	....	....	....	....	....	....	....
West Kimberley	....	....	....	444	**489**	444	**489**
Pilbara	Marble Bar	107	**116**	879	**865**	986	**981**
	Nullagine	91	**2**	....	....	91	**2**
West Pilbara	....	....	....	2 619	**2 703**	2 619	**2 703**
Ashburton	....	....	....	104	**106**	104	**106**
Gascoyne	....	....	....	178	**12**	178	**12**
Peak Hill	....	4	**10**	1 323	**1 533**	1 327	**1 543**
East Murchison	Lawlers	2	....	....	....	2	....
	Wiluna	1	....	....	....	1	....
	Black Range	....	**2**	....	....	....	**2**
Murchison	Cue	5	**4**	4	**7**	9	**11**
	Meekatharra	32	**21**	....	....	32	**21**
	Day Dawn	....	....	....	....	....	....
	Mt. Magnet	17	**19**	....	....	17	**19**
Yalgoo	....	14	**15**	8	**4**	22	**19**
Mt. Margaret	Mt. Morgans	4	**2**	....	....	4	**2**
	Mt. Malcolm	31	**51**	....	....	31	**51**
	Mt. Margaret	6	**27**	201	**212**	207	**239**
North Coolgardie	Menzies	10	**18**	....	....	10	**18**
	Ularring	16	**10**	1	....	17	**10**
	Niagara	4	**2**	....	....	4	**2**
	Yerilla	5	**7**	....	....	5	**7**
Broad Arrow	....	12	**23**	....	....	12	**23**
North-East Coolgardie	Kanowna	3	**4**	....	....	3	**4**
	Kurnalpi	3	**6**	....	....	3	**6**
East Coolgardie	East Coolgardie	224	**233**	....	....	224	**233**
	Bulong	3	**2**	....	....	3	**2**
Coolgardie	Coolgardie	90	**114**	1 560	**1 522**	1 650	**1 636**
	Kunanalling	12	**26**	....	....	12	**26**
Yilgarn	....	42	**57**	153	**152**	195	**209**
Dundas	....	222	**223**	2	**2**	224	**225**
Phillips River	....	....	**2**	2	....	2	**2**
South-West Mineral Field	....	....	....	3 621	**3 740**	3 621	**3 740**
Northampton Mineral Field	....	....	....	....	....	....	....
Greenbushes Mineral Field	....	....	....	134	**156**	134	**156**
Outside Proclaimed Goldfield	....	....	....	3	**5**	3	**5**
Collie Coalfield	....	....	....	870	**896**	870	**896**
Total—All Minerals	....	960	**996**	12 106	**12 404**	13 066	**13 400**

Minerals Other than Gold—	1978	1979
Alumina	2 804	**2 947**
Barytes	....	**14**
Building Stone	6	**7**
Clays	14	**20**
Coal	870	**896**
Dolomite	....	**3**
Emeralds	4	**6**
Felspar	4	**4**
Garnet Sands	2	**2**
Glass Sand	11	**8**
Gypsum	14	**15**
Iron Ore	5 151	**5 435**
Limestone	20	**33**
Manganese	....	**3**
Mineral Beach Sands	736	**692**
Nickel	1 748	**1 731**
Petroleum (Crude Oil)	102	**106**
(Natural Gas)	9	**9**
Ochre	1	**1**
Salt	400	**221**
Semi Precious Stones	13	**13**
Talc	28	**36**
Tanto/Columbite	6	**4**
Tin	160	**198**
Tungsten Ore (Scheelite)	1	....
Vermiculite	2	....
Total—Other Minerals	12 106	**12404**

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 1979, gold, silver, tungsten, lead, copper, tantalite and garnet ores to the value of $53 337 815 have been treated at the State Batteries. $50 927 121 came from 4 110 359 tonnes of gold ore; $501 146 from 85 380 tonnes of tin ore; $73 764 from 5 060·1 tonnes of tungsten ore; $1 643 301 from 72 412·7 tonnes of lead ore; $11 932 from 224 tonnes of copper ore; $100 350 from 3 121 tonnes of tantalite ore; $72 341 from 2 052·6 tonnes of garnet ore; and silver valued at $7 860 from the cyanidation of gold tailings.

During the year 59 315·65 tonnes of gold ores were crushed for 414·517 kilograms of bullion estimated to contain 351·4733 kilograms of fine gold equal to 5·92 grams per tonne The average value of sands after amalgamation was 2·2 grams per tonne making the average head value 8·12 grams per tonne. Cyanide plants produced 41·1338 kilograms of fine gold giving a total estimated production for the year of 392·607 kilograms of fine gold valued at $3 479 844.

The working expenditure for all plants was $1 928 035 which does not include depreciation, interest or Superannuation. Since the inception of State Batteries the Capital expenditure has been $2 120 005 made up of $1 505 663 from General Loan Funds $529 526 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 $282 409 compared with $243 354 for 1978.

The actual expenditure from inception to the end of 1979 exceeds revenue by $16 167 452.

(B) PROSPECTING SCHEME

At the end of the year, one man was in receipt of prospecting assistance as in 1978.

Total expenditure for 1979 was $912·50 and there were no refunds during the year.

There were no crushings by the assisted prospector during the year.

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

Expenditure—$1 057 174·00
Refunds—$205 089·00
Ore Crushed—131 245 tonnes
Gold Won—1 813·275 kilograms

The rate of assistance remained at $17·50 per man per week in the more remote localities and $15·00 per man per week in the less isolated areas.

(C) GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

In addition to advice and information given directly to mining companies, the Branch has published a Mineral Resources Bulletin on molybdenum, tungsten, vanadium, and chromium; and Reports on laterite profiles in the Darling Range, and aspects of petrology of the Eastern Goldfields. Seventeen additional 1:250 000 scale geological maps were issued by the Survey in conjunction with the Commonwealth Bureau of Mineral Resources.

The collection of open-file company reports on microfilm has grown to 118 rolls, and the library facilities for reading and copying microfilm are being used almost to capacity. A geological excursion to the Nabberu Basin, and a series of public lectures in Perth were both well attended.

A regional office was opened in Kalgoorlie; this office has a duplicate collection of open-file company reports and facilities for reading and copying them. A second regional office, at Karratha, is expected to be open in 1980.

PART 4—GOVERNMENT CHEMICAL LABORATORIES

The Laboratories continued this year to provide a wide range of analytical advisory and consultative services to Government Departments and to the public, where such facilities were not available in the private sector. The range of services are indicated in part by the titles of the eight Divisions of the Laboratories:

Agricultural Chemistry Division
Engineering Chemistry Division
Food and Industrial Hygiene Division
Forensic Chemistry Division
Industrial Chemistry Division
Kalgoorlie Metallurgical Laboratory
Mineral Division
Water Division

Details of the breadth of the work carried out is contained in their summarised reports in Division VII of this report. The Agriculture Department continued to be the major client of the Laboratories, with Public Works Department, Public Health Department, Police Department, Road Traffic Authority, this Department and Metropolitan Water Board being the next users of the services.

The increased demands of these Departments in plant nutrition, soil, animal, water quality, water treatment, effluent and waste disposal, pesticide residues, food quality, occupational health, mineral, environmental, drug and criminal problems have thrown an increasing burden this year on the already stretched resources of the Laboratories.

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 1 311 permits were issued for various purposes related to explosives import, manufacture, storage, sale and use.

Both general and professional officers of the Branch made more than 6 000 inspections during the year to give advice on the safe storage of dangerous goods at licenced and non-licensed premises and also checked vehicles conveying flammable liquids in bulk throughout the State. A total of 5 200 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 4 163 examinations were made under the Mine Workers' Relief Act. Of the examinations under the Mine Workers' Relief Act, 3 655 were new applicants and 387 were re-examinees.

Compensation under the Miners' Phthisis Act paid during he year was $4 087 compared with $4 782 in the previous year. The number of beneficiaries under the Act as at 31/12/1979 was 20, being 2 ex-miners and 18 widows.

PART 7—SURVEYS AND MAPPING BRANCH

Once again, the staff in all Branches were called upon to meet increased demands for mapping work and services. The continuation of diamond exploration resulted in more maps being prepared to cover these areas. A record number of geological plans of all types was prepared and the full impact of the withdrawal of Commonwealth funds for geological mapping was felt.

A heavy overtime programme was used as partial compensation. Applications for mining tenements continued at the rate of 1 000 per month and the sale of maps doubled in number and two and one half times in value.

The survey of tenements continued including photogrammetric surveys and investigations into the development of computer methods was carried out.

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.

B. M. ROGERS,
Under Secretary for Mines.

Department of Mines,
Perth.

DIVISION II

Report of the State Mining Engineer for the Year 1979

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 which report is divided into six sections, namely:—

- Mineral and Metal Production, Accident Statistics and Mine Inspection.
- Metalliferous Mining:—
  - Port Hedland/Karratha Inspectorate.
  - Perth Inspectorate.
  - Kalgoorlie Inspectorate.
- Coal Mining.
- Drilling Operations.
- Board of Examiners for:—
  - Mine Manager's and Underground Supervisors Certificates.
  - Quarry Manager's Certificates-
  - Coal Mining Certificates.
- Ventilation Board.

The value of mineral production (excluding petroleum and construction materials) at $1 972 566 667 was 21 per cent greater than the value of output for the previous year. Product price increases accounted for part of the overall increase but generally increased outputs in most minerals and metals assisted the continuing trend of higher annual values.

Although there was a decrease in output of nearly 2 000 kilograms of gold, as compared with the previous year, it is evident that there will be a significant increase in the coming year as several mines are being re-opened following increased gold prices. Iron ore sales at $1 040 million accounted for nearly 53 per cent of the total value of mineral production for the year. Western Australian output of iron ore is now in excess of 85 million tonnes per annum.

Alumina output from Pinjarra and Kwinana increased by 475 065 tonnes to nearly 4 million tonnes which figure indicates a doubling of annual output in six years. Nickel ore and concentrate production reached 479 119 tonnes an increase of 10 178 tonnes on the 1978 production. Output from the Collie Coalfield continues to increase in line with the change-over to coal burning equipment by the State Energy Commission.

ACCIDENTS

There were 7 fatal and 451 serious mining accidents reported during the year from a workforce of 21 954 persons. In the previous year there were 7 fatal and 567 serious accidents reported. The accident rate per 1 000 men employed in 1979 was 0·32 for fatal accidents and 20·54 for serious accidents.

DRILLING

As part of the State-wide ground water investigation the Drilling Section completed 7 938 metres of exploratory drilling near Quindalup, Lake Clifton, Bunbury, Woodmans Point and in the Fortesque Valley. In addition 200 metres of drilling was completed as part of an investigation to determine the effects of logging on the groundwater in the Manjimup area and to investigate recharge and the effects of the effluent disposal at Canning Vale.

STAFF

Retirements:—

Wilson, A. Y., State Mining Engineer	1/3/79
Jacobson, E. W., Workmen's Inspector of Mines	27/6/79

Promotions:—

Lloyd, J. K. N., State Mining Engineer	30/5/79
Faichney, J. M., Assistant State Mining Engineer	23/8/79
Dodge, G. J., Mining Engineer-Principal Senior Inspector of Mines	8/11/79

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

MINERAL AND METAL PRODUCTION—MINE DEVELOPMENT

Comprehensive details of Mining activity and production throughout the State are contained in the reports of the three Senior Inspectors of Mines which follow immediately after this section.

However the following tables summarise the various mineral production and mine development statistics:—

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

TABLE 1

Mineral and Metal Output (excluding Petroleum)

Mineral Production	1978		1979	
	Production	Value	Production	Value
	Tonne (t)	$A	Tonne (t)	$A
Alumina	3 470 380	277 630 400	3 945 445	422 162 615
Antimony	....	....	....	....
Barytes	....	....	34 658	482 235
Bentonite	....	....	....	....
Building stone	4 356	113 904	2 961	63 037
Clays	290 557	202 310	419 829	418 622
Coal	2 403 503	28 642 245	2 735 230	44 407 880
Cobalt	172·29	854 689	215·86	2 660 628
Copper—Metal	1 501·42	1 330 712	1 740·81	2 256 476
Dolomite	....	....	585	3 510
Emeralds—Carats (cut)	7	875	1 205	7 230
Emeralds (grams)	668	5 346	....	....
Felspar	889	29 278	1 929	82 999
Garnet Sand	479	33 474	42	3 480
Glass Sand	104 697	Not Available	278 091	Not available
Gold (kg)	13 332·42	72 882 596	11 581·99	108 322 743
Gypsum	159 537	588 660	243 210	966 783
Ilmenite (includes upgraded and reduced ilmenite)	1 039 331	23 687 589	1 143 286	27 699 090
Iron Ore	82 498 589	956 965 039	85 171 982	1 039 594 173
Iron Ore—Pig Iron	65 700	3 760 667	85 051	4 767 928
Leucoxene	13 273	1 773 702	29 196	3 919 851
Limestone	715 490	1 373 387	676 596	1 560 229
Mica	....	....	310	65 773
Manganese	922	16 140	1 395	24 427
Monazite	10 457	1 848 767	17 352	4 033 271
Nickel Ore and Concentrates	468 941	186 088 405	479 119	227 304 194
Ochre	281	4 776	222	3 772
Palladium (kg)	229·72	418 136	213·89	625 772
Platinum (kg)	92·10	557 698	85·88	862 865
Ruthenium (kg)	....	....	....	....
Rutile	114 643	22 422 136	94 351	19 887 292
Salt	3 888 065	27 410 412	3 731 854	27 024 382
Semi-precious Stones (kg)	11 523	10 575	4 973	9 600
Silver (kg)	2 178·11	203 253	1 856·65	374 968
Talc	120 352	Not Available	110 359	Not available
Tanto-Columbite	138·52	2 751 264	172	7 454 069
Tin Concentrate	692·34	5 341 725	694·9	7 542 231
Tungsten Ores and Concentrates—Scheelite	·14	1 108	....	....
Vermiculite	244	2 440	....	....
Xenotime	13	12 138	44	53 990
Zircon	151 297	8 614 435	337 197	17 920 552
Totals		1 625 578 281	....	1 972 566 667

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

Mineral or Metal	Mining District	Mine	Shaft Sinking (metres)	Decline and Incline (metres)	Driving and Cross Cutting (metres)	Rising and Winzing (metres)	Exploratory Diamond Drilling (metres)
Gold	East Coolgardie	Kalgoorlie Mining Assoc.—Mt. Charlotte	....	286	2 871	490	971
		Kalgoorlie Mining Assoc.—Fimiston Leases	....	....	1 781	135	205
		North Kalgurli	....	....	....	....	2 300
		Daisy Gold Mine	....	....	60	....	....
	Dundas	Central Norseman	....	480	111	288	26 331
	N. Coolgardie	Aspacia Gold Mine	....	....	115	18	273
	Yilgarn	W.A. Gold Development....	....	....	22	72	....
	Murchison	Ingliston Gold Mine	12	....	62	6	....
		Nannine Gold Mine	11	....	....	....	....
		Hill 50 Gold Mine—Water Tank Hill	52	....	....	....	5 141
	Pilbara	Telfer Gold Mine (Exploratory development)	....	....	126	8	....
		Total Gold Development	75	766	5 148	1 017	35 221
Nickel	Mt. Margaret	W.M.C. Windarra	....	572	1 096	84	14 912
	Coolgardie	Metals Exploration	....	....	2 056	456	7 100
		Selcast Exploration	....	....	117	118	31
		W.M.C. Kambalda	....	2 367	11 994	5 440	80 671
	E. Murchison	Agnew Mining Co.	340	720	53	890	6 892
		Total Nickel Development	340	3 659	15 316	6 988	109 606
		Total Development	415	4 425	20 464	8 005	144 827

TABLE 3

Principal Gold Producers

Mine	1978			1979		
	Tonnes Treated	Yield † Kilograms	Grams Per Tonne	Tonnes Treated	Yield † Kilograms	Grams Per Tonne
Kalgoorlie Lake View Pty. Ltd.	....	*71·26	....	....	*81·03	....
Kalgoorlie Lake View Pty. Ltd. (Mt. Charlotte)	636 153	3 089·26	4·8	716 791	3 307·80	4·6
Central Norseman Gold Corporation N.L.	149 813	2 710·10	18·1	136 687	2 260·76	16·5
Mulga Mines Ltd.	1 589	44·90	27·7	....	....	....
Newmont Pty. Ltd.	435 612	7 000·17	16·0	439 510	5 292·04	12·0
Minor Producers	57 005	368·43	7·3	77 890	556·87	7·1
Total State Production	1 280 172	13 284·12	10·4	1 370 878	11 498·50	8·4

* From mill clean-up.
† Does not include alluvial or dollied gold.

NOTE: The calculated value of the gold produced in 1979 was $108 322 743 which includes $94 808 078 distributed by the Gold Producers Association from the sale of 11 669·258 kilograms of gold at an average premium of $8 124.60 per kilogram.

TABLE 4

Overseas Iron Ore Exports

Company	1978		1979	
	Exported	Grade	Exported	Grade
	(tonnes)	(% Fe)	(tonnes)	(% Fe)
Hamersley Iron Pty. Ltd.	29 771 495	63·88	29 159 716	63·61
Mt. Newman Mining Co. Pty. Ltd.	24 055 334	63·00	23 600 402	63·00
Cliffs W.A. Mining Co. Pty. Ltd.	12 002 957	59·29	13 976 711	59·09
Goldsworthy Mining Ltd.	5 879 249	63·35	6 689 032	63·08
Dampier Mining Co. Ltd.	2 488 116	67·82	3 206 035	67·29
Totals	74 197 151	62·94	76 631 896	62·71

TABLE 5

Nickel Producers

Product and Company	1978			1979		
	Quantity	Grade	Value	Quantity	Grade	Value
	tonnes	% Ni	$A	tonnes	% Ni	$A
NICKEL CONCENTRATES—						
Western Mining Corporation Ltd.—Kambalda	307 896	13·07	146 046 772	337 962	12·64	189 713 958
Western Mining Corporation Ltd.—Windarra	76 677	10·60	22 154 466	3 964	9·50	893 634
Selcast Exploration Ltd.—Emu Rock	10 809	16·67	7 232 306	12 482	16·50	9 440 647
Anaconda Aust. Inc.—Redross	9 146	13·09	4 196 699	....	....	....
Agnew Mining Co. Pty. Ltd.—Agnew	....	....	....	58 693	10·79	18 233 728
Total Concentrates	404 528	12·70	179 630 243	413 101	12·46	218 281 967
NICKEL ORE—						
Metals Exploration N.L.—Nepean	71 544	3·29	7 049 104	66 018	3·67	9 022 227

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* 1979—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.

DIAGRAM OF FATAL ACCIDENTS

SEGREGATED ACCORDING TO CLASS OF MINING

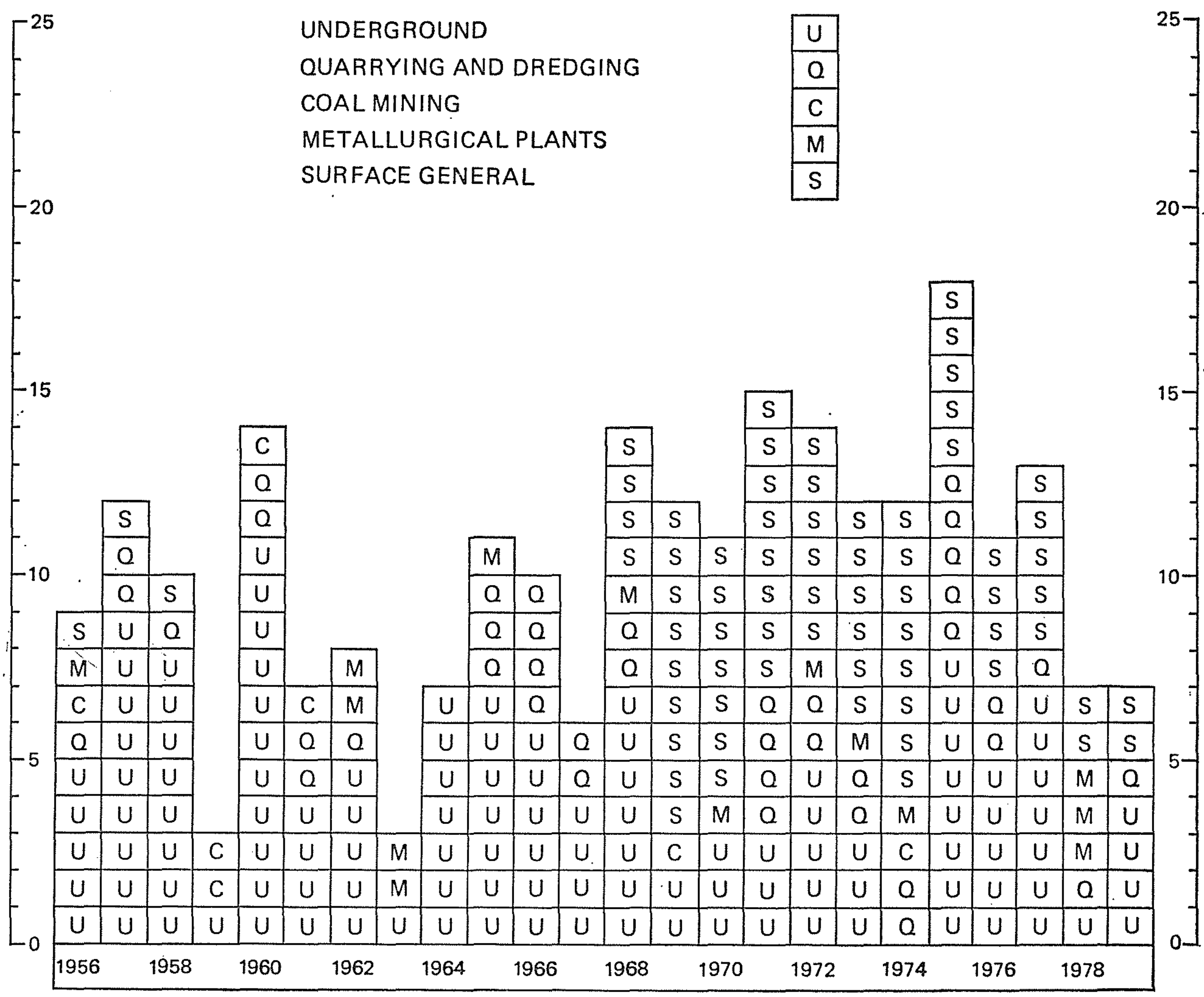


TABLE "A"

SERIOUS ACCIDENTS FOR 1979

Class of Accident	Yalgoo	Pilbara	West Pilbara	Peak Hill	Gas-coyne	Mount Mar-garet	East Cool-gardie	Cool-gardie	Dundas	South West	Green-bushes	Yilgarn	East Murchi-son	North Cool-gardie	Eucla	Collie	Murchi-son	West Kim-berley	Broad Arrow	Total
Major Injuries (exclusive of fatal)—																				
Fractures—																				
Head	....	....	....	1	....	....	....	....	....	2	....	....	....	....	....	....	....	....	....	3
Shoulder	....	....	1	....	....	....	....	....	....	3	....	....	....	....	....	....	....	....	....	4
Arm	....	2	1	1	....	....	....	1	....	....	....	....	2	....	....	....	....	....	....	7
Hand	....	....	....	1	....	....	3	1	....	2	....	....	1	....	....	....	....	....	....	8
Spine	....	....	....	....	....	....	....	....	....	1	....	....	....	1	....	....	....	....	....	2
Rib	....	....	....	....	....	....	....	2	....	5	....	....	....	....	....	....	....	....	....	7
Pelvis	....	1	....	....	....	....	....	1	....	....	....	....	1	....	....	1	....	....	....	4
Thigh	....	....	....	....	....	....	....	....	1	....	....	....	....	....	....	....	....	....	1	2
Leg	....	1	....	....	....	....	....	6	....	....	....	1	2	....	....	1	....	....	....	11
Ankle	....	1	....	....	1	....	1	1	....	....	....	....	....	....	....	....	....	....	....	4
Foot	....	2	....	....	....	....	1	3	....	3	....	....	2	....	....	....	....	....	....	11
Amputations—																				
Arm	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Hand	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Finger	....	1	1	....	....	....	1	1	....	1	....	....	1	....	....	1	....	....	....	7
Leg	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Foot	....	....	....	....	....	....	1	....	....	....	....	....	....	....	....	....	....	....	....	1
Toe	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Loss of Eye	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Serious Internal	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Hernia	....	2	....	....	....	....	....	2	....	6	....	....	....	....	....	....	....	....	....	10
Dislocations	....	2	....	....	....	....	....	....	....	1	....	....	....	....	....	....	....	....	....	3
Other Major	....	1	1	....	....	....	....	....	....	6	....	....	....	....	....	1	....	1	....	10
Total Major	....	13	4	3	1	....	7	18	1	30	....	1	9	1	....	4	....	1	1	94
Minor Injuries—																				
Fractures—																				
Finger	....	4	9	3	....	....	2	9	....	4	1	....	1	....	....	3	....	....	....	36
Toe	....	1	1	....	....	....	1	2	....	1	....	....	....	....	....	....	1	1	....	8
Head	....	....	....	....	....	....	1	3	....	2	....	....	....	....	....	4	....	....	....	10
Eyes	....	1	1	1	....	....	1	2	....	2	....	1	....	....	....	1	....	....	....	10
Shoulder	....	....	1	....	....	....	....	3	3	4	....	....	....	....	....	4	....	....	....	15
Arm	....	2	1	2	....	....	....	2	4	1	1	....	1	....	....	....	....	....	....	14
Hand	....	6	12	1	1	1	6	12	3	3	....	2	4	....	....	1	....	....	....	52
Back	....	11	6	7	1	....	11	12	4	24	2	1	....	....	....	17	....	....	....	96
Rib	....	....	....	....	....	....	1	2	....	....	....	....	....	....	....	2	....	....	....	5
Leg	....	4	10	3	1	1	2	9	3	15	2	....	....	....	1	4	....	....	....	55
Foot	1	3	2	1	1	....	7	7	1	5	....	....	1	....	....	2	....	....	....	31
Other Minor	....	3	6	....	....	....	2	6	2	4	....	....	....	....	....	1	....	1	....	25
Total Minor	1	35	49	18	4	2	34	69	20	65	6	4	7	....	1	39	1	2	....	357
Grand Total	1	48	53	21	5	2	41	87	21	95	6	5	16	1	1	43	1	3	1	451

There were no serious accidents in the following Mining Districts:—North East Coolgardie, Phillips River, Kimberley, Ashburton, Northampton, Warburton and Nabberu.

TABLE "B"

ACCIDENTS SEGREGATED ACCORDING TO MINERAL MINED AND PROCESSED

Mineral	Men Employed	Accidents		
		Fatal	Serious	Minor
Bauxite (Alumina)	3 189	....	47	157
Coal	896	....	43	449
Gold	1 043	2	57	185
Ilmenite etc.	800	....	25	69
Iron	12 164	2	123	469
Nickel	2 675	3	129	331
Salt	433	....	9	39
Tin	228	....	6	29
Other Minerals	298	....	5	6
Rock Quarries	228	....	7	32
Totals	21 954	7	451	1 766

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	....	....	....	....	....	....	....	....	....	....	....	3	....	3
Pilbara	....	....	....	1	....	....	....	....	....	....	....	47	....	48
West Pilbara	....	....	....	....	....	....	....	....	....	....	1	53	1	53
Ashburton	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Peak Hill	....	....	....	....	....	....	....	....	....	....	1	21	1	21
Gascoyne	....	....	....	....	....	....	....	....	....	....	....	5	....	5
Murchison	....	....	....	....	....	....	....	....	....	....	....	1	....	1
East Murchison	....	....	....	1	....	3	....	....	....	1	....	11	....	16
Yalgoo	....	....	....	....	....	1	....	....	....	....	....	....	....	1
Northampton	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Mount Margaret	....	....	....	1	....	....	....	....	....	....	....	1	....	2
North Coolgardie....	....	....	....	....	....	1	....	....	....	....	....	....	....	1
Broad Arrow	....	....	....	....	....	....	....	....	....	....	....	1	....	1
North East Coolgardie	....	....	....	....	....	....	....	....	....	....	....	....	....	....
East Coolgardie	....	....	....	1	1	1	....	....	1	10	....	29	2	41
Coolgardie	....	....	1	11	1	1	....	1	....	47	....	27	2	87
Yilgarn	....	....	....	....	....	....	....	....	....	....	....	5	....	5
Dundas	....	....	....	2	....	....	....	....	....	13	....	6	....	21
Phillips River	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Greenbushes	....	....	....	....	....	....	....	....	....	....	....	6	....	6
South West	....	1	....	....	....	....	....	....	....	....	1	94	1	95
Collie	....	....	....	2	....	....	....	....	....	27	....	14	....	43
Nabberu	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Warburton	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Eucla	....	....	....	....	....	....	....	....	....	....	....	1	....	1
Total for 1979	....	1	1	19	2	7	....	1	1	98	3	325	7	451
Total for 1978	....	2	1	20	....	9	2	2	....	151	4	383	7	567

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

Name and Occupation	Date	Mine	Details and Remarks
A. F. Crowe (Crusher Operator)	1/2/79	Western Mining Corporation Ltd. Kambalda Nickel operations	Died from a severe fracture of the base of the skull sustained while travelling to surface of Otter Juan Shaft in a service cage.
P. A. Guy (Apprentice Electrician)	7/2/79	Western Mining Corporation Ltd. Kambalda Nickel operations	Died from multiple injuries as a result of a rock fall in the 607/2 stope, Hunt Decline.
W. Mitchell (Contract Miner)	7/3/79	"White Hope" Gold Mine	He fell down the shaft and sustained a fractured skull.
E. W. Johns (Lube Greaser)	1/7/79	Mt. Newman Mining Co. Mt. Whaleback	Died of multiple injuries after being crushed between a tracked dozer and a lube truck.
W. Sims (Crane Driver)	2/7/79	Western Mining Corporation Ltd. Kwinana Nickel Refinery	Died of Pulmonary Embolus following a minor leg injury on the 23rd June 1979 when a steel beam being slung for lifting rolled against his leg.
V. O'Sullivan (Car Examiner)	16/9/79	Hamersley Iron Pty. Ltd. Railway	Died from severe head injuries after the vehicle he was driving rolled over onto the railway track and was then struck by a train.
G. Ramus (Diesel Fitter)	4/12/79	Kalgoorlie Mining Associates Mt. Charlotte	Crushed between the cross member of the bucket arms and the body of a 966 front end loader while working on the lift rams. He died of crush injuries in the chest.

WINDING MACHINERY ACCIDENTS

Five accidents involving winding machinery and associated equipment occured. All were investigated and remedial action taken. Brief details are as follows:—

Rope Failure or Damage

1. On March 20 the rope on the south drum of the Nepean Shaft (Metals Exploration N.L.) failed after jumping from the head sheave during an ore haulage cycle. The incident occurred as the result of an undetected slack rope condition brought about by a skip hang up.
2. At the Agnew Shaft of Agnew Mining Co. Pty Ltd (Construction by Thyssen Mining) severe rope damage occurred to the right hand drum rope on the 3rd July, when it fouled the brake post. The rope became loose on the drum permitting it to jump the flange for the following reasons:
   (i) Winding at full speed without any conveyance attached to the rope
   (ii) Inadequate drum flange

Cage/Skip Hang-Ups

1. The Skip was derailed in the Regent Shaft of Central Norseman Gold Corporation on the 15th August. A build up of ore on the rails caused the mishap.
2. A second derailment occurred in the Regent Shaft on the 23rd August. The incident was brought about by a rail failure, the reason for which was not determined. No damage resulted from the accident.
3. On the 7th September the cage became jammed at the 9 level plat of the Long Shaft, at W.M.C.'s Kambalda Nickel Operations. The chairing horns at the base of the cage fouled shaft bratticing which had been dislodged by nearby development blasting. No rope damage resulted.

PROSECUTIONS

There were no prosecutions commenced or completed during the year.

CERTIFICATES AND PERMITS

Certificates of Exemption

Only two certificates were granted under section 46 of the Mines Regulation Act.

Authorised Mine Surveyor's Certificate

The survey board issued three certificates during the year. One was an initial certificate, whereas the other two were re-issued under Regulation 10.4 of the Mines Regulation Act 1946–74.

Certificates were issued as follows:

S. A. Silvester—Certificate No. 040
G. J. Dodge—Certificate No. 041
B. J. D. van der Hoek—Certificate No. 042

Power Shovel Operators Certificate of Competancy

As anticipated in last year's report, a marked increase in the number of applicants for examination as Power Shovel Operators occurred during 1979. The Department issued 179 certificates under the provisions of Regulation 17.3, two of which were issued to female operators at Shay Gap.

Sunday Labour Permits

Thirteen permits covering twenty-two shifts and involving a total of 77 men were issued to five mining companies, all in the Kalgoorlie inspectorate. The permits were issued for various reasons, but on the whole the works undertaken could not be carried out safely during normal working shifts.

Permits to Fire Outside Prescribed Times

Seven permits were issued to fire outside the times prescribed in the Mines Regulation Act, Regulation 7.30.

W.M.C. Kambalda Nickel Operations—Two permits were granted for work within the Fisher Decline operations. One to construct a rise for ventilation and the other to strip an existing ventilation rise to improve ventilation. Permits were also granted for the development of the Gellatly Decline extension and the 8 level cross cut on the Jan Shaft.

W.M.C. Windara Nickel Project—A permit was granted for the continuing development of the main decline.

Central Norseman Gold Corporation—A permit was granted for the development of the North Royal Decline.

Agnew Mining Company—A permit was issued to permit uninterrupted mining of two access ramps to stoping blocks in the Agnew Nickel Mine.

VENTILATION

Ventilation staff continues to sample atmospheric contaminants and to measure air flows and temperatures as and where required throughout the mining industry. Concerted efforts have been made to have dust emissions in quarries and treatment plants reduced and to locate and reduce the emissions of toxic gases and vapours. The checking of diesel engine emissions and resultant contaminants in the underground ventilation systems continued to be a major portion of the workload for Kalgoorlie Ventilation staff.

Throughout the State, 927 personal gravimetric dust samples were taken, of which 20.3% exceeded the standard of purity (S.O.P.) for the particular dust sampled. In addition, a further 393 positional, total dust samples were taken.

Underground—Dust Sampling

Dust sampling revealed that jumbo drill operators are susceptible to high dust concentrations on many mines. On one mine 56% of the samples taken exceeded the S.O.P. In siliceous mines, this is a matter for concern which has received considerable attention from the inspectors of mines who wish to see the dust eliminated. However, the problem is complex, and a satisfactory solution has not yet been found.

Routine sampling in Nickel Mines indicated that free silica could be a problem in some areas, particularly in development headings in waste. A programme was commenced, and is continuing, to isolate areas where siliceous dust is generated.

Underground —Diesel Engines and Associated Gas Sampling

There were 62 new diesel engine permits issued for underground use during the year. In addition to the normal replacement of loaders and trucks with more modern equipment, the new permits covered such equipment as a diamond drill, a cable laying machine, a Swiss made S.I.G. hydraulic jumbo and a number of personnel carriers.

Sampling of undiluted diesel exhausts for Carbon Monoxide and nitrous gas concentrations were carried out on all diesel mines at frequent intervals. Of a total of 410 diesel engines tested, 1% were found to exceed the CO limit of 2 500 ppm and 2·5% the NOx limit of 2 000 ppm.

Fifteen areas were tested for carbon monoxide content in the underground atmosphere. One was found to exceed the S.O.P. of 50 ppm. Similarly, one of thirteen areas tested for nitrogen dioxide exceeded the S.O.P., as did one of eight, taken for carbon dioxide.

Although the majority of underground vehicles satisfactorily passed the undiluted exhaust gas tests, many were found to require maintenance to achieve a satisfactory standard of safety. Far too often, it was found necessary to withdraw vehicles from service and send them to the workshop for repairs.

One trackless, underground diesel engined vehicle operator had his certificate suspended for one month as permitted under Regulation 13.13 of the Mines Regulation Act 1946 and Regulations.

Underground—Airflows

A number of problems arose with primary ventilation circuits in several mines and for a number of different reasons. In some instances it was necessary to close down all diesel equipment for several shifts while the ventilation circuits were rectified. Shortcircuiting of air flows due to changing conditions within the mines were the causes of most major ventilation problems. In other cases, a gradual deterioration, due to late construction of exhaust raise bore holes, led to situations whereby it was necessary to suspend, or reduce, the use of diesel equipment until the raise bores had been completed.

On many occasions, inspectors found it necessary to suspend work in stopes and development ends where forced ventilation was necessary, but found to be non-existent or deficient. Such instances were often found to be attributable to poor supervision, combined with a lack of interest on the part of the workmen for their own health and well being.

Underground—Natural Gas Emissions

Diamond drilling operations encountered pockets of gas occurring naturally in the rock on three occasions. Two were on the Kambalda Nickel Mines, while the third was on a drill hole collared on the Kalgoorlie State Battery Reserve. All holes were plugged upon completion.

Surface—Dust Sampling

Inspectors continued to measure personal dust exposure of the surface workforce during the year, and continued their efforts to have dust emmissions minimized. On the whole, concentrations of air borne dust in the working places have continued to be reduced, particularly so, in treatment and processing plants.

The mining industry generally, is taking a more active and responsible approach to dust control and large sums of money have been spent over the past few years on dust suppression and collection equipment. Dust control in the iron ore plants has improved considerably and all have now achieved a reasonable standard of control.

This gradual improvement has permitted inspectors to concentrate more of their efforts into rectifying particular problem areas. It has been found that some plant maintenance personnel, mobile equipment operators, crusher operators and workmen in some sample preparation rooms are regularly exposed to excessive dust concentrations. Mining companies are co-operating and much has already been done such as the fitting of pressurised cabins on equipment and crushers, and improved ventilation in sample preparation rooms. Reduction of high dust exposure by some maintenance personnel is more complex and will take some time to fully eliminate.

Surface—Gas Sampling

Emissions of gasses from treatment plants such as the smelter refineries and blast furnaces were measured on a regular basis. Also checked, were gold rooms for Hg vapour and various work shops for organic vapours and solvents used in gluing and cleaning processes.

Fumings

During 1979, there were 12 fuming incidents involving 15 mine personnel. Of the ten underground incidents, two were quite serious, one rendering the miner unconcious and resulting in his hospitalisation for several days. The majority of underground fumings were associated with blasting fumes and were caused by miners entering confined areas before fumes had properly cleared, or by a failure to sufficiently water down broken dirt.

A front end loader operator was seriously affected when diesel exhaust fumes entered his cabin from a faulty exhaust manifold. Even though this unit was working on the surface, the operator was in hospital for a week. The second surface fuming resulted from a concentration of sulphur dioxide at a treatment plant.

Fires

Four underground fires were reported to the Department; all occurred in diesel engined equipment. Two resulted from hydraulic hose failure which permitted flammable hydraulic fluid to spray onto hot engine manifolds causing ignition. One fire was due to an electrical fault, and the fourth was caused by a vacuum hose breaking loose and falling onto the engine turbo charger. All fires were extinguished by the operators and no personnel were affected by fumes or smoke.

Seismic Recordings and Complaints

Complaints of excessive vibrations from quarry blasting were relatively few during the year. Co-operation by quarry managers, in keeping blast sizes and explosive per delay ratios to a minimum, is of great assistance in minimizing disturbance to the public. In no instances were vibrations found to be excessive.

Assistance was given to Westrail and the Metropolitan Water Supply, Sewerage and Drainage Board in measuring the effects of ground vibrations from trains and earthmoving equipment (respectively) upon various structures.

At Kalgoorlie, the vibrations generated during the blasting of a crown and a rib pillar (involving 224 000 tonnes of ore) below the 13 level were measured in the town. Ground vibrations remained within recommended limits.

Rehabilitation

In the Eastern Goldfields, little rehabilitation is practised because the majority of the mines are either underground or are large open cuts. However, most companies now maintain a responsible approach and endeavour to disturb as little of the native flora as possible.

Rehabilitation of the iron ore mines in the Pilbara is somewhat impossible because of their immense size, however, the Mt Newman Mining Co is endeavouring to establish native shrubs and trees on its waste dumps. So far, the results are sufficiently encouraging for the Company to maintain its efforts. At Pannawonica, C.R.R.I.A. are deep ripping the floors of the pits (which are now the new tops of the mesas) to assist the establishment of native vegetation.

The major rehabilitation efforts are undertaken in the South West of the State in the Bauxite, Mineral Sands and Tin Mining areas. Such operations cover relatively large areas for the tonneages mined when compared with deep open pit mines, and are all sited on land which can be readily put to productive use after mining.

Rehabilitation of Alcoa's mining operations at Jarrahdale, Del Park and Huntly has now become such a routine part of the mining operation that most mined areas are rehabilitated in less than 12 months from the time of clearing. The Forest Department maintains strict control on clearing and rehabilitation procedures.

Progress in rehabilitating mineral sand operations at Eneabba has been slow, largely due to the drought conditions which have prevailed over the past few years. Trial seedings and experiments aimed at the establishment of native flora on mine tailings, are continuing.

At Capel, Associated Minerals Consolidated Ltd is now well into the State Pine Forest. Five thousand tree seedlings were planted on restored tailings. Experimental plantings of Tuart seedlings are under way; results to date are encouraging. Previously established pastures continue to do well.

Westralian Sands Ltd and Cable Sands continue to rehabilitate with pastures and crops for cattle and sheep grazing.

Rehabilitation of both old and recent pits continued at Greenbushes throughout the year. Under the terms of their current agreement, the company is bound to spend $50 000 per year on rehabilitation. The company has made very responsible and worthwhile progress over the last few years and many long standing scars are now rapidly returning to the forest environment.

METALLIFEROUS MINING
PORT HEDLAND/KARRATHA INSPECTORATE

A. W. Ibbotson

Senior Inspector of Mines—Karratha

During October 1979 members of the State Mining Engineer's staff at Port Hedland moved into new quarters and offices at Karratha.

The inspectorate will be known as the Karratha Inspectorate as from 1980.

EMPLOYMENT

Company returns indicate an increase of approximately 6% in employment figures over the previous year. I would anticipate a further increase in mining activity associated with gold, salt and tin/tantalite production. Statistics related to diamond exploration and production are not required under the exploration conditions prevailing.

Mineral	Employment	
	Full Year	Part Year
Barite	23	....
Crushed Rock	....	38
Gold	230	....
Iron	11 613	....
Mica	10	....
Salt	315	....
Silver/Lead/Zinc	....	16
Tin/Tantalite	47	6
	12 238	60

EXPLORATION

Exploration for diamonds in the Kimberley and West Kimberley Goldfields has proceeded at a greatly increased rate. Applications for mining tenements have been lodged on an unprecedented scale in the Kimberley and West Kimberley areas. Exploration groups have also directed attention to certain areas of the Ashburton and Gascoyne Goldfields, but specific details are not known.

BARITE

Dresser Minerals experienced a somewhat frustrating year with its project at the North Pole centre, due primarily to problems associated with the definition of the orebody and with difficulties in the separation of ore from waste through the mine-site upgrade plant. As a direct result of these problems the annual output fell well below the production envisaged in 1978.

A total of 36 000 tonnes of ore and 78 000 tonnes of waste was mined at the North Pole centre and 33 000 tonnes of crude ore was transported by road to Port Hedland. 7 298 tonnes of this was processed into fine powder at the Port Hedland plant and the balance was subsequently shipped to the Gulf Coast, U.S.A.

New equipment obtained during 1979 included a Le Roi hydraulic drill, a Caterpillar D8K Bulldozer, and a Galion model 600 Road Grader.

A new office block, six two-bedroom married quarters and another single men's unit were established at the mine-site.

Exploratory drilling of potential ore bodies amounted to some 900 metres percussion drilling and 670 metres of diamond drilling during 1979.

CRUSHED ROCK

Specified Services Pty Limited

During 1979 this Company operated from deposits alongside the Harding River on Woodbrook Station screening and crushing river shingle, where they produced 90 000 tonnes of crushed stone and 60 000 tonnes of sand, most of which has been stockpiled.

They then moved to Mt. Regal where the Company began quarrying hardrock for the production of concrete railway sleepers, which will be manufactured by Humes Limited who have established a plant near the Hamersley Iron railroad where it passes Mt. Regal.

The Company employed an average of ten men on these operations.

The Readymix Group (W.A.) operated at three northern sites during 1979. From a quarry site 17 kilometres south of Karratha, the Company produced aggregate for the construction industry in and around Karratha. They then moved to Paraburdoo where they screened and crushed river shingle for the Main Roads Department for the sealing of the Tom Price-Paraburdoo Highway. 34 000 cubic metres yielded 17 000 cubic metres of saleable product.

Towards the end of 1979 the mobile crushing and screening plant was moved to Nillibubacca about 100 kilometres east of Broome along the Derby Highway, where some 80 000 cubic metres of material yielded 38 000 cubic metres of road sealing aggregate for the Main Roads Department.

An average of 18 employees and 10 transport subcontractors were engaged in these operations.

Bell Basic Industries Limited and Pioneer Quarries both reported nil production during 1979 within the area of the Port Hedland Inspectorate.

GOLD

The Telfer Project reported that during 1979 a total of 6 561 814 tonnes of material was mined, of which 439 510 tonnes was selected for treatment. A total of 5 294 kg of fine gold was recovered.

During 1979 an experimental drive (adit) was commenced from an horizon some 88 metres below the upper edge of the mine pit. The object of this experimental development was to test the holding capacity of the ground by advancing a normal sized heading along the orebody formation for some 70–80 metres and then to crosscut into the footwall country rock and to test the holding capacity of it under stoping conditions.

The Company reported that after attempting to advance a rise they experienced very hazardous conditions and withdrew the contractors accordingly. The scheme has not been abandoned but has been shelved indefinitely.

Included in the new equipment installed during 1979 is a continuous straking machine which must be of great advantage when so much gold is recovered by the strake cloth method of extraction.

Exploration drilling was quoted at 29 136 metres and development details were:—

Driving 77 metres

Crosscutting 49 metres

Rising 8 metres

A total of 220 persons including contractors were engaged on this project.

"Star of Mangaroon" G.M.—Gascoyne Goldfield

The owner of this mine has picked up the collar of the underlay shaft by concreting it down for a distance of some eight metres and in 1980 intends to sink the shaft a further 16 metres to an underlay depth of approximately 66 metres.

Sundry small prospectors are seeking gold at Bamboo Creek, Marble Bar, Sharks Gully, and at the Five Mile and Middle Creek centres out from Nullagine.

IRON ORE

Statistics from the five producing companies show that, in comparision with the year 1978, there was an increase of 762 in the number of employees; a decrease of 15.19 million tonnes in the amount of ore broken; and an increase of 1.95 million tonnes in the quantity of ore shipped.

Hamersley Iron Pty Limited

Tom Price

Mining during 1979 took place on 16 operating benches of 15 metres height.

Principal items of heavy equipment used on these operations included—

33 x 120B Wabco Haulpak Trucks

5 x 3200B Wabco Haulpak Trucks

1 x 191M Marion 9 m³ Diesel Electric Shovel

4 x 191M Marion 9 m³ Electric Shovels

4 x 2100BL P & H 9 m³ Electric Shovels

2 x 60R Bucyrus Erie Rotary Drills (Diesel electric)

3 x 61R Bucyrus Erie Rotary Drills (Electric)

3 Nobel Amerind Anfo Pumper Trucks

Two 152 cm x 226 Allis Chalmers gyratoray crushers process feed for the crushing and screening plant which is fed from three primary stockpiles.

The capacity of the Tom Price plant is 25 million tonnes per annum and the mine-site stockpile has a capacity of 800 000 tonnes.

PRODUCTION AND SHIPPING (MILLION TONNE UNITS)

Company	Persons Employed	Ore Broken	Ore Shipped			
			Lump	Fines	Pellets	Total
Hamersley Iron	4 226	43·089	13·497	14·810	1·787	30·094
Mt. Newman	3 851	35·896	15·157	14·815	(other ore) ·607	30·579
C.R.R.I.A.	1 677	13·386	....	9·225	3·994	13·219
Goldsworthy Mining	1 268	6·275	3·582	3·428	....	7·010
Dampier Mining	591	3·487	3·022	·437	....	3·459
Totals	11 613	102·133	35·258	42·715	6·388	84·361

Paraburdoo

Mining during 1979 took place on seven operating benches of 14 metres height.

The major items of plant in use comprised—

15 x 150 tonne Terex 33.15B Haul Trucks
4 x 2100BL P & H 9 m³ Electric Shovels
2 x 2100B P & H 9 m³ Electric Shovels
2 x 60R Bucyrus Erie Rotary Drills (diesel electric)
1 x 60R Bucyrus Erie Rotary Drill (electric)
2 Nobel Amerind Anfo Pumper Trucks

The plant feed is directed through one 152 cm x 226 Allis Chalmers gyratory crusher. The crushing and screening plant has a capacity of 16 million tonnes per annum and the product stockpile has a capacity of one million tonnes.

The port system comprises stockpiling and shiploading facilities at Parker Point, with stockpile capacity of two million tonnes and berthing facilities to handle ships of up to 120 000 DWT, and at East Intercourse Island which accommodates ships of up to 160 000 DWT with a stockpile capacity of 3 million tonnes.

The facilities at Parker Point also include a 2.8 million tonne per annum pellet plant.

Material Broken (million tonnes)

Location	High Grade Ore	Low Grade Ore	Waste	Total
Tom Price	18·460	9·240	4·320	32·020
Paraburdoo	12·006	3·383	3·848	19·237

New Plant and Equipment Installed

Tom Price: Commissioning of concentrator and associated lump loadout tunnel.

Dampier: Parker Point Commissioning of new fixed track slewing bucket-wheel reclaimer and fixed track slewing and luffing stacker.

Commissioning of new Central Control Room with Programmable Logic Controllers (PLC) controlling conveyor system and screenhouse and Fox 230 computer as data logger.

Commissioning of new stockpile area to increase stockpiling capacity to 2 million tonnes.

Commissioning of three new screens and vibrating feeders on screens.

East Intercourse Island: Commissioning of four new stockpile areas to increase stockpiling capacity to 3 million tonnes.

Commissioning of two new screens and vibrating feeders to all screens.

Exploratory Drilling (metres)

	Rotary	Percussion	Diamond Drilling
Tom Price	Nil	130 275	6 383
Paraburdoo	118	13 971	557

Underground Development (metres)

Tom Price—Shaft Sinking (exploration) 72
Paraburdoo—Exploration Shafts 74
Hamersley employed a total of 4 216 persons during the year.

Mt. Newman Mining Co. Pty Limited

Ore is mined from Mt. Whaleback and during 1979 a total of 29.69 million tonnes of ore was produced and railed to Nelson Point in Port Hedland.

During 1979 the company commissioned its new beneficiation plant at Mt. Whaleback.

At Point Cooke, construction was commenced on 45 new houses.

Exploratory Drilling (metres)

M.L. 244 SA—	
Percussion	6 781
Other Rotary	3 649
Temporary Reserves—	
Percussion	1 313·5
Other Rotary	799·5
Total	12 543 m

Mt. Newman Mining employed a total of 3 851 persons at its mine sites during 1979.

Cliffs Robe River Iron Associates

Ore is mined from goethitic iron ore cappings of mesas along the valley of the Robe River. The ore is railed 165 km to Cape Lambert where it is processed into pellets and fines for export.

Production during 1979 amounted to 13.60 million tonnes of ore which was railed to Cape Lambert. A total of 3.45 million tonnes of pellets averaging 62.56% Fe were produced and shipped, as well as 9.37 million tonnes of fines which averaged 67.07% Fe.

Exploratory Drilling

Rotary (vacuum) 13 000 metres

Number of Employees

	Cape Lambert	Pannawonica
Staff	250	78
Wages	880	388
Contractors	75	6
Total	1 205	472

A total of 1 677 persons were employed on Cliffs mining operations during 1979.

Goldsworthy Mining Limited

This company produces ore from Goldsworthy and Shay Gap from where the primary crushed ore is railed to Finucane Island and crushed and screened. The product is shipped to Japan with spot sales to Korea.

Production during 1979 (*million tonne units*)

Goldsworthy—3·00 M dry tonnes ore

Shay Gap—2·33 M dry tonnes ore

Sunrise Hill—0·94 M dry tonnes ore

Goldsworthy Mining Ltd employed 1 218 persons at its mine sites during 1979.

Dampier Mining Company Limited

This Company operates two mining operations at Yampi Sound, one at Cockatoo Island and the other on adjoining Koolan Island.

Cockatoo Island

During 1979, 1·188 million tonnes of ore was produced and of this 737 000 tonnes was shipped as lump ore and 437 000 tonnes as fines. The average grade of the ore shipped was 68·8 per cent Fe.

The operation at Cockatoo Island is nearing the end of life of the deposit with only about 12 months ore in sight above the RL 12M horizon. Some 5·0 million tonnes are known to exist below high water mark, but the extraction of this ore will present some major problems.

Koolan Island

Ore from two separate ore bodies is being mined and when crushed is stored in a 60 000 tonne capacity bin prior to ship loading.

Ore production during 1979 amounted to 2·299 million tonnes.

New Plant and Equipment acquired during 1979

1—JD 770 Grader

1—John Deere Backhoe/Front end Loader

1—ECM 350 Crawlair Drill and 850 CFM Compressor

1—BHB 8 tonne Mobile Crane

2—Euclid R85 Haulage Trucks

Exploratory Drilling

Percussion—1 572 metres

Rotary Drilling—947 metres (mineral exploration)

The number of persons employed by Dampier Mining on the islands during 1979 totalled 601, being 139 on Cockatoo and 462 on Koolan.

Texasgulf Australia Ltd

From their temporary reserve 5585H, the company advised that they intended to sink an exploration winze to a depth of 43 metres for the purpose of collecting bulk samples for metallurgical testwork and to collect data on bulk densities of the various types of ore.

I have been advised that the test winze was sunk and samples obtained. It was stopped at approximately 36 metres.

MANGANESE

The Mt. Sydney Manganese Syndicate which has regained possession of some of the 53 mineral claims located in the Woodie Woodie and Ripon Hills localities, is investigating the feasibility of upgrading the 250 000 tonnes of manganese fines at Woodie Woodie to a marketable grade.

MICA

Pilbara Mica Corporation Pty Ltd reported the production of 850 cubic metres of mica bearing material from mineral claims on Pippingara Pastoral Lease. From this, a total of 390 tonnes of mica was despatched from the Port Hedland upgrade plant at Wedgefield light industrial area.

There is a good demand for muscovite mica in certain drilling operations and the proprietors of this group are confident that the demand will increase.

They have quoted their ore reserves as 27 000 tonnes of proved ore and 500 000 tonnes inferred and indicated.

An average of ten persons have been engaged on this venture during 1979.

SALT

Leslie Salt Co. This solar salt installation consists of a series of concentrating and evaporating ponds with associated pumps, a salt washing plant, stockpiling and shiploading facilities, together with site offices and workshops.

The operation involves pumping seawater at a rate of up to 180 000 gallons per minute into the evaporation ponds. Solar evaporation brings the seawater to a concentrated brine which is nearly at saturation point for sodium chloride.

The brine is pumped to crystallizing ponds where further evaporation causes the sodium chloride to precipitate.

When the depth of salt in the crystallizing ponds has reached a depth of approximately 20 cm, the brine has drained off and the bed of salt harvested by means of a Palmer-Richards harvester.

At the washing plant the salt is washed with brine which removes magnesium, calcium, and insoluble impurities. The salt is stockpiled for further drainage and then transported to the portside stockpile and shiploading site.

Leslie Salt Co. reported that during 1979 the following production of NaCl was achieved:

Harvested—1 171 898 tonnes

Shipped—1 160 752 tonnes

Stockpiled 31/12/79—152 984 tonnes

For this production the company utilised 9 concentrating ponds covering 7 100 ha. and 18 crystallizing ponds covering 600 ha. A total of 78 persons were employed on mining operations.

Dampier Salt Limited

This company has taken over the operations previously controlled by the Broken Hill Pty Co. Limited at Lake McLeod and now operates two subsidiary companies, Dampier Salt (Operations) Pty Limited, Dampier Division, and Dampier Salt (Operations) Pty Limited, Lake McLeod Division.

Dampier Division—Production 1979

Salt harvested—2·38 million tonnes

Salt shipped—2·61 million tonnes

Salt stockpiled—·36 million tonnes

Production was obtained from six pre-concentration ponds totalling 8 237 ha and 30 crystallizers totalling 735 ha and using bitterns (waste ponds) of 1 226 ha.

Number of Employees during 1979:

185 persons (including some transferred from Lake McLeod following cyclone Hazel).

Lake McLeod Division

Damage occasioned by cyclone Hazel during March 1979 caused a complete shutdown of operations. Work has been commenced for the purpose of re-establishing production but no production has been possible since 31/1/79.

Production from 1/1/1979–13/3/1799

Harvested—192 050 tonnes

Shipped—202 940 tonnes

Under the new policy to recommence salt production 16 crystallizer ponds totalling 330 ha. will be used as was the case prior to cyclone Hazel.

The salt washing plant will be doubled in capacity and an enlarged power house will be established at Lake McLeod. A power line will supply power to Cape Cuvier where the port facilities are currently undergoing reconstruction.

SILVER/LEAD/ZINC

Aquataine Australia Minerals Pty Ltd commenced a decline on a mineral prospect in the Sorby Hills area near Kununurra.

Considerable difficulties were experienced in supporting the incompetent country rock and in handling the inflow of water.

The decline was of 8·89 m^2 cross-sectional area and was supported at metre intervals by steel arch sections. Each set was fully lagged with timber.

Total development achieved was 150·8 metres with the decline finishing at 122·8 metres in from the portal.

An average of 16 persons were engaged. The project is currently on a care and maintenance basis whilst studies are undertaken to determine the feasibility of a full-scale operation.

TIN/TANTALITE

Endeavour Resources Limited

This Company operates at Moolyella. A new treatment plant has been erected and during the year 330 000 tonnes of alluvial wash was treated for the recovery of 95·2 tonnes of tin concentrates, which averaged 71% Sn and 3·1 Ta_2O_5 and 7·89 tonnes of tantalite concentrates averaging 25% Ta_2O_5.

Some 500 000 tonnes of overburden had to be removed during the excavation of the alluvial wash.

The treatment plant has a capacity of 80 m^3 per hour.

An average of 28 persons were employed at the site.

Pilgan Mining Pty Ltd—Pilgangoora

A small 40 m^3 per hour captivity plant is used to treat shallow alluvial deposits of tantalum bearing mineral.

During 1979, 137 250 tonnes of material was treated for the recovery of 40·5 tonnes of 25% Ta_2O_5 concentrates. This represents an average recovery rate of approximately 0·295 kg/tonne.

An average of 15 persons were engaged at the site.

Pilgan Mining Pty Ltd—Yinnietharra

A small wet treatment plant was established some 30 kilometres north west of Yinnietharra homestead in the Gascoyne Goldfield.

Some high grade areas of alluvial tantalite and monazite have been located and the venture should prove to be reasonably profitable, although the throughput will be limited due to the restricted water supplies currently established.

Five persons are engaged on this project.

PERTH INSPECTORATE

H. L. Burrows—Mining Engineer/Senior Inspector of Mines

Mining of bauxite and beach sands remain the dominant activities in this inspectorate. The increased activity in gold mining and prospecting promises a possible return to more underground mining.

ALUMINA

Alcoa of Australia Ltd. From three minesites, the company mined 14 563 000 tonnes of bauxite from an area of 157·9 hectares. The two refineries produced slightly under 4 million tonnes of alumina which was an increase of 477 000 tonnes over the previous year's production. Kwinana and Bunbury were the two ports of shipment.

Average depth mined was 3·65 metres at Jarrahdale and 4·25 metres at Del Park and Huntley.

Total employment figures were given as 3 189 men. Rehabilitation took place over 267·3 hectares equivalent to 169% of the year's area of mining.

At Pinjarra, additions included a bottom drainage caustic tailings dam, an atmospheric digestion unit and a 75 meter high stack to discharge gases from the powerhouse boilers.

At Del Park and Huntley minesites new equipment included a D10 bulldozer, a 637D scraper, a 992C loader and four 773 trucks.

Extensive tests were carried out with the D10 bulldozer in its ripping capacity with the aim of reducing or eliminating the use of explosives in sensitive areas near townsites.

At the Jarrahdale minesite new plant included a D10 bulldozer, six 773 trucks, five 772 trucks and three new water trucks.

ATTAPULGITE

Mallina Holdings Ltd commenced mining on Lake Nerramyne on Pinegrove Station during the year.

This magnesium clay occurs about 2 metres below the lake bed. The clay is mined and stacked to dry before being carted to Narngulu where it is crushed, kiln dried and stored in various grades and sizes.

Attapulgite is a source of "Fullers Earth" which is used for decolouring oil.

Twenty-one men were employed over the three months operation.

BUILDING STONE

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

Work at 15 quarries was reported but it is probable that a few other small quarries may have been worked for short periods during the year.

Adelaide Quarry Industries Ltd operated a quarry at Cranbrook to supply road metal for the Department of Main Roads and various Shire Councils. A new quarry was opened up west of Mt Magnet to supply road metal for the Department of Main Roads.

Bell Basic Industries Pty Ltd operated their quarry at Maddington throughout the year and upgraded the crushing facilities by installing a parallel secondary and tertiary circuit.

New equipment included two cone crushers, three double deck screens, eight conveyors and various bins.

A second quarry is being opened up as the older quarry is phased out.

Bruce Rock Shire Council operated a granite quarry on a summer basis, producing an estimated 8 000 tonnes of crushed aggregate and employing six men.

John Holland (Constructions) Pty Ltd ceased work on the Wungong Dam quarry early in the year and towards the end of the year closed the Meckering quarry after completing a contract for railway ballast. Sufficient crushed and screened material was also prepared to satisfy requirements for a contract for concrete sleepers.

Pioneer Concrete (WA) Pty Ltd operated rock quarries at Herne Hill, Byford and Walkaway.

The Readymix Group (WA) operated quarries at Gosnells, Albany, Bunbury, Merredin and Lake Camm.

The Gosnells quarry operated throughout the year, the northerly end breaking into an old quarry which has not been worked for many years.

Some overburden over the dolerite section was sold to brick manufacturers, being suitable clay for the manufacture of bricks.

The Bunbury quarry operated throughout the year. The Albany quarry operations were limited to two months. The Merredin quarry was worked at full capacity for five months then in a re-screening capacity for four months before the plant was moved to Lake Camm where quarrying continued for two months.

Wells Bros (Walkaway): This small quarry operation with associated crushing and screening plant was purchased from Goldfields Quarries. Wells produced parcels of crushed stone for local customers.

CLAYS AND SHALES

Clays and shales suitable for brick manufacturing are mined in the areas of Byford, Bullsbrook, Maylands, Muchea, Orange Grove, Red Hill and Wendale Park.

An average of 60 men were employed in the various pits.

Midland Brick Co Pty Ltd continued as the largest producer, employing 46 men and excavating 893 223 cubic metres of clay. Of interest, is the production of 23 000 cubic metres of material from the very old pit at Maylands.

EMERALDS

The Aga Khan mine at Poona was reopened and production was reported as 1 205 carats valued at $7 230 from a parcel of 20 tonnes.

Ridolfo Transport head a syndicate which has reopened an open cut mine. A small crushing and screening plant was installed and water supply problems were overcome when a suitable supply was obtained by drilling.

Lightning Ridge and Great Eastern Mines are exercising a working option and have commenced underground development.

FELSPAR

Magnet Metal Industries operated the quarry at Mukinbudin throughout the year. The two men employed prepared 1 030 tonnes of crushed and screened felspar and quartz material, the majority of which would be felspar.

Chandilla Exploration and Investment Pty Ltd broke 379 tonnes from the open cut at Goodinow in the Yalgoo Goldfield. Operations only take place to fill orders received.

GARNET

Target Minerals N.L. produce garnet sand from a deposit at Port Gregory. This currently small operation resulted in 833.91 tonnes of sand being transported to, and concentrated at the Northampton State Battery. Two hundred and ninety eight tonnes of clean garnet sand was recovered.

GOLD

Peak Hill District: Two prospectors crushed a parcel of 300 tonnes from an open cut at the old Horseshoe Lights mine for a return of approximately 1.2 kilograms of gold.

The "Spencer" group operated a trommel sluicing plant at Peak Hill for six months for a reported return of 4.367 kilograms of gold.

Availability of surface water controls the period of operation.

Meekatharra District: The syndicate operating the Ingliston mine crushed 870 tonnes of ore for a return of 24.762 kilograms. Crushing was restricted by the capacity and availability of the State Battery. A further 1 000 tonnes of broken ore is stockpiled on the surface and 1 600 tonnes broken ore remains in the 6 level stope. This stoping plus the level development was completed during the year.

Development figures:—

Shaft sinking 12 metres

Driving and crosscutting 62 metres

Winzing 6 metres

The syndicate plan to erect their own treatment plant.

"Haveluck Mine" Whim Creek Consolidated: The company treated a parcel of 340 tonnes of ore from the open cut for a return of 621 grams. The installation of a heap leaching treatment is in progress and this should be in operation early in 1980. Work is in hand to ensure a suitable water supply.

Nannine Mining Pty Ltd commenced work on reopening the old "Nannine" mine. The Pump shaft has been rehabilitated and further sinking of 11 metres was carried out. A small headframe, pumping equipment and a stationary compressor were installed.

A number of prospectors are active in the area, including some working shallow open cuts and quite a number operating with metal detectors.

A total of 1 910 tonnes of prospectors ore yielded 4 546 grams of gold.

The number and size of any nuggets found is unknown.

Cue District: Again, a number of people are prospecting with the aid of metal detectors.

Causten Pty Ltd has erected a small treatment plant at Day Dawn but has not yet operated.

"*Tuckabianna Gold*", an offshoot of the above company, treated a parcel of 255 tonnes of ore which yielded 482 grams of gold.

Mt Magnet District: Crushings from six prospects totalled 2 681 tonnes of ore which yielded 5 037 grams of gold.

Hill 50 Gold Mines N.L. have carried out an extensive testing and preparation programme at the Morning Star and Water Tank Hill shafts. The Morning Star shaft has been unwatered and is being sampled and geologically mapped.

The Water Tank Hill shaft has been equipped and sunk to 52 metres. An extensive diamond drilling programme has been carried out.

Payne's Find District

Ark Gold Mine: H. & L. Constructions gained the controlling interest in this mine during the year. Production in the early part of the year was 113 tonnes which yielded 1 738 grams of gold.

Carnation Mine Leases: The Taylor partners mined 120 tonnes of ore for a return of 1 476 grams of gold.

The other prospects, Sweet William Extended, Galah, and Bonney Venture North, which are open cut workings, produced a total of 225 grams from 110 tonnes of ore.

GYPSUM

Shark Bay Gypsum: This operation is worked in conjunction with the salt extraction, the same workforce being engaged on both projects.

Agnew Clough Limited which holds the controlling interest, employed 106 men in the combined operation.

Production was halted for three weeks early in the year following cyclone damage. Final repairs took another three months to complete.

New installations included a 543 m artesian bore to provide a fresh water supply for wet screening at the gypsum crushing and classifying plant.

Gypsum Industries of Australia Pty Ltd mined approximately 1 200 tonnes from Lake Cowcowing.

IRON

Australian Iron and Steel at Kwinana produced 650 566 tonnes of pig iron from 1 027 881 tonnes of ore. An average of 350 men were employed.

Wundowie Iron and Steel at Wundowie produced 54 500 tonnes of pig iron from 84 421 tonnes of ore. An average of 65 persons were employed.

The production increased when No. 1 blast furnace was brought back into service.

LEAD

Northampton Lead Mines This company was formed as a joint venture between the Mary Springs Syndicate and Hampton Goldmining Areas to bring the lead mine at Mary Springs into production.

The 30 metre and 60 metre levels were cleaned up and a connection made between a 60 metre level stope and the 30 metre level providing a ventilation circuit and a second access. way.

Three hundred and seven point three tonnes of ore was treated in Northampton State Battery concentrating mill, giving 31·15 tonnes of lead concentrates.

An average of 8 men were employed until the mine closed down on 14 December, 1979.

LIMESTONE

A total of 17 limestone pits operated in the metropolitan area and a further five operated at country towns. Most produced road base material while several produced building stone.

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

Total employment was 56 men.

MANGANESE

Universal Milling selectively mined open cut deposits in the Mt Fraser area in the Peak Hill Mining District producing 1 379 tonnes with an average grade of 47·5%. A small crushing and screening plant was commissioned at the end of the year.

MINERAL SANDS

The mineral sands operators again increased total annual production with a reduced labour force. An increase of 145 452 tonnes of total minerals was produced by a workforce reduced by 85 men.

The included table gives figures for each individual company.

Allied Eneabba Pty Ltd Production from this pit west of the railway line is drawing to a close. The east pit will come into full production as the old pit is phased out.

At the Eneabba plant, a new workshop and store facility was constructed.

At the Narngulu dry mill where concentrates are treated, the relatively large tonnage of monazite mined required modifications to the plant.

Total Annual production increased by 17%.

Associated Minerals Consolidated Ltd

Eneabba Operations Alterations and additions to the plant are. continuing. Total annual production increased by 42% Mining tenements and equipment purchased from Jennings Industries Ltd (WA) Mining Division which closed down in December, will allow for increased production and increased reserves.

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.	211	5 416	244 627	....	9 656	46 694	....	107 560	408 537
Associated Minerals Consolidated Ltd.—Capel	181	2 601	303 656	4 794	1 931	....	25	25 136	335 542
Associated Minerals Consolidated Ltd.—Eneabba	114	3 034	68 000	....	....	35 725	....	71 150	174 875
Cable Sands Pty. Ltd.	84	1 283	128 287	5 922	742	....	....	17 449	152 400
Jennings Industries Ltd. (Mining Division)	50	857	99 770	....	402	18 673	....	10 407	129 252
Westralian Sands Ltd	160	2 430	373 241	16 831	1 728	....	....	37 046	428 846
Total	800	15 621	1 217 581	23 547	14 459	101 092	25	268 748	1 629 452

Capel Operations Mining operations continued on a South-Westerly direction. As the primary wet plant is now approximately 3 km from the secondary treatment plant, the company now transports its concentrate by road in lieu of pumping.

The recommissioning of the "A" Beneficiation Plant to boost production of synthetic rutile commenced in June and completion is planned early in 1980.

Cable Sands Pty Ltd Mining continued on the ore deposit at Ambergate near Busselton. An increase of 43% in tonnage mined was attained but final product tonnage showed a decrease of 2½% on the previous year.

At the Bunbury treatment plant additions included:—

Extension of covered area for secondary concentrate drainage to assist in reducing fuel costs for drying; secondary wet treatment feed slab was redesigned and relocated adjacent to the plant; the monazite circuit reconstructed with addition of spirals and two rotary disc magnetic separators; replacing three Induced Roll magnetic separators in the ilmenite plant and the addition of two Induced Roll separators in the secondary dry treatment plant non conductor circuit.

Jennings Industries Ltd (WA) Mining Division This company closed on December 14th due to a depressed world market for mineral sands. Although operating on a smaller scale and with a relatively small capital base compared to other operators around the Eneabba area, the company was generally acknowledged to be quite efficient.

Westralian Sands Ltd Mining continued throughout the year at the North Capel and Yoganup Extended deposits. Increase in production over the previous year was 20% in mining of ore and 21% in total product.

NICKEL

Western Mining Corporation Limited—Kwinana Nickel Refinery

Production increased again to 21 938 tonnes, almost 18% above the previous year.

By-products produced were:— ammonium sulphate 92 440 tonnes; copper sulphide 2 885 tonnes and mixed sulphides 1 389 tonnes.

An average of 395 persons were employed throughout the year.

OCHRE

Murchison Goldfield Universal Milling extracted 222 tonnes of red ochre from its Weld Range deposit. The open cut is only operated when a specific order is placed.

SALT

Gascoyne Goldfield Shark Bay Salt Joint Venture operations at Useless Loop continued throughout the year, although some production time was lost following a cyclone and accompanying rains.

The Reverse Osmosis domestic water treatment plant was upgraded to double capacity, ship loading belt speed was increased to allow quicker handling and the mine airstrip was upgraded to allow for scheduled charter service to Perth via Geraldton.

SAND

Thirty-eight sand pits were operated in the metropolitan area while ten were operated at country centres. Excluding truck drivers, 56 men were employed in these operations.

TALC

Three Springs Talc Pty Ltd: Production and sales again increased over the previous year's figures. Mining of ore and waste totalled 154 208 tonnes, an increase of 11%. Of this, 78 664 tonnes of ore plus 3 747 tonnes of fines recovered from an old waste dump were shipped out. This total shipment of 82 411 tonnes of talc was an increase of 1½%.

Operations in the current open pit are drawing to a close and a new pit just south is proposed.

Demand for talc is increasing and alterations are being made to the plant to allow work on a two shift per day basis.

Westside Mines Pty Ltd: This company operating on Mt Seabrook Station in the Peak Hill Goldfield is now a fully owned subsidiary of Bellway Pty Ltd.

Production increased to 59 215 tonnes of talc.

Total ore crushed was 86 308 tonnes.

TIN AND TANTALITE

Greenbushes Tin N.L.: The high price of tin and tantalite permitted the company to continue mining lower grade sections of the ore body.

One million four hundred and thirty-seven thousand five hundred and sixteen cubic metres of ore was mined and 1 434 281 cubic metres treated for a return of 537 255 tonnes of concentrate valued at approximately $8·5 million.

Average number of men employed was 178.

At the plant, more efficient ore/wash facilities were provided, a smelter building was erected and 3 x 50 tonne dump trucks were purchased for use in the quarry.

Yalgoo Goldfield

Chandilla Exploration and Investment Pty Ltd have a man treating an alluvial patch on Goodinow Station. Tantalite sold was 0.14 tonnes valued at $5 352.

The Bowen Syndicate operating out of Warda Warra, near Dalgaranga mined 1 200 tonnes of ore from an open cut. Recovery was poor and the grade was known to be low.

VANADIUM

Agnew Clough Limited are preparing to mine a vanadium deposit at Coates Siding near Wundowie.

A treatment plant, estimated to cost $11 million is under construction and is scheduled to be ready in July 1980.

KALGOORLIE INSPECTORATE

I. W. Loxton

Mining Engineer/ Senior Inspector of Mines

General

Rising world prices for gold and base metals produced activity similar to the nickel boom era within the Kalgoorlie Inspectorate during 1979.

With the price of gold reaching $467 (Aust) at the end of the year, an air of confidence has returned to the area. The repegging of known gold occurrences and investigations into the potential of old gold mines such as Lancefield, Mt Ida and White Hope were some of the highlights of the year.

Central Norseman Gold Mines have reportedly encountered encouraging gold intersections from their surface diamond drilling programme at Norseman and in order to investigate these intersections further, work has commenced on re-opening the Ajax shaft which was sunk to a vertical depth of some 600 metres and then closed in the early 1940's.

An important step in the proposed re-opening of the Fimiston leases of the Golden Mile by Kalgoorlie Mining Associates was initiated in May when a development heading was fired on the 13 level off the Perseverance shaft.

Custom milling commenced at the Croesus plant of North Kalgurli Mines during April when open cut ore from Hampton Areas Location 50 was introduced into the mill. North Kalgurli Mines announced that it would be re-opening the Main shaft and the Croesus shaft early in 1980

Construction commenced in October on the building of a metallurgical pilot plant just north of Kalgoorlie. W.M.C. Ltd propose to use this plant in the initial stages to metallurgically test uranium ore from their Yeelirrie prospect.

An announcement was made by the joint partners of the Teutonic Bore copper, zinc and silver prospect that production should commence about mid 1981. Towards the latter part of this year civil works had commenced with regard to the construction of the townsite and administration buildings.

It is interesting to note that Queen Margaret Gold Mines N.L. was floated as a public company in November of this year. Records show that it is the first gold mining company to be floated as a public company for many years. The $4·5 million raised by the float will finance a programme of exploration in the eastern and north eastern goldfields.

Prospecting activity was very prominent within the Inspectorate and the five departmental mobile compressors which are available for hire to prospectors were in constant demand.

The number of men currently employed in the mining industry within the Kalgoorlie Inspectorate was estimated to be 3 272 at the end of December. This was about 200 less than 1978.

A summary of mining and exploration activity within this Inspectorate during 1979 is as follows:

Arsenic

There was very little arsenic trioxide concentrate produced from the treatment of mining residues at Wiluna. The owner-operator is at present constructing a kiln adjacent to the residue dump at the old Wiluna mine site.

Clay

Chandler Clay Pty Ltd produced some 3 937 tonnes of absorbent clay from the former State potassium works tailings dump at Chandler. Production was down some 2 000 tonnes on last year.

Cobalt

Mining of and exploration for this metal continued in a very active vein during the year due to the continual rising world price for the metal. Western Mining Corporation in particular were very active in both the Siberia and Bulong areas of the Inspectorate. Two open pits are being mined in the Siberia district, while preparations are in hand to commence mining operations in the Bulong area. Some 74 565 tonnes of cobalt-nickel ore was mined at Siberia of which 27 691 tonnes were delivered to the Kalgoorlie Nickel Smelter.

Copper

The only copper produced within the Inspectorate was as a by-product from nickel mining operations. However, it has been announced by the joint partners of the Teutonic Bore project that contracts for removing the overburden and the initial mining of the copper, zinc and silver ore body by the open cast method of mining will be let early in 1980. Proven ore reserves are quoted at 2·5 million tonne and civil works have commenced at the proposed town site.

Crushed Rock

The Readymix Company was active within the Inspectorate throughout the year with plants operating at Kalgoorlie and Agnew. The company secured a contract from Westrail to supply 125 000 tonnes of ballast for the upgrading of the Kalgoorlie-Leonora railway line.

The South Australian based company, Quarry Industries, completed a contract for the Main Roads Department at the Cocklebiddy quarry during the year.

Wundowie Iron and Steel used their iron ore crushing facilities at Koolyanobbing to produce 1 262 cubic metres of granite screenings for local civil engineering works.

The ex-Kalgoorlie Shire crushing plant operated by a small private company operated periodically during the year producing small tonnages of crushed metal from mullock obtained from the Mount Charlotte mine.

Gold

There was a noteworthy increase in the prospecting for and mining of this precious metal during the year. Many former gold mining areas have been re-pegged and revaluation of several old gold mines has been recommenced.

Kalgoorlie Mining Associates enjoyed the benefit of the increase in the price of gold and attained maximum production by treating 100 000 more tonnes of ore and recovering 181 kg of gold more than the previous year. Production was obtained mainly from the No. 15 level of the Main ore body and the No. 14 level of the Southern ore body. Development of the No. 16 and 18 levels of the Main ore body continued during the year so as to bring these ore blocks into early production. The main decline has been extended to the No. 19 level horizon while surface diamond drilling was also initiated to test the main ore body below this horizon.

In April KMA announced the re-opening of the Perseverance and Lake View shafts at Fimiston and by the close of the year some 9 levels above the No. 15 level were re-opened and numerous development headings commenced. Ore obtained from the above development is being stockpiled at the surface awaiting the construction of treatment facilities for refractory ore.

Ore treated during the year amounted to 727 890 tonnes for a recovery of 3 268·992 kg with an additional 209·500 kg of gold being recovered from the old Chaffers plant cleanup.

Tributors continued to recover small amounts of ore from various open cuts on the company's Fimiston leases and during the year treated some 5 000 tonnes at the Kalgoorlie State Battery.

North Kalgurli Mines Ltd treated 37 910·8 tonnes of free milling gold custom ore from various customers during the year. The plant was converted to gold treatment after the company was successful in obtaining a ½ million dollar loan from the State Government in 1978.

In November North Kalgurli Mines announced plans to re-commence underground development on its leases following the discovery of promising ore potential from surface exploratory diamond drilling between the Main shaft and Croesus shaft. Development to the area of drill intersections will be made from the 19 and 20 levels off the Main shaft. Meanwhile it is proposed to de-water the Croesus shaft and investigate remnant ore potential.

At Mt Monger the Daisy Gold Mine produced some 860 tonnes of ore from the 5 and 6 levels of the main shaft and between the 2 and 6 levels of the south shaft. Work has begun on rehabilitating hoisting facilities on the adjoining Milano lease to the north.

Hampton Areas Australia Pty Ltd completed an investigation into the potential of the White Hope gold mine. Because of the small potential indicated by sampling and drilling on the No. 5 level the company intends to let the mine out on tribute. The company also completed exploratory drilling of a low grade porphyry deposit at Celebration. Several thousand tonne of open cut ore was treated at the Croesus custom mill before the venture was abandoned.

In the Yilgarn Mining District the main projects which were announced during the year were the re-opening of the Francis Furness mine, and the treatment plant at the Marvel Loch mine. A cyanide treatment circuit is to be incorporated in the plant and ore from the Corinthian open cut located north of Southern Cross will be treated prior to the dewatering of the underground workings of Marvel Loch mine.

Meanwhile WA Gold Development re-opened the Francis Furness mine at Marvel Loch and at the end of the year had produced 5 100 tonnes of ore for treatment at the Radio surface treatment plant.

At the Radio plant a total of 21·305 9 kg of gold was recovered from 8 168 tonnes of ore and mining residues. In addition, 619 tonnes of ore from the Boomalli Ltd Jupiter mine at Southern Cross was treated for a recovery of 1·648 5 kg of bullion.

Tailings retreatment at Evanston has been completed but the tailings operation at the Edna May mine near Westonia is continuing. A new treatment plant has also been installed at the Frasers mine at Southern Cross.

More than twenty part time prospectors have been active in the Coolgardie and Higginsville areas. The largest producers have been the Mount mine at Widgiemooltha and the Fairplay open cut operation at Higginsville.

Work has commenced on re-opening the Paris gold mine to test for extensions to the main ore body previously worked out.

Central Norseman Gold Corporation N.L. enjoyed the benefit of a higher price for their gold, although the company recovered slightly less gold and silver than last year. Ore treated during the year amounted to 140 846 tonnes for a recovery of 2 237·584 3 kg of gold and 756·996 5 kg of silver. Ore reserves at 17/7/79 are quoted at 434 500 tonnes.

The decline, advanced to the 5 level from the bottom of the Royal No. 1 pit is nearing completion. Extensive re-equipping of the Ajax shaft is in progress in order to be able to drive off this shaft to potential ore areas indicated by diamond drill intersections.

Work on a new washing plant at the North Royal was commenced during the year and is expected to be in operation early in 1980.

Meanwhile Pennzoil of Australia Ltd signed an agreement with Poseidon Ltd whereby they were required to carry out an extensive surface drilling programme over the old Porphyry gold mining leases at Yarri. This programme is continuing and shows promise.

At the Aspacia mine near Menzies a diamond drill programme met with little success and it seems only a matter of a short time before ore reserves are depleted.

The recently floated company of Queen Margaret Gold Mines N.L. is to re-open the Mt Ida mine and investigate the potential of the Queen Margaret mine at Bulong and the Bellevue and Vanguard mines at Sir Samuel. Limited drilling has been completed at the Vanguard mine while the Mt Ida mine has been dewatered to below the 6 level.

The syndicate, who until recently owned the Mt Ida mine, erected and commissioned a treatment plant at the mine during the year and from a trial parcel of 600 tonnes of material taken from an old mullock dump recovered 1 234 grammes of gold.

Gold continues to be won from the Sons of Gwalia leases by several prospectors while at nearby Tower Hill good grade ore is also being mined.

Western Mining Corporation intend to dewater and clean out a vertical shaft at the Lancefield mine so as to obtain a trial parcel of ore for metallurgical tests.

Prospectors have been active in all mining districts during the year and many alluvial gold nuggets have been found using metal detectors. One area that is very popular is around the town of Sandstone.

The Scheelite gold mine at Barrambie was worked spasmodically during 1979. The mine only produced 65 tonnes of ore for a recovery of 0·71 kg of gold.

State Batteries at Kalgoorlie, Coolgardie, Ora Banda, Marvel Loch, Menzies, Leonora, Laverton and Norseman have continued to be kept busy due mainly to the large amounts of ore being mined by open cast methods.

Gypsum

Two companies continued to mine gypsum from deposits located at Lake Seabrook and Lake Brown. W.A. Plaster Mills railed 28 556 tonnes from Koolyanobbing to the metropolitan area after having transported the gypsum from Lake Seabrook.

At Lake Brown, H B Brady Co Pty Ltd harvested 27 000 tonnes and railed 25 093 tonnes to the metro area.

Iron

Iron ore continues to be mined at Koolyanobbing by both the Dampier Mining Company and Agnew Clough Ltd.

Dampier Mining railed some 1 385 553 tonnes of ore to Kwinana at a grade ranging from 19·4% Fe to 60·9% Fe. The very low grade ore comprised of 11 153 tonnes of Dowd's Hill jaspilite. Ore reserves quoted by the company amounted to 197 million tonnes—a decrease of two million tonnes. The workforce remained the same at 125.

Wundowie Iron and Steel increased their production rate in August as a result of the re-commissioning of a second blast furnace at Wundowie. Ore railed amounted to 95 032 tonnes which is a substantial increase on last years tonnage. The grade of ore remained the same at 62·5% Fe. An average of 11 men were employed during the year.

Magnesite

Norseman Mines are still actively engaged in metallurgical testing of their deposits in the Ravensthorpe area.

Nickel

The Kambalda nickel operations Of Western Mining Corporation continue to employ the most number of people within the Inspectorate. Some 1 282 men are employed at Kambalda. Nickel ore is being won from five vertical shafts and four declines and during the year 1 221 766 tonnes of nickel ore was broken. Tonnes of ore treated amounted to 1 208 593. Ore reserves are quoted at 21 000 000 tonnes at a grade of 3·28% nickel.

Operations at the Durkin shaft are tending more to pillar recovery and during the year some 94 956 tonnes of sand fill was placed in operating stopes and pillar recovery areas. This represents a little over 50% of the 175 237 tonnes produced from the mine during 1979.

At the Long shaft an extensive development programme was carried out during the year. Problems were encountered on the 17 level when minor rock bursts occurred when cross cutting through porphyry bars. However, once the basalt was reached this problem ceased. It has taken nearly 4·5 years to complete shaft sinking and the necessary development work to bring this mine to the production stage.

During the year considerable gold was won from the D zone of the Hunt decline and consideration is now being given by management to convert this decline to a gold mine.

At the Jan shaft ore production increased to around 9 500 tonne per period and lateral development was concentrated on the 7, 8, 9, 12 and 13 levels to open up the downward continuation of the lode system. No decision has been made to date to investigate the distant Foster shoot from the Jan shaft.

Operations at the Edwin shaft ceased in August but it is planned to sink this shaft further in the near future.

The Otter Juan decline continued as a major tonnage producer and is yielding about 30 000 tonne per period. Declining is continuing in the Juan west shoot area and is approaching the 15 level.

No major development has occurred at the Silver Lake shaft during the year, however mining activity was stepped up at the Fisher decline so that this area may be brought into full production in 1980. Some areas of the McMahon decline have all but been worked out and the economics of this operation are now being studied.

WMC Ltd commenced development of a new nickel deposit at Carnilya Hill during the latter part of the year. The deposit is located north east of Kambalda and services and ore treatment of this area will be integrated with the existing Kambalda Nickel Operations complex. At the end of the year the portal area had been excavated and declining was ready to commence.

Metals Exploration have all but completed major development operations on the 11 and 12 levels of their Nepean mine. The mine is again working on a three shift basis employing 163 men. During the year some 65 800 tonnes of ore was treated for a recovery of 2 370 tonnes of nickel.

Due to depletion of ore reserves, Selcast Exploration Ltd at Spargoville announced the closure of their mining operations during the year. Several surface amenities such as change rooms, offices etc. are to be transferred to the Teutonic Bore project.

Production of nickel-copper concentrates at the Kalgoorlie Nickel Smelter remained on a par with the previous year. However, production of cobalt enriched ore increased significantly. Major modifications to the Smelter complex included the installation of a new crushing and grinding complex to handle the reverts, silica flux and lateritic ore. An average of 356 personnel are employed at this site. Production figures recorded are *viz:—*

Concentrate treated—284 145 tonnes

Laterite ore treated—44 934 tonnes

Matte production (Ni, Cu)—35 301 tonnes

Matte production (Ni, Co) 21 257 tonnes

At Windarra WMC Ltd continued their policy of development. Some 572 metres of advance was accomplished in the main decline and off this decline 1 096 metres of crosscutting and driving was completed. Off the decline a position has been excavated at the 10 level horizon to allow a 3 metre diameter raise bore hole to be drilled from the surface. This raise is expected to be used as a haulage shaft. An underground crushing station access drive has also been driven.

The decline at the Agnew Mining project had advanced 1 606 metres from the portal by the end of the year and production was being obtained from three stopes. Stages 1 and 2 of the sand fill plant have been completed. Meanwhile the No. 1 shaft sink was advanced 339 metres to a total depth of 658 metres. Four plats have been excavated during sinking and plat areas concreted. Pumps have been installed to handle all mine water but to date the shaft has been comparatively dry.

The foundations for and the building to house the new haulage winder have been completed and it is expected that installation of the winder will commence early in the new year. Ore treated during the year amounted to 222 506 tonnes for a recovered concentrate of 56 997 tonnes at 10.8% Ni and 0.53% Cu. Ore reserves are quoted at 46 531 500 tonnes at 2.06% Ni and the average number of employees was 254, plus 41 employed contractors.

No activity was reported from Mt Keith, Forrestonia or Mt Edwards during the year.

Salt

W.A. Salt Company produced some 16 380 tonnes of salt from their Esperance and Lake Deborah salt leases during the year. Due to a down turn in world demand production ceased at the Lake Lefroy plant of Lefroy Salt Pty Ltd in April. Only 21 800 tonnes of salt was exported through Esperance.

Silica Flux

The mining of this ore for use at the Kalgoorlie Nickel Smelter resumed during the year. The initial pit at Siberia is being enlarged to create additional stockpiles. The operation will involve the removal of some 185 000 cubic metres of material.

Scheelite

Although some interest has been shown in prospecting for this metal there was very little activity to report on during the year.

Tin

Poldark Mines continued to experiment with the recovery of tin from its Mt Deans prospect but to date have had little success.

A small syndicate also constructed a jigging plant to treat alluvial tin at Binneringie, south of Kambalda. This area was worked many years ago with very little success.

Uranium

Western Mining have commenced construction of a metallurgical test plant on the northern outskirts of Kalgoorlie. This plant will initially test ore obtained from the Yeelirrie deposits of the company.

Apart from exploration work conducted by various companies in the Lake Way area south of Wiluna no other discoveries of uranium have been reported to date.

Vermiculite

The remaining stockpiled ore (145 tonnes) from the Young River mine site was transported to Perth during the year but no mining was undertaken.

No activity was reported by Consolidated Goldfields on the vermiculite occurrence located at Coonana on the trans line.

COAL MINING

R. S. Ferguson—Mining Engineer—Senior Inspector of Coal Mines

Another record output of coal was produced from the Collie Coalfield during the year. The output of 2 735 230 tonnes produced during 1979 was 331 727 tonnes more than the previous record output of 2 403 503 tonnes produced during 1978. This was the fifth successive year in which over two million tonnes of coal were produced from the coalfield.

The open cut component of the total output from the field was won from the Muja Open Cut and Western No. 5 Collieries and amounted to 2 143 280 tonnes or 78.36 per cent of the year's output.

The total value of the coal produced during 1979 was $44 407 880, an increase of $15 765 653 compared with the 1978 value of $28 642 245.

Western Collieries Limited. Western No. 2 Mine.

The new record output of 591 950 tonnes of coal produced during the year was 38 101 tonnes more than the previous year's then annual report output of 553 849 tonnes. The output from this mine was the entire underground mined production from the field and was 21.64 per cent of the total output.

Upgrading of conveyor installations to improve guarding and fencing of machinery is necessary at this mine. Towards the end of the year, these requirements were receiving concentrated attention. Colliery conveyor installation standards and systems designs typical of those in general application several decades ago are no longer acceptable or satisfactory. The advances and improvements in machinery design and guarding which have taken place elsewhere must be brought to effect this colliery and must be introduced from the outset at any new collieries to be opened out on the coalfield.

Large quantities of detonators and explosives are used at this mine where nearly all of the coal is blasted from the solid coal faces. Improved procedures for training and appointing shotfirers and controlling the handling and use of detonators were beginning to receive responsible attention from Management.

High recovery pillar splitting semi full extraction trials were continuing in several areas of the mine, notably in No. 6A East District "C" Panel.

A Dosco Dintheader continuous mining machine with a "bridge" or transfer section for delivering coal on to a belt conveyor was installed in No. 3A East District in September. The results achieved were quite satisfactory and indicated that larger types of continuous miners may have successful applications in properly designed and laid out working places where the strata are adequately pre-drained.

The workings are very widespread at this colliery, including the East Extended Area which is separate from the main workings. Vertical depths of cover down to the current workings in the coal seam range from 20 m in No. 1 South "C" Panel to 146 m in No. 3B West "A" Panel.

Western Collieries Limited. Western No. 5 Open Cut

In the second successive year during which this mine produced over three quarters of a million tonnes of coal, the output of 873 759 tonnes was an increase of 115 293 tonnes over the previous year's output of 758 466 tonnes.

The Company's Consultants advised against re-routing the temporarily diverted portion of the South Branch of the Collie River back through the backfilled area. In view of this, further developments down dip or to the west from the Main Excavations shall necessitate another temporary diversion ahead of the workings.

Contouring and adjoinment of dumps, spreading and stacking topsoil, reclamation backfilling and seeding and planting with native species were features of the ongoing systematic rehabilitation procedures being practiced at the mine.

The deepest excavations at the mine are approximately 45 m from the top of the high wall to the floor of the Neath Seam in parts of the Main Excavation. Good progress was made on overburden removal from the South Extension to this area while all of the Cardiff Seam coal and most of the Neath Seam coal was won from adjoining areas.

The stabilising effects of the scraper deposited and compacted bunds or dumps down dip of the toe lines of truck dumped debris standing at the natural angle of repose are important, particularly as excavation depths and backfill dump heights increase in an area like the Main Excavation where mining shall be resumed along the highwall, some short distance down from the bottom of the backfill.

At the Western No. 5A Area, coal winning from the Cardiff and Neath Seams was completed with the exception of a small strip of Neath Seam coal under an access road. Systematic backfilling into this area continued with truck dumped debris transported from the nearby Western No. 5B Area where very good progress was made on opening out areas of coal down from the subcrop lines of the Cardiff and Neath Seams on the C11 and N19 Blocks, respectively.

Detail drilling in the Western No. 5B Area was completed and bush clearing was then carried out following delineations of additional blocks of coal to be opened out.

The Griffin Coal Mining Company Limited—Muja Open Cut

This colliery continued to be the largest single producer on the field. In the fourth successive year in which over one million tonnes of coal were produced, the new record output was 1 269 521 tonnes, an increase of 178 333 tonnes over the previous year's output of 1 091 188 tonnes and an increase of 167 036 tonnes over the previous record output of 1 102 485 produced in 1977.

The overburden removal and coal winning excavations were in widespread areas of the extensive workings at this mine. All remaining Eos, Flora and Galatea Seams coal was won from Block No. 8 and at the end of the year, a significant area of Hebe Seam coal was exposed. Iona Seam coal was removed down the west wall but this thin seam which underlies the Hebe Seam by approximately 2·0 m may be left intact along the lower area of the block if the monitored ground water pressures appear to be high.

Forward stripping on Block No. 10 and the North Extension, Phase 2 Areas was carried out with mobile scrapers. Good progress was being made on top overburden removal and coal exposure on Block No. 9. Very significant progress was made on overburden removal and coal exposure and winning from both sides of the fault line which trends along the long axis of the basin in East Section, Panel No. 7.

Drainage holes drilled through the series of strata between chosen locations within the excavations and the old underground workings of the Hebe Mine proved to be very useful in dewatering the sediments and maintaining relatively dry and safe working conditions. These holes were lined with slotted casings and gravel packed down to the top of the Hebe seam. Dewatering of strata under the Hebe Seam in relation to increasing depth of working continued. The use of piezometer installations to monitor pressure in the underfloor acquifers and in backfilled overburden were important aspects of the continuing geotechnical investigation which included periodic reviews of overburden dump stability.

Backfilling continued satisfactorily with the fifth 20 m high layer of the current series of lifts being formed. Practically all of the overburden from Block No. 8 was backfilled.

Special precautions were taken to ensure that safe working conditions were maintained while final overburden was removed over areas of the Hebe Seam overlying old underground workings and while the coal was being won over these galleries. Generally, the final stages of overburden removal were effected by hydraulic backhoe excavators located on a berm or platform 4·6 m higher than the roof of the seam. Only drilling machines, rubber tyred dozers, explosives trucks and light ancillary vehicles were permitted to be operated on top of the seam over old workings.

Tidying up of previously dumped overburden along the East Extension Area Back Wall resulted from recent backfilling operations where the latter work provided an improved and stable profile of acceptable material over previously unstable areas of very toxic, highly acidic overburden.

The Demag H241 Hydraulic Excavator and fleet of nine WABCO Haulpak 120 tonne dump trucks contributed greatly to the increased developments at the mine during the year.

General

There were 492 reported accidents of which 449 were minor and 43 were classified as serious where an employee was absent from work for fourteen days or more.

There were 896 persons employed in the industry at Collie at the end of the year.

Of the total saleable output of 57 845 859 tonnes of coal produced during eighty one years of mining at Collie, 36 927 260 tonnes were produced from underground collieries. Open Cuts produced 20 918 599 tonnes.

The three current operating mines have together produced 26 486 052 tonnes or 45·8 per cent of the total quantity of coal won from the field.

Future developments proposed for increased production from underground and open cut mines show with certainty that the industry has a sound and assured future. The increased tempo and larger scale of working in the industry shall call for resourceful and skilled management, a co-opreative and trained workforce and legislation appropriate to the circumstances in order to maintain the admirable safety record which has been evident in the collieries at Collie.

DRILLING OPERATIONS

D. A. Macpherson—Drilling Engineer

During 1979 the Drilling Section was responsible for the drilling of 8 138 metres in 390 bores, the development of aquifers in 95 bores, and the testing of aquifers in 28 bores. The work was carried out by Departmental employees and equipment. The total meterage drilled is 612 metres above the figure for 1978.

During the year the Geological Survey of Western Australia increased the projected depth on one of its main investigation jobs from 1 200 metres to 1 500 metres, this presented the Section with various technical and financial problems and has considerably increased the Engineering workload.

Of the total expenditure by the Drilling Section, about one fifth is spent on actual drilling, and four fifths is spent on extraction of information from the drilled holes, provision and placement of structual materials in holes, access and site work, and movement of plant and materials.

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

At the start of the year bore 8A was in progress, the drill string became stuck part way down this hole and some of it was abandoned and the hole continued past the lost tools. Bore 9A on this line is the deepest bore drilled to date by the Department, having a total depth of 1 471 metres. Bore 10A some drilling tools were abandoned near hole bottom and the bore was completed above the lost tools. By the end of the year minor drilling and site completion work were all that remained to finish this job.

Bunbury (Shallow Aquifers): This job forms part of the statewide groundwater investigations 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 of 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. The bore is then screened and tested. On completion of the main bore, one or two shallower bores are drilled at each site to provide additional information on water levels in the area.

This job was in progress at the beginning of the year and virtually all drilling work was completed before the drilling unit was withdrawn for the northern drilling season, later in the year pumping test operations were commenced and all suitable bores tested. At the end of the year the only work required to complete this job was reconstruction and re-testing of three bores.

Fortescue Valley Job: This job forms part of the statewide groundwater investigation conducted by the Geological Survey of Western Australia and is financed by the Department of Mines. The job is required to provide information on stratigraphy and groundwater conditions over a considerable portion of the Fortescue Valley. The work consisted of drilling at selected sites, one bore to target depth to provide strata samples and geophysical bore logs. Each bore was screened and tested by airlifting, and the bore was left in suitable condition for continuous water level measurement.

During 1979 a further seven bores were drilled, sixteen developed and twenty tested. 224 seismic shot holes were drilled in the flood plain of the Fortescue and Robe rivers as part of this job.

Further work will be carried out on this job when finance is available.

Manjimup Woodchip Industry: 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 measurement points for long term recording of groundwater variations in the area.

During the year 4 bores were drilled and completed as water level measurement points.

Lake Clifton: 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. Investigation is 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 costal 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.

During the year 51 bores were constructed. The work will be continued when finance is available.

South Canning Dam Job: This job was carried out for and was financed by the Metropolitan Water Supply Sewerage and Drainage Board. It was located up stream of the proposed South Canning Dam ponded area.

The work consisted of drilling a number of seismic shot holes on lines across the river valley and drilling groundwater monitoring bores at sites selected as a result of the seismic work. Information obtained during the construction of the bores and by monitoring the groundwater levels and quality in the bores is required to assess interrelation between groundwater and surface water when the new dam is constructed.

62 Seismic holes and 22 investigation bores were constructed.

Woodmans Point Job: This job was carried out for and financed by the Metropolitan Water Supply Sewerage and Drainage Board. The job consisted of drilling, developing and testing a bore at the Woodmans Point Sewerage Treatment Works to determine whether a suitable supply of water could be obtained from groundwater for use in the treatment plant. The investigation was successful and the bore will be used by the Board.

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 Canningvale sewerage effluent disposal works, the purpose of the work was to investigate recharge and sewerage effluent disposal effects on groundwater in the area. A total of 5 bores were constructed.

Staff: On 29/1/1979 Mr. G. Dowdall died from natural causes.

On 18/6/79 Mr. R. Bulner was appointed to the staff as Technical Officer to fill the vacancy left by Mr. Dowdall.

Plant: The Jacro 1500 rotary drilling rig which had reached the end of its economic life was rebuilt in preference to replacement. 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 DURING YEAR ENDED 31/12/79

Place	Purpose	Type of Work	Done By	No. of Bores	Meterage
Quindalup Line	Groundwater Investigation	Rotary Drilling	Dept. of Mines	5	4 617.38
		Development	Dept. of Mines	5	
Lake Clifton	Groundwater Investigation	Rotary Drilling	Dept. of Mines	51	1 491.63
		Development	Dept. of Mines	53	
South Canning Dam	Groundwater Investigation	Rotary Drilling	Dept. of Mines	84	355
	Seismic			1 abnd	
Bunbury Shallow Job	Groundwater Investigation	Rotary Drilling	Dept. of Mines	9	665
		Development	Dept. of Mines	11	
		Pump Test	Dept. of Mines	7	
Manjimup	Investigate effect of Forest clearing of groundwater and surface water	Rotary Drilling	Dept. of Mines	4	90
		Development	Dept. of Mines	4	
Canning Vale	Investigation of recharge and sewerage effluent disposal on groundwater	Rotary Drilling	Dept. of Mines	5	110
		Development	Dept. of Mines	5	
Woodmans Point	Groundwater Investigation	Rotary Drilling	Dept. of Mines	1	52
		Development	Dept. of Mines	1	
		Pump test	Dept. of Mines	1	
Fortescue Valley	Groundwater Investigation	Rotary Drilling	Dept. of Mines	7	309.35
		Development	Dept. of Mines	16	
		Pump Test	Dept. of Mines	20	
		Reamed slag	Dept. of Mines	12	
Fortescue Valley	Groundwater Investigation	Rotary Drilling	Dept. of Mines	224	448
Robe River	Seismic				
			TOTALS:		
			Drilling	390	8 138.36
			Developing	95	
			Pump Test	28	

BOARD OF EXAMINERS
FOR MINE MANAGER'S AND UNDERGROUND SUPERVISOR'S CERTIFICATES

W. J. Cahill—Secretary

MINING LAW EXAMINATION

The examination in Mining Law for Mine Manager's Certificates of Competency was held on April 23, 1979. Details of this examination are as follows:—

Entries	10
Admitted	10
Passed	5
Did not sit	1

The names of the successful candidates were:—

F. J. P. Fiore
C. A. McIntyre
B. White
L. P. McTavish
F. Sibbel

UNDERGROUND SUPERVISOR'S EXAMINATION

The examination was held on Monday September 10, 1979 and attracted the following applications:—

Kalgoorlie 31
Windarra 8

The following number of applications were accepted:—

Kalgoorlie 33
Windarra 7

* Two late applications were approved at the meeting held on October 19, 1979.

Results were as follows:—

Passed 27
Failed 6

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

Kalgoorlie

Dowding, P.
Edgerton, W.
English, S. C.
Frecheville, J.
Green, M. R.
Kean, I. A.
Kinna, L. J.
Lee, M. J.
McAuliffe, W. R.
Main, J. G.
Livingstone, R. H.
Miller, K. A.
Murtagh, M.
O'Byrne, N. J.
Phillips, J. B.
Purdue, K. M.
Ryan, M. M.
Ticehurst, K. J.
Treen, D. J.
Fiore, F. J. P.
Craig, K. C.

Candidate K. R. Little was successful in the examination but required additional underground practical experience and was not eligible for consideration at the time of the last Board meeting.

Windarra

*Coe, L. J.
Dunkley, R. A.
Naughton, M. F.
Orr, G. R.
*Small, L. O.

*both certificates to be endorsed: "Restricted to Windarra Nickel Operations of Western Mining Corporation".

In addition to the above certificates approved after the normal examination method, the following certificates were also approved for issue after oral examinations held at request of Mining Companies.

Agnew

I. R. McNee: "Restricted to the Mining Operations of the Agnew Mining Co. at Leinster".

H. H. Baule: "Restricted to shaft sinking operations at the Agnew No. 1 shaft".

MINE MANAGER'S CERTIFICATES

The following were successful applicants for First Class Mine Manager's Certificates of Competency:

S. D. Ireland
D. H. Austin
A. D. Owens
R. P. Denbrok
A. R. Jackson
L. P. McTavish
R. D. Fraser
M. J. Rimes
K. M. Hollands
F. Sibbel
J. A. A. James

GENERAL

Three Board meetings were held on March 26, July 23 and October 19.

The Board visited Windarra to carry out oral examinations for the general Underground Supervisor's examinations.

During the year the writer resigned as Secretary to the Board initially from September 30, 1979. However, at the request of the Chairman he agreed to remain until the finalisation of the September Underground Supervisor's examinations and to write the current Annual Report for 1979. He will therefore officially cease duties on December 31, 1979.

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 CERTIFICATES OF COMPETENCY

Mining Law examinations were held on 2nd April, 1979 and 4th September, 1979 and 12 applications were received.

Those successful in the April examination were:

R. P. Morgan
L. P. McTavish
J. E. Gatt
D. Ronaldson

Those successful in the September examination were:

P. D. Hallam
S. Reid
R. C. Medbury
R. Hobbs

Quarry Manager's Certificate of Competency were issued to:

J. E. Gatt
L. P. McTavish
R. P. Morgan
D. Ronaldson
R. C. Medbury

Messrs Hallam, Reid and Hobbs were not issued with certificates during 1979 as all statutory requirements had not been met.

RESTRICTED QUARRY MANAGER'S CERTIFICATES OF COMPETENCY

Mining Law and Quarrying examinations were held on 3rd September, 1979 and ten applications were received.

Those successful in the examinations were:

H. B. Harris
C. G. Warren
R. A. Cordery
M. Powell
J. F. Fradd
J. L. Ey
A. Chappelhow
R. S. Hammond

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

W. E. Leslie
A. S. Cooper
R. H. Carroll
P. J. Meyer
J. N. B. Hughes
C. P. Szolkowski
W. R. McWhirter
M. G. Teague
D. L. Tendardi
F. M. Saliba
M. T. Powell
H. B. Harris
R. S. Hammond
A. Chappelhow
P. A. Williams

Messrs Warren, Cordery, Fradd and Ey were not issued with certificates during 1979 as all statutory requirements had not been met.

GENERAL

Four meetings were held during the year and a total of 20 certificates were granted. This is half the number of certificates issued the previous year and it now appears the original influx of applicants for certificates has subsided.

Some board members visited Newman and Cockatoo Island to interview applicants and conduct oral examinations for the Restricted Quarry Manager's Certificate of Competency.

Members of the Board of Examiners as at December, 1979 were:—

Mr. J. K. N. Lloyd (Chairman)—Department of Mines
Mr. G. J. Dodge—Department of Mines
Mr. H. Duncan—Education Department
Mr. B. L. Grieve—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

Following the retirement in March, 1979, of the Acting Chief Coal Mining Engineer and Chairman of the Board, Mr A. Y. Wilson, the remaining five meetings held during the year were chaired by his successor, Mr J. K. N. Lloyd.

At the first meeting the Board Members and incoming Chairman recorded their appreciation of Mr Wilson's work on the Board.

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

The following five candidates passed the examinations and were granted certificates of competency:—

Second Class Mine Manager—A. W. Sanford
Third Class Deputy—R. J. Tyler
Open Cut Mine Manager—R. W. Archer
Deputy (Open Cut)—T. G. Hunter, D. S. Smith

A sixth candidate, Mr A. L. Piavanini was successful in the Deputy's (Open Cut) examination but was required to gain some additional shotfiring experience before a certificate is granted.

Three candidates for Second Class Certificates of Competency failed to pass the examinations.

Three applications were received for certificates of competency to be granted on the basis of qualifications awarded by other approved Boards.

Mr R. J. Parkin was granted a First Class Certificate of Competency in recognition of his United Kingdom qualifications.

Of two applicants for Open Cut Mine Managers Certificates, one was refused on account of inadequate practical experience and the other was allowed but was deferred pending the provision of additional documentary evidence.

The Board noted the important developments which were taking place during the year in relation to meetings and discussions on Coal Industry Training and Education in the Collie region. The Chamber of Mines, Coal Mining Companies, Education Department, Technical Education Division and the Western Australian Institute of Technology (School of Mines) were represented in these discussions.

Announcements that a sum of $200 000 would be made available to provide facilities for the training and education of persons in coal mining disciplines: $100 000 from C.S.R. Limited and $50 000 from each of Western Collieries Limited and the Griffin Coal Mining Company Limited, indicated that tangible progress was being made. Progress was evident too, towards the appointment of an "Extension Officer" who, while attached to the School of Mines, would be located in Collie to assist in the development of courses and provide tuition for candidates for statutory certificates of competency.

VENTILATION BOARD

J. Suda—Secretary

During 1979 the Ventilation Board met on ten occasions:—

The members of the Board as at December, 1979 were:—

Mr. J. K. Lloyd (Chairman)
Dr. F. Heyworth
Mr. R. Powell
Mr. G. Dodge
Mr. I. Loxton

DUST SAMPLING

All dust sampling results were data processed by a system of programmes called "mindust" which provided for computer storage of dust sample information collected at various minesites throughout the State. The dust samples were collected by the mining companies and submitted, on a monthly basis for processing, to the Ventilation Board.

The statistical reports produced by the computer allowed the Board to evaluate for selected mines:—

Whether or not methods of dust control were effffective.

The level of dust over a given period for certain fixed positions within a minesite.

The amount of dust to which certain categories of workers within a mine were exposed to over a given period.

Most companies were diligent in forwarding results to the Board during 1979 and members were generally impressed at the reduction of dust levels, especially in the iron ore mines, however results obtained from some categories were unacceptable and are still causing concern.

Following establishment of the "Mindust" system the Board commenced examination of ways and means for the measuring of toxic gasses. During 1980, the Board hopes to prepare a set of preliminary guidelines recommending the types of instruments to be used, and the sampling methods applicable for the measuring of toxic gases found in the mining industry.

PUBLICITY

The Board published a pamphlet entitled "The Dust Hazard" which was distributed to all Mining Companies. The purpose of the pamphlet was to explain to employees within the mining industry the hazardous efiect dust can have upon their health; the reasons for dust sampling; and to seek their co-operation in company sampling programmes.

VISITS

During the year members visited some mining centres to meet staff and discuss matters associated with dust control.

GENERAL

Members of the Board met with the Chamber of Mines Ventilation Committee to discuss the forming of a technical subcommittee to research and investigate the performance of cyclones when sampling for respirable dust. It has been realised by all parties concerned that the cyclones are not performing according to the makers specifications.

An approach has been made for Government funds to permit a two year research programme to be undertaken with the aim of establishing performance factors for the various types of cyclones.

DIVISION III

Report of the Superintendent of State Batteries—1979

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, 1979.

Crushing Gold Ores

One 20-head, five 10-head, and eight 5-head mills crushed 59 315·65 tonnes of ore made up of 546 separate parcels, an average of 108·6 tonnes per parcel. The bullion recovered amounted to 414 kilograms, estimated to contain 351·295 kilograms of fine gold, equal to 5·92 grams per tonne of ore.

The average value after amalgamation but before cyaniding was 2·20 grams per tonne, giving an average value of ore received of 8·13 grams per tonne, compared with 8·33 grams per tonne for 1978.

The cost of crushing 59 315·65 tonnes, was $27·85 per tonne. In 1978, 56 465·15 tonnes were crushed at the gold plants for a cost of $25·81 per tonne.

Cyaniding

Eight plants treated 15 485 tonnes of tailings from amalgamation for a product of 41·1338 kilogrammes of fine gold. The average content was 3·67 grams per tonne before cyanidation, while the residue after treatment was 1·03 grams per tonne giving a theoretical recovery of 73·3 per cent. The actual extraction was 72·20 per cent. The cost of cyaniding was $15.16 per tonne, lower than the previous year when 14 625 tonnes were treated at a cost of $19·68 per tonne.

Silver recovered by the cyaniding of gold tailings was valued at $1 436.92.

TREATMENT OF ORE OTHER THAN GOLD

Lead Ores

The Northampton Battery crushed 925·7 tonnes of lead ore for the recovery of 97·17 tonnes of concentrates.

Tungsten Ores

The Marble Bar Magnetic Plant crushed 33·8 tonnes of Scheelite ore for a recovery of 523 kilograms of concentrates.

Tin Ore

The Marble Bar Magnetic Plant treated 3·5 tonnes of tin ore for a recovery of 0·363 tonnes of concentrates.

Tantalum Ores

The Tin Ore treated at Marble Bar Magnetic Plant also produced 114 kilograms of tantalum concentrates.

Garnet Sands

The Northampton Battery treated 631·2 tonnes of Garnet Sands for the recovery of 380·25 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:—

	1979 $	Since Inception $
GOLD		
Gold	3 479 844	50 927 121
OTHER METALS		
Silver	1 437	7 860
Tin (Concentrate)	2 742	501 146
Tungsten (Concentrate)	2 380	73 764
Copper (Ores for Agricultural Use)	....	11 932
Lead and Zinc (Concentrate)	70 338	1 643 301
Tantalite—columbite (Concentrate)	4 115	100 350
Garnet (Concentrate)	30 420	72 341
Total other Metals	111 432	2 410 694
Grand Total	$3 591 276	$53 337,815

FINANCIAL

	Tonnes	Expenditure $	Receipts $	Loss $
Crushing—Gold Mills	59 315·65	1 648 180	202 389	1 445 791
Crushing—Northampton Lead Plant	1 556·8	41 029	5 006	35 963
Magnetic Separator	37·6	4 002	527	3 475
Cyaniding	15 485·0	234 824	86 907	147 917
	76 395·05	1 928 035	294 889	1 633 146

The loss of $1 633 146 is an increase of $46 634 on the previous year. It does not include depreciation and interest on capital.

Capital expenditure was incurred as follows:—

	$
Kalgoorlie (Spares and Extensions)	4 353.00
Laverton (Bin and Ramp)	3 777.00
Leonora (Housing Improvements)	7 456.00
Meekatharra (Extensions)	53 305.00
Norseman (Housing Improvements)	761.00
Northampton (Gyrex Crusher)	1 639.00
Ora Banda (Housing Improvements)	190.00
	71 481.00

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
1977	46 469·5	7 957·9	17·12
1978	57 325·9	7 844·9	13·68
1979	60 910·0	12 977·1	21·30

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

Administrative

Expenditure was $282 409, equal to $3·70 per tonne crushed and cyanided, compared with an expenditure of $243 354, $3·38 for 1978.

	1978 $	1979 $
Salaries	116 586	107 846
Payroll Tax	57 451	59 785
Workers Compensation	58 750	94 170
Travelling and Inspection	7 089	17 201
Sundries	3 478	3 407
	$243 354	$282 409

Staff

Foremen A. Dunn and K. Boase resigned during the year to take up gold prospects. It is feared that the rising price of gold and the lack of many trained gold operators in the State may deplete our trained staff in the future. The present staff are doing excellent work under adverse conditions and pressure caused by high gold prices.

General

The average price of gold during the year was $275·70 an ounce. A rise of $105·20 on the previous year average. The tonneage of gold ore crushed (59 315·65) increased again on last years high (56 282·15).

During the latter part of the year the Ball-Mill installation at Meekatharra was finalised and initial crushing started. Some recovery problems are expected with the type of surface ore which are scheduled for this unit and further modifications may be necessary.

A carbon-in-pulp treatment of tailings is to be started at Kalgoorlie in the coming year. It is hoped that the use of this type of treatment will improve tailings handling of the future.

E. J. GREEN,

Superintendent of 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, 1979

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	34	3 336	12·329 9	10·448 7	4·026 9	14·475 6	4·33
Coolgardie	90	7 697·75	29·350 4	24·874 0	14·077 8	38·951 8	5·06
Kalgoorlie	164	16 797·5	188·030 0	159·354 8	38·745 4	198·100 2	18·22
Laverton	32	4 239	12·496 0	10·590 1	6·170 8	16·760 9	3·95
Leonora	45	5 023	31·799 8	26·966 4	16·439 6	43·406 0	8·64
Marble Bar	24	977·35	4·585 6	3·885 9	1·758 3	5·644 2	5·77
Marvel Loch	45	4 063·5	27·546 0	23·344 8	12·455 3	35·800 1	8·88
Meekatharra	21	3 468	50·587 0	42·872 0	7·604 4	49·938 9	13·68
Menzies	18	2 573	12·274 6	10·401 5	10·374 1	20·775 6	8·00
Norseman	22	2 436	14·448 0	12·244 4	5·118 5	17·362 9	7·12
Ora Banda	26	5 663·3	18·033 2	15·282 6	9·263 5	24·546 1	4·33
Paynes Find	7	363·25	4·833 3	4·096 0	0·773 1	4·869 1	13·40
Sandstone	7	559	2·306 5	1·954 5	0·721 8	2·676 3	4·78
Yarri	11	1 939	6·086 0	5·157 6	3·127 5	8·285 1	4·43
	546	59 315·65	414·517 3	351·473 3	130·657	482·130 3	8·13

Average Per Parcel .... 108·6 tonnes
Average Yield by Amalgamation (Fine Gold) .... 5·92 grams per tonne
Average Tailing Grade (Fine Gold) .... 2·20 grams per tonne

Schedule No. 2
DETAILS OF EXTRACTION—TAILINGS TREATMENT 1979

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	101	4·26	0·429 2	1·06	0·106 8	0·321 8	74·9	0·319	74·3
Kalgoorlie	4 850	3·49	16·963	0·87	4·246 5	12·593 3	74·2	12·335 8	72·7
Leonora	5 160	2·60	13·454 7	0·67	3·486 3	9·998 6	74·3	9·829	73·0
Marvel Loch	2 554	2·81	7·193 1	0·71	1·835 8	5·420 6	75·35	5·187	72·1
Meekatharra	1 440	4·0	5·760	1·52	2·191 2	4·420 8	76·75	4·393	76·2
Menzies	360	3·1	1·116	1·67	0·601	0·515	46·0	0·592	53·0
Norseman	480	20·45	9·816	5·10	2·448	7·368	75·0	7·373	75·1
Ora Banda	540	4·12	2·224 8	2·06	1·112 4	1·112 4	50·0	1·105	49·7
	15 485	3·67	56·956 8	1·03	16·028	41·750 5	73·30	41·133 8	72·2

Schedule No. 3
DIRECT PURCHASE OF TAILINGS YEAR ENDED 31st DECEMBER, 1979

Battery	Tonnes of Tailings Purchased	Initial Payment to $28.00 per ·0311 kg
Boogardie	83·7	361·03
Coolgardie	378·8	391·48
Kalgoorlie	1 960·8	1 244·02
Laverton	38·7	30·58
Leonora	1 261·9	3 151·43
Marble Bar	26·8	107·06
Marvel Loch	294·0	1 387·83
Meekatharra	374·4	201·64
Menzies	226·8	767·81
Norseman	87·3	464·49
Ora Banda	51·3	242·80
Paynes Find	18·0	7·18
Total	4 802·5	8 357·35

Schedule No. 4

STATEMENT OF RECEIPTS AND EXPENDITURE FOR YEAR ENDED 31st DECEMBER, 1979

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	3 336·00	20 299.38	41 330.89	16 794.20	78 424.47	23.51	6 426.71	26 366.18	111 217.36	33.34	10 974.92	3.29	....	100 242.44
Coolgardie	7 697·75	23 703.49	48 885.65	22 589.52	95 178.66	12.36	5 209.20	30 672.42	131 060.28	17.03	22 940.25	2.98	....	108 120.03
Cue	....	....	....	....	....	....	....	....	....	....	1 704.00	....	1 704.00	....
Kalgoorlie	16 797·5	96 229.92	183 044.05	63 898.13	343 172.10	20.43	45 426.97	86 693.88	475 292.95	28.30	58 562.50	3.48	....	416 730.45
Laverton	4 239·00	11 296.01	39 403.31	12 427.71	63 127.03	14.89	2 313.59	17 967.07	83 407.69	19.68	12 470.35	2.94	....	70 937.34
Leonora	5 023·00	14 847.68	45 596.23	15 011.95	75 455.86	15.02	11 563.87	24 071.62	111 091.35	22.12	16 245.25	3.23	....	94 846.10
Marble Bar	977·35	12 798.00	24 481.58	3 642.50	40 922.08	41.87	2 994.34	6 930.83	50 847.25	52.02	3 534.72	3.61	....	47 312.53
Marvel Loch	4 063·50	16 936.74	56 810.61	14 464.22	88 211.57	21.71	2 829.67	16 408.76	107 450 00	26.44	14 634.93	3.60	....	92 815.07
Meekatharra	3 468·00	28 509.33	83 213.49	12 475.48	124 198.30	35.81	17 189.73	18 758.74	160 146.77	46.18	10 767.00	3.10	....	149 379.77
Menzies	2 573·00	11 089.90	45 375.35	8 248.11	64 713.36	25.15	2 989.71	11 098 81	78 801 88	30 63	8 472.25	3.29	....	70 329.63
Norseman	2 436·00	13 662.44	41 383.86	13 344.15	68 390.45	28.07	5 493.24	11 420.92	85 304.61	35.02	7 813.11	3.20	....	77 491.50
Ora Banda	5 663·30	13 522.99	62 238.87	24 644.58	100 406.44	17.73	2 971.88	25 403.70	128 782.02	22.74	13 281.46	2.34	....	115 500.56
Paynes Find	363·25	7 586.92	13 394 03	3 481 44	24 462.39	67.34	4 279.26	4 217.74	32 959.39	90.73	1 325.75	3.65	....	31 633.64
Peak Hill	....	....	....	....	....	....	....	....	....	....	240.00	....	240.00	....
Sandstone	559·00	11 640.23	14 490.33	2 659.94	28 790.50	51.50	362.89	5 898.73	35 052.12	62.71	1 967.00	3.51	....	33 085.12
Yarri	1 939·00	9 712.25	26 511.14	8 748.07	44 971.46	23.19	2 677.07	9 118.14	56 766.67	29.28	5 668.75	2.92	....	51 097.92
Head Office	....	....	....	....	....	....	....	....	....	....	11 786.91	....	11 786.91	....
Sub total	59 135·65	291 835.28	726 159.39	222 430.00	1 040 424.67	17.59	112 728.13	295 027.54	1 648 180.34	27.87	202 389.15	3.42	13 730.91	1 459 522.10
Mag. Plant	37·60	....	4 001 76	....	4 001.76	106.43	....	....	4 001.76	106.43	527.00	14.02	....	3 474.76
Northampton	1 556.80	13 305.32	16 210.69	3 073.94	32 589.95	20.93	1 197.62	7 241.20	41 028.77	26.35	5 066.37	3.25	....	35 962.40
Total	60 730·05	305 140.60	746 371.84	225 503.94	1 077 016.38	17.73	113 925.75	302 268.74	1 693 210.87	27.88	207 982.52	3.42	13 730.91	1 498 959.26

Schedule No. 5

STATEMENT OF RECEIPTS AND EXPENDITURE FOR YEAR ENDED 31st DECEMBER, 1979

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	....	....	....	....	....	....	....	29.67	29.67	....	....	....	....	29.67
Coolgardie	101	....	2 886.19	1 442.41	4 328.60	42.86	905.10	51.91	5 285.61	52.33	47.29	.46	....	5 238.32
Kalgoorlie	4 850	....	39 717.31	21 296.55	61 013.86	12.50	3 402.40	37 943.31	102 359.57	21.11	9 289.30	1.91	....	93 070.27
Laverton	....	....	....	....	....	....	....	220.00	220.00	....	....	....	....	220.00
Leonora	5 160	3 996.93	31 967.35	12 868.92	48 833.20	9.46	163.20	18 457.62	67 454.02	13.07	41 815.50	8.10	....	25 638.52
Marvel Loch	2 554	....	19 178.42	3 225.38	22 403.80	8.77	....	7 664.31	30 068.11	11.77	32 882.29	12.87	2 814.18	....
Meekatharra	1 440	....	3 760.00	4 682.03	8 442.03	5.86	1 482.18	7 481.05	17 405.26	12.09	3 092.15	2.14	....	14 313.11
Norseman	480	....	4 585.11	1 233.97	5 819.08	12.12	476.50	1 956.81	8 252.39	17.19	1 586.49	3.30	....	6 665.90
Ora Banda	540	....	286.00	1 027.59	1 313.59	2.43	370.60	176.40	1 860.59	3.45	319.81	....	....	1 540.78
Paynes Find	....	....	....	....	....	....	....	121.96	121.96	....	....	....	....	121.96
Yarri	....	....	1 724.00	42.69	1 766.69	....	....	....	1 766.69	....	....	....	....	1 766.69
Menzies	360	....	....	....	....	....	....	....	....	....	2 194.52	....	2 194.52	....
Total	15 485	3 996.93	104 104.38	45 819.54	153 920.85	9.94	6 799.98	74 103.04	234 823.87	15.16	91 227.35	5.89	5 008.70	148 605.22
							Less Interest Paid to Treasury				4 320.00			4 320.00
									234 823.87		86 907.35			152 925.22

STATE BATTERIES

TRADING AND PROFIT LOSS ACCOUNT FOR THE YEAR ENDED 31st, DECEMBER, 1979

1978 $	1978 $		1979 $	1979 $
		Trading Costs—		
1 077 031		Wages	1 158 564	
262 561		Stores	271 323	
122 733		Repairs, Renewals and Battery Spares	120 726	
327 445		General Expenses and Administration	376 372	
	1 789 770			1 926 985
		Earnings —		
	203 111	Milling and Cyaniding and Mag Plant Charges		294 890
	1 586 659	**Operating Loss for Year**		1 632 095
		Other Charges—		
63 435		Interest on Capital	63 435	
28 968		Depreciation	34 980	
46 268		Superannuation—Employers Share	54 788	
	138 671			153 203
	1 725 330	Total Loss for Year		1 785 298

STATE BATTERIES BALANCE SHEET AS AT 31st DECEMBER, 1979

FUNDS EMPLOYED

1978 $		1979 $	1979 $
	Capital—		
1 505 663	Provided from General Loan Fund	1 505 663	
502 932	Provided from Consolidated Revenue Fund	529 526	
2 008 595			2 035 189
	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—		
3 014 789	Interest on Capital		3 078 224
	Other Funds—		
14 504 256	Provided from Consolidated Revenue Fund (Excess of payment over collections)		16 167 452
19 612 456			21 365 681
	Deduct—		
	Profit and Loss:		
17 786 832	Loss at Commencement of Year	19 512 162	
1 725 330	Loss for Year	1 785 298	
19 512 162	Total Loss from Inception		21 297 460
$100 294			$68 221

EMPLOYMENT OF FUNDS

1978 $		1979 $	1979 $
	Fixed Assets—		
1 977 513	Plant, Buildings and Equipment	2 024 107	
1 743 493	*Less* Depreciation	1 778 473	
254 020			245 634
	Current Assets—		
66 598	Debtors	93 557	
57 902	Stores	96 109	
27 443	Battery Spares	44 191	
	Purchase of Tailings:		
41 043	Treasury Trust Account	47 352	
55 826	Tailings not Treated	49 298	
16 275	Estimated Gold Premium	14 428	
169 087			344 935
519 107	Total Assets		590 569
	Deduct—		
62 613	Current Liabilities: Creditors	113 428	
339 056	Liability to Treasurer (Superannuation—Employers Share)	393 843	
	Purchase of Tailings:		
869	Creditors	649	
16 275	Estimated Premium Due	14 428	
418 813			522 348
$100 294			$68 221

DIVISION IV

Annual Report of the Geological Survey Branch of the Mines Department for the Year 1979

CONTENTS

REPORTS

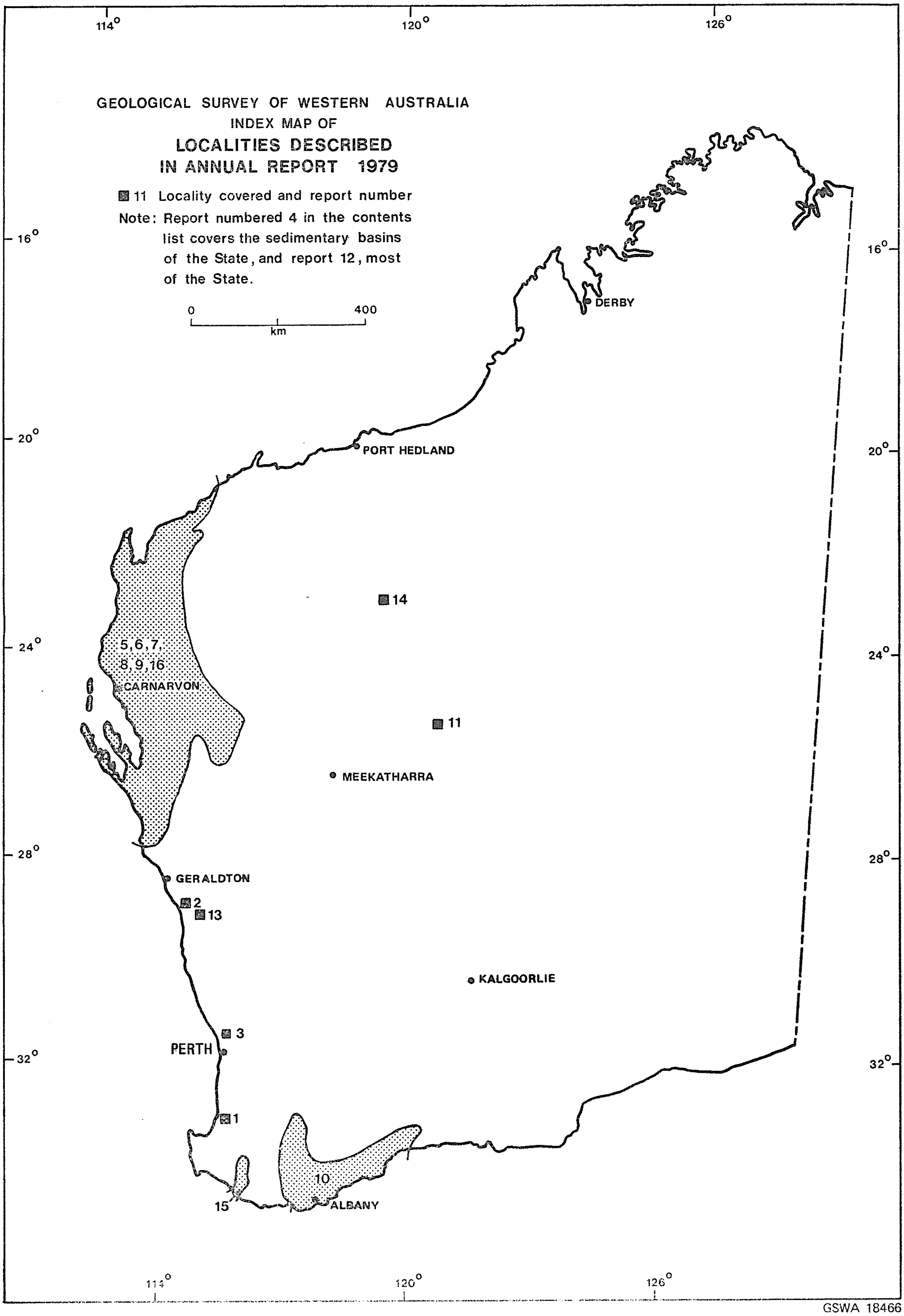


Figure 1 Index map showing areas and localities described in the Annual Report for 1979.

DIVISION IV

Annual Report of the Geological Survey Branch of the Mines Department for the Year 1979

Under Secretary for Mines:

It is my privilege to present a report on the activities of the Geological Survey of Western Australia during 1979, together with selected reports on investigations and studies made for Departmental purposes, for the information of the Honourable Minister for Mines.

INTRODUCTION

The interest and expansion of exploration activities continued to gain momentum during 1979, and boom conditions were approaching by the end of the year. The increased mineral prices, particularly for energy minerals and gold, were the main stimulus. Also improved metal prices regenerated interest in the search for base metals.

The demand for temporary reserves as prospecting tenements increased as shown in the following statistics:

Temporary Reserves Approved
(other than gold, iron and coal)

Year	New applications	Renewals	Total
1973	182	....	182
1974	47	28	75
1975	20	18	38
1976	117	11	128
1977	92	37	129
1978	228	33	281
1979	290	112	402

Uranium remains the most sought mineral being included in 233 of the 290 new applications approved, while diamond was included in 170. These new temporary reserves approved cover an area of 47 386 km² with a minimum exploration expenditure commitment of $9·477 million during the first 12 months of tenure.

In addition to the above temporary reserves at the end of 1979, 75 were held for gold, 166 for iron ore and 115 for coal. This is a total of 759 temporary reserves held compared with 463 in 1978, an increase of 64 per cent.

Exploration for uranium continues on both Precambrain areas and in the Phanerozoic basins. While traces of mineralization have been located in several localities none has yet shown sufficient promise to suggest a major deposit. Preparations for the development of the Yeelirrie deposit continues but the development of the Lake Way occurrence near Wiluna has been abandoned.

Diamonds continue to be the glamour mineral sought in many parts of the State. While diamond indicator minerals have been found elsewhere, the Kimberley remains the area of major activities. The Ashton Syndicate, with Conzinc Riotinto of Australia (CRA) as operator, continues to expend millions of dollars on exploration in the Kimberley particularly in the Ellendale area, 120 km east-southeast of Derby where assessment work continues. In the latter part of the year the Syndicate made a very exciting discovery on Smoke Creek which now flows into Lake Argyle near Kununurra—formerly it flowed into the Ord River. Here a kimberlite pipe (AK1) has been discovered on the upper reaches of Smoke Creek covering some 45 ha and preliminary sampling is reported to give 150 carats per 100 tonne, The diamonds shed from this pipe have been located for some 32 km downstream to the edge of Lake Argyle in alluvials ranging from 50 m to some hundreds of metres wide and 1 to 5 m in depth. Preliminary sampling of the alluvial is reported to have produced up to 750 carats per 100 tonne near the pipe decreasing to 60 to 65 carats per 100 tonnes at more than 30 km from the pipe. The largest diamond found to date weighed 7·03 carats. The assessment of quality has not yet been made.

Detailed sampling has continued on the Ellendale pipes, in particular pipe B which has produced 4 706 carats from 34 560 tonnes (13·6 carats per 100 tonnes) and has been tested to a depth of 175 m. Ellendale diamonds as tested are 60 per cent gem quality, 37 per cent, near-gem quality and only 3 per cent industrial quality. The largest stone found is 6·23 carats from pipe D.

The results suggest that a rich diamond mine should be developed at Smoke Creek shortly followed by a mine in the Ellendale area.

Exploration for iron ore, particularly in the Hamersley Basin, continued at a similar level as in 1978. The number of temporary reserves held for iron ore increased from 127 to 166 at the end of the year. With the forecast of an increase in the world demand for iron ore it is hoped that arrangements can be made to develop a new mining complex in the Hamersley shortly

There was considerable interest in the coal potential of the State and many companies and consultants carried out regional assessments. A large number of temporary reserves (115) were taken up for coal particularly in the Fortescue valley, but to date there has been no report of success.

The spectacular increase in the price of gold particularly towards the end of 1979, stimulated even more the interest in gold. The Telfer, Central Norseman and Mount Charlotte mines remain the major producers together with many small operators who kept State Batteries fully occupied. Two other former major mines, North Kalgurli and Kalgoorlie Mining Associates (Golden Mile) have begun rehabilitation of workings in order to re-commence mining operations. It will probably be up to two years before the two operations are onstream

Plans are being implemented to re-open small mines with treatment plants at Mount Ida, Marvel Loch and north of Bullfinch. Numerous other centres are being investigated such as Queen Margaret (Bulong), Mount Sir Samuel, Mount Magnet and Meekatharra.

Due to the lifting of water restrictions in the metropolitan area and probably as a result of advice given in recent years, the number of enquiries for hydrogeological advice dropped from over 4 000 in 1978 to 2 727 in 1979. In addition 107 inspections of properties outside the metropolitan area were made. Further work confirmed the major water resource of very good quality, located in the Quindalup area and eastwards. The resources of the Fortescue-Robe River area were further examined with satisfactory results. The Hydrogeological Division is becoming more and more involved in the study and monitoring of possible pollution of ground water aquifers, e.g. Laporte, Hertha Road, Kwinana red mud ponds, etc.

After many years of regional geological mapping on 1:250 000 scale, the field work required to give a complete coverage of the State was completed this year. It will probably take another 3 or 4 years to compile, to draw and to publish the remaining maps.

Even at this stage many sheets have been remapped where new information and ideas have shown that the original required re-interpretation. There are a number of sheets which require remapping and no doubt there will be many others in the future.

The activity on petroleum exploration continued during 1979 both offshore and onshore. While there was a decrease in seismic activity compared with the previous year, the number of holes drilled and the total depth of holes increased considerably.

Drilling in deep water on the Exmouth Plateau commenced and seven holes were completed with one (Vinck) still drilling at the end of the year. The deepest hole drilled was Jupiter 1 (Phillips) to 4 946 m while the site with the greatest water depth was the hole (Vinck) drilling in 1 383 m.

There was a considerable interest in the offshore Browse Basin and some onshore areas, particularly by the smaller operators.

Two holes Brecknock and Scarborough located gas but both were abandoned because of the locality and depth of water. These gas discoveries may be of interest in the longer term.

Year	Total holes drilled	Total metrage drilled	Seismic (km)	
			Land	Marine
1971	29	70 620	2 744	19 933
1972	29	102 876	3 266	43 218
1973	22	63 612	1 776	14 904
1974	21	48 172	559	11 815
1975	6	17 115	484	2 733
1976	6	22 171	443	2 599
1977	8	35 339	Nil	5 994
1978	15	48 110	1 143	38 996
1979	17	66 428	909	26 312

Public lectures: Three half days of public lectures were presented on 19 and 20 April. Attendance varied greatly according to the topics, the maximum present being 75. The main public interest is obviously associated with Precambrian geology geochronology and exploration potential.

Field excursions: An excursion to the Nabberu Basin was organized. On the evening of 23 April lectures on the basin were presented in Meekatharra. This was followed by a 4-day field trip observing the general geology and type sections and localities of the basin. Despite the remoteness of the area concerned some 70 geologists and prospectors attended.

On 26 November lectures were presented at the departmental theatrette on the geology of the Collie and Pemberton 1:250 000 sheets. This was followed by a 4-day field excursion. While over 70 attended the lecture only 44 could be accommodated on the tourist bus used for transport.

These excursions continue to be well-patronized and it is proposed to continue to organize one or two each year.

Microfilm library: For the second year this has been a very popular and well-used public facility. The demand for open-file material grows as the exploration boom develops. At the end of 1979 there were 118 rolls (35 mm 500 frame per roll) of company reports on mineral exploration and 95 rolls on oil and gas exploration available in the library.

A printer-reader has been installed in the Kalgoorlie office together with a set of film on mineral exploration.

All Records produced are being made available on microfiche form as are some of the frequently asked for out-of-print bulletins.

STAFF

The stability of geological staff experienced in recent years came to an end in 1979 with the development of the exploration boom. There were seven resignations and more are expected early in the new year. As well as the booms creating a shortage of geologists in this State, a number of our geologists have been dedicated regional Precambrian geological mappers for 5 to 7 years, so it is appropriate time at the end of the first edition of mapping to broaden their experience, as they cannot all be promoted within the Survey.

PROFESSIONAL

Appointments

Name	Position	Effective Date
Smith, R. A., B.Sc. (Hons)	Geologist L1	11/1/79
Hall, J. W., B.Sc. (Hons)	Geologist L1	28/5/79
Moore, P. S., B.Sc. (Hons)	Geologist L1	21/6/79
Tuckson, M., B.Sc. (Hons), M.A. (Hons), Ph.D.	Geologist L1	4/7/79
Martin, M. W., B.Sc. (Hons)	Geologist L1	17/12/79

Promotions

Hocking, R. M.	Geologist L2	26/1/79

Resignations

Green, K. H.	Geologist L1	23/2/79
Leech, R. E. J.	Geologist L2	16/3/79
Briese, E. H.	Geologist L1	6/4/79
Elias, M.	Geologist L1	21/9/79
Bunting, J. A.	Geologist L2	28/9/79
Lavaring, I. H.	Geologist L1	30/11/79
Moore, P. S.	Geologist L1	18/12/79

CLERICAL AND GENERAL

Appointments

McKenzie, J.	Clerk	3/1/79
Bryce, A.	Laboratory Assistant	5/2/79
Brzusek, M.	Laboratory Assistant	19/3/79
Hazel, T.	Typist	19/3/79
Munz, R.	Technical Assistant	2/4/79
Toohey, J.	Technical Assistant	2/4/79
Mountier, A.	Typist	8/6/79
Watt, M. S.	Geological Assistant	3/9/79
Wilson, C.	Laboratory Asssitant	25/10/79
Wall, H.	Technical Assistant	10/12/79

Transfer In

Healy, J.	Clerical Assistant	10/8/79

Transfer Out

Stevens, M.	Laboratory Assistant	6/7/79
Cusan, M.	Clerical Assistant	15/8/79
Monaghan, R.	Technical Assistant	19/10/79

Resignations

Pritchard, D.	Technical Assistant	2/2/79
McDonald-Goodall, A.	Technical Assistant	23/2/79
Graham-Sutton, P.	Geological Assistant	20/4/79
Hammill, N.	Technical Assistant	26/4/79
Brown, T.	Geological Assistant	4/5/79
Hazel, T.	Typist	24/5/79
Kerr, R.	Laboratory Assistant	23/11/79
Willis, B.	Technical Officer	27/12/79

ACCOMMODATION

During the year the required extensions to the store at Russell Street, Morely were commenced and completed to provide additional space, particularly for storage of publications and company reports.

Additions to the Dianella core library will be required within the next 1 or 2 years.

The proposed extension to Mineral House would be a welcome addition, allowing the Hydrogeology and Engineering Geology Divisions to return to the main office and to expand our library facilities.

OPERATIONS

HYDROGEOLOGY DIVISION

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.

Drilling for water resources investigations has been maintained at about the same level as last year. Three deep bores that have been drilled in, and east of, Busselton, together with five shallow bores, complete the programme of exploration on the Quindalup line of bores across the southern part of the Perth Sedimentary Basin. One of these bores (No. 9A), located 8 km south of Donnybrook, was completed to a depth of 1 469 m, a record depth for a water bore in the Perth Basin. This important line of bores has proved very large storages of fresh groundwater between Busselton and Donnybrook.

In the metropolitan area a further eight bores have been drilled to between 421 and 908 m to aid exploration of the deeper aquifers and provide information on the geological structure and recharge relations. Three shallow drilling projects have also been undertaken in the Perth Basin: the Bunbury shallow aquifer investigation has been completed with the construction of a further eight bores and an extensive programme of test pumping, 51 bores have been drilled in the Southwest coastal groundwater area to complete the first phase of that project and north of Perth the Metropolitan Water Board has drilled 11 bores at Lake Mariginiup to aid a water balance study.

The effects of bauxite mining and of the woodchip industry on groundwater and stream salinities continue to be studied on an inter-departmental basis. Other salinity studies include the interpretation of groundwater monitoring in the Harvey-Waroona irrigation schemes, Lake Toolibin, and close to Lake Muir.

In the west Pilbara, seven new bores have been drilled and an extensive programme of test pumping has been carried out. This completes work in the upper part of the Robe catchment.

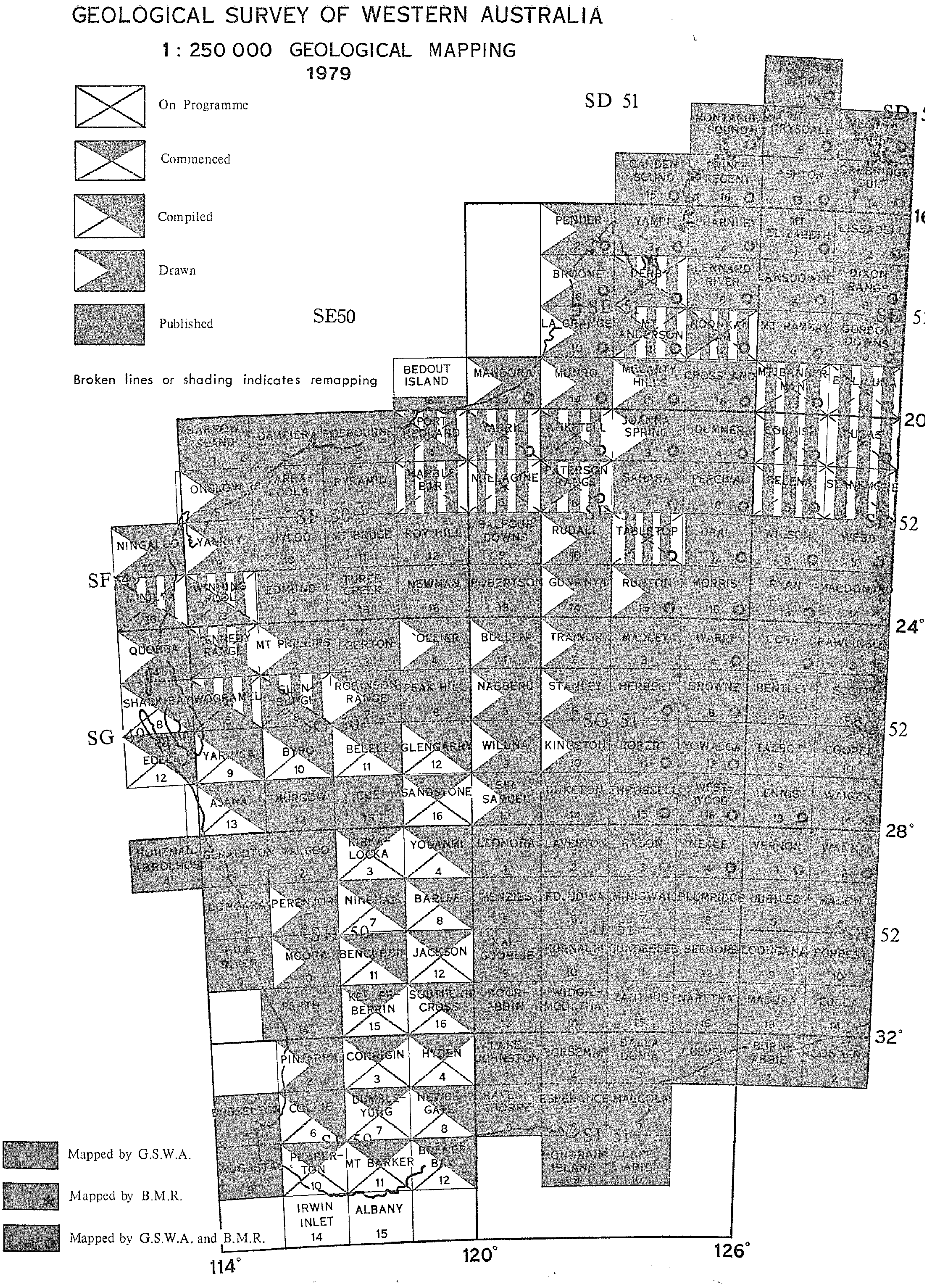


Figure 2 Progress of 1:250 000 and 4 mile geological mapping to the end of 1979.

GSWA 18467

The lifting of water restrictions in the metropolitan area and the consequent reduction in demand for private bores, resulted in a marked fall in the number of enquiries to 2 727 for advice on prospective drilling depth and other details. A similar fall to 107 was experienced in the demand for bore site selection by farmers.

Groundwater pollution surveys have been undertaken in several areas at the request of the Public Works Department, and hydrogeological studies of acid effluent disposal at Australind continue. Advice has been provided to the Main Roads Department regarding sources of compaction water for three road-improvement schemes and 23 reports have been written in response to requests for investigations or advice by other Government departments. The compilation of bore records throughout the State continues.

ENGINEERING GEOLOGY DIVISION

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

Activities were confined to investigations for other Government Departments and instrumentalities including.

Department of Public Works:

(a) Further investigations made at Harding River dam site in the Pilbara, at two dam sites near Manjimup, and at two damsites on Marrinup Brook.

(b) Geological reconnaissance made of dam sites on the Tone and Kent Rivers.

(c) Foundation studies for several tank sites between Millstream and Karratha and a study of the foundations of the Kokardine tank, damaged by the Cadoux earthquake.

(d) Minor investigations carried out including a rock quarry site for the proposed breakwater at Rocky Point near Dunsborough.

Metropolitan Water Board:

(a) Continued mapping and provision of geological advice during construction of Wungong Dam.

(b) Continued studies on South Canning, New Victoria and Bickley dam sites.

(c) Reports completed on Wungong and Bibra tunnels.

(d) Studies commenced on Little Dandalup dam site.

Westrail:

(a) Geological advice given on the selection of quarry sites and rail routes.

Miscellaneous:

(a) Geological mapping of surface features associated with the Cadoux earthquake.

REGIONAL GEOLOGY DIVISION

R. D. Gee (Supervising Geologist), I. R. Williams (Senior Geologist), P. C. Muhling, J. A. Bunting, R. Thom, A. T. Brakel, R. J. Chin, M. Elias, S. J. Williams, and I. W. Walker.

Regional mapping, at 1:250 000 scale, saw the completion of field work for the Precambrian portion of the State. Field work was completed on Barlee, Jackson, Bencubbin, Kellerberrin, Corrigin and Dumbleyung. Field mapping on Sandstone and Youanmi was completed with the assistance of three geologists from the Bureau of Mineral Resources, Canberra.

One regional mapping officer has been positioned in the regional office at Kalgoorlie to re-map the Widgiemooltha sheet.

Work on the Bangemall Basin and Nabberu Basin Bulletins is almost complete. Preliminary work has begun on a Gascoyne Province Bulletin.

SEDIMENTARY DIVISION

M. H. Johnstone (Supervising Geologist), K. A. Crank, H. T. Moors, P. D. Denman (Senior Geologists), M. N. Megallaa (Senior Geophysicist), R. M. Hocking, B. P. Butcher, P. S. Moore.

The processing of data submitted by petroleum companies continued. In 1979, wells located by the extensive seismic surveys of 1978 were drilled but none produced hydrocarbons in economic quantities. Seismic surveys continued offshore (but at a lower rate than in 1978) and onshore, mainly to detail structures for drilling. An extensive seismic survey was completed in deep water off the southern Eucla Basin, but most seismic and drilling activity continued to be on the Northwest Shelf and the Exmouth Plateau.

Field work in the Carnarvon Basin was completed in 1979 with the mapping of the Kennedy Range 1:250 000 Sheet and the northeastern corner of the Wooramel Sheet. Preparation of a bulletin covering both the onshore and the economically important offshore portions of the basin commenced. Preparation of the explanatory notes for the remaining Winning Pool, Kennedy Range, and Wooramel map sheets proceeded.

MINERAL RESOURCES DIVISION

J. G. Blockley (Supervising Geologist), J. D. Carter and R. J. Marston (Senior Geologists), J. L. Baxter, A. H. Hickman, J. Morrison, S. A. Wilde, S. L. Lipple, D. F. Blight.

Compilation of the Collie and Kirkalocka Sheets were completed and draft Explanatory Notes prepared. Compilation of Pemberton is continuing.

Mapping of the Warriedar fold belt at a semi-regional scale began and, together with associated specialist studies, will continue into 1980. Preliminary work on a detailed study of the Mount Monger area has started.

A bulletin on the State's nickel deposits is near completion. A first report on Ministerial Iron Ore TRs was written and a second is in preparation. An inspection of Jennings Mining Ltd's operation at Eneabba was made before the mine closed.

An assessment of the State's reserves and resources of nickel, bauxite and mineral sands was completed while work continues on a compilation of gold resources.

During 1979, 27 rolls of microfilm were produced for the open-file library.

COMMON SERVICES DIVISION

Petrology

W. G. Libby, J. D. Lewis.

Demand for petrographic services remained at the same high level of the past two years; 85 petrological reports were completed, on a total of 1 860 rock samples. Further thin sections were studied for incorporation into the computer based petrological data system.

The co-operative geochronology programme with WAIT continued, with one paper published and four others prepared for publication. Fifteen projects are in various stages of completion and have been carried over the 1980 programme.

The laboratory prepared 2 400 thin sections, 292 polished thin sections, and 223 rocks were cut and faced for further examination. In addition 372 samples were crushed for geochronology and chemical analysis, 350 specimens were stained for carbonate and potash feldspar identification and a number of specimens were subject to grain size analysis, and heavy mineral separation.

The Government Chemical Laboratories continued to identify mineral samples and provided access to X-ray diffractometer and computer facilities.

Palaeontology

A. E. Cockbain, J. Backhouse, K. Grey.

Thirty-four reports were written during the year and 820 samples were added to the Survey fossil collection. In addition 16 000 palaeontological samples from relinquished petroleum tenements were catalogued. As in previous years most of the reports covered three main fields (a) Perth Basin palynology (for the Hydrogeology Division), (b) Precambrian palaeontology (for the Regional Geology Division) and (c) Carnarvon Basin invertebrate fossils (for the Sedimentary Division).

A long-term study of the stromatoporoids from the Devonian reef complexes of the Canning Basin was completed and a report prepared. A record summarizing the stratigraphical distribution of Proterozoic stromatolites was published during the year.

Geophysics

D. L. Rowston, I. R. Nowak.

The decline in exploratory drilling by the Metropolitan Water Board was reflected by lower well-logging activity in 1979 when only 77 logging operations were carried out by comparison with 144 in 1978. Aggregate total depths were 28 396 m and 25 720 m respectively indicating a trend towards exploitation of deeper aquifers. The deepest water bore yet logged by the Section, Quindalup 9A to 1 469 m, encountered potable formation water over an interval in excess of 1 100 m.

Seismic refraction surveys were undertaken at two prospective dam sites at Manjimup, and at Victoria and Wungong dams. Seismic sections were also obtained across four forestry coupes at Manjimup to augment groundwater salinity projects and on the coastal plain environs of the Robe and Fortescue Rivers in the Pilbara to aid selection of exploratory waterbore sites. Experimental seismic work to delineate the "channel sand" aquifer in the Mirrabooka area was unsuccessful, apparently because of inadequate velocity contrasts with the Osborne and superficial formations.

In conjunction with MRD the search for unexploded artillery shells at Warnbro was resumed and a proposed roadway area amounting to 14 ha was investigated. The proton magnetometer was discarded in favour of equally sensitive but more manoeuvrable commercial metal detectors.

The high demand for field salinity determinations continued; salinity monitoring projects involved 510 measurements and the public submitted about 320 water samples, mainly from metropolitan bores, for testing. Normal laboratory and electronic servicing facilities were maintained and some 70 public enquiries on geophysical matters answered.

Environmental Geology

E. R. Biggs, R. H. Archer.

A study of Perth's sand resources, supply and demand was completed and the results published as a Survey Record. The examination of Perth's aggregate requirements was completed and a map and report supplied to the Darling Escarpment Aggregate Resources Committee. Maps have been drawn showing the areal extent of basic raw materials for the construction industry in Perth.

Geological information has been supplied for nine Town or Shire planning schemes and for several other projects including development at Joondalup and Herdsman Lakes. Appraisal of environmental review and management programme reports continues an important part of the section's activities, as do committees and liaison meetings.

Geochemistry

R. Davy.

Reconnaissance exploration of the Saddleback greenstone belt, and a literature survey on the possible use of geochemistry for prospecting for chromite have been completed.

Work has continued, in co-operation with the Petrology Section, on the study of the granitoids of the Mount Edgar and Corunna Downs batholiths.

Liaison has been maintained with the Government Chemical Laboratories.

Technical Information

W. B. Hill, M. E. Wenham, J. F. Cameron, P. Hind.

During the year the Survey undertook, for the first time, the publication of the 1:250 000 geological series with explanatory notes which have previously been published by the Bureau of Mineral Resources. Of the 6 sheets with explanatory notes sent to press, 5 have been published and sell for $5.00 each. Eleven sheets with explanatory notes were published by the BMR who are finalizing their publishing commitment.

This year the annual report, one mineral resources bulletin, two reports and one Urban Geology map were published. One bulletin was sent to press and two bulletins were already in press. Five explanatory notes were edited and proof read. Nine records were published and also issued on microfilm. Two information pamphlets were revised and one is in progress.

Requisitions raised on the Surveys and Mapping Branch for drafting, photography and copying totalled 1 306.

Rising gold prices and the success of prospecting with metal detectors have led to an influx of gold prospecting enquiries from the general public. The section answered 1 653 requests for information including rock identifications 308 of which entailed detailed research; and 4 511 members of the public visited the library for research purposes. Book loans to the staff totalled 7 782, and loans to and from other libraries 601.

The open file system for the "M" series reports continued to expand, 1 011 public users and 122 staff visited the microfilm library.

ACTIVITIES OF THE COMMONWEALTH BUREAU OF MINERAL RESOURCES

Geological and geophysical projects carried out by the Bureau of Mineral Resources included the following:

(i) three geologists joined our geologists on the mapping of the Sandstone and Youanmi sheet.

(ii) analysis and study of rocks from the Pilbara Block as continuation of a joint geochemical project with this Survey.

PROGRAMME FOR 1980

HYDROGEOLOGY DIVISION

1. Continuation of the hydrogeological survey of the Perth Basin including deep drilling on the Boyanup line, completion of report on the Quindalup line and planning of the Harvey and Gillingarra lines.
2. Hydrogeological investigations and/or exploratory drilling for groundwater in the following areas:
   (a) Completion of work in the Millstream-Weelumarra area and continuation of work on the Robe and Fortescue flood plains.
   (b) Re-assessment of the groundwater resources along Gascoyne and Arrowsmith Rivers, on Rottnest Island, Eneabba, Pinjarra, Dawesville, and the Swan Valley.
   (c) Continuation of the investigation of the water resources of the Collie Basin.
3. Town water supply investigations and/or drilling for the following: Salvado, Busselton, Lake Clifton, Port Gregory, New Norcia, Bunbury.
4. Hydrogeological investigations for the Metropolitan Water Supply Board:
   (a) Deep drilling for artesian monitoring scheme.
   (b) Shallow drilling at Mirrabooka and East Mirrabooka.
   (c) Continuation of pollution studies at Gnangara and Kwinana.
   (d) Continuing study of water balance in coastal lakes.
5. Interdepartmental studies concerning groundwater salinity problems in the Darling Range bauxite and woodchip areas.
6. Continuation of bore census of selected areas, salinity and pollution studies and supervision of consultant's work.
7. A preliminary study of the occurrence and the feasibility of using any moderate to high temperature water which may occur in the Perth Basin, for energy purposes.
8. Miscellaneous investigations and inspections as required by Government departments and the public.

ENGINEERING GEOLOGY

1. South-West Division dam sites investigations: Wungong (completion report), South Canning, North Dandalup, Little Dandalup, Dirk Brook, Manjimup, Brockman River and on the Tone, Frankland, Kent and Denmark Rivers.
2. North West dam site and pipeline investigations: Harding River.
3. Geological studies and advice during construction of the Wungong and Bibra Lake tunnels.
4. Geological advice to Westrail on quarry sites and railway construction.
5. Geological advice on miscellaneous problems for Public Works and other Government departments and authorities.

SEDIMENTARY GEOLOGY

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.
2. Continuation of the study of the surface and sub-surface geology and geophysics of the Carnarvon Basin.
3. Preparation and commencement of the mapping and study of the Bonaparte Gulf Basin.
4. Continuation of the compilation of a bulletin on stratigraphic studies of Devonian reef complexes in the Canning Basin.
5. Minor geological investigations as required.

REGIONAL GEOLOGY DIVISION

1. Completion of compilation and explanatory notes for the remaining 1:250 000 first edition geological maps of Western Australia. All field work having been completed.
2. Geological synthesis of the Gascoyne Province.
3. Commence re-mapping of Balfour Downs, Wyloo and eastern portion of Cue 1:250 000 sheets.
4. Detailed mapping of the Fraser Front in the Ravensthorpe and Bremer Bay area.
5. Completion of the re-mapping of Peak Hill 1:250 000 sheet.

MINERAL RESOURCES DIVISION

1. Maintain records and assess mineral potential and resources in Western Australia.
2. Completion of mapping and study of the Warriedar fold belt.
3. Commence bulletin on the geology and bauxite occurences of the Darling Range area.
4. Completion of assessment of iron ore on Ministerial Reserves.
5. Prepare a mineral deposit map of Western Australia.

6. Prepare geological map of the southwest mineral sands area.
7. Review of the Mortimer Hills uranium prospect.
8. Miscellaneous investigations as required.

COMMON SERVICES DIVISION

Petrology

1. Carry out petrological investigations as required by other Divisions.
2. The following topics to be investigated:
   (a) Alkaline granitoids of the Eastern Goldfields.
   (b) Rb:Sr geochemistry in and about the Black Range dolerite.
   (c) Proterozoic effects on the petrology of the Archaean rocks in the southwestern corner of Western Australia.
   (d) Petrology of the kimberlites and related rocks of the Kimberley division.
   (e) Petrology of the Corunna Downs and Mount Edgar batholiths.
3. Miscellaneous minor petrological studies.

Palaeontology

1. Carry out palaeontological investigations as required by other Divisions.
2. Completion of the study of Precambrian stromatolites and micro-fossils.
3. Continuing palynological study of the Early Cretaceous of the Perth Basin.
4. Biostratigraphy and systematics of the Devonian radiolarians from the Canning Basin.
5. A study of the Gneudna stromatoporoids (Carnarvon Basin).

Geophysics

1. Well-logging on groundwater drilling projects as required.
2. Seismic surveys for numerous potential dam sites in South-West and for railway construction purposes.
3. Gravity survey to define the Southern Cross-Bullfinch greenstone belt.
4. Gravity and magnetic surveys of
   (a) Warriedar fold belt
   (b) Mount Monger area
   (c) Fossil drainages.
5. Miscellaneous geophysical investigations as required.

Geochemistry

1. Continuation of the study of the Corunna Downs and Mount Edgar batholiths.
2. Completion of the study on:
   (a) Mount McRae Shales
   (b) Mercury in sulphides
   (c) Yarrie ironstones.
3. Commence geochemical studies on:
   (a) Warriedar fold belt
   (b) Mount Monger area
   (c) Kimberlites.

Environmental Geology

1. Continue the compilation of urban geology maps for the Roebourne, Port Hedland and Bunbury areas.
2. Assessment of environmental reports as required.
3. Studies of the basic raw material resources of the metropolitan area.
4. Examination of miscellaneous environmental geological problems as required

Regional Offices

Kalgoorlie

1. Re-mapping of the Widgiemooltha 1:250 000 sheet.
2. Detailed mapping and mineral study of the Mount Monger area.
3. Study of the Phanerozoic sediments and fossil drainages of the Kalgoorlie-Norseman area.

Karratha (It is hoped to establish this office in the latter part of 1980)

1. Re-mapping Wyloo 1:250 000 sheet.
2. Detailed study of the mineralized parts of the Wyloo sheet.
3. Hydrogeological studies for the Pilbara region.

PUBLICATIONS

Issued during 1979

Annual Report 1978.

Mineral Resources Bulletin 11: Molybdenum, tungsten, vanadium and chromium in Western Australia.

Report 8: A study of the laterite profiles in relation to bedrock in the Darling Range near Perth, W.A.

Report 9: Contributions to the geology of the Eastern Goldfields Province of the Yilgarn Block.

Geological map of Duketon 1:250 000 sheet (SG/51-14 International Grid) with explanatory notes.

Geological map of Marble Bar 1:250 000 sheet (SF/50-8 International Grid) with explanatory notes.

Geological map of Morris 1:250 000 sheet (SF/51-16 International Grid) with explanatory notes.

Geological map of Mount Bannerman 1:250 000 sheet (SE/52-13 International Grid) with explanatory notes (second edition)

Geological map of Mount Egerton 1:250 000 sheet (SG/50-3 International Grid) with explanatory notes.

Geological map of Nullagine 1:250 000 sheet (SF 51-5 International Grid) with explanatory notes.

Geological map of Percival 1:250 000 sheet (SF/51-8 International Grid) with explanatory notes.

Geological map of Perth 1:250 000 sheet (SH/50-14 International Grid) with explanatory notes.

Geological map of Plumridge 1:250 000 sheet (SH/51-8 International Grid) with explanatory notes.

Geological map of Robert 1:250 000 sheet (SG/51-11 International Grid) with explanatory notes.

Geological map of Runton 1:250 000 sheet (SF/51-15 International Grid) with explanatory notes.

Geological map of Ryan 1:250 000 sheet (SF/52-13 International Grid) with explanatory notes.

Geological map of Sahara 1:250 000 sheet (SF/51-7 International Grid) with explanatory notes.

Geological map of Sir Samuel 1:250 000 sheet (SG 51-13/International Grid) with explanatory notes.

Geological map of Tabletop 1:250 000 sheet (SF/51-11 International Grid) with explanatory notes (second edition).

Geological map of Ural 1:250 000 sheet (SF/51-12 International Grid) with explanatory notes.

Geological map of Wilson 1:250 000 sheet (SF/52-9 International Grid) with explanatory notes.

Urban geological maps 1:50 000: Pinjarra, Baynton, Karratha, Nickol Bay-Legendre, Point Samson-Delambre Island.

(*Available in microfiche form*)

Record 1979/1 Wells drilled for petroleum exploration in Western Australia to the end of 1978, by K. A. Crank.

Record 1979/2 Preliminary results for biostratigraphic studies of Proterozoic stromatolites in Western Australia, by Kathleen Gray.

Record 1979/3 Explanatory notes on the Glengarry 1:250 000 geological sheet, Western Australia, by M. Elias, J. A. Bunting, and P. H. Wharton.

Record 1979/4 Prospecting for chromite, by R. Davy.

Record 1979/5 Explanatory notes on the Southern Cross 1:250 000 geological sheet, Western Australia, by R. D. Gee.

Record 1979/6 Sand in the Perth metropolitan area, by E. R. Biggs.

Record 1979/7 Explanatory notes on the Ajana 1:250 000 geological sheet, Western Australia, by R. M. Hocking, W. J. E. van de Graaff, J. G. Blockley, and B. P. Butcher (in prep.).

Record 1979/8 Geochemical exploration Saddleback Greenstone Belt, by R. Davy.

Record 1979/9 Geology and groundwater resources of the south-western Canning Basin, Western Australia, by R. E. J. Leech.

Record 1979/10 A geophysical study of the south-central Carnarvon Basin, by M. N. Megallaa (in prep.).

Record 1979/11 Explanatory notes on the Collie 1:250 000 geological sheet, Western Australia, by S. A. Wilde and I. W. Walker (in prep.).

Record 1979/12 The geology and hyrdogeology of the Moora Borehole Line and adjacent area, Perth Basin, by E. H. Briese (in prep.).

Record 1979/13 A reassessment of the effects of bauxite mining on groundwater hydrology at Del Park, by E. H. Briese.

In Press

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.

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 Yanrey-Ningaloo 1:250 000 sheet (SF/50-9, SF/49-12 International Grid) with explanatory notes.

Urban Geological maps 1:50 000: Baynton, Karratha, Nickol Bay-Legendre, Point Samson-Delambre Island, Dampier, Roebourne.

Mineral Resources of Western Australia.

In preparation

Bulletin 127: Geology of the Pilbara Block and its environs.

Bulletins: The geology of the Bangemall Basin; The geology of the Earaheedy Group, Nabberu Basin.

Mineral Resources Bulletin: Nickel.

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, Trainor, 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

Baxter, J. L., 1979, Mineral Sands, *in* Mining in Western Australia (Rex T. Prider, ed.): Univ. Western Australia Press, 304 pp.

Blockley, J. G., 1979, Copper, lead, zinc and tin, *in* Mining in Western Australia (Rex T. Prider, ed.): Univ. Western Australia Press, 304 pp.

Carter, J. D., 1979, Uranium, *in* Mining in Western Australia (Rex T. Prider, ed.): Univ. Western Australia Press, 304 pp.

de Laeter, J. R., and Trendall, A. F., 1979, The contribution of geochronology to Precambrian studies in Western Australia: Roy. Soc. West. Australia Jour. v. 62, p. 21–31.

Gee, R. D., 1979, Structure and tectonic style of the Western Australian Shield: Tectonophysics v. 58, p. 327–369.

Geological Survey of Western Australia, 1979, Perth's underground water, *in* Western Australian Year Book No. 17—1979: Australian Bureau of Statistics Western Australian Office, 558 pp.

Johnstone, M. H., 1979, A case history of Rough Range: Australia Petrol. Expl. Assoc. Jour. v. 19(1), p. 1–6.

Lord, J. H., 1979, Coal, *in* Mining in Western Australia (Rex T. Prider, ed.): Univ. Western Australia Press, 304 pp.

Lord, J. H., 1979, History of Geology in Western Australia: Roy. Soc. West. Australia Jour, v. 62, p. 3–11.

Lord, J. H., and Morrison, R. J., 1979, Mineral Reserve Reporting for Government Requirements, *in* Estimation and Statement of Mineral Reserves: Australasian Inst. Min. Metall. Sydney, p. 225–263.

O'Driscoll, E. P. D., 1979, Ground-water and its importance to the mineral industry, *in* Mining in Western Australia (Rex T. Prider, ed.): Univ. Western Australia Press, 304 pp.

Playford, P. E., 1979, Stromatolite research in Western Australia: Roy. Soc. West. Australia Jour. v. 62, p. 12–20.

Playford, P. E., 1979, Oil and gas, *in* Mining in Western Australia (Rex T. Prider, ed.): Univ. Western Australia Press, 304 pp.

Rowston, D. L., 1979, Geophysical methods, *in* Mining in Western Australia (Rex T. Prider, ed.): Univ. Western Australia Press, 304 pp.

Trendall, A. F., 1979, Iron, *in* Mining in Western Australia (Rex T. Prider, ed.): Univ, Western Australia Press, 304 pp.

Trendall, A. F., 1979, The Lower Proterozoic Meteorite Bore Member, Hamersley Basin, Western Australia, *in* Pre-Pleistocene Tillites: Cambridge University Press.

Trendall, A. F., 1979, A progress review of the Hamersley Basin: Geol. Survey Finland Bull.

Veeh, H. H., Schwebel, D., van de Graaff, W. J. E., and Denman, P. D., 1979, Uranium-series ages of coralline terrace deposits in Western Australia: Geol. Soc. Aust. Jour. v. 26, p. 285–303.

J. H. LORD,
Director.

21st January, 1980.

THE GEOLOGICAL SURVEY OF WESTERN AUSTRALIA OVER TWO DECADES 1960-1979

by J. H. Lord

INTRODUCTION

Every continuing activity or organization should be reviewed from time to time to ensure that it is developing along the desired lines, and that its achievements are in keeping with its objectives. It is appropriate that on entering the eighties one should review the past two decades of development and achievements of the Geological Survey of Western Australia. Why these two decades? This has been the period required to redevelop the Survey and to achieve most of the objectives formulated when a major expansion of the Survey was planned in 1960.

In late 1959 and early 1960 the Government was interested in the development of mineral resources other than gold, which was then declining rapidly in production. The Minister for Mines, the Hon. A. F. (now Sir Arthur) Griffith, M.L.C., and the Under Secretary for Mines, the late A. H. Telfer, investigated ways and means of expanding and developing the Survey. This included an inspection of other State Surveys, in particular South Australia, which was reputed to be one of the best in Australia at that time.

As a result, a new position, Deputy Government Geologist, was created and was advertised throughout Australia, with the

Proviso that the successful applicant should succeed the then Government Geologist, H. A. Ellis, who was due for retirement in mid-1961. The main purpose of this early appointment was for the appointee to plan the redevelopment of the Survey into a much larger organization. I was appointed to this position on 12 December 1960. During 1961 the Government approved a proposal to divide the Survey into divisions and to increase the professional staff establishment from 13 to 29.

DEVELOPMENT

The proposed five divisions were: Hydrology and Engineering, Mineral Resources, Regional Geology (for Precambrian mapping), Sedimentary (Oil), and Common Services. The Common Services Division was divided into petrology, palaeontology, geophysics, technical information, and clerical sections.

This basic structure has survived until now, except for some expansion. The Hydrology and Engineering Division has been divided into separate Hydrogeology and Engineering Geology Divisions, and the Common Services Division has had additional sections added, namely the geochemistry, environmental geology, laboratory and geological service sections.

STAFF

During the decade of the 1960s the professional staff increased from 29 in the initial reorganized structure to 51. During the 1970s the staff establishment increased further to 63.

The non-professional staff grew from 4 in 1960 to 36 in 1979 (Fig. 1).

In the early part of the expansion there were insufficient geologists available in Australia, and many were recruited from overseas, particularly from the United Kingdom. A very good group of geologists was assembled which developed considerable expertise; then came the mineral boom of 1968–72. This caused many staff to resign, mostly for more lucrative positions in industry. As a result the Survey had to recruit and train new staff, and it was 1973 before it was stabilized again.

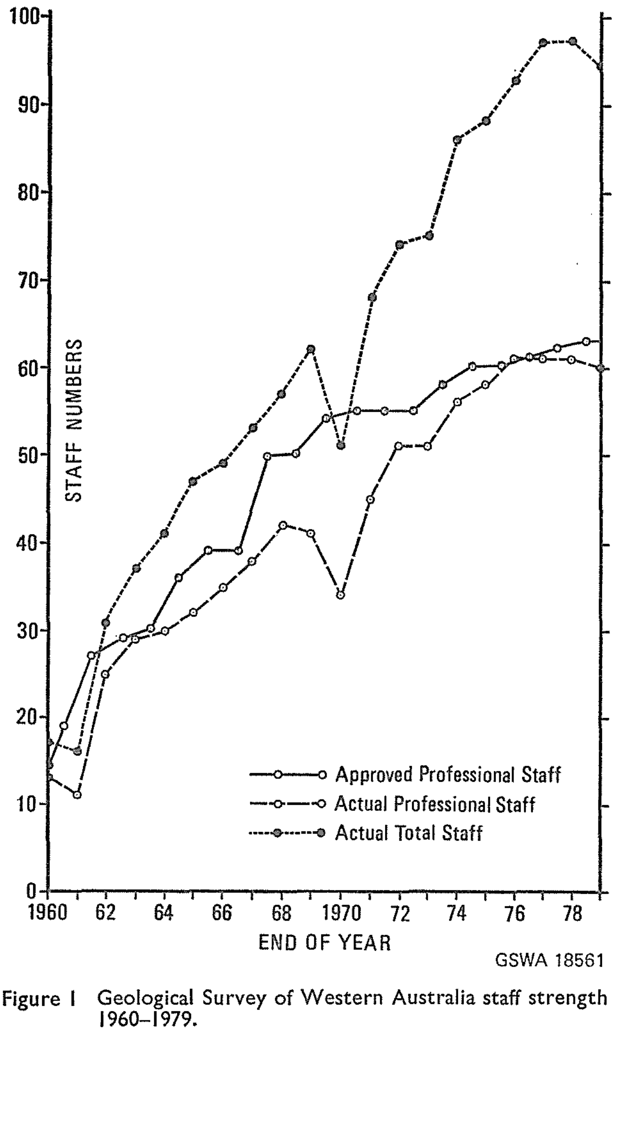


Figure 1 Geological Survey of Western Australia staff strength 1960–1979.

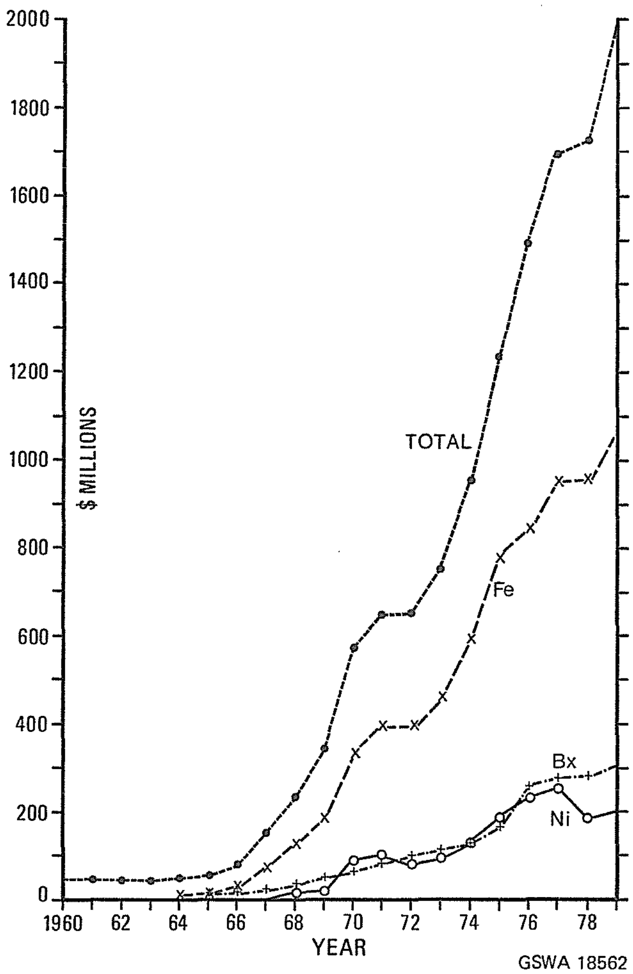


Figure 2 Value of total mineral production, also iron (Fe), bauxite (Bx), and nickel (Ni) over the period 1960–1979.

From 1973 to 1979 there was little movement of staff, but in 1979, with exploration beginning to boom and young staff of several years' experience being in demand, the movement of staff out of the Survey recommenced. This is to be expected, because geology is a profession which requires broad experience in different styles and places of work. Similarly it is believed that recruitment from different universities and countries is advantageous to a geological survey and prevents the possibility of local inbreeding of ideas and methods. During the two decades some 86 geologists have left the Survey, but the vast majority have contributed to the knowledge of the geology of this State and we have benefited from their time with the Survey.

One of the policies instilled into the staff has been that of service to industry. It is believed that for active exploration and prospecting to be attracted to Western Australia the Survey has to play its part by providing the basic geological data on which exploration is based, and by giving willing and courteous service and encouragement to industry. It is believed that this policy has materially assisted in the remarkable growth of the State's mineral industry, from a total production value of $44 million in 1960 to over $2 000 million in 1979 (Fig. 2).

ACCOMMODATION

Initially the Survey suffered badly from inadequate accommodation, situated in a depressed part of the city. By 1970 six different buildings were occupied as offices and laboratories, including a converted church and lodging house, and the upper floor of a warehouse.

In 1970, with the building of Mineral House, the Survey came together for the first time for many years, and also for the first time with the rest of the Department of Mines. This building provided ideal modern accommodation until 1977 when, due to the growth of the Department, it was necessary to move the Hydrogeology and Engineering Geology Divisions to another office block.

In 1960 the only storage available was a small shed at the rear of the Western Australian Museum. A small core library was built in late-1961 at Dianella and an adjacent shed was used for equipment and vehicle storage. The core library has since been extended twice. In 1969 it was necessary to move the equipment and vehicles to a larger new store built at Morley which houses geological equipment, publications, and a geophysical workshop and includes an adequate vehicle park.

ACHIEVEMENTS

In a number of fields of geology, the Survey can claim achievements over the past two decades. The critic may ask, "what mine did they find?". The answer in this case is "none", simply because it is not the task of the Survey to find mines. It has been Government policy during this period for the Survey to assist prospecting and exploration. This includes the provision of geological advice, basic maps, and services to encourage the search for new deposits, and at the same time to advise Government on development. This policy is based on the principle that the people should not have their taxes used for the very high-risk activity of exploration for mines.

The items described below are some in which it is considered the Survey's work and enterprise have assisted in the development of this State over the past two decades.

HYDROGEOLOGY

One of the first items to receive attention during the 1961 reorganization was hydrogeology. This was essential for Western Australia, the driest State within the driest continent. Rotary-drilling methods and electric-well-logging-processes were established by the Survey for water exploration, and in 1963 it was fortunate in attracting Mr E. P. O'Driscoll, one of Australia's leading hydrogeologists, to take charge of the Survey's Hydrogeology Division.

This Division was recognized by the Metropolitan Water Board and the Department of Public Works as their official source of geological advice and services in respect of groundwater exploration.

In 1962 the Survey, on its own initiative, drilled near Lake Gnangara, and this led eventually to the identification of the Gnangara Mound of groundwater, which now provides large supplies for Perth. Later the Jandakot Mound was located and developed. Groundwater from both deep and shallow aquifers now can supply at least 40% of the requirements of the Metropolitan area. This has been of immense value during the current four-year drought period.

All the coastal towns of the Pilbara area are drawing their supplies from sources of groundwater discovered and delineated by the Survey. Further potential supplies have been located along the Robe and Fortescue Rivers and in the West Canning Basin, and are available for future development in the Pilbara.

In the Perth Basin supplies have been proven at Allanooka (for Geraldton), Arrowsmith River (for Morawa), Agaton, Eneabba, Gingin and in the Bunbury-Busselton-Donnybrook areas.

During the drought of 1969 and 1970 in the wheatbelt the Survey helped with the crash programme of investigation and drilling for water in areas where the chances of success were very poor. This involved drilling 2 639 holes with an aggregate depth of 67 294 metres. The success rate was one hole in 10, locating poor-quality stock water or better.

The recent drought and water restrictions in the Metropolitan area resulted in the Survey being inundated with enquiries for advice on the water potential of Metropolitan lots. In 1978 advice was given on more than 4 000 enquiries.

REGIONAL GEOLOGY

In 1960 there was a lack of comprehensive regional geological maps to assist exploration. It was decided to map the whole State at the International scale of 1:250 000, a mammoth task involving some 163 map sheets with explanatory notes. The Bureau of Mineral Resources assisted by providing staff for joint field parties and earlier by printing all of the maps.

By the end of 1979 all the field work for this project was completed. A number of sheets still remain to be compiled, and these should be completed during 1980, while drafting will probably take another two years. Some 103 map sheets with explanatory notes have been published, while 60 sheets are in progress between compilation and printing.

Some sheets have already been remapped and there are many others waiting to be done.

GEOCHRONOLOGY

The rapid progress of Precambrian mapping during the sixties, particularly in the Pilbara and Hamersley Range, highlighted the need for age determination of rocks. Liaison was established in 1961 with Dr W. Compston, of the Australian National University, and he was encouraged by the Survey to continue work on Western Australian rocks. Later, in 1968, a suitable laboratory was established at the Western Australian Institute of Technology under Dr J. R. de Laeter, and arrangements were made for the Survey to co-operate in its geochronological studies. Through these two laboratories the Survey has played a significant part in establishing a firm time framework for the Precambrian rocks of this State. The published results have been of immense value for the work of the Survey.

EVALUATION SECTIONS

Originally it was not necessary to report results of exploration work to the Government, so that much valuable information was lost. It was often necessary for a person exploring an area to repeat work previously done. In 1968 the Department of Mines, at the instigation of the Survey, regulated under the Mining Act that all results of work on tenements should be reported on an annual basis. This had also been made a requirement under the Petroleum Act (1967) and the Petroleum (Submerged Lands) Act (1967).

The new data requirements coincided with the mineral boom of 1968–72, which resulted in the Survey being inundated with information and results of exploration.

The Survey established sections in the Mineral Resources and Sedimentary Geology Divisions to handle this information and to make it available to the public as permitted under the various acts.

This exercise has taken some considerable time to develop methods, procedures, indexes, etc. It was found that the only way to make such a mass of material readily available for the public was to photograph it all on 35 mm film. At the end of 1979, 213 rolls of such film had been made, with 500 frames on each roll. Many frames include two pages of reports and the others maps.

Evaluation sections also review the activity on each tenement to ensure that the programme of work is being done in accordance with the condition of granting. Also from these results Survey geologists can assess the mineral potential of a particular area or a particular mineral.

FILM LIBRARY

A film library has been established for the use of the public and staff, with 35 mm and 16 mm reader-printers available. These are used to consult roll film or microfiche of exploration reports and Survey publications.

This film library is in constant use by the public and was the first to be established in Australia by a Geological Survey. The results indicate that with the volume of reports being produced it will become more and more necessary to use film instead of hard copy.

URBAN GEOLOGY

In association with the creation of the environmental geology section, the production of urban geology map sheets at the scale of 1:50 000 was commenced. These sheets cover areas around development centres in the State to provide the extractive industry, town planners, engineers, etc. with information of a geological nature to assist development. Eight of these coloured maps have been published and seven more are proceeding towards that end.

REGIONAL OFFICES

Due to the mineral booms, regional mapping, and other activities, it was not until 1979 that a regional office was established. It is at Kalgoorlie, associated with the W.A. School of Mines. The purpose is to provide geological assistance to the mining industry in the field and also to establish, from the regional centre, a convenient base for detailed local studies.

PUBLICATIONS

There has been an expansion in the types of publications issued by the Survey. The new series of 1:250 000 geological maps with explanatory notes provides an outlet for a huge amount of geological information gathered in the field. Individual sets of notes range from 20 to 40 printed pages.

The Geological Bulletin and Mineral Resources Bulletin series were continued, and in these were published the results of many long and detailed studies, such as the Perth Basin, iron formations of the Precambrian Hamersley Group, the Blackstone region, and many others.

The Annual Report series was continued, but due to size problems could include only a selection of short reports prepared during each year.

A Report series has been commenced to include reports that are too long for the Annual Report, but are not of sufficient length for the Bulletin series, and also to save expense and time by using the offset printing method.

For small reports and those which require quick release a Record series was commenced. This is now considered as a publication because it is freely available to the public in microfiche form.

Probably the most ambitious publication attempted was Memoir 2, "The Geology of Western Australia". Unfortunately it was being prepared when the Survey suffered many staff resignations, which caused delays and other problems. The final text, which included sections by numerous authors within the Survey, was published in 1975.

Numerous other pamphlets and maps were published. The total publications issued during the two decades were:

Memoirs	1
Geological Bulletins	12
Mineral Resources Bulletins	5
Annual Reports	21
Reports	9
Records	445
Information Pamphlets	13
Maps: International scale—	
1:2 500 000	3
1:1 000 000	2
1:250 000 (with explanatory notes)	103
1:50 000	20

There were also about 130 papers published in outside journals.

In press there are three bulletins and a number of other publications, particularly maps.

CONCLUSION

The Survey has been through two waves of development during the period 1960 to 1979. The first was the enlargement of the Survey in the early 1960s and the recruitment and training of staff, so that an efficient organization had been established by the latter part of the decade. This situation was somewhat shattered by the mineral boom, when there was more than a 50% turnover of the professional staff between 1969 and 1971.

From 1972 onwards professional staff were more readily available, allowing for a second wave of development. It was necessary to recruit and train another group of geologists, who became highly productive in the latter part of the seventies.

Once again in 1979 a mineral boom commenced and staff began leaving to seek alternative employment in private enterprise. The Survey is a training ground for young geologists and is of such a size that all persons cannot be promoted to the higher levels justified by their ability and experience. Consequently a high staff turnover during periods of expanding exploration activity is to be expected.

Any achievements of the past two decades have resulted from the attracting and training of good professional staff from varying backgrounds. The Survey owes a debt of gratitude to many of these geologists who have contributed to its development in recent times.

With a third wave of development about to commence in the eighties, it is an opportune time for a change of leadership. The present operation of the Survey should be reviewed as there are probably areas where reconstruction and alteration of emphasis could be effected, remembering always that the Survey is required to serve the State and the people.

THE GEOLOGY AND HYDROGEOLOGY OF THE PICTON BOREHOLE LINE

by P. H. Wharton

ABSTRACT

The Picton Line of bores comprises seven bores at four sites drilled on an east-west line across the onshore Perth Basin, from Bunbury to south of Burekup. They were drilled to a maximum depth of 1 200 m (Picton Line 1) and had an aggregate depth of 4 069 m.

The drilling showed that the Leederville Formation (Early Cretaceous) fills an asymmetric syncline which is thought to have resulted from the compaction of Phanerozoic sediments over basement fault blocks. The Leederville Formation unconformably overlies an easterly dipping sequence of non-marine fluviatile sediments of the Yarragadee Formation (Late Jurassic) and Cockleshell Gully Formation (Early Jurassic).

Major groundwater flow systems are recognized in the Leederville Formation, and in the Yarragadee and Cockleshell Gully Formations. Both flow systems contain groundwater with a salinity generally less than 500 mg/L TDS, which extends to a depth of between 500 and 700 m below sea level. Below that depth the groundwater is saline, and there is almost no groundwater movement.

Large potable groundwater resources are available across the coastal plain, but principally in the central and western parts.

INTRODUCTION

The Picton Line consists of seven bores drilled at four sites on an east-west line across the coastal plain from Bunbury to south of Burekup (Fig. 1).

The bores were drilled as part of a long-term drilling programme to evaluate the deep groundwater resources of the Perth Basin. The nearest lines of deep bores are at Mandurah, approximately 100 km to the north (Commander, 1974), and the Quindalup Line, 32 km south (Probert, 1968). Bores drilled for the Bunbury Shallow Project (Commander, 1975, in prep.) in the vicinity of the Picton Line provided additional data for this report.

A more detailed account of the drilling procedures, geology and hydrogeology of the Picton Line is given by Wharton (in press).

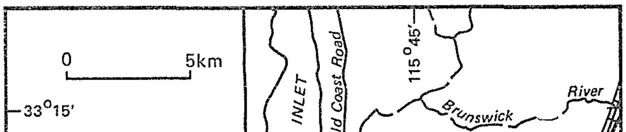


Figure 1 Locality map, Picton Line.

PHYSIOGRAPHY

The Picton Line bores are situated on the Swan Coastal Plain (Saint-Smith, 1912), a low-lying, gently undulating area formed by coastal-dune and shoreline deposits. These sediments extend from the coast to the Whicher Scarp (Fig. 1), a late Tertiary or Pleistocene shoreline (Playford and others, 1976). The coastal plain has been divided into three physiographic units by Low (1972): the Pinjarra Plain, consisting of an alluvial plain formed by fine-grained alluvial and piedmont deposits; the Bassendean Dunes, of decalcified quartz sand; and the Coastal Belt, a band of fixed calcified dunes, with modern dunes along the coast.

INVESTIGATION PROGRAMME

A summary of drilling and bore information is given in Table 1.

The bores were drilled using a Franks Explorer Rocket (Picton Line 1, PL1) and a Midway Skytop (PL2 to PL4), both mud-flush rotary rigs. Two bores were drilled at each of sites 2 to 4: a deep bore, designated "A", was constructed to monitor two aquifer intervals separated by a compressible packer, and a second bore, designated "B", monitors a shallow aquifer. At site 1 only a deep bore was drilled, as Bunbury Shallow bores BS1B and BS1C, drilled for another project to depths of 84 m and 19 m respectively, are located about 30 m to the east. In PL1 compressible packers were used to isolate each of six intervals, to permit individual development, testing and sampling.

Sludge samples were collected at 3 m intervals from the deep bore at each site. On completion of drilling, gamma-ray and long- and short-normal resistivity logs were run on each bore, and other logs were obtained as required. Sidewall cores were recovered from shales or siltstones at about 30 m intervals in each deep bore.

All bores, except PL2B and PL4B, were completed with 155 mm casing to below the bottom aquifer interval to be tested, and the selected intervals were perforated with shaped explosive bullets. In PL2B and PL4B the test interval was screened with a 0·05 inch aperture 100 NB stainless-steel continuous-slot screen.

Each interval was developed by airlifting and surging until the water cleared and the salinity was constant, thus indicating that the sample was uncontaminated and suitable for analysis. Water samples taken after development were analysed by the Government Chemical Laboratories.

GEOLOGY

SETTING

The Picton Line of bores was drilled in the northern part of the Bunbury Trough, a structural subdivision of the Perth Basin (Playford and others, 1976). The Bunbury Trough is a deep graben, bounded to the east by the Darling Fault and to the west by the Busselton Fault. It probably contains at least 10 000 m of Phanerozoic sediments.

STRATIGRAPHY

Sediments encountered by the Picton Line bores range in age from Holocene to Early Jurassic. The formations recognized are given in Table 2, and are described below.

Subdivision of Mesozoic sediments

The Mesozoic sediments intersected by the Picton Line bores cannot be as readily subdivided into formations as they can in the northern Perth Basin. The upper part of the Yarragadee Formation in PL4A, where a younger section of the Yarragadee Formation is preserved, is lithologically indistinguishable from the overlying Leederville Formation. Similarly, in PL1 and PL2A, the Yarragadee Formation closely resembles the Cockleshell Gully Formation. Consequently, subdivision of the sediments into formations has been made primarily on biostratigraphic and geophysical evidence, rather than on lithology.

Jurassic

Cockleshell Gully Formation: The Cockleshell Gully Formation was encountered in bores PL1, PL2A, and PL3A, and extends beneath all the coastal plain. It consists of fine-sand to granule grade, mostly moderately sorted, angular to subrounded, weakly consolidated quartz sandstone, with accessory garnet and pyrite. The sandstone is interbedded with subordinate grey silty shale and carbonaceous shale in beds up to 12 m thick, which contain thin beds of soft lignite.

TABLE 1. SUMMARY OF BORE DATA

Bore	Latitude S	Longitude E	Drilling		Elevation (m) AHD		Total Depth (m)	Tested Interval (m bns)	Head (m) AHD Jan 1979	Salinity TDS by evap. (mg/L)	Aquifer (Formation)	Status
			Commenced	Completed	Surface	Casing top						
PL1	33°20′44″	115°41′36″	2/5/74	26/5/74	7·570	8·37	1 200	1 070–1 108	—21·77*	51 700	Cockleshell Gully	Abd
								829–837	—4·52*	14 800	Cockleshell Gully	Abd
								666–674	5·40	910	Cockleshell Gully	Obs
								599–607	6·59*	520	Cockleshell Gully	Abd
								414–422	6·97*	340	Yarragadee	Abd
								205–213	12·53	490	Leederville	Obs (flowing)
PL2A	33°22′07″	115°38′42″	3/1/78	7/3/78	5·82	6·682	772	576–586	4·78	460	Cockleshell Gully	Obs
								410–420	4·02	260	Cockleshell Gully	Obs
PL2B	33°22′07″	115°38′42″	8/3/78	15/3/78	5·81	6·662	207	192–201	3·37	310	Yarragadee	Obs
PL3A	33°20′55″	115°45′08″	22/3/78	20/4/78	18·07	18·941	794	440–446	7·55	360	Yarragadee	Obs
								308–314	8·01	370	Yarragadee	Obs
PL3B	33°20′55″	115°45′08″	19/5/78	26/5/78	18·10	18·674	228	126–132	16·45	300	Leederville	Obs
PL4A	33°20′59″	115°48′30″	18/6/78	15/8/78	44·03	44·855	823	699–705	....	360	Yarragadee	Abd
								669–675	7·82	720	Yarragadee	Obs
								564–570	8·25	410	Yarragadee	Obs
PL4B	33°20′59″	115°48′30″	13/7/78	14/7/78	43·93	44·840	45	38·5–44·5	24·51	490	Leederville	Obs

* Previous measurement, water level could not be re-measured.
bns—Below natural surface.
Abd—Abandoned test interval
Obs—Observation bore

TABLE 2. STRATIGRAPHIC SUCCESSION ENCOUNTERED IN THE PICTON LINE BORES

Age	Group/Formation	Thickness (m)				Summary lithology	Remarks
		PL1	PL2	PL3	PL4		
Quaternary	Kwinana Gp	19	15	18	7	Sand and clay	Minor local aquifer
	Leederville Fm	261	....	244	?96	Sand, siltstone and shale	Multilayered aquifer
Early Cretaceous	Bunbury Basalt	....	....	....	....	Basalt	Aquiclude. Present between PL2 and PL1
Late Jurassic	Yarragadee Fm	?286	?187	471	>720	Sandstone, minor shale	Major aquifer
Middle to Early Jurassic	Cockleshell Gully Fm	>634	>570	>61	....	Sandstone and shale	Multilayered aquifer

Sidewall cores from PL1 and PL2A yielded palynomorph assemblages of a general Early Jurassic age. However, a sidewall core from a silty shale at the base of PL3A contained spores and pollen including *Lecaniella foveolatus*, previously only recorded from the Cadda Formation (Backhouse, 1978a). This indicates a mid-Jurassic age (Early to Middle Bajocian), the shale probably representing the uppermost part of the Cockleshell Gully Formation at this locality. The palynology of samples from the Cockleshell Gully Formation intersected in the Picton Line drilling is consistent with a nonmarine environment of deposition.

The Cockleshell Gully formation is about 2 000 m thick (Playford and others, 1976), of which a maximum thickness of about 635 m was intersected in PL1. The formation is conformably overlain by the Yarragadee Formation.

Yarragadee Formation: The Yarragadee Formation is composed of weakly consolidated, predominantly very coarse-grained sandstone, with minor shale beds. Although it is very similar lithologically to the Cockleshell Gully Formation at PL1 and PL2, the Yarragadee Formation varies from a clean sandstone with almost no shale at the base (PL2) upward to a very shaly section (PL4). The abundance of fine-grained sediments may indicate a low-energy environment towards the end of the Yarragadee Formation sedimentation.

The quantity of lignite and carbonaceous material in the formation increases from west to east. No lignite or carbonaceous material was recorded from the Yarragadee Formation in PL2. In PL1 carbonaceous material was common below a depth of 445 m, while in PL3A and PL4A bands of soft to moderately hard lignite were encountered; in PL4A the short-normal resistivity log indicated lignite at depths of 358·5 to 360 m, 400 to 402 m and 458 to 460·5 m, but geophysical logging in PL3 failed to give a similar indication.

The Yarragadee Formation extends beneath all the coastal plain, and ranges in thickness from ?187 m (PL2) to greater than 720 m (PL4). It is unconformably overlain by the Leederville Formation from PL1 eastwards, by the Bunbury Basalt between PL1 and PL2, and by the Kwinana Group from PL2 westwards (Fig. 2). The palynology of samples from the formation indicates a nonmarine environment of deposition.

Cretaceous

Bunbury Basalt: The Bunbury Basalt was not intersected by any of the Picton Line bores, but is known to occur between PL2 and PL1, where Bunbury Shallow bore BS4A intersected basalt from a depth of 30 to 49 m. The basalt varies from fresh with columnar jointing, to very deeply weathered, and is represented by clay where it has been completely weathered.

Leederville Formation: Sediments of the Leederville Formation were intersected at sites 1, 3 and 4, and consist of sand (or weakly consolidated sandstone), clayey sand, silt, and shale, with common to abundant thin layers of soft lignite and carbonaceous material. The sand is mainly coarse to very coarse grained and it may contain granules. Shales are commonly micaceous and carbonaceous. Accessory minerals include mica and pyrite.

Sludge samples from the 60 to 66 m depth interval in PL3A consist of 50% moderately hard lignite flakes and 50% calcareous shale. A conventional core was run from 58 to 67 m depth in PL3B to determine the characteristics of the lignite. There was no recovery, and sidewall cores and accurate geophysical logs could not be obtained because of washouts. However, from the platy nature of the lignite fragments it is likely that the lignite forms thin lenses of local extent.

Sidewall core samples from the Leederville Formation had unusually sparse assemblages of spores and pollen (Backhouse, 1978b). The palynomorphs indicate a general Late Neocomian to Aptian age, and a nonmarine environment of deposition.

Quaternary

Kwinana Group: Two formations of the Kwinana Group were intersected in the Picton Line drilling; the Guildford Formation (PL1, PL3 and PL4) and the Bassendean Sand (PL2).

The Guildford Formation consists of light-brown clay and clayey sand, commonly ferruginized. The sand is mostly fine to very coarse-grained and poorly sorted, although some

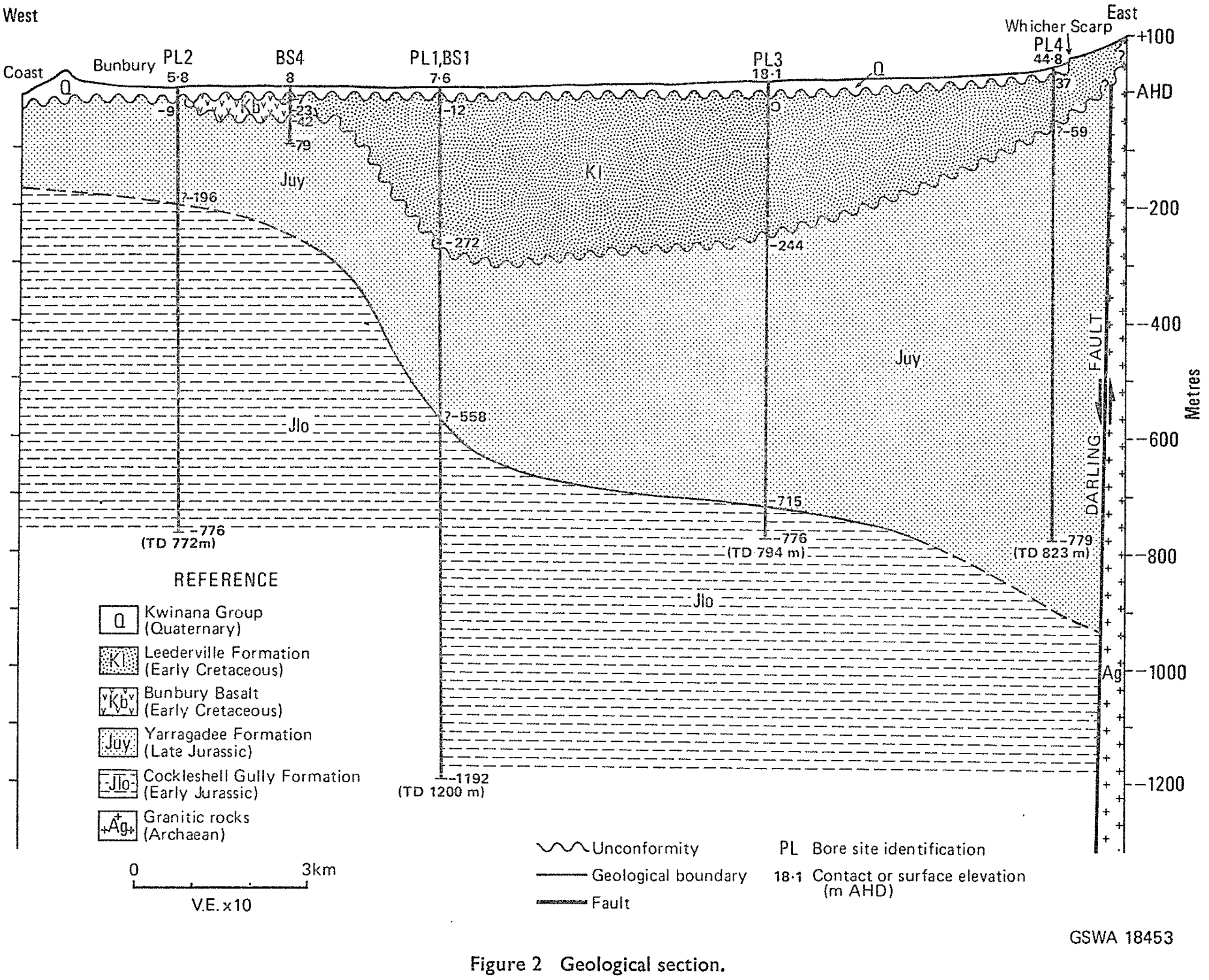


Figure 2 Geological section.

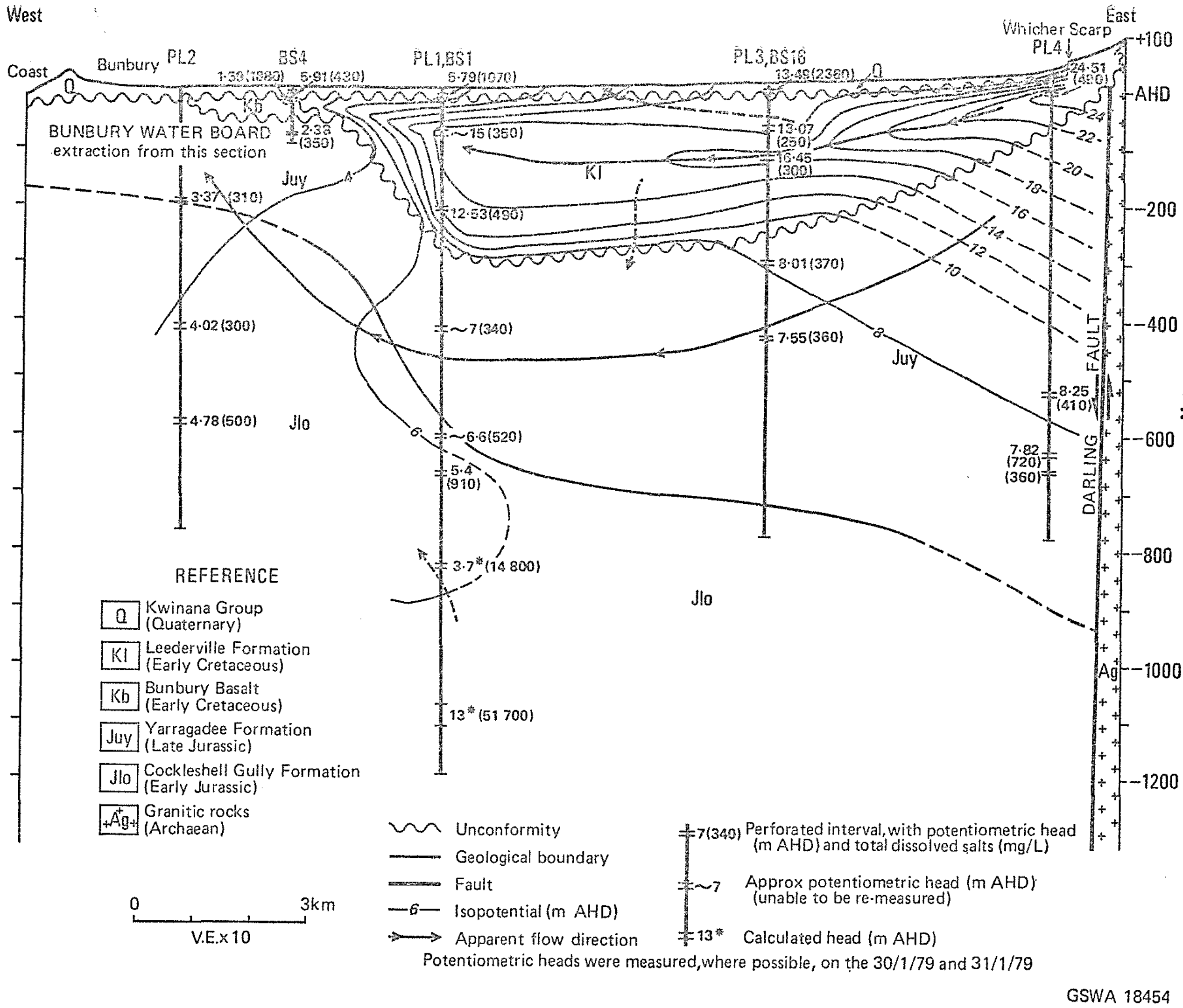


Figure 3 Section showing apparent flow systems.

well-sorted very coarse-grained sand was encountered in PL3. Sand grains are often iron stained. Heavy minerals were common in the Guildford Formation at PL1.

The Bassendean Sand intersected at PL2 is medium to coarse grained, poorly sorted, angular to subrounded, with some iron staining of the quartz grains.

STRUCTURE

The inferred geological structure in the section through the Picton Line bores is shown in Figure 2.

The Cockleshell Gully and Yarragadee Formations dip gently eastwards with an average dip of about 3°. The Yarragadee Formation is locally unconformably overlain by the Bunbury Basalt, and regionally by the Leederville Formation.

The Leederville Formation occupies an asymmetric synclinal depression which is presumed to be either a fault angle depression, resulting from vertical movements on a fault between PL1 and PL2, or a downwarp resulting from the differential compaction of sediments over faulted Precambrian basement. The latter explanation is preferred as it more readily explains the shape of the unconformity at the base of the Leederville Formation west of PL1, and because Cope (1972) has claimed that differential compaction may have controlled deposition of all the Cretaceous sediments in the onshore Perth Basin.

HYDROGEOLOGY

AQUIFER RELATIONSHIPS

A section showing the apparent direction of groundwater flow in the Leederville Formation and the Yarragadee and Cockleshell Gully Formations is given in Figure 3. The two flow systems are separated by shale beds within the Leederville Formation, and by the impermeable Bunbury Basalt.

In the Leederville Formation the section shows an apparent east-to-west component of groundwater flow with possible minor recharge from the Kwinana Group west of PL1, minor leakage into the underlying Yarragadee Formation, and upward discharge into the Kwinana Group east of PL1.

The groundwater flow in the Yarragadee and Cockleshell Gully Formations flow system also has an east-west component, with discharge via the Kwinana Group to the sea in the vicinity of Bunbury. Water-level measurements made by the Public Works Department (Boyd, 1979) indicate that abstraction from the Yarragadee Formation may seasonally reverse the hydraulic gradient, inducing some recharge to the Yarragadee Formation from the Kwinana Group.

Groundwater movement at depth in the Cockleshell Gully Formation is probably negligible, as shown by the presence of highly saline groundwater, and the high vertical hydraulic gradient in PL1 (Fig. 3).

KWINANA GROUP

The Kwinana Group is 10 to 20 m thick, and consists of sand and limestone with some clay in the Coastal Belt and Bassendean Dunes, and clay with minor sand beneath the Pinjarra Plain. These sediments form an unconfined aquifer in which the groundwater is derived from the direct infiltration of rainwater, and west of PL1, by upward leakage from the Leederville Formation. Groundwater movement is to the west, with discharge to the Collie, Ferguson and Preston Rivers, and along the coast. Large evapotranspiration losses are presumed to occur, especially from the Pinjarra Plain where the water table is close to the surface, with the result that extensive areas have brackish groundwater.

The Kwinana Group sediments are unimportant as a major groundwater source because of the extensive area underlain by clayey sediments (Pinjarra Plain). Supplies of fresh groundwater are sometimes obtained from the Bassendean Dunes, and are usually available from the sand and limestone of the Coastal Belt. Groundwater from the Kwinana Group is used for some small farm supplies, and for garden reticulation along the Coastal Belt.

LEEDERVILLE FORMATION

The Leederville Formation is a multi-layered aquifer system, consisting of sand, clayey sand, silt, and shale, with the proportion of sand, or clayey sand, to shale decreasing from about 80% at PL1 to less than 50% at PL4. The formation ranges in thickness from 260 m at PL1 to approximately 95 m at PL4.

Groundwater in the formation is confined by shale beds, and local artesian flows may be encountered, as in PL1.

Groundwater movement is from the southeast (Commander, in prep.), where much of the recharge probably originates from the infiltration of rainfall on the Blackwood Plateau. There may be minor recharge from the overlying Kwinana Group west of PL1.

Vertical isopotentials (Fig. 3) indicate an east to west component of groundwater flow along the Picton Line section, and a low vertical permeability, resulting from sand/shale stratification.

Discharge from the Leederville Formation is presumed to occur from the upper part of the flow system via the Kwinana Group to the sea in the vicinity of the Leschenault Inlet, and by downward leakage from the lower part of the flow system into the underlying Yarragadee Formation, except in areas where the Bunbury Basalt is present.

All water samples taken from the Leederville Formation had a salinity of less than 500 mg/L TDS (Fig. 4), apart from one, of 1 880 mg/L, from Bunbury Shallow bore BS4C, which was possibly a result of local brackish groundwater recharge from the Kwinana Group.

Ferrous iron in sufficient concentrations to cause staining occurs in groundwater from the Leederville Formation, and it is likely that groundwater would require treatment for iron before being used for domestic, industrial or public water-supply purposes. One sample, from PL4B, had the very high iron concentration of 38 mg/L.

The extent of the formation, the high proportion of sand, and the low salinity of the groundwater in it, make the Leederville Formation an important aquifer system. The formation has been utilized for farm and some industrial supplies, but is still virtually undeveloped.

YARRAGADEE FORMATION

The Yarragadee Formation consists of weakly consolidated, mostly very coarse-grained sandstone, with minor shale beds. Shale becomes more common towards the east, notably in the upper part of the formation (PL4).

Head measurements indicate that the Yarragadee and Cockleshell Gully Formations form a single flow system (Fig. 3). The east-to-west component of groundwater flow along the Picton Line results from recharge in the south or southeast, with discharge via the Kwinana Group to the sea near Bunbury.

The salinity of groundwater in the Yarragadee Formation, where intersected by the Picton Line bores, ranges from 300 to 8 000 mg/L TDS (Fig. 4). The groundwater is fresh in the upper part of the flow system (above -500 to -700 m AHD), with the salinity generally less than 500 mg/L TDS. Groundwater in the lower part of the flow system is brackish to saline. Brackish groundwater at shallow depths near the coast at Bunbury may be associated with a salt-water interface which has moved inland as a result of overpumping (Commander, 1975).

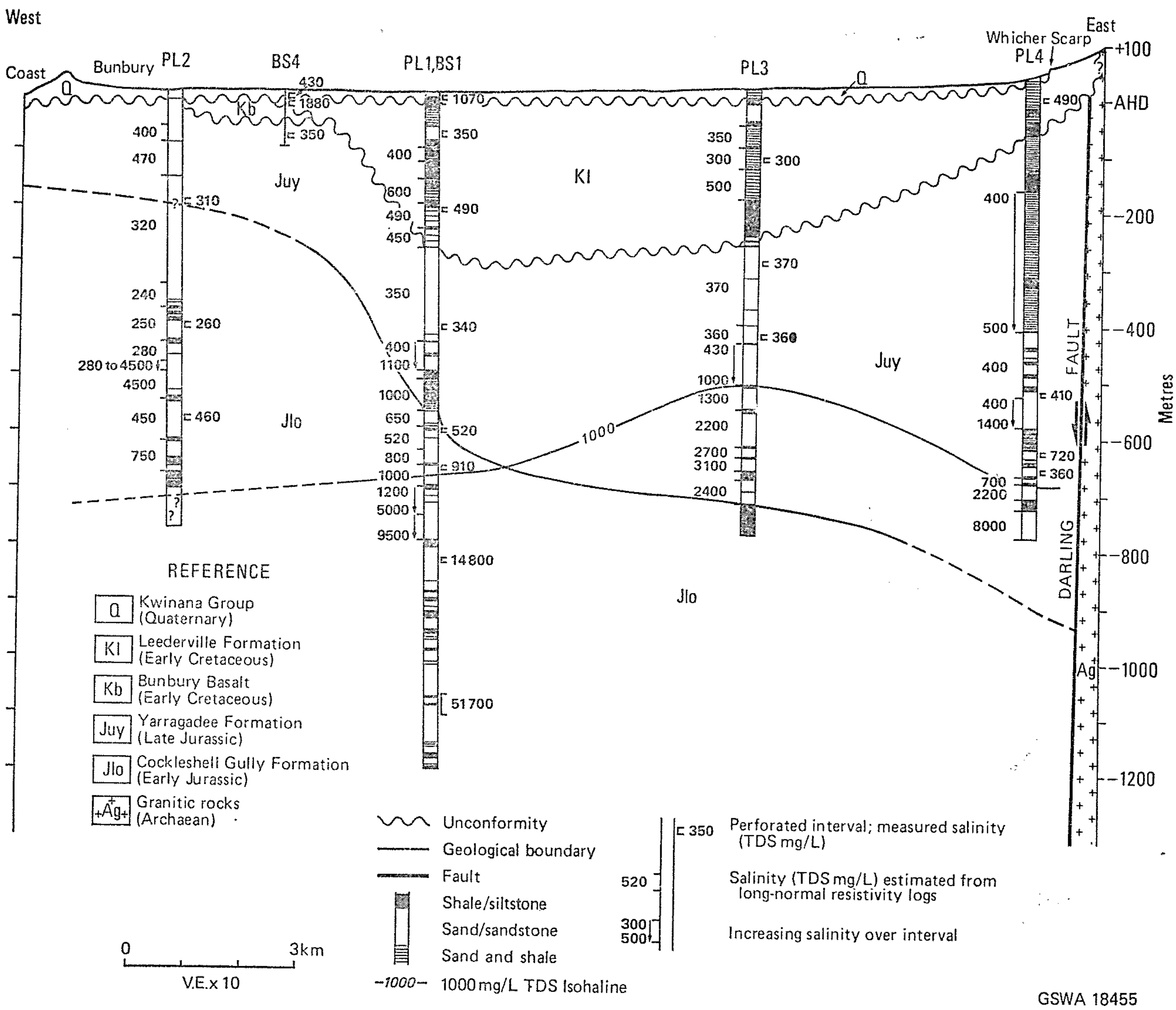


Figure 4 Variation in groundwater salinity.

Five samples of groundwater from the formation were analysed for iron, from bores PL2B, PL1 and PL4A, and ranged from 0·46 (PL4A) to 49 (PL2B) mg/L. Water from the Yarragadee Formation used for the Bunbury water supply also has a high iron content and requires treatment before use.

High manganese concentrations occur in the Bunbury Water Board Withers Bore (Commander, 1975), and may be present in other groundwater from the formation; however, samples analysed from the Picton Line bores had manganese concentrations of less than 0·5 mg/L.

Groundwater in the Yarragadee Formation is being exploited for town water supplies at Bunbury and Eaton, industrial usage at Australind and Bunbury, and the irrigation of parks and reserves in Bunbury. Commander (1975) estimates an average abstraction from the formation of about 30 000 m^3/day (11 x $10^6 m^3$/year).

The substantial thickness of sand containing fresh water, and its extent, make the Yarragadee Formation the most important aquifer in the region. It is capable of considerable further exploitation outside the area of influence of Bunbury water supply bores.

COCKLESHELL GULLY FORMATION

The Cockleshell Gully Formation is composed of weakly consolidated sandstone interbedded with some beds of silty shale and shale up to 12 m thick.

Groundwater in the Yarragadee Formation and the top of the Cockleshell Gully Formation forms a single flow system from PL4 westwards. Recharge to the Cockleshell Gully Formation takes place from the overlying Yarragadee Formation where head differentials are downward, and groundwater movement is not restricted by confining beds (Fig. 3). There is probably little groundwater movement in the formation east of PL1 and below a depth of about –700 m (AHD), where the formation contains saline to hypersaline groundwater. Discharge from the Cockleshell Gully Formation takes place west of PL1 where there are few shales and an upward head gradient (Fig. 3).

The measured heads of the two lower (saline) perforated intervals in PL1 were below sea level. Water from the interval 829 to 837 m had a salinity of 14 800 mg/L TDS and a head of –4·5 m AHD, and the 1 070 to 1 108 m interval had a salinity of 51 700 mg/L TDS and a head of –21·8 m AHD. To compare these heads with those of the fresh-water intervals, the environmental-water heads (vertical heads) were calculated using formulae given by Luscyzynski (1961). The calculation of environmental-water head corrects for the density distribution resulting from salinity variations, and allows the definition of the vertical hydraulic gradient. The environmental-water heads computed were 3·7 m AHD for the 829 to 837 m interval and 13 m AHD for the 1 070 to 1 108 m interval. These heads indicate a high hydraulic gradient and a very low vertical permeability of the confining beds.

The hypersaline groundwater in the Cockleshell Gully Formation at PL1 may have originated as connate water, with a concentration of salts by reverse osmosis (ultra-filtration). The main confining beds are probably the shales at depths of 797 to 808 m and 924 to 935 m.

The Cockleshell Gully Formation contains groundwater with salinities ranging from about 200 mg/L TDS to greater than 50 000 mg/L TDS. Groundwater with a salinity of less than 1 000 mg/L TDS occurs to a depth of about –700 m AHD in the Cockleshell Gully Formation, apart from a layer of more saline water (4 500 mg/L TDS) intersected in PL2A from 495 to 545 m (Fig. 4). Fresh water extends to a similar depth in the overlying Yarragadee Formation east of PL1. Below about –700 m AHD the Cockleshell Gully Formation contains water with salinities greater than 1 000 mg/L TDS.

This aquifer is undeveloped, but has the potential to provide large supplies of low-salinity groundwater in the western part of the basin.

GROUNDWATER TEMPERATURE

Differential temperature logs were run to the top of the packers in the deep bore at each site. The logs were run six months after the drilling had been completed to ensure that the groundwater temperature in the bores had readjusted to the ambient geothermal gradients. Temperature gradients range from 2·7 to 4·1°C/100 m to a depth of 250 to 420 m below surface, and about 1·7 to 1·8°C/100 m at greater depths. The high gradients were generally associated with shales of low thermal conductivity.

CONCLUSIONS

Drilling of the Picton Line bores has provided new geological and hydrogeological information on a section across the Perth Basin in the vicinity of Bunbury.

Sediments of the Cockleshell Gully and Yarragadee Formations dip gently to the east and are unconformably overlain by the Leederville Formation. The Leederville Formation occupies an asymmetric syncline, believed to have developed as a result of differential compaction of the Phanerozoic sediments over a faulted basement.

Two major groundwater flow systems are recognized, one in the Leederville Formation, and the other in the Yarragadee and Cockleshell Gully Formations. The Leederville Formation flow system occurs in a multi-layered aquifer up to 280 m thick. It is mainly confined and contains groundwater with a salinity generally less than 500 mg/L TDS. The flow system of the Yarragadee and Cockleshell Gully Formations is considerably larger. Groundwater with salinities mostly less than 500 mg/L TDS extends to a depth of about –700 m AHD. Below this depth the groundwater is saline and groundwater movement is probably negligible.

The two flow systems constitute a very large groundwater resource which is capable of substantial further development.

REFERENCES

Backhouse, J., 1978a, Palynology of Picton No. 3A bore hole: West. Australia Geol. Survey Palaeont. Rept No. 21/1979 (unpublished).

——— 1978b, Palynology of Picton Junction No. 3B borehole: West. Australia Geol. Survey Palaeont. Rept No. 28/1978 (unpublished).

Boyd, D. W., 1979, Bunbury groundwater management review: Public Works Dept, Water Resources Technical Rept No. 85.

Commander, D. P., 1974, Hydrogeology of the Mandurah-Pinjarra area: West. Australia Geol. Survey Ann. Rept 1973, p. 20–25.

——— 1975, Bunbury groundwater investigation—preliminary report to December, 1975: West. Australia Geol. Survey Hydro. Rept No. 1354 (unpublished).

——— 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.

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).

Luscyzynski, N. J., 1961, Head and flow of groundwater of variable density: Jour. Geophys. Research, v. 66, no. 12, p. 4247–4256.

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., 1968, Groundwater in the Busselton area, progress report on exploratory drilling: West. Australia Geol. Survey Ann. Rept 1967, p. 12–17.

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., in press, The geology and hydrogeology of the Picton Line of bores, Perth Basin: West. Australia Geol. Survey Rec.

GEOLOGY AND HYDROGEOLOGY OF THE ALLANOOKA AREA (GERALDTON WATER SUPPLY), NORTHERN PERTH BASIN, WESTERN AUSTRALIA

by A. D. Allen

ABSTRACT

The Allanooka area is about 50 km southeast of Geraldton, in the northern part of the Perth Basin. It is underlain by Permian to Quaternary sedimentary rocks overlying Precambrian cyrstalline basement. The Permian to Cretaceous sediments are of marine and nonmarine origin, and range in thickness from 60 m in the north to 4 000 m in the extreme southeast. They dip gently to the southeast and have been dislocated by faulting into a series of rectangular fault blocks. The Tertiary to Quaternary sediments occur in a belt about 15 km wide along the coast. They are up to 150 m thick and consist of a flat-lying sequence of eolian, littoral and alluvial deposits.

Major groundwater flow systems occur in the Kwinana Group (?Tertiary-Quaternary), Yarragadee Formation (Late Jurassic-Early Cretaceous), and Cockleshell Gully Formation (Early Jurassic). They contain mainly brackish groundwater with the exception of large resources of potable groundwater (less than 1 000 mg/L TDS) in the upper part of the flow system in the Yarragadee Formation. Small localized resources of potable water also occur in the Kwinana Group and Cockleshell Gully Formation.

The Yarragadee Formation consists of sandstone, siltstone and shale of fluviatile origin. It ranges in thickness from about 20 to 1 000 m. The sandstones, which comprise about 60% of the formation, form a multilayer aquifer in which there is a regional groundwater flow system. This is recharged by rainfall on the upland in the eastern part of the Allanooka area, and flows southwestward, to be discharged from springs at the margins of the upland, and by subsurface discharge into the Kwinana Group. Potable groundwater is restricted to the upland area, and is underlain and in lateral continuity with brackish groundwater. The potable groundwater extends to an average depth of 90 m below the water table, and has a mean salinity of 700 mg/L TDS. In an area of 1 550 km² there is estimated to be about 20 000 x 10⁶ m³ of potable groundwater in storage. From chlorinity data the average annual recharge is estimated to be about 3% of average annual rainfall (477 mm) or about 20 x 10⁶ m³/year.

INTRODUCTION

LOCATION

Geraldton is about 500 km north of Perth, adjacent to Champion Bay (Fig. 1). It has a population of about 18 000, and is the fourth largest town in Western Australia. The town is an important port serving rock-lobster fisheries, and inland agricultural and mining districts. It is also important for market-gardening, light industry and tourism.

The Allanooka area is about 50 km southeast of Geraldton. It is about 2 500 km² in extent and is bounded by the Greenough River in the north, the Irwin River in the south, the Kockatea Creek and the Irwin River in the east, and by the coast in the west (Fig. 1).

PURPOSE AND SCOPE

Most of Geraldton's water supply is obtained from the Allanooka Scheme based on a borefield situated near Lake Allanooka, about 50 km southeast of Geraldton. Some water is also supplied from a borefield at Wicherina (Fig. 1), from which all of Geraldton's water supply was obtained prior to 1967. Dongara and Port Denison, about 25 km southwest of Lake Allanooka, are also supplied from the Allanooka Scheme.

Abstraction from the Allanooka Scheme commenced in 1967 and has steadily increased to 6·7 x 10⁶ m³/year in 1977–1978. At present the scheme consists of 24 production bores

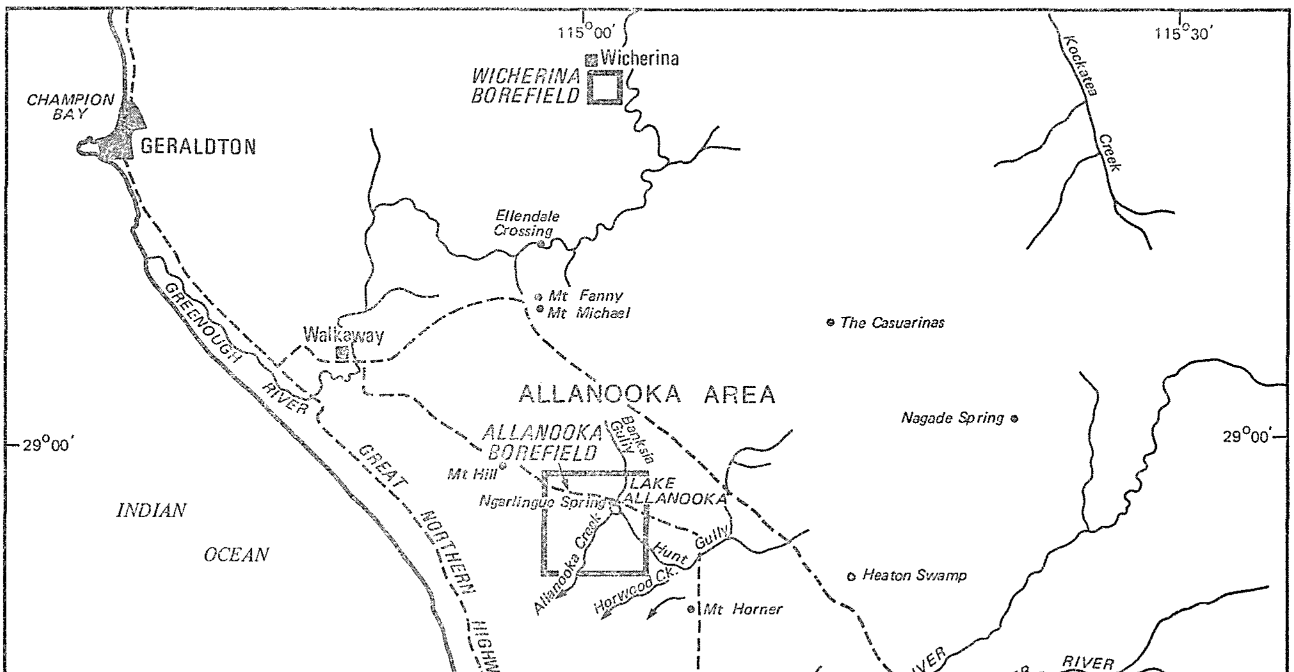


Figure 1 Locality plan.

TABLE 1. AVERAGE RAINFALL, EVAPORATION AND TEMPERATURE DATA FOR GERALDTON (COMMONWEALTH DEPARTMENT OF METEOROLOGY)

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total (year)
Rainfall (mm)	7	12	12	27	74	119	100	65	28	20	8	5	477
Potential evaporation (mm)	377	332	310	212	160	107	102	117	143	217	273	352	2 700
Mean max. (°C)	31·6	32·2	30·6	26·7	24·0	20·6	19·4	19·8	21·6	24·5	27·1	29·9	25·1
Mean min. (°C)	18·7	19·1	17·5	14·9	12·6	11·2	9·2	8·7	8·8	10·9	13·7	16·7	13·5

in an area of about 60 km² (Fig. 1). The first production bores were too close together and not located to best intercept throughflow. As a result local lowering of the water table by up to 12 m has occurred on the north side of Lake Allanooka. Production bores drilled since 1973, to the south of Lake Allanooka, are wider spaced, and observation bores have not detected any marked lowering of the water table.

The present abstraction exceeds the estimated local throughflow, and future demand is expected to continue to increase. The Public Works Department (PWD), therefore, carried out exploratory drilling and testing between 1974 and 1977 in order to plan an extension of the scheme. This paper summarizes the main results of this work.

CLIMATE AND LAND USE

The Allanooka area has a Mediterranean-type climate, with hot, dry summers and cool, wet winters.

The nearest available climatic data are for Geraldton (Table 1). These are expected to be similar to the coastal part of the Allanooka area, but inland, average rainfall and the mean minimum temperature are likely to be less, while potential evaporation and the mean maximum temperature are probably higher, than for Geraldton.

About 85% (413 mm) of the average annual rainfall (477 mm) falls during the winter months between April and September. The remainder falls during the summer, and is usually associated with local thunderstorms or the southward movement of a tropical cyclone. The annual rainfall shows wide variability between extremes of 220 mm and 843 mm, and sequences of years having low or high rainfall have occurred frequently. The potential evaporation is about 5·5 times the rainfall, and is only exceeded by rainfall in June or July.

The climate in the Allanooka area favours cereal growing. The arable land on the coastal plain has been cleared and developed for many years, but in the upland area large-scale clearing of the sandplain has only occurred during the last 15 to 20 years. Extensive areas of coastal dunes and limestone ridges remain uncleared on the coastal plain, and large tracts of low sclerophyll heath still remain in the upland sandplain.

PREVIOUS WORK

The first description of groundwater in the Allanooka area was by Maitland (1913) who discussed the groundwater encountered in deep bores drilled to explore for coal at Dongara and Yardarino. Later, a broad subdivision of the region into various groundwater provinces was made by Johnson and others (1954). They applied the name Irwin View groundwater province to the upland part of the Allanooka area and noted that the army had obtained water supplies in the area.

Prior to the construction of the Allanooka Scheme an extensive exploratory drilling programme was carried out by the Geological Survey Branch of the Mines Department (GSWA) and PWD, the results of which, together with a regional account of the hydrogeology, are given by Allen (1963, 1964, 1965). After the scheme had been in operation for 4 years, Forth (1971, 1972) made an assessment of the results of long-term pumping of the Allanooka Scheme, and noted a decline in the water table and possible hydraulic-barrier boundary effects caused by faults.

Later, after study of data from a bore census made by the GSWA, Forth (1973) recommended an exploratory drilling programme (Irwin View Project and Allanooka production bores) to extend information about the area to the southeast of the Allanooka borefield. Bores were drilled by the PWD, and the results were briefly examined by Davidson (1976) who recommended further drilling in the same general area (Irwin View Project).

Ventriss and Parsons (1978) made a brief study of the effects of abstraction from the Allanooka Scheme. They noted that water levels were continuing to fall in bores on the north side of Lake Allanooka but that there had been no apparent increase in groundwater salinity.

DRILLING PROGRAMMES

Data incorporated in this report are from the Allanooka Project (AP) drilled prior to the construction of the Allanooka Scheme; Allanooka production bores (A); the Irwin View Project (I); and the Dongara (D) and Mount Hill (MH) bores. General data for the bores are given in Table 2, except for the Allanooka Project bores for which reference should be made to Allen (1965).

Several of the drilling programmes have been carried out over a number of years. In these cases the bores are numbered in sequence followed by a suffix indicating the year (e.g. I1/73). Those bores which are designated by letters as well as numbers (Table 2) refer to sites recommended by Forth (1971, 1973) and Davidson (1976).

DRILLING, BORE CONSTRUCTION AND TESTING

The exploratory bores and production bores drilled prior to 1973 were drilled by cable-tool methods. Subsequently production and exploratory bores have been drilled using a PWD-owned and operated Walker-Neer mud-flush rotary rig, with the exception of D1–2/75 which were drilled with a rotary rig by a private contractor. Drilling conditions were found to give no problems for either cable-tool or rotary drilling techniques.

A variety of bore sizes and types of construction have been used. Production bores have been constructed using 260 mm casing, while the exploratory bores have 189 or 143 mm OD casing. Some bores prior to 1973 were constructed with gravel-packed slotted casing but subsequently all bores have had single or multiple, in-line, v-section wire-wound screens. Mild-steel screens were used in the exploratory bores, and stainless-steel screens in the production bores.

Sludge samples were collected during drilling at 3-m intervals for all bores. These have been geologically logged, and small samples are stored in the GSWA core library. Gamma ray, and long- and short-normal wireline logs have been run by the GSWA on all bores drilled since 1973.

Single borehole pumping tests using a shaft-driven turbine pump, and measuring water levels by airline, were carried out on all bores drilled since 1973 (Table 2). In most of the bores the results of the pumping tests could not be analysed.

Groundwater samples were taken at the end of the pumping tests, and partial analyses made by the Government Chemical Laboratories (GCL). Total dissolved solid and sodium chloride results, are given in Table 2. Standard analyses of groundwater from various formations were made by GCL for the Allanooka Project bores (Allen, 1965), and are given in Table 3.

The natural surface (ns) and top of casing (tc) of each bore is levelled to the Australian Height Datum (AHD), except for the Allanooka Project bores which had been levelled to Low Water Mark, Fremantle.

Groundwater levels are measured by the PWD. Observation and production bores in the Allanooka borefield are measured monthly while more distant Allanooka and Irwin View project bores are measured at 3-monthly intervals. The data are stored in the PWD computerized groundwater-levels recording system.

PHYSIOGRAPHY

GENERAL

The Allanooka area includes an upland having the form of a relatively flat plateau with a dissected margin, and a coastal plain which bounds it to the west.

The generalized topography and location of the major drainage divides are given in Figure 2. The physiographic subdivisions (inset Fig. 2) and the important drainage features are described below.

TABLE 2. SUMMARY OF RESULTS FROM ALLANOOKA, DONGARA, IRWIN VIEW AND MOUNT HILL BORES

Name	Drilling		RL ns AHD (m)	RL tc AHD (m)	Depth (m)	Test interval bns (m)	Water table btc (m)	Test yield (m^3/d)	Draw-down (m)	TDS (mg/L)	NaCl (mg/L)
	Com-menced	Com-pleted									
Dongara No. 1	24/2/64	26/3/64	....	....	133·5	....	7·9	....	....	2 660 26 100	....
Pilot Bore No.—											
1	10/2/65	10/2/65	....	....	87·8	....	42·1	....	....	....	....
2	22/2/65	8/3/65	....	....	81·1	....	34·1	....	....	....	....
3	12/3/65	15/3/65	....	....	87·2	....	40·2	....	....	....	....
4	16/3/65	25/3/65	....	....	83·5	....	34·8	....	....	....	....
5	31/3/65	3/4/65	....	....	73·5	....	26·5	....	....	....	....
Allanooka Production No.—											
1	27/8/65	26/9/65	....	....	59·5	49·5 – 59·5	12·7	2 236	....	560	....
2	1/10/65	....	....	....	83·8	57·5 – 67·4	35·2	2 261	....	620	....
3	24/3/66	....	....	....	125·0	45·35– 55·2	28·2	2 182	....	430	....
4	....	11/2/66	....	....	46·9	37·19– 47·1	7·7	2 236	....	670	....
5	20/1/67	....	....	....	53·4	38·97– 48·87	12·3	2 199	....	....	....
5A*	18/10/66	4/12/66	....	....	56·4	46·73– 56·65	3·3	1 762	....	....	....
6	6/4/67	....	....	....	120·7	76·14– 86·05	57·3	975	....	1 150	....
7	27/6/67	....	....	....	64·6	54·72– 64·60	26·7	2 317	....	500	....
8	24/7/67	19/8/67	....	....	59·5	48·17– 58·07	20·5	2 306	....	570	....
9	25/11/68	....	....	....	64·3	53·37– 63·10	26·3	2 290	....	750	....
10	24/1/69	....	....	....	67·7	53·09– 62·80	28·6	2 191	....	520	....
11	2/9/69	....	....	....	103·7	92·76–102·40	48·8	2 313	....	380	....
12	29/10/69	....	....	....	100·6	87·27– 96·95	51·8	2 191	....	360	....
13*	5/12/69	20/12/69	....	....	94·5	....	....	....	....	....	....
14	27/1/70	16/2/70	....	....	100·6	82·03– 91·76	56·4	2 191	....	660	....
Allanooka—											
1/73	27/4/73	....	....	....	129·4	119·71–129·23	81·07	2 191	21·9	1 210	1 030
2/73	18/6/73	....	....	....	126·5	117·04–126·49	70·42	2 191	7·8	1 480	1 230
3/73	12/7/73	....	....	....	92·2	81·53– 90·98	36·89	2 191	11·2	2 080	1 680
1/74	7/9/74	19/9/74	82·06	....	286	120·4 –131·3	37·18	1 495	20·1	940	780
2/74	3/10/74	8/10/74	87·39	....	349	208·22–219·00	37·03	2 138	32·6	1 100	900
3/74	25/10/74	30/10/74	86·77	....	282	70·58– 80·0	37·18	2 793	11·6	740	585
4/74	–/11/74	12/11/74	88·94	....	197	96·25–110·14	39·3	2 793	18·9	790	635
Irwin View—											
1/74 (E)	28/11/74	4/12/74	169·58	169·94	240	193·88–200·00	77·46	No test	....	....	....
1/75 (F)	10/2/75	13/2/75	114·629	115·079	211	67·52– 75·33; 97·83–110·33	52·55	1 156	5·6	420	348
2/75 (A)	31/10/75	10/11/75	149·010	149·290	221	187·96–195·95	68·30	895	17·6	470	300
3/75 (A)*	16/11/75	?3/12/75	....	....	60	....	....	....	....	....	....
4/75 (B)	4/12/75	8/12/75	101·608	101·936	157	125·8 –132·0	57·91	1 626	16·1	550	280
Dongara—											
1/75 (V)	12/10/75	14/10/75	33·18	33·84	152·5	64·47– 73·7	20·47	1 636	9·1	1 050	760
2/75 (W)	27/10/75	30/10/75	33·49	....	137·5	51·07– 54·10; 84·65– 93·89	18·84	2 793	9·0	1 010	730
Allanooka—											
1/76 (A)	25/8/76	31/8/76	103·42	104·19	269	74·08– 80·30	61·80	1 636	4·2	760	561
2/76 (B)	9/9/76	14/9/76	86·33	86·94	208	139·94–149·30	43·20	1 636	38·0	1 080	900
3/76 (C)	29/9/76	30/9/76	85·38	85·98	220	124·88–134·00	40·50	1 636	20·5	not analysed	....
4/76 (D)	7/10/76	13/10/76	93·78	94·33	214	148·94–158·30	46·60	1 636	32·2	860	680
5/76 (E)	6/12/76	10/12/76	100·39	100·98	239	126·65–139·50	49·70	2 188	10·5	1 260	988
Irwin View—											
1/76 (J)	28/1/76	12/2/76	180·904	181·254	253	121·2 –129·0	69·4	1 156	6·2	410	353
2/76 (I)	23/2/76	27/2/76	145·713	146·014	207	50·3 – 55·0; 101·3 –106·0	57·9	1 156	5·1	480	407
3/76 (H)	11/3/76	18/3/76	112·326	112·651	306	115·06–119·73; 135·06–139·73	32·3	1 156	8·5	500	396
4/76 (C)	29/3/76	31/3/76	87·69	88·36	208	99·27–105·48; 131·99–138·18	45·7	1 156	2·8	....	....
5/76 (D)	8/4/76	13/4/76	85·487	85·779	222	117·3 –122·0; 141·3 –146·0	44·99	1 156	5·1	....	....
6/76 (G)	30/4/76	5/5/76	173·090	173·395	239·5	103·89–109·00	86·50	....	....	not analysed	....
Allanooka—											
1/77 (G)	26/1/77	1/3/77	79·16	....	221	109·1 –115·3; 136·18–142·4	36·8	2 032	40·9	990	790
2/77 (H)	14/2/77	18/2/77	88·67	....	233	100·07–106·30; 115·08–161·30	46·80	2 239	11·5	1 100	900
3/77 (J)	1/8/77	5/8/77	97·00	....	227	129·9 –142·3	54·00	2 190	....	990	780
4/77 (K)	16/8/77	22/8/77	100·69	....	207	118·74–125·00; 137·74–144·0	51·00	1 637	6·5	530	401
5/77 (L)	30/8/77	2/9/77	71·91	72·28	201	121·86–134·30	43·0	1 526	38·5	1 210	1 010
Irwin View—											
1/77 (K)	28/2/77	4/3/77	84·378	84·698	221	81·58– 87·78; 100·08–106·28	65·30	1 145	6·0	550	336
2/77 (M)	14/3/77	18/3/77	....	145·109	208	196·06–205·30	46·80	982	....	540	284
3/77 (S)	29/3/77	1/4/77	57·746	58·156	220	92·33–101·63	11·50	1 145	23·0	490	320
4/77 (R)	6/4/77	18/4/77	52·004	52·346	203	40·46– 50·70	21·30	1 625	5·0	1 370	1 040
5/77 (T)	22/4/77	28/4/77	....	88·004	214	57·06– 66·30	10·40	1 625	18·5	460	345
6/77 (W)	5/8/77	12/5/77	228·518	228·85	270	216·57–225·81	118·25	Bailed	....	630	402
7/77 (O)	20/5/77	25/5/77	140·241	140·538	195	138·51–147·75	92·48	245	15·9	470	272
8/77 (P)	1/6/77	3/6/77	147·223	147·584	229·9	85·12– 94·30	54·20	1 244	15·2	560	404
9/77 (L)	13/6/77	15/6/77	36·809	37·088	215	39·21– 48·30	20·75	1 625	....	1 330	979
10/77 (N)	21/6/77	23/6/77	47·679	48·009	208	45·18– 54·30	30·70	1 625	4·8	670	432
11/77 (Q)	29/6/77	30/6/77	....	110·567	212	80·97– 90·30	29·85	1 244	9·7	400	297
12/77 (U)	8/7/77	13/7/77	177·16	176·69	215	111·12–120·39	88·00	840	....	520	415
13/77 (V)	20/7/77	22/7/77	180·73	181·25	202·6	111·22–114·30; 135·22–138·33; 141·22–144·30	65·5	1 985	5·0	360	250
Mount Hill—											
1/77	14/9/77	21/9/77	31·51	31·77	201	38·16– 44·30	13·0	1 363	....	540	452
2/77	28/9/77	3/10/77	30·33	31·13	183	32·16– 38·30	15·5	130	....	1 310	979

* Abandoned
AHD—Australian height datum
ns—Natural surface
tc—Top of casing
bns—Below natural surface
btc—Below top of casing

LANDFORMS

Victoria Plateau

The Victoria Plateau (Playford and others, 1976) is a relatively flat sandplain, 200 to 300 m above sea level, bordered by steep escarpments (breakaways). The sandplain is composed of a gently undulating sand-sheet, about 6 m thick, overlying laterite. It is probably of Miocene age.

Arrowsmith Region

The Arrowsmith Region (Playford and others, 1976) is a deeply dissected part of the Victoria Plateau, 100 to 200 m above sea level, with remnants of the Victoria Plateau preserved as mesas and buttes. The present drainages are underfit and dissection must have occurred during more humid conditions, possibly during the Pleistocene. The boundary with the Victoria

TABLE 3. STANDARD CHEMICAL ANALYSES FROM ALLANOOKA PROJECT BORES (Milligrams per litre)

Name	Depth (m)	GCL No.	pH	Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3	SiO_2	Fe	TDS Cond.	TDS Evap.	Formation
Allanooka No. 1	13·1– 60·9	5349/62	6·8	6	10	181	8	71	38	257	<1	....	<0·1	571	540	Yarragadee Fm
Allanooka No. 1	13·1– 93·9	10088/62	6·8	5	11	215	9	76	58	293	<1	....	0·1	....	600	Yarragadee Fm
Allanooka No. 2	96·0–115·9	10091/62	6·8	10	9	224	14	68	51	396	<1	....	0·2	....	690	Cockleshell Gully Fm
Allanooka No. 2	178·4–196·6	58/63	7·4	207	135	1 810	71	155	546	3 120	2	7	0·1	....	6 030	Proterozoic basement
Allanooka No. 3	24·4– 33·5	10090/62	7·6	117	133	655	39	305	159	1 300	80	....	0·1	....	2 650	Kwinana Group
Allanooka No. 4	275·3–282·9	6923/63	7·6	32	26	426	27	224	133	586	....	....	0·2	1 400	1 380	Cockleshell Gully Fm
Allanooka No. 5	50·3– 79·3	3234/63	6·6	11	27	208	9	46	50	363	<1	36	0·9	....	730	Yarragadee Fm
Allanooka No. 5	195·1	4875/63	7·0	34	54	608	24	136	171	971	<1	....	0·2	2 050	1 950	Yarragadee Fm
Allanooka No. 5	50·6–140·2	6327/63	6·3	14	26	206	9	54	45	362	....	....	<0·1	730	770	Yarragadee Fm
Allanooka No. 5	50·6–140·2	6329/63	6·8	16	33	301	14	73	82	499	....	....	0·1	1 010	1 040	Yarragadee Fm
Allanooka No. 6	36·9	7111/63	7·8	38	17	329	17	208	61	473	....	....	0·6	1 120	1 060	Yarragadee Fm
Allanooka No. 7	36·6	2644/64	7·3	36	26	194	13	131	55	333	....	....	0·4	830	740	Yarragadee Fm
Allanooka No. 8	128·7	9987/63	6·6	100	159	1 360	74	101	485	2 390	....	....	<0·1	4 690	4 690	Cockleshell Gully Fm
Allanooka No. 9	79·3	2645/64	7·4	16	13	92	2	58	16	164	<1	....	0·2	390	340	Yarragadee Fm
Allanooka No. 10	39·6	863/64	7·3	16	17	189	9	70	41	307	....	....	1·2	710	620	Yarragadee Fm
Allanooka No. 11	39·6	2647/64	7·0	3	5	180	7	49	19	262	<1	....	0·4	600	520	Yarragadee Fm
Allanooka No. 12	29·0– 39·3	2646/64	6·8	23	33	346	18	73	50	607	<1	....	0·3	1 270	1 100	Yarragadee Fm
Allanooka No. 13	41·5	897/64	6·6	54	54	286	15	55	56	634	....	....	<0·1	1 320	1 140	Yarragadee Fm
Allanooka No. 14	91·5	9988/63	6·8	10	17	207	8	82	40	317	....	....	0·1	760	670	Yarragadee Fm
Allanooka No. 15	152·4	2648/64	7·1	7	12	144	11	113	21	198	<1	....	0·1	520	440	Yarragadee Fm
Allanooka No. 16	85·3– 91·5	9986/63	7·5	7	12	203	7	113	36	274	....	....	<0·1	710	620	Yarragadee Fm
Allanooka No. 17	140·2–152·4	2649/64	7·0	8	14	259	12	128	35	296	120	....	0·6	860	780	Yarragadee Fm
Allanooka No. 18	76·2	3320/64	7·0	35	87	869	42	128	243	1 440	<1	....	<0·1	2 800	2 700	Yarragadee Fm
L. Allanooka	....	8426/63	7·2	10	10	157	12	131	21	208	....	....	....	560	550	Surface 21/8/63

Plateau is generally a steep breakaway up to 10 m high which, in some areas, may have weathered sedimentary rocks exposed beneath. Locally, as in Hunt Gully, some large laterite-capped areas that are detached from the Victoria Plateau may be landslips.

Lake Allanooka occurs at the boundary of the Arrowsmith Region and Swan Coastal Plain. It is a circular lake about 0·2 km^2 in area, occupying a shallow topographic depression about 95 m AHD. The lake is a discharge site for runoff from Banksia and Hunt Gullies, and was also the site for groundwater discharge from Ngarlingue Spring prior to discharge ceasing as a result of pumping from the Allanooka Scheme. The outlet from the lake is Allanooka Creek (Fig. 2) which flows for about 11 km before dissipating on the coastal plain (Allen, 1965).

The lake fills from direct rainfall and runoff during the winter, and when full is about 0·3 m deep and contains about 3 600 m^3 of water. It is underlain by about 2 m of kaolinitic clay which is presently being mined for brickmaking.

The lake is at the head of an extensive relatively flat topographic depression (Fig. 2), which extends onto the coastal plain. The depression appears to have been formed by runoff during and after the formation of the coastal plain, and the topography suggests that the depression may have been the site of a large temporary lake, of which Lake Allanooka is the remains.

Swan Coastal Plain

The Swan Coastal Plain (Playford and others, 1976) abuts against the western edge of the Arrowsmith Region. The boundary coincides with a fairly abrupt change in slope, marking the position of the Gingin Scarp, a former Quaternary or late Tertiary shoreline.

The coastal plain consists of a conspicuous belt of modern dunes along the coast abutting and overlying two older calcreted dune complexes which rise to an elevation of about 50 m. The calcreted dunes form a distinctive irregular topography, often with limestone exposed on the crests of the hills. Small fertile flood plains are associated with the major rivers, and small interdunal depressions are the sites of temporary lakes after flooding by the major rivers (Fig. 3). The plain is of ?Pliocene to Holocene age.

DRAINAGES

Greenough River

The Greenough River is a major river which reaches the sea, and which forms the northern boundary of the Allanooka area. It is intermittent, usually flowing during the winter and persisting during the summer as a series of partially interconnected pools upstream of Ellen Crossing. Flows are brackish and have an average salinity of 3 610 mg/L TDS (PWD data). This appears to be a natural condition of the river as its salinity was commented on by Grey (1841) prior to European settlement.

Irwin River

The Irwin River is a major river which reaches the sea, and which forms the southern boundary of the Allanooka area. It is an intermittent river with the major flows usually occurring during the winter months. The main catchment area is in salt-prone country to the east of the Allanooka area. Consequently, flows are brackish and have an average salinity of 3 480 mg/L TDS (PWD data).

Where the river traverses the Arrowsmith Region there is a small contribution of fresh groundwater from minor spring-fed tributaries, such as Springy Creek, and at the sites of some semi-permanent pools in the river bed.

GEOLOGY

SETTING

The Allanooka area (Fig. 3) is in the northern part of the Perth Basin. It is immediately south of the Northampton Block, within the Dandaragan Trough and Dongara Saddle structural subdivisions of the basin (Jones and Pearson, 1972; Playford and others, 1976).

STRATIGRAPHY

The stratigraphic succession consists of Phanerozoic sedimentary rocks resting on Precambrian crystalline basement rocks of the Northampton Block. Sedimentation has been controlled by the structurally high Northampton Block, and by subsidence in the Dandaragan Trough. Consequently, Mesozoic sediments on the Northampton Block form a thin shelf sequence, about 60 m thick (Playford, 1959), which thicken rapidly southeastward through the Allanooka area to about 4 000 m in the axis of the Dandaragan Trough.

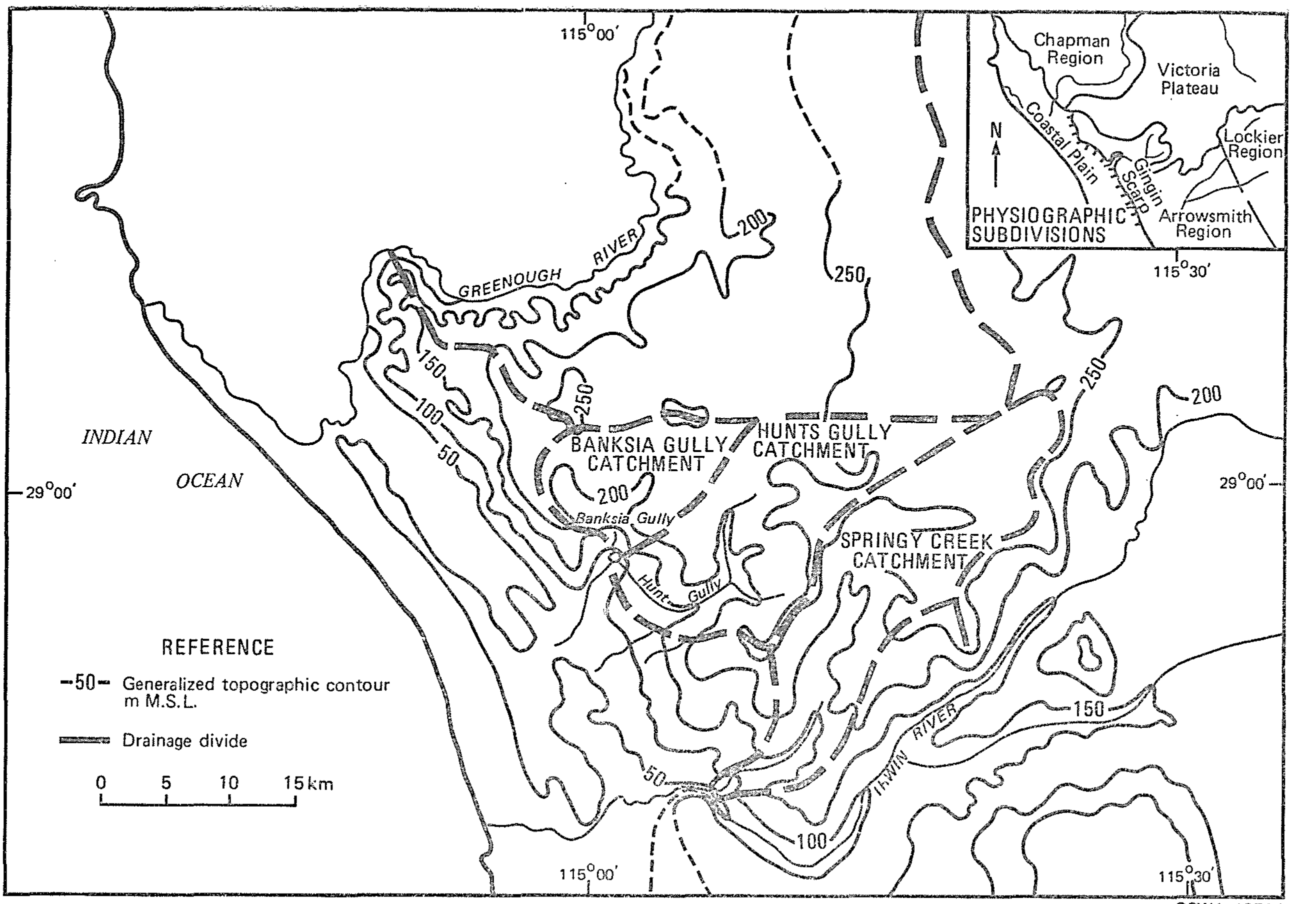


Figure 2 Generalized topography and drainage basins.

TABLE 4. MESOZOIC AND CAINOZOIC STRATIGRAPHIC SEQUENCE IN THE ALLANOOKA AREA

Age	Group/Formation	Maximum Thickness (m)	Lithology/Remarks
CAINOZOIC Quaternary	Kwinana Group	150	Calcarenite, alluvium, clay, calcareous sand, limestone, minor gravel. Major unconfined aquifer containing brackish water.
	UNCONFORMITY		
Tertiary	Laterite	20	?Eolian sand and pisolitic laterite.
	NONCONFORMITY		
MESOZOIC ?Cretaceous-Jurassic	Yarragadee Formation....	1 000	Interbedded sandstone, siltstone and shale. Major aquifer containing fresh and brackish water.
Jurassic	Cadda Formation	400	Shale, siltstone, minor limestone. Confining bed.
Jurassic	Cockleshell Gully Formation	1 200	Sandstone, siltstone, shale, minor coal. Aquifer containing brackish and minor fresh water.
	UNCONFORMITY		
Triassic	Kockatea Shale	?100	Shale, minor silstone, rare sandstone. Confining bed.
PALAEOZOIC Permian	Undifferentiated	2 500	Nonmarine, minor marine, and glacigene formations.
	UNCONFORMITY		
PROTEROZOIC	Undifferentiated	....	Granulite, granite, dolerite.

In the Allanooka area the formations containing or affecting the occurrence of potable groundwater resources are of Mesozoic to Holocene age. The formations, together with a brief description of their lithology, are given in Table 4. The lithology of the main aquifers is described in detail in the section on hydrogeology, but for detailed descriptions of the other formations reference should be made to Playford and others (1976).

STRUCTURE

The geological structure of the Allanooka area (Fig. 4) is relatively well known as a result of intensive seismic exploration following the 1963 discovery, and subsequent exploitation, of gas and a minor amount of oil from Yardarino, near Dongara.

In the Allanooka area the Mesozoic sedimentary rocks thicken and have a regional southeasterly dip toward the axis of the Dandaragan Trough. This general pattern is

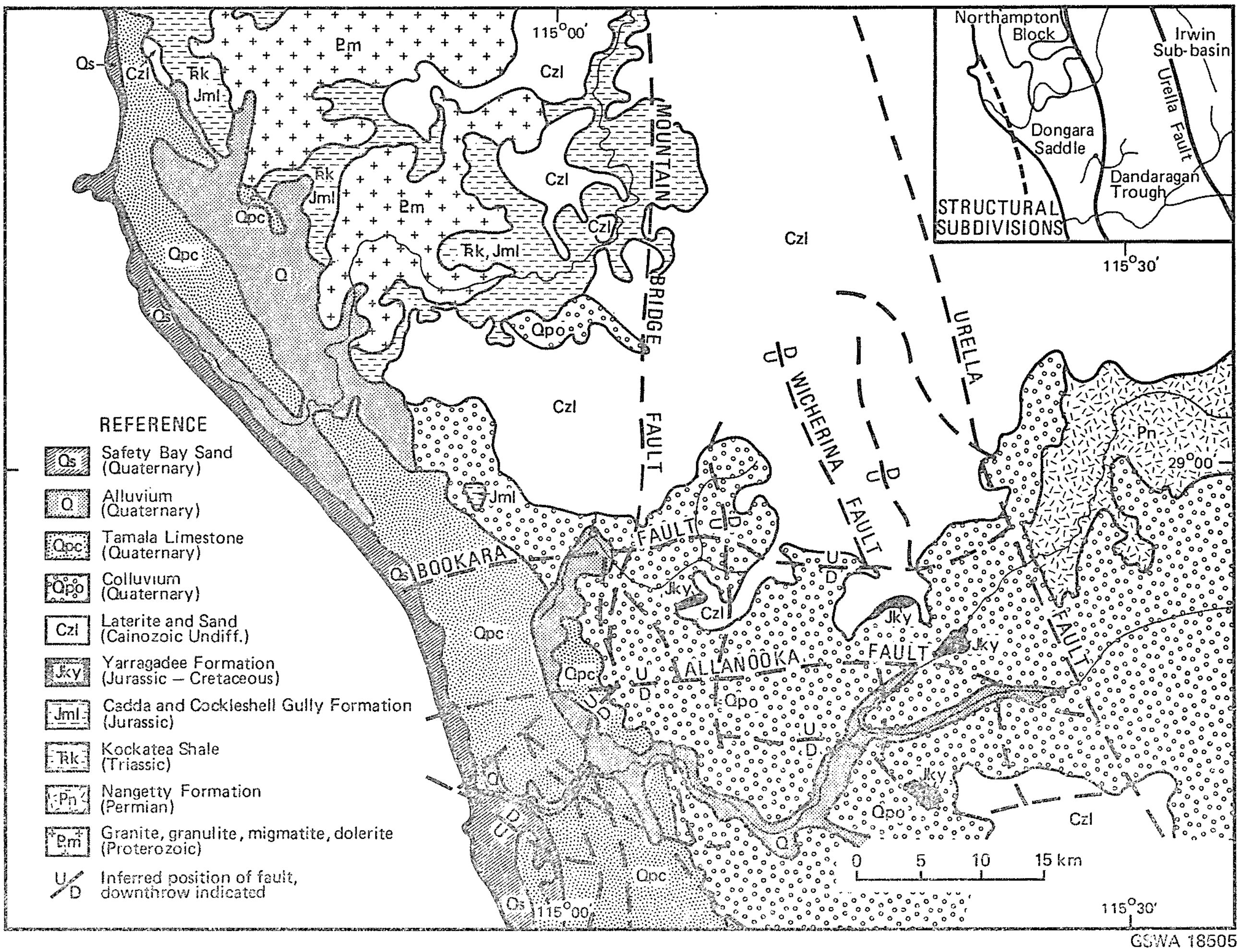


Figure 3 Generalized geology.

disrupted by a set of large north-trending normal faults parallel to the Urella Fault, and by a younger set of east-west normal faults. The result is that the Mesozoic rocks are faulted into a complex series of rectangular fault blocks.

The approximate position of the major faults, based on data supplied by West Australian Petroleum Pty Ltd, are given in Figure 3. In addition, there are numerous minor faults which are not shown. Allen (1965) inferred the location of several faults in the Allanooka borefield, and suggested that the roughly rectilinear drainage pattern may be fault controlled. However, the locations and trends of these and other minor faults cannot be established by drilling because of the difficulty of correlating sections of the Yarragadee Formation.

The Kwinana Group, which overlies the Yarragadee Formation on the coastal plain, is flat lying and not known to be faulted. The base of the group dips westward from about 90 m above sea level to 30 m below sea level. Some deep infilled channels incised into the Yarragadee Formation may occur near where the major drainages meet the coastal plain (Allen, 1965).

HYDROGEOLOGY

AQUIFERS

All of the Mesozoic and Cainozoic formations in the Allanooka area may locally contain groundwater, but major groundwater flow systems only occur in the Kwinana Group, and the Yarragadee and Cockleshell Gully Formations.

Kwinana Group

Lithology: The Kwinana Group (Playford and others, 1976) consists of the surficial deposits on the coastal plain, which rest unconformably on the Yarragadee Formation. The group is up to 150 m thick, and along the coast extends to a depth of about 30 m below sea level. The upper part of the group consists of eolian coastal dunes (calcarenite), calcreted dunes of sandy calcarenite, and red alluvial silt, clay and gravel associated with the major drainages. These overlie fossiliferous shallow-water marine deposits consisting of medium-to-coarse-grained calcareous sand, limestone and clay, which locally contain concentrations of heavy minerals. The sediments are Pliocene to Holocene in age.

Flow system: The Kwinana Group contains an unconfined groundwater flow system in lateral and vertical hydraulic continuity with the flow system in the Yarragadee Formation. The Greenough and Irwin Rivers (except in their tidal estuaries) form hydraulic recharge boundaries to the system, and the sea and tidal estuaries of the rivers form a discharge boundary.

The configuration of the water table is not well known, but water-table contours based on a few bore records, and elevation data interpolated from topographic maps, are given in Figure 5. The water table slopes downward to the south-west, except near Irwin River where a ridge in the water table is sustained by recharge from the river. There is a low groundwater gradient across the coastal plain, except along the eastern edge where there is a steep gradient near the contact with the Yarragadee Formation mainly resulting from the difference in transmissivity between the Kwinana Group and the Yarragadee Formation.

Recharge: Recharge to the Kwinana Group is by upward leakage from the Yarragadee Formation, and by flow losses from the Greenough and Irwin Rivers, and from streams draining the Arrowsmith Region. Some recharge by direct infiltration from rainfall also occurs, but this is believed to be small because the water table is about 50 m deep over large areas, and because of the extent of clayey alluvial plains where recharge is minimal. Data are insufficient to determine the amount of recharge from each source. However, from observed increases in salinity with depth (see section on quality), and the large upward head potential between the Yarragadee Formation and the Kwinana Group, leakage from the Yarragadee Formation is considered to be the major source of recharge.

Storage: The shallow-water marine sand comprises most of the water-bearing part of the Kwinana Group. Assuming that this has a specific yield of 0·30 and an average saturated

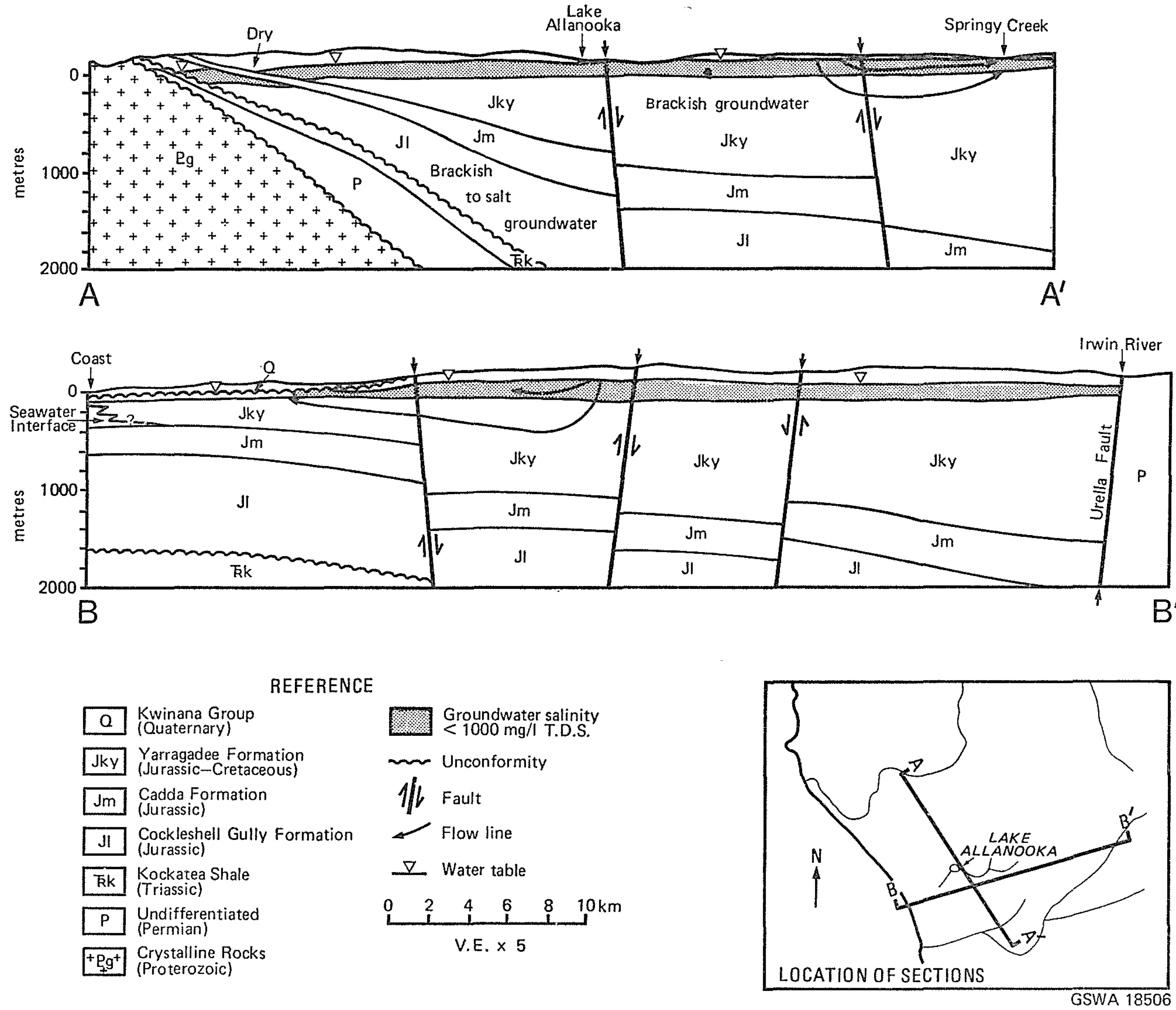


Figure 4 Diagrammatic hydrogeological cross sections.

thickness of 20 m, then the volume of groundwater in storage beneath the coastal plain between the Greenough and Irwin Rivers (375 km²) is:

$$0{\cdot}3 \times 20 \text{ m} \times 375 \text{ km}^2 = 2\,250 \times 10^6 \text{ m}^3.$$

Discharge: Discharge from the flow system takes place along the coastline and into the estuaries of the Greenough and Irwin Rivers. Outflow can be calculated from the form of the Darcy equation:

$$Q = TIL \quad .... \quad .... \quad .... \quad .... \quad (1)$$

where Q = outflow (m³/day),
T = transmissivity (saturated aquifer thickness m x hydraulic conductivity, m/day),
I = hydraulic gradient (dimensionless),
and L = width of flow section (m)

Assuming a saturated aquifer thickness of 25 m, and a hydraulic conductivity of 30 m/day, and using a measured hydraulic gradient of 0·002, and a flow section of 35 km (C–D in Fig. 5), then the outflow from the Kwinana Group, between the Greenough River and Irwin River, is:

$$25 \times 30 \times 0{\cdot}002 \times 35\,000 = 52\,500 \text{ m}^3\text{/day},$$
$$\approx 20 \times 10^6 \text{ m}^3\text{/year}.$$

Quality: Groundwater in the Kwinana Group generally has a salinity of 2 000 to 3 000 mg/L TDS. In areas of local recharge such as interdunal swales and deep depressions in the limestones ridges, and where some of the small drainages from the Arrowsmith Region meet the coastal plain, groundwater with a salinity ranging from 250 to 1 000 mg/L TDS may be obtained in the upper part of the flow system. Groundwater with a salinity of between 6 500 and 19 000 mg/L is known from the base of the flow system, probably near the seawater interface, along the coast (Allen, 1963). In general the salinity of the groundwater increases with depth and with distance westward across the coastal plain.

Along the eastern edge of the coastal plain there is a relatively abrupt change in salinity from fresh groundwater in the contiguous Yarragadee Formation to brackish groundwater in the Kwinana Group. Evapotranspiration is not likely to cause the increase in salinity because of the depth to the water table. The increased salinity of groundwater in the Kwinana Group may result from flushing of seawater entrapped in shale and siltstone when the sea extended to the Gingin Scarp.

Local occurrences of fresh groundwater occur in the coastal dunes as a thin layer of fresh water resting on brackish water. However, only small supplies are available and the salinity may vary depending on the season and pumping rate. In addition, the groundwater is hard and may contain hydrogen sulphide.

Development: Several hundred bores and wells are used to abstract groundwater in the Kwinana Group for stock, and rarely for domestic supplies. Generally the salinity of the groundwater has prevented large-scale development of the groundwater resources. An exception to this was the former Port Denison water supply, where 16 000 m³/year of variable quality groundwater were abstracted by a series of spears in an interdunal depression (Allen, 1963). The supply was abandoned when water from the Allanooka Scheme became available.

Should large volumes of brackish groundwater be required in the future, the Kwinana Group in the Allanooka area contains a major, easily developed resource.

Yarragadee Formation

Lithology: The Yarragadee Formation consists of interbedded sandstone, siltstone, and shale. The beds of sandstone are discontinuous and range from 2 to 30 m in thickness, with an average of about 10 m. They are cross-bedded and consist of medium- to very coarse-grained, subangular, poorly sorted

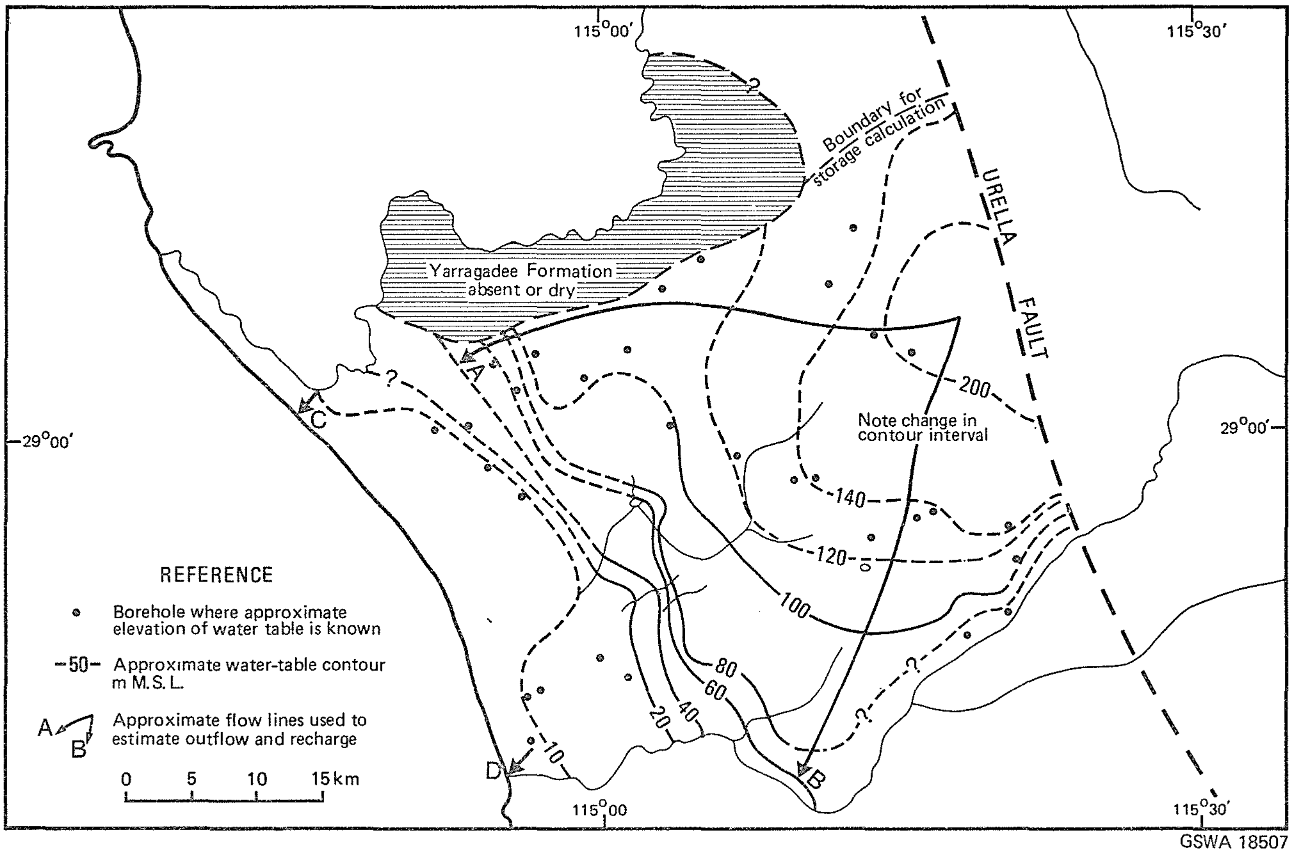


Figure 5 Approximate contours on regional water table.

to well-sorted sand. The sandstones are feldspathic, tending to arkose, and contain thin beds of conglomerate, and layers and nodules of pyrite. The siltstones and shales are usually laminated, and frequently contain mica, pyrite, and carbonaceous material. The upper part of the formation tends to be composed of alternating thin-bedded units, whereas at the base the beds are thicker.

The Yarragadee Formation is oxidized by weathering from the surface to some distance below the present water table. This zone is white, cream, red or yellow-brown; the feldspar is kaolinized, and the pyrite is altered to ferruginous layers or ferruginous nodules. Below the oxidized section the sandstones are grey and the siltstones and shales are dark grey or black. Allen (1965) has suggested that the oxidized zone extending below the water table may indicate that the water table has been lower in the past.

Beds of sandstone in the formation have porosities, measured from geophysical logs, ranging from 0·33% to 0·40%, with an average of 0·36%, from 14 determinations (WAPET, written communication, 5.4.65.) The specific yield for the sandstone has been estimated by Forth (1971) to be 0·26%, and the hydraulic conductivity to be 5 m/day (Forth, 1971) to 17 m/day (Forth, 1973). A value of 10 m/day is adopted for subsequent calculations.

The formation is between 20 and 1 000 m thick. It conformably overlies the Cadda Formation and is unconformably overlain by the Kwinana Group. On the Victoria Plateau and parts of the Arrowsmith Region a laterite profile is developed on the surface of the formation.

In the Allanooka area the Yarragadee Formation is of Middle Jurassic to ?Lower Cretaceous age. Further south in the Dandaragan Trough a tripartite division of the formation is possible into "upper" Yarragadee Formation, Otorowiri Siltstone Member, and "lower" Yarragadee Formation (Barnett, 1977; Commander, 1978). This subdivision has been recognized as far north as Mingenew, but the Otorowiri Siltstone Member was not identified in the Allanooka area and subdivision is not possible.

The formation was deposited mainly in a nonmarine fluviatile environment, hence the variable and discontinuous nature of its component beds.

Flow system: The Yarragadee Formation is a multilayer aquifer containing a regional groundwater flow system. Its boundaries are the Urella Fault in the east; the outcrop of the base of the formation south of the Greenough River; a groundwater divide (not shown) to the south of the Allanooka area (Commander, 1978); and the hydraulic discharge boundary formed by the sea. The flow system is isolated from the one in the Cockleshell Gully Formation by the Cadda Formation (confining bed), except where local interconnection may occur across faults. It is in lateral and vertical hydraulic connection with the Kwinana Group on the coastal plain (Fig. 4).

The upper part of the flow system forms a water table varying from about 15 to 120 m below the surface. At depth beneath the water table, the groundwater is confined to varying degrees because of the layered nature of the formation. Downward head gradients occur on the Victoria Plateau, as in AP4 (Allen, 1965), and upward head gradients occur along the edge of the Arrowsmith Region (AP1) and on the coastal plain, as in the Dongara and Yardarino bores (Maitland, 1913).

Faults may affect the flow system. Gouge or silicification along the fault planes may reduce hydraulic conductivity, and sandstones and siltstones may be brought into juxtaposition, impeding groundwater flow. The actual importance of faulting is uncertain. Allen (1965) considered that the configuration of the water table near Lake Allanooka was the result of faulting. Forth (1972) accepted this explanation, and Ventriss and Parsons (1978), studying hydrographs from the Allanooka Scheme, considered that faults forming boundary conditions were probably responsible for the limited area affected by the production bores. It now appears that the steep groundwater gradients at the edge of the Arrowsmith Region may result from upward flow, and the limited extent of drawdown caused by abstraction is mainly the result of close spacing between the pumping bores. Nevertheless, the fault blocks probably behave as groundwater compartments in which groundwater flow is affected at the fault boundaries.

A regional water-table map is given in Figure 5 and a more detailed water-table map for the area southeast of the Allanooka Scheme in Figure 6. Figure 5 is based on nonsynoptic water levels and bores for which the locations and elevations are approximate.

Figure 5 shows that the water table forms a regional mound reaching an elevation of over 200 m AHD beneath the highest part of the Victoria Plateau. The groundwater mound is relatively flat, with steeper gradients where upward groundwater discharge takes place on the eastern edge of the coastal plain and along the Irwin River.

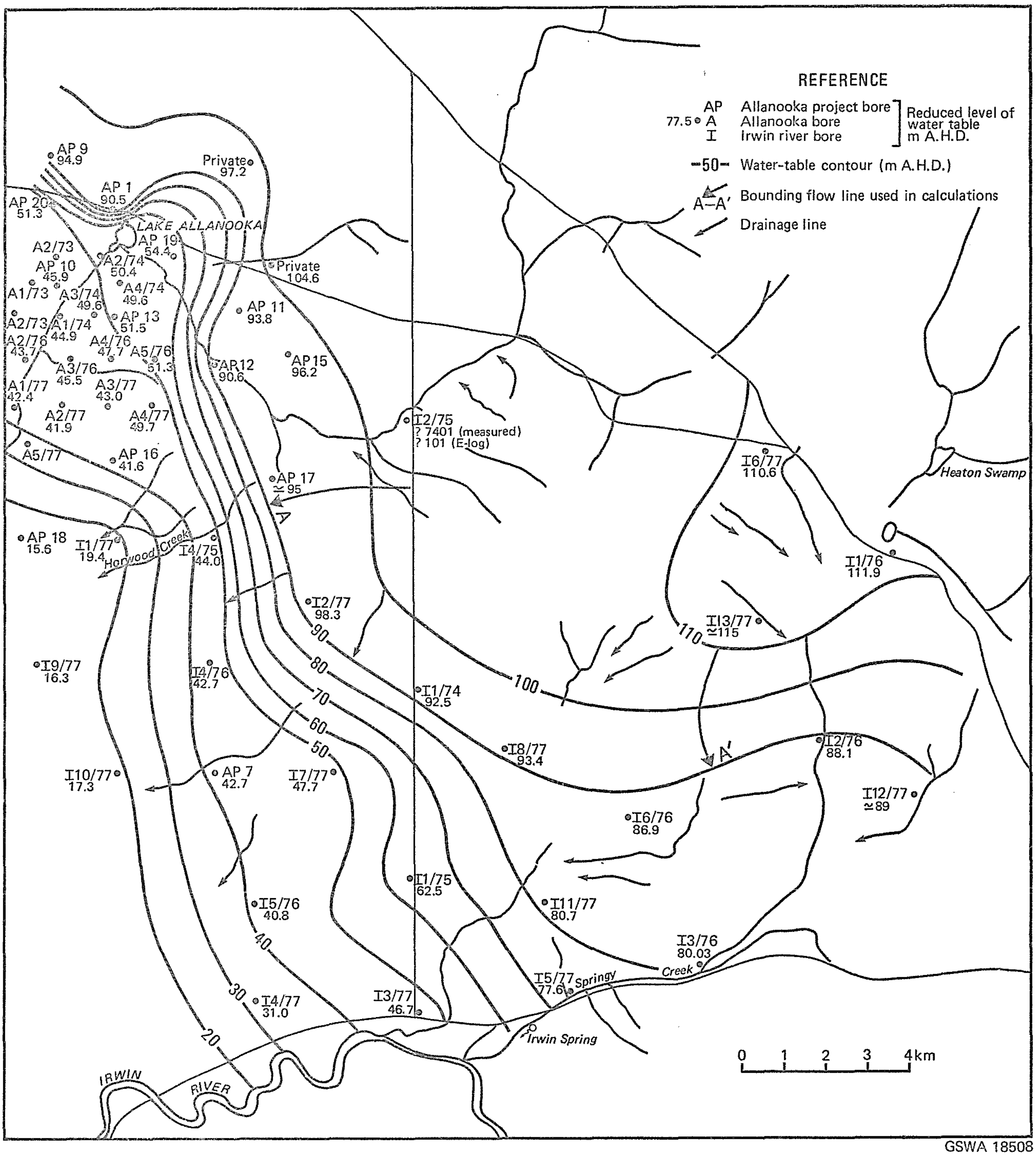


Figure 6 Water-table contours (nonsynoptic) in vicinity of Allanooka Scheme.

Recharge: Immediately south of the Greenough River the base of the Yarragadee Formation is at a higher elevation than the river bed, thus preventing recharge from that source. In the same area for about 2 km downdip it was observed in AP6, AP8 and Levetts bore (Allen, 1965) that the formation was unsaturated and a water table did not occur (Fig. 5).

The Victoria Plateau is overlain by a thick sand sheet which facilitates rainfall recharge. However, the water table is generally more than 100 m below the surface, and this, together with the impedence of recharge by interbedded siltstone and shale, results in the development of numerous perched water tables above the regional water table. The perched aquifers intercept much of the recharge which is discharged from springs and soaks around the edge of the Victoria Plateau, and only a small proportion eventually reaches the regional water table.

In the Arrowsmith Region the sand overlying the Yarragadee Formation is relatively thin, with the result that sufficient runoff occurs to sustain stream flow, as in Hunts Gully. An exception is Banksia Gully, where stream flow does not occur, possibly because it contains a thick valley-fill of sand.

Hydrographs of observation bores in the Allanooka borefield, redrawn from Ventriss and Parsons (1978), are given in Figure 7. Those bores on the northern side of Lake Allanooka show a gradual downward trend resulting from pumping, whereas those to the south show no effect. Bores PW1 and A1 show marked seasonal fluctuations. They are in sand, with the water table 15 to 20 m below surface. The other bores, due to depth to the water table or presence of interbedded siltstone or shale, do not show any seasonal fluctuations. It is probable that the water table beneath the Victoria Plateau and most of the Arrowsmith Region shows a similar lack of response.

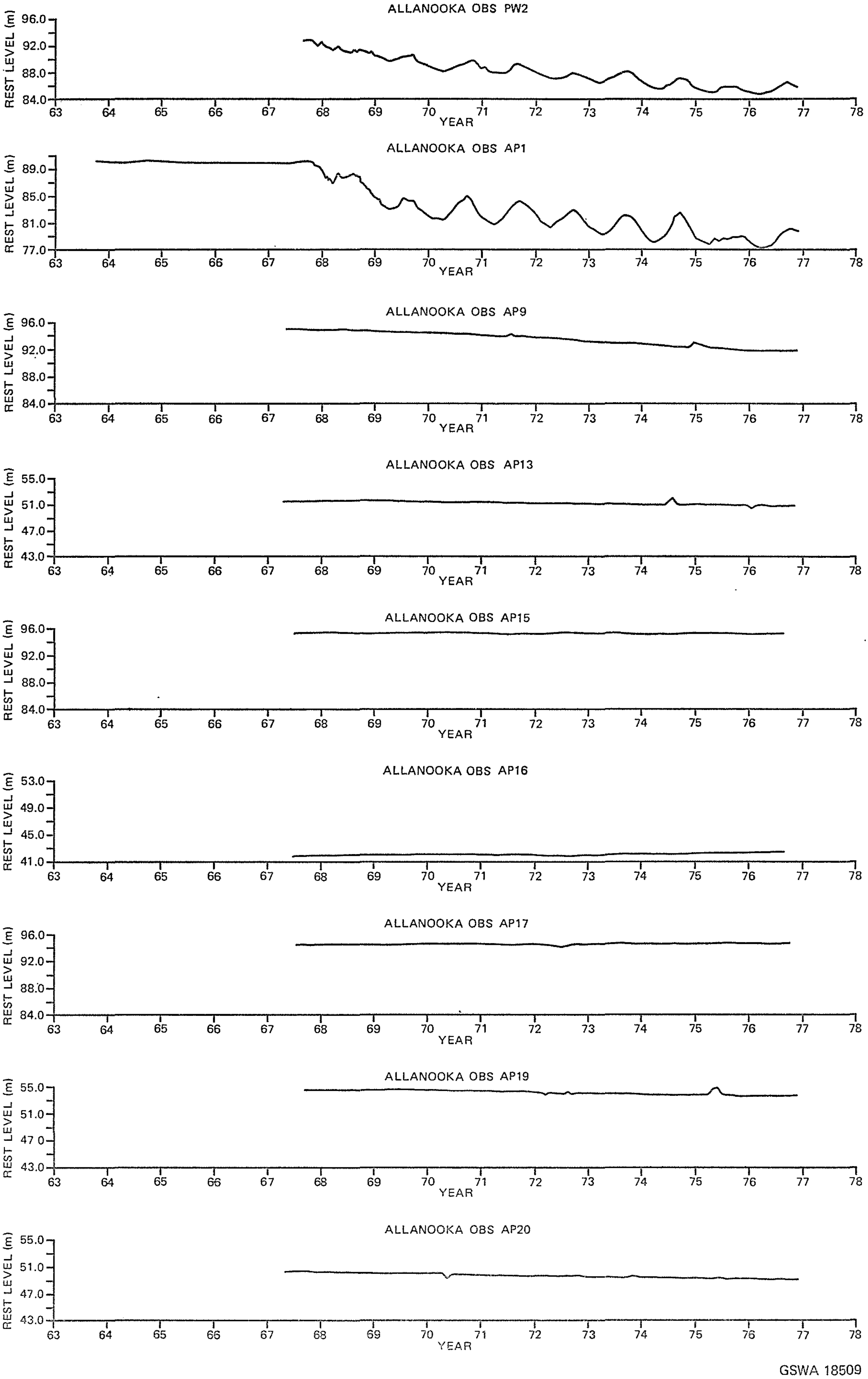


Figure 7 Selected hydrographs of observation bores in the Allanooka borefield (after Ventriss and Parsons, 1978).

Hence, it is inferred that recharge reaching the main flow system is relatively small and that it may only occur at a few favourable localities. It is possible that the present flow system is not in dynamic equilibrium with the prevailing climatic conditions.

Average throughflow normally equates to annual recharge, but in the Allanooka area reliable data on water-table contours, thickness of potable groundwater, and proportion of sand are only reliably known for the area to the southeast of the Allanooka Scheme (Fig. 6). In this area the throughflow past the 90 m water-table contour through the section A–A (14 km) may be derived from equation (1). The water table has an average gradient of 0·005 43, and the thickness of aquifer containing potable water is 100 m, of which 40% is sand with an assumed hydraulic conductivity of 10 m/day. Substituting derived and assumed values in equation (1) and solving:

$$Q = 10 \times 100 \times 0{\cdot}40 \times 0{\cdot}005\,43 \times 14\,000$$
$$= 30\,435 \text{ m}^3/\text{day}$$
$$= 11{\cdot}1 \times 10^6 \text{ m}^3/\text{year}$$
$$\approx 0{\cdot}8 \times 10^6 \text{ m}^3/\text{year/km}.$$

If the average annual outflow per kilometre is assumed to be $0{\cdot}8 \times 10^6$ m³/year then the outflow from the whole Allanooka area past the 60-m contour (Fig. 5) between A-B (47 km) is:

$$47 \times 0{\cdot}8 \times 10^6 = 37{\cdot}6 \times 10^6 \text{ m}^3/\text{year}.$$

The area contributing the throughflow is about 735 km²; therefore, the recharge expressed as a percentage of average annual rainfall (477 mm) is:

$$\frac{37{\cdot}6 \times 10^6}{735 \times 10^6} \times \frac{1}{0{\cdot}477} \times \frac{100}{1} = 10{\cdot}7\%$$

This estimate appears too large.

An alternative estimate of recharge may be made from the ratio of the chloride in rainfall to the chloride in the upper part of the flow system. The average chlorinity of all bores pump tested and found to produce potable groundwater was 268 mg/L from 26 samples (Table 2). The chlorinity of rainfall at Dongara during 1973–74 was 11·3 mg/L (Hingston and Gailitis, 1977). Assuming that the average chlorinity of rainfall in the Allanooka area is 10 mg/L, then the average recharge is:

$$\frac{10}{268} \times \frac{477}{1} = 17{\cdot}8 \text{ mm}$$
$$\approx 3{\cdot}7\% \text{ of average rainfall.}$$

This estimate of recharge may be of the correct magnitude. However, it does not take into account recharge which is intercepted and discharged from the perched aquifers; hence the average annual recharge to the main groundwater body may be 3% or less of the average annual rainfall.

The limited westward extent of potable water in the Yarragadee Formation and Kwinana Group beneath the coastal plain confirms that the recharge and resultant outflow of potable groundwater is relatively small.

Storage and movement: The aquifer system contains predominantly brackish groundwater, but potable groundwater is present in the upper part of the flow system beneath the Victoria Plateau and Arrowsmith Region. This zone of potable groundwater is known to range in thickness from 12 to 144 m below the water table, and to average 90 m. In general the zone is thinnest in the west near the edge of the coastal plain, and tends to be thicker toward the east. Apart from this trend there is no evident pattern to the thickness of the zone, or its relationship to the elevation of the water table, or to sea level.

The proportion of sandstone to siltstone and shale in the upper part of the flow system containing potable groundwater was estimated from geophysical logs. It ranged from 26% to 88%, and averaged 60%. The specific yield of these sandstones from the known abstraction and dewatering in the Allanooka Scheme was estimated by Forth (1971, 1973) to be 0·26.

Potable groundwater extends beneath about 1 550 km² of the Victoria Plateau and Arrowsmith Region (Fig. 5). If the zone of potable groundwater has the assumed specific yield, thickness, and proportion of sand, then the volume of potable groundwater in storage is:

$$1\,550 \times 10^6 \times 90 \times 60/100 \times 0{\cdot}26 = 21\,762 \times 10^6 \text{ m}^3$$
$$\approx 20\,000 \times 10^6 \text{ m}^3$$

The general direction of groundwater movement is towards the southwest (Fig. 5). Movement towards Irwin River in the south is also indicated, but it is considered that this probably only involves the upper part of the flow system.

Discharge: Subsurface groundwater discharge takes place from the Yarragadee Formation into the Kwinana Group. The low-salinity groundwater, from the upper part of the flow system, is discharged into the eastern part of the Kwinana Group, and progressively deeper, more saline, parts of the flow system are discharged westward beneath the coastal plain.

Surface discharge from the upper part of the flow system formerly occurred from Ngarlingue Spring near Lake Allanooka, and occurs along the Irwin River and especially its tributary, Springy Creek, where the largest spring (Irwin Spring) discharges about 400 m³/day of groundwater with a salinity of 450 mg/L TDS.

Numerous springs and soaks which occur around the margin and occasionally on the top of the Victoria Plateau are discharge sites from the perched aquifers, and are not directly connected with the main flow system.

Brackish springs such as Nagadee Spring with a salinity of 8 650 mg/L TDS occur adjacent to the Urella Fault on the eastern side of the flow system. Whether or not they are related to the flow system in the Yarragadee Formation is uncertain.

Quality: The salinity of groundwater in the Yarragadee Formation increases with depth. This has been observed in various bores (Maitland, 1913; Allen, 1965), and from geophysical logs of exploratory bores drilled since 1973. The geophysical logs show a wide variation in salinity between, and occasionally within, aquifers, which is a common feature of a multilayer aquifer system. The groundwater salinity is rarely less than 400 mg/L TDS and is most commonly in the range of 650 to 750 mg/L TDS.

Analyses for TDS and sodium chloride in groundwater taken during pumping tests of bores drilled since 1973 are given in Table 2, and standard analyses from the Allanooka Project bores from Allen (1965) are given in Table 3. From the analyses, most of the water is of a sodium-chloride type, in which sodium chloride comprises 65 to 85% of the dissolved salts.

Ferrous iron and manganese occur in the groundwater from the Yarragadee Formation, but usually in low concentrations. Analyses indicate iron concentrations ranging from less than 0·05 mg/L to 6·0 mg/L with a wide variability, but generally sufficiently low in production bores of the Allanooka Scheme not to warrant treatment. Manganese concentrations are also variable but are generally 0·05 mg/L or less.

Some bores produce gas-charged groundwater. Two samples from AP5 (Allen, 1965) contained 4·3% and 3·3% of carbon dioxide, 12·5% and 11·9% of oxygen and 83·2% and 84·8% of nitrogen, respectively. The gas has the composition of air, except that there has been a large increase in the percentage of carbon dioxide, and the oxygen content has been reduced by half. Ventriss and Parsons (1978) noted that the levels of carbon dioxide have been responsible for the deterioration of some concrete-lined pipes and tanks in the Allanooka Scheme.

Gas is also present in some of the confined beds of sand above the water table. Bores "blowing" or "sucking" gas, depending on the atmospheric conditions, were noted during drilling of the Allanooka Project bores.

Nitrate levels in the groundwater are generally less than 1 mg/L. An exception is a sample from AP17 which contained 120 mg/L. The use of nitrogenous fertilizers for agriculture may ultimately lead to an increase in the nitrate content of the groundwater, but because of the depth to the water table and the low rate of recharge, this may take many years.

Thermal wire-line logs were run on I2/75, I4/75 and I4/76. They show a general increase of temperature with depth at rates ranging from 1·3 to 4·5°C/100 m, and groundwater temperatures ranging from 23·3 to 28·2°C. These temperatures are within the range of those measured during pumping tests for the Allanooka Project.

Development: On the Victoria Plateau and in the Arrowsmith Region about 250 private bores and wells abstract groundwater for domestic and stock use from the Yarragadee Formation. Some of these, as at "The Casuarinas", are probably obtaining supplies from perched aquifers. Those bores producing from the regional flow system are usually over 100 m deep and only small supplies are pumped by jack-pump or windmill. Assuming a daily abstraction of 5 m³/day then the annual abstraction is only about $0{\cdot}5 \times 10^6$ m³ year.

The largest abstraction from the Yarragadee Formation is by the Allanooka Scheme which has been in operation since 1967. Annual abstraction statistics since commencement of the scheme are given in Table 5.

The present borefield consists of 24 bores within an area of about 60 km². The bores produce about 18 000 m³/day of groundwater, which is pumped into a 22 500 m³ storage

TABLE 5. ALLANOOKA SCHEME ANNUAL PRODUCTION STATISTICS (JULY—JUNE), 1967 TO 1978

Year	67–68	68–69	69–70	70–71	71–72	72–73	73–74	74–75	75–76	76–77	77–78
Yield ($m^3 \times 10^6$)....	2·37	3·02	3·30	3·08	3·75	4·42	4·87	5·81	5·81	6·46	6·74

tank about 127 m above sea level, and gravitated to service tanks at Geraldton and Dongara. The water is chlorinated and fluoridized before being reticulated.

In 1977–78 the borefield produced $6 \cdot 7 \times 10^6$ m^3, and since commissioning has produced about 50×10^6 m^3. Forth (1971) estimated the throughflow to the Allanooka borefield to be about $5 \cdot 5 \times 10^6$ m^3/year, which is exceeded by the abstraction and indicates that limited mining of the groundwater is occurring.

The Yarragadee Formation contains large potable groundwater resources, and very large brackish resources. In general, the depth to the water table on the Victoria Plateau and the Arrowsmith Region precludes large-scale private development, while on the coastal plain the salinity is suitable only for industrial use.

Cockleshell Gully Formation

Lithology: The Cockleshell Gully Formation consists of interbedded, silty, carbonaceous, pyritic, medium- to coarse-grained sandstone, with carbonaceous and micaceous siltstone and shale. It ranges in thickness from about 60 m on the Northampton Block to about 1 200 m in the southeast adjacent to the Urella Fault. The formation is conformably overlain by the Cadda Formation, and unconformably overlies the Kockatea Shale. It is of nonmarine, possibly fluviatile origin, and is of Early Jurassic age.

Flow system: The Cockleshell Gully Formation is a multi-layer aquifer system confined above by the Cadda Formation, and below by the Kockatea Shale. The boundaries to the flow system are the Urella Fault in the east, a groundwater divide about 90 km to the south of the area (Commander, 1978), the Greenough River, and the sea. The flow system is isolated from that in the Yarragadee Formation, except where faults may have brought the two systems into partial juxtaposition.

Groundwater in the flow system is confined, except at the intake around the outcrop to the south of Greenough River. The configuration of the potentiometric surface is not known but is presumed to be similar to that in the Yarragadee Formation.

Recharge: Rainfall recharge is inferred to occur on the outcrop of the formation immediately south of Greenough River, between the eastern edge of the coastal plain and Ellendale Crossing. At the outcrop the formation is unsaturated so that bores drilled into it are dry, as in Levitts bore (Allen, 1965), but downdip it contains potable groundwater as in AP6 (Fig. 4).

East from Ellendale Crossing the groundwater in the formation is in hydraulic continuity with the Greenough River, and the aquifer is presumed to be recharged by the river. This is suggested from the geological structure and the similarity in head between the river and bores in the adjacent Cockleshell Gully Formation (e.g. AP8).

Storage, movement, and discharge: The volume of groundwater in storage is very large but most is brackish. Groundwater movement is presumed to be from the intake area towards Mount Hill and the southwest. Discharge is probably by upward leakage, or upward movement along faults, into overlying formations and ultimately into the sea.

Quality: Groundwater with a salinity less than 1 000 mg/L is restricted to the area where rainfall recharge is inferred to occur to the north of Mount Hill. The composition of the groundwater is indicated in analyses from AP2 (Table 3) and MH 2/77 (Table 2). Elsewhere groundwater in the formation is brackish.

Development: A limited amount of brackish groundwater for stock is abstracted 2 to 8 km to the south of the Greenough River, east of Ellendale Crossing, where the Yarragadee Formation is unsaturated or does not contain usable supplies. A few bores obtain groundwater of about 1 000 mg/L TDS in the Arrowsmith Region north of Mount Hill. The formation has been tested adjacent to the Allanooka Scheme pipeline by MH 1/77 and 2/77, which proved that small supplies of potable water are available. These may be developed in the future.

CONCLUSIONS

Large resources of potable groundwater have been proven in the Allanooka area, 50 to 80 km southeast of Geraldton. They are the nearest resources which can be developed for Geraldton's water supply, and are currently being exploited by the Allanooka Scheme.

The present abstraction from the Allanooka Scheme exceeds the estimated throughflow to the borefield, and gradual mining of the groundwater is presumed to be occurring. This is probably being accompanied by very gradual upward and lateral leakage of brackish water. Consideration should now be given to extending the borefield to meet increasing demands, so that abstraction does not exceed throughflow, and the salinity of the groundwater is not impaired.

REFERENCES

Allen, A. D., 1963, Report on groundwater prospects, Dongara Township: West. Australia Geol. Survey Hydro. Rept No. 53 (unpublished).

——— 1964, Progress report on drilling for water to supplement the Geraldton town water supply: West. Australia Geol. Survey Ann. Rept 1963, p. 15.

——— 1965, Hydrogeology of the Allanooka Area, Geraldton District, Western Australia: West. Australia Geol. Survey Rec. 1965/15 (unpublished).

Barnett, J. C., 1977, Report on groundwater prospects for Mingenew town water supply: West. Australia Geol. Survey Hydro. Rept No. 1518 (unpublished).

Commander, D. P., 1978, Geology and hydrogeology of the Eneabba borehole line: West. Australia Geol. Survey Rec. 1978/7.

Davidson, W.A., 1976, Irwin View proposed drilling: West. Australia Geol. Survey Hydro. Rept No. 1461 (unpublished).

Forth, J. R., 1971, An appraisal of the effects of long term pumping in the Lake Allanooka Area: West. Australia Geol. Survey Hydro. Rept No. 862 (unpublished).

——— 1972, A reappraisal of the Yule River Area: Port Hedland Town Water Supply, and an appraisal of the effects of long-term pumping in the Lake Allanooka area: West. Australia Geol. Survey Rept Series No. 2.

——— 1973, Additional water supplies for Geraldton Town: West. Australia Geol. Survey Hydro. Rept No. 1151 (unpublished).

Grey, G., 1841, Journals of two expeditions of discovery in North-West and Western Australia, during the years 1837, 38, and 39: Boone, London.

Hingston, F. J., and Gailitis, V., 1977, Salts in rainfall in Western Australia (1973–1974): Australia CSIRO Division Land Resources Management Tech. Memo 77/1.

Johnson, W., de la Hunty, L. E., and Gleeson, J. S., 1954, The geology of the Irwin River and Eradu Districts and surrounding country: West. Australia Geol. Survey Bull. 108.

Jones, D. K., and Pearson, G. R., 1972, The tectonic elements of the Perth Basin: Australian Petroleum Explor. Ass. Jour., v. 12 pt. 1, p. 12–22.

Maitland, A. G., 1913, The artesian water resources of Western Australia: Appendix M in Rept Interstate Conference on Artesian Water, Sydney.

Playford, P. E., 1959, Jurassic stratigraphy of the Geraldton District, Western Australia: Roy Soc. West. Australia Jour., v. 42, p. 101–124.

Playford, P. E., Cockbain, A. E., and Low, G. H., 1976, Geology of the Perth Basin, Western Australia: West. Australia Geol. Survey Bull. 124.

Ventriss, H. B., and Parsons, G. W. 1978, Groundwater system review—Allanooka: West. Australia Public Works Dept, Water Resources Section, P.D. & I. Branch Rept, June 1978.

Western Australia Public Works Department, 1967, Geraldton, Allanooka Water Supply: Official Opening Pamphlet.

THE HYDROGEOLOGY OF LAKE JANDABUP, SWAN COASTAL PLAIN, W.A.

by A. D. Allen

ABSTRACT

Lake Jandabup is one of a chain of round or oval-shaped, shallow lakes on the Swan Coastal Plain. It is up to 1·5 m deep and is 3·95 km² in area. The lake is filled by reeds (*Cladium* spp.) except for a central area of open water 1·2 km² in extent. It contains lake deposits of diatomite up to 0·8 m thick extending over 55% of the lake bed while the remainder is sand. These deposits rest on sandy Pliocene-Holocene sediments which unconformably overlie Late Cretaceous sediments. A regional groundwater flow system (Gnangara Mound) occurs in the Pliocene-Holocene superficial formations. The system is in hydraulic continuity with the lake water so that variations in water table levels also affect lake levels. Groundwater flow into the lake occurs through the sandy sediments on its eastern side and outflow takes place through the lake deposits around the southwest margin. Rainfall adds a significant volume of water to the lake but losses by evapotranspiration are greater. Between April 1977 and March 1978 inflow was estimated to be 4·49 x 10⁶ m³; rainfall 2·04 x 10⁶ m³; outflow 1·10 x 10⁶ m³; and evapotranspiration 5·87 x 10⁶ m³. The groundwater inflow to the lake was from the upper part of the flow system while the lower part moved beneath the lake and into the underlying Cretaceous sediments. A plume of groundwater with a chlorinity five times that of the inflow was proved to extend downstream from the lake.

INTRODUCTION

LOCATION AND TENURE

Lake Jandabup is about 22 km north of Perth and 3 km east of Wanneroo (Fig. 1).

The lake is surrounded by freehold land except for a small area of Crown Land on its southeastern shore. The boundaries of the freehold land include part of the lake so that over a third of the lake is privately owned. The central part, including most of the open water, is a C class reserve for the conservation of flora and fauna, vested in the Department of Fisheries and Wildlife. There are also existing mineral claims for the extraction of diatomite.

CLIMATE AND VEGETATION

The climate in the vicinity of Lake Jandabup is Mediterranean with hot, dry summers and mild, wet winters. The annual rainfall is about 840 mm of which about 90% is received during the winter months between April and October. During the summer, temperatures and evaporation are high. The average maximum temperature ranges from 29·5°C in February to 17·0°C in July. Evaporation is highest in January (262 mm) when on extreme days it exceeds 12 mm, and is lowest in June (50 mm). The annual average evaporation is 1 707 mm, twice as much as the rainfall.

The vegetation in and around Lake Jandabup has been mapped by Marchant, in How (1978). It consists of algae and a few aquatic plants in the area of open water; a narrow zone of reeds (*Cladium junceum*) bordering the open water; a broad zone of reeds (*Cladium articulatum*) extending to the shores of the lake; and a narrow zone of sedges and grasses around the periphery of the zone subject to occasional inundation. Large trees are very sparse. Those which occur are restricted to a number of small groves amongst low scrub growing on the higher, old shorelines.

Around the northeastern part of the lake the marginal vegetation has been cleared up to 200 m from the present shoreline, toward the centre of the lake.

INVESTIGATION

An investigation programme for Lake Jandabup and other lakes on the coastal plain was proposed by Allen (1976b). The present study is a modification of the original proposals. Work commenced in 1976 and after construction of the observation bores, water samples were obtained for analysis and water levels monitored for a year prior to compilation and analysis of the results.

Observation bores

A trial bore (S9) was drilled near the southern shore of the lake in October 1976. Later, between January and August 1977, 31 bores at 16 sites (1 to 3 bores per site) were drilled around the lake (Fig. 1). A deep bore in the centre of the

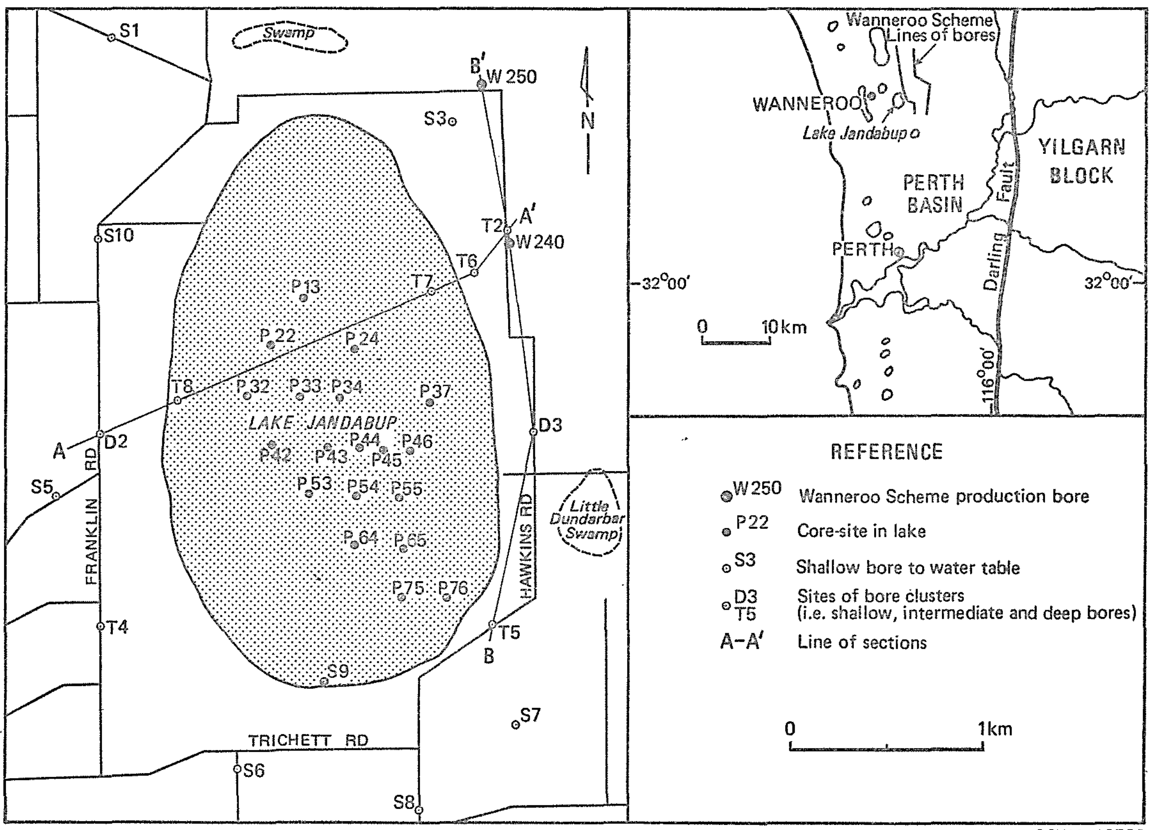


Figure 1 Locality plan.

TABLE 1. SUMMARY OF CABLE-TOOL DRILLING RESULTS

Name	Commenced	Completed	m A.H.D.		Depth (m)	Slotting (m bns)	Water level (A.H.D.) 28/3/78	Chloride (mg/L) (May 1978)	Status	Base Superficial Formations (m bns)	Remarks
			Surface	Steel Casing							
S1	11/5/77	12/5/77	52·31	52·89	15	9–15	43·80	39	Shallow	....	
S3	11/7/77	12/7/77	57·20	57·92	22	10–20	n.a.	50	Shallow, not in use	....	
S5	1/7/77	7/7/77	63·87	64·20	22	10–22	42·76	201	Shallow	....	
S6	13/7/77	14/7/77	62·76	63·28	30	18–30	42·80	257	Shallow	....	
S7	18/7/77	18/7/77	49·44	49·97	12	6–10·7	45·67	35	Shallow	....	
S8	7/7/77	8/7/77	50·70	51·29	18	6–16	43·10	76	Shallow	....	
S9	26/10/77	26/10/77	n.a.	n.a.	6·2	0–6·2	n.a.	....	Shallow, not in use	....	
S10	9/7/77	11/7/77	57·06	57·63	22	10–22	43·38	102	Shallow	....	
D2A	15/3/77	23/3/77	55·85	55·83	70	62–64	43·22	267	Deep	65	
D2B	26/3/77	28/3/77	55·86	55·83	30	26–28	42·98	223	Intermediate	....	WM21 used as a shallow monitoring bore this site
D3A	9/3/77	14/3/77	52·91	53·38	62	50–52	45·98	73	Deep	54	?Poison Hill Greensand at base
D3B	2/3/77	4/3/77	52·99	53·45	22	18–20	46·53	73	Intermediate	....	
D3C	7/3/77	7/3/77	52·90	53·34	7	0–7	46·29	38	Shallow	....	
T2A	14/2/77	22/2/77	52·09	52·70	62	51–53	46·15	59	Deep	60·5	?Poison Hill Greensand at base
T2B	28/2/77	29/2/77	52·06	52·63	32	28–30	46·98	63	Intermediate	....	
T2C	1/3/77	1/3/77	52·07	52·61	7	0–7	48·56	62	Shallow	....	
T4A	29/3/77	6/4/77	63·02	63·04	77	62–64	42·56	197	Deep	74	
T4B	12/4/77	13/4/77	63·12	63·14	31	27–29	42·52	140	Intermediate	....	
T4C	14/4/77	15/4/77	63·18	63·22	20	18–20	42·70	....	Shallow	....	
T5A	24/1/77	2/2/77	50·50	50·53	60·3	50–52	45·46	102	Deep	58	
T5B	7/2/77	9/2/77	50·48	50·51	28	25–27	45·58	108	Intermediate	....	
T5C	10/2/77	10/2/77	50·38	50·41	7	0–7	45·43	25	Shallow	....	
T6A	8/6/77	22/6/77	47·74	48·24	62	50–52	45·88	51	Deep	54	
T6B	29/6/77	30/6/77	47·63	48·28	31	26–28	45·77	39	Intermediate	....	
T6C	29/6/77	30/6/77	47·64	48·20	9	0–8·2	45·84	63	Shallow	....	
T7A	17/5/77	1/6/77	46·79	47·20	58	51–53	44·98	63	Deep	54	?Poison Hill Greensand at base
T7B	19/5/77	2/6/77	46·68	47·07	29	24–26	45·17	49	Intermediate	....	
T7C	3/6/77	3/6/77	47·34	46·83	8	0–8	44·64	38	Shallow	....	
T8A	27/7/77	11/8/77	46·33	46·77	60·6	45–47	43·70	235	Deep	54	
T8B	17/8/77	19/8/77	46·33	46·72	26	21–23	43·62	252	Intermediate	....	
T8C	26/7/77	26/7/77	46·33	46·68	10	0–10	43·68	240	Shallow	....	

lake was also proposed but was not drilled because of the high cost. The bores were drilled by private contractors using cable-tool drilling rigs. They ranged in depth to 77 m and had an aggregate depth of 956·3 m (Table 1).

The sites were designated T (3 bores, deep, intermediate and shallow), D (2 bores, intermediate and shallow), and S (1 bore, shallow). The deep, intermediate and shallow bores were distinguished by the suffixes A, B, and C respectively. However, a deep bore was also drilled at all the D sites so that T and D sites were the same, with the exception of site D2 where a shallow bore (D2C) was not drilled because of the proximity of Wanneroo Monitoring No. 21 (WM21) shallow bore, which could be used.

At the T and D sites the deep bore was drilled first. Strata samples were taken at 2 m intervals and a bottom-hole sample was obtained for palaeontological examination after penetrating the underlying Cretaceous formation. On reaching total depth, or after casing the bore, a gamma ray log was run to assist correlation and to define bed boundaries.

An observation interval was selected near the bottom of each deep bore, at the base of the superficial formations. Then 80 mm class 9 PVC casing with bottom cap, sump, 2 m slotted interval and blank casing back to the surface was inserted. This was sand packed back to about 0·5 m above the slotted interval and the rest of the annulus was filled with cement slurry. For each intermediate bore an interval toward the middle of the Kwinana Group was selected and a bore drilled and constructed similar to the deep bore. The shallow bores were drilled to about 7 m below the water table and 80 mm class 9 PVC casing slotted over its entire length was inserted and stabilized with a sand pack. All the bores were fitted with protective steel sleeves fitted with hinged caps and set in a concrete block or, in some cases, fitted with flush magnetic caps set into the cement block. After construction the bores were developed by bailing, and later pumped, using a portable submersible pump to obtain water samples for chemical analysis.

Coring lake deposits

In January-March 1977 attempts were made to core the lake deposits at the sites shown in Figure 1. The coring was done using a pontoon-mounted "Vibroseis" rig designed and operated by the Harbours and Rivers Branch of the Public Works Department. Owing to the difficulty of moving through reeds, sites were limited to a 250 m grid in the area of open water. The rig vibrated a core barrel of 64 mm diameter PVC into the lake deposits. When no further penetration could be obtained the core barrel was removed from the hole. The core was retained by friction within the core barrel, which was cut lengthwise when the core was to be examined. However, the cores were usually partially or completely washed out and frequently were not retained in the core barrel. Roots and bog limestone also occasionally prevented penetration of the barrel. Coring was tried in 24 bores at 19 sites. Measured from the surface of the lake the aggregate depth of coring was about 115 m and the maximum depth cored was 7·9 m. Because of the generally unsatisfactory nature of the cores this programme was abandoned after considerable experimentation.

Augering and trenching

In March 1977 and February 1978 when the lake level was low, augering and trenching to examine sediments and groundwater movement was carried out in and around the lake.

Water sampling

On completion of some of the observation bores bailed samples were taken for partial analysis. Later, in May 1978, groundwater samples for standard analysis (Table 2) were obtained from the majority of the observation bores using a portable submersible pump. The bores were pumped at 0·3 L/sec (25·9 m^3/d) for 20, 30, or 60 minutes depending on whether the bore was shallow, intermediate or deep. Water samples from the surface of the lake (at the core sites) were taken on 25th March 1977 for partial analysis. All analyses were made by the Government Chemical Laboratories.

Levelling and monitoring

The natural surface and top of casing for all bores were levelled to the Australian Height Datum (AHD).

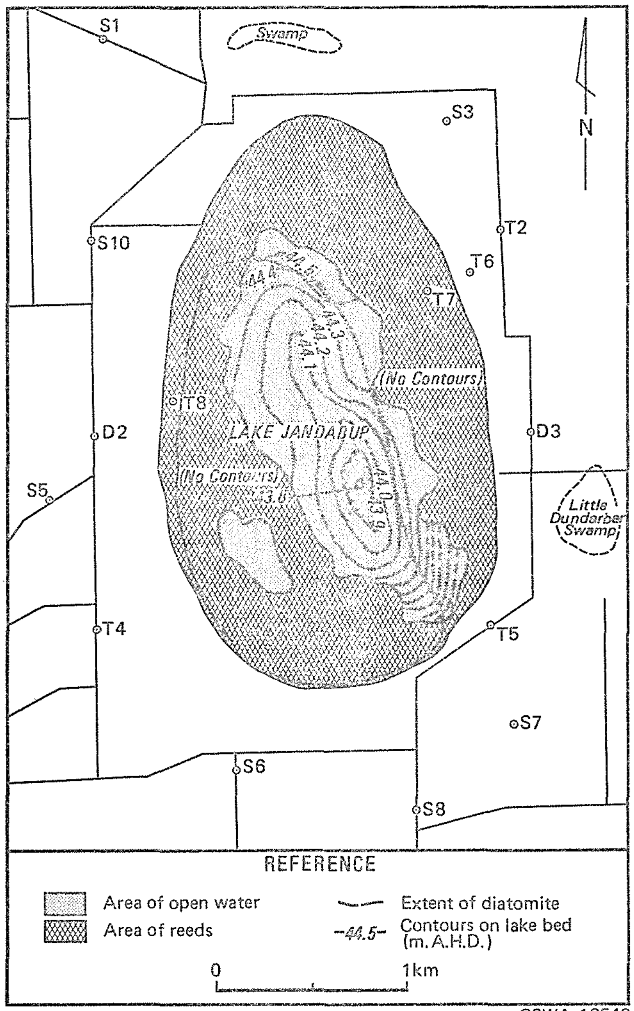
Groundwater levels were measured at synoptic, monthly intervals except at sites S3 and S9 which were omitted by mistake, and bore WM21 (to be used in lieu of D2C) which was damaged. The water levels are recorded in the MWB computerized groundwater levels record system.

PHYSIOGRAPHY

Lake Jandabup is situated in a depression which extends in a northwesterly direction, from where Bennet Brook enters the Swan River, to Lake Pinjar. The main part of the depression is near the junction of the Spearwood and Bassendean Dune Systems (McArthur and Bettenay, 1974). It appears the depression was a shallow, temporary arm of the Swan estuary during a period of high sea level, probably at the time of formation of the Spearwood Dunes. Subsequently the depression was modified and partly infilled with beach ridges, lunettes, and eolian dunes, which have produced the present system of isolated lakes and swamps.

Lake Jandabup occupies a shallow, north-south oval basin about 3 km long, 2 km wide and with an elevation of 50 m. The basin is closed by sand ridges except in the northwestern part where there is a low saddle marking the margin of an adjoining depression containing a series of small lakes and swamps.

The size of Lake Jandabup varies seasonally, and from year to year. The outer margin of the vegetation which marks the shoreline is at about 45·5 m A.H.D. Within this boundary the lake is about 2·8 km long and 1·7 km wide with an area of 3·95 km² and a circumference of about 6·5 km. Open water in the lake is restricted to a reed-bounded area of about 1·2 km² in the centre. Contours of the lake bed (Fig. 2), beneath the area of open water, show that this occupies a canoe-shaped depression with the deepest point at 43·8 m A.H.D. The rest of the lake bed is relatively flat except for a small depression in the southwest marked by an area of open water. The maximum water depth varies from 1·5 m in winter to about 0·5 m in summer and the corresponding volumes are about 3·0 x 10⁶ m³ and 1·5 x 10⁶ m³.

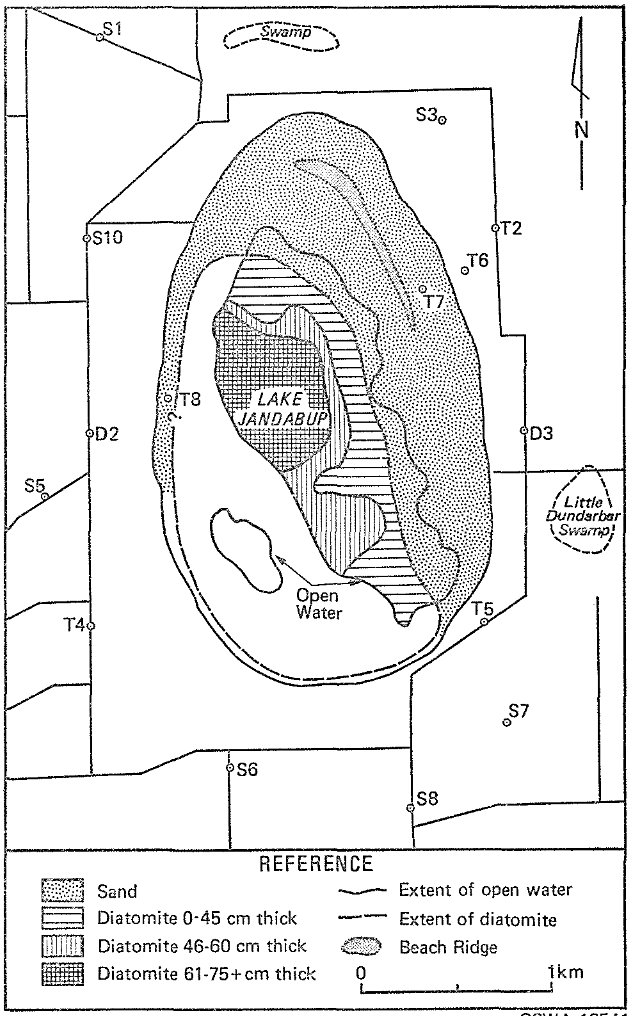


GSWA 18540

Figure 2 Contours of lake bed.

Fifty five per cent of the lake bed is covered with organic sediments, mainly diatomite, while the peripheral part is covered with carbonaceous sand (Fig. 3). The sand is most extensive in the northeastern part of the lake, possibly as a result of shoreline erosion, as this part faces the prevailing southwesterly wind. Near the edge of the diatomite the sand on the lake bed is strewn with rounded pebbles of diatomite 20 mm to 100 mm in diameter, which locally form pebble pavements grading laterally into diatomite which has an irregular but smoothed surface.

Around the northeastern shore of the lake, former shorelines can be recognized at about 46 m A.H.D. and 48 m A.H.D. These are distinguishable by changes in slope and vegetation cover. The 46 m A.H.D. shoreline around the northern and eastern edges of the lake is associated with beach ridges which locally support large trees, indicating that lake levels have been lower than 46 m A.H.D. for a considerable time. The pebble pavement of diatomite at about 44·2 m A.H.D. indicates that the diatomite has formerly been exposed to subaerial weathering or shallow wave action, indicating former low lake levels.



GSWA 18541

Figure 3 Lake deposits (diatomite and sand).

GEOLOGY

SETTING

Lake Jandabup is situated within the Perth Basin. It occupies a shallow depression, in Late Tertiary-Quaternary superficial formations which unconformably overlie Permian to Early Tertiary sedimentary rocks about 10 000 m thick. The lake contains a thin sequence of Quaternary lake deposits.

STRATIGRAPHY

The stratigraphic sequence at Lake Jandabup is given in Table 3.

Cretaceous

Poison Hill Greensand: The Poison Hill Greensand (Fairbridge, 1953) is believed to underlie the Lake Jandabup area. It has tentatively been identified on palaeontological evidence (Backhouse, 1977a, b, c). The formation was intersected in the base of all the deep bores and consists of dark-green to olive-green, glauconitic, sandy, slightly calcareous siltstone; and dark-green, clayey, poorly consolidated sandstone, which contains rare fossil fragments. The total thickness of the formation is not known, but it exceeds 8 m in D3A. It is unconformably overlain by the superficial formations.

Tertiary-Quaternary

Superficial formations: The superficial formations consist of an unconsolidated sequence of shallow-water marine and eolian deposits. The lower third of the sequence consists of a discontinuous sandy calcarenite lithologically similar, and possibly referable to the Ascot Beds (Playford and others, 1976). This section is principally a calcareous, slightly fossiliferous sand and a fine to coarse bimodal sand containing heavy minerals. Locally it contains quartz pebbles, pyrite, feldspar and carbonaceous fragments. These sediments are overlain by a uniform fine to coarse sand which tends to be feldspathic and contains occasional thin beds of clay and silt, which are, in turn, overlain by fine- to medium-grained

TABLE 2. STANDARD ANALYSES OF GROUNDWATER, SAMPLED MAY 1978

	GCL Lab. No.	pH	Turbidity,	Colour (APHA units)	Odour	C mS/m at 25°C	TDS (Evap.) (milligrams per litre)	TDS (Cond.)	Free CO_2	Total Hard. (as $CaCO_3$)	Total Alk. (as $CaCO_3$)	Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4	NO_3	SiO_2	B	F	Fe	Mn	Cu	Pb	As	P	Nitrogen NH_4	Nitrogen NO_3	Remarks
S1	82491/78	6·1	60	220	nil	22	130	140	....	42	17	7	6	20	2	nil	21	39	15	....	8	0·07	<0·1	1·2	<0·02	<0·02	<0·01	<0·01	0·01	0·27	0·02	
S3	82702/78	5·2	14	18	nil	21	130	130	....	18	7	1	4	31	2	nil	9	50	11	....	7	0·05	<0·1	0·76	<0·02	0·07	0·01	<0·01	0·01	0·12	<0·02	
S5	82578/78	5·6	150	5	nil	79	440	510	50	85	10	6	17	119	3	nil	12	201	40	16	10	<0·05	<0·01	0·30	<0·02	0·07	0·01	<0·01	0·01	0·18	3·66	45 mins at 27m³/day
S6	82579/78	5·7	700	120	H_2S	93	540	600	83	81	33	11	13	149	7	nil	40	257	17	<1	9	0·03	<0·1	0·46	<0·02	0·03	0·01	<0·01	0·05	0·40	0·03	Ditto
S7	82701/78	5·5	35	200	H_2S	16	140	100	....	14	10	1	3	23	1	nil	12	35	7	<1	6	0·19	<0·1	0·36	<0·02	0·03	0·01	<0·01	0·01	0·14	<0·02	45 mins at 27m³/day
S8	82492/78	5·6	610	225	nil	31	190	200	....	35	20	4	6	46	2	nil	24	76	11	....	8	0·06	<0·1	1·1	<0·02	<0·02	<0·01	<0·01	0·05	0·25	0·02	
S10	82493/78	6·2	200	165	nil	49	280	310	....	86	35	13	13	57	2	nil	43	102	18	19	8	0·08	<0·1	0·4	<0·02	<0·02	0·02	<0·01	0·03	0·18	4·2	
D2A	82490/78	6·4	13	25	H_2S	114	630	730	....	166	135	32	21	160	8	nil	165	267	13	....	38	0·09	<0·1	<0·05	<0·02	<0·02	<0·01	<0·01	0·02	3·4	0·02	
D2B	82576/78	6·8	80	<5	nil	99	560	630	48	177	150	43	17	129	7	nil	183	223	3	<1	29	0·1	0·1	0·14	0·07	<0·02	0·02	<0·01	0·01	2·90	<0·02	30 mins at 27m³/day
D2C	82577/78	5·6	4	120	nil	69	400	440	75	60	15	6	11	104	6	nil	18	188	11	1	9	0·16	<0·1	0·36	<0·02	0·04	0·01	<0·01	0·01	0·79	0·13	Ditto
D3A	82558/78	6·9	250	66	nil	52	290	330	38	160	150	46	11	42	4	nil	183	73	4	<1	12	0·06	0·1	3·2	0·04	<0·02	<0·01	<0·01	0·05	0·49	0·03	1 hour at 27m³/day
D3B	82559/78	5·4	1 000	17	nil	27	150	170	80	37	10	5	6	37	2	nil	12	73	6	<1	9	0·01	0·1	0·08	<0·02	<0·02	<0·01	<0·01	0·01	0·09	<0·02	30 mins at 27m³/day
D3C	82560/78	5·5	20	16	nil	19	90	120	44	26	7	4	4	27	1	nil	9	38	12	16	7	0·02	<0·1	<0·05	<0·02	0·05	<0·01	<0·01	0·01	0·08	3·65	20 mins at 27m³/day
T2A	82555/78	6·0	300	78	H_2S	29	180	190	90	50	45	10	6	36	3	nil	55	59	4	<1	12	0·06	<0·1	<0·05	0·52	<0·02	0·01	<0·01	0·05	0·25	0·02	1 hour at 27m³/day
T2B	82556/78	5·4	600	49	nil	25	140	160	80	23	10	3	4	36	2	nil	12	63	5	<1	10	0·06	<0·1	<0·05	0·16	<0·02	0·02	<0·01	0·01	0·23	0·03	30 mins at 27m³/day
T2C	82557/78	5·4	5	210	H_2S	25	150	160	80	26	10	2	5	36	1	nil	12	62	8	<1	9	0·06	<0·1	0·5	<0·02	<0·02	<0·01	<0·01	0·01	0·21	0·05	20 mins at 27m³/day
T4A	82580/78	6·7	10	22	musty	88	480	560	44	123	110	26	14	120	7	nil	134	197	5	<1	20	0·22	0·1	1·5	0·04	<0·02	0·05	<0·01	0·04	2·50	0·03	Max permitted Pb, 1 hour at 27m³/day
T4B	82581/78	6·1	300	100	H_2S	95	540	610	60	107	43	15	17	143	7	nil	52	240	44	<1	6	0·29	<0·1	0·54	<0·02	<0·02	<0·01	<0·01	0·01	0·39	0·02	30 mins at 27m³/day
T5A	82506/78	6·4	20 000	70	musty	51	260	330	....	79	76	12	12	65	4	nil	92	102	6	....	9	0·08	0·1	....	....	....	....	....	....	....	....	Too clayey to analyze metals and nutrients
T5B	82507/78	6·0	28	230	H_2S	42	250	270	....	53	17	5	10	54	2	nil	21	108	4	....	10	0·09	<0·1	0·28	<0·02	<0·02	<0·01	<0·01	0·01	0·30	0·02	
T5C	82508/78	5·8	1 000	69	nil	13	90	80	....	19	12	3	3	17	2	nil	15	25	12	....	7	0·06	<0·1	0·17	<0·02	<0·02	<0·01	<0·01	0·09	0·31	0·06	
T6A	82561/78	7·1	1 700	50	organic	52	300	330	30	171	186	57	7	38	4	nil	226	51	2	....	15	0·03	0·1	5·9	0·16	<0·02	<0·01	<0·01	0·04	0·27	0·05	1 hour at 27m³/day
T6B	82562/78	5·7	7 000	15	nil	19	120	120	68	15	17	3	2	30	1	nil	21	39	10	<1	8	0·05	<0·1	0·54	<0·02	<0·02	<0·01	<0·01	0·06	0·10	0·06	30 mins at 27m³/day
T6C	82563/78	5·1	50	240	nil	26	170	170	79	40	5	3	8	35	2	nil	6	63	24	<1	8	0·07	<0·1	0·86	<0·02	0·02	<0·01	<0·01	0·03	0·18	<0·02	20 mins at 27m³/day
T7A	82564/78	7·4	19 000	48	organic	54	310	350	15	186	183	58	10	37	5	nil	223	63	2	<1	10	0·06	0·1	1·1	<0·02	<0·02	<0·01	<0·01	0·04	0·27	<0·02	1 hour at 27m³/day
T7B	82565/78	5·3	300	25	nil	22	130	140	70	13	7	2	2	34	2	nil	9	49	13	<1	9	0·04	<0·1	0·06	<0·02	<0·02	<0·01	<0·01	0·03	0·15	<0·02	30 mins at 27m³/day
T7C	82566/78	5·5	70	410	H_2S	18	160	120	63	9	10	2	1	32	1	nil	12	38	15	<1	9	0·13	<0·1	0·74	<0·02	0·02	<0·01	<0·01	0·03	0·52	<0·02	20 mins at 27m³/day
T8A	82698/78	6·1	2	210	H_2S	85	510	540	....	63	40	9	10	142	7	nil	49	235	10	<1	8	0·05	<0·1	0·76	<0·02	0·02	0·01	<0·01	0·06	0·89	<0·02	1 hour at 27m³/day
T8B	82699/78	7·7	310	88	H_2S	118	670	760	....	228	198	57	21	150	7	nil	241	252	11	<1	30	0·09	0·1	0·06	0·12	<0·02	<0·01	<0·01	0·08	3·4	<0·02	30 mins at 27m³/day
T8C	82700/78	6·2	5	63	H_2S	87	470	560	....	81	45	11	13	138	6	nil	55	240	5	<1	13	0·05	<0·1	0·28	<0·02	<0·02	<0·01	<0·01	0·02	0·92	<0·02	20 mins at 27m³/day
W250*	10249/74	6·0	25	60	H_2S	....	190	140	70	46	38	12	4	35	2	nil	46	5	58	....	11	0·05	0·1	0·37	<0·05	<0·05	<0·02	<0·02	0·03	0·25	<0·02	

* Sampled 22/5/74

TABLE 3. STRATIGRAPHIC SEQUENCE, LAKE JANDABUP AREA

Age	Formation	Max. thickness (m)	Lithology	Remarks
Quaternary	"Lake deposits"	2	Diatomite, peat, sand, minor limnic peat and bog limestone	
		?DISCONFORMITY		
Late Tertiary-Quaternary	Superficial formations	75	Fine-medium sand, calcareous sand, limestone, minor clay and ferruginous sand	Variable thickness and lithology
		UNCONFORMITY		
Late Cretaceous	?Poison Hill Greensand	8+	Glauconitic sand, glauconitic siltstone	Formation not definitely identified

sand of probable eolian origin. An irregular layer of limonite-cemented sand (coffee rock) occurs at the water table in the vicinity of the swampy depressions (Fig. 4).

The superficial formations rest unconformably on Cretaceous sediments, probably the Poison Hill Greensand, and are overlain by the lake deposits with probable disconformity. The unconformity with the Cretaceous is at a depth of about −1 m A.H.D. to −18 m A.H.D. and the thickness of the superficial formations ranges from about 45 m to 75 m depending on the topography.

No identifiable fossils were obtained from samples but the sediments probably range from Pliocene to Holocene age (Playford and others, 1976).

Lake deposits: The lake deposits (Fig. 3) consist of medium to coarse carbonaceous sand about 0·1 m thick which grades up into a carbonaceous diatomite towards the centre of the lake. This diatomite is as much as 0·8 m thick and locally contains layers of limnic peat and limestone up to ·05 m thick. These sediments are still in the process of deposition. The beach ridges, which mainly occur around the northeastern shore of the lake, are included with the lake deposits. They consist of medium sand with a thickness of up to 2 m.

Simpson (1903) gave a brief description of the diatomite occurring in Lake Jandabup and was of the opinion that the deposit may have been burned by bush fires during previous dry periods. The extent of the diatomite and approximate isopachs are given in Figure 3, which shows that the area of its greatest thickness does not coincide with the deepest part of the lake (Fig. 2). It is estimated that about 800 000 m^3 of diatomite occur within the lake. Samples of diatomite contained the following tentatively identified genera of diatoms, *Synedra*, *Surinella* and *Navicula* (Grey, 1977). Locally the diatomite also contained siliceous sponge spicules. The carbonaceous sand contains fragments of paperbark (*Melaleuca* sp.) not presently found growing around the lake. The age of the lake deposits is probably Late Pleistocene to Holocene.

STRUCTURE

Geological sections through the Lake Jandabup area illustrating the stratigraphy and geological structure are given in Figure 4.

The ?Poison Hill Greensand is believed to be flat-lying, but there is considerable relief on the unconformity between it and the superficial formations. There is a prominent east-west ridge in this unconformity which rises to an elevation of −2 m A.H.D. beneath the east-central part of the lake, and then falls to about −18 m A.H.D. beneath the southwestern side. The overlying superficial formations are flat-lying, but the apparent irregularity of some units suggests there are erosional breaks in the sequence. The overlying lake deposits form a thin saucer-shaped deposit slightly asymmetric toward the west, which probably disconformably overlies the superficial formations.

HYDROGEOLOGY

INTER-RELATIONSHIP OF LAKE AND GROUNDWATER

Lake Jandabup is in hydraulic connection with a regional groundwater flow system referred to as the Gnangara Mound (Allen, 1976a). This flow system is in dynamic balance between topography, geology, climatic factors, and vegetation. At present these factors combine so that the water table on

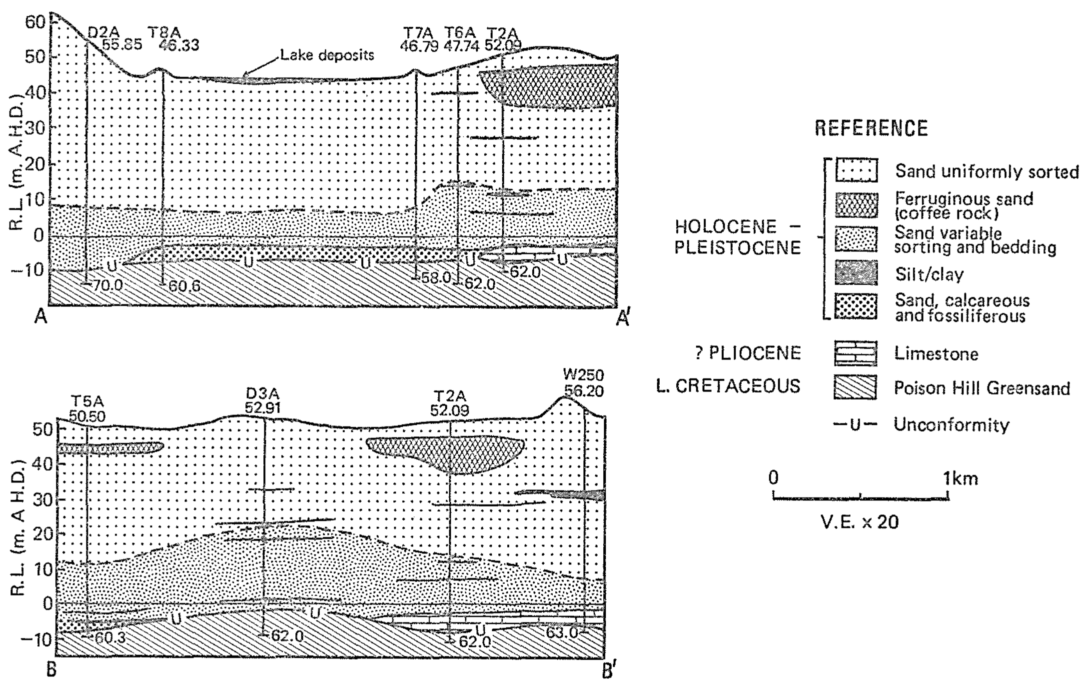


Figure 4 Geological sections.

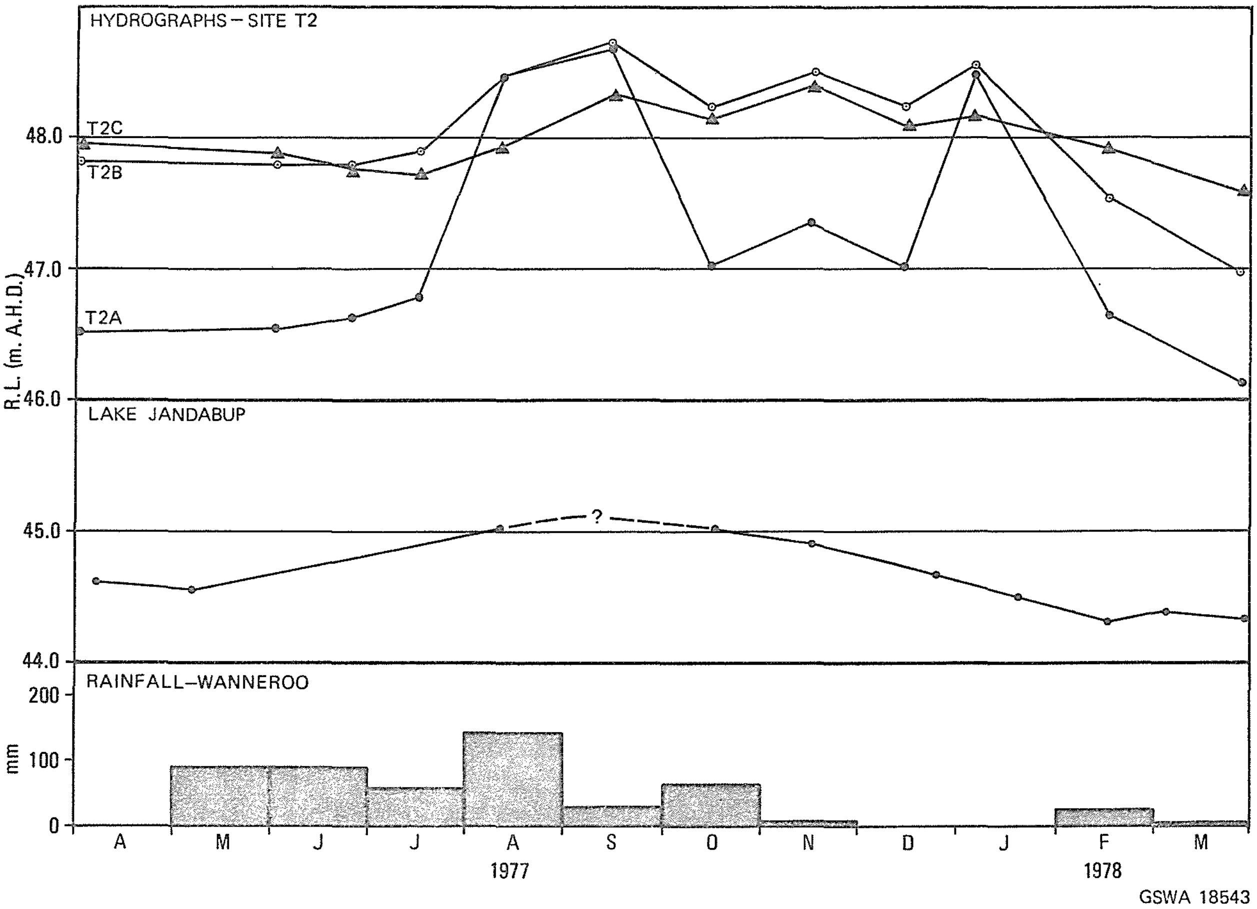


Figure 5 Hydrographs showing relationship to rainfall, lake level.

the eastern side of the lake is at a higher elevation than the lake bed, with the result that inflowing groundwater, together with rainfall, maintain water in the lake.

The lake level and the water table vary in phase, though it is probable that heavy rainfall events would affect the lake more rapidly than the groundwater. The water table and consequent lake level are usually highest in October after the winter rainfall and lowest in March at the end of summer (Fig. 5).

Maps of the water table around Lake Jandabup for October 1977 (winter) and March 1978 (summer) show that on the eastern side of the lake the groundwater has a relatively steep gradient with flow lines converging on the lake (Fig. 6). To the west the gradient is flatter and flow lines diverge. The pattern is essentially the same for winter and summer except that in winter the elevation of the water table is higher and the sections contributing inflow and accepting outflow are slightly longer. The water table decline between October 1977 and March 1978 ranged from 0·4 m to 0·8 m, with the greatest decline occurring along the southwestern margin of the lake where outflow is presumably greatest.

Sections approximately normal to the water table contours incorporating head measurements at different depths in the flow system for October 1977 and March 1978 are given in Figure 7. They show (in two dimensions) that groundwater inflow into the lake is from the upper half of the flow system and that as a result of evapotranspiration the outflow is considerably less than the inflow. The sections also show that during the winter there is flow into the underlying ?Poison Hill Greensand, whereas in the summer there is throughflow beneath the lake.

The groundwater inflow and outflow from the lake were confirmed by augering. On the northeastern side of the lake small artesian flows with head increasing with depth were observed from below a depth of 0·25 m, and runnels can be seen in the sandy lake deposits suggesting the sands form a broad seepage face. On the southwestern shore augering showed a slight decrease in head with depth, indicating the potential for downward flow. Presumably outflow takes place through part of the lake bed and around the sandy shoreline.

WATER BALANCE

A water balance is an accounting of all water entering and leaving a water system. For Lake Jandabup it can be expressed by the equation:

$$G_i + R + V_{77} = D + E_t + V_{78} \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

where G_i = groundwater inflow
R = rainfall
D = outflow
E_t = evapotranspiration
V_{77} = volume of the lake in April 1977
V_{78} = volume of the lake in March 1978

The various components of the water balance are evaluated below for the period April 1977 to March 1978.

Groundwater inflow

The annual groundwater inflow into the eastern side of the lake was estimated by using the form of the Darcy equation:

$$Q = KbIL \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

where Q = groundwater inflow (m^3/d)
K = hydraulic conductivity (m/d)
b = aquifer thickness (m)
I = hydraulic gradient (dimensionless)
L = width of flow section (m)

The hydraulic conductivity was taken as 30 m/d; the thickness of the upper part of the aquifer contributing to groundwater inflow was measured on the 46·5 m (winter) and 46 m isopotentials (summer) in Figure 7; the average hydraulic gradient in summer and winter and the width of the flow section A-A' were measured from Figure 6. The groundwater inflow in October 1977 was:

$$Q = 30 \times 25 \times 0{\cdot}005\,9 \times 2\,960$$
$$= 13\,098 \text{ m}^3/\text{d}$$

and in March 1978 was

$$Q = 30 \times 25 \times 0{\cdot}004\,8 \times 3\,200$$
$$= 11\,520 \text{ m}^3/\text{d}$$

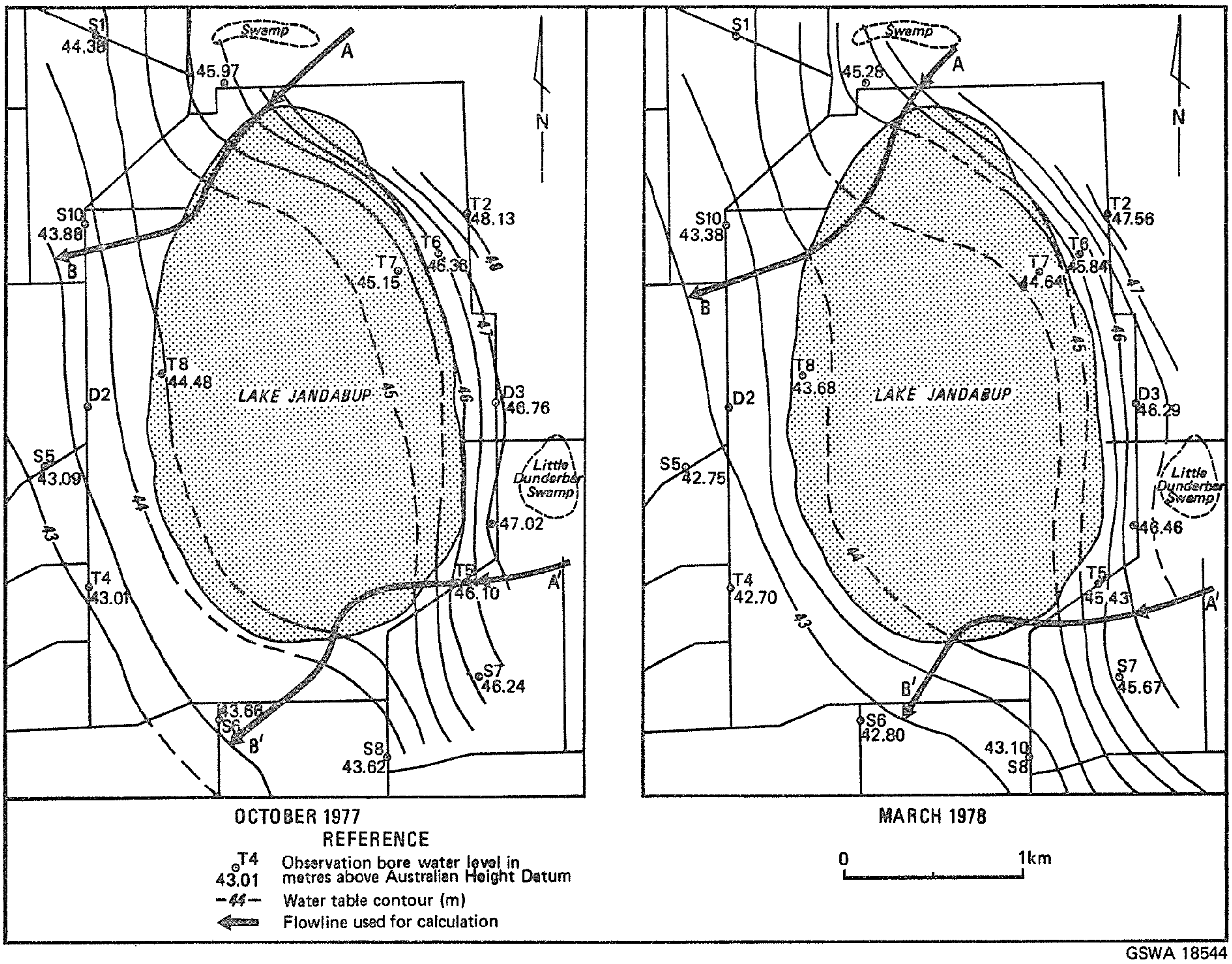


Figure 6 Water table contours.

The annual groundwater inflow from the average of the winter and summer groundwater inflow was $4 \cdot 49 \times 10^6$ m³.

The average annual groundwater throughflow passing beneath the eastern side of the lake for the same isopotentials, gradient and width of cross-section was $4 \cdot 54 \times 10^6$ m³.

Outflow

The average annual outflow from the lake contains a component of water received from direct rainfall. It is assumed to be the average of the winter and summer outflow using the measured aquifer thickness between flow lines on the 43 m isopotential (summer) and 43·5 m isopotential (winter) given in Figure 7, and the average gradient between the 43·0 and 43·5 m contours (summer) and 43·5 and 43·0 contours (winter) for the flow widths shown in Figure 6. The outflow in October was:

$$Q = 30 \times 39 \times 0 \cdot 001\,4 \times 2\,840$$
$$= 4\,652 \text{ m}^3/\text{d}$$

and in March was

$$Q = 30 \times 9 \times 0 \cdot 001\,9 \times 2\,720$$
$$= 1\,395 \text{ m}^3/\text{d}$$

The annual outflow from the average of the summer and winter outflows was $1 \cdot 10 \times 10^6$ m³.

Rainfall

The rainfall input to the lake will vary from year to year. In addition there may also be minor local run-off from around the shores of the lake, but for the present estimate this is disregarded. The area of the lake is 3·95 km² and for the period April 1977 to March 1978 the rainfall was 517 mm (Table 4).

The rainfall input to the lake was:

$$3 \cdot 95 \times 10^6 \times 0 \cdot 517 = 2 \cdot 04 \times 10^6 \text{ m}^3.$$

TABLE 4. RAINFALL AT WANNEROO JANUARY 1977 TO MARCH 1978, IN MILLIMETRES (DEPARTMENT OF METEOROLOGY)

1977												1978		
J	F	M	A	M	J	J	A	S	O	N	D	J	F	M
2	0	2	0	93	93	58	144	28	64	8	0	0	26	3

Evapotranspiration

Evaporation from the free water surface of the lake must be considerable considering the size, shallow depth and exposure, of the lake to wind. Similarly, the reeds extending over an area of about 2·8 km² with their root systems permanently beneath water or drawing from the water table must transpire large volumes of water. It is not possible to reliably estimate these components. They are considered together as evapotranspiration and are assumed to approximate 0·8 of the Class A pan evaporation figures applied to the area of the lake.

The Class A pan evaporation figures for Perth for the period of study are given in Table 5.

Between April 1977 and March 1978 the pan evaporation was 1 857·6 mm compared with an annual average of about 1 706·6 mm (Australian Standard Tank).

Knowing the area of the lake and applying the assumed coefficient to the pan evaporation figures the estimated evapotranspiration loss was:

$$3 \cdot 95 \times 10^6 \times 1 \cdot 857\,6 \times 0 \cdot 8 = 5 \cdot 87 \times 10^6 \text{ m}^3$$

TABLE 5. PAN EVAPORATION AT PERTH IN MILLIMETRES (DEPARTMENT OF METEOROLOGY)

1977												1978		
Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
248·5	226·0	190·3	150·3	74·6	64·6	70·3	88·4	111·9	152·6	199·1	253·8	261·3	219·2	211·8

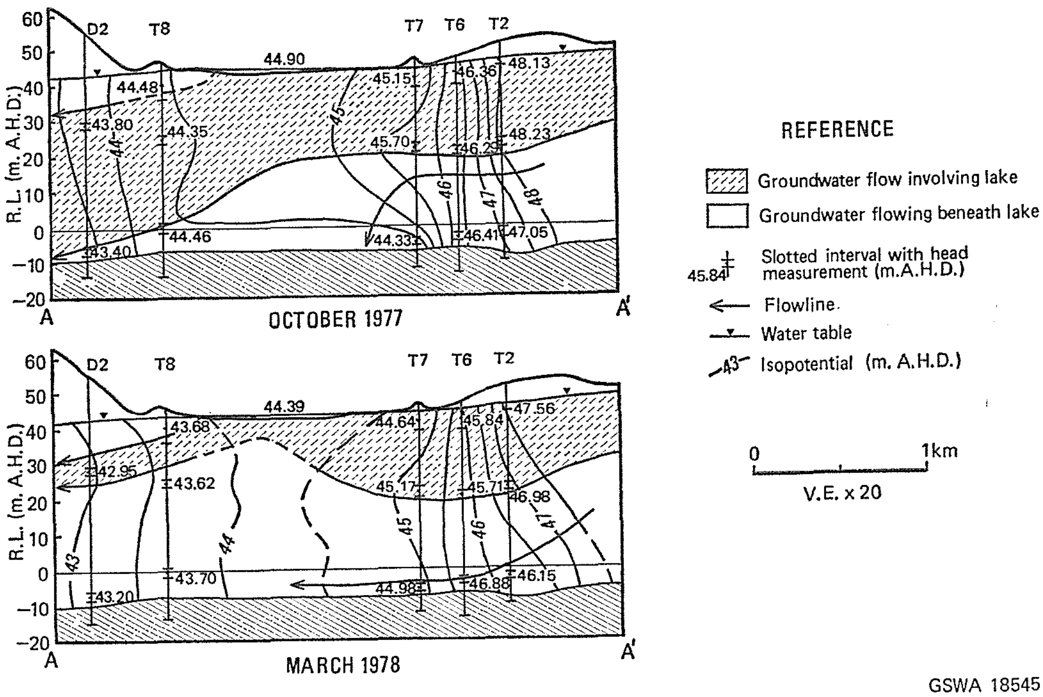


Figure 7 Vertical head variation approximately parallel to direction of groundwater flow.

Change in lake storage

The volume of water in the lake varies between years depending on the seasonal conditions. On 4 April 1977 the level was 44·60 m A.H.D. whereas on 27 April 1978 it was 44·26 m A.H.D., showing a decline of 0·34 m in the lake level and a net reduction in lake storage.

In April 1977 water in the lake extended over an area of about 1·2 km² and from the bottom contours it is calculated that the lake contained about 0·31 x 10^6 m³. In March 1978 the area of the lake was about 0·8 km² and the volume 0·19 x 10^6 m³. The net loss in storage for the year was 0·12 x 10^6 m³.

Balance

Substituting the estimates of the components of the water balance in equation (1) the water balance (millions of cubic metres) is:

$$4{\cdot}49 + 2{\cdot}04 + 0{\cdot}31 \approx 1{\cdot}10 + 5{\cdot}87 + 0{\cdot}19$$
$$6{\cdot}84 \approx 7{\cdot}16$$

The result is a fair balance considering the various assumptions and nature of the data used for calculation. The main features which the balance shows are that rainfall is significant in maintaining the lake and that evapotranspiration is a major source of water loss.

CHLORIDE BALANCE

The chloride in the lake and the groundwater flow system originates from rainfall. The total concentration of chloride is not known to be affected by the aquifer matrix or by vegetation. Consequently if the volumes and chloride concentrations of water entering the lake are known, it is possible to obtain a chloride balance which provides a check on the water balance.

Ignoring evapotranspiration which does not alter the mass of chloride in the system, the chloride balance can be expressed by the following equation:

$$G_i.C_{icl} + R.C_{rcl} + V_{77}.C_{L77c} = D.C_{ocl} + V_{78}.C_{L78cl} \quad .... \quad (3)$$

where G_i = groundwater inflow

C_{icl} = concentration of chloride in groundwater inflow

R = rainfall

C_{rcl} = concentration of chloride in rainfall

V_{77} = volume of lake in April 1977

C_{L77cl} = concentration of chloride in the lake in April 1977

D = outflow

C_{ocl} = concentration of chloride in outflow

V_{78} = volume of the lake in March 1978

C_{L78cl} = concentration of chloride in the lake in March 1978

The mass of chloride of the components in the balance is the product of the volume of water (m³) by the chlorinity (mg/L) which give the chloride content in grams.

Groundwater inflow

Isochlors for the upper part of the groundwater flow system (to 7 m below water table) are given in Figure 8. These show water of relatively uniform chlorinity on the eastern side of the lake and a plume of chloride-enriched groundwater extending from the southwestern side of the lake. The isochlors of the lake water also show an increase in concentration toward the southwest, confirming the direction of groundwater flow (Fig. 6).

Vertical variation in chlorinity in the flow system is shown in the section A-A′ in Figure 8. These data taken together with the vertical isopotentials (Fig. 7) show that groundwater in the upper part of the flow system which enters the lake has an average chlorinity of 43·5 mg/L (Site T7, average of shallow and intermediate bores). As the groundwater inflow for the period has been estimated to be 4·49 x 10^6 m³, the associated chloride input becomes 4·49 x 10^6 x 43·5 = 195·3 t.

Rainfall

The mean annual chloride concentration in rainfall decreases with increasing distance inland. In Perth the mean annual chloride concentration was 12·0 mg/L in 1973 and 10·7 mg/L in 1974 (Hingston and Gailitis, 1977). Lake Jandabup occurs at a similar distance inland and the average of these

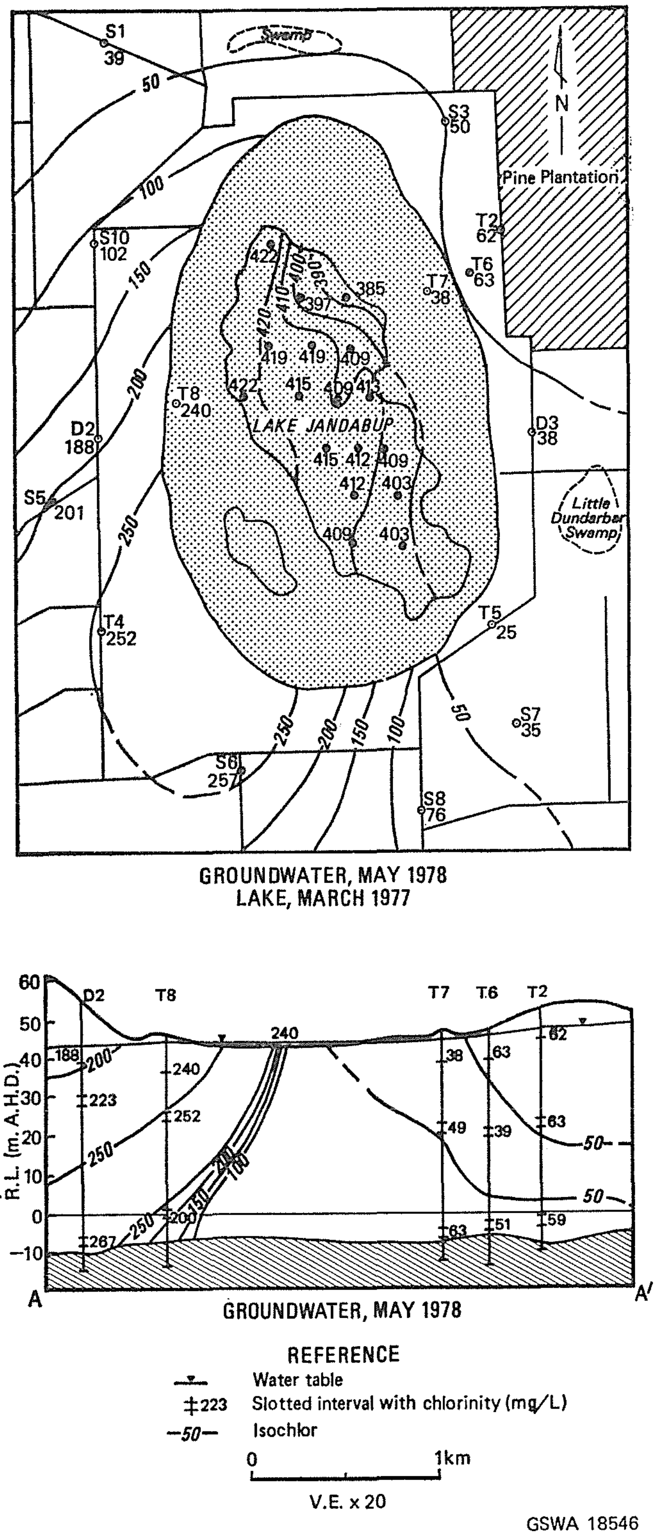


Figure 8 Variations in chlorinity at the water table and in a section approximately parallel to the direction of groundwater movement.

two values, 11·4 mg/L, is assumed to be the rainfall chlorinity for April 1977 to March 1978. As the rainfall input was 2·04 x 10^6 m^3, the mass of chloride added to the lake was 2·04 x 10^6 x 11·4 = 23·3 t.

Lake Water

The chloride content in Lake Jandabup varies throughout the year, being lowest at the end of winter and highest toward the end of summer. It also varies from year to year depending mainly on the amount of rainfall and rate of evaporation. Chloride analyses for the water from Lake Jandabup (Table 6) show the seasonal and annual variations which may occur.

TABLE 6. CHLORIDE ANALYSES FROM LAKE JANDABUP

Date	25/3/77	Early 5/1977*	Late 5/1977*	28/10/77*	23/5/78
Cl (mg/L)	410	373	355	185	240

*After How (1978)

In April 1977 the lake extended over about 1·2 km^2 and from the lake-bottom contours and known water levels it is estimated to have contained about 0·31 x 10^6 m^3 of water, with an average chlorinity of about 410 mg/L; the chloride storage was then 127·1 t.

In March 1978 the lake was about 0·8 km^2 in extent and contained 0·19 x 10^6 m^3 of water with a chlorinity of about 230 mg/L (by interpolation from data in Table 6). This gave a chloride storage of 43·7 t.

Outflow

Figure 8 shows that the outflow from Lake Jandabup is associated with a plume of groundwater with a chloride concentration about five times that of the inflow. The pattern of chlorinity variation agrees well with the flow pattern inferred from the vertical isopotentials (Fig. 7) except that the plume of chloride-enriched water extends to the base of the superficial formations. This may result from downward groundwater movement in the winter (Fig. 7) when some of the groundwater flow beneath the lake goes into the ?Poison Hill Greensand. The distribution of chloride in the outflow is also probably affected by dispersion and diffusion. From Figure 8 the chlorinity of the outflow can be seen to exceed 250 mg/L and the highest measured value to be 267 mg/L at the base of the superficial formations in bore D2A. The chlorinity of water in the lake (Table 6) is generally higher than these values except after rainfall. It is possible that the chlorinity of outflow varies seasonally; however, for the purpose of the chloride balance it is assumed to be 265 mg/L. The annual groundwater outflow is calculated to be 1·10 x 10^6 m^3 so that the estimated mass of the chloride discharged is 1·10 x 10^6 x 265 = 291·5 t.

Balance

The computed values for the various components of the chloride balance in tonnes may be substituted in equation (3):

$$195 \cdot 3 + 23 \cdot 3 + 127 \cdot 1 \approx 291 \cdot 5 + 43 \cdot 7$$

$$345 \cdot 7 \approx 335 \cdot 2$$

This is a reasonable balance considering the quality of the data and it tends to confirm that the water balance is of the correct order.

CONCLUSION

Lake Jandabup is a surface expression of part of the Gnangara Mound flow system. It is maintained by groundwater inflow from the upper half of the flow system and by rainfall. The lake behaves as an evaporative basin from which outflow is impeded by organic lake deposits. As a result about 90% of the groundwater inflow and rainfall is lost by evapotranspiration. Consequently a plume of relatively more saline groundwater extends downstream from the lake.

Other circular lakes on the coastal plain are probably maintained in a similar way. However, there are likely to be some differences from one lake to another as a result of variations in size, topography and subsurface geology.

REFERENCES

Allen, A. D., 1976a, Outline of the hydrogeology of the superficial formations of the Swan Coastal Plain: West. Australia Geol. Survey Ann. Rept 1975, p. 31–42.

——— 1976b, Proposed hydrogeological investigation of selected lakes in the Metropolitan area: West. Australia Geol. Survey Hydrology Report No. 1361 (unpublished).

Anon, 1970, Evaporation from water storages: Australian Water Resources Council Hydrol. Series No. 4.

Backhouse, J., 1977a, Palynology of Lake Jandabup No. D2A borehole: West. Australia Geol. Survey Palaeontological Rept No. 38/1977 (unpublished).

——— 1977b, Palynology of Lake Jandabup No. D3A borehole: West. Australia Geol. Survey Palaeontological Rept No. 39/1977 (unpublished).

——— 1977c, Palynology of Lake Jandabup No. T7A borehole: West. Australia Geol. Survey Palaeontological Rept No. 63/1977 (unpublished).

Bestow, T. T., 1971, The water balance in the North Gnangara area: West. Australia Geol. Survey Ann. Rept 1970, p. 14–17.

Burton, C. W., 1976, Water balance of the Coastal Plain—future, *in* Carbon, B. (Ed.), Groundwater resources of the Swan Coastal Plain: Proceedings EPA and CSIRO symposium.

Fairbridge, R. W., 1953, Australian stratigraphy: Univ. West. Australia Text Books Board, Perth.

Grey, K., 1977, Diatomite from Lake Jandabup: West. Australia Geol. Survey Palaeontological Rept No. 61/1977 (unpublished).

Hingston, F. J., and Gailitis, V., 1977, Salts in the rainfall in Western Australia (1973–74): Australian CSIRO Div. Land Resour. Management Tech. Memo 77/1.

How, R. A. 1978, The environment of the Northern Swan Coastal Plain, consideration of faunal changes and recommendations, *in* Faunal studies of the Northern Swan Coastal Plain: The West. Australia Museum.

McArthur, W. M., and Bettenay, E., 1974, The development and distribution of the soils of the Swan Coastal Plain: Australia CSIRO Soil Pub. No. 16, 2nd edition.

Playford, P. E., Cockbain, A. E., and Low, G. H., 1976, Geology of the Perth Basin, Western Australia: West. Australia Geol. Survey Bulletin 124.

Simpson, E. S., 1903, Diatomaceous earth, Wanneroo: West. Australia Geol. Survey Ann. Rept 1902, p. 79–81.

PETROLEUM EXPLORATION IN WESTERN AUSTRALIA IN 1979

by K. A. Crank

ABSTRACT

The level of petroleum exploration in Western Australia continued its upward trend during 1979. Activity has increased steadily each year since 1975, when exploration was at its lowest level for many years.

In 1979, 17 exploration wells were completed compared with 15 in 1978, and four were drilling ahead at the end of the year, for a total penetration of 66 428 m, an increase of 18 318 m, or 38 per cent, compared with the previous year. Expressed in rig months, the increase was 84 per cent compared with 1978. Drilling was mainly offshore, in the Carnarvon, Canning, Browse, and Bonaparte Gulf Basins, but the most significant activity of the year was the drilling of seven wells in the deeper waters of the Exmouth Plateau area. Forty development wells were completed in the Barrow Island Oil Field during 1979.

No major discoveries were made, although significant non-commercial gas discoveries were reported in Brecknock 1 in the Browse Basin and in Scarborough 1 in the Exmouth Plateau area, and hydrocarbon shows were encountered in several other wells.

The only notable decrease in activity was in marine seismic surveys, which declined by 32 per cent compared with 1978, and totalled 26 312 line kilometres.

INTRODUCTION

Exploratory drilling for petroleum in Western Australia over the past two years is illustrated in the following table:

Type of well	Wells completed		Wells drilling on 31 December	
	1978	1979	1978	1979
New-Field Wildcats	13	15	0	4
New-Pool Wildcats	2	1	0	0
Extension Tests	0	1	1	0
Total	15	17	1	4

Total effective drilling: 1978—48 110 m
1979—66 428 m

Two non-commercial gas discoveries were made in 1979, at Brecknock 1 in the Browse Basin, and at Scarborough 1 in the Exmouth Plateau area.

Figure 1 summarizes seismic activity since 1967. Geophysical survey activity in 1979 is shown below:

Type of survey	Line kilometres		Party months or geologist months	
	1978	1979	1978	1979
Land seismic	1 143	909	....	....
Marine seismic	38 996	26 312	....	....
Land gravity	459	0	....	....
Marine gravity	1 023	9 626	....	....
Aeromagnetic	1 847	0	....	....
Marine magnetic	2 336	4 903	....	....
Oceanographic	....	....	3·5	0
Geological	....	....	2	0
Geochemical	....	....	2	0

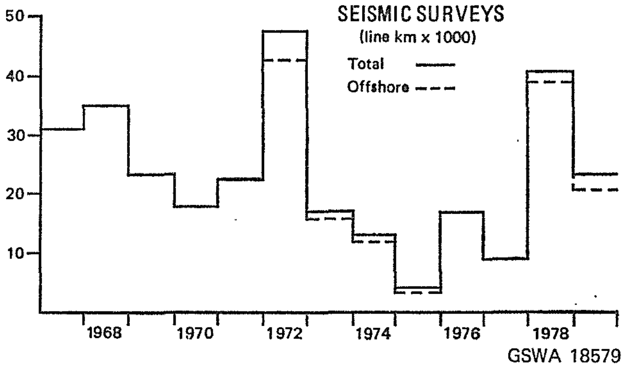


Figure 1 Seismic surveys since 1967.

DRILLING

DRILLING OPERATIONS

Expressed in rig months, overall exploration operations increased by 84 per cent to 44·8 rig months in 1979 compared to 24·3 rig months in 1978. Offshore operations increased by 89 per cent compared with 1978 (40·0 compared with 21·2 rig months), and onshore operations increased by 55 per cent (4·8 compared with 3·1 rig months). In addition, 11·0 rig months were spent on a 40-well development program on Barrow Island in 1979. This compared with 4·7 rig months spent on seven wells in 1978.

A total of nine rigs, seven offshore and two onshore, operated in Western Australia. Early in the year the drill-ship Penrod 74 drilled one well for Getty Oil, Tamar 1, and then left Western Australian waters. The semi-submersible Southern Cross was not utilized further after drilling Bruce 1 in August; and, after completing Pueblo 1 for Woodside, the Ocean Digger (semi-submersible) drilled one more well in Northern Territory waters before being laid up. Other details of rig deployment are shown in Figure 2.

Only one tropical cyclone ("Hazel"), which occurred in March, affected operations during the year, when four days were lost while drilling Sultan 1, as well as 3 days on Zeewulf 1, and one day on Pueblo 1.

Figure 3 is a summary comparison of drilling operations for the 13-year period 1967–1979.

WELLS COMPLETED IN 1979

The locations of wells drilled for petroleum exploration in Western Australia during 1979 are shown in Figure 4. Details relating to wells drilled during the year are given in Table 1. All petroleum exploration wells drilled in Western Australia up to the end of 1979 are listed in the Geological Survey Record 1980/1 (Crank, 1980). A summary of the principal results of drilling in each basin during the year is as follows:

TABLE 1. WELLS DRILLED FOR PETROLEUM EXPLORATION IN WESTERN AUSTRALIA DURING 1979

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	Com-menced	Reached TD	Rig released			
Bonaparte Gulf	Tamar 1	WA-70-P	Getty	NFW	11°52′15″	126°12′40″	....	31	64	15/2/79	11/4/79	23/4/79	2 863	Triassic	Dry, P & A
Browse	Brecknock 1	WA-33-P	Woodside	NFW	14°26′13″	121°40′21″	....	11	544	31/7/79	9/11/79	12/12/79	4 300	Triassic	Gas shows, P & A
	Barcoo 1	WA-32-P	Woodside	NFW	15°20′38″	120°38′12″	....	11	720	14/12/79	....	....	2 174	....	Drilling
Canning	Bruce 1	WA-58-P	W. Energy	NFW	19°22′32″	117°55′41″	....	21	77	19/7/79	3/8/79	11/8/79	2 168	L/M Triassic	Dry, P & A
	Ellendale 1	EP101	Amax	NFW	17°54′18″	124°42′15″	95	100	....	24/7/79	1/10/79	15/10/79	3 190	?U. Devonian	Gas shows, P & A
	Puratte 1	EP104	Esso	NFW	17°05′16″	123°14′18″	27	33	....	3/11/79	31/12/79	....	3 750	....	Logging
Carnarvon	Goodwyn 5	WA-28-P	Woodside	EXT	19°40′42″	115°53′45″	....	8	129	5/12/78	27/1/79	27/2/79	3 664	U. Triassic	Gas well
	Sultan 1	WA-25-P	WAPET	NFW	20°02′39″	115°11′21″	....	21	146	18/1/79	7/3/79	20/3/79	3 620	U. Triassic	Dry, P & A
	Pueblo 1	WA-28-P	Woodside	NFW	19°46′32″	115°51′43″	....	30	112	8/3/79	20/4/79	26/4/79	3 485	U. Triassic	Gas shows, P & A
	Campbell 1	WA-23-P	WAPET	NFW	20°24′42″	115°43′00″	....	22	145	20/3/79	27/4/79	30/4/79	2 750	U. Jurassic	Dry, P & A
	Walcott 1	WA-28-P	Woodside	NFW	19°37′05″	116°22′17″	....	8	81	13/7/79	16/11/79	23/11/79	4 383	M. Jurassic	Gas shows, P & A
	Barrow F72	PL1H	WAPET	NPW	20°51′12″	115°22′40″	9	12	....	18/8/79	22/8/79	24/8/79	796	L. Cretac.	Oil well
	Parker 1	WA-28-P	Woodside	NFW	20°00′08″	115°40′08″	....	8	80	26/11/79	....	....	3 078	....	Drilling
"Exmouth Plateau"	Zeewulf 1	WA-96-P	Esso	NFW	21°06′33″	113°37′01″	....	10	1 194	5/3/79	28/4/79	5/5/79	3 500	U. Triassic	Gas shows, P & A
	Gandara 1	WA-93-P	Hudbay	NFW	19°16′31″	115°49′15″	....	21	308	9/5/79	8/7/79	15/7/79	4 361	U. Triassic	Dry, P & A
	Investigator 1	WA-96-P	Esso	NFW	20°21′07″	112°58′01″	....	10	841	7/5/79	11/7/79	17/7/79	3 746	U. Triassic	Gas shows, P & A
	Jupiter 1	WA-84-P	Phillips	NFW	19°34′54″	113°31′58″	....	10	960	16/5/79	14/10/79	17/10/79	4 946	? Triassic	Gas shows, P & A
	Resolution 1	WA-97-P	Esso	NFW	21°17′58″	113°41′24″	....	10	1 086	23/7/79	1/11/79	10/11/79	3 884	U. Triassic	Gas shows, P & A
	Mercury 1	WA-84-P	Phillips	NFW	19°33′54″	113°52′42″	....	10	1 142	29/10/79	19/12/79	31/12/79	3 812	U. Triassic	Dry, P & A
	Scarborough 1	WA-96-P	Esso	NFW	19°53′06″	113°08′45″	....	10	912	11/11/79	9/12/79	19/12/79	2 360	U. Jurassic	Gas shows, P & A
	Vinck 1	WA-97-P	Esso	NFW	20°35′04″	112°11′34″	....	10	1 383	20/12/79	....	....	2 515	....	Drilling

Getty: Getty Oil Development Co. Ltd
Woodside: Woodside Petroleum Development Pty Ltd
W. Energy: Western Energy Pty Ltd
Amax: Amax Iron Ore Corporation
Esso: Esso Exploration & Production Aust. Inc.
WAPET: West Australian Petroleum Pty Ltd
Hudbay: Hudbay Oil (Aust.) Ltd
Phillips: Phillips Australian Oil Co.

NFW: New-field-wildcat well
NPW: New-pool-wildcat well
EXT: Extension test well
P & A: Plugged and abandoned

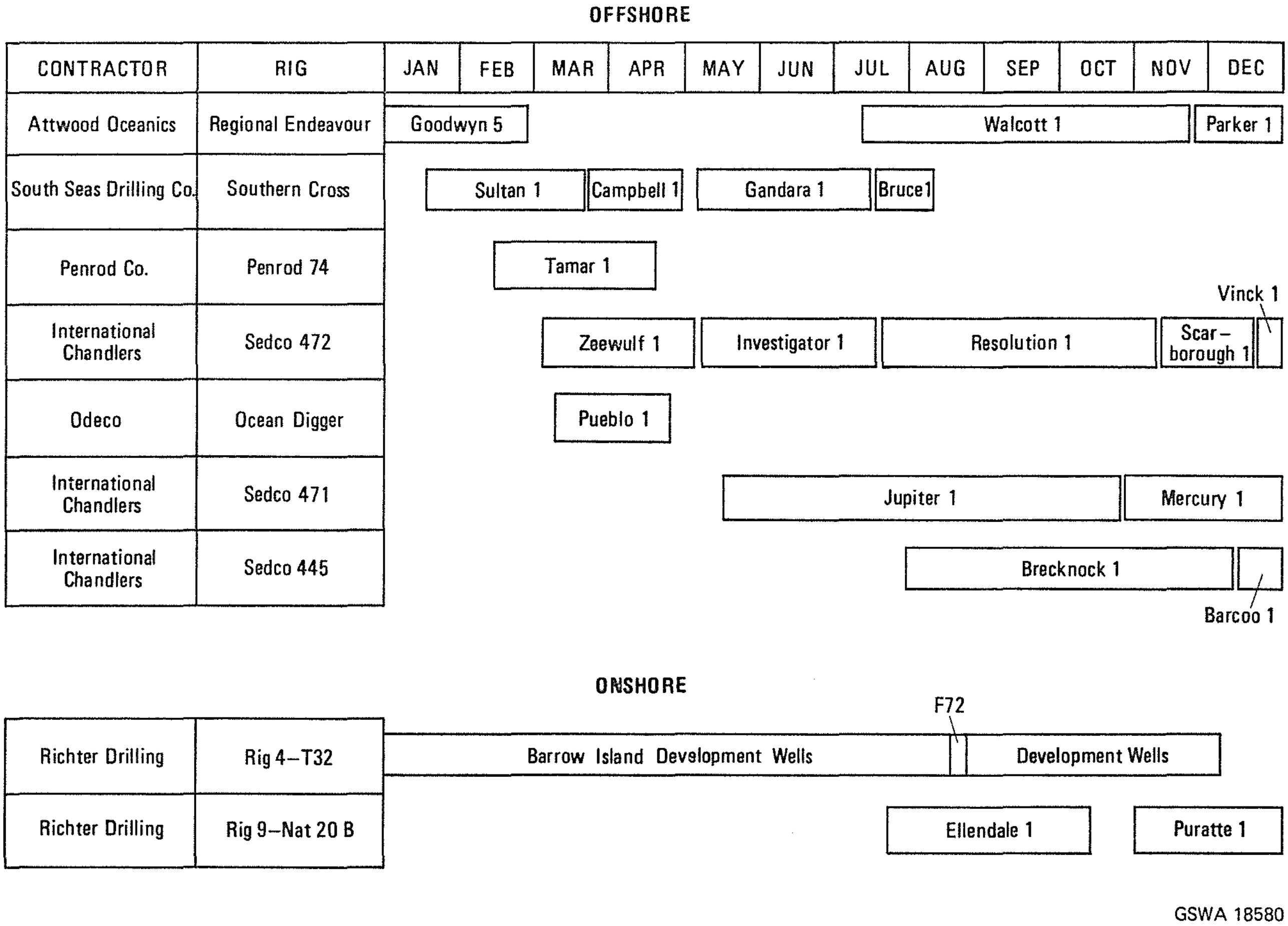


Figure 2 Rig utilization, 1979.

Bonaparte Gulf Basin

Getty Oil Development Co. Ltd completed one well, Tamar 1, in the Bonaparte Gulf Basin in 1979. This was drilled in Exploration Permit WA–70–P on an anticlinal structure, 76 km southwest of Eider 1 and 100 km south-southwest of Flamingo 1. The main objectives were Middle to Lower Jurassic sands and, although porous sands were encountered in all target horizons, there were no significant hydrocarbon shows. The well was plugged and abandoned at a total depth of 2 863 m in Upper Triassic rocks.

Browse Basin

Woodside Petroleum Development Pty Ltd completed one well in the Browse Basin (Brecknock 1) and was drilling a second (Barcoo 1) at the end of the year. Brecknock 1 was drilled in WA–33–P in 544 m of water on a horst block on the Scott Reef trend, located about 32 km south-southwest of Scott Reef 2. Gas-bearing sandstones were encountered in the section between 3 843 and 3 934 m. A production test was attempted on this zone but it failed for mechanical reasons. It is believed that this is the deepest water in which such a production test has been attempted anywhere in the world. The well was abandoned at a total depth of 4 300 m. Although this discovery cannot be considered economic at current prices and with current production technology because of the water depth, the well was encouraging in confirming the Browse Basin as a hydrocarbon-bearing province.

Canning Basin

In the Canning Basin one offshore well and one onshore well were completed, and a second onshore well, Puratte 1, drilled by Esso, reached its total depth on December 31st.

The offshore well, Bruce 1, was drilled by Western Energy Pty Ltd on the southern edge of the Beagle Sub-basin, in WA–58–P, on a large fault-induced anticlinal feature, about 22 km west-southwest of Poissonnier 1. The well was drilled to a depth of 2 168 m in the Triassic, penetrating a total of 1 121 m of Triassic sediments. No significant hydrocarbon shows were reported, and the well was plugged and abandoned.

In the onshore Canning Basin, Amax Iron Ore Corporation completed Ellendale 1 in EP101, about 26 km northwest of Mt Hardman 1. The objectives of this well were Lower Carboniferous sands and possible carbonate build-ups in the Late Devonian. At the total depth of 3 190 m, the well was probably in the Upper Devonian. Three drillstem tests were conducted, the first of which, over the interval 2 366 to 2 373 m, was mechanically unsuccessful. DST 2, over the interval 2 155 to 2 173 m, yielded some low-pressure gas and a trace of low-gravity oil. DST 3, over the interval 1 649 to 1 701 m, also recovered a small amount of gas and a trace of condensate. It was abandoned as a dry hole.

Carnarvon Basin

Four new-field-wildcat wells were drilled in the offshore Carnarvon Basin, as well as one new-pool-wildcat on Barrow Island. One extension test, Goodwyn 5, commenced in 1978, and was completed as a suspended gas well, and one exploratory well, Parker 1, was drilling at the end of the year.

Woodside completed three wells: Goodwyn 5, Pueblo 1, and Walcott 1. Pueblo 1 was drilled in WA–28–P, in 112 m of water, to investigate Upper Triassic sandstones on a fault block downdip from Goodwyn 3. Only very thin gas sands were penetrated in this well, and it was abandoned as a dry hole at 3 485 m.

Walcott 1 was drilled in 81 m of water in WA–28–P, approximately 3·8 km north-northeast of Madeleine 1, to test sandstone below the Jurassic unconformity, in an upthrown position relative to the Madeleine structure. This well bottomed in Middle Jurassic shales. Some gas was encountered, but permeability was low, and the well was plugged and abandoned.

Two wells were drilled by West Australian Petroleum Pty Ltd (WAPET) in the offshore Carnarvon Basin: Sultan 1 and Campbell 1. Sultan 1 was completed in WA–25–P, on a structural closure on the Rankin Trend, between the West Tryal Rocks discovery and North Tryal Rocks 1. No significant hydrocarbon shows were encountered, and the well was abandoned at 3 620 m in Upper Triassic rocks.

Campbell 1 was drilled on a simple anticlinal feature in WA–23–P, on a trend with the Barrow Anticline, 25 km to the southwest, and the Rosemary-Legendre feature to the northeast. No significant shows of gas and oil were encountered, and the well was plugged and abandoned at 2 750 m in the Upper Jurassic Dupuy Formation.

Barrow F72 was drilled by WAPET on Barrow Island, and was classified as a new-pool wildcat. The well found oil in the "Windalia sand" (Lower Cretaceous) in a separate small fault block to the south of the main Barrow Island Oil Field.

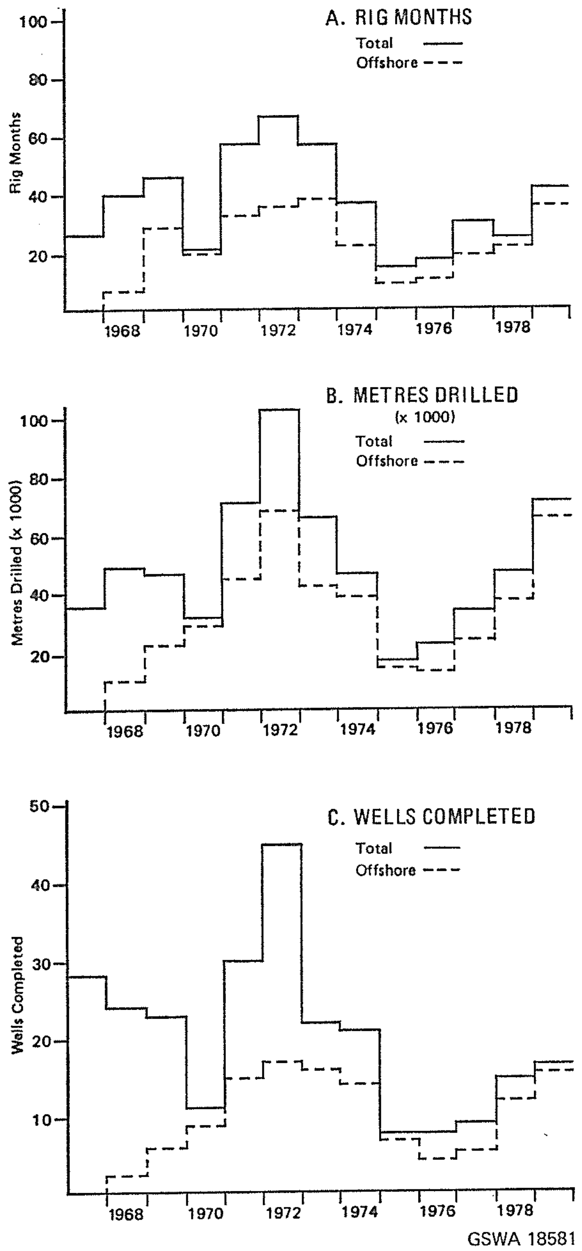


Figure 3 Drilling operations since 1967.

Barrow Island development wells

During 1979 40 development wells were drilled by WAPET within the Barrow Island Oil Field. Ten of these were classed as development wells, 26 as infill wells, two as water-injection wells, one as a water-source well, and one was a dry hole.

The status of these wells at the end of the year is shown in Table 2. A total of 28 433 m of development drilling was carried out in the year. Twenty-seven of the wells were completed as "Windalia sand" oil producers, one as a Muderong Shale oil producer, one as a Gearle Siltstone oil producer, and one as a Gearle Siltstone gas producer. Three were completed as water-injection wells, three were awaiting stimulation, one was testing, and three were shut in.

Exmouth Plateau area

The most significant feature of Western Australian petroleum exploration in 1979 was the drilling of seven wells in the deep-water areas of the Exmouth Plateau, in water depths between 841 m and 1 194 m. At the end of the year, Esso was drilling Vinck 1 in 1 383 m of water, which is very close to the maximum water depth in which a conventional oil-well drilling programme has been carried out anywhere.

Esso completed four wells in this area: Zeewulf 1, Investigator 1, Resolution 1 and Scarborough 1. Zeewulf 1 was drilled in WA–96–P, in 1 194 m of water, 82 km northwest of Muiron 1, on a northeast-trending horst feature. Only minor hydrocarbon shows were recorded after encountering porous sands, and the well was abandoned at a total depth of 3 500 m, in Upper Triassic rocks.

Esso's second well, Investigator 1, also in WA–96–P, in the central part of the Exmouth Plateau, was located about 200 km north-northwest of North West Cape, and was drilled in 841 m of water to a total depth of 3 746 m, in rocks of Late Triassic age. Although some minor gas was encountered, the well was plugged and abandoned.

Following this well, Esso drilled Resolution 1 in WA–97–P, 22 km south-southeast of Zeewulf 1, in 1 086 m of water. Although some minor gas was recorded the well was plugged and abandoned in Upper Triassic rocks, after having been sidetracked from 3 758 to a total depth of 3 884 m.

Esso's fourth well, Scarborough 1 was drilled on a broad domal structure located 55 km north-northeast of Investigator 1, and 145 km north-northwest of Zeewulf 1, in 912 m of water. The well encountered gas-bearing Lower Cretaceous sandstone, but because of the water depth this discovery is not considered to be commercial, and the well was abandoned.

Phillips Australian Oil Company drilled two wells, Jupiter 1 and Mercury 1, in its Exmouth Plateau permit, WA–84–P. Jupiter 1 was located near the crest of the plateau in 960 m of water on one of the largest and highest of a series of tilted fault blocks. Only minor gas shows were recorded and the well was abandoned at 4 946 m in the Triassic.

Mercury 1 was drilled, about 40 km east-northeast of Jupiter 1, in a water depth of 1 142 m. It is on the eastern side of the Exmouth Plateau Arch on the first major closed structure west of the Kangaroo Syncline. No significant hydrocarbon shows were encountered, and the well was plugged and abandoned.

Hudbay Oil (Aust.) Ltd drilled one well (Gandara 1) in its permit WA–93–P, in relatively shallow water (308 m) on a horst block on the Brigadier Trend, which, although in the general Exmouth Plateau area, is considered to be in the

TABLE 2. STATUS OF BARROW ISLAND DEVELOPMENT WELLS

Well Name	TD	Status	Well Name	TD	Status
L28	762	Oil producer—Windalia	L41G	626	Shut in
L18	762	Oil producer—Windalia	L32G	643	Oil producer—Gearle
G87A	707	Oil producer—Windalia	F72	796	Oil producer—Windalia
B15A	741	Oil producer—Windalia	F81A	721	Oil producer—Windalia
G85A	744	Oil producer—Windalia	G88A	686	Oil producer—Windalia
B13A	753	Oil producer—Windalia	B18A	683	Oil producer—Windalia
G84A	760	Oil producer—Windalia	B26A	709	Oil producer—Windalia
B14A	724	Oil producer—Windalia	B25A	706	Oil producer—Windalia
G86A	716	Oil producer—Windalia	B21A	770	Oil producer—Windalia
B24A	732	Oil producer—Windalia	B22A	753	Oil producer—Windalia
B17R	677	Water injection	B11A	777	Oil producer—Windalia
B16M	926	Oil producer—Muderong	B12A	762	Oil producer—Windalia
Q87	774	Oil producer—Windalia	G81A	771	Oil producer—Windalia
Q85	778	Oil producer—Windalia	G82A	786	Oil producer—Windalia
L15	777	Oil producer—Windalia	G83A	757	Oil producer—Windalia
L17	753	Water injection	B32A	750	Oil producer—Windalia
Q86	762	Water injection	B33A	737	Awaiting stimulation
E21G	504	Shut in	B34A	716	Awaiting stimulation
L78G	455	Gas producer—Gearle	B35A	707	Awaiting stimulation
L58G	436	Shut in	R88G	433	Testing

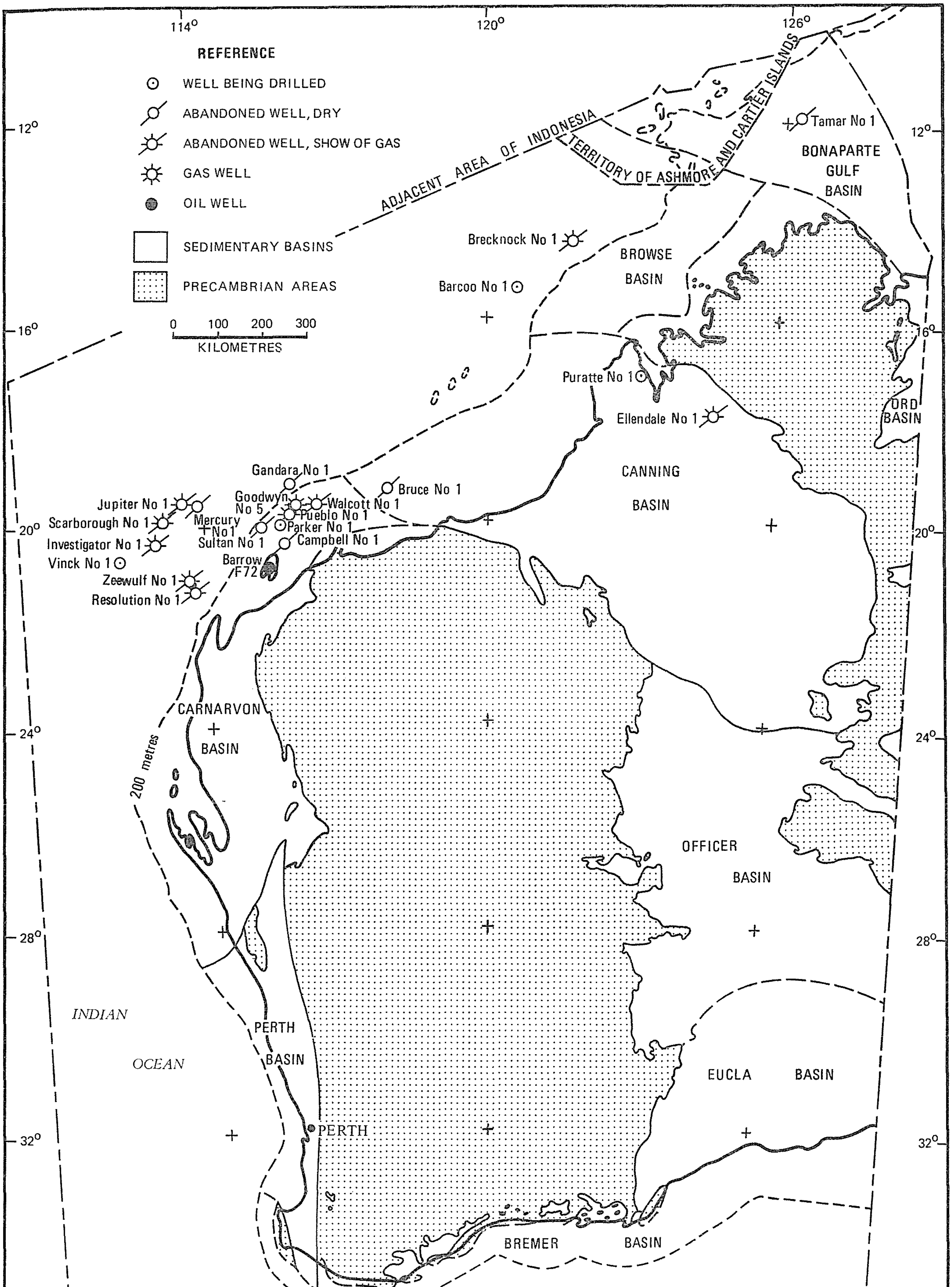


Figure 4 Map showing wells drilled for petroleum in W.A. during 1979.

northern part of the Carnarvon Basin. No significant shows of oil or gas were recorded, and the well was abandoned as a dry hole.

GEOPHYSICAL SURVEYS

Geophysical surveys consisted mainly of seismic surveys. These decreased in line kilometres by about 32 per cent compared to 1978. This decrease was to be expected because 1978 had been the year when the exploration companies conducted their initial large regional surveys on the newly awarded Exmouth Plateau permits. In the second stage of exploration in this deep-water area there was more emphasis on drilling.

Other geophysical activities were marine gravity and magnetic surveys, largely in conjunction with seismic surveys.

SEISMIC

During 1979, offshore seismic surveys were conducted in the Eucla Basin (3 151 km), Carnarvon Basin (4 642 km), Canning Basin (1 789 km), Browse Basin (1 994 km), Bonaparte Gulf Basin (1 906 km), and in the Exmouth Plateau area (12 830 km). Onshore seismic surveys were conducted in the Perth Basin (257 km), the Carnarvon Basin (2 km), and the Canning Basin (650 km). Details are as follows:

SEISMIC SURVEYS—ONSHORE

Basin	Tenement	Company	Line km
Perth	EP96	XLX N.L.	60
	EP100	N.W. Mining	187
	EP111	Jervois Sulphates (NT) Ltd	10
Carnarvon	EP137	J. O. Clough & Son Pty. Ltd	2
Canning	EP104	Esso Exploration & Production Aust. Inc.	182
	EP102	Amax Iron Ore Corporation	137
	EP129	Home Oil Aust. Ltd	331
Total			909

SEISMIC SURVEYS—OFFSHORE

Basin	Tenement	Company	Line km
Eucla	WA-125-P WA-126-P	Esso Exploration & Production Aust. Inc.	3 151
Carnarvon	WA-28-P	Woodside Petroleum Development Pty Ltd	333
	WA-58-P	Western Energy Pty Ltd	459
	WA-64-P	Offshore Oil N.L.	360
	WA-81-P	Continental Oil Co. of Aust. Ltd	1 389
	WA-102-P	Canada North West Land Ltd	1 789
	WA-110-P	CNW Oil (Aust.) Pty Ltd	161
	WA-116-P	Geometals N.L.	151
Canning	WA-62-P	Oxoco International Inc.	402
	WA-79-P	Getty Oil Development Co. Ltd	725
	WA-109-P	Esso Exploration & Production Aust. Inc.	662

SEISMIC SURVEYS—OFFSHORE—*continued*

Basin	Tenement	Company	Line km
Browse	WA-32-P	Woodside Petroleum Development Pty Ltd	70
	WA-33-P	Woodside Petroleum Development Pty Ltd	389
	WA-34-P	Woodside Petroleum Development Pty Ltd	115
	WA-37-P	Woodside Petroleum Development Pty Ltd	73
	WA-68-P	Oxoco International Inc.	262
	WA-104-P	Oberon Oil Pty Ltd	1 085
Bonaparte Gulf	WA-74-P	Pelsart Oil N.L.	1 021
	WA-77-P	Magnet Metals Ltd	487
	WA-103-P	Lennard Oil N.L.	398
Exmouth Plateau Area	WA-84-P	Phillips Aust. Oil Co.	3 716
	WA-90-P	Woodside Petroleum Development Pty Ltd	1 072
	WA-93-P	Hudbay Oil (Aust.) Ltd	1 382
	WA-96-P	Esso Exploration & Production Aust. Inc.	4 164
	WA-97-P	Esso Exploration & Production Aust. Inc.	2 496
Total			26 312

GRAVITY

One marine gravity survey was conducted, mainly over Exploration Permits WA-1-P and WA-28-P, and other gravity surveys were carried out in conjunction with marine seismic surveys, as follows:

GRAVITY SURVEYS—OFFSHORE

Basin	Tenement	Company	Line km
Carnarvon	WA-1-P	Woodside Petroleum Development Pty Ltd	1 924
	WA-28-P	Woodside Petroleum Development Pty Ltd	2 746
	WA-102-P	Canada North West Land Ltd	130
Exmouth Plateau Area	WA-84-P	Phillips Aust. Oil Co.	3 700
	WA-90-P	Woodside Petroleum Development Pty Ltd	53
	WA-93-P	Hudbay Oil (Aust.) Ltd	1 073
Total			9 626

MAGNETIC

Magnetic surveys carried out in conjunction with seismic surveys were as follows:

MAGNETIC SURVEYS

Basin	Tenement	Company	Line km
Carnarvon	WA-102-P	Canada North West Land Ltd	130
Exmouth Plateau Area	WA-84-P	Phillips Aust. Oil Co.	3 700
	WA-93-P	Hudbay Oil (Aust.) Ltd	1 073
Total			4 903

REFERENCE

Crank, K. A., 1980, Wells drilled for petroleum exploration in W.A. to the end of 1979: West. Australia Geol. Survey Rec. 1980/1.

A FORMATION TEMPERATURE STUDY OF THE CARNARVON BASIN

by H. T. Moors

ABSTRACT

From borehole temperature measurements in 120 oil exploration wells in the Carnarvon Basin, approximately 350 formation temperatures were determined. The temperature gradient in each well was calculated using the difference between the surface temperature and the deepest measured formation temperature. These range from 2·08 to 14·9°C/100 m, with a median value of 3·3°C/100 m. Heat input from ancient crystalline basement is well expressed by low temperature gradients where the sedimentary section is thick (Barrow Sub-basin), and increased gradients where the section thins (at the base margin). High temperature anomalies are associated with faults; the excess heat could be due to residual mechanical energy from Miocene and younger movement, or hot deeper formation fluids migrating up the fault planes. Up-dip migration of hot basinal waters is suggested to explain high anomalies in the Robe River area. A thick Tertiary carbonate wedge in the offshore northwestern part of the basin lowers the geothermal gradient, because of its rapid rate of deposition, and also because its porous nature allows dissipation of heat by convective processes in formation fluids, with concurrent heat conduction.

INTRODUCTION

Estimates of the formation temperatures to be encountered in a sedimentary basin are essential for the prediction of the porosity of potential reservoir rocks, the maturity of potential source rocks, and hence the time of migration and generation of oil and gas. To this end, all the temperature data available from oil-exploration wells in the Carnarvon Basin were examined, and as many formation temperatures as possible were calculated. The present-day overall geothermal gradient (from the surface to the deepest formation temperature determined) for each well was plotted and contoured to provide coverage for the whole basin (Fig. 1). The calculated formation temperatures for each well are presented in Table 1, as well as sectional and overall gradients between data points. The average surface temperature is taken as 25°C both on land and on the sea bottom. Investigation of sea-water temperatures has revealed that a high degree of mixing results in a uniform water temperature at all depths, at least on the continental shelf. A plot of temperature/depth relationships of all the wells, extrapolated to the surface, gives a broad range of surface temperatures, but suggests that 25°C is a valid assumption. The extrapolated surface temperatures of the land wells appear to be somewhat higher, but with the sparse data available no adjustment is justified.

CALCULATION OF FORMATION TEMPERATURE

It is standard practice to include a mercury, maximum-reading thermometer with the sondes for each suite of electric logs run in exploration wells. However, it is obvious that the bore-hole temperature (BHT) measured cannot be the true formation temperature. Circulation fluids, used whilst drilling, cool the surrounding formation to below its natural temperature and, therefore, the BHT requires adjustment to true formation temperature.

Numerous methods of correction are available, but that adopted here is the time-ratio method, simply described by Fertl and Wickmann (1977). It utilises the ratio between the time (T_1) of formation cooling whilst drilling and the times (T_2) of temperature build-up in the form $T_1 + T_2/T_2$. Cooling takes place during drilling and circulating before logging, while temperature build-up commences at the end of mud circulation and continues while the suite of logs is run. The true formation temperature is not regained until the time of thermal build-up is much larger than the time of cooling. This is achieved when the time ratio $T_1 + T_2/T_2$ approaches one. Therefore, the BHT for each log run is plotted against its time ratio (for simplicity on a logarithmic axis) and a line through these points is extended to a time ratio of one. The associated temperature is recorded as the true formation temperature (Fig. 2). A more mathematical treatment with additional references can be found in Evans and Coleman (1974), and Dowdle and Cobb (1975).

Unless the daily drilling log for the well under study is available, it is usually necessary to estimate the time of cooling, T_1. As the temperature is recorded some distance above the bottom of the drilled hole, cooling takes place while the drill is penetrating beyond the point at which the reading is subsequently made. It is also frequently necessary to circulate for a period after drilling stops, to bring up samples or to condition the mud and hole before logging. At shallower depths, the rate of drilling is usually faster and mud circulation takes less time, so a lower value of T_1 is selected. At depths less than 1 000 m, 2 hours is used for T_1; between 1 000 and 2 000 m, 3 hours; between 2 000 and 3 000 m, 4 hours; between 3 000 and 4 000 m, 5 hours; and below 4 000 m, 6 hours. Complications such as reconditioning of the hole and/or mud have not been taken into account. Some examples are given in Figure 2.

The largest maximum difference recorded between a bore-hole temperature and the calculated formation temperature is approximately 30°C, but the difference is usually less. Not only is the formation temperature significant in the rate of temperature readjustment, but the lithology (depth of invasion of circulation fluid), and perhaps the drilling conditions (bore diameter, etc.), have an effect. This may explain why in some wells the rate of temperature readjustment appears to be above, or below, the norm, throughout the whole temperature range of the well (Fig. 2b). In some cases, a marked divergence in rate of change from the norm for a given temperature can be attributed to a variation in lithology.

Only one temperature was recorded for the whole logging suite in early wells and to utilize these data a nomogram was constructed. The temperature build-up-trends from all wells with a good fit of three or more points (e.g. Fig. 2a, Anchor 1, 2 143 m, 3 051 m, but not 1 217 m) were plotted on one set of axes (Fig. 2b). Two or more apparently independent families occur, presumably due to differing drilling techniques or formation lithology, and only the more common family (solid lines) was adopted in this study. For a single value well, a time ratio of 1·5 is chosen (as a general value assuming the temperature was taken on the middle log run), and the measured temperature was corrected by moving parallel to the nearest build-up trend line. In the example in Figure 2b, a measured temperature of 133°C is thus corrected to 141°C as the formation temperature.

SOURCES OF HEAT

Sources of heat in a sedimentary basin fall into two basic categories:

(1) sources from outside the sediments, which include
- (i) heat flow from deep within the earth via basement,
- (ii) heat from igneous intrusives, and
- (iii) heat introduced by migrating fluids; and

(2) sources within the sediments
- (i) radiogenic content,
- (ii) clay-mineral diagenesis,
- (iii) compactional friction, and
- (iv) deformational energy.

No obvious evidence exists for the presence of igneous intrusives, but proximity to basement is well expressed in the temperature-gradient pattern, and an anomalously high geothermal gradient in the Robe River area could be attributed to migration of hot fluids. The intra-sedimentary sources would have greatest expression on vertical temperature profiles, but because of the limited vertical control (usually only three temperature values per well), if they are present, they have not been detected in this study. However, anomalous high temperatures in the North West Cape region could possibly be due in part to recent activity of adjacent faults providing deformational energy.

GEOTHERMAL GRADIENT DISTRIBUTION

Over 120 wells were found to contain sufficient information for an estimate of the formation temperature to be made, providing nearly 350 separate values. Many of the shallower wells have only one temperature reading, taken at the completion of the well. The deeper oil exploration wells usually have three temperature values, taken progressively as the well is drilled, but two or four values are common.

Unfortunately, the distribution of the data points is very uneven, with a concentration of 100 wells in the northern Mesozoic portion of the basin, but only 20 wells in the south. The northern area thus shows much more detail than the south, is more reliable, and can be sensibly contoured with a finer contour-interval spacing. A lot of gradient data are available in the south from water-bore temperatures. Unfortunately, most of these come from shallow depths and the geothermal gradient is thus very susceptible to inaccuracy of formation-temperature measurements or surface-temperature estimation. The water-bore gradients have been used very generally as form lines in areas of little data, but at best only reflect the near-surface gradients and are disregarded if in conflict with deeper data. As a rule, it has been possible to contour the data points without conflict. Discrepancies occur, but apart from Locker 1 and Onslow 1 they are fairly minor, or are shown to be spurious by adjacent data, for example North Rankin 3 or Goodwyn 4.

The maximum overall present-day geothermal gradient is 14·9°C/100 m at Mulyery 1, and the minimum is 2·08°C/100 m at Kalbarri 1. The 3·3°C/100 m contour divides the study area into almost equal portions and can be regarded as the basin average. A world-wide average geothermal gradient is considered to be 3·0°C/100 m (Tissot and Welte, 1978), making the Carnarvon Basin a slightly hot area.

The most obvious trend on the geothermal-gradient map is an increase in the gradient from west to east. This trend in the eastern portion of the basin is probably controlled by the depth to basement. The basement can be assumed to be in thermal equilibrium and conducts heat at a fixed rate. The younger, overlying sediments, on the other hand, are still in disequilibrium because of their more recent deposition and thermal insulative properties. Thus, where the sedimentary section is thin, the sediments more rapidly reach thermal equilibrium, and a higher temperature gradient results, than in other areas where the sedimentary blanket is thicker. The thick sedimentary piles of the Lewis, Barrow and Merlinleigh Sub-basins are thus well expressed by trends of low geothermal gradient.

The continued decrease in geothermal gradient in the north-western portion of the basin is a function of the thick pile of Tertiary sediments in this area. During rapid sedimentation the thermal front cannot keep pace with the rapidity of burial, and the geothermal gradient drops. As well, the Tertiary

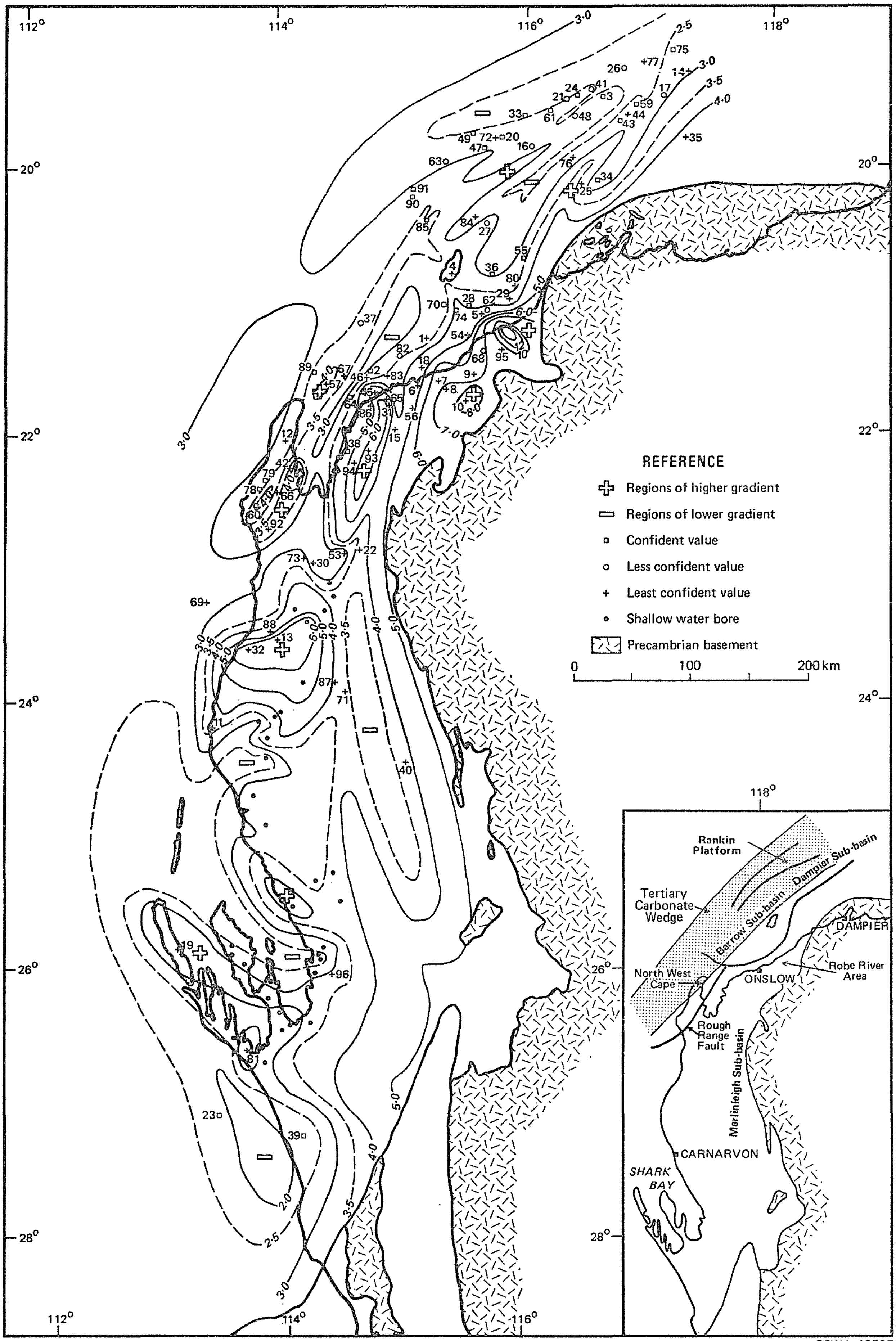


Figure 1 Contour map of present-day overall geothermal gradients, in °C/100 m, Carnarvon Basin. Simplified in the Robe River area due to congestion of data. Wells used are keyed to Table 1.

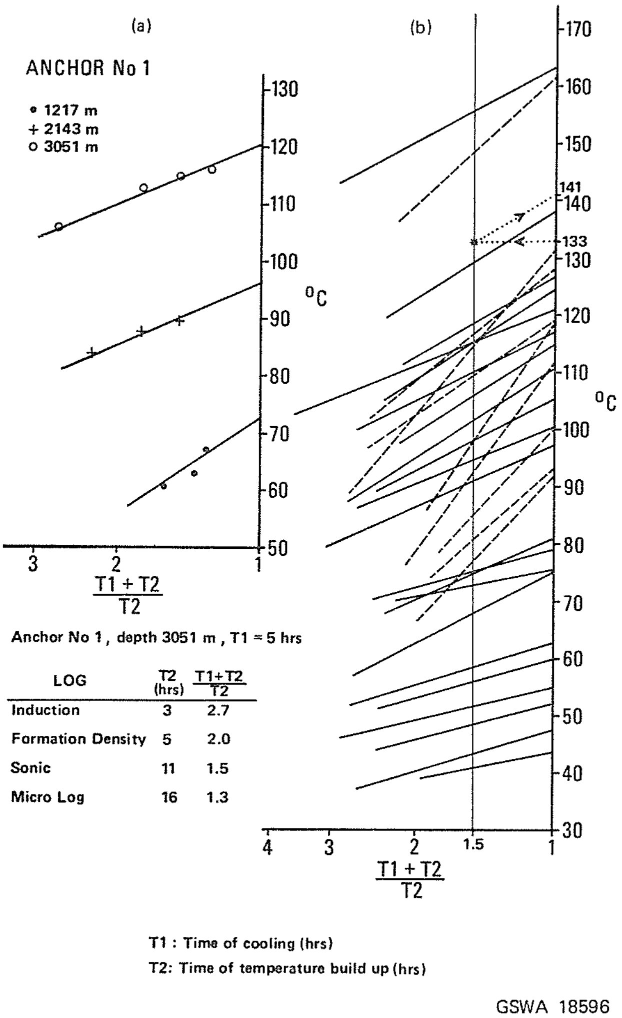


Figure 2 Time-ratio graphical solution of true formation temperature from bore-hole temperature.

(a) Example well, Anchor No. 1.

(b) Nomogram developed for formation temperature estimation for 36 wells, with only one bore-hole temperature reading in each. Measured temperature entered at time-ratio 1·5, moved parallel to trend lines to true formation temperature at time ratio 1. Solid lines are favoured trend, dashed lines probably reflect variations in lithology or drilling operations.

section consists predominantly of coarse, porous and permeable carbonates through which formation water is able to circulate freely. Thus, a convection process of heat transfer occurs in tandem with the conductive process, making heat transfer more efficient. This lowers the formation temperature, resulting in a lower geothermal gradient. As the carbonate wedge thins beyond the Rankin Platform, the geothermal gradient can be expected to rise again.

Conversely, in the case where there is no permeability, the geothermal gradient is usually increased. The high gradient trends to the south of the Rankin Platform, and the Dampier trend, could be manifestations of this process. In these areas overpressured shales are prevalent. These shales are very porous, but lack permeability, making the convective process of heat transfer inoperable, thus increasing the formation temperature and hence the gradient. A compounding feature is that the overpressured shales contain large volumes of water, which has a thermal conductivity four to five times less than the constituent minerals, making the conductive transfer of heat even less efficient than in a normal shale.

Another obvious feature of the contour map is the presence of linear zones of high geothermal gradient in the North West Cape region. Their linear nature suggests that they are probably associated with the underlying Rough Range and Paterson Faults. The Cape Range and Rough Range Anticlines are generally believed to be due to late Miocene to Quaternary reactivation along these faults. The high geothermal gradients may be due to insufficient time having elapsed for dissipation of the deformational energy. A more likely reason, however, could be the presence of high-temperature formation fluids, from deep within the basin, migrating up the fault planes. The location of a small oil accumulation at Rough Range 1 also suggests that the faults may have acted as conduits for deeper expelled fluids.

The hot anomaly in the Gnaraloo 1—Chargoo 1 area may also be due to fluids migrating up faults associated with the anticlines in this area.

The anomaly with greatest amplitude occurs in the Robe River area. Gradients above 10°C/100 m exist with a maximum of 14·9°C/100 m recorded in Mulyery 1. Unfortunately, temperature data in many of the wells are unreliable, and as the sedimentary section here is very thin (100–200 m) even small temperature errors lead to large variations in the calculated geothermal gradient. Nonetheless, the presence of anomalously high values cannot be denied.

A possible explanation is that fluids from deeper in the basin are channelled through this region. Thomas (1978) has shown that the so-called "Robe River Embayment" acted as a migration path for hydrocarbons from the Barrow Sub-basin; presumably even more formation water has passed the same way. The Barrow Island structure drains a large portion of the Barrow Sub-basin, and has a spill point offshore from the Robe River. Fluids gathered by the structure are channelled through the spill point. The path taken by these fluids can be traced by an inflection in the gradient contours all the way to Barrow Island, though the magnitude diminishes as the sediment pile thickens. Thomas (1978, Fig. 12) produced salinity data suggesting the flow of surface water into the basin. He also pointed out that he believed this inflow ceased towards the end of the Tertiary (Thomas, 1978, p. 16), and that the present flow may again be out of the basin, but flushing is still incomplete. This would still be compatible with the hypothesis presented here.

The reason for the region of high geothermal gradients in the Shark Bay area is not clear. The data available are poor and widely spaced so that the contouring shown in this area on Figure 1 may be inaccurate. It would be expected that this area should be a geothermal low as it is basically in a position of thick sediments and is underlain by the evaporitic sequence of the Dirk Hartog Formation. Evaporites are very efficient conductors of heat, which should result in a low geothermal gradient. This is clearly shown in Yaringa 1, where the temperature change of only 4°C between 868 m and 2 288 m can be attributed to the evaporitic section over this interval.

CONCLUSIONS

The present-day geothermal gradient of the Carnarvon Basin is higher than the world-wide average. Control of the geothermal gradient by varying thermal transmissibility properties is clearly shown by the part played by the Tertiary carbonates east of the Rankin Platform, and over-pressured shales in parts of the Dampier Sub-basin. The influence of external energy sources such as, proximity to basement, deformational energy, or migration upwards of deeper fluids, can also be detected, for example in the Cape Range and Robe River areas.

REFERENCES

Dowdle, W. L., and Cobb, W. M., 1975, Static formation temperature from well logs—An empirical method: Jour. Petroleum Technology, v. 27, p. 1326–1330.

Evans, T. R., and Coleman, N. C., 1974, North Sea geothermal gradients: Nature, v. 247, p. 28–30.

Fertl, W. H., and Wickmann, P. A., 1977, How to determine static BHT from well log data: World Oil, v. 184(1), p. 105–106.

Klemme, H. D., 1972, Heat influences size of oil giant, Pt. 1 and 2: The Oil and Gas Journal, v. 70, no. 29, p. 136–144, and no. 30, p. 76–78.

Thomas, B. M., 1978, Robe River—an onshore shallow oil accumulation: Aust. Oil and Gas, v. 24 (6), p. 10–17.

Thomas, B. M., and Smith, D. N., 1976, Carnarvon Basin, *in* Leslie, R. B., Evans, H. J., and Knight, C. L., (eds) Economic geology of Australia and Papua New Guinea, Petroleum: Australasian Inst. Mining Metall. Monograph 7, p. 126–155.

Tissot, B. P., and Welte, D. H., 1978, Petroleum formation and occurrence: Springer-Verlag, New York, 538 p.

TABLE 1. FORMATION TEMPERATURE AND GEOTHERMAL GRADIENTS, SECTIONAL AND PROGRESSIVE OVERALL; OIL EXPLORATION WELLS, CARNARVON BASIN. WELL NUMBERS ARE KEYED TO FIGURE 1.

Well Name	Fig. 1 No.	Derrick Floor Elevation (m)	Depth (m)	Temperature (°C)	Sect. Grad. (°C/100 m)	Overall Grad. (°C/100 m)
Airlie 1	1	5	1 050	(65)	3·81	3·81
			2 220	(100)	2·99	3·38
Anchor 1	2	42	1 217	73	4·09	4·09
			2 143	97	2·59	3·43
			3 051	121	2·64	3·19
Angel 1	3	89	1 490	(59)	2·43	2·43
			2 463	(90)	3·19	2·74
			3 027	(104)	2·48	2·69
			3 177	(109)	3·33	2·72
			3 408	115	2·60	2·71
Barrow Deep 1	4	27	888	63	4·41	4·41
			1 795	79	1·76	3·05
			2 589	100	2·64	2·93
			3 054	(118)	3·87	3·07
			3 215	(124)	3·73	3·11
			3 254	(122)	−5·13	3·01
			3 267	(125)	23·08	3·09
			3 572	(133)	2·62	3·05
			3 616	(133)	0	3·01
			3 622	(132)	−16·67	2·98
			3 654	(133)	3·13	2·98
			3 868	(149)	7·48	3·23
			3 938	(145)	−5·71	3·07
			4 151	163	8·45	3·35
			4 535	(172)	2·34	3·26
Beagle 1	5	1	561	(50)	4·46	4·46
Bidgemia 1		....	....	N.A.	....	....
Cane River 1	6	8	696	(57)	4·65	4·65
Cane River 2	7	8	413	(53)	6·86	6·86
Cane River 3	8	2	255	(44)	7·51	7·51
Cane River 4	9	2	173	(36)	6·43	6·43
Cane River 5	10	2	202	(41)	8·00	8·00
Cape Cuvier 1	11	0	557	(45)	3·59	3·59
Cape Range 1	....	3	2 472	(105)	3·24	3·24
Cape Range 2	12	3	1 154	(60)	3·04	3·04
			3 078	(115)	2·86	2·93
			3 360	(130)	5·32	3·13
Chargoo 1	13	2	428	(52)	6·34	6·34
Coonga 1	....	....	....	N.A.	....	....
Cossigny 1	14	125	1 291	(55)	2·57	2·57
			3 198	(79)	1·26	1·76
Cunaloo 1	15	3	795	(61)	4·55	4·55
Dampier 1	16	85	1 083	48	2·30	2·30
			2 618	75	1·76	1·97
			3 162	116	7·54	2·96
			3 804	(118)	0·31	2·50
			4 137	138	6·00	2·79
De Grey 1	17	124	1 116	49	2·15	2·15
			2 003	83	3·83	2·90
Direction Island 1	18	1	671	(58)	4·92	4·92
Dirk Hartog 17B	19	3	366	(35)	2·75	2·75
			974	(56)	3·44	3·19
			1 290	(64)	2·55	3·03
			1 410	(66)	0·83	2·91
			1 523	(82)	14·16	3·75
Dockrell 1	20	140	1 413	55	2·36	2·36
			3 144	(95)	2·31	2·33
			3 500	112	4·78	2·59
			3 890	124	3·08	2·64
Eaglehawk 1	21	132	1 304	(52)	2·30	2·30
			3 067	(96)	2·50	2·42
			3 475	100	0·98	2·24
East Marilla 1	22	1	637	(48)	3·61	3·61
Edel 1	23	123	1 002	44	2·16	2·16
			1 411	56	2·93	2·41
			2 749	80	1·79	2·09
Egret 1	24	130	1 254	(48)	2·05	2·05
			3 251	106	2·90	2·60
			3 651	118	3·00	2·64
Enderby 1	25	63	881	(52)	3·30	3·30
			2 139	(95)	4·53	3·37
Finucane 1	26	147	1 715	59	2·17	2·17
			2 968	95	2·87	2·48
Flag 1	27	60	1 256	(62)	3·09	3·09
			2 357	(95)	3·00	3·05
			2 769	(105)	2·43	2·95
			3 231	(109)	0·87	2·65
			3 525	(135)	8·84	3·17
			3 802	145	3·61	3·21
Flinders Shoal 1	28	41	1 203	75	4·30	4·30
			2 134	95	2·15	3·34
			3 032	115	2·23	3·01
			3 353	143	8·72	3·56
			3 505	150	4·61	3·61
			3 616	153	2·70	3·58
Fortescue 1	29	1	610	(48)	3·78	3·78
Giralia 1	30	2	1 237	(60)	2·83	2·83
Glenroy 1	31	5	648	(62)	5·75	5·75
Gnaraloo 1	32	2	502	(59)	6·80	6·80
Goodwyn 1	33	156	1 290	45	1·76	1·76
			2 744	76	2·13	1·97
			3 520	112	4·64	2·59
Grierson 1	....	....	....	N.A.	....	....
Grierson 2	....	....	....	N.A.	....	....
Grierson 3	....	....		N.A.	....	....
Hampton 1	34	83	1 196	60	3·14	3·14
			2 560	93	2·42	2·75
Hauy 1	35	95	393	(42)	4·33	4·33
Hermite 1	36	43	2 232	(93)	3·11	3·11
			2 495	(97)	1·52	2·94
			3 304	122	3·09	2·97
Hilda 1A	37	157	2 058	(88)	3·32	3·32
			2 555	(91)	0·60	2·75
			3 205	126	5·38	3·31
			3 454	140	5·62	3·48
Hope Island 1	38	9	1 426	81	3·95	3·95
Kalbarri 1	39	1	456	49	5·31	5·31
			1 539	57	0·74	2·08
Kennedy Range 1	40	4	615	(58)	5·40	5·40
			1 193	(69)	1·90	3·70
			2 215	(111)	4·11	3·89

TABLE 1. FORMATION TEMPERATURE AND GEOTHERMAL GRADIENTS, SECTIONAL AND PROGRESSIVE OVERALL; OIL EXPLORATION WELLS, CARNARVON BASIN. WELL NUMBERS ARE KEYED TO FIGURE 1—*continued*

Well Name	Fig. 1 No.	Derrick Floor Elevation (m)	Depth (m)	Temperature (°C)	Sect. Grad. (°C/100 m)	Overall Grad. (°C/100 m)
Lambert 1	41	135	1 280	(52)	2·36	2·36
			3 186	101	2·57	2·49
			3 701	116	2·91	2·55
Learmonth 2	42	3	1 501	(82)	3·81	3·81
			1 732	(95)	5·63	4·05
Legendre 1	43	64	1 036	57	3·29	3·29
			2 162	83	2·84	3·05
			2 488	93	1·23	2·81
			3 238	110	2·27	2·68
Legendre 2	44	57	1 130	(54)	2·70	2·70
			1 940	(79)	3·09	2·87
			2 054	(80)	0·88	2·75
			2 588	(88)	1·50	2·49
			3 617	(127)	3·79	2·87
Locker 1	45	1	767	(65)	5·22	5·22
Long Island 1	46	9	814	(61)	4·47	4·47
			1 389	(78)	2·96	3·84
			2 159	(98)	2·60	3·40
Lowendal 1	47	115	1 197	52	2·50	2·50
			3 630	123	2·92	2·79
Madeleine 1	48	78	1 188	(57)	2·70	2·70
			2 764	(92)	2·22	2·42
			3 154	(114)	5·64	2·82
			3 686	125	2·07	2·71
			4 212	(138)	2·47	2·68
Malus 1	49	96	1 446	63	2·81	2·81
			3 652	112	2·22	2·45
Mangrove 1	50	1	284	(63)	13·38	13·38
Mardie 1	51	1	222	(40)	6·76	6·76
Mardie 2	52	8	165	(41)	10·19	10·19
Marilla 1	53	3	305	(35)	3·28	3·28
			456	(38)	1·99	2·85
Mary Anne 1	54	1	533	51	4·89	4·89
Merlinleigh 1	....	1	304	(43)	5·92	5·92
Merlinleigh 2	....	1	304	(43)	5·92	5·92
Merlinleigh 3	....	....	....	N.A.	....	....
Merlinleigh 4	....	....	....	N.A.	....	....
Merlinleigh 5	....	....	....	N.A.	....	....
Mermaid 1	55	55	465	(47)	5·37	5·37
			1 268	66	2·37	3·38
Minderoo 1	56	12	344	(33)	2·41	2·41
			500	(37)	2·56	2·46
			696	(38)	0·51	1·90
Moogooree 1	....	....	....	N.A.	....	....
Moogooree 2	....	....	....	N.A.	....	....
Muiron 1	57	9	1 012	(97)	7·18	7·18
			1 781	(110)	1·69	4·80
Mulyery 1	58	6	140	(45)	14·9	14·9
Nelson Rocks 1	59	85	1 153	47	2·06	2·06
			2 049	(77)	3·35	2·65
			2 186	80	2·19	2·62
Ningaloo 1	60	4	668	48	3·46	3·46
			1 229	75	4·81	4·08
North Rankin 1	61	152	1 704	(60)	2·26	2·26
			2 958	84	2·08	2·18
			3 431	115	5·41	2·74
			3 530	(118)	3·03	2·75
North Sandy 1	62	1	607	50	4·13	4·13
North Tryal Rocks 1	63	118	1 820	(63)	2·23	2·23
			3 060	(98)	2·82	2·48
			3 652	125	4·57	2·83
Observation 1	64	4	986	62	3·77	3·77
			2 157	93	2·65	3·16
Onslow 1	65	5	535	(47)	4·15	4·15
			917	(59)	3·14	3·73
			1 791	(85)	3·89	3·36
			2 999	(119)	2·81	3·14
Paterson 1	66	4	1 269	(69)	3·47	3·47
			1 408	(81)	8·63	3·99
			1 855	(96)	3·36	3·85
			2 282	(103)	1·64	3·42
Peak 1	67	4	698	(43)	2·59	2·59
			1 513	(73)	3·68	3·18
			2 141	(102)	4·62	3·60
Peedamulla 1	68	2	328	47	6·75	6·75
Pendock 1	69	1	1 048	(44)	2·10	2·10
			1 854	(77)	4·09	3·04
			2 498	(92)	2·33	2·85
Pepper 1	70	35	462	(48)	5·39	5·39
			1 327	79	3·58	4·18
			2 539	(108)	2·39	3·31
			2 606	117	13·43	3·58
			2 745	117	0	3·39
Quail 1	71	3	882	(77)	5·92	5·92
			1 373	(91)	2·85	4·82
			2 795	(112)	1·48	3·12
			3 261	(137)	5·36	3·44
			3 580	(152)	4·70	3·55
Rankin 1	72	102	1 610	(58)	2·19	2·19
			2 919	(99)	3·13	2·63
			3 494	(118)	3·30	2·74
			4 109	(135)	2·76	2·75
Remarkable Hill 1	73	11	153	(47)	15·49	15·49
			933	(70)	2·95	4·88
			2 214	96	2·03	3·22
			3 206	(132)	3·63	3·35
Ripple Shoal 1	74	32	1 101	(44)	1·78	1·78
			2 278	115	6·03	4·01
Ronsard 1	75	170	1 300	(45)	1·79	1·79
			2 837	93	3·10	2·55
Rosemary 1	76	74	1 802	67	2·43	2·43
			1 864	(71)	6·45	2·56
			2 915	(105)	3·24	2·82
			3 265	(115)	2·86	2·82
Sable 1	77	163	1 386	48	1·88	1·88
			2 745	85	2·72	2·32
			3 806	(113)	2·64	2·42
			3 969	(116)	1·84	2·39
Sandy Point 1	78	4	1 222	66	3·37	3·37
			1 994	(104)	4·92	3·97

TABLE 1. FORMATION TEMPERATURE AND GEOTHERMAL GRADIENTS, SECTIONAL AND PROGRESSIVE OVERALL; OIL EXPLORATION WELLS, CARNARVON BASIN. WELL NUMBERS ARE KEYED TO FIGURE 1—*continued*

Well Name	Fig. 1 No.	Derrick Floor Elevation (m)	Depth (m)	Temperature (°C)	Sect. Grad. (°C/100 m)	Overall Grad. (°C/100 m)
Sandy Point 1—*continued*			2 466	(108)	0·85	3·37
			2 514	(108)	0	3·31
			3 045	120	1·51	3·12
Sandy Point 2	79	4	647	(42)	2·64	2·64
			1 680	87	4·36	3·70
Sholl Island 1	80	5	734	(52)	3·70	3·70
			1 269	(67)	2·80	3·32
Surprise 1	....	....	....	N.A.	....	....
Tamala 1	81	4	527	56	5·88	5·88
			1 225	(74)	2·58	4·00
Thevenard 1	82	4	969	79	5·60	5·60
			1 994	102	2·24	3·87
Tortoise 1	83	4	787	(56)	3·96	3·96
			1 563	(90)	4·38	4·17
			2 133	(100)	1·75	3·52
Trimouille 1	84	4	685	(45)	2·94	2·94
			1 175	(59)	2·86	2·90
			2 400	(89)	2·45	2·67
Tryal Rocks 1	85	74	1 220	55	2·62	2·62
			1 923	(82)	3·84	3·08
			3 033	123	3·69	3·31
			3 696	152	4·37	3·51
Urala 1	86	2	763	(61)	4·73	4·73
Wandagee 1	87	3	807	(64)	4·85	4·85
			1 071	(72)	3·03	4·40
Warroora 1	88	1	1 824	(110)	4·66	4·66
West Muiron 2	89	92	965	63	4·35	4·35
			1 816	82	2·23	3·31
			2 163	91	2·59	3·19
			3 306	134	3·76	3·39
West Tryal Rocks 1	90	150	3 432	126	3·08	3·08
			3 864	145	4·40	3·23
West Tryal Rocks 2	91	138	1 495	54	2·14	2·14
			3 206	118	3·74	3·03
			3 815	144	4·27	3·24
Whaleback 1	92	3	1 048	58	3·16	3·16
			1 116	(61)	4·41	3·23
			1 168	(66)	9·61	3·51
			1 366	(77)	5·56	3·82
			1 527	(80)	1·86	3·61
Windoo 1	....	....	....	N.A.	....	....
Wonangara 1	93	2	571	(63)	6·68	6·68
Woorawa 1	....	....	....	N.A.	....	....
Yanrey 1	94	3	428	(49)	5·61	5·61
Yarraloola 1	95	2	163	(54)	17·90	17·90
			269	(50)	-3·77	9·33
Yaringa 1	96	6	742	(68)	5·84	5·84
			868	76	6·35	5·91
			2 288	(80)	0·28	2·41

NOTES: **83** Confident formation temperature with good extrapolation of 3 or more points.
83 Temperature with poor fit of 3 or more points or only 2 points.
(83) Poor temperature—only one point or no temperature range.
N.A. Not Available.

MODIFIED STRATIGRAPHIC NOMENCLATURE AND CONCEPTS IN THE PALAEOZOIC SEQUENCE OF THE CARNARVON BASIN, W.A.

by R. M. Hocking, P. S. Moore and H. T. Moors

ABSTRACT

The following amended names applicable to the Palaeozoic sequence of the Carnarvon Basin, are proposed: Nannyarra Sandstone, Cordalia Sandstone, Mallens Sandstone, Nalbia Sandstone, Coolkilya Sandstone and Jimba Jimba Calcarenite Member (of the Billidee Formation). The following names, formerly applicable to the Permian Byro Group, are deleted: "Newman Subgroup", "Minilya Subgroup", "Madeline Formation", "Bogadi Greywacke", and "Warra Warringa Formation". These changes result from (a) the deletion of the term "greywacke" from the Carnarvon Basin nomenclature and (b) a better understanding of the stratigraphy of the Byro and Wooramel Groups.

INTRODUCTION

Various parts of the stratigraphy of the Carnarvon Basin have been revised since publication by the Bureau of Mineral Resources of a bulletin on the Carnarvon Basin (Condon, 1965a, 1967, 1968), although this bulletin is still a standard reference. The present paper proposes more changes to Palaeozoic formation and group names and ranks in the basin, and summarizes the revisions made in the Permian stratigraphy since 1967.

"GREYWACKE" AND SANDSTONE NOMENCLATURE

History and rationale

In erecting formal stratigraphic nomenclature for the Carnarvon Basin, the term "greywacke" was commonly used in Palaeozoic formation names by Condon (1954, 1962) and Konecki, Condon, Dickins and Quinlan (1958). Of these, the Nannyarra "Greywacke" (Devonian), Cordalia "Greywacke", Mallens "Greywacke", Nalbia "Greywacke" and Coolkilya "Greywacke" (Permian) remain valid formations, but we here suggest that the lithological term "greywacke" is inappropriate for these units and should be deleted from the names of valid formations. The "Coyango" and "Koomberan Greywackes" were relegated to member status by van de Graaff and others (1977), the name "Norton Greywacke" was abandoned in favour of Nalbia "Greywacke" by Playford and others (1975), and the name "Bogadi Greywacke" is abandoned in this paper.

Condon (1965a, p. 14) defined greywacke as "Arenite consisting of angular and/or subrounded quartz and/or rock fragments with or without feldspar and with a fine-grained matrix which is generally micaceous and/or chloritic". This is a purely qualitative definition, although he made reference to his earlier article which has quantitative limits for a much

TABLE 1. ROCK-TYPE COMPOSITION OF RELEVANT PALAEOZOIC FORMATIONS AND MEMBERS. USE OF "WACKE" AND "ARENITE" AS BY DOTT (1964)

Formation	Age	Dominant rock-type	Subsidiary rock-types
Nannyarra Sandstone	Early-Middle	Coarse- to fine-grained quartz and feldspathic wacke and arenite.	Siltstone, sandy siltstone
Cordalia Sandstone	Early Permian (Artinskian)	Medium- to very fine-grained silty quartz wacke and arenite.	Siltstone, sandy siltstone, minor claystone
Mallens Sandstone	Early Permian (Artinskian)	Medium- to very fine-grained quartz wacke and arenite	Minor siltstone
Nalbia Sandstone	Early Permian (Artinskian)	Medium- to very fine-grained quartz wacke and arenite	Sandy siltstone
Coolkilya Sandstone	Early Permian (Kungurian)	Fine- to very fine-grained quartz wacke and arenite	Siltstone, sandy siltstone
Coyango Member, Lyons Formation	Early Permian (Sakmarian)	Feldspathic and quartz arenite and wacke	Diamictite, siltstone, conglomerate
Koomberan Member, Lyons Formation	Early Permian (Sakmarian)	Feldspathic wacke and arenite	Diamictite, siltstone, limestone, quartz wacke

broader "Greywacke Group". In the earlier definition, he stated: "... the only essential component of this group is the matrix ..." (Condon, 1952, p. 54), which he defined as ranging between 30% and 50%.

By using the terms "sandstone" and "greywacke" in formation names, Condon differentiated between sand-sized siliclastic sediments with negligible matrix (termed sandstones), which are potential aquifers and hydrocarbon reservoirs, and those with significant matrix (termed greywackes), which lack economic reservoir properties.

Current usage and definitions

Greywacke is a term which has been used in many different senses and has been much abused in the past (cf. Dott, 1964; Pettijohn, Potter and Siever, 1972; Sanders, *in* Fairbridge and Bourgeois, 1978). The *Glossary of Geology* (Gary and others, 1972, p. 312) lists eight modern definitions and concludes "... the term 'greywacke' should not be used formally without either a specific definition or a reference to a readily available published definition." Condon's (1965a) definition is neither widely known nor accepted. Folk (1968) recommended that the term be used only in non-quantitative field descriptions. Pettijohn (1975) restricted the term to the "classical" usage, two of the essential requirements being a dark, fine-grained matrix, and a lithic clastic component in the framework. In addition, he considered that greywackes generally occur in deformed, marine, flysch-type, miogeosynclinal or eugeosynclinal environments.

Applicability

Carnarvon Basin "greywackes" are not dark grey and are not highly indurated. They do not contain an appreciable amount of lithic material within their framework (Table 1), which is an essential feature of all common definitions (Gary and others, 1972). Moreover, none that we have examined contain as much as 30% matrix, the minimum amount required by Condon's (1952) definition.

Furthermore, Carnarvon Basin "greywackes" certainly were not deposited in Flysch-type, geosynclinal environments. All were deposited in shallow-marine environments in an intracratonic basin, or (for the Nannyarra, "Coyango" and "Koomberan Greywackes") in partly fluviatile environments. Further details on the depositional environments of the Mallens, Nalbia and Coolkilya "Greywackes" are presented by Moore, Denman and Hocking (1980) and Moore, Hocking and Denman (1980) in this volume.

Thus, the "greywackes" of the Carnarvon Basin are not greywackes by common definition, common usage, or Condon's (1952, 1965a) definition.

Modified stratigraphic nomenclature

We propose to modify the names "Nannyarra Greywacke", "Cordalia Greywacke", "Mallens Greywacke", "Nalbia Greywacke" and "Coolkilya Greywacke", amending them to Nannyarra Sandstone, Cordalia Sandstone, Mallens Sandstone, Nalbia Sandstone, and Coolkilya Sandstone. The last three were originally named "sandstone" by Teichert (1950). Sandstone is the predominant lithology in all these units (Table 1) and "sandstone" is thus the preferred term to "formation".

Sandstone classification

Although it is considered that "greywacke" is an inappropriate term for the Carnarvon Basin sandstones, we appreciate the need to discriminate between those sandstones with negligible matrix, and those with a significant matrix. There are many schemes of sandstone classification (such as those proposed by Folk (1968), Dott (1964), Pettijohn (1957, 1975), Packham (1954) and Crook (1960)), of which we prefer the scheme by Dott (1964) (Fig. 1), because it discriminates between impure sandstones (wackes) and clean sandstones (arenites) in a logical, gradational manner. The scheme also avoids the term "greywacke" and has the advantage of wide acceptance and usage.

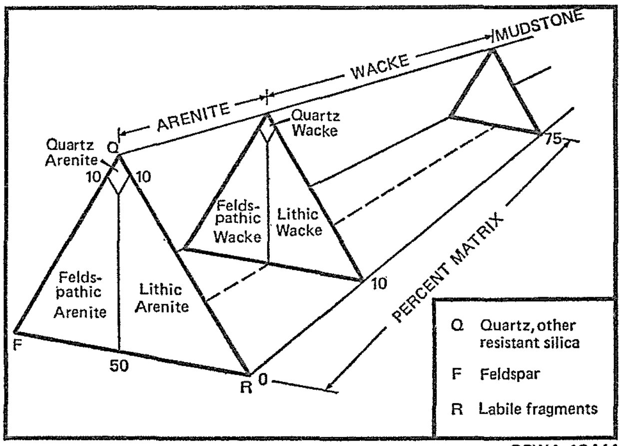


Figure 1 Nomenclature of sandstones as proposed by Dott (1964).

LYONS FORMATION

Members

Van de Graaff and others (1977) reduced the "Lyons Group" to formation status, and relegated the constituent formations, proposed by Condon (1962), to member status. However, of these seven members only a basal sandstone, the Austin Member, has been consistently recognized throughout the Carnarvon Basin. More detailed work is needed to clarify the validity and extent of the remaining six units, which cannot be distinguished beyond their immediate type areas at 1:250 000 scale, and thus are not shown in Table 2.

Age

Condon (1967) and Playford and others (1975) considered the Lyons Formation to be wholly Permian (Sakmarian) in age, but Kemp and others (1977), on palynological grounds, place the lower part of the formation in the Late Carboniferous. Also, 850 m of unnamed glacigene sediments in the Remarkable Hill 1 well (22°57′36″S, 114°09′27″E, Fig. 2) is of apparent Carboniferous age (Berven, 1969) and in our opinion should be included within the conformably overlying Lyons Formation. Lastly, lithological correlatives of the Lyons Formation in the Canning Basin (Grant Formation) and the Perth Basin (Nangetty Formation) have been shown to extend into the Carboniferous (Balme, *in* Johnson, 1968; Kemp and others, 1977), on more evidence than is available for the Lyons Formation.

Carrandibby Formation

We consider that the Carrandibby Formation is a lateral variant of the uppermost Lyons Formation, transitional into the overlying Callytharra Formation. Although it is too

TABLE 2. MODIFICATIONS IN LATE CARBONIFEROUS AND LOWER PERMIAN STRATIGRAPHY SINCE 1967

AGE		CONDON (1965, 1967) MERLINLEIGH SUB-BASIN	CONDON (1965, 1967) BYRO SUB-BASIN	PLAYFORD AND OTHERS (1975) MERLINLEIGH SUB-BASIN	PLAYFORD AND OTHERS (1975) BYRO SUB-BASIN	REVISIONS 1975-1980 MERLINLEIGH SUB-BASIN	REVISIONS 1975-1980 BYRO SUB-BASIN
PERMIAN	KUNGURIAN	KENNEDY GROUP: BINTHALYA FM		KENNEDY GROUP: BINTHALYA FM		KENNEDY GROUP: BINTHALYA FM	Age uncertain, no diagnostic fossils
		MUNGADAN SST		MUNGADAN SST		MUNGADAN SST	
		COOLKILYA GWKE		COOLKILYA GWKE ?	3	COOLKILYA SST2	4
	?ARTINSKIAN	BYRO GROUP, MINILYA SUB-GROUP: BAKER FM		BYRO GROUP, MINILYA SUB-GROUP: BAKER FM		BYRO GROUP2: BAKER FM	
		NORTON GWKE		NALBIA GWKE		NALBIA SST2	
		WANDAGEE FM		WANDAGEE FM		WANDAGEE FM	
		QUINNANIE SH		QUINNANIE SH		QUINNANIE SH	
		CUNDLEGO FM		CUNDLEGO FM ?		CUNDLEGO FM	
		NEWMAN SUB-GROUP: BULGADOO SH	WARRA WARRINGA FM	NEWMAN SUB-GROUP: BULGADOO SH	WARRA WARRINGA FM	BULGADOO SH	
		MALLENS GWKE	BOGADI GWKE	MALLENS GWKE	BOGADI GWKE	MALLENS SST2	
		COYRIE FM	MADELINE FM	COYRIE FM	MADELINE FM	COYRIE FM	
		WOORAMEL GROUP: BILLIDEE FM	KEOGH FM, ONE GUM FM, BILLIDEE FM	WOORAMEL GROUP: BILLIDEE FM	KEOGH FM, ONE GUM FM, BILLIDEE FM	WOORAMEL GROUP: BILLIDEE FM	KEOGH FM, BILLIDEE FM1
		JIMBA JIMBA CA		JIMBA JIMBA CA		JIMBA JIMBA CA MBR 2	
		MOOGOOLOO SST	MOOGOOLOO SST, CURBUR FM, CONGO FM, MONUMENT FM, NUNNERY SST	MOOGOOLOO SST	NUNNERY SST, MOOGOOLOO SST	MOOGOOLOO SST	
		CORDALIA GWKE		CORDALIA GWKE		CORDALIA SST2	
		CALLYTHARRA FM					
	SAKMARIAN		CARRANDIBBY FM	CALLYTHARRA FM		CALLYTHARRA FM	
		LYONS GROUP: WEEDARRA SH		LYONS GROUP: WEEDARRA SH	CARRANDIBBY FM	CARRANDIBBY FM	
		THAMBRONG SLT		THAMBRONG SLT	LYONS GP	LYONS FM1	
		MUNDARIE SLT		MUNDARIE SLT			
		KOOMBERAN GWKE		KOOMBERAN GWKE			
		DUMBARDO SLT		DUMBARDO SLT			
		COYANGO GWKE		COYANGO GWKE			
		HARRIS SST	AUSTIN FM	AUSTIN FM			
LATE CARBONIFEROUS				HARRIS SST		? AUSTIN MBR1 ?; HARRIS SST	

GSWA 18443

Zig-zag boundary indicates formation is discontinuous. Modifications by (1) Van de Graaff and others (1977); (2) this paper; (3) Cockbain (1980); (4) Moore, Hocking and Denman (1980).

small to be mapped at 1:250 000 scale, it is present in the Merlinleigh Sub-basin as well as in the Byro Sub-basin, and is therefore shown as such in Table 2.

Harris Sandstone

The validity and stratigraphic relationships of the Harris Sandstone are uncertain. It has only been recognized near Moogooree homestead and in its type area near Williambury homestead (Fig. 2). Condon (1967) considered that the outcrops near Moogooree homestead belonged to the basal Lyons Formation (Austin Member), but we (in agreement with Read and others (1973)) consider that they should be assigned to the Harris Sandstone. Condon (1967) correlated the Harris Sandstone (which he only recognized in the Williambury area) with the Austin Member of the Lyons Formation, but we are not certain whether this correlation is valid or, alternatively, whether the Harris Sandstone is older than the Austin Member. The lithology and outcrop pattern of the two units are very similar, but the relationship of one to the other has not been established at any locality. No evidence of glacial influence has been found in any outcrops mapped as Harris Sandstone; in contrast, the Austin Member locally contains glacigene boulder beds at its base and exhibits soft-sediment ice-drag striae near the Weedarra Inlier (Fig. 2).

Read and others (1973) postulated an angular unconformity between the Lyons Formation and Harris Sandstone, near Moogooree homestead. This has not been proved by later mapping; we can find no definite evidence of angular discordance between the two units. Both the Harris Sandstone and Austin Member are of varying thickness and crop out discontinuously, and each unit appears to have been substantially scoured before or during deposition of the overlying glacigene diamictites.

We tentatively retain the Harris Sandstone as a separate unit, possibly unconformable beneath the Lyons Formation; because no evidence of glacial influence has been found within it, and there is some remaining doubt regarding its correlation with the Austin Member of the Lyons Formation.

WOORAMEL GROUP

Condon (1965b) defined the Jimba Jimba Calcarenite (a bioclastic limestone with subordinate quartz sand) as a formation within the Wooramel Group and conformable between the Moogooloo Sandstone below and the Billidee Formation above. At that time, the type section west of Gascoyne Junction and a section in BMR 8 (Mount Madeline) well (Fig. 2) were the only known occurrences of this lithology within the Wooramel Group. Since then, outcrops of identical lithology have been found at the top of the Billidee Formation on Dairy Creek Station (about 4 m thick) and in the middle of the Billidee Formation on Mount Sandiman Station (about 60 m thick). In both cases, the calcarenite is clearly conformable with adjacent strata, and is not a structurally isolated remnant of Callytharra Formation, which is very similar in outcrop.

The outcrops on Mount Sandiman Station consist of lenses of fossiliferous, variably coarse-grained, quartzose calcarenite, separated by dark, ferruginized siltstone and fine-grained silty sandstone. The calcarenites appear to have formed as shoals of coarser grained material on a low- to moderate-energy marine shelf. We consider that the other occurrences formed in the same manner, as isolated areas of carbonate shoals. Their distribution and variable stratigraphic position within the Billidee Formation indicates that coarse-grained carbonate debris was only available in limited amounts at any one place or time.

These lithologically identical calcarenites cannot be grouped as one member within the Billidee Formation because they are stratigraphically separate. However, they are clearly related and represent a specific subenvironment within the overall environment of deposition of the Billidee Formation. Therefore we propose to redefine the Jimba Jimba Calcarenite in its type area as a member within the Billidee Formation and to consider the other occurrences (which may well be isolated lenses) as facies equivalents of the Jimba Jimba Calcarenite Member but not to name them at this time.

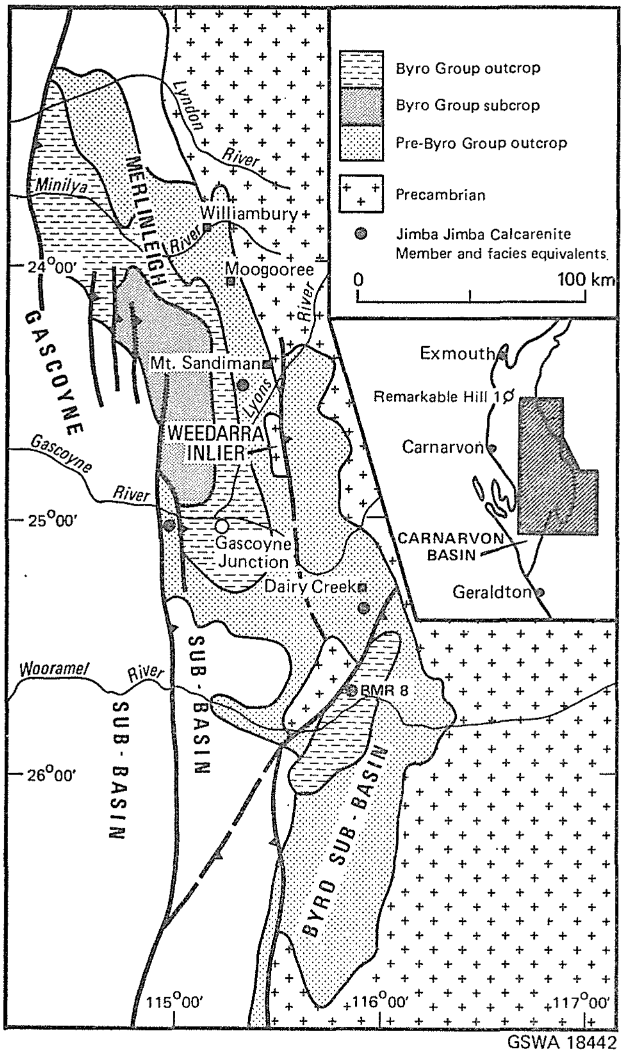


Figure 2 Locality map, showing distribution of the Byro Group and Jimba Jimba Calcarenite Member of the Billidee Formation.

BYRO GROUP

The Byro Group was divided into the (lower) Newman Subgroup and the (upper) Minilya Subgroup by Condon (1962), who recognized an unconformity between the Bulgadoo Shale below and the Cundlego Formation above. As evidence, Condon (1965b) stated "... this unconformity is well shown on the map south-west of Gascoyne Junction, although the relationship has not been observed in outcrop." This has not been substantiated by remapping of the relevant areas of the Wooramel 1:250 000 Geological Sheet. The anomalous dips recorded in the upper part of the Bulgadoo Shale by Condon (1965b) are due to soil creep and salt heaving (caused by weathering).

Elsewhere, as in the type section along the Minilya River, and in the reference section at the northern end of Kennedy Range, the base of the Cundlego Formation is defined as a thin (average 0·15 m) conglomerate bed. Such beds are common in the Cundlego Formation, and are interpreted as intraformational, transgressive lag conglomerates, which do not constitute evidence of a disconformity (Moore, Denman and Hocking, 1980). Thus, the Cundlego Formation is considered to rest conformably on the Bulgadoo Shale throughout the area of outcrop.

Since the sediments of the Newman and Minilya Subgroups are lithologically and sedimentologically similar, and the boundary between them is apparently conformable, without any major faunal change (Dickins, 1970), we propose that the names Newman and Minilya Subgroups be abandoned.

The Byro Group in the Byro Sub-basin was divided into the Madeline Formation, Bogadi "Greywacke" and Warra Warringa Formation by Konecki, Condon, Dickins, and Quinlan (1958). Condon (1967) considered that all three were lateral equivalents of the Coyrie Formation (Table 2), but Konecki, Dickins and Quinlan (1958), Playford and Cope (1971), and Playford and others (1975) only correlated the Madeline Formation with the Coyrie Formation, equating the Bogadi "Greywacke" with the Mallens Sandstone (amended herein), and the Warra Warringa Formation with the Bulgadoo Shale. Although there is no continuity of outcrop or subcrop between the two areas, the formations are lithologically and sedimentologically very similar, and contain comparable faunas. We interpret these similarities as indicating original continuity of deposition in a basin with very uniform marine conditions and laterally persistent environments. A slightly finer grain-size in the Merlinleigh Sub-basin outcrops is attributed to deposition in an environment which is marginally further offshore than in the Byro Sub-basin (Moore, Denman and Hocking, 1980). The names "Madeline Formation", "Bogadi Greywacke" and "Warra Warringa Formation" are therefore abandoned in favour of the Coyrie Formation, Mallens Sandstone and Bulgadoo Shale, which have historical precedence.

REFERENCES CITED

Berven, R. J., 1969, Remarkable Hill No. 1 well completion report: Marathon Petroleum Pty Ltd Rept (unpublished).

Cockbain, A. E., 1980, Permian ammonoids from the Carnarvon Basin—a review: West. Australia Geol. Survey Ann. Rept 1979. p. 100–105.

Condon, M. A., 1952, Nomenclature of fragmental silicate rocks: Australian Jour. Science v. 15, p. 53–55.

——— 1954, Progress report on the stratigraphy and structure of the Carnarvon Basin, Western Australia: Australia Bur. Mineral Resources Rept 15.

——— 1962, Kennedy Range, W.A.: Australia Bur. Mineral Resources 1:250 000 Geol. Series Explan. Notes.

——— 1965a, The geology of the Carnarvon Basin, Western Australia, Part 1: Pre-Permian Stratigraphy: Australia Bur. Mineral Resources Bull. 77.

——— 1965b, Wooramel, W.A.: Australia Bur. Mineral Resources, 1:250 000 series Explan. Notes.

——— 1967, The geology of the Carnarvon Basin, Western Australia, Part 2: Permian stratigraphy: Australia Bur. Mineral Resources Bull. 77.

——— 1968, The Geology of the Carnarvon Basin, Western Australia, Part 3: Post-Permian stratigraphy; structure; economic geology: Australia Bur. Mineral Resources Bull. 77.

Crook, K. A. W., 1960, Classification of arenites: Amer. Jour. Science, v. 258, p. 419–428.

Dickins, J. M., 1970, Correlation and subdivision of the Permian of western and eastern Australia, *in* Palaeontological Papers 1968: Australia Bur. Mineral Resources Bull. 116, p. 17–28.

Dott, R. H., Jnr., 1964, Wacke, greywacke and matrix—what approach to immature sandstone classification?: Jour. Sedimentary Petrol., v. 34, p. 625–632.

Fairbridge, R. W. and Bourgeois, J., (eds), 1978, The Encyclopedia of Sedimentology: Stroudsburg, Pennsylvania, Dowden, Hutchinson and Ross.

Folk, R. L., 1968, Petrology of Sedimentary Rocks: Austin, Texas, Hemphills, 170 p.

Gary, M., McAfee, R., Jnr, and Wolf, C. L. (eds), 1972, Glossary of Geology: Amer. Geological Institute, Washington, D.C.

Johnson, N. E. A., 1968, Blackstone No. 1 well completion report: West Australian Petroleum Pty Ltd Rept (unpublished).

Kemp, E. M., Balme, B. E., Helby, R. J., Kyle, R. A., Playford, G. and Price, P. L., 1977, Carboniferous and Permian palynostratigraphy in Australia and Antarctica: a review: Jour. Australian Geology and Geophysics, v. 2, p. 177–208.

Konecki, M. C., Condon, M. A., Dickins, J. M. and Quinlan, T., 1958, *in* McWhae, J. R. H., Playford, P. E., Lindner, A. W., Glenister, B. F., and Balme B. E., 1958, The stratigraphy of Western Australia: Geol Soc. Australia Jour. v. 4, pt. 2.

Konecki, M. C., Dickins, J. M. and Quinlan, T., 1958, The geology of the coastal area between the lower Gascoyne and Murchison Rivers, Western Australia: Australia Bur. Mineral Resources Rept 37.

Moore, P. S., Denman, P. D., and Hocking, R. M., 1980, Stratigraphy and sedimentology of the Lower Permian Byro Group, Carnarvon Basin, W.A.: West. Australia Geol. Survey Ann. Rept 1979, p. 55–64.

Moore, P. S., Hocking, R. M. and Denman, P. D., 1980, Stratigraphy and sedimentology of the Kennedy Group (Permian), Carnarvon Basin, W.A.: West. Australia Geol. Survey Ann. Rept 1979, p. 65–72.

Packham, G. H., 1954, Sedimentary structures as an important factor in the classification of sandstones: Amer. Jour. Science, v. 252, p. 466–476.

Pettijohn, F. J., 1957, Sedimentary Rocks (2nd ed.): New York, Harper, 718 p.

——— 1975, Sedimentary Rocks (3rd ed.): New York, Harper and Row, 628 p.

Pettijohn, F. J., Potter, P. E., and Siever, R., 1972, Sand and Sandstone: New York, Springer-Verlag, 618 p.

Playford, P. E., and Cope, R. N., 1971, The Phanerozoic stratigraphy of Western Australia: a correlation chart in two parts: West. Australia Geol. Survey Ann. Rept 1970, p. 32–33.

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. 223–445.

Read, J. F., Alcock, P. J. and Hoseman, P., 1973, Harris Sandstone-Yindagindy Formation relationships and possible position of Permo-Carboniferous boundary, Carnarvon Basin, Western Australia: Roy. Soc. West. Australia Jour, v. 56, p. 80–85.

Teichert, C., 1950, Some recent additions to the stratigraphy of Western Australia: Amer. Assoc. Petroleum Geologists Bull., v. 34, p. 1787–1794.

van de Graaff, W. J. E., Hocking, R. M. and Denman, P. D., 1977, Revised stratigraphic nomenclature and interpretations in the east-central Carnarvon Basin, W.A.: West. Australia Geol. Survey Ann. Rept 1976, p. 37–39.

SEDIMENTOLOGY OF THE BYRO GROUP (LOWER PERMIAN), CARNARVON BASIN, WESTERN AUSTRALIA

by P. S. Moore, P. D. Denman and R. M. Hocking

ABSTRACT

The Lower Permian (Artinskian) Byro Group is a sequence of shale, siltstone and sandstone which crops out in the southeastern Carnarvon Basin. The sedimentology of the group can be expressed in terms of six facies which represent deposition in the offshore, transition, and shoreface environments. The oscillation between these environments was controlled both by natural progradation of the coastline and by tectonic readjustments of the sedimentary basin. The facies reflect a balance between wave processes, which predominated in the shoreface zone, and biogenic processes, which predominated below effective wave base in the offshore and transition zones.

INTRODUCTION

The Lower Permian (Artinskian) Byro Group, as defined by Condon (1954, p. 60) is the sequence of siltstone, shale and sandstone between the sandy Wooramel Group below and the sandy Kennedy Group above. It crops out in the Byro and Merlinleigh Sub-basins of the Carnarvon Basin (Fig. 1). The stratigraphy of the group is simplified by Hocking and others (1980). As now defined (Table 1) the Byro Group consists of eight formations, all of which are represented in the Merlinleigh Sub-basin. Only the Coyrie Formation, Mallens Sandstone and Bulgadoo Shale are preserved in the Byro Sub-basin.

Although the original choice of formation boundaries was strongly influenced by palaeontological zoning (Teichert, 1950, 1951, 1957), the boundaries as now mapped correspond to lithological changes. The eight formations differ mainly in the ratio of sandstone to shale and siltstone. A slightly coarser grain-size, with respect to lateral equivalents in the Merlinleigh Sub-basin, suggests that the Byro Sub-basin sequence was deposited marginally closer to the shoreline. However, we believe the lithological, sedimentological and faunal similarities of the Byro Group sequences in the Byro and Merlinleigh Sub-basins indicate original continuity of marine deposition between these separate areas of outcrop.

FACIES ANALYSIS

For simplicity, the sequence in the Byro Group is discussed in terms of facies, six of which are distinguished. They are grouped into two major facies associations (fine-grained association and sandstone association), and a simplified facies model, showing the major depositional environments, is presented in Figure 2. Terminology is based on Howard (1972) and Reading (1978).

FINE-GRAINED FACIES ASSOCIATION

Dark-grey to black shales and fine to medium-grained grey siltstones occur in all formations of the Byro Group, except the Mallens Sandstone. Units range in thickness from a few centimetres to several tens of metres. The finer-grained, darker units are commonly rich in selenite and are pyritic.

Black-shale facies (lower offshore)

The black-shale facies consists of evenly laminated, dark-grey to black shale and fine siltstone. Burrows are rare or absent, and body fossils mainly comprise small articulated chonetids and ostracods. Pyrite-infilled foraminifera from the Baker Formation (Condon, 1967), and concentrations of foraminifera from the Quinnanie Shale (Crespin, 1958) are also attributed to this facies. The black shales are commonly pyritic or contain limonitic imprints of original pyrite. Secondary gypsum (selenite) is extremely abundant, and deep-red, pale-grey, and black ferruginous concretions up to 1 m across are common. The black-shale facies is best represented by outcrops of the Bulgadoo and Quinnanie Shales. It is also well represented in the upper part of the Wandagee Formation and in the more northwesterly outcrops of the Baker Formation.

The black shales were deposited in a very quiet-water, offshore-marine environment, under strongly reducing conditions. Phosphate concentrations of up to 1·25 per cent are recorded by Russell (1965), and suggest slow deposition in a restricted basin (Pettijohn, 1975, p. 434). Recent weathering of the pyritic and weakly calcareous shales in the presence of water is believed to have released iron and sulphate ions. Reprecipitation of the iron produced ovoid limonitic concretions and minor jarosite. The release of the sulphate ions created an acidic environment, favouring the dissolution of calcite and the eventual precipitation of secondary gypsum (selenite). We believe that all the gypsum in the Byro Group was formed in this manner.

The small size of the fossils and the pyritic nature of the black shale suggest that this facies was formed in a restricted environment of deposition. A broad marine shelf, with a pyritic shale facies in the deeper, quieter water zone (as outlined by Reading, 1978) is favoured over the more specialized silled-basin hypothesis of Condon (1967). According to Reading (1978) mud-dominated offshore shelf deposits probably accumulated preferentially in areas of low wave and current agitation, particularly where suspended sediment concentrations were high.

Grey-siltstone facies (upper offshore)

The grey-siltstone facies consists mainly of evenly laminated to very thinly bedded, fine- to coarse-grained, mid-grey siltstone (Fig. 4A) with abundant, small curved burrows including *Chondrites* and minor *Planolites*. In the upper part of the Bulgadoo Shale at the type section along the Minilya River, the grey-siltstone facies contains thin sandstone interbeds, bearing the bipinnate, branching trace fossil *Lophoctenium* (Fig. 4B). Body fossils are uncommon, and are mainly small, articulated chonetid brachiopods. The grey-siltstone facies characterizes outcrops of the Baker Formation, especially in the eastern Kennedy Range area, and is also well developed in the lower portions of coarsening-upward cycles (generally 1.5–6.0 m thick) in the Cundlego and Wandagee Formations. It forms a minor part of most other formations in the Byro Group.

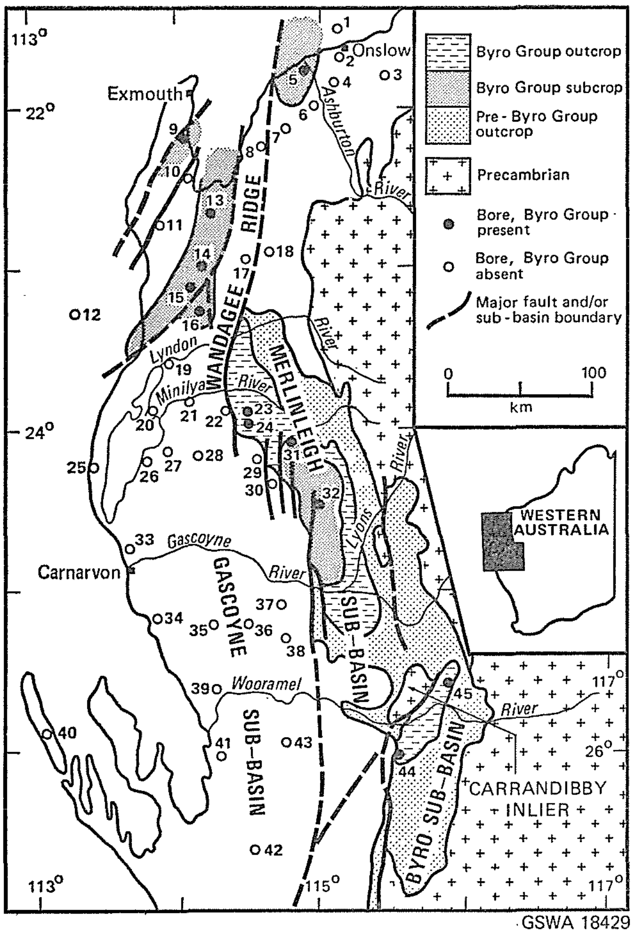


Figure 1 Surface and inferred subsurface distribution of the Byro Group.
Bores used in the compilation are: (1) Direction Island 1; (2) Cane River 1; (3) Cane River 5; (4) Minderoo 1; (5) Onslow 1; (6) Cunaloo 1; (7) Wonangarra 1; (8) Yanrey 1; (9) Learmonth 1; (10) Rough Range 1; (11) Whaleback 1; (12) Pendock 1; (13) BMR 5: Giralia; (14) Giralia 1; (15) Cardabia 2: WB; (16) Cardabia 1: WB; (17) Marrilla 1; (18) East Marrilla 1; (19) Chargoo 1; (20) Minilya 3: WB; (21) Minilya 8: WB; (22) Wandagee 1; (23) Wandagee 2; (24) Quail 1; (25) Cape Cuvier 1; (26) Gnarraloo 1; (27) Minilya 5: WB; (28) Jeeribuddy 1: WB; (29) BHP Wandagee 6; (30) BHP Wandagee 7; (31) BMR 6 & 7: Muderong; (32) Kennedy Range 1; (33) Pelican Hill 1: WB; (34) Brickhouse 4: WB; (35) Marron 1: WB; (36) Marron 2: WB; (37) Yalobia 1: WB; (38) Yalobia 3: WB; (39) Wodra 1: WB; (40) Dirk Hartog 17B; (41) Yaringa 1; (42) Hamelin 10: WB; (43) Woodleigh 4: WB; (44) Byro Deep 2; (45) BMR 9: Dairy Creek. WB indicates water bore. All others are petroleum bores.

The grey siltstones were deposited in a low-energy, moderately reducing marine environment without marked current or wave activity. The sediment contained abundant organic matter and supported an active fauna of deposit-feeding organisms and rare filter-feeders. Thin interbeds of planar-laminated to very low-angle cross stratified fine sandstone are associated with the facies in the better developed sections, and are interpreted as thin storm-deposits carried into the quieter, deeper parts of the basin during increased wave and current activity. The presence of *Lophoctenium* in some of the sandy interbeds is further evidence of deposition under quiet, relatively deep-water conditions, since this trace fossil is characteristic of the *Nereites* ichnofacies (Seilacher, 1978, Fig. 6). The grey-siltstone facies is interpreted as a shoreward equivalent of the black-shale facies.

SANDSTONE FACIES ASSOCIATION

Greyish-green to brown, very fine- to medium-grained sandstones and silty sandstones are common in the Byro Group, and are best developed in the Mallens and Nalbia Sandstones. Four facies are recognized and are discussed below in order of increasing grain-size. The four sandstone facies are interpreted as representing laterally adjacent sedimentary environments, which developed shoreward of the fine-grained facies association.

Bioturbated sandstone facies (transition zone)

The bioturbated sandstone facies consists of evenly bedded, greyish-green to brown, poorly to moderately sorted, fine to very fine-grained sandstone and silty sandstone. The most characteristic feature of the facies is the intense bioturbation which commonly obliterates the original bedding features entirely. Body fossils are mainly bivalves, brachiopods and gastropods. The facies is best developed in the Nalbia Sandstone, particularly in the middle portion, and is also developed sporadically throughout the Mallens Sandstone. Thin intervals of bioturbated sandstone (generally less than 1 m thick) occur in the Coyrie, Wandagee and Cundlego Formations.

The bioturbated sandstone facies is the result of deposition on a marine shelf below effective wave base, where the rate of sedimentation was sufficiently slow to allow extensive reworking of the sediment by burrowing organisms. Two subfacies are recognized, based on the degree of bioturbation and the trace-fossil assemblage. The quieter water, more offshore subfacies is characterized by an abundance of simple *Zoophycos*, in association with other inclined and subhorizontal burrows, and is well developed in the middle portion of the Nalbia Sandstone (Fig. 4C). *Scalarituba* and *Rhizocorallum*, occur uncommonly and *Cosmorphaphe* rarely in this subfacies. The moderate organization and complexity of the feeding burrows represent intense exploration for food by infaunal organisms which lived in an environment characterized by a low oxygen level and a soupy sediment surface (Simpson, 1970; Seilacher, 1978).

The second subfacies is characterized by less intense bioturbation, and by the presence of small, bulb-shaped hollows interpreted as bivalve burrows (Fig. 4D). The tubular cavity through which the siphon was extended is rarely preserved, indicating that the substrate was being gently reworked by waves and currents. Subvertical worm burrows are also

MERLINLEIGH SUB-BASIN		BYRO SUB-BASIN
KENNEDY GROUP		
BYRO GROUP	Baker Formation	
	Nalbia Sandstone	
	Wandagee Formation	
	Quinnanie Shale	
	Cundlego Formation	
	Bulgadoo Shale	Bulgadoo Shale
	Mallens Sandstone	Mallens Sandstone
	Coyrie Formation	Coyrie Formation
WOORAMEL GROUP		WOORAMEL GROUP

GSWA 18440

Table 1 Stratigraphy of the Byro Group in the Byro and Merlinleigh sub-basins (after Hocking and others, 1980).

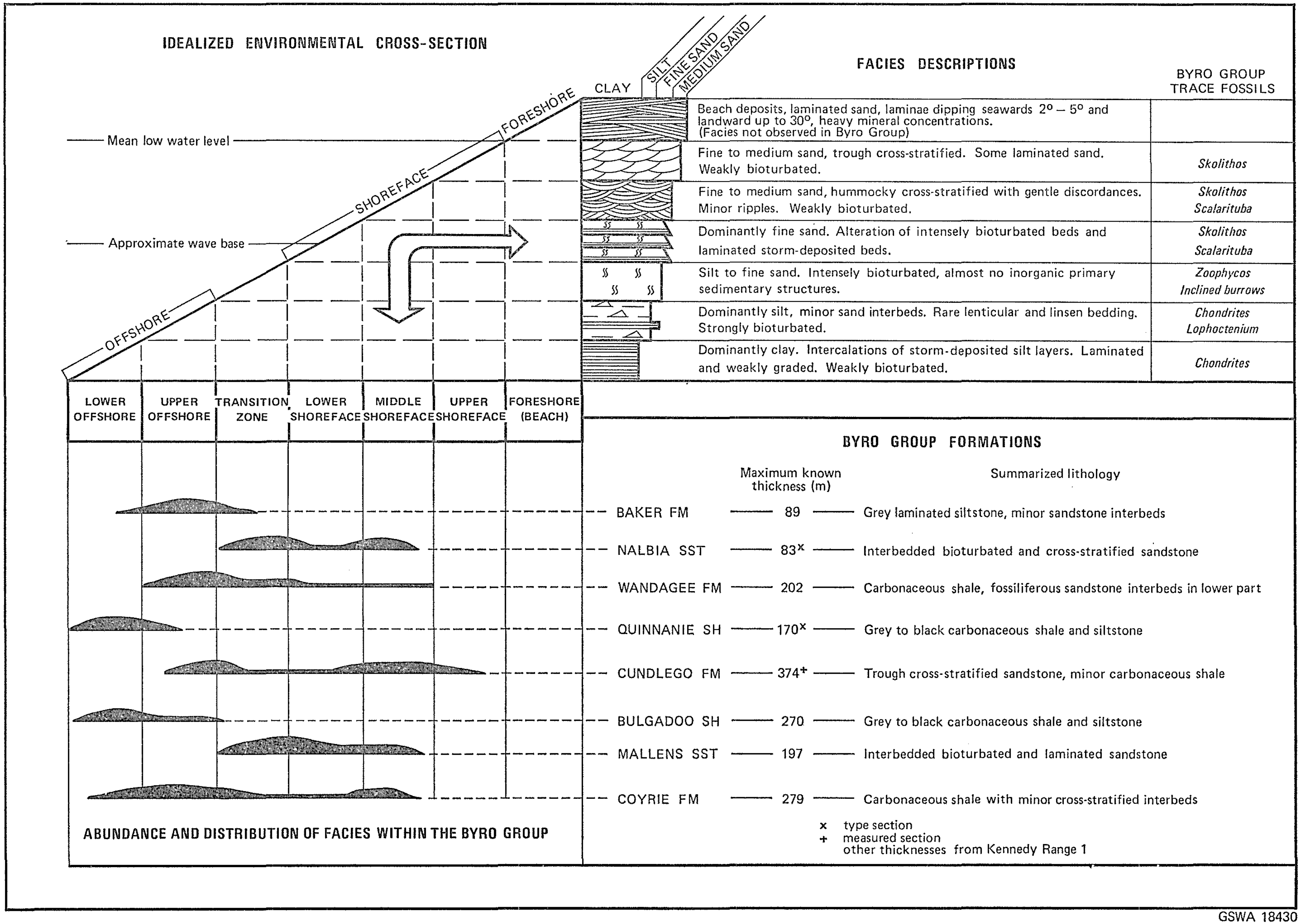


Figure 2 Depositional model and facies distributions for the Byro Group.

present, and they commonly originate from the base of abandoned bivalve burrows (*cf.* Warme and McHuron, 1978, Fig. 7a). The sand-dwelling association of *Oriocrassatella*, *Schizodus*, *Stuchburia* and *Astartila* dominates the bivalve assemblage. Gastropods which occur in this facies of the Nalbia Sandstone probably had a mobile existence in clear water on a firm bottom (Dickens, 1963).

Laminated-to-burrowed sandstone facies (*lower shoreface*)

The laminated-to-burrowed sandstone facies is very distinctive and consists of units which are plane laminated to very low-angle cross-stratified near the base, becoming intensely bioturbated towards the top (Fig. 4E). Units range in thickness from about 0.3 m to many metres, however the basal laminated portion is generally 0.2–0.5 m thick, and rarely exceeds 0.8 m. The sediment is fine- to very fine-grained, moderately sorted and micaceous. Each unit rests on the underlying one with a slightly erosive contact. Rarely, subvertical (escape) burrows penetrate the erosion suface, but the laminated sandstones are generally devoid of burrows in the lower portion. Bioturbation increases upwards, and commonly an interval containing large *Skolithos* is overlain by intensely bioturbated sandstone. Body fossils are mainly disarticulated brachiopods and bivalves. The facies is well developed in the Mallens Sandstone and is also present at rare intervals in the Nalbia Sandstone and Coyrie and Cundlego Formations.

The distinctive, laminated-to-burrowed facies is considered by Howard (1966, 1972) and Reading (1978) to be indicative of deposition at, or slightly below, storm-wave base, where storm deposits alternate with quiet-water sedimentation. During periods of quiescence, incoming sediment is extensively bioturbated by infaunal and epifaunal organisms. During a major storm, wave base is temporarily lowered, and the upper portion of the substrate is reworked. In addition, offshore-directed storm-generated density currents may carry sand into deeper, quieter water environments (Walker, 1979). Thus, the storm deposit rests erosionally on the underlying bioturbated sanstone. Following the storm, conditions of normal sedimentation resume, but the burrowing organisms are generally unable to penetrate more than about 0.2–0.3 m into the substrate and after severe storms an interval of laminated sandstone is preserved which is devoid of bioturbation in the lower part. The thickness of the overlying intensely bioturbated sandstone reflects both the position in the lower shoreface environment in which the sequence was deposited, and also the time duration between major storms.

Hummocky cross-stratified facies (*middle shoreface*)

The hummocky cross-stratified facies is very extensively developed and consists of intersecting sets of very low-angle cross-stratified fine-grained sandstone (Fig. 4F). Harms and others (1975) termed this bedform "hummocky cross-stratification". Bedsets are generally only 0.1–0.3 m thick, and are internally laminated, with rare current lineations. Each set rests erosionally on the underlying sequence, however the bounding surface between sets rarely slopes at more than about 15°. Cross-stratification is subparallel to the base of the set, however where the base is scoured, the laminations tend to drape into the scoured troughs. The dip directions of erosional set boundaries and of the overlying laminae are widely scattered. The tops of hummocky cross-stratified sandstone units may bear wave ripples and contain sinuous, subhorizontal burrows. Small current-drag features and dewatering structions are rare. Trace fossils are also rare, comprising mainly *Scalarituba* and small ?*Skolithos*. Body fossils are mainly concentrated as thin, lenticular coquinas. The bivalve association of *Oriocrassatella, Schizodus, Stuchburia* and *Astartila* dominates the assemblage and is considered by Dickins (1963) to be indicative of an unconsolidated, sandy, current-swept bottom. The hummocky cross-stratified facies is best developed in the Mallens Sandstone and Cundlego Formation, and is also present in parts of the Coyrie Formation and in the lower and upper portions of the Nalbia Sandstone. Thin sandstone interbeds in the Baker Formation and uppermost Bulgadoo Shale are hummocky cross-stratified.

The paucity of trace fossils and the abundance of shallow scour sufaces in this facies indicate constant reworking of sand in the marine environment. Walker (1979) and Hamblin and Walker (1979) believe that hummocky cross-stratification is a good indicator of deposition below fair weather wave base but above storm-wave base, with the hummocky topography being controlled by storm waves. The lack of consistently orientated or well-formed directional features suggests deposition on a shallow marine shelf, seawards of the breaker zone. As noted by Harms and others (1975, p. 88), ". . . stormy seas, dominated by locally generated waves, have complex surface patterns, and the bottom wave surges and current drift can be varied in their directions". Hummocky cross-stratification is formed in response to relatively strong wave action; certainly greater than that required to produce wave ripples in an equivalent depth of water. Rare current lineations indicate temporary periods of upper-regime flow, and, given the average grain-size of fine sand, indicate wave-generated current velocities reaching at least 0.65 m/s (Harms and others, 1975, Figs. 2–5). The resulting bedforms comprised poorly organized sets of shallow swales and low hummocks 2–5 m apart and 0.2–0.6 m high.

Trough-cross-stratified sandstone facies (?*upper shoreface*)

The trough-cross-stratified sandstone facies consists of multiple, intersecting sets of trough-cross-stratified, fine- to medium-grained, well-sorted sandstone. Troughs are generally 2–4 m wide (average 2.5 m) and 0.2–0.5 m deep. Ripple-laminated and planar-laminated sandstone interbeds are rare. The facies contains only minor subvertical burrows, and body fossils are limited to rare spiriferied and bivalve coquinas. The trough-cross-stratified sandstones are mainly restricted to the Cundlego Formation although thin units of trough-cross-stratification are present in the Nalbia Sandstone on the east side of Kennedy Range. The facies is also poorly developed in the Mallens Sandstone, where isolated, broad, shallow troughs are interbedded with hummocky cross-stratified sandstones.

The close association with hummocky cross-stratification and the presence of marine body fossils and trace fossils in the facies suggest that the trough-cross-stratification was formed by the migration of low-amplitude megaripples in a moderate-to-high-energy nearshore environment. The orientation of 45 cross-sets was measured in excellent exposures of the Cundlego Formation in the bed of the Minilya River, and considerable variability was noted; megaripple migration in westerly, southwesterly and northerly directions (Fig. 3A),

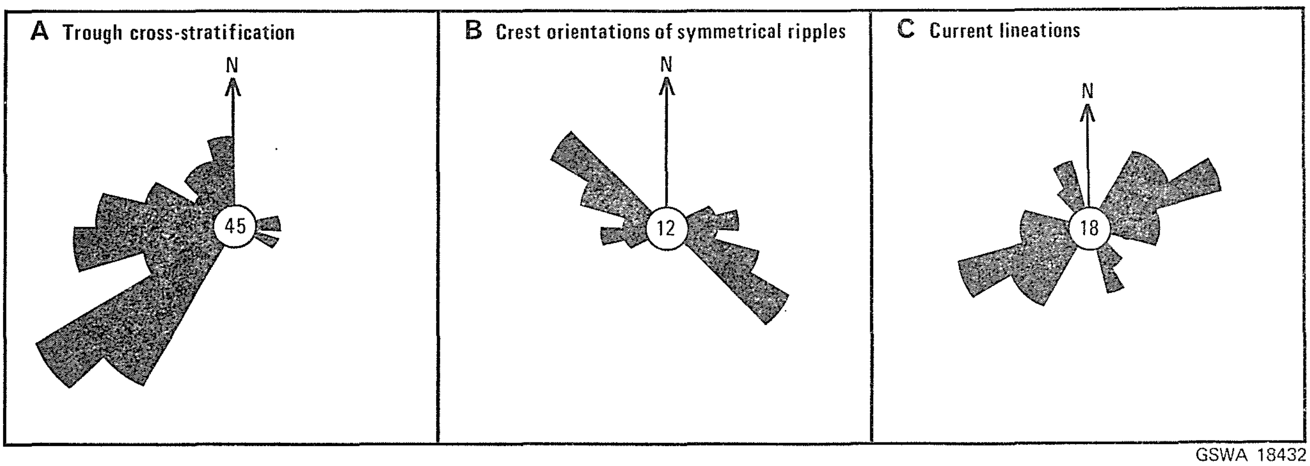


Figure 3 Palaeocurrents, Cundlego Formation, Minilya River. Lengths of arc segments are proportional to number of readings in each segment. Total number of readings shown in central circle. Symmetrical wave ripple crests from the hummocky cross-stratified facies were probably aligned subparallel to the shoreline. Current lineations indicate flow perpendicular and in minor cases parallel to the coastline and trough cross-stratification is directed mainly to the southwest and west (offshore).

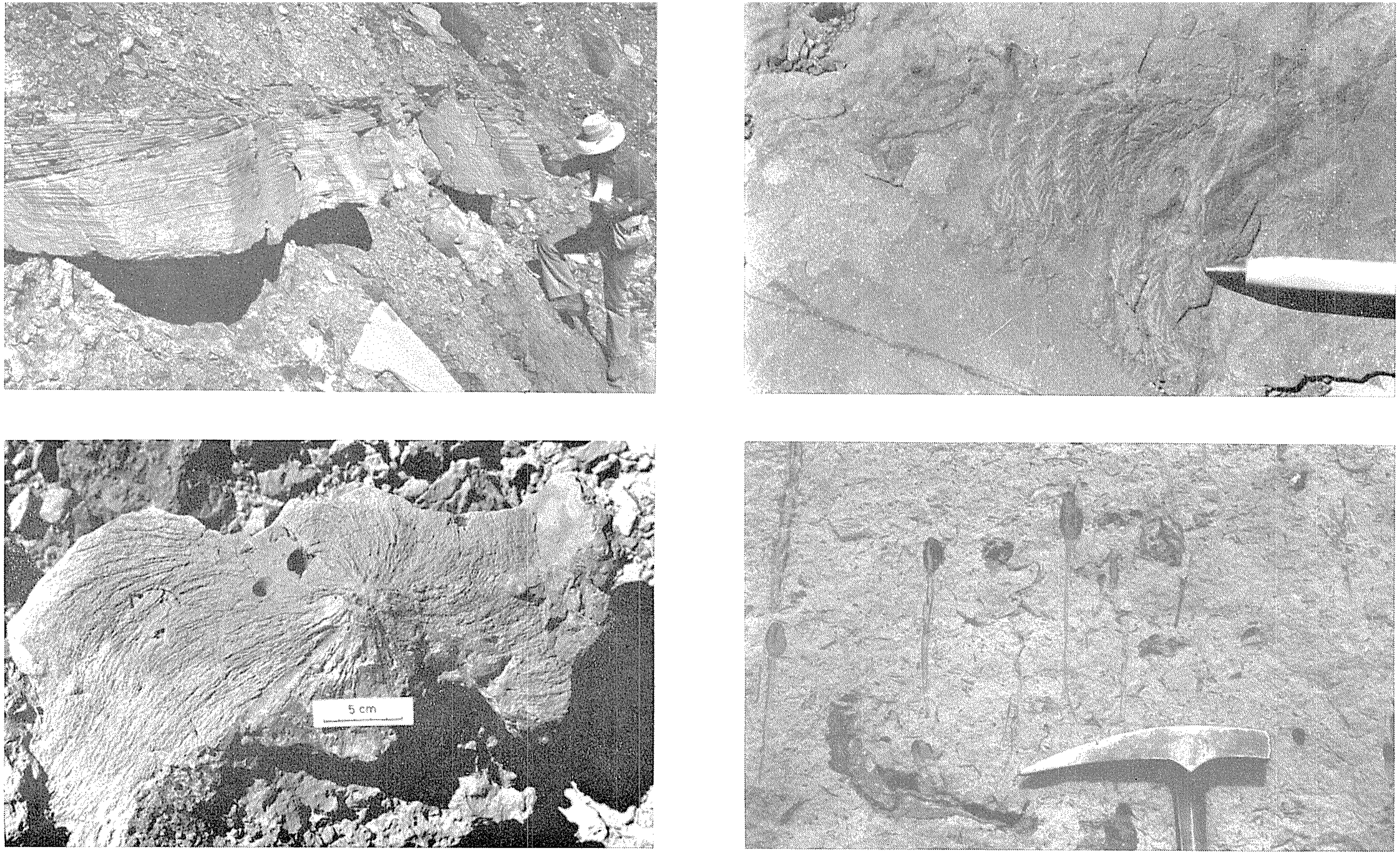


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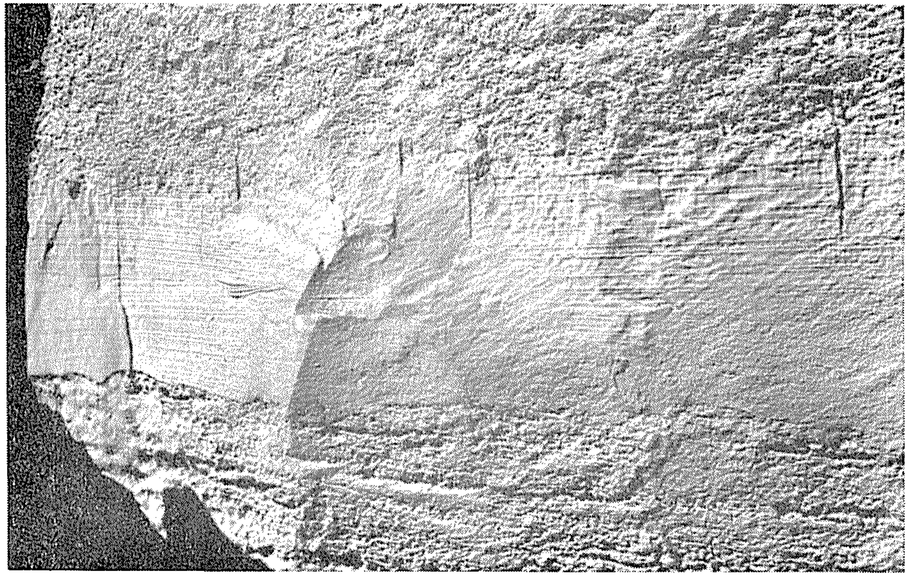
Figure 4 (A) Very low angle cross-stratified sandstone, interpreted as a storm deposit, interbedded in friable and poorly outcropping, bioturbated grey siltstone. Grey-siltstone facies, Baker Formation type section, northern Kennedy Range.

(B) Thin sandstone interbedded with trace fossil *Lophoctenium*. Grey siltstone facies, Bulgadoo Shale type section near the contact with the Cundlego Formation, Minilya River.

(C) Simple *Zoophycos* showing conical, spiral form. Bioturbated sandstone facies, middle portion of Nalbia Sandstone in Blackheart Valley section, northern Kennedy Range.

(D) Evenly bedded sandstone with bulb-shaped cavities interpreted as bivalve burrows. Note subsequent burrowing by worms, with subvertical worm burrows originating from, or penetrating, earlier-formed cavities. Bioturbated sandstone facies, lower portion of Nalbia Sandstone in prominent cliff, 1 km northwest of Blackheart Valley section, northern Kennedy Range.

E



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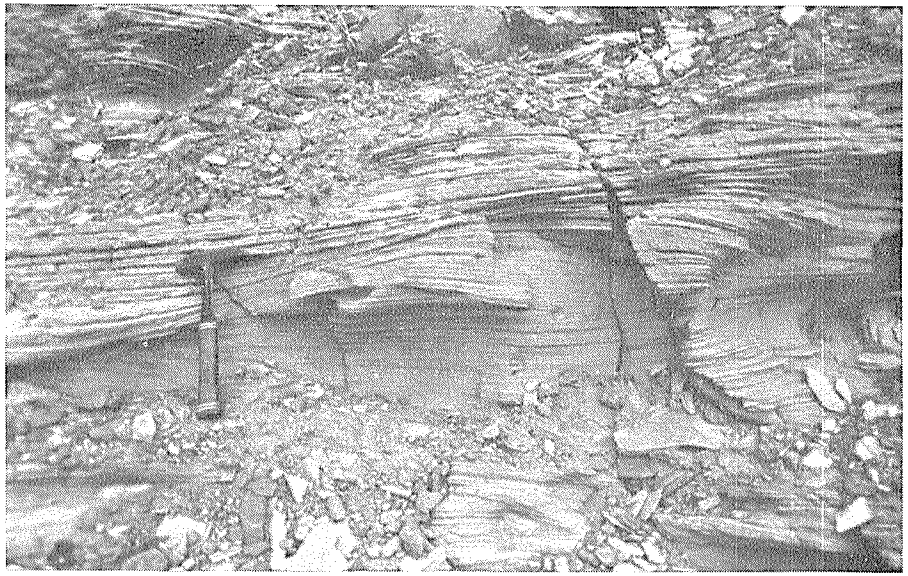

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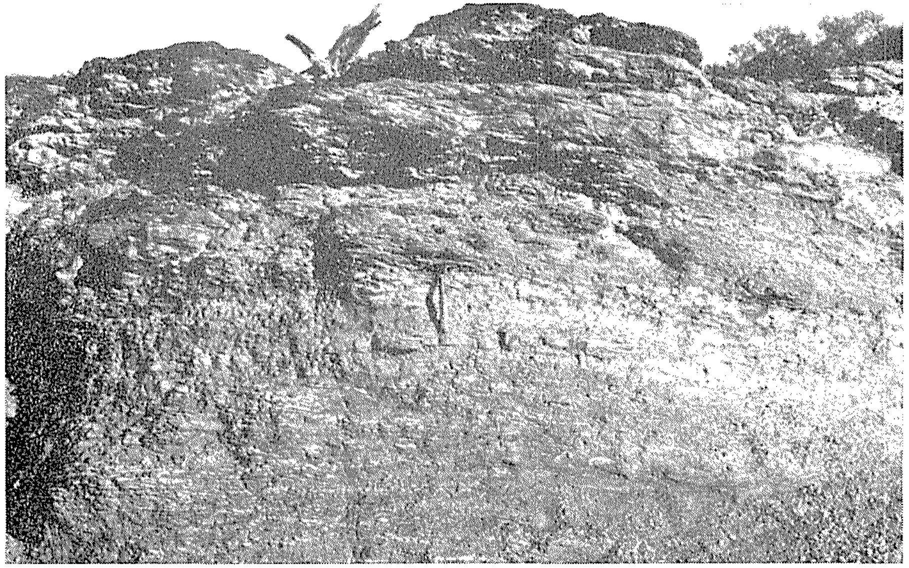

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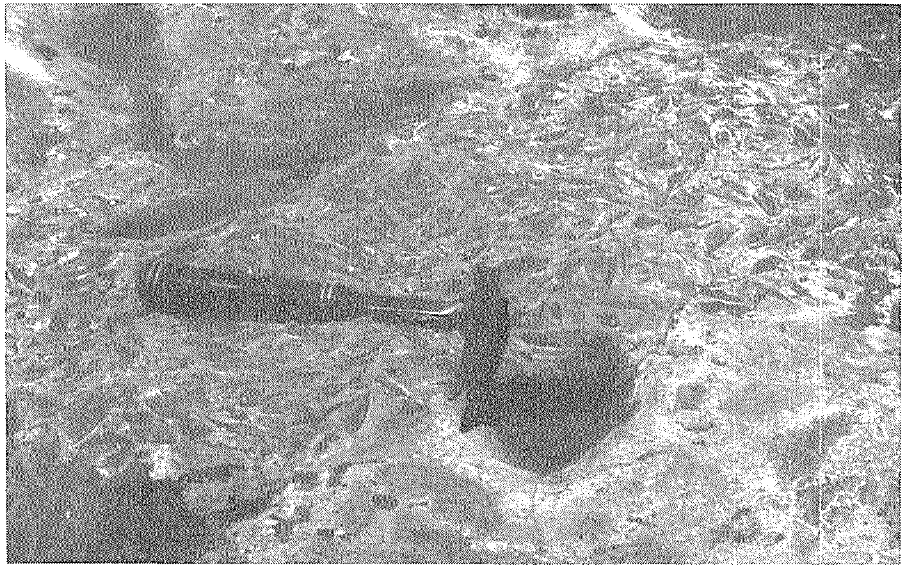


(E) Laminated-to-burrowed facies, upper portion of Mallens Sandstone, 200 m east of Kimbers Well, northern Kennedy Range. Intensely bioturbated sandstone overlain erosively by 0·8 m thick unit of laminated sandstone with *Skolithos* in the upper part. Passes gradationally into intensely bioturbated sandstone.

(F) Hummocky cross-stratified sandstone facies, basal Nalbia Sandstone in prominent cliff, 1 km northwest of Blackheart Valley section, northern Kennedy Range. Note undulose bedding and low-angle truncation surfaces.

(G) Coarsening-upward cycle in Wandagee Formation type section, adjacent to Minilya River. Grey siltstone passes gradationally into fossiliferous, bioturbated sandstone. The cycle has a sharp top.

(H) Transgressive lag-concentrate of spiriferids in shallow scour at top of coarsening-upward cycle. Wandagee Formation, Salt Gully Creek, 16 km west of Gascoyne Junction.

presumably in response to longshore and offshore directed currents, is inferred. This paleocurrent pattern characterizes upper shoreface deposits of barred coastlines (Hunter and others, 1979). In this environment, offshore-directed trough-cross-stratification is produced by seaward-flowing rip currents, and longshore-directed cross-stratification reflects current flow along bar troughs. However, unlike the thin sequences predicted by Hunter and others (1979), cross-stratified units in the Cundlego Formation may be many metres thick. Thus, although we favour an upper shoreface, barred coastline origin for the bulk of the trough-cross-stratification (Fig. 2), the possibility remains that this facies formed further offshore, on an open marine shelf where currents were controlled by factors other than shoaling waves (*cf.* Walker, 1979; Daily and others, in press).

DEPOSITIONAL MODEL

Modern counterparts of the sequence of facies preserved in the Byro Group are documented by Bernard and others (1962), Howard (1971), Howard and Reineck (1972), Reineck and Singh (1971) and Kumar and Sanders (1976). The sequences discussed in these papers occur along moderate-energy linear clastic shorelines and in the adjacent offshore environment. Figure 2 summarizes the depositional model which has evolved as a result of these studies, and shows its relationship to the sequence of facies preserved in the Byro Group.

An example of an ancient sequence similar in character to the Bryo Group is the Upper Cretaceous Blackhawk Formation of Utah (Howard, 1966, 1972), although in this example the transition facies contains cross-bedded sandstones. Other related examples are presented by Harms and others (1965) for the Fox Hills Sandstone of Wyoming; by Masters (1967) for the Mesa Verde Formation of Colorado; and by Hamblin and Walker (1979) for two Jurassic formations in the Rocky Mountains. Coarsening-upward cycles, resulting from natural progradation of the shoreface, are recognized in all of these examples. The cycles described show considerable variation in thickness, in that the fine-grained (offshore) part of the cycles may be up to several hundred metres thick. However, the sandy shoreface-foreshore part is invariably thin—a maximum of about 12 m. Harms and others (1975) concluded that the thickness of coarsening-upward cycles is influenced by wave-energy regime, tidal range and relative rates of progradation and subsidence.

In general, the six Byro Group facies do not occur in well-developed cycles. However, cyclicity is noticeable in the Coyrie and Cundlego Formations, the uppermost Bulgadoo Shale and the lower half of the Wandagee Formation. The cycles (2–20 m thick) typically consist of a coarsening-upward unit of grey, bioturbated siltstone containing thin interbeds of laminated sandstone in the upper portion (upper offshore facies), capped by an interval (0.5–6.0 m thick) of hummocky cross-stratification. Wave ripples may be developed on the upper surface of the hummocky cross-stratified unit, which is overlain by grey fine-grained siltstones of the succeeding cycle. These cycles are interpreted as representing regressive events on the outer part of the marine shelf. The bioturbated transition facies and the laminated-to-burrowed lower-shoreface facies are generally not developed. This indicates that the regression occurred rapidly, typically as a result of major storm events, but in some cases apparently in response to tectonic readjustment of the basin, since, in these examples, the hummocky cross-stratified sandstones are too thick to represent single storm episodes (e.g. basal Mallens Sandstone, parts of the Cundlego Formation and basal Nalbia Sandstone). In the Cundlego Formation, the hummocky cross-stratified facies may be overlain by an interval of trough-cross-stratification, indicating continued regression, with the development of the upper-shoreface facies.

Some of the coarsening-upward cycles in the Cundlego Formation are separated by a thin pebble-to-cobble conglomerate 0.05–0.25 m thick, consisting of subangular to subrounded clasts of sandstone and siltstone, with minor fossil fragments (brachiopods, bivalves and rare crinoids and bryozoans) in a silty matrix. The clasts are eroded fragments from the underlying facies. It is probable that periods of basinal stability, or rarely, mild uplift, promoted the development of coarsening upward, prograding shoreline sequences. New coarsening-upward sequences were initiated by periodic, rapid subsidence, with the only preserved record of the rapid transgressions being the thin lag conglomerates. Similar examples of coarsening-upward cycles with thin, trangressive lag conglomerates at the base are described by Walker and Harms (1975) from the Upper Devonian Catskill Formation of Pennsylvania.

Coarsening-upward cycles in the lower half of the Wandagee Formation are characterized by the typical absence of hummocky and trough-cross-stratification. The cycles are 3–8 m thick and consist of grey fine siltstone in the lower portion which becomes progressively coarser and more strongly bioturbated upwards and passes into a thin unit (average 0.8 m) of poorly bedded, bioturbated and richly fossiliferous brown sandstone (Fig. 4G). The coarsening-upward cycles in this case represent a passage from the offshore environment into the transitional environment, probably associated with natural progradation of the shoreline. In rare cases, thin units of

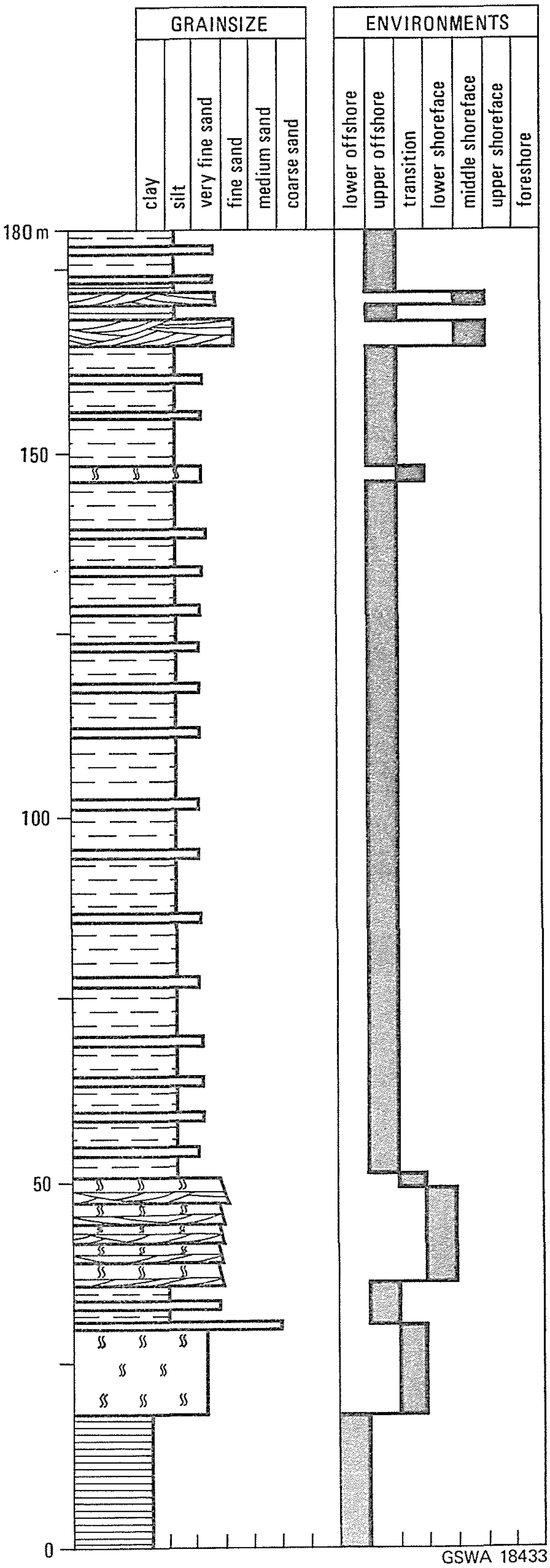


Figure 5 Stratigraphic log, Coyrie Formation type section, northern Kennedy Range. For explanation of the symbols, see Figure 2.

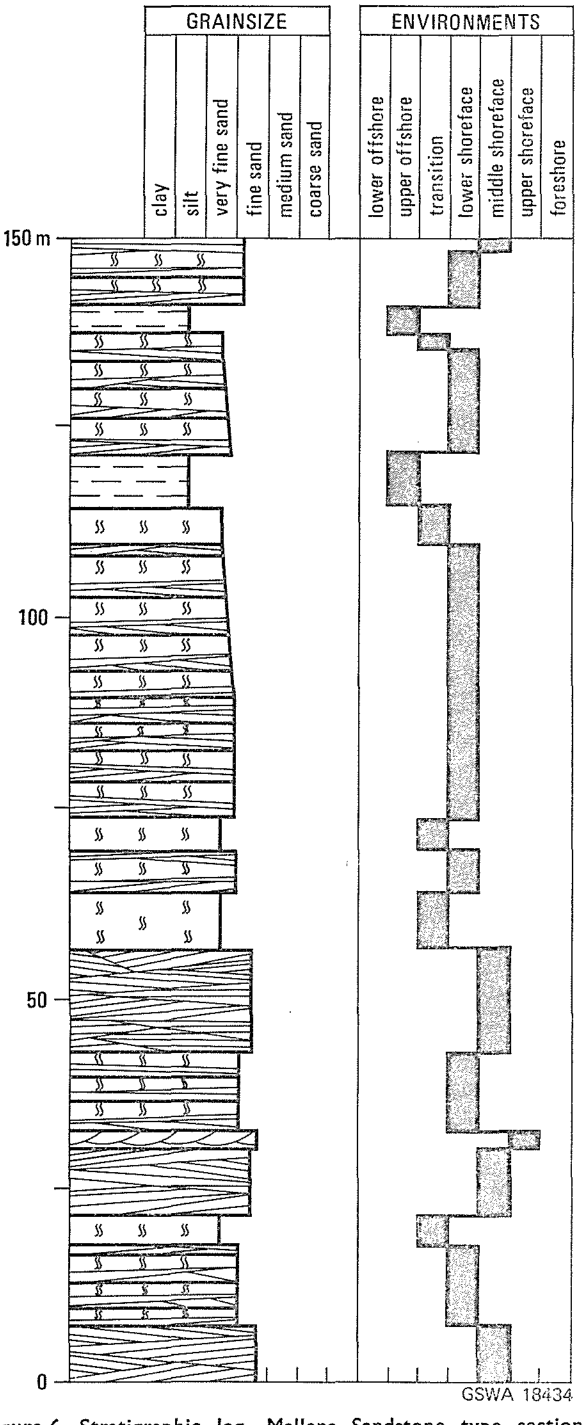


Figure 6 Stratigraphic log, Mallens Sandstone type section, northern Kennedy Range.

symmetrically rippled or laminated sandstone are present in the upper part of the cycles, indicating the development of the lower shoreface facies. The limited thickness of the cycles and the abundance of articulated and relatively unbroken fossils suggest that the sedimentation occurred slowly in a quiet-water environment. In the type section of the Wandagee Formation beside the Minilya River, fossils commonly occur as lag-concentrates. Their preservation in cores of ferruginous nodules caused Condon (1967) to interpret these accumulations as fossiliferous mud-balls. However, the enclosing ferruginous nodules are clearly of post-depositional (diagenetic) origin.

Many cycles in the Wandagee Formation contain lag concentrates of fossils (especially brachiopods) at the base. The relationships of the fossils to the adjacent coarsening-upward cycles is clearly shown in an excellent exposure in Salt Gully Creek, 16 km west of Gascoyne Junction, where spiriferids are concentrated in shallow hollows which average 1·5 m long, 0.8 m wide and 0.15 m deep (Fig. 4H). The hollows represent part of the original topography of the sea floor on the outer sandy shelf (transition facies), and were preserved by the rapid transgression which capped the sequence with grey (offshore facies) siltstone. The fossils were either washed into the hollows by natural processes immediately prior to the transgression or (more likely) were killed by the sudden influx of mud as the transgression progressed, and were subsequently washed into nearby topographic lows. In the Salt Gully Creek exposures, the hollows are all elongate in approximately the same direction (mean of 140° from 11 readings). This suggests that the elongation of the hollows is in some way related to the orientation of the palaeo-shoreline. It is possible that the hollows were wave-generated swales and were thus aligned parallel to the shoreline, but as yet we have no firm evidence to substantiate this theory. The lag concentrates of fossils are similar to the lag conglomerates of pebbles described from the Cundlego Formation, and both are interpreted as indicating repeated subsidence of the basin.

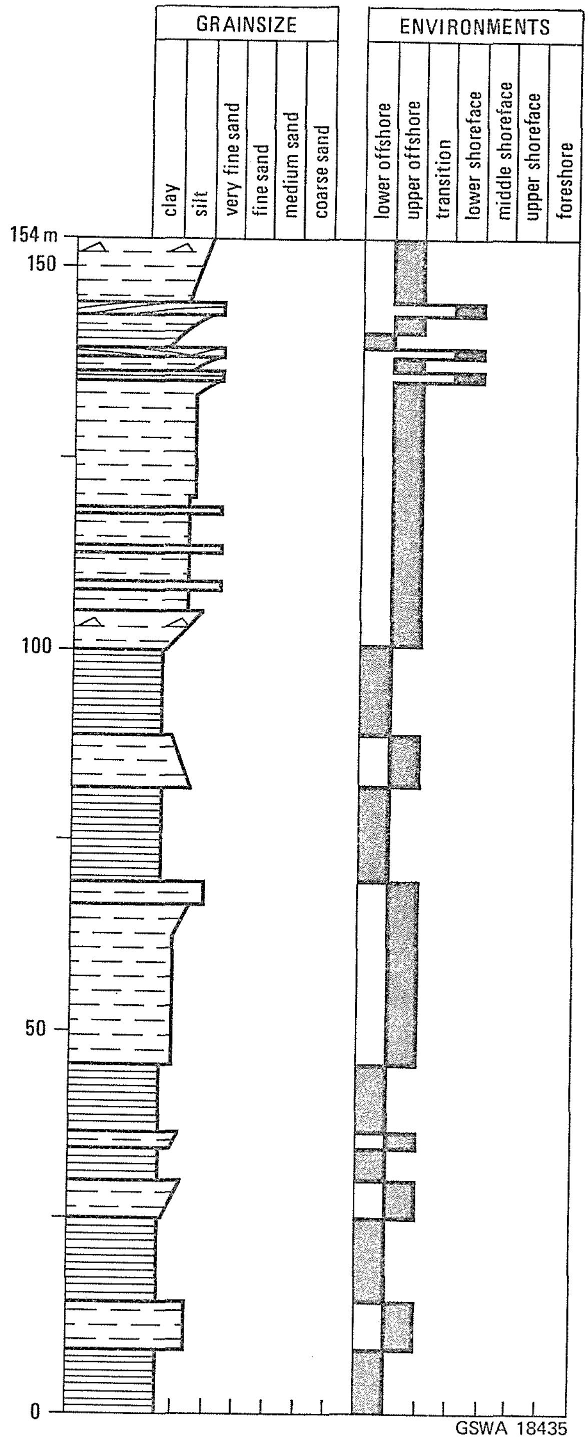


Figure 7 Stratigraphic log; Bulgadoo Shale type section, Minilya River, Wandagee. The lower portion of the sequence is not exposed at this locality.

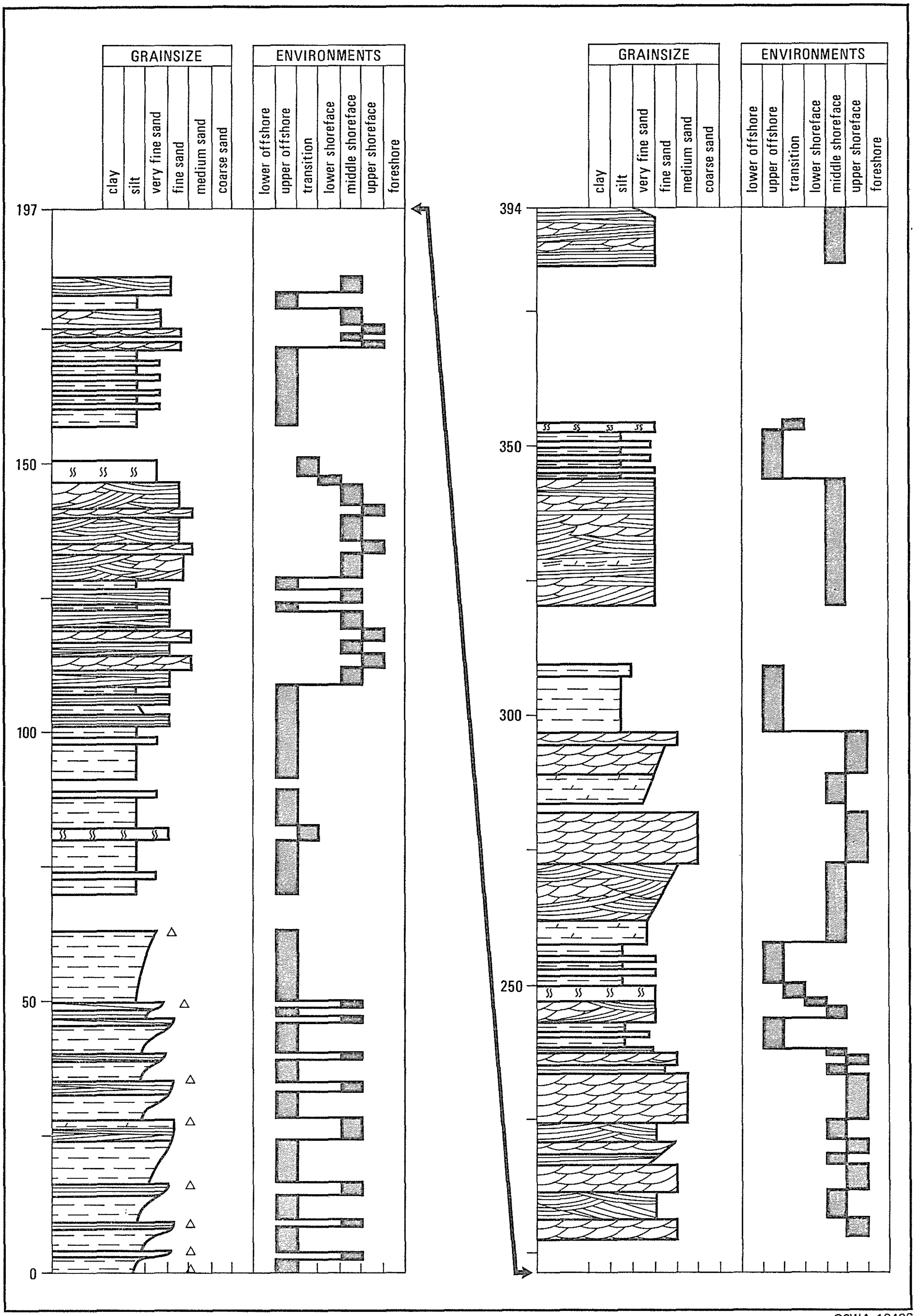


Figure 8 Stratigraphic log, Cundlego Formation reference section, Minilya River. This section is in part fault repeated, and the column shown here is our interpreted reconstruction of the original sequence, based on Condon's (1967) type section, nearby. Major faults causing repetition occur at approximately 65 m and 152 m. (△'s indicate pebble bands.)

PALAEOGEOGRAPHY

Little is known about the palaeogeography of the Carnarvon Basin during deposition of the Byro Group. Condon (1967, Fig. 123) attempted a basic palaeogeographic reconstruction for the upper part of the group, but the position of his palaeo-shoreline is highly speculative and in part relies on his structural interpretation of the Carnarvon Basin, which did not recognize most of the major faulting. We believe that there is no evidence to suggest emergence of the Carrandibby Inlier during deposition of the Byro Group, nor is there any evidence to support Condon's (1967) view that the Gascoyne and Merlinleigh Sub-basins were partly or largely isolated by a basinal sill at this period of time. Furthermore, there is little preserved record of the Byro Group west of the Wandagee-Ajana Fault System (Fig. 1), so the nature of the facies and the location of the westerly shoreline (if one existed nearby) during deposition of the Byro Group remains unknown. Thomas and Smith (1976, p. 154) concluded that the uniformity of the Byro Group facies over a wide area indicates that it was deposited during a tectonically quiet period and that only relatively uniform, fine-grained material was being transported from the land. However, we do not see the need for deposition to have been in restricted arms of the sea, as they imply.

The foreshore (beach) environment is not represented in the sequence of facies preserved in the Byro Group outcrops, but we envisage that during periods of maximum regression, the eastern shoreline probably lay a short distance east of the present outcrop belt along the Kennedy Range.

SYNTHESIS

The Byro Group was deposited in the Carnarvon Basin during a period of relative tectonic stability. The sediments accumulated on a broad marine shelf and in the adjacent 'offshore' environment, and the preserved sequence of facies

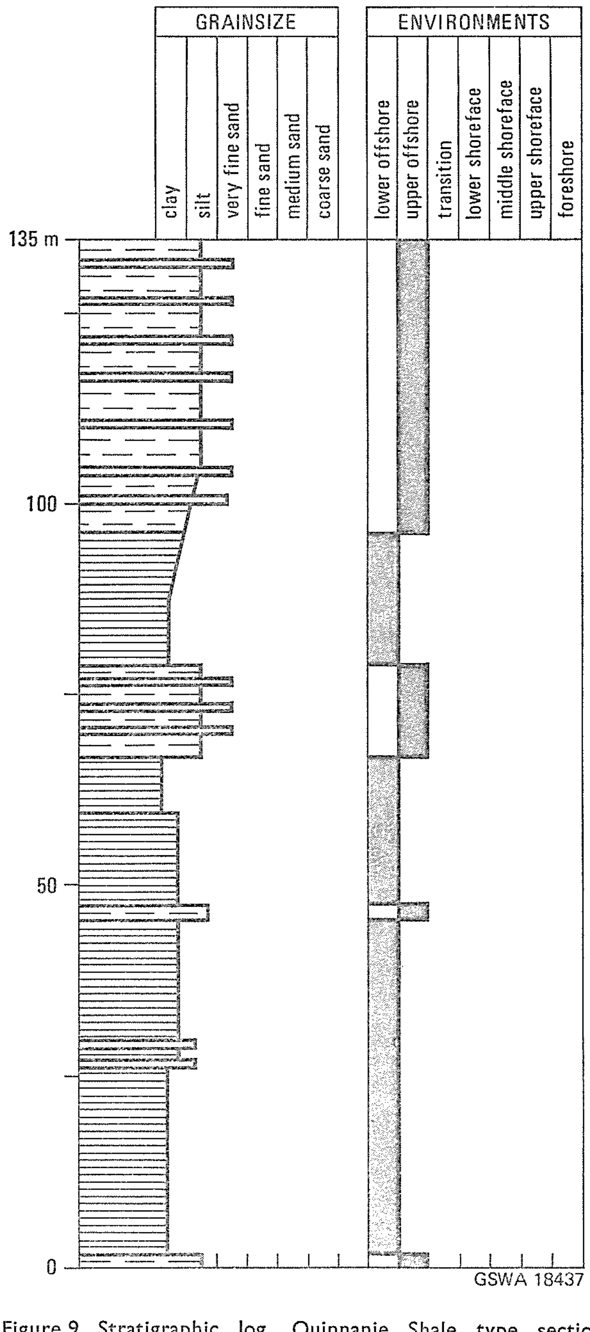


Figure 9 Stratigraphic log, Quinnanie Shale type section, Minilya River, Wandagee.

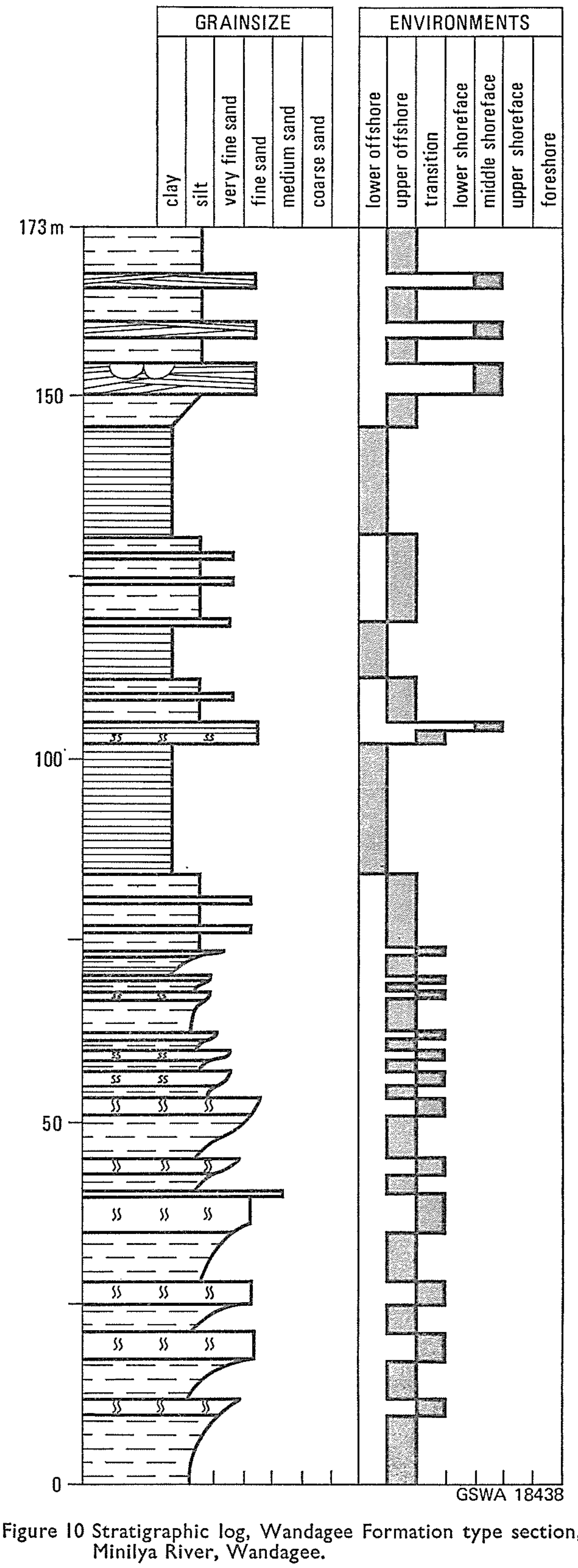


Figure 10 Stratigraphic log, Wandagee Formation type section, Minilya River, Wandagee.

developed in response to the interplay of wave activity and biogenic reworking. According to Crespin (1958) most genera of foraminifera in the Coyrie Formation, Mallens Sandstone and Bulgadoo Shale are cold-water forms, and amelioration of the climate occurred prior to or during the deposition of the Cundlego Formation.

The first unit of the Byro Group to be deposited was the Coyrie Formation (Fig. 5) which comprises an interbedded sequence of offshore, transition and minor shoreface rocks. Grey offshore shales and siltstones predominate in the lower portions of the sequence and a gradual regression is indicated by an increase upwards in the abundance of hummocky cross-stratification.

The overlying Mallens Sandstone (Fig. 6) was deposited in a generally shallower water environment, largely in the middle shoreface zone, and the persistence of the laminated-to-burrowed facies suggests that sedimentation and subsidence were very evenly balanced. Reading (1978) suggested that this facies is best developed along coastlines of moderate wave energy. Certainly the bivalve association described by Dickins (1963) is primarily suited to life on a soft, sandy current-swept substrate.

Deposition of the Mallens Sandstone in the outcrop area was terminated by a marine transgression. The contact with the Bulgadoo Shale is transitional, and the sequence fined upwards as the transgression progressed. The sediments of the Bulgadoo Shale were deposited mainly in an offshore environment (Fig. 7), and very restricted conditions for at least part of the sequence are supported by Thomas's (1958) study of the brachiopod association. The upper part of the Bulgadoo Shale is silty, indicating the start of a regression which was responsible for deposition of the overlying Cundlego Formation.

The dominant facies in the Cundlego Formation (Fig. 8) are the upper offshore (grey-siltstone) and the middle shoreface (hummocky cross-stratified sandstone) facies. The paucity of bioturbated sandstones in the Cundlego Formation suggests that the sequence was deposited relatively rapidly in a subsiding basin. As suggested previously, coarsening-upward cycles may have been tectonically controlled in part, although Reading (1978) suggested that similar sequences could result along shorelines of high wave energy.

The Quinnanie Shale (Fig. 9) is considered by Condon (1954, 1967) to be laterally equivalent to the upper part of the Cundlego Formation. Since the Quinnanie Shale is absent from the southern outcrop areas, this suggests that the basin was relatively shallow in this region, and became deeper towards the north and northwest. The black shale is attributed to the lower offshore facies, and a restricted environment of deposition is supported by the general fossil assemblage (Thomas, 1958) and particularly by the presence of *Lingula* (Moore and others, 1952, p. 222).

Stable, quiet-water conditions prevailed during deposition of the Wandagee Formation (Fig. 10) as indicated by the abundance of body fossils and bioturbated units. Coarsening-upward cycles, dominated by the offshore and transition facies, developed in response to shoreline progradation, and new cycles were initiated by periodic subsidence. The upper part of the formation was deposited under slightly deeper water conditions, with dominance of the offshore facies.

Deposition of the overlying Nalbia Sandstone (Fig. 11) was probably initiated by tectonic uplift of the basin margins and adjacent source areas, since a thick unit of hummocky cross-stratified middle shoreface sandstone occurs at the base. The overlying sequence of bioturbated transition facies sandstones indicates a gradual deepening of the basin as a sand-dwelling bivalve-gastropod association (upper transition zone) is succeeded by intensely bioturbated (lower transition zone) sandstones rich in *Zoophycos*. A gradual regression is indicated in the upper part of the formation, and the hummocky cross-stratified facies dominates in the upper 20–30 m. A comparison was made between the type section at the northern end of Kennedy Range and outcrops along the edge of the range, about 30 km to the southeast. It was noted that the incidence of *Zoophycos* was less, and hummocky cross-stratification greater, in the southeastern outcrops, suggesting that this area was relatively close to the shoreline.

The Baker Formation (Fig. 11) mainly consists of the upper offshore facies, and developed in response to a marine transgression. The relative abundance of brachiopods in the sequence in comparison with bivalves, and the nature of the brachiopod association suggests a relatively deep-water, somewhat restricted environment of deposition (Thomas, 1958). Hummocky cross-stratified interbeds are interpreted mainly as thin storm deposits, and do not represent changes in relative sea level. The sequence becomes sandier and coarser grained towards the southeast, presumably as the basin margin is approached.

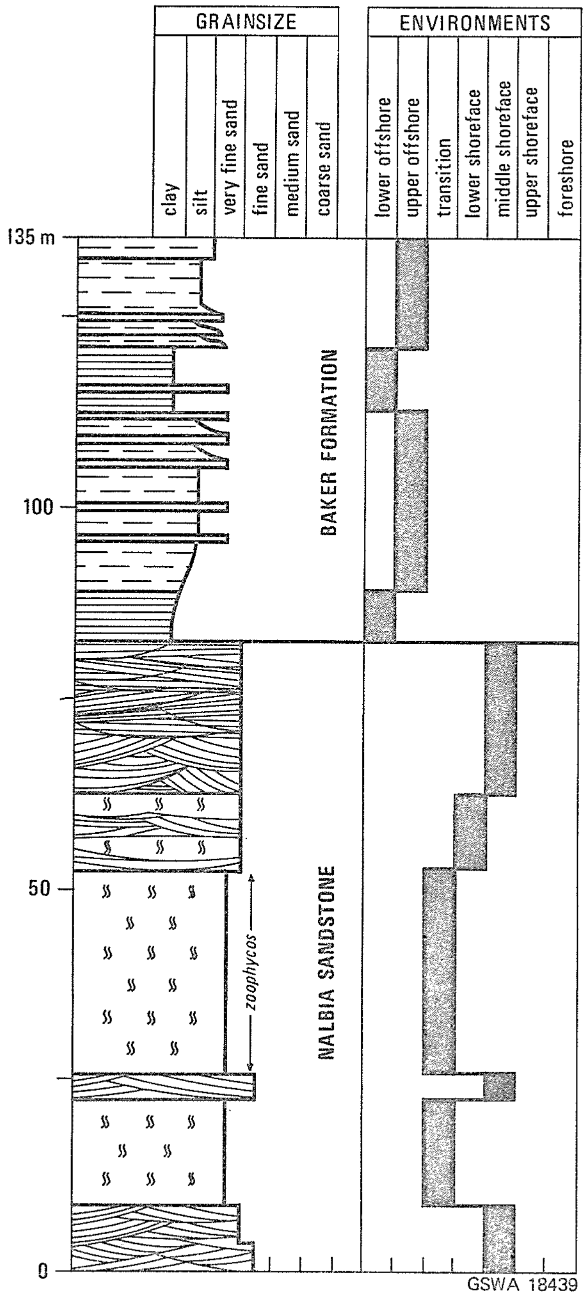


Figure 11 Stratigraphic log: Nalbia Sandstone and Baker Formation, Blackheart Valley, northern Kennedy Range.

Deposition of the Byro Group was terminated by a major regression, associated with the extensive development of the hummocky cross-stratified middle shoreface facies in the lower portions of the Kennedy Group.

CONCLUSIONS

The Byro Group was deposited in a marine environment, and can be divided into six facies which represent deposition in the offshore, transition and shoreface zones. Modern and fossil counterparts are moderately well documented in recent literature, but to the best of our knowledge, the Byro Group is the thickest (1 660 m) sequence of this kind to be examined in detail so far. The shoreface to offshore transition is extremely well developed, and suggests that the sequence was deposited in a wave-dominated environment, and that a great deal of sedimentation occurred as a result of storms. Laminated sandstone interbeds in the offshore facies lend support to Walker's (1979) hypothesis that distribution of sand below wave base is primarily by offshore-directed storm-induced density currents. We have found no evidence of tidal or oceanic-current redistribution of sand in the zone below wave base.

Offshore-directed cross-stratification in the Cundlego Formation is attributed to density or rip currents in the nearshore zone. However, the low angle of the cross-strata and the fine grain-size of the cross-stratified sandstone facies are inconsistent with deposition in high-energy barred-coastline environments of the southern Oregon type (Hunter and others. 1979). It appears from our evidence that density or rip currents are capable of producing cross-stratification, possibly in a more offshore environment, and certainly possess different characteristics to examples from the southern Oregon coast. Further study of this facies is warranted.

Coarsening upward cycles are present in the Byro Group, although cyclic sedimentation is not as well developed as in many of the classic sequences documented to date. The cycles are interpreted as representing regressive events due to shoreline progradation. In addition, we have identified thin lag conglomerates at the base of some cycles which we interpret as transgressive lag conglomerates. Although transgressive conglomerates are known to occur at the base of coarsening-upward cycles in fine-grained deposits (Harms and Walker, 1975), this is the first time that they have been documented from a sandy marine sequence of this type.

The recognition of upper and lower zones in both the offshore and transition environments represents a degree of discrimination not presented by previous workers. However, we believe that the black-shale facies (lower offshore environment) will only develop in response to moderately restricted circulation. Possible environments of deposition are silled basins and some epicontinental seas, although this facies is known to occur in the offshore zone along open coastlines where oceanic currents are very weak. There is no supporting evidence for a silled-basin origin for the Byro Group facies, and the question of whether the Carnarvon Basin was epicontinental at that time remains unresolved, since very similar sediments to those of the Byro Group are known along shorefaces exposed to the open ocean.

The presence of *Lophoctenium* in the upper offshore zone raises doubts as to the validity of this trace fossil as an indicator of deep-water conditions, and the recognition of *Zoophycos* in the lower transition zone emphasises that factors other than water depth (such as degree of bottom turbulence and availability of nutrients) probably also control its distribution.

REFERENCES

Bernard, H. A., Le Blanc, R. J., and Major, C. F., 1962, Recent and Pleistocene geology of southeast Texas, *in* Geology of Gulf Coast and central Texas guidebook: Houston Geol. Soc., p. 175–224.

Condon, M. A., 1954, Progress report on the stratigraphy and structure of the Carnarvon Basin, Western Australia: Australia Bur. Mineral Rept. 15.

———, 1962, Kennedy Range, W.A.: Australia Bur. Mineral Resources 1:250 000 Geological Series Explan. Notes.

———, 1967, The geology of the Carnarvon Basin, Western Australia, Part II: Permian stratigraphy: Australia Bur. Mineral Resources Bull. 77.

Crespin, I., 1958, Permian Foraminifera of Australia: Australia Bur. Mineral Resources Bull. 48.

Daily, B., Moore, P. S., and Rust, B. R., in press, Terrestrial-marine transition in the Cambrian rocks of Kangaroo Island, South Australia: Sedimentology.

Dickins, J. M., 1963, Permian pelecypods and gastropods from Western Australia: Australia Bur. Mineral Resources Bull. 63.

———, 1970, Correlation and subdivision of the Permian of western and eastern Australia, *in* Palaeontological Papers 1968: Australia Bur. Mineral Resources Bull, 116, p. 17–28.

Hamblin, A. P., and Walker, R. G., 1979, Storm-dominated shelf deposits: the Fernie-Kootenay (Jurassic) transition, Southern Rocky Mountains: Canadian Jour. Earth Sci., v. 16.

Harms, J. C., MacKenzie, D. B., and McCubbin, D. G., 1965. Depositional environment of the Fox Hills Sandstones near Rock Springs, Wyoming, *in* Sedimentation of Late Cretaceous and Tertiary outcrops, Rock Springs uplift: Field Conference, 19th, Wyo. Geol. Soc., p. 113–130.

Harms, J. C., Southard, J. B., Spearing, D. R., and Walker, R.G., 1975, Depositional environments as interpreted from primary sedimentary structures and stratification sequences: Soc. Econ. Paleontologists and Mineralogists, Short Course Notes No. 2.

Hocking, R. M., Moors, H. T., and Moore, P. S., 1980, Modified stratigraphic nomenclature and concepts in the Palaeozoic sequence of the Carnarvon Basin, W.A.: West. Australia Geol. Survey Ann. Rept. 1979, p. 51–55.

Howard, J. D., 1966, Characteristic trace fossils in Upper Cretaceous sandstones of the Book Cliffs and Wasatch Plateau, central Utah: Utah Geol. Min. Survey Bull. 8, p. 35–53.

———, 1971, Comparison of the beach to offshore sequence in modern and ancient sediments, *in* Recent Advances in Palaeoecology and Ichnology: Amer. Geol. Inst. p. 148–183.

———, 1972, Trace fossils as criteria for recognising shorelines in the stratigraphic record: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 16, p. 215–225.

Howard, J. D., and Reineck, H. E., 1972, Physical and biogenic sedimentary structures of the nearshore shelf: Senckenbergiana Marit., v. 4, p. 81–123.

Hunter, R. E., Clifton, H. E., and Phillips, R. L., 1979, Depositional processes, sedimentary structures and predicted vertical sequences in barred nearshore systems, southern Oregon coast: Jour. Sed. Petrology v. 49, p. 711–727.

Kumar, N., and Sanders, J. E., 1976. Characteristics of shoreface storm deposits: modern and ancient examples: Jour Sed. Petrology v. 46, p. 145–162.

Masters, C. D., 1967, Use of sedimentary structures in determination of depositional environments, Mesaverde Formation, Williams Fork Mountains, Colorado: Am. Assoc. Petroleum Geologists Bull. v. 51, p. 2033–2043.

Moore, R. C., Lalicher, C. G., and Fischer, A. G., 1952, Invertebrate fossils: McGraw-Hill, Lond.

Pettijohn, E. J., 1975, Sedimentary Rocks: Harper and Row, New York.

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. 223–433.

Reading, H. G., 1978, Sedimentary environments and facies: Blackwell Sci. Pub., Lond.

Reineck, H. E., and Singh, I. B., 1971, Der Golf von Gaeta/Tyrrheneschеs Meer: Senckenbergiana Marit, v. 3, p. 185–201.

Russell, R. T., 1965, Examination of well samples for sedimentary phosphate, Carnarvon Basin, Western Australia: Mines Expl. Pty Ltd Report (unpublished).

Seilacher, A., 1978, Use of trace fossil assemblages for recognising depositional environments, *in* Trace fossil concepts (P. B. Basan, ed.): Soc. Econ. Paleontologists and Mineralogists Short Course Notes No. 5.

Simpson, S., 1970, Notes on *Zoophycos* and *Spirophyton*, *in* Trace fossils (Crimes, T. R., and Harper, J. C., eds.): Geol. Jour. Spec. Issue No. 3.

Teichert, C., 1950, Some recent additions to the stratigraphy of Western Australia: Amer. Assoc. Petrol. Geol. Bull. v. 34, p. 1787–1794.

———, 1951, The marine Permian faunas of Western Australia: Paläont. Z., v. 24, p. 75–90

———, 1957, Notes on the geology of the Carnarvon (Northwest) Basin, Western Australia: Roy. Soc. West. Australia Jour., v. 40 p. 65–72.

Thomas, B. M., and Smith, D. N., 1976, Carnarvon Basin, *in* Economic geology of Australia and Papua New Guinea—Petroleum, (R. B. Leslie, H. J. Evans, and C. L. Knight, eds.): Australasian Inst. Mining Metall. Mon 7, p. 126–155.

Walker, R. G., 1979, Shallow marine sands, *in* Facies Models (R. G. Walker, ed.): Geoscience Canada Reprint Series 1, p. 75–89.

Walker, R. G., and Harms, J. C., 1975, Shorelines of weak tidal activity: Upper Devonian Catskill Formation, central Pennsylvania, *in* Tidal deposits; a casebook of Recent examples and fossil counterparts (R. N. Ginsberg, ed.): Springler-Verlag, New York.

Warme, J. E., and McHuron, E. J., 1978, Marine borers: trace fossils and their geological significance, *in* Trace fossil concepts (P. B. Basan, ed.): Soc. Econ. Paleontologists and Mineralogists Short Course Notes No. 5.

SEDIMENTOLOGY OF THE KENNEDY GROUP (PERMIAN), CARNARVON BASIN, WESTERN AUSTRALIA

by P. S. Moore, R. M. Hocking and P. D. Denman

ABSTRACT

The Permian Kennedy Group is a shallow-marine sequence which consists of, in ascending order, the Coolkilya Sandstone, Mungadan Sandstone and Binthalya Formation. It is the youngest exposed Permian group in the Carnarvon Basin and is restricted to the eastern portion of the basin. Eight facies are recognized and indicate deposition in silty offshore, sandy-shelf, and shoreface environments, of which the second is the most prominent. Facies associations suggest two distinct but related depositional models:

(1) a moderate palaeoslope model with a comparatively narrow transition zone of bioturbated sandstone separating offshore and shoreface environments, applicable to the Coolkilya Sandstone, and

(2) a broad sandy shelf with a very low palaeoslope, containing three distinct facies separating offshore and shoreface environments, applicable to the Mungadan Sandstone and Binthalya Formation.

This progressive change in the nature of the overall sedimentary environment is attributed to stabilization and infilling of the Carnarvon Basin in the Kungurian, with the consequent development of a broad, sandy, shallow-marine shelf.

INTRODUCTION

The Lower to ?Upper Permian Kennedy Group, as defined by Condon (1954) and amended by Hocking and others (1980) consists of three formations of fine- to coarse-grained sandstone and minor siltstone (Table 1). Outcrop is restricted to the Kennedy Range area and Wandagee Hill (Fig. 1) in the central Carnarvon Basin. This paper discusses the sedimentology and palaeogeography of the Kennedy Group, and comments on the stratigraphy and distribution of the sequence.

Condon (1962a, 1967) considered the Kennedy Group to rest unconformably on the Baker Formation, but a transitional contact is clearly exposed along the eastern flank of Kennedy Range. The transition from grey pyritic shale and siltstone into laminated and bioturbated fine-grained sandstone represents a change from a quiet-water, muddy, offshore environment to a moderate-energy, sandy, lower-shoreface environment, thus indicating a minor regression. Results of the stratigraphic bore BMR 6, which Condon (1967) also cites as evidence for the unconformity, are inconclusive and open to several interpretations (Perry, 1965; Belford, 1968). At the southern end of Kennedy Range near Calvary Well (Fig. 1), Condon (1967) reports a major unconformity at the base of the Kennedy Group. However recent detailed mapping indicates that this contact is a fault.

The Coolkilya Sandstone is of known Kungurian age (Condon, 1967). Dickins (1970) has suggested that the Binthalya Formation may be upper Kazanian; however, Playford and others (1975) indicated that the formation is probably basal Kazanian. Neither the Binthalya Formation nor the Mungadan Sandstone contain age-diagnostic fossils. Cockbain (1980) assigns the Coolkilya Sandstone to the Roadian, a substage of the upper Artinskian (which is broadly equivalent to the lower Kungurian).

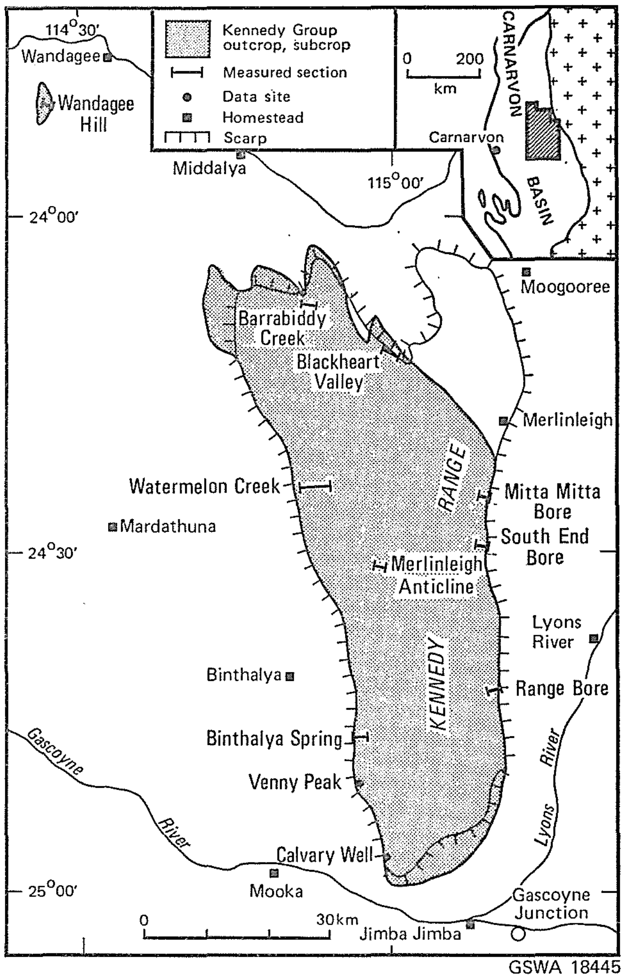


Figure 1 Distribution of the Kennedy Group and positions of measured sections.

FACIES ANALYSIS

Stratigraphic sections were measured through portions of the Kennedy Group at eight localities (Fig. 1), and eight facies were identified. The results of this study are summarized in Figures 2 and 5. In these figures, three related, silty, offshore facies have been grouped together for convenience and simplicity. The relative abundance of the facies at any single data site is a function of both the geographic and stratigraphic position of that site. Two stratigraphic sections of the Coolkilya and Mungadan Sandstones illustrate this spatial variation in facies abundance, with the transition from Range Bore

TABLE 1. KENNEDY GROUP STRATIGRAPHIC TABLE

Age	Group	Formation	Maximum known thickness (m)	Lithology
PERMIAN	KENNEDY GROUP	Binthalya Formation	(a) 544	Siltstone to fine-grained quartz sandstone; poor to moderate sorting.
		Mungadan Sandstone	(b) 116	Fine to coarse quartz sandstone, minor siltstone; moderate to good sorting.
		Coolkilya Sandstone (d)	(c) 285	Siltstone to medium-grained quartz sandstone; poor sorting.
	BYRO GROUP			

(a) type section. (b) measured section. (c) from Kennedy Range 1 (Lehmann, 1967). (d) modified from "Coolkilya Greywacke" by Hocking and others (1980).

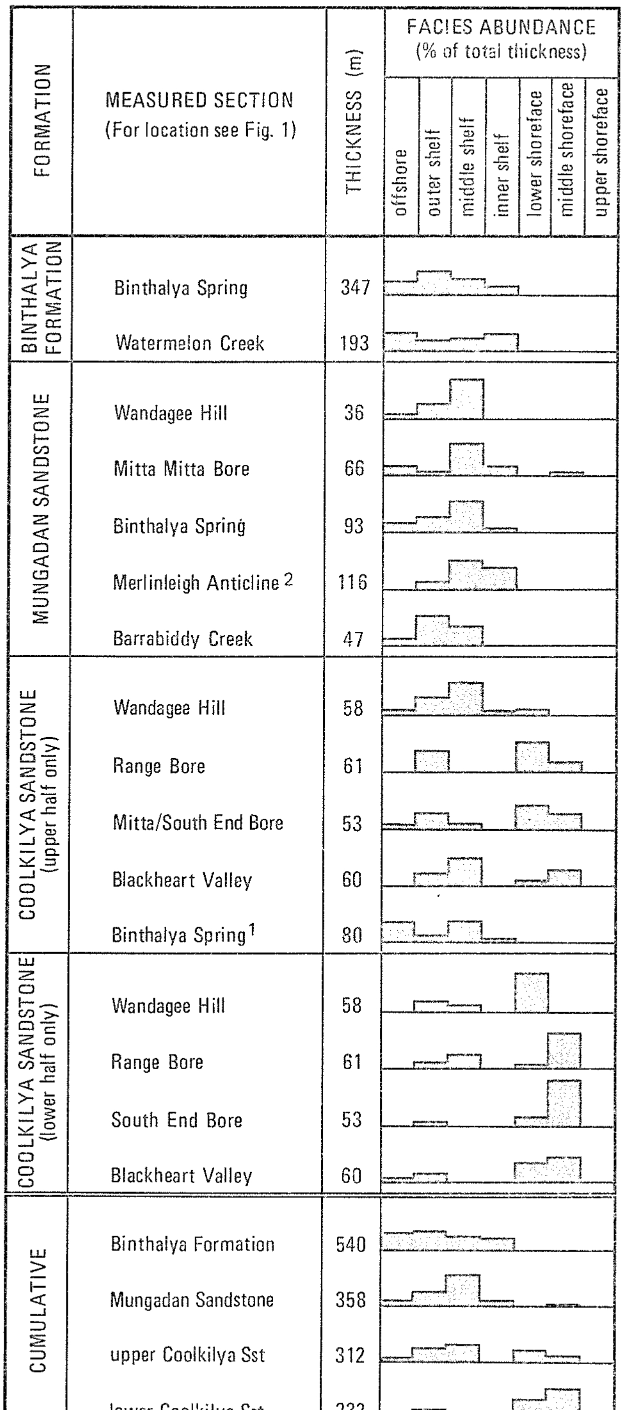


Figure 2 Thicknesses and facies abundances in measured sections of the Kennedy Group: (1) Lower part not exposed; total formation thickness unknown; (2) Incomplete section; probably fault repeated in part.

(Fig. 3A) to Wandagee Hill (Fig. 3B) reflecting the more offshore location of the latter area. In addition, a 347 m thick section of the Binthalya Formation is represented in Figure 4.

FINE-GRAINED FACIES ASSOCIATION

Two major siltstone facies are recognized: one with rippled sandstone lenses and the other without. All gradations between the two end members occur, and the facies spectrum represents the result of deposition in a moderately reducing, offshore-marine environment. A third facies, comprising coarse sandy siltstone, is mainly restricted to minor intervals in the Mungadan Sandstone along the eastern edge of the Kennedy Range. The black-pyritic-shale facies (lower-offshore environment) recognized in the underlying Byro Group (Moore and others, 1980) has no equivalent in the Kennedy Group outcrops (Figs. 3 and 4).

Grey-siltstone facies (*offshore*)

The grey-siltstone facies consists of evenly laminated to very thinly bedded, medium- to coarse-grained pale-grey siltstone and sandy siltstone (Fig. 6A) containing common small curved burrows and minor small subvertical burrows. The grey-siltstone facies is present in all three formations. Units are generally only 0·5–4·0 m thick.

The grey siltstones were deposited below wave base in a quiet-water, reducing marine environment. In contrast with the equivalent facies in the Byro Group, laminated sandstone interbeds are rare, indicating relatively slow deposition in an area isolated from the effects of major storms.

Lenticular-and-linsen-bedded facies (*offshore*)

Lenticular-and-linsen-bedded units (cf. De Raaf and others, 1977), constitute minor facies mainly in the Binthalya Formation. The facies consists of isolated ripple-lenses and connected ripple-trains of fine sandstone in a grey, coarse-siltstone matrix (Fig. 6F). The ripple-lenses generally have an undulatory base, and are symmetrical or near-symmetrical in form. Internal laminae are strongly curved and may be form-discordant. The surrounding, grey siltstone is evenly laminated, the entire facies is bioturbated, and small curved burrows are common.

The lenticular-and-linsen-bedded facies developed in a low-energy, reducing environment, which received small inputs of sand, probably during periods of storm activity. The ripple-lenses contain many features typical of wave-formed structures (De Raaf and others, 1977). Reineck and Singh (1972) have suggested that such ripples develop as thin storm sand layers which are reworked by wave agitation related to the same storm. Thus, the facies probably represents active deposition at approximate maximum wave-base.

Coarse-sandy-siltstone facies (*?offshore*)

The coarse-sandy-siltstone facies is a very minor facies which has been observed in the Mungadan Sandstone along the eastern edge of the Kennedy Range and at rare intervals in the Binthalya Formation along Watermelon Creek. It is characterized by the intimate association of white, very coarse-grained sandstone and white (?leached) shale or fine siltstone. In some cases, the sand grains are dispersed in a silty matrix, but more commonly the sandstone forms thin, even beds or lenses separated by centimetre-thick bands of white fine siltstone. The siltstone bands are generally discontinuous over a metre or less, and in a few cases, have been reworked to form mudstone intraclasts.

Deposition took place mainly by suspension-settling in a low-energy environment, although the presence of coarse, traction-deposited sandstones indicates the nearby proximity of a much higher energy environment. It is tentatively suggested that this facies is a variation of the more typical offshore-siltstone facies; and that the modification results from a greater-than-normal palaeoslope (causing the juxtaposition of high- and low-energy regimes) and/or the proximity of a major supply of coastal sand. Likely environments are thus: offshore from a distributary system, or in a protected environment adjacent to a barrier island (Goldberg, 1979).

SANDSTONE FACIES ASSOCIATION

Bioturbated-sandstone facies (*lower transition or outer shelf*)

Bioturbated sandstone is a major component of the Coolkilya Sandstone and Binthalya Formation, and is present in the Mungadan Sandstone, particularly in the northwestern outcrops (Fig. 2). The facies consists of intensely bioturbated, greyish-brown to reddish-brown, poorly sorted, fine- to very fine-grained sandstone and silty sandstone. Disarticulated bivalves and brachiopods, mostly preserved as lenticular coquinas, are rare. A great variety of subvertical, inclined and subhorizontal burrows is present, and *Zoophycos* occurs in the middle portion of the Coolkilya Sandstone.

The bioturbated-sandstone facies formed below effective wave base, where sedimentation was slow enough to allow extensive reworking of the sediment by infaunal and epifaunal organisms.

Evenly-bedded-and-ripple-laminated-sandstone facies (*mid-shelf*)

The evenly-bedded-and-ripple-laminated-sandstone facies is common in the Kennedy Group, especially in the Mungadan Sandstone and Binthalya Formation. It consists of thin (0·2–0·7 m) intervals of evenly bedded to ripple-laminated, fine- to medium-grained sandstone (Fig. 6D), commonly with oscillation ripples developed on the upper surface. The units

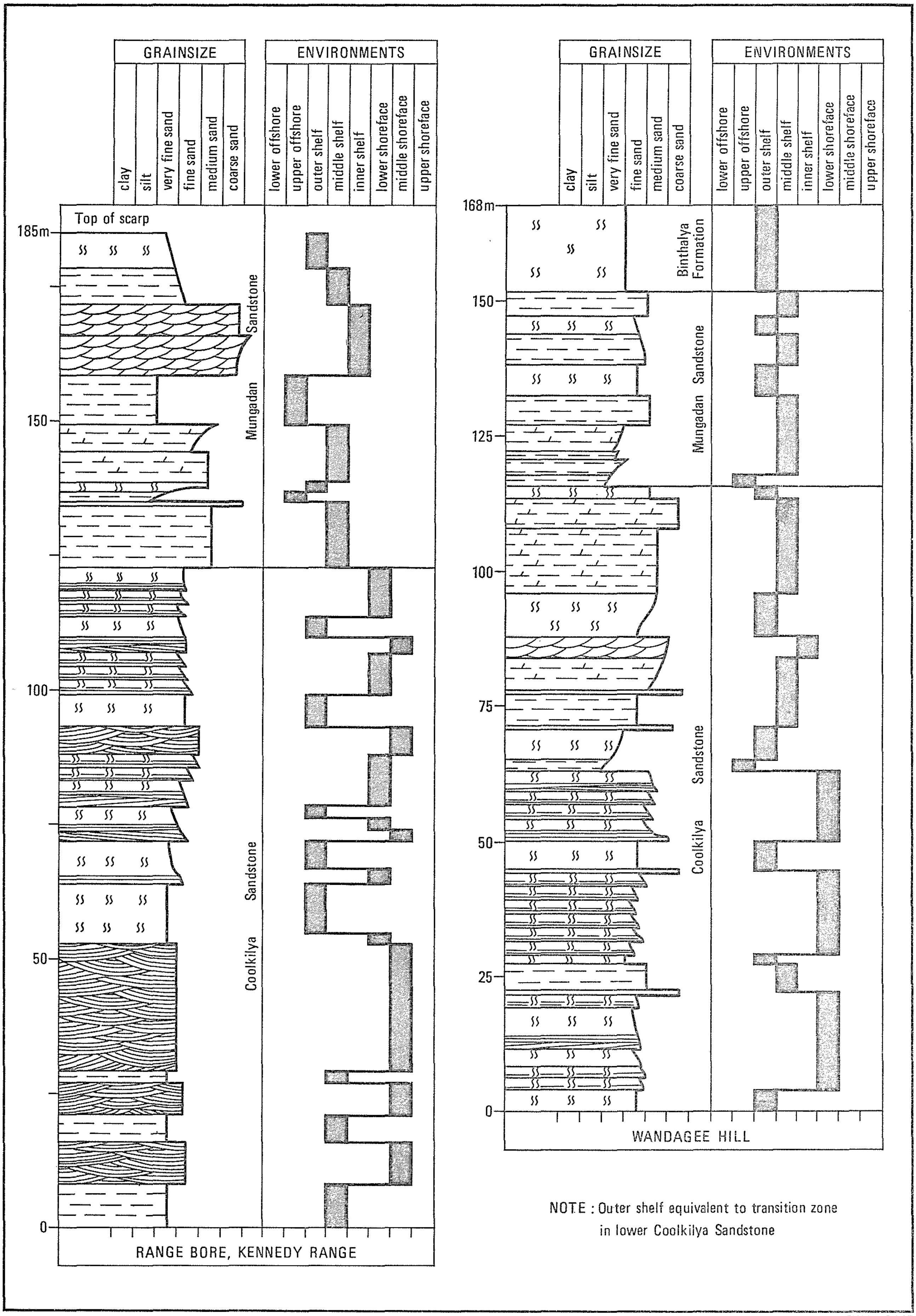


Figure 3 Stratigraphic logs, Coolkilya and Mungadan Sandstones, Range Bore and Wandagee Hill, showing lateral facies variation. For explanation of the symbols see Figure 5.

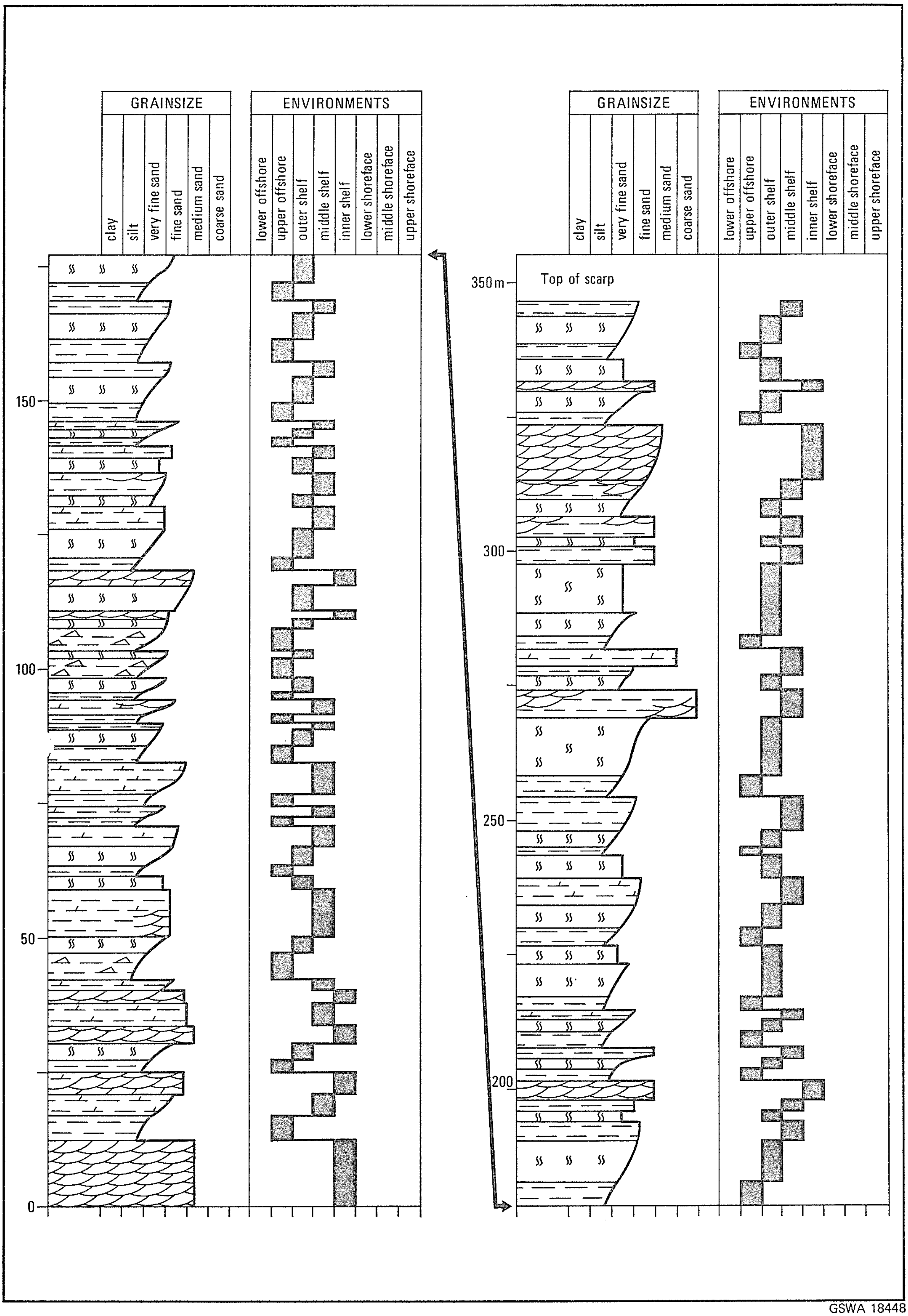


Figure 4 Stratigraphic log, Binthalya Formation, 800 m south of Binthalya Spring. For explanation of symbols, see Figure 5.

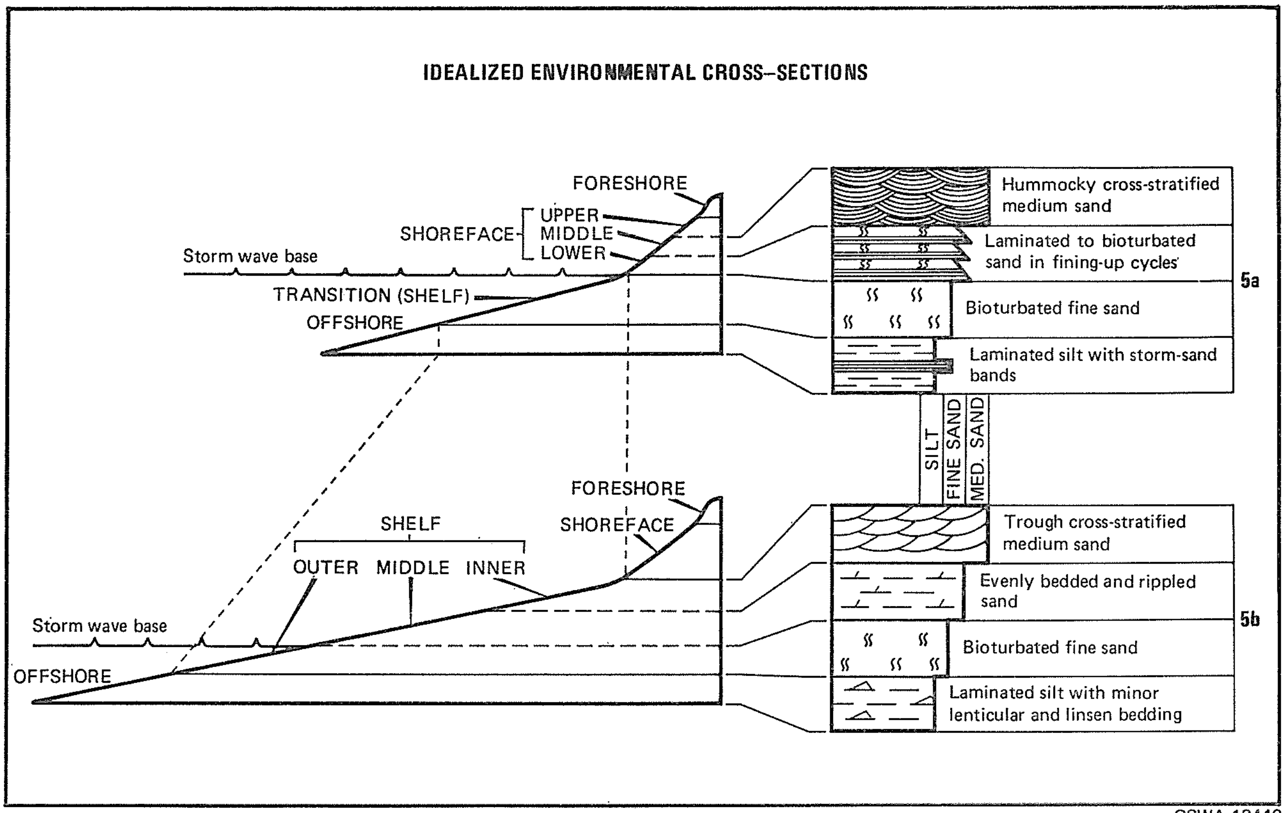


Figure 5 Depositional models for the Kennedy Group.
(a) Lower portion of bioturbated sandstone separates the offshore and shoreface environments.
(b) Mungadan Sandstone and Binthalya Formation. A broad sandy shelf separates the shoreface and offshore environments. The upper Coolkilya Sandstone shows features which are intermediate between these two models.

are weakly bioturbated, although rippled surfaces and major bedding planes in places contain excellent examples of *Scalarituba* (Fig. 6G), *Rhizocorallum* (Fig. 6H) and *Cosmorphaie* (Fig. 6I).

The evenly bedded and rippled sandstones were deposited above wave base in response to moderate wave and/or current activity. Deposition occurred too quickly for the sediment to be extensively bioturbated. Oscillation ripples developed on the surface of the sandstone beds during periods of relative quiescence.

Cross-stratified-sandstone facies (*inner shelf*)

The cross-stratified-sandstone facies consists mainly of multiple, intersecting sets of trough-cross-stratified, fine- to coarse-grained sandstone (Fig. 6E). Solitary troughs and small tabular cross-beds are also present. Troughs are generally 1·5–2·5 m wide and 0·3–0·6 m high, and contrast to the broader, shallower troughs of the Byro Group sequences (Moore and others, 1980). Cross-stratification is common in parts of the Binthalya Formation, and occurs sporadically in the Coolkilya and Mungadan Sandstones.

The trough-cross-stratified sandstones were formed by the migration of megaripples in a moderate to high-energy, nearshore-marine environment. Minor tabular cross-sets were formed by the migration of sand waves (Harms and others, 1975).

Laminated-to-burrowed-sandstone facies (*lower shoreface*)

The laminated-to-burrowed-sandstone facies consists of units of fine to very fine sandstone which are planar laminated to hummocky cross-stratified near the base, becoming intensely bioturbated towards the top (Fig. 6C). The units are 0·4–1·5 m thick, and have a slightly erosive base. *Skolithos* is prominent in the bioturbated intervals. The laminated-to-burrowed facies is poorly represented in the Kennedy Group, occurring mainly in the lower portion of the Coolkilya Sandstone. Units are generally thin in comparison with their counterparts in the Byro Group (Moore and others, 1980).

The laminated-to-burrowed units were probably deposited at approximate wave base. The thin, traction-deposited sandstones formed in response to storm activity and alternate with bioturbated sandstones formed during quiet-water sedimentation, when burrowing organisms were able to rework the upper part of the substrate (Howard, 1972).

Hummocky-cross-stratified-sandstone facies (*middle shoreface*)

This facies consists of laminated to very low-angle cross-stratified sandstone, occurring in thin (0·1–0·4 m) sets separated by minor discordances (Fig. 6B). Body fossils (mainly disarticulated bivalves) are rare and trace fossils are mainly of small subvertical burrows. The hummocky-cross-stratified sandstone facies is confined to the lower portion of the Coolkilya Sandstone.

This facies developed in response to constant reworking of sand in a shallow-marine environment above mean wave base. Reading (1978) believes that it characterizes the middle shoreface zone of a moderate-energy, linear clastic shoreline.

DEPOSITIONAL MODELS

The sequences of facies developed in the Kennedy Group cannot be explained by a single depositional model. Rather, the Kennedy Group is best considered in terms of two distinct but related models, one which characterizes the deposits of the Coolkilya Sandstone, and the other which explains the sequences in the Mungadan Sandstone and Binthalya Formation.

The depositional model presented for the underlying Byro Group (Moore and others, 1980) is readily applicable to the lower portion of the Coolkilya Sandstone; however, it is less applicable to the upper part and is commonly quite inconsistent with the sequences of facies developed in the Mungadan Sandstone and Binthalya Formation. A diagrammatic summary of the model is presented in Figure 5A. The offshore siltstones are not represented in the Coolkilya Sandstone itself, but are present at the top of the conformably underlying Baker Formation. The sequence of facies produced by natural progradation of the shoreline is grey siltstone at the base, followed successively by bioturbated silty sandstone, laminated-to-burrowed sandstone and hummocky cross-stratified sandstone. Such sequences ideally coarsen upwards, although individual units of laminated-to-burrowed facies may fine upwards. During deposition of the lower portion of the Coolkilya Sandstone and the underlying Byro Group, the transition zone, or the sandy part of the marine shelf, was probably only of moderate width because of the combined effects of a limited supply of sand and a relatively steep palaeoslope. Distribution of sand was primarily by wave action, and much of the sandy sequence reflects the influence of storms. The transition environment is characterized by quiet-water deposition, and there is no evidence that currents redistributed the sand in this zone below wave base. A feature of this model is the presence of the laminated-to-burrowed facies, which can only develop where relatively quiet-water deposition occurs immediately seaward of the shoreface zone.

The absence of the laminated-to-burrowed facies in the Mungadan Sandstone and Binthalya Formation (Fig. 2) is considered to be very significant. In these formations, small-scale (1·5–15 m thick) coarsening-upward cycles are common, particularly in the southeastern outcrops (Figs. 6A and 6D) and a complete cycle (Fig. 5B) is presented as a basic depositional model for this part of the sequence. The coarsening-upward cycles reflect a progressive increase in depositional energy in which bioturbated, sub-wave base sandstones on the outer shelf pass gradationally into wave and ?current worked, evenly bedded and rippled sandstones. These in turn may pass laterally into medium- and large-scale cross-stratified sandstones formed by megaripple and minor sand-wave migration. Although there is minor herringbone cross-stratification in the sequence (Fig. 6E), there are no other features indicative of tidal influence. In particular, the fining upward "BC" sequences typical of sandy intertidal and subtidal deposits (Klein, 1971) are notably absent. The cycles are not deltaic in origin either. Beds are laterally very continuous, there is an absence of prominent channelling, and the widespread distribution of the facies is inconsistent with deltaic deposition (Broussard, 1975). Thomas and Smith (1976) suggested that the Kennedy Group was deposited in estuarine and lacustrine environments. However, the lateral persistence of the Kennedy Group facies over such a large area, and the considerable thickness of the sequence are inconsistent with deposition in these environments (Lauff, 1967; Greer 1975; Picard and High, 1972). Furthermore, there is no evidence of abnormal salinity conditions or restricted circulation patterns which characterize lacustrine deposition (Matter and Tucker, 1977).

The coarsening-upward cycles of Figure 5B are thus interpreted as resulting from the natural progradation of the shoreline. The relatively consistent thickness of the cycles and the considerable stratigraphic thickness over which they occur (Figs. 3 and 4) suggest that the depositional basin was undergoing gentle downwarp, so that the rates of subsidence and sedimentation were approximately balanced.

Three possible depositional models may be considered to explain the evolution of the Mungadan Sandstone and Binthalya Formation cycles. The first of these is that the cycles represent shoreline oscillations along a barred coastline. Rip currents are prominent along barred coastlines, and their deposits have a high preservation potential. Furthermore, according to Komar (1976) rip currents are the principal way in which offshore-orientated large-scale cross-stratification is generated in the non-deltaic marine environment. The coarsening-upward sequences described by Hunter and others (1979) in their barred-coastline model are similar to cycles in the Binthalya Formation where cross-stratification is preserved. However, such a model is inconsistent with the extensive regional distribution of the cross-stratified facies in the Kennedy Group. Although Davidson-Arnott and Greenwood (1976) have shown that the maximum seaward extent of rip currents is probably enhanced by the development of multiple bars, present data suggest that even in this situation, rip currents are wholly confined to the nearshore zone, within about 1 km of the foreshore. However, we have found no evidence of the foreshore environment in any of the Kennedy Group outcrops, as should be expected in such a sequence. For example, outcrops of Mungadan Sandstone in the Merlinleigh Anticline (Fig. 1) are prominently cross-stratified with a major offshore mode (Fig. 7C), yet in outcrops 20 km to the southeast (roughly shorewards) in the same formation there is no evidence of the strandline.

A second possible model is presented by Anderson (1976). The sequence from evenly bedded siltstone through linsen-bedded and ripple-laminated sandstone into large-scale cross-stratified sandstone can develop on open marine shelves swept by strong currents. Although the currents are generated by oceanic tides, they may be essentially unidirectional, and bedforms indicative of tidal oscillation may be absent. However, in this model, the currents typically flow sub-parallel to the shoreline (Belderson and Stride, 1966) and ripples, where preserved, are highly asymmetrical (linguoid), unlike the oscillation ripples of the Mungadan and Binthalya sequences. Furthermore, in marked contrast to the Kennedy Group sequences, fossil examples of the 'tidal path circulation' model do not show examples of cyclicity (Anderson, 1976) and indeed, none are likely from theoretical considerations of the model.

The third and simplest model, and the one that we favour, is of a broad, prograding sandy marine shelf which consisted of bioturbated and rippled sand in the outer zone and megaripples in the inner zone. Long-crested, symmetrical and near-symmetrical wave ripples on the outer shelf were probably aligned with their crests parallel to the shoreline (Picard. 1967: Picard and High, 1968). The orientation of wave ripple crests (Fig. 7) and the regional distribution of facies (Fig. 2), indicate that the shoreline lay to the southeast of the outcrop area during deposition of the Mungadan Sandstone and Binthalya Formation (Fig. 7). The ripples were formed in a low-energy zone near approximate wave base, which on a broad sandy shelf, may have been a considerable distance offshore in moderately deep water. For example, Draper (1967) concluded that waves in certain cases can move bottom sediments at depths of over 100 m in the open-shelf environment. Similar observations at even greater depths on shelves adjacent to northwestern Australia, South America and Thailand are reported by the Australian Institute of Petroleum Limited (1979).

In zones of higher energy, presumably shoreward of the rippled zone, megaripples were a common bedform and migrated in a variety of directions but mainly to the northwest. This predominantly offshore orientation is unusual, particularly in a non-barred, wave-dominated system where megaripples most commonly face shorewards (Clifton and others, 1971). However, Banks (1973) and Daily and others (in press) have suggested that offshore-directed, storm-generated currents may be prominent in the evolution on nearshore sequences on broad marine shelves, and their deposits should have a high preservation potential. Walker (1979) and Walker and Hamblin (1979) argue that the storm-generation of offshore-directed density currents is a major geological process, and is capable of producing cross-stratification. However, our understanding of this important process is far from complete.

Thus, we conclude that the Mungadan Sandstone and Binthalya Formation developed mainly on a broad sandy shelf, and the sequence of facies reflects a shoreward increase in grain-size and scale of preserved sedimentary structures in response to increased depositional energy. The abundance of long-crested oscillation ripples in an environment considered to be seaward of the zone of megaripple migration (Fig. 5B) suggests that the cross-stratification was produced in a zone above storm wave base, and therefore possibly formed mainly in response to offshore directed, storm-generated currents. Minor redistribution of sand by tidal currents is probable.

PALAEOGEOGRAPHY AND GEOLOGIC HISTORY

Palaeogeographic maps for four time intervals during deposition of the Kennedy Group are presented in Figure 7. The position of boundaries between depositional environments is based primarily on the regional distribution of facies, but also takes account of the fact that oscillation (wave) ripples are typically aligned with their crests sub-parallel to the coastline.

Deposition of the Coolkilya Sandstone was initiated by a mild regression which terminated Byro Group deposition and promoted shoreface sedimentation in a belt along what is now the eastern side of Kennedy Range (Fig. 7A). Thick sequences of hummocky cross-stratification (middle shoreface environment) occur in the lower half of the Coolkilya Sandstone at Range Bore, South End Bore and Blackheart Valley, and constitute a narrow zone which defines the orientation of the palaeo-shoreline. Around Wandagee Hill, which was further offshore, sedimentation was mostly in the lower shoreface and transition environments. Palaeocurrent data are rare in these deposits.

A broadening of the sandy shelf began during the deposition of the upper part of the Coolkilya Sandstone (Fig. 7B), probably as a result of an increase in the supply of sand. This increased supply rate may have been due to uplift of distant source areas, particularly to the south and southeast. The lower shoreface environment is still prominently represented in outcrops at Range Bore, South End Bore and Mitta Mitta Bore, but sandy, bioturbated and ripple-laminated shelf facies are dominant in outcrops to the west. Palaeocurrent data are sparse, but shoreward and longshore migration of megaripples (large scale cross-stratification) is indicated. Oscillation ripples have a variety of orientations.

Continued mild transgression and further broadening of the sandy marine shelf are indicated by the development of the Mungadan Sandstone (Fig. 7C). The predominance of quartz and moderate to good sorting of the sand suggest considerable reworking of the sediment by waves and currents, although poorly sorted silty sandstones were still being deposited in a more offshore environment at Wandagee Hill. The gradual change in facies from northwest to southeast suggests that land lay to the southeast beyond the area of outcrop, and this interpretation is supported by the orientation of wave-ripple

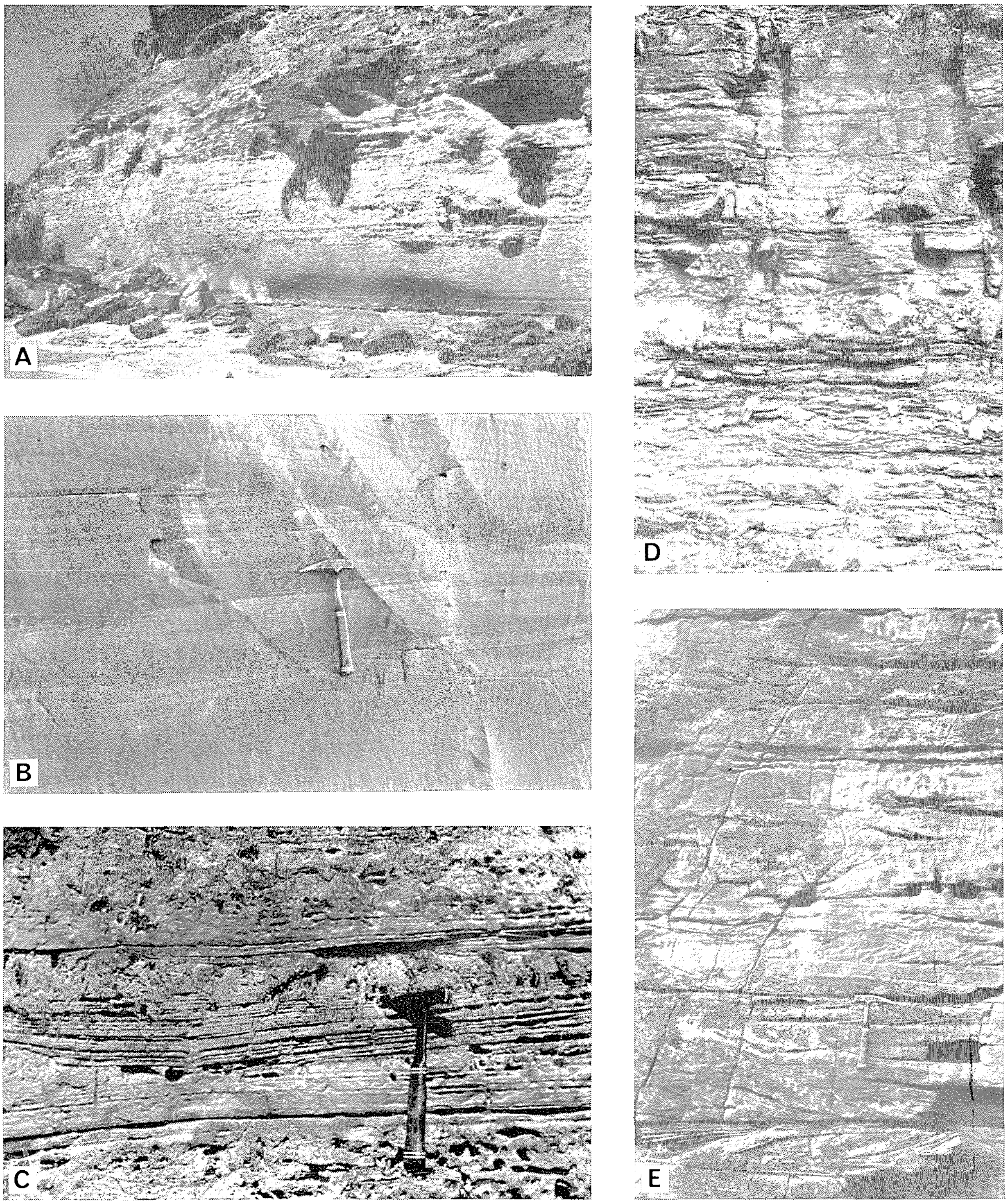


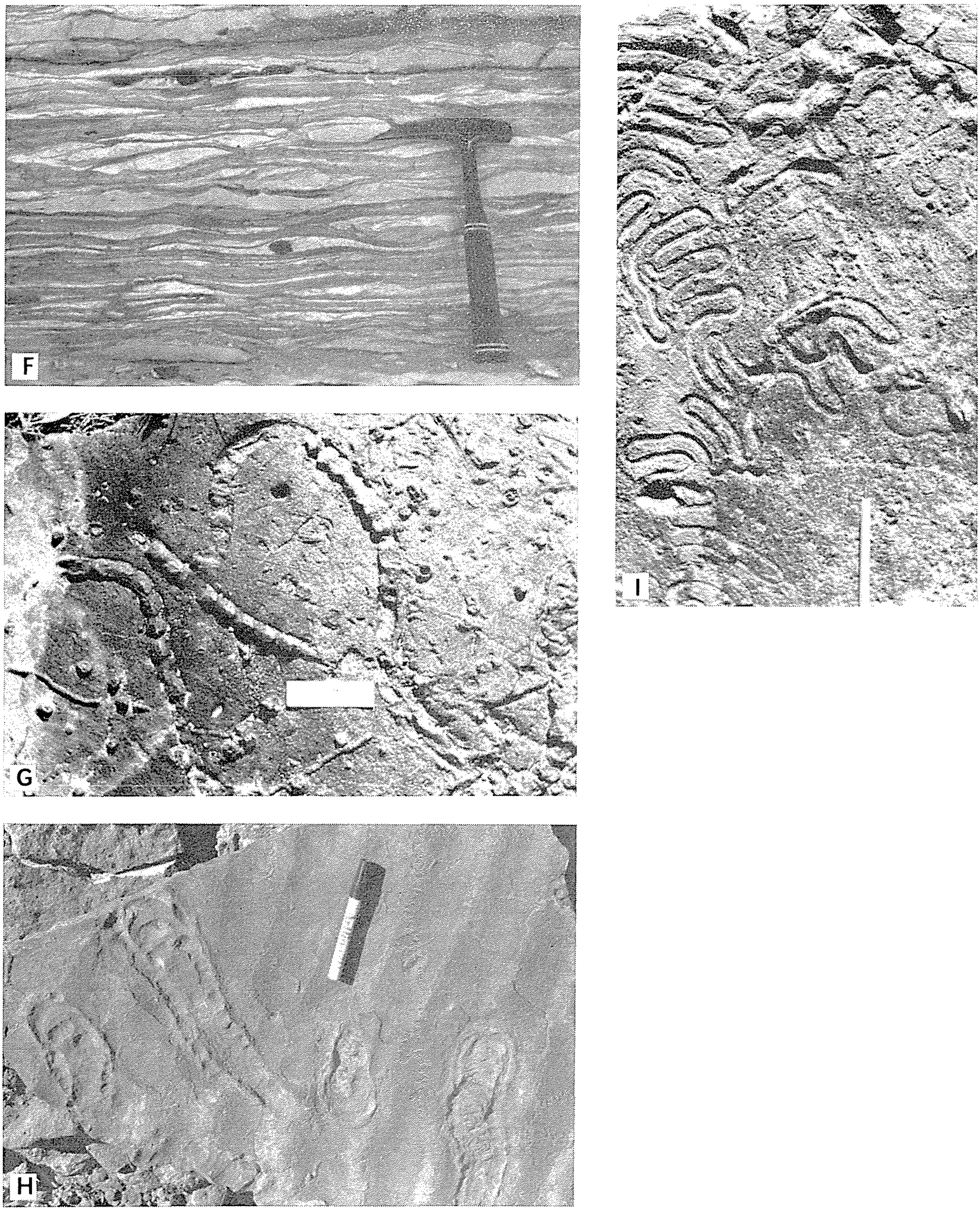
Figure 6 (A) General view of grey-siltstone facies, coarsening-upward into poorly outcropping bioturbated sandstone. Binthalya Formation, south bank of Watermelon Creek, western Kennedy Range.

(B) Hummocky cross-stratified facies, consisting of low-angle intersecting sets of cross-stratification with minor shallow scours. Very weakly bioturbated Lower Coolkilya Sandstone, west side of Blackheart Valley, northern Kennedy Range.

(C) Thin units of laminated-to-burrowed facies. Middle portion of Coolkilya Sandstone at Range Bore, eastern Kennedy Range.

(D) Evenly bedded-sandstone facies, showing coarsening-upward tendency from underlying grey siltstones. Cycle has a sharp top and is overlain by grey siltstone. Mungadan Sandstone in measured section 800 m south of Binthalya Spring, southwestern Kennedy Range.

(E) Cross-stratified-sandstone facies, with common herringbone structures. This sequence was probably deposited under the influence of tidal currents. Offshore (ebb) -directed palaeocurrents predominate. Basal Mungadan Sandstone, south side of WAPET road, Merlinleigh Anticline.



(F) Rippled-sandstone lenticles in grey siltstone. Lenticular-and-linsen-bedded facies, Binthalya Formation, north bank of Watermelon Creek, western Kennedy Range.

(G) *Scalarituba* in evenly bedded-sandstone facies. Lower part of Binthalya Formation in measured section 800 m south of Binthalya Spring, southwestern Kennedy Range.

(H) *Rhizocorallum* on wave-rippled bedding surface. Evenly bedded sandstone facies, basal Binthalya Formation, south side of WAPET road, Merlinleigh Anticline.

(I) Sinuous feeding burrow of *Cosmorphaie*. Evenly bedded facies, Binthalya Formation, north bank of Watermelon Creek, western Kennedy Range.

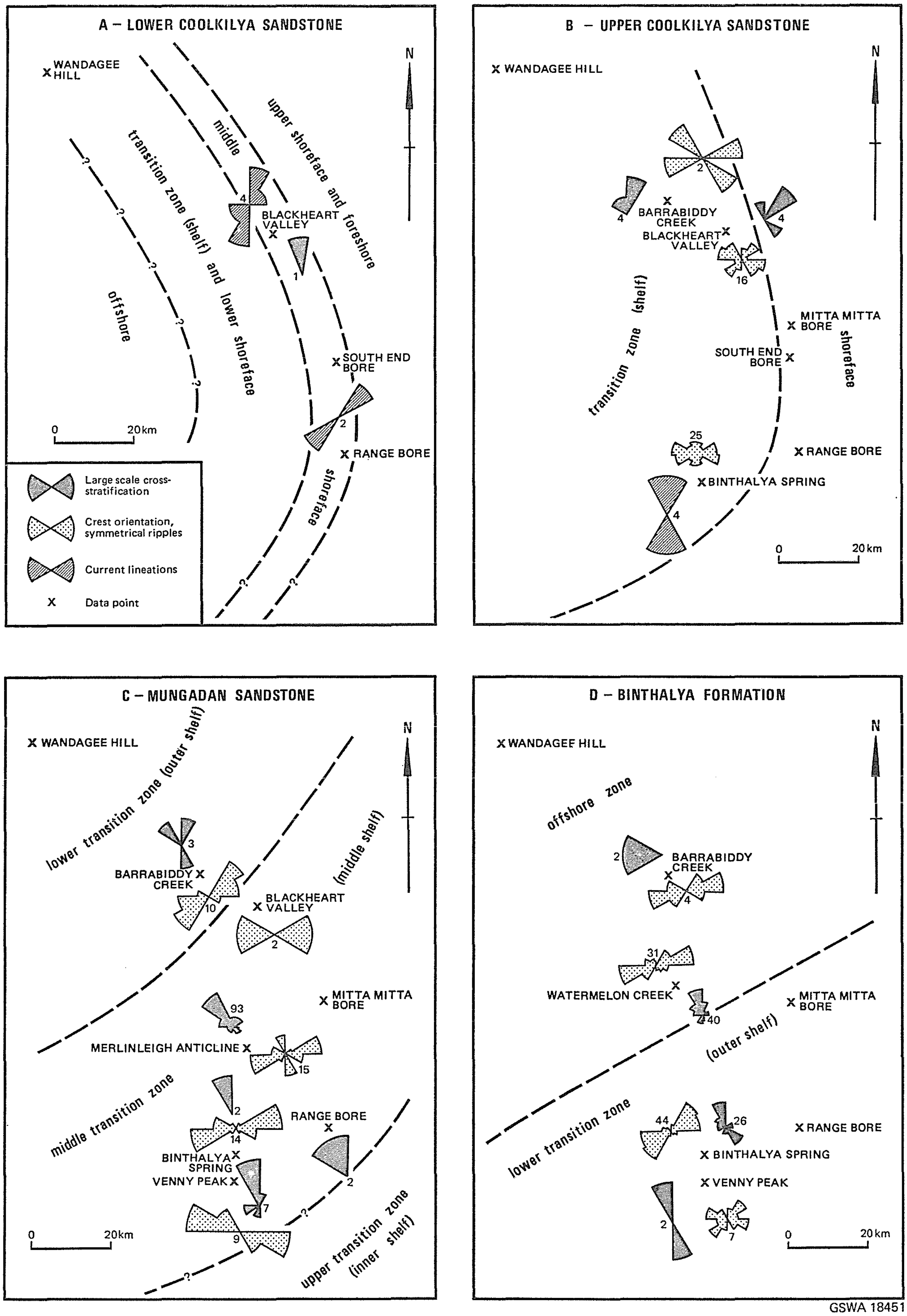


Figure 7 Palaeogeographic maps for four time intervals during deposition of the Kennedy Group.

crests in the sequence. Offshore-orientated large-scale cross-stratification probably resulted mainly from storm-generated currents, as discussed previously.

Offshore siltstones are common in scattered outcrops of the basal Binthalya Formation in the north and northwest, and a palaeogeographic reconstruction for this period of time is shown in Figure 7D. Further reorientation of the shoreline is suggested by the alignment of wave-ripple crests. Megaripple migration was predominantly on and off shore, presumably in response to onshore wave attack and offshore storm-generated currents.

CONCLUSIONS

The Kennedy Group, a siliciclastic sandy sequence with minor siltstone, was deposited on a very broad, sandy marine shelf and in the adjacent offshore and shoreface environments. Sequences of this type are poorly documented in recent literature, and a great deal remains to be learned about the sandy marine shelf. One critical question is how the sand is distributed in this zone below mean wave base.

In the Kennedy Group, we have distinguished three facies in the sandy-shelf environment. Bioturbated sandstones formed where wave and current activity were weak, whereas rippled and evenly bedded sandstones indicate more rapid deposition and stronger reworking by physical processes. Minor cross-stratified sandstones indicate current flow in a moderate to high-energy environment. Although in many cases these three facies are randomly interbedded, coarsening-upward cycles are present, particularly in the southeastern outcrops. We interpret these cycles as representing regressive events associated with shoreline progradation. Thus, bioturbated sandstones dominate on the outer shelf, rippled and evenly bedded sandstones dominate on the mid-shelf, and cross-stratified sandstones, representing megaripple migration, dominate on the inner shelf. The abundance of wave ripples in the sequence suggests that wave activity was an important process for sand distribution. Some cross-stratification probably has a tidal origin, but the majority is attributed to offshore-directed, storm-generated currents. Note however, that although several prominent workers have recently suggested storm currents as a means of generating offshore-directed cross-stratification on marine shelves, the process has yet to be demonstrated in the modern environment.

A progressive broadening of the sandy shelf during deposition of the Kennedy Group is indicated by a gradual change in the style of sedimentation and the preserved sequence of facies. The broadening was associated with, and possibly caused by, an increase in the rate of sand supply, which in turn was probably related to rejuvenation and increased erosion of relatively distant source areas to the southeast. The orientation of the palaeoslope swung from roughly north-south at the commencement of Kennedy Group deposition to northeast-southwest during deposition of the Binthalya Formation, possibly heralding the end of this phase of sedimentation.

REFERENCES

Anderson, R., 1976, Tidal shelf sedimentation: an example from the Scottish Dalradian: Sedimentology, v. 23, p. 429–458.

Australian Institute of Petroleum Ltd., 1979, Something new under the sea: Petroleum Gazette, v. 21, p. 40–42.

Belderson, R. H. and Stride, A. H., 1966, Tidal current fashioning of a basal bed. Mar. Geol., v. 4, p. 237–257.

Belford, D. J., 1968, Permian foraminifera from bores B.M.R. 6, 7, 8 and 9, *in* Palaeontological papers 1965: Australia Bur. Mineral Resources Rept. 80, p. 1–14.

Broussard, M. L., 1975, Deltas, models for exploration: Houston, Texas, Houston Geol. Soc.

Clifton, H. E., Hunter, R. E., and Phillips, R. L., 1971, Depositional structures and processes in the non-barred, high-energy nearshore: Jour. Sed. Petrology, v. 41, p. 651–670.

Cockbain, A. E., 1980, Permian ammonoids from the Carnarvon Basin—a review: West Australia Geol. Survey Ann. Rept 1979, p. xx–xx.

Condon, M. A., 1954, Progress report on the stratigraphy and structure of the Carnarvon Basin, Western Australia: Australia Bur, Mineral Resources Rept 15.

——— 1962, Kennedy Range, W.A.: Australia Bur. Mineral Resources, 1:250 000 Geological Series Explan. Notes.

——— 1967, The geology of the Carnarvon Basin, Western Australia, Part II: Permian stratigraphy: Australia Bur. Mineral Resources Bull. 77.

Daily, B., Moore, P. S., and Rust, B. R., in press, Terrestrial-marine transition in the Cambrian rocks of Kangaroo Island, South Australia: Sedimentology.

Davidson-Arnott, R. G. D. and Greenwood, B., 1976, Facies relationships on a barred coast, Kouchibouguac Bay, New Brunswick, Canada, *in* (Davis, R. A. Jr. and Ethington, R. L., eds) Beach and nearshore sedimentation: Soc. Econ. Palaeontologists and Mineralogists Spec. Publ. 24, p. 149–168.

Dickins, J. M., 1970, Correlation and subdivision of the Permian of western and eastern Australia, *in* Palaeontological Papers 1968: Australia Bur. Mineral Resources Bull. 116, p. 17–28.

Draper, L., 1967, Wave activity at the sea bed around northwestern Europe: Mar. Geol., v. 5, p. 133–140.

Goldbery, R., 1979, A textural inversion phenomenon within Lower Jurassic red beds of the Ardon Formation, Makhtesh Ramon, (Israel): Jour. Sed. Petrology, v. 49, p. 891–900.

Greer, S. A., 1975, Sandbody geometry and sedimentary facies at the estuary-marine transition zone, Ossabaw Sound, Georgina: a stratigraphic model: Senckenberg. Mar., v. 7, p. 105–135.

Hamblin, A. P. and Walker, R. G., 1979, Storm-dominated shelf deposits: the Fernie—Kootenay (Jurrassic) transition, southern Rocky Mountains: Canadian Jour, Earth Sci., v. 16.

Harms, J. G., Southard, J. B., Spearing, D. R. and Walker R. G., 1975, Depositional environments as interpreted from primary sedimentary structures and stratification sequences: Soc. Econ. Palaeontologists, Short Course Notes No. 2.

Hocking, R. M., Moore, P. S. and Moors, H. T., 1980, Modified stratigraphic nomenclature and concepts in the Palaeozoic sequence of the Carnarvon Basin, W.A.: West. Australia Geol. Survey Ann. Rept 1979, p. 51–55.

Howard, J. D., 1972, Trace fossils as criteria for recognising shorelines in the stratigraphic record: Soc. Econ. Palaeontologists and Mineralogists Spec. Publ. 16, p. 215–225.

Hunter, R. E., Clifton, H. E. and Phillips, R. L., 1979. Depositional processes, sedimentary structures, and predicted vertical sequences in barred nearshore systems, southern Oregon coast: Jour, Sediment. Petrol., v. 49, p. 711–727.

Klein, G. deV., 1971, A sedimentary model for determining paleotidal range: Geol. Soc. America Bull., v. 82, p. 2582–2592.

Komar, P. D., 1976, Beach processes and sedimentation: Prentice-Hall, New Jersey.

Lauff, G. H., 1967, Estuaries: American Assoc, Adv. Sci. Publ. 83.

Lehmann, P. R., 1969, Kennedy Range No. 1 well completion report: West Australian Petroleum Pty. Ltd. Rept (unpublished).

Matter, A. and Tucker, M. E., 1979, Modern and ancient lake sediments: Int. Assoc. Sedimentologists Spec. Publ. 2.

Moore, P. S., Denman, P. D. and Hocking, R. M., 1980, Sedimentology of the Byro Group (Lower Permian) Carnarvon Basin, Western Australia: West. Australia Geol. Survey Ann. Rept 1979, p. 55–64.

Picard, M. D., 1967, Paleocurrents and shoreline orientations in Green River Formation (Eocene), Raven Ridge and Red Wash areas, northeastern Uinta Basin, Utah: American Assoc. Petrol. Geol. Bull., v. 51, p. 2471–2475.

Picard, M. D., and High, L. R. Jr., 1968, Shallow marine currents on the Early (?)Triassic Wyoming Shelf: Jour. Sediment. Petrol., v. 38, p. 411–423.

——— 192, Criteria for recognizing lacustrine rocks, *in* Recognition of ancient sedimentary environments (Rigby, J. K. and Hamblin, Wm. K., eds): Soc. Econ. Paleontologists and Mineralogists Spec. Publ. 16.

Perry, W. J., 1965, Completion report, stratigraphic and structural bores BMR 6 and 7, Muderong, Western Australia: Australia Bur. Mineral Resources Rept 81.

Raaf, de J. F. M., Boersma, J. R. and Gelder, van A., 1977, Wave generated structures and sequences from a shallow marine succession, Lower Carboniferous, County Cork, Ireland: Sedimentology, v. 24, 451–483.

Reading, H. G., 1978, Sedimentary environments and facies: London, Blackwell Sci. Pub.

Reineck, H. E. and Singh, I. B., 1972, Genesis of laminated sand and graded rhythmites in storm-sand layers of shelf mud: Sedimentology, v. 18, p. 123–128.

Thomas, B. M. and Smith, D. N., 1976, Carnarvon Basin, *in* Economic geology of Australia and Papua New Guinea—Petroleum (Leslie, R. B., Evans, H. J. and Knight, C. L. eds.) Australasian Inst. Mining Metall. Mon 7 p. 126–155.

Walker, R. G., 1979, Shallow marine sands *in* Facies models (Walker, R. G., ed): Geoscience Canada Reprint Series 1, p. 75–89.

ENVIRONMENTAL CONTROLS ON THE MORPHOLOGY OF MODERN STROMATOLITES AT HAMELIN POOL, WESTERN AUSTRALIA

by Phillip E. Playford

ABSTRACT

Environmental factors are generally dominant in controlling the external morphology of stromatolites at Hamelin Pool, but biological factors also influence some external features, and they largely control the internal stromatolite fabrics.

Many Hamelin Pool stromatolites are elongate parallel to the wave-translation direction. However, the prevailing winds are also believed to influence the growth direction of some forms. Columnar stromatolites that are inclined to the south and seif (linear) stromatolites that trend nearly north-south, are thought to have developed in response to the prevailing southerly winds. The seif stromatolites show characteristics suggesting that they have formed as a result of wind-induced paired helical vortices (Langmuir circulation) in water.

The Hamelin Pool stromatolites generally require a hard substrate on which to grow. This consists variously of indurated Pleistocene beach ridges, Tertiary quartzite, and calcrete over Cretaceous calcilutite or Pleistocene limestone. Where stromatolites have grown on Pleistocene beach ridges they tend to form curvilinear reefs, with parallel lines of stromatolites in each reef controlled by resistant beds in the underlying beach ridges. In other areas large domal stromatolites have grown over eroded remnants of indurated solution pipes cutting Cretaceous calcilutite.

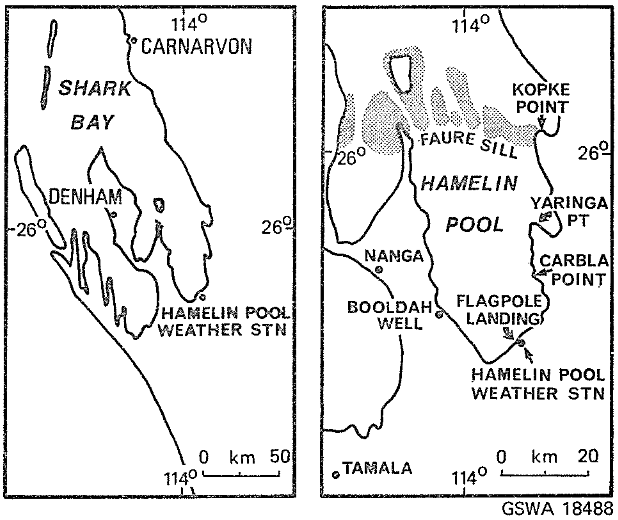


Figure 1 Locality maps, Hamelin Pool area.

INTRODUCTION

The algal stromatolites growing today around the margins of Hamelin Pool are believed to be the most diverse and abundant forms known from modern seas. They are of considerable importance as modern analogues of ancient stromatolites, and have consequently been the subject of extensive research over the past 20 years (Logan, 1961; Logan and others, 1974; Playford and Cockbain, 1976; Hoffman, 1976, Monty; 1976; Golubic, 1976; Playford, 1979; Bauld and others, 1979).

Hamelin Pool is a hypersaline marine embayment, barred from the rest of Shark Bay by a limesand and seagrass bank known as the Faure Sill (Fig. 1). The restricted tidal exchange through this sill, combined with low precipitation and high evaporation, have resulted in hypersaline conditions in Hamelin Pool, with salinities in the range 55 000 to 70 000 mg/L throughout the year. As a result, the Hamelin Pool biota is very restricted compared with that of the more open-marine areas elsewhere in Shark Bay. The virtual absence in Hamelin Pool of gastropods that graze on algae is believed to be the main factor allowing stromatolites and flat algal mats to flourish there. Further details of the Hamelin Pool environment and descriptions of the geology are given by Logan and others (1970), Playford and Cockbain (1976), van de Graaff and others (in press), and Butcher and others (in press).

Early work on the Hamelin Pool stromatolites emphasized the role of environmental factors in controlling stromatolite morphology. Subsequent research has confirmed the strong influence of these factors on the gross external features of stromatolite morphology, but has also shown that internal fabrics are largely governed by the stromatolite-building algal assemblages.

The present paper is intended as a progress report on aspects of recent work at Hamelin Pool by the Geological Survey, concentrating on some of the main environmental controls on stromatolite morphology.

THE STROMATOLITES

Algal stromatolites and flat algal mats are growing today over wide areas of the sublittoral platform and adjacent intertidal zone in Hamelin Pool, extending to water depths of at least 3·5 m (Playford and Cockbain, 1976). The living intertidal forms are commonly backed by older dead stromatolites, which extend to about 1 m above sea level. Tectonic, rather than eustatic, emergence of these old stromatolites seems probable.

However, not all stromatolites in the intertidal zone and on the sublittoral shelf are living; a significant proportion are dead. Some can be shown to have died through being overwhelmed by sediment, such as moving sand megaripples, and to have later been uncovered. In some cases uncovered dead forms have afterwards been recolonized by stromatolitic algae, allowing growth to recommence over all or part of the stromatolites. However, many dead stromatolites, both intertidal and subtidal, are bare of living stromatolitic algae, even though they seem to be in favourable positions for renewed growth. The reason for this is unknown.

Observations utilizing non-corrosive nails (placed as markers) and photographs taken over intervals of several years show that the Hamelin Pool stromatolites are extremely slow growing; indeed most living intertidal forms seem to be virtually static, with growth of the algal mats approximately balanced by erosion through wave action. The maximum net growth rate of a marked stromatolite, amounting to no more than 0·5 mm per year, has been recorded from a subtidal colloform-mat stromatolite. Field experimental data obtained by Bauld and others (1979) showed the highest primary productivity in subtidal colloform mat (113 mg C $m^{-2}h^{-1}$) and the lowest in intertidal smooth mat (17 mg C $m^{-2}h^{-1}$).

The slowness of growth suggests that many individual stromatolites are hundreds of years old. However, it seems possible that conditions for stromatolite growth in Hamelin Pool today are not as favourable as they were in the recent past. This possibility is supported by the occurrence of extensive areas of dead stromatolites in both intertidal and subtidal areas.

Most, but not all, living stromatolites at Hamelin Pool, both intertidal and subtidal, are being lithified penecontemporaneously. The nature of the cementing process has not been studied, and the reason why some stromatolites remain virtually uncemented is unknown. Time may be a factor, but there is no evidence at present to indicate that uncemented stromatolites have grown more rapidly than cemented forms.

Early workers did not recognize biological controls on stromatolite morphology at Hamelin Pool, claiming instead that growth forms are controlled solely by environmental factors (Logan, 1961; Logan and others, 1964). However, subsequent research has shown that although environmental factors have exerted a dominant influence on gross external stromatolite morphology (to be discussed in the next section) the stromatolite-building algal mats also influence external morphology to some extent, and they largely control the internal fabrics. Figure 2 illustrates the distribution of the three principal mat types that build stromatolites at Hamelin Pool, the dominant algal species in each mat, and associated surface features and internal fabrics of the stromatolites. However, considerable additional work remains to be done before there is an adequate understanding of the biological influences on the morphology of these stromatolites. The Hamelin Pool stromatolites may well provide the key to explaining why fenestral fabrics are common in shallow-water Phanerozoic stromatolites, but are apparently absent from Precambrian forms.

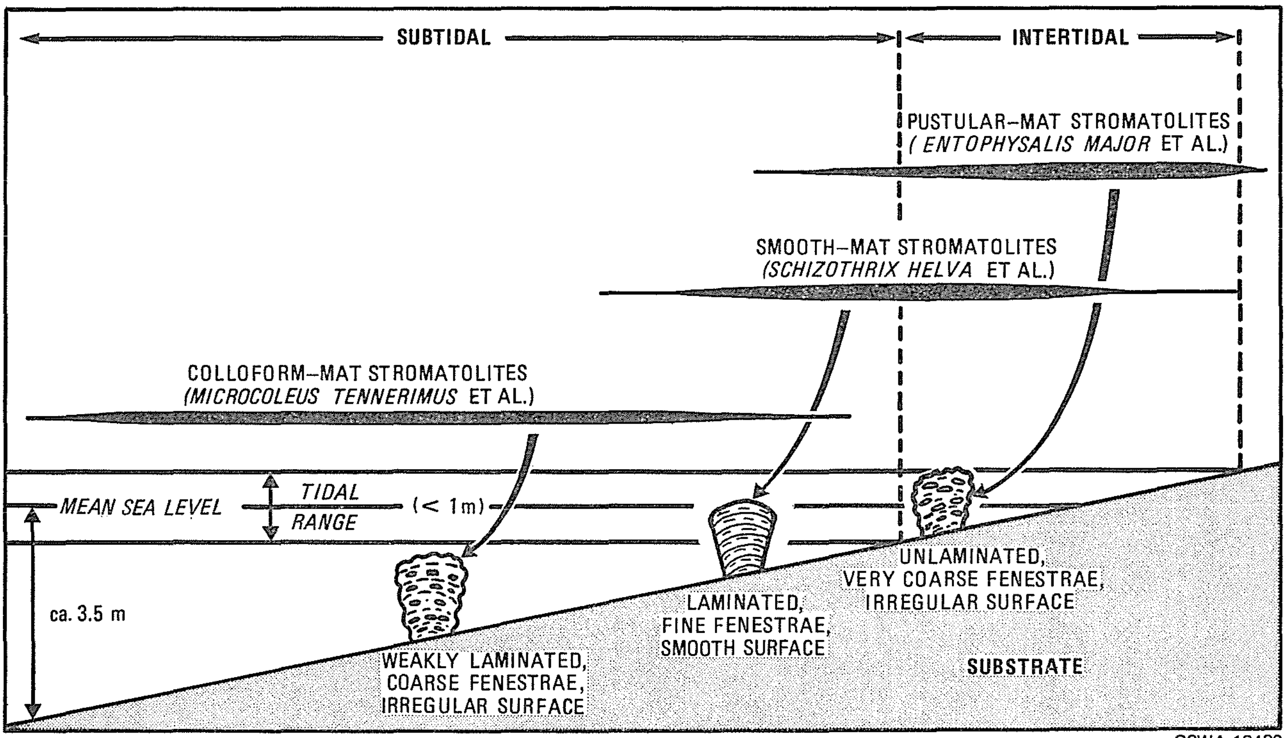


Figure 2 Diagram illustrating distribution of stromatolite-building algal mats and their dominant algal species, and some associated morphological features of the stromatolites.

ENVIRONMENTAL CONTROLS ON STROMATOLITE MORPHOLOGY

The three environmental controls on stromatolite morphology and distribution at Hamelin Pool to be discussed in this paper are the wave-translation direction, prevailing wind direction, and nature of the substrate (Fig. 3).

WAVE-TRANSLATION DIRECTION

The fact that stromatolites at Hamelin Pool, both intertidal and subtidal, are commonly elongate in the wave-translation direction (Figs. 8A, B) has been documented by Logan and others (1974) and Playford and Cockbain (1976). Many authors have applied this principle in explaining the origin of elongate stromatolites in the ancient record, and the analogy seems to be generally valid. However, there is evidence that the prevailing wind direction and nature of the substrate also influence the elongation and trends of some stromatolites at Hamelin Pool, and these factors should be borne in mind when interpreting environmental controls on the morphology of ancient stromatolites.

WIND DIRECTION

The prevailing wind direction over most of the Shark Bay area is from the south to south-southwest, as shown by records at Carnarvon (Fig. 4) and personal observations at Denham, Tamala, Nanga, and Dirk Hartog Island. These winds are especially strong and persistent during the summer. However, records from Hamelin Pool weather station show that winds there are weaker and more variable, and the prevailing wind direction is southeast to south (Fig. 4). This is because the weather station is situated near the southeastern end of Hamelin Pool, which is more subject to land-influenced atmospheric circulation than other parts of the Shark Bay area.

Playford and Cockbain (1976) reported that small "leaning" columnar stromatolites in the Carbla Point area are inclined to the south, although they occur in lines parallel to the direction of wave translation (Fig. 8C, D). They hypothesized that this inclination has developed in response to prevailing southerly winds. The inclined stromatolites are constructed by a combination of smooth and pustular mats. They show fine lamination on the north and top sides of the columns, and no lamination on the south sides. However, further observations will be neccessary to confirm the hypothesis of wind control and to determine the growth mechanism involved.

Some striking stromatolite growth forms that are thought to be wind controlled are developed in places along the west side of Hamelin Pool, especially in the Booldah Well area (Figs. 5, 9). They were termed seif stromatolites by Playford (1979), having been previously referred to as stromatolite ridges by Playford and Cockbain (1976). These stromatolites are built by pustular mat as elongate flat-topped ridges 1–3 m wide and about 0·3 m high, separated by bare sandy areas, usually about 5–10 m apart. They extend up to 800 m offshore, from lower intertidal to shallow subtidal areas. The ridges are subparallel (Figs. 5, 9), and the average elongation is nearly north-south. They show "tuning-fork junctions", normally opening to the south (upwind). It is suggested that they have formed in response to paired helical vortices (Langmuir circulation) in shallow water, induced by strong southerly winds (Fig. 6). Their resemblance in form to subaerial seif dunes, which result from paired helical vortices in air (Crowe, 1975), is striking. However, further observations and experimentation are required to confirm the suggested origin of these stromatolites.

Near Booldah Well there is a track 300 m long which was cut through the seif stromatolites about 65 years ago by camel-drawn wagons (Mac Hoult, pers. comm., 1976). They were used here until the mid-1930s to load wool and sandalwood from Nanga Station onto lighters anchored in shallow water just beyond the belt of stromatolites. However, although they have not been in use for more than 40 years there has been very little regrowth of stromatolites over the track. Indeed, where single sets of wheel marks deviate from the main track they are still clearly visible cutting through the stromatolite ridges (Figs. 9C, 10A). This illustrates the fragility and very slow growth of stromatolites in this area, and it raises the question of whether the seif stromatolites may have developed in their present form at some time in the recent past when conditions for algal growth were more favourable, and southerly winds were stronger, than today. However, the seif stromatolites near Booldah Well are younger than the dead and emergent stromatolite reefs which occur along the shoreline in this area (Figs. 5, 9B).

Indurated flat algal-mat limestone between the shoreline and the seif stromatolites near Booldah Well is also criss-crossed by individual wagon tracks (Fig. 10B); the tracks appear almost as clear today as when they were formed more than four decades ago.

SUBSTRATE

The nature of the substrate is an important factor controlling the development of stromatolites at Hamelin Pool. They generally require a hard substrate, preferably with an irregular surface, on which to grow. In various areas this may consist of calcretized Cretaceous chalk (Toolonga Calcilutite).

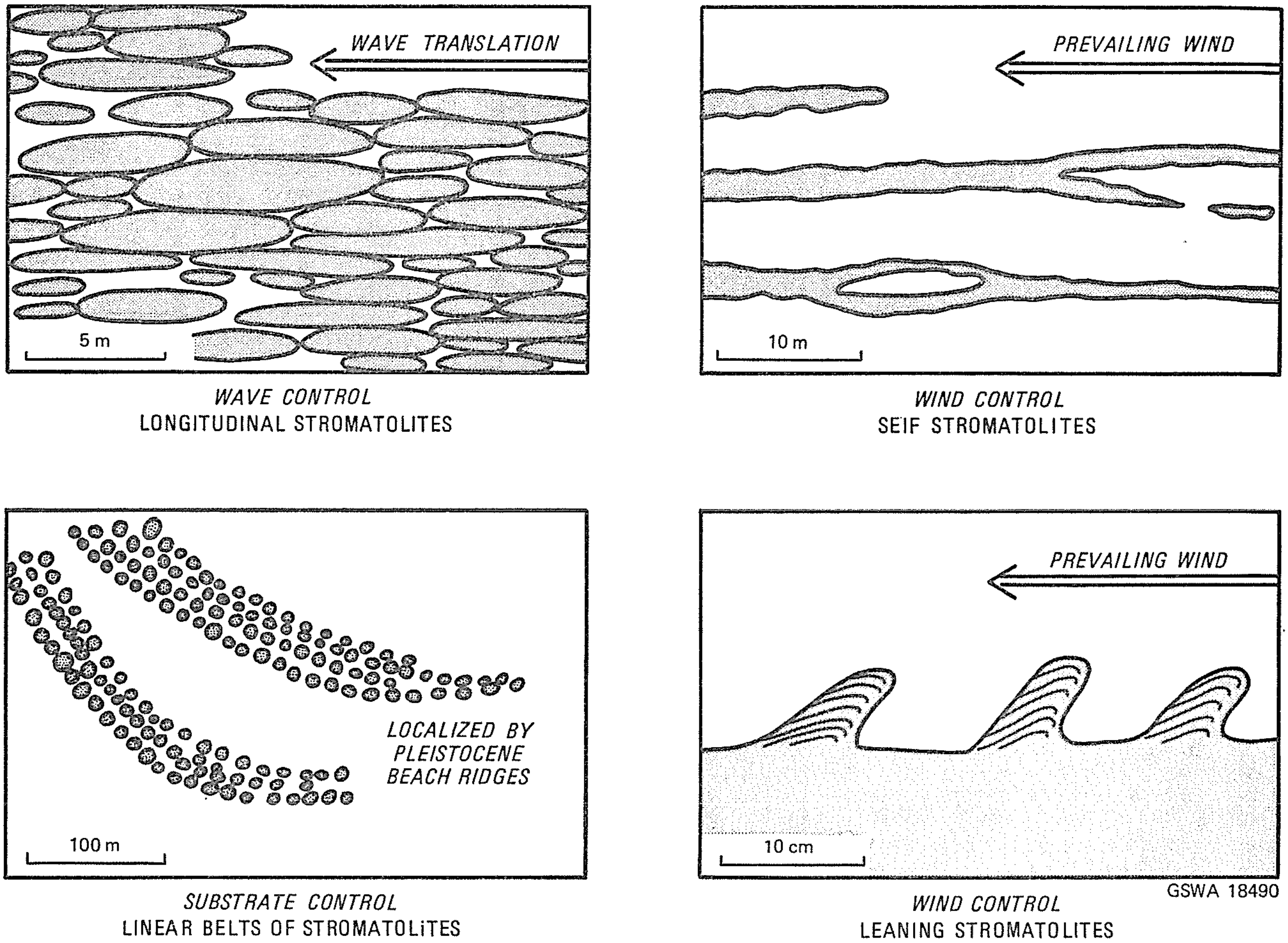


Figure 3 Diagram illustrating some environmental controls on stromatolite morphology at Hamelin Pool.

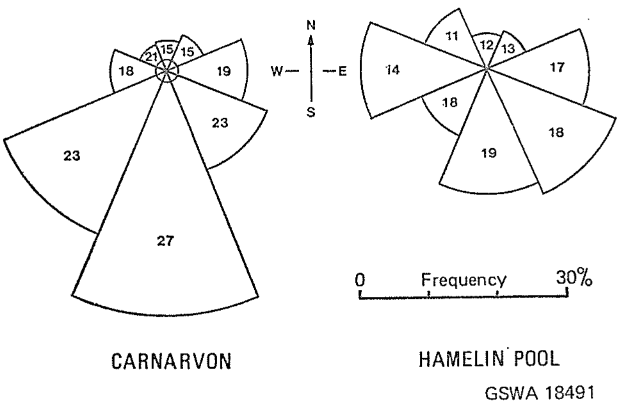


Figure 4 Annual wind-rose diagrams for Carnarvon and Hamelin Pool weather station. Figures show average wind velocities (kilometres per hour). The circle in the centre of the wind rose for Carnarvon illustrates the percentage of calms (1·5%). Calms at Hamelin Pool weather station average 0·2%.

Tertiary quartzite (Lamont Sandstone), and calcretized or otherwise indurated Late Pleistocene beach ridges or marine limestone (Bibra Limestone). Stromatolites are commonly best developed around headlands rather than in front of bays, because the headlands are localized by rocky outcrops which form a suitable substrate on which stromatolites can grow. Small closely spaced headlands, with associated stromatolites, on the east side of Hamelin Pool are localized by Tertiary quartzite (Lamont Sandstone), while the more widely spaced headlands on the west side are generally controlled by indurated Pleistocene beach ridges.

However, rocky substrates also occur just below the modern sediments and on contemporary hardgrounds in front of some bays, and in such cases stromatolites develop there also. Where there is no rocky substrate flat algal mats tend to develop rather than columnar stromatolites.

Curvilinear stromatolite reefs, often subparallel to the modern shorelines, are conspicuous features of the shallow sublittoral platform in many areas (Fig. 11). The reefs are localized by successive beach ridges of the Late Pleistocene Bibra Limestone, which have acted as foundations for stromatolite growth. Each reef may consist of many parallel lines of stromatolites (Fig. 11C, D), in some cases meeting at angles in the form of giant "cross bedding". These lines of stromatolites are controlled by indurated beds in the underlying Pleistocene beach ridges, which stood up as linear features on the sea floor when the stromatolites began growing.

There are many examples of such reefs controlled by Bibra Limestone beach ridges around the shore of Hamelin Pool, conspicuous examples being 21 km north of Booldah Well (Fig. 11A), 10 km north-northeast of Yaringa Point (Figs. 7, 11B–D), and 1 km north of Flagpole Landing.

Another form of substrate control on stromatolite morphology at Hamelin Pool is that resulting from eroded calcrete-rimmed solution pipes in the Cretaceous Toolonga Calcilutite (van de Graaff and others, in press). These solution pipes extend downwards for several metres below the calcreted Pleistocene land surface on top of the formation. They are filled with cemented rubbly soil and are rimmed by strongly indurated calcrete, in turn surrounded by soft chalky calcilutite. Consequently, where the Toolonga Calcilutite is truncated by marine erosion on tidal flats, the solution pipes are differentially eroded out as circular mounds (Fig. 10C). These have been overgrown in some areas by stromatolite-building algal mats to form conspicuous domal stromatolites, circular in plan, which are considerably larger than any other stromatolites in the area (Fig. 10D).

CONCLUSIONS

Environmental factors exert a major influence on the morphology and distribution of modern stromatolites at Hamelin Pool. Living stromatolites extend from the intertidal zone to depths of 3·5 m or more on the sublittoral platform, and their shapes and trends are largely controlled by the wave-translation direction, prevailing wind direction, and nature of the substrate. It is suggested that each of these environmental factors may have relevance in interpreting the environment of deposition of ancient stromatolites.

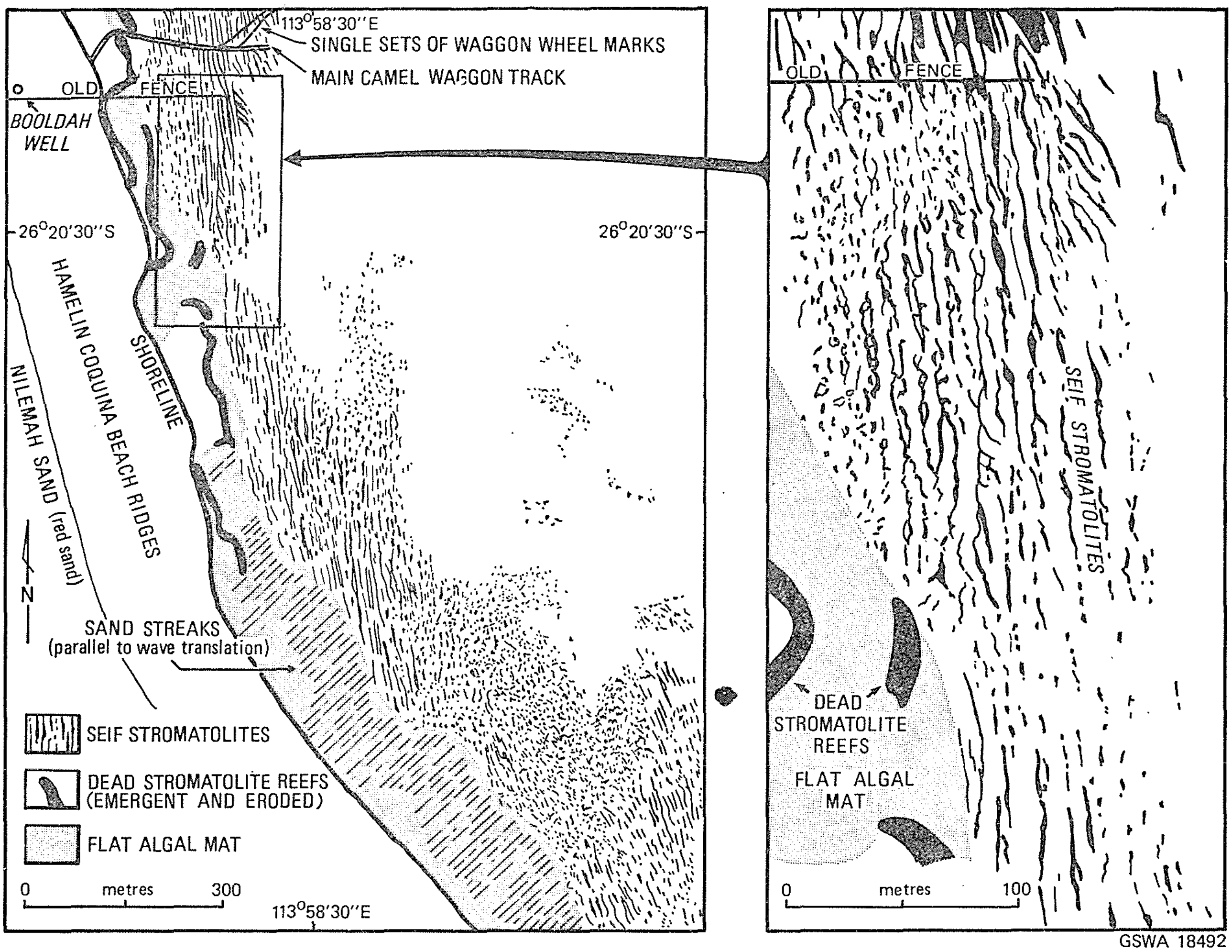


Figure 5 Maps illustrating distribution of seif stromatolites near Booldah Well, on the west side of Hamelin Pool.

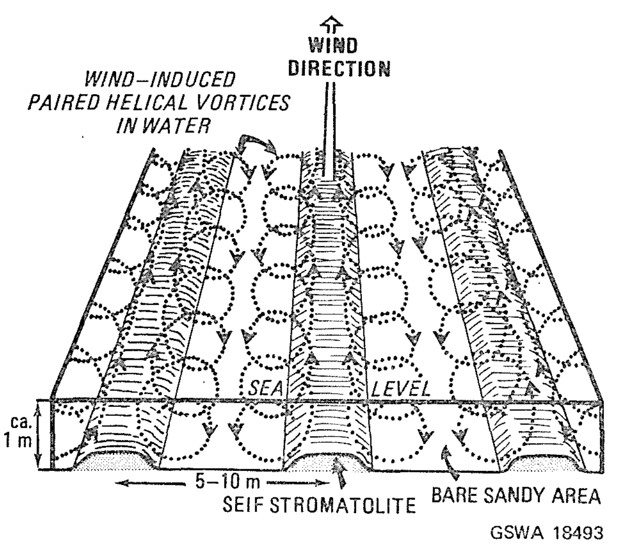


Figure 6 Diagram illustrating hypothetical control of seif stromatolites by wind-induced paired helical vortices (Langmuir circulation) in water.

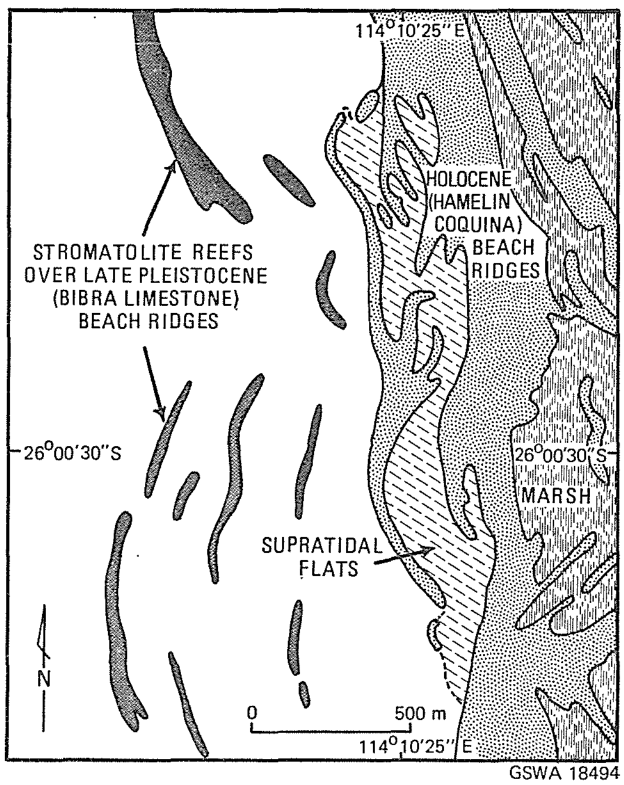


Figure 7 Map of area 10 km north-northeast of Yaringa Point showing stromatolite reefs localized by Late Pleistocene (Bibra Limestone) beach ridges.

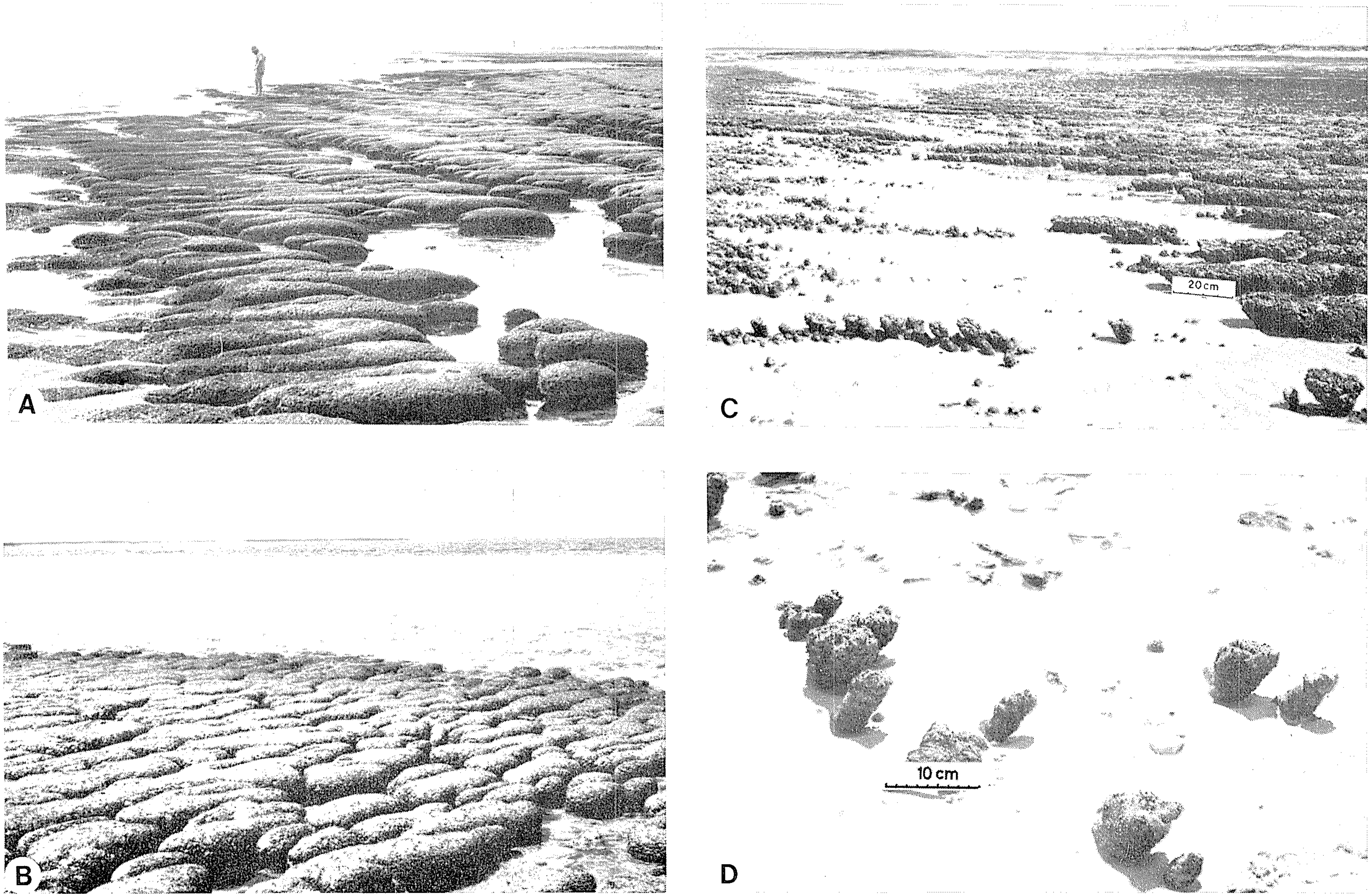


Figure 8

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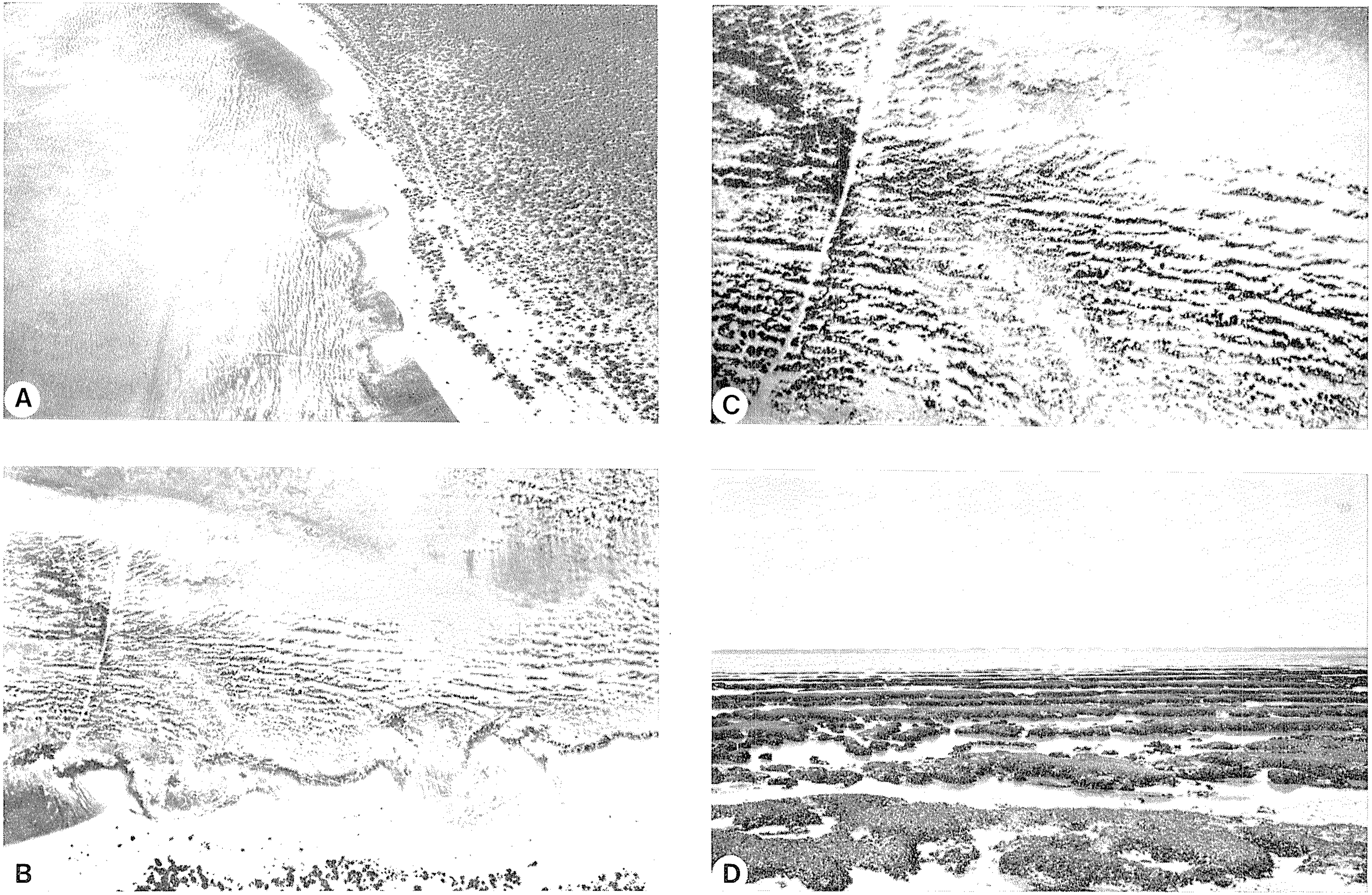

Figure 9

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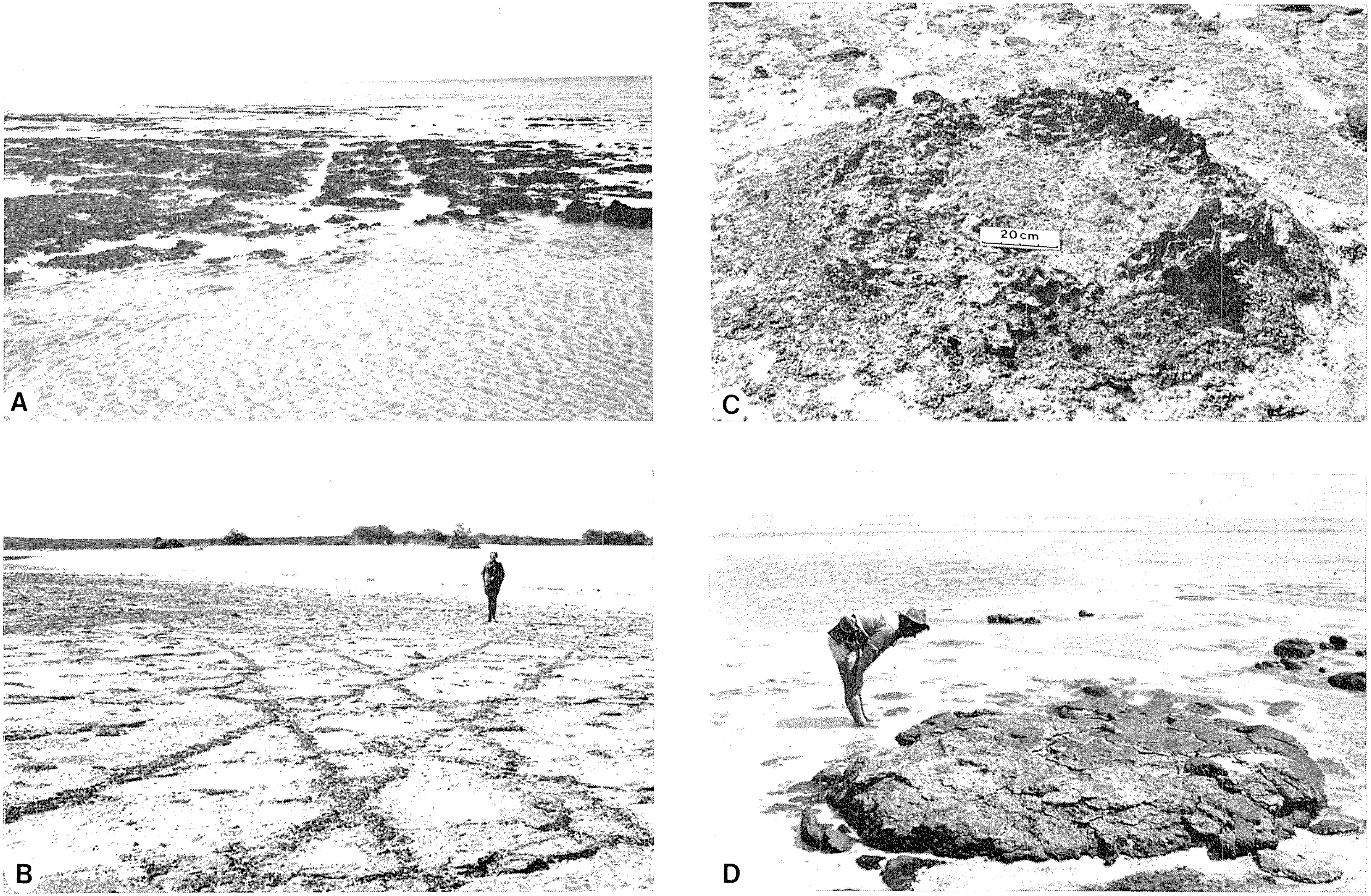

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Figure 10

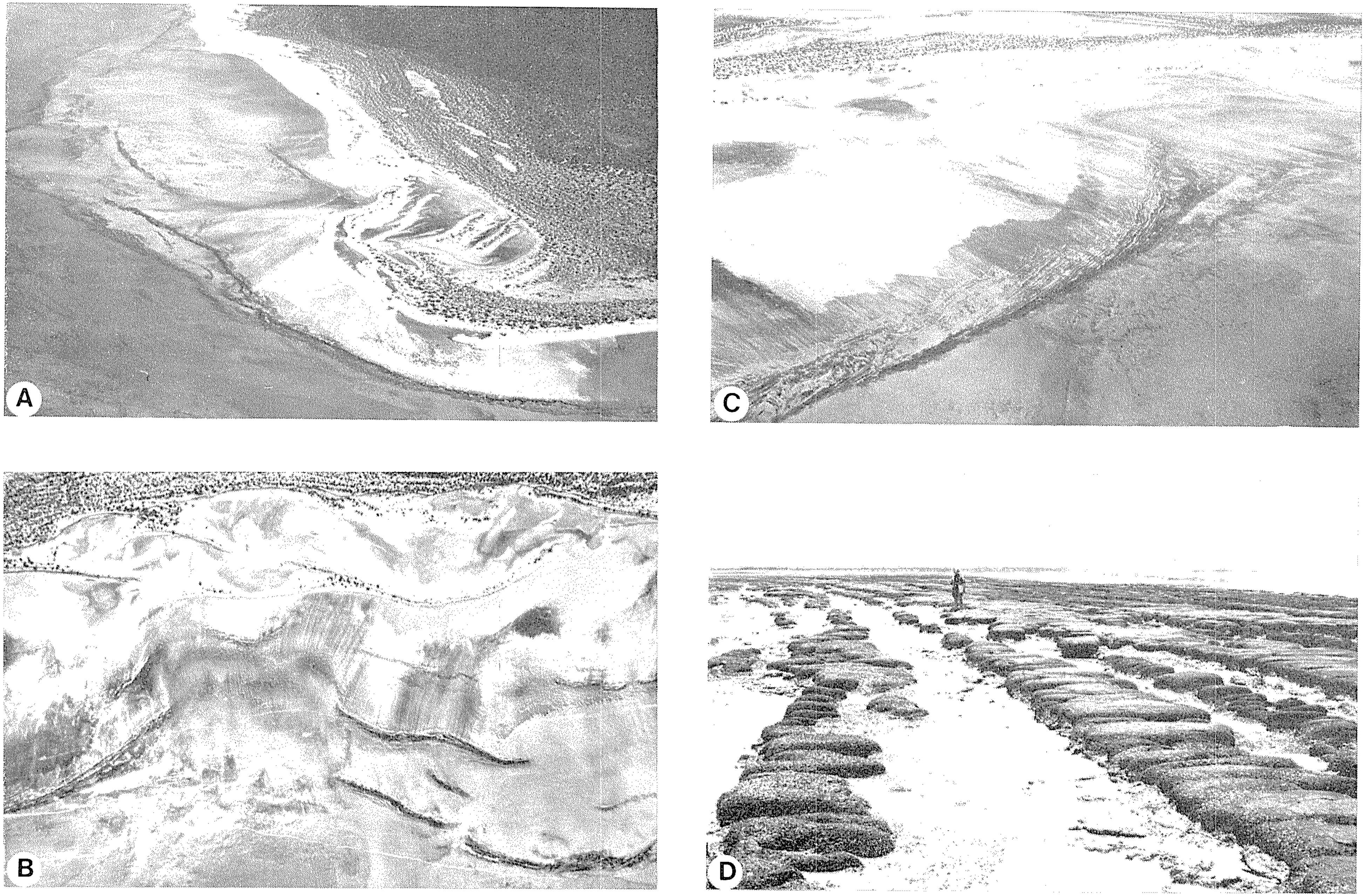

Figure 11

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Figure 8 (A) Stromatolites elongate in the direction of wave translation, 4 km south of Yaringa Point. The stromatolites occur in belts controlled by Late Pleistocene beach ridges.
(B) Stromatolites elongate in the direction of wave translation, 150 m south of Carbla Point.
(C) Inclined stromatolites 1 km southeast of Carbla Point. They occur in lines parallel to the direction of wave translation, but individual stromatolites are inclined steeply to the south, towards the prevailing winds.
(D) Closer view of inclined stromatolites 1 km southeast of Carbla Point.

Figure 9 (A) Oblique aerial view looking south near Booldah Well, showing seif stromatolites aligned nearly north-south, parallel to the prevailing southerly winds. A camel-waggon track through the stromatolites, last used more than 40 years ago, is visible in the foreground. The photo covers essentially the same area as is shown in Figure 5.
(B) Vertical air photo (north to the left) of seif stromatolites near Booldah Well, covering part of the area shown in the foreground of photo A. Note the "tuning fork" junctions opening to the south (towards the prevailing winds) and the dead stromatolite reefs adjoining the shoreline.
(C) Vertical air photo showing more detail of the seif stromatolites near Booldah Well (north to the left). Note single sets of waggon wheel marks diverting to the left of the main track (see also Figure 10 (A)).
(D) Seif stromatolites exposed at very low tide near Booldah Well. This photo was taken at about the centre of the area shown in photo B.

Figure 10 (A) Single set of camel-waggon wheel marks cutting through seif stromatolites off the main waggon track (in the foreground) near Booldah Well. These wheel marks, made more than 40 years ago, illustrate the fragility and slow growth rates of these stromatolites. Photo taken at extremely low tide.
(B) Camel-waggon wheel marks on indurated flat algal-mat limestones near Booldah Well. The wheel marks are filled with living pustular mat.
(C) Calcrete-rimmed solution pipe, filled with indurated rubbly soil, cutting through soft chalk of the Toolonga Calcilutite, 1·5 km northeast of Flagpole Landing. The resistant pipe forms a low mound on the intertidal flat, and similar pipes have formed foundations for large domal stromatolites (see photo D).
(D) Domal stromatolite, near Flagpole Landing, which has grown over an indurated solution pipe of the type shown in photo C.

Figure 11 (A) Oblique aerial view looking southwest, 21 km north of Booldah Well, showing stromatolite reefs (dark bands in the left and lower parts of the photo) controlled by underlying Late Pleistocene beach ridges. Successive modern beach ridges are seen on the right, behind the present shoreline.
(B) Vertical air photo (north on the left) of the area 10 km north-northeast of Yaringa Point, showing stromatolite reefs (dark bands in the central and lower parts of the photo) controlled by Late Pleistocene beach ridges, and backed by modern beach ridges.
(C) Oblique aerial view looking southeast over the area 10 km north-northeast of Yaringa Point showing a stromatolite reef (in the foreground) which has grown over Late Pleistocene beach-ridge deposits. Lines of stromatolites follow resistant bedding in the beach ridges (see also Photo D). This reef is the same as that shown in the lower left of photo B.
(D) Lines of stromatolites which have grown on resistant beds in underlying Late Pleistocene beach ridges. This is part of the stromatolite reef depicted in photo C. The elongation of individual stromatolites is parallel to the direction of wave translation.

REFERENCES

Bauld, J., Chambers, L. A., and Skyring, G. W., 1979, Primary productivity, sulfate reduction, and sulfur isotope fractionation in algal mats and sediments of Hamelin Pool, Shark Bay, W.A.: Australian Jour. Marine and Freshwater Research, v. 30, p. 753–764.

Butcher, B. P., van de Graaff, W. J. E., and Hocking, R. M., in prep., Shark Bay—Edel, Western Australia: West. Australia Geol. Survey 1:250 000 Geol. Series Explanatory Notes.

Crowe, R. W. A., 1975, The classification, genesis and evolution of sand dunes in the Great Sandy Desert: West. Australia Geol. Survey Ann. Rept 1974, p. 46–49.

Golubic, S., 1976, Organisms that build stromatolites, *in* Walter, M. R. (ed.), Developments in sedimentology, 20, Stromatolites: Elsevier, Amsterdam, p. 113–126.

Hoffman, P., 1976, Stromatolite morphogenesis in Shark Bay, Western Australia, *in* Walter, M. R. (ed.), Developments in sedimentology, 20 Stromatolites: Elsevier, Amsterdam, p. 261–271.

Logan, B. W., 1961, *Cryptozoon* and associate stromatolites from the Recent of Shark Bay, Western Australia: Jour. Geology, v. 69, p. 517–533.

Logan, B. W., Davies, G. R., Read, J. F., and Cebulski, D. E., 1970, Carbonate sedimentation and environments, Shark Bay, Western Australia: Amer. Assoc. Petroleum Geologists, Mem. 13, 223 p.

Logan, B. W., Hoffman, P., and Gebelein, C. D., 1974, Algal mats, cryptalgal fabrics and structures, Hamelin Pool, Western Australia: Amer. Assoc. Petroleum Geologists, Mem. 22, p. 140–194.

Logan, B. W., Rezak, R., and Ginsburg, R. N., 1964, Classification and environmental significance of stromatolites: Jour. Geology, v. 72, p. 68–83.

Monty, C. L. V., 1976, The origin and development of cryptalgal fabrics, *in* Walter, M. R. (ed.), Developments in sedimentology, 20, Stromatolites: Elsevier, Amsterdam, p. 193–259.

Playford, P. E., 1979. Stromatolite research in Western Australia, *in* Cockbain, A. E. (ed.), Aspects of science in Western Australia 1829–1979: Royal Soc. West. Australia Jour., v. 62, p. 13–20.

Playford, P. E., and Cockbain, A. E., 1976, Modern algal stromatolites at Hamelin Pool, a hypersaline barred basin in Shark Bay, Western Australia, *in* Walter, M. R. (ed.), Developments in sedimentology, 20, Stromatolites: Elsevier, Amsterdam, p. 389–411.

Van de Graaff, W. J. E., Hocking, R. M., and Butcher, B. P., in prep., Yaringa, Western Australia: West. Australia Geol. Survey 1:250 000 Geol. Series Explanatory Notes.

CLASTIC DYKES NEAR THE SOUTH COAST OF WESTERN AUSTRALIA

by R. Thom

ABSTRACT

Several clastic dyke occurrences near the south coast of Western Australia are described or reviewed, and comments are given on their possible age, mechanism of formation, and significance.

All dykes are composed of feldspathic wacke, are similar in appearance, and are considered to be of the one age. Lithologically they contrast with the nearby Mount Barren and Stirling Range Beds, from which they are probably partly derived. Field relationships suggest that the clastic dykes post-date the 1 200–1 300 m.y. tectonothermal event in the Albany-Fraser Province, and the emplacement of adamellite 1 100 m.y. ago. The dykes are considered to be due to the downward injection of water-saturated sediment, possibly during ancient seismic activity.

INTRODUCTION

Clastic dykes within Precambrian crystalline rocks have been reported or described at several localities (Fig. 1) in the southwest of Western Australia: at Ravensthorpe (Woodward, 1909), Dillon Bay (Clarke and others, 1954), Watheroo (Logan, 1958), Billeranga Hills (Arriens and Lalor, 1959), and Albany and Wagin (Kay, 1974). During recent geological mapping several clastic dykes were discovered near Warriup Hill and Cape Riche, and similar sedimentary material was found as boulders of uncertain significance near Denmark (J. S. Moncrieff, pers. comm.) and near Katanning (P. C. Muhling, pers. comm.). This article describes the occurrences at Warriup Hill, Cape Riche and Wagin; reviews the occurrences at Ravensthorpe, Dillon Bay and Albany; and comments on the possible age, mechanism of formation, and significance of the dykes.

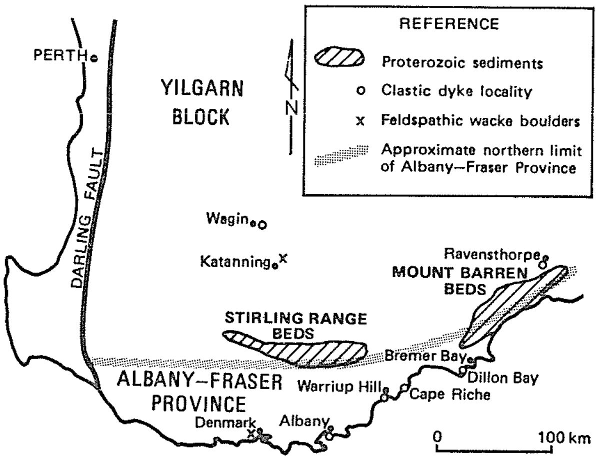

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Figure 1 Location of clastic dykes.

DYKE OCCURRENCES

RAVENSTHORPE

The earliest known reference to clastic dykes in Western Australia is the following description by Woodward (1909, p. 15) of ferruginous sandstone occurring within the Ravensthorpe Quartz Diorite:

> "Near the Explosives Reserve one of these small outliers occupies so peculiar a position that at one time considerable doubt existed as to its origin since in its general character it presents a striking resemblance to a dyke; however upon a careful microscopic examination of the rock it proves to be a ferruginous sandstone, and therefore must have resulted from the infilling of an open fissure with sand from the surface."

This locality has not been re-examined, but the original thin section shows that the sandstone, which has a ferruginous cement, consists of small (0·02–0·4 mm) subrounded quartz grains, larger (0·3–0·8 mm) rounded quartz grains, including some with worn overgrowths, and a small proportion of feldspar. Most of the lithic clasts are of quartzite. This rock closely resembles the other feldspathic wacke dykes of the south coast (Table 1).

DILLON BAY

Clarke and others (1954) noted a sandstone dyke 15 inches (about 0·4 m) wide, on the west side of Dillon Bay, near Bremer Bay (the width was originally published incorrectly as 15 feet (about 4·5 m) wide). This dyke, which is subvertical and trends 350°, clearly cross-cuts the west-southwest gneissosity of the crystalline basement. The dyke lies within the wave-splash zone, and a carbonate crust obscures features such as the presence, type and distribution of larger clasts within the dyke. Samples collected from the dyke indicate that it is a feldspathic wacke with lithic clasts, comparable to the other dykes along the south coast.

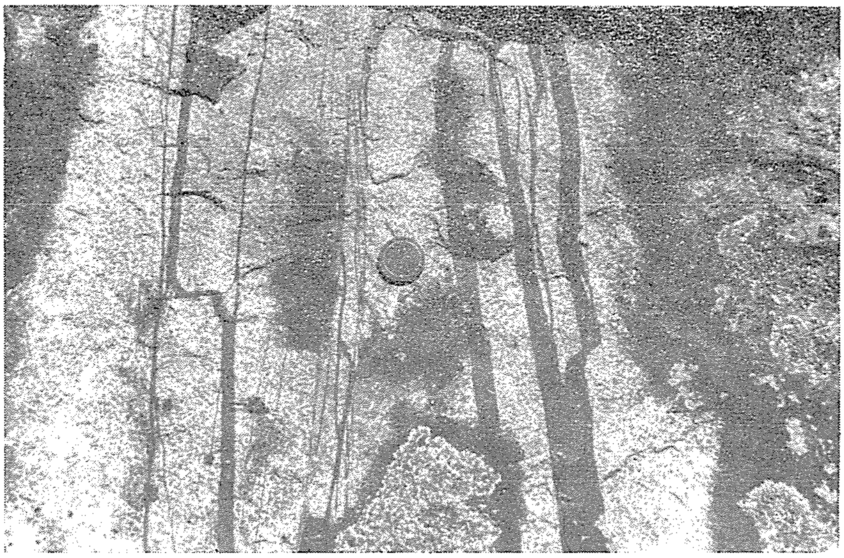
ALBANY

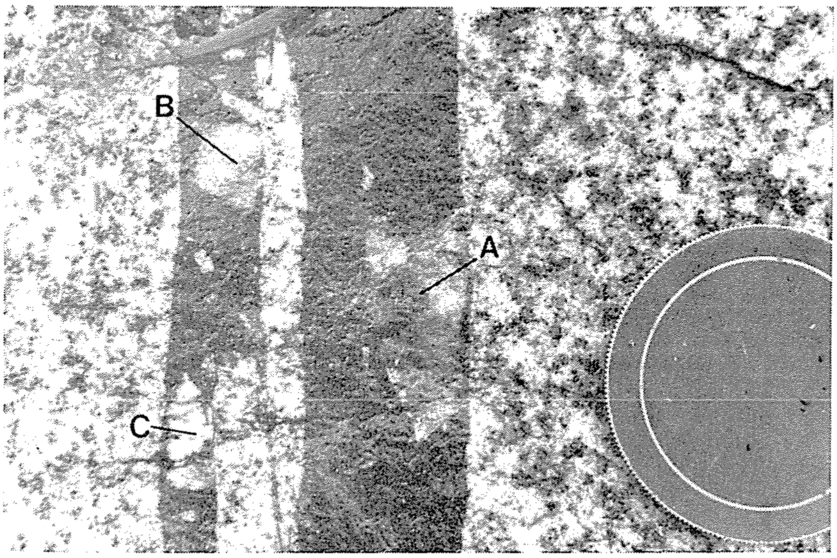
Four well-lithified feldspathic wacke dykes at Albany have been described by Kay (1974), who observed that they simulate igneous intrusives. The subvertical dykes, which trend at

TABLE 1. COMPARISON OF FELDSPATHIC WACKES

	G.S.W.A. thin Section No.	Modal %				Type of lithic clast	Approximate grain size and roundness†				Sorting
		Qtz	Felds.	Matrix*	Lithic clasts		Quartz		Lithic clasts		
							mm		mm		
ALBANY	41589 41590	51 58	11 8	25 23	13 11	Mainly quartzite	0·1–1·5	(R)	> 0·5	(A)–(R)	Poor
CAPE RICHE	41585A 41585B 41586 41587 41588	40 36 34 49 40	13 19 22 14 13	24 23 19 15 15	23 22 25 22 32	Quartzite; mylonite; chert‡; minor phyllite, granitoid and schist	0·1–1·5	(A)	> 0·5	(A)	Poor
WARRIUP HILL	55274 41576	45 31	17 10	18 14	19 45	Quartzite; chert; minor schist and phyllite	0·1–1·5	(A)	> 0·5	(A)	Poor
DILLON BAY	41582 41583	55 59	12 14	9 9	24 18	Quartzite; mylonite; chert	0·1–1·5	(A)–(R)	> 0·5	(R)	Poor
DENMARK	48144A 48144B	46 48	14 12	16 20	24 20	Quartzite; minor schist	0·1–1·5	(A)	> 0·5	(A)	Poor
RAVENSTHORPE	909	62	5	25	8	Mainly quartzite	0·02–0·4 0·3–0·8 (bimodal)	(A)–(R) R	> 0·5	R	Poor
PUNTAPIN ROCK	41579 41580 41581	62 61 58	2 6 4	28 25 28	8 8 10	Quartzite; chert; quartz arenite; minor phyllite and granitoid	0·1–0·2 0·5–1·5 (bimodal)	(A)–(R) R	> 0·5	(R)–R	Poor

* Now mainly fine-grained phyllosilicates
† (A): Subangular, (R): Subrounded, R: Rounded
‡ Including jasper





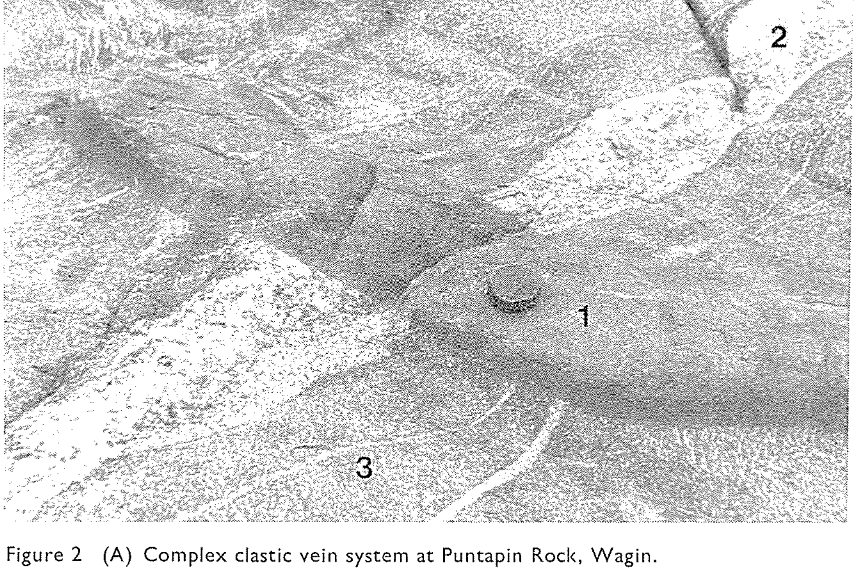


Figure 2 (A) Complex clastic vein system at Puntapin Rock, Wagin.
(B) Clasts of granitoid (A), quartzite (B) and feldspar (C) within narrow vein of feldspathic wacke, Puntapin Rock, Wagin.
(C) Feldspathic wacke dyke (1) cuts across pegmatite vein (2) and foliated hornblende-biotite granodiorite country rock (3). Headland southwest of Warriup Hill.

about 300°, distinctly cross-cut the west-southwest-trending foliation of the gneiss, and include fragments of country rock. Three of the dykes are less than 0·1 m wide and the largest is about 1 m wide.

The composition of the dyke rock is shown in Table 1. The matrix, which forms about 25% of the rock, now consists mainly of chlorite, biotite, muscovite and limonite, and Kay suggested that the predominance of chlorite in the matrix of the narrower dykes gives them their greyish-green colour, whereas the dark, purplish-brown colour of the widest dyke is due to the predominance of limonite and muscovite in the matrix. Kay considered the alteration of the original clay matrix to phyllosilicates and limonite to be authigenic, but he did not exclude the possibility of slight metamorphism. He also considered, from the presence of secondary mica and the degree of lithification, that the dykes may be of considerable age, but he knew of no comparable sediments in the Albany area.

WAGIN—PUNTAPIN ROCK

Puntapin Rock is a partially recrystallized Archaean adamellite, largely homogeneous, but with some deformed leucocratic veining. The strong northwest-trending foliation is cut by an easterly trending clastic intrusion, which has the form of a narrow, braided vein system in three offset lengths exposed over a total length of about 600 m. The width of individual sedimentary veins ranges from a few millimetres to a few tens of millimetres, and the zone of anastomosing veins is commonly about 0·2 or 0·3 m across (Fig. 2A). The sedimentary intrusion post-dates narrow, quartz-filled cross-fractures. Each of the three offset vein systems peters out into straight, parallel veins only a few millimetres wide.

For most of its length, the clastic infilling is fine grained, with random distribution of mesoscopic lithic clasts. In places, clasts up to 10 mm across occur in groups extending across the width of the dyke and laterally for 100 mm or more. Elsewhere, single clasts may occupy the entire width of narrow veins (Fig. 2B), but over much of the dyke mesoscopic clasts are absent. Most clasts are of jasper, chert or quartzite, and there are rare angular fragments of country-rock gneiss.

Lithologically the rock is a fine-grained poorly sorted wacke (Table 1), with quartz grains in two sizes; nearly 50% of the rock is fine-grained quartz (0·1–0·2 mm), and 5–15% of the rock is quartz in the 0·5–1·5 mm range. Lithic clasts are common in the 0·5–1·5 mm range, but may be even larger, up to about 20 mm.

WARRIUP HILL

A zone of clastic dykes occurs within Proterozoic gneiss and granite forming the coastal headland southwest of Warriup Hill (Fig. 1). The dykes trend at about 250°, with a northerly dip of about 45°. Branching and offsetting of these sedimentary intrusions makes their exact number difficult to determine, but there are at least six different dyke portions, each with a width greater than 150 mm (Fig. 2C). The widest dyke, which reaches 600 mm across, is also the longest, being exposed for over 200 m before passing below sea level on each side of the headland. Other dykes peter out at one or both ends within the headland, such that as one dyke dies out another begins some metres to the north or south. This offset arrangement, which may be either sinistral or dextral, is not fault displacement, as the dykes end in narrow, parallel dykelets or in zig-zag stringers (Fig. 3A) rather than abrupt truncations. Although the fissures that now contain the dykes may have been generated immediately prior to infilling (see section on mechanism of formation), some fractures in the country rock were pre-existing; one dyke abruptly changes course along an older cross-fracture for 1·5 m before resuming its overall trend (Fig. 3B).

The dykes are undeformed. Except at their extremities, dykes tend to maintain uniform widths, and although some dykes are sinuous, they are not considered to be folded.

Subrounded pebbles of jasper, quartzite, quartz, feldspar, chert and jaspilite, commonly up to 10 mm across, are prominent throughout the length of the dykes. Clasts tend to concentrate towards the middle of some dykes so that margins appear relatively fine grained. The dykes contain a few angular clasts which were apparently derived from the adjacent gneiss. Lithologically the dyke rock is a well-lithified, poorly sorted feldspathic wacke (Table 1). Muscovite, sericite, epidote, sphene, tourmaline and fluorite occur in small amounts, and iron oxide occurs as detrital grains and as a local cement. Dykelets and stringers owe their pale-greenish colour to the abundance of epidote, whereas the dark purplish-brown dykes have less epidote and more iron oxide. The presence of epidote and sericite indicates that the dykes, if not merely altered, are only mildly metamorphosed. The muscovite flakes are detrital, and have been deformed during compaction of the rock.

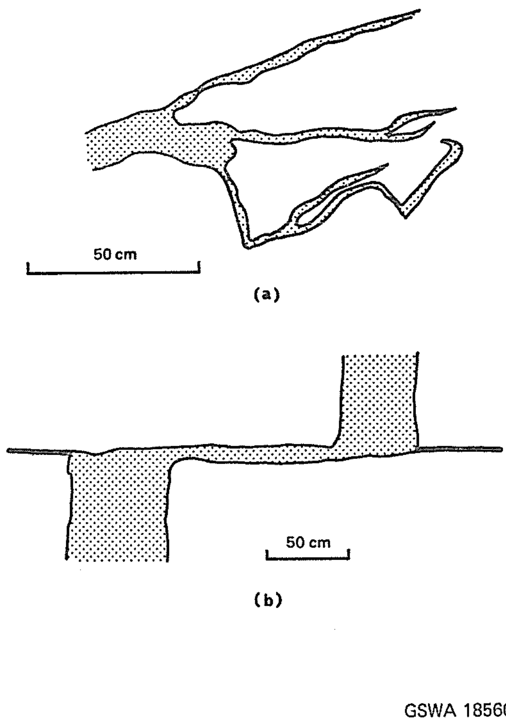


Figure 3 (a) Sketch of clastic dyke passing into narrow zig-zag stringers at its termination. Warriup Hill locality.
(b) Clastic dyke changes direction along a pre-existing fracture (heavy black line) before resuming its overall trend. Warriup Hill locality.

CAPE RICHE

There are two adjacent clastic dyke occurrences near Cape Riche, both within deformed Proterozoic gneiss.

At the easternmost locality, feldspathic wacke occurs in two or three subparallel dykes trending 225°, dipping 75°SE, and exposed over about 20 m. The widest dykes, up to 150 mm across, are pinkish brown in colour and have straight, sharp margins. Narrower dykes, up to a few tens of millimetres across, are dark-greenish in colour and tend to anastomose.

At the other locality, a single dyke 650 mm wide, trending 240° and dipping 75°SE, is exposed over a distance of 55 m. In the middle of the dyke is a faint but distinct banding, probably due to flow, in which there is relative depletion of matrix in planes parallel to the dyke margin. There is also a dimensional preferred orientation of elongate quartz grains parallel to this direction. Near the contact the host gneiss is pinkish in colour and is no doubt the source of the fragments of pink gneiss within the clastic dyke. Few of these elongate clasts are oriented parallel to the dyke margins.

OTHER LOCALITIES OF FELDSPATHIC WACKE

Several boulders and a possible *in situ* exposure of feldspathic wacke were discovered in a gravel pit west of Denmark (J. S. Moncrieff, pers. comm.). It is not known whether the boulders represent clastic dykes or stratified sediment, but in the absence of evidence for considerable transportation they are assumed to be of local origin. In appearance and composition (Table 1) these boulders resemble the feldspathic wacke of the south coastal dykes.

A single boulder of feldspathic wacke was found in a boulder deposit, near Katanning (P. C. Muhling, pers. comm.). In view of the uncertainty of its origin, this boulder is not considered further here.

AGE OF THE CLASTIC DYKES

An approximate maximum age can be deduced for the dykes on the basis of local and regional geology. This is particularly so for the Warriup Hill locality, where there are three main types of country rock:

(a) *Gneiss, including augen gneiss and banded granodiorite gneiss.* These have been recrystallized, perhaps to upper amphibolite or granulite facies, and have undergone multiple deformation. Isoclines of variable orientation have been overprinted by smaller penetrative cross-folds plunging consistently to the southwest. These two groups of folds are considered to be Proterozoic on two grounds:

(i) They have been tentatively correlated with particular fold generations recognized in the Mount Barren Beds, which is considered to be a Middle Proterozoic succession.

(ii) The folds and the present metamorphic grade of the gneisses are believed to be products of the tectonothermal event throughout the Albany-Fraser Province which reset the ages of the gneisses at 1 200–1 300 m.y. (Wilson and others, 1960; Compston and Arriens, 1968; Arriens and Lambert, 1969; Bunting and others, 1976).

(b) *Hornblende-biotite granodiorite*. Although this rock has been partially recrystallized and has a prominent foliation, it is evidently a younger rock than the gneisses. It lacks gneissosity and polyphase folding, and cuts across the gneissosity and folds of the banded gneiss. On both these grounds it can be concluded that the granodiorite post-dates the main tectonothermal event, although the foliation and recrystallization may represent the waning stages of Proterozoic metamorphism put at about 1 100 to 1 150 m.y. (Stephenson and others, 1977). The clastic dykes are located mainly within this hornblende-biotite granodiorite.

(c) *Porphyritic adamellite*. Several varieties may be distinguished on the basis of biotite and phenocryst abundance, and on field relationships, but all varieties are characterized by mild deformation and metamorphism. The porphyritic adamellites cross-cut folds and other structures related to the main tectonothermal event. These porphyritic adamellites resemble the Albany Adamellite, which has been dated at 1 100 $\pm$ 50 m.y. (Turek and Stephenson, 1966), and they have been grouped with the same episode of magma emplacement (Stephenson and others, 1977). The porphyritic adamellites at Warriup Hill may be slightly older than those at Albany, as they show some deformation.

The clastic dykes cut the folds in the gneisses, intrude the hornblende-biotite granodiorite and cut veins emanating from the porphyritic adamellites. Moreover, as the dykes themselves are unaffected by the deformation that affected the granites, they are likely to be younger than 1 100–1 200 m.y.

Similarly, at Dillon Bay, Albany and Cape Riche clastic dykes cut deformed gneisses, and the dykes themselves, which lie well within the Albany-Fraser Province, post-date all the penetrative deformation and metamorphism. The clastic dykes at Puntapin Rock are unmetamorphosed, but this does not prove a maximum age of 1 200–1 300 m.y., as they are too far north to be affected by Proterozoic metamorphism centred on the Albany-Fraser Province. The dykes at Puntapin Rock cut nothing younger than Archaean.

RELATIONSHIP TO ADJACENT PROTEROZOIC SUCCESSIONS

Although most of the clastic dykes occur in the vicinity of the Mount Barren and Stirling Range Beds (Fig. 1), correlation of the material filling the dykes with these units is discounted because:

(a) The dykes are feldspathic, whereas the Mount Barren and Stirling Range Beds are without feldspar.

(b) The Mount Barren Beds exhibit a strong metamorphic gradient towards the south coast, whereas the dykes, which are only slightly metamorphosed, show no detectable variation in metamorphic grade over a wider geographical area.

(c) The Mount Barren and Stirling Range Beds are considered to be at least 1 300–1 400 m.y. old (Turek and Stephenson, 1966; Thom, 1977), whereas the deduced maximum age of the dykes is about 1 100 m.y.

(d) Lithic clasts within the dykes may be tentatively identified with particular lithologies in the Mount Barren and Stirling Range Beds. For example, most lithic clasts are of quartzite with highly sutured grains and mylonitic fabrics typical of quartzites in the Mount Barren Beds. The ubiquitous jasper may derive from jasper concretions within dolomite in the Mount Barren Beds. One dyke contains rounded clasts of pinkish-brown shale similar to shale near the base of the Stirling Range Beds. In some dykes quartz tends towards a bimodal size distribution; the larger quartz grains seem to have inherited some of their roundness and sphericity, and the presence of occasional worn overgrowths supports the view that these larger grains derive from pre-existing arenite. It seems likely that the Mount Barren and Stirling Range Beds were sources of detritus for the dyke sediment.

MECHANISM OF FORMATION

The clastic dykes described in this article occur within fractures in crystalline basement, and it is clear that the fractures were infilled from an overlying source of detritus. Two kinds of clastic dyke must be considered here:

(a) Clastic dykes which result from the gradual infill, grain by grain, under the influence of gravity, of pre-existing open fractures.

(b) Clastic dykes which result from the downward injection of overlying sediment and which, therefore, have the same composition as their parent sediment. The commonest mechanism invoked for this type involves momentary liquefaction of overlying water-saturated sand by earthquake shock, followed by downward forceful injection into fissures opened by the shock. The driving force for injection is the pressure of the overlying strata (Potter and Pettijohn, 1963). Dykes of this type are here called injection dykes.

The clastic dykes at Watheroo (Logan, 1958) and at Billeranga Hills (Arriens and Lalor, 1959) were proposed as injection dykes, because in both cases the dykes lack the stratification expected from the gradual infill of open joints, and because the lithology of the dykes closely resembles particular units in the local Proterozoic successions. In both cases the mechanism proposed is that of seismically induced basement fissuring followed by downward injection of water-saturated sediment, and Logan suggested that in the case of the Watheroo dykes the seismic activity may be related to the Darling Fault.

The clastic dykes near the south coast are also considered to be injection dykes. They lack horizontal stratification and show evidence of intrusion or flow, and they occupy dynamically produced brittle fractures. The zig-zag terminations of the dykes at Warriup Hill seem consistent with seismically induced brittle fractures, or possibly with propagation of fractures during forceful injection of overlying water-saturated sediment in a lateral and downward direction. The infilled anastomosing fracture at Puntapin Rock was clearly not a joint, but a complex fracture zone. Other evidence of flowage includes:

(a) the tendency for pebbles to be concentrated near the middle of some dykes, which is probably the result of wall-effect during flow;

(b) the presence of alternating matrix-enriched and matrix-depleted layering parallel to dyke margins, which is probably flow-banding; and

(c) the presence in some dykes of a dimensional preferred orientation of elongate quartz grains parallel to dyke margins.

It seems unlikely that the seismicity invoked to produce the dykes along the south coast would have been related to the Darling Fault.

CONCLUSIONS

The clastic dykes near the south coast of Western Australia are similar in appearance and composition and are thought to be of the one age. Their feldspar content and immaturity distinguish them from the Mount Barren and Stirling Range Beds, and there is some petrographic evidence that they are partly derived from these successions. On limited geochronological, structural and metamorphic grounds they have a maximum age of about 1 100 m.y.

The formation of injected sedimentary dykes of this type seems to require the presence of overlying water-saturated sediments during seismically induced basement fissuring. If the dykes near the south coast are of the one age, this seems to imply the former existence of overlying, stratified feldspathic wacke at least as extensive as the present distribution of the clastic dykes. This hypothetical sediment would be younger than the Mount Barren and Stirling Range Beds, with a maximum age of about 1 100 m.y., and with little deformation or metamorphism. The seismic activity which led to the formation of the dykes seems unlikely to have been related to the Darling Fault, as was suggested for the Watheroo dykes (Logan, 1958), but could have been related to some fault bounding the Albany-Fraser Province. Alternatively, it is interesting to note that the known clastic dyke localities in the southwest of Western Australia are within or adjoining the South West Seismic Zone (Doyle, 1971; Gordon, 1972), which may follow a crustal weakness already present in the Proterozoic.

REFERENCES

Arriens, P. A., and Lalor, J. H., 1959, The geology of the Billeranga Hills, Western Australia: Univ. West. Australia Hons thesis (unpublished).

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. Australia Special Publication 2, p. 377–388.

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.

Clarke, E. de C., Phillipps, H. T., and Prider, R. T., 1954, The Pre-Cambrian geology of part of the south coast of Western Australia: Royal Soc. West. Australia Jour., v. 38, p. 1–64.

Compston, W., and Arriens, P. A., 1968, The Precambrian geochronology of Australia: Canadian Jour. Earth Sciences, v. 5, p. 561–583.

Doyle, H. A., 1971, Seismicity and structure in Australia: Roy. Soc. New Zealand Symp. on Recent Crustal Movements.

Gordon, F. R., 1972, Earthquake hazard in Western Australia: West. Australia Geol. Survey Ann. Rept 1971, p. 25–37.

Kay, J. G., 1974, Clastic dykes at Albany, Western Australia: Royal Soc. West. Australia Jour., v. 57, p. 9–10.

Logan, B. W., 1958, Clastic dykes from Watheroo, Western Australia: Royal Soc. West. Australia Jour., v. 41, p. 27–28.

Potter, P. E., and Pettijohn, F. J., 1963, Palaeocurrents and basin analysis: Academic Press, New York.

Stephenson, N. C. N., Russell, T. G., Stubbs, D., and Kalocsai, T. G., 1977, Potassium-argon ages of hornblendes from Precambrian gneisses from the south coast of Western Australia: Royal Soc. West. Australia Jour., v. 59, p. 105–109.

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.

Thom, R., 1977, The evolution of Proterozoic rocks near the Fraser Front at Ravensthorpe, Western Australia: Univ. London PhD thesis (unpublished).

Wilson, A. F., Compston, W., Jeffrey, P. M., and Riley, G. H., 1960, Radioactive ages from the Precambrian rocks in Australia: Geol. Soc. Australia Jour., v. 6, p. 179–195.

Woodward, H. P., 1909, Geological report upon the gold and copper deposits of the Phillips River Goldfield: West. Australia Geol. Survey Bull. 35.

EVIDENCE FOR THE AGE AND CRYPTOEXPLOSIVE ORIGIN OF THE TEAGUE RING STRUCTURE, WESTERN AUSTRALIA

by J. A. Bunting, J. R. de Laeter* and W. G. Libby

ABSTRACT

The Teague Ring Structure, at the northeast margin of the Yilgarn Block, consists of a circular core of pyroxene-quartz syenite and granite, some 10 km in diameter, surrounded by a ring syncline, 18 to 20 km across, in Early Proterozoic sedimentary rocks of the Nabberu Basin. Rb-Sr data suggest that the age of the structure is probably 1 630 m.y. with a further event of unknown origin and significance at about 1 260 m.y. Quartz syenite from outside the structure gives a model age of 2 367 m.y. The presence of shatter cones, quartz deformation lamellae and pseudotachylite veins is indicative of shock metamorphism and hence suggests a cryptoexplosive origin for the structure. There is inconclusive evidence that the cause was non-random, and therefore may not have been a meteorite impact as suggested by the shock metamorphism. A possible terrestrial cause could be a volatile-generated explosion in an alkaline magma.

INTRODUCTION

The Teague Ring Structure is a circular feature about 100 km northeast of Wiluna, Western Australia, at the junction of the Archaean Yilgarn Block and the Early Proterozoic Nabberu Basin (Fig. 1). The circular structure consists of a core, 10 km in diameter, of granitic and syenitic rocks surrounded by Early Proterozoic sedimentary rocks which form a ring syncline between 18 and 20 km across. It was first described by Butler (1974), who suggested it was due to either the intrusion of a granitoid plug, or the eroded remnant of a giant meteorite impact scar (astrobleme). He compared the structure with the Vredefort Dome of South Africa, which Dietz (1961) regarded as an impact structure. Horwitz (1975) suggested that the structure may be due to the interference of mild folds, and therefore related to the regional stress pattern. Bunting and others (1977) proposed an origin by cold re-emplacement of a plug of syenite, possibly at high strain rates, by localized compressive stresses related to the regional fold trend. In this paper, we present another hypothesis—that the structure formed as a result of an explosion of volatiles related to alkaline magmatism.

A major problem in the interpretation of the Teague Ring Structure has been the age of the granitic and syenitic rocks in the core. In an attempt to solve this, samples from the core, along with two samples of quartz syenite from outside the structure, were submitted for Rb-Sr age determination as part of the joint Geological Survey of Western Australia—Western Australian Institute of Technology geochronology programme. The purpose of this paper is to present the geochronological data, to describe the structure, to discuss previous theories, and to present evidence for a cryptoexplosive origin.

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REGIONAL SETTING

The structure lies along the exposed line of unconformity between the Archaean Yilgarn Block and the Early Proterozoic Nabberu Basin (Fig. 1). The Archaean rocks of the Yilgarn Block are predominantly granitoid intruding poorly exposed remnants of greenstone belts (metamorphosed mafic and felsic volcanic rocks and associated metasediments). The regional granitoid in the vicinity of the Teague structure is medium- to coarse-grained adamellite, displaying a strong gneissic fabric where it is marginal to the greenstone belts. Deformational fabrics in both granitoid and greenstone trend north-northwest, and major strike faults in this direction can be followed for many hundreds of kilometres (Elias and Bunting, 1978). Two elliptical plutons of hornblende-quartz monzonite (containing less than 20 per cent quartz) and a small body of quartz syenite intrude the adamellite immediately southwest of the Teague structure.

The overlying Early Proterozoic sediments form the Earaheedy Group of the Nabberu Basin (Hall and others, 1977). A basal clastic unit with minor carbonate (Yelma Formation) is overlain by the Frere Formation which consists of interbedded granular iron-formation and shale. This is overlain by the Wandiwarra Formation (ferruginous sandstone, fine-grained lithic sandstone and shale) and the Princess Ranges Quartzite (interbedded quartz arenite and kaolinitic siltstone).

Outside the area affected by the ring structure the sediments dip gently northeast at between 5° and 10°. Regional deformation in the vicinity of the structure is slight, but increases northwards into the Stanley Fold Belt. The dominant fold trend is west-northwest, and axial surfaces dip steeply to the north. A second generation of scattered medium-scale folds trends northeast.

Figure 2 is an outcrop map of the structure. The non-exposed areas are covered with superficial sediments, mainly sand and pebble colluvium, salt-lake deposits, valley calcrete and alluvium, and eolian sand related to the salt lakes.

THE RING STRUCTURE

THE CORE

Outcrop is restricted to the northeast side of the core, which is about 10 km in diameter. Two main rock types are present—quartz syenite and leucogranite.

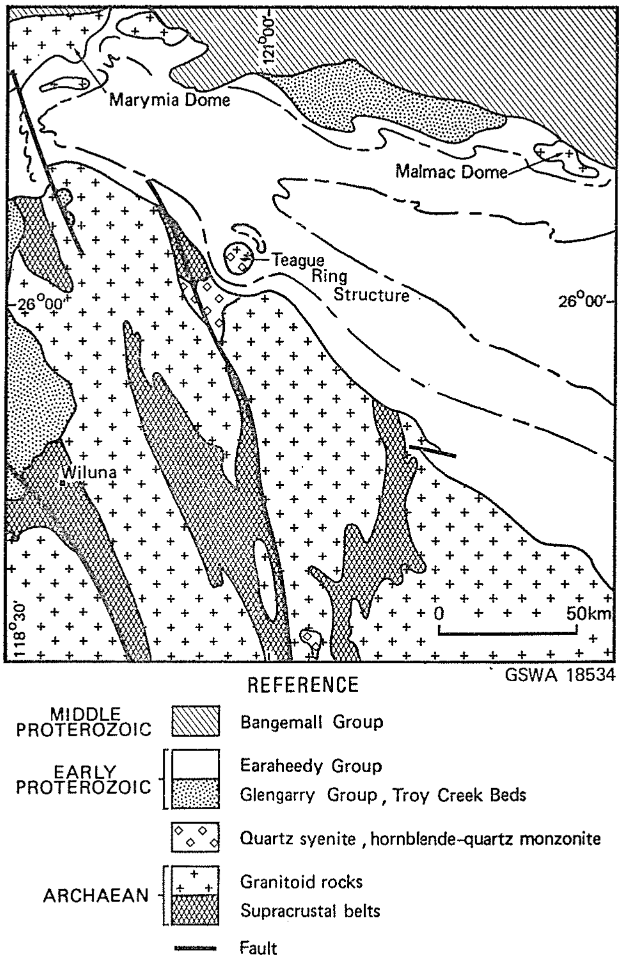


Figure 1 Regional setting of the Teague Ring Structure.

The leucogranite is medium grained and is probably unconformable beneath the Yelma Formation. It contains about 30 per cent quartz, which in some samples displays a weak gneissic foliation and slight strain extinction. Albite usually constitutes about 40 per cent of the rock, and alkali feldspar, which is invariably severely kaolinized, makes up about 30 per cent. A small amount of weathered biotite is the only mafic mineral present.

The quartz syenite is much more variable, both in grain size (from medium to very coarse) and mineral composition. Quartz ranges in abundance from about 30 per cent to 5 per cent. Perthitic microcline is usually coarser than quartz and plagioclase, and is always dominant over plagioclase, the ratio ranging from 3:2 to 3:1. The mafic mineral is a bright-green sodic pyroxene, which commonly has a greyish-blue or pale-green amphibole in the core. Accessories include sphene, apatite and rare zircon. Fluorite is common along fractures in sample 46513, and less abundant in 46515.

Field relationships between these two granitoid types and the cover sequence are not clear. The leucogranite is seen to within 1 m of the basal Yelma Formation, and a lack of intrusive phenomena, plus the continuity of the basal beds and weak gneissic foliation in the granitoid, indicate that the contact is an unconformity. The quartz syenite probably intrudes the leucogranite, but was not observed within 1 km of the cover sequence.

THE RING SYNCLINE

The ring syncline is between 18 and 20 km across and shows a marked asymmetry about a northwest-southeast plane. Sub-vertical, locally overturned dips on the northeast rim become gentler to the southwest, and folding becomes more open. Normal, steeply dipping faults form a polygonal pattern around the northeastern side of the structure (Fig. 3), but are lacking in the less-deformed southwestern side. The faults indicate an overall upward movement of the core. Small-scale faulting and fracturing are common in laminated shales of the Frere Formation.

The preservation of a much thicker stratigraphic sequence on the northeast side (4 000 m from Yelma Formation to Wongawol Formation) compared with the southwest side (about 1 000 m of Yelma Formation and Frere Formation(is a function of the regional tilt of the sequence, and is not necessarily related to any genetic asymmetry of the structure.

GEOCHRONOLOGY

GEOLOGICAL EVIDENCE

Geological constraints on the age of the structure are few. It obviously post-dates the formation of the Earaheedy Group sediments, and hence is probably younger than about 1 700–1 800 m.y. (Bunting and others, 1977). There is no geological evidence to provide a minimum age limit.

The structure is within a belt of alkalic granitoids (similar to quartz syenites within the structure) extending in a south-southeasterly direction across the Eastern Goldfields (Libby, 1978). The only geochronological data previously available for this suite (from Fitzgerald Peaks) gives an age of 2 360 m.y. (de Laeter and Lewis, 1978).

GEOCHRONOLOGICAL SAMPLING

The freshest samples possible were obtained from surface exposures, and all but two are from within the core of the structure. The samples range from moderately fresh to fresh in megascopic appearance but in thin section all are at least slightly altered, presumably by weathering (see Table 1).

TABLE 1. ROCK TYPE AND ALTERATION

Sample	Rock type	Alteration
40397	Pyroxene-quartz syenite	Slight
46301	Alkali granite....	Severe
46302	Pyroxene-quartz syenite	Moderate
46303	Pyroxene-quartz syenite	Slight
46304	Amphibole-quartz syenite	Slight
46511	Granite, possibly alkalic	Severe
46512	Albite-rich granite	Moderate to severe
46513	Pyroxene-quartz syenite	Moderate
46514	Pyroxene-quartz syenite	Moderate
46515	Pyroxene-quartz syenite	Moderate
46518	Pyroxene syenite	Moderate
	Not included in geochronological analysis:	
46516	Albite-rich granite	Severe
46517	Albite-rich granite	Severe
46519	Albite-rich granite	Severe

Sampling localities are shown on Figure 2. All localities are within the Teague Ring Structure except 46304 which is about 5 km south of the structure, and 40397 which is about 185 km south of the structure near Yandal on the Sir Samuel 1:250 000 sheet (Bunting and Williams, 1979).

EXPERIMENTAL PROCEDURE

The experimental procedures for Rb/Sr analyses used in this laboratory are essentially the same as those described by Lewis and others (1975). The value of $^{87}Sr/^{86}Sr$ for the NBS 987 standard measured during this project is 0·710 2 ± 0·000 1, normalized to a $^{88}Sr/^{86}Sr$ value of 8·375 2. The value of $1{\cdot}42 \times 10^{-11} yr^{-1}$ was used for the decay constant of ^{87}Rb (Steiger and Jäger, 1977).

The measured Rb/Sr and $^{87}Sr/^{86}Sr$ ratios are given in Table 2. Errors accompanying the data are at the 95 per cent confidence level. The Rb and Sr concentrations in each sample are also listed. However, these concentrations are only accurate to ±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.

TABLE 2. ANALYTICAL DATA—TEAGUE RING STRUCTURE GEOCHRONOLOGY

Sample	Rb (ppm)	Sr (ppm)	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
46301	290	150	1·945±0·02	5·67±0·06	0·807 91±0·000 29
46302	320	200	1·58 ±0·02	4·6 ±0·05	0·792 44±0·000 30
46303	200	315	0·65 ±0·01	1·87±0·02	0·756 85±0·000 12
46511	170	300	0·572±0·01	1·66±0·02	0·736 34±0·000 12
46512	180	300	0·60 ±0·01	1·74±0·02	0·753 81±0·000 15
46513	275	190	1·45 ±0·02	4·23±0·05	0·811 37±0·000 23
46514	220	430	0·52 ±0·01	1·51±0·02	0·746 91±0·000 28
46515	225	190	1·19 ±0·02	3·46±0·04	0·794 28±0·000 22
46518	170	180	0·925±0·01	2·68±0·03	0·754 04±0·000 25
46304	55	500	0·110±0·002	0·32±0·005	0·712 95±0·000 18
40397	195	380	0·510±0·005	1·48±0·02	0·754 96±0·000 21

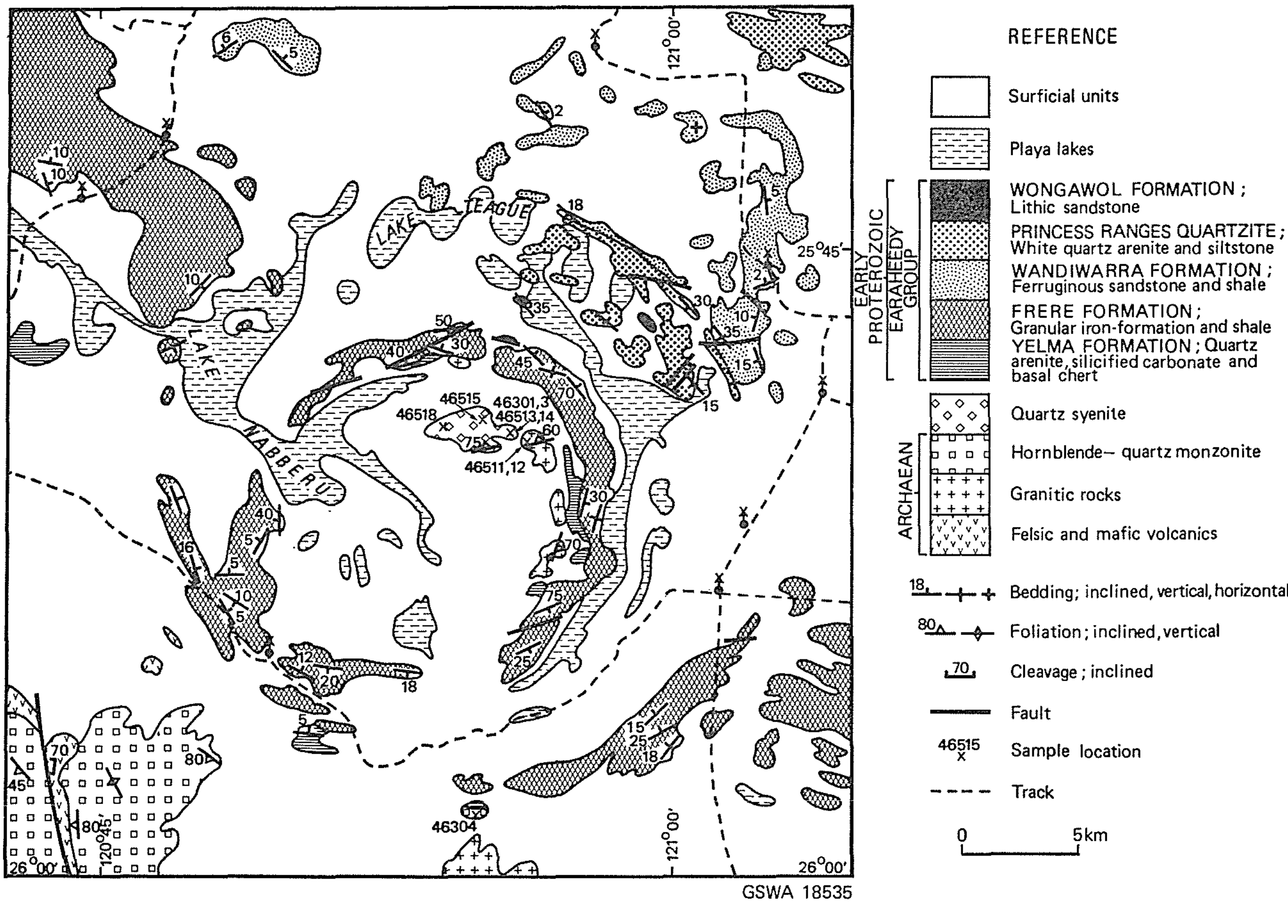


Figure 2 Geology and sample locations.

RESULTS

The geochronological results are presented in Figure 4 and Table 2.

The data fail to define a simple isochron, but rather fall into three groups:

(a) the two samples outside the structure;

(b) a group of five samples which plot near a 1 630 m.y. reference isochron; and

(c) a group of four samples which plot near a 1 260 m.y. reference isochron.

DISCUSSION

The samples from outside the structure were included for comparison of the alkaline granitoids of the Teague Ring Structure with the alkaline suite of the Eastern Goldfields (Libby, 1978). The only reliable age for this suite is 2 360 m.y. (R_i = 0·704 36 for the Fitzgerald Peaks Syenite (de Laeter and Lewis, 1978) in the southern Eastern Goldfields. Using the initial ratio from Fitzgerald Peaks and sample 40397 the age is 2 367 m.y., almost identical to the results from the Fitzgerald Peaks. This supports the supposition that the alkaline suite in the northern Eastern Goldfields is late Archaean.

Data from samples within the ring structure plot roughly along two reference isochrons, one at 1 630 m.y., the other at 1 260 m.y., both clearly Proterozoic.

These results can be interpreted as random points shifted various amounts to the right of an Archaean isochron by preferential loss of radiogenic strontium relative to rubidium during weathering (Bottino and Fullagar, 1968; Dasch, 1969). Alternatively, the disposition of points along the two reference isochrons may have geochronological significance. A simple re-equilibration of 1 630 m.y. rocks at 1 260 m.y. seems unacceptable as the two isochrons fail to cross. The suites are unlikely to have had different initial $^{87}Sr/^{86}Sr$ ratios as they are of similar lithology and are geographically intermixed. They differ systematically only in degree of alteration.

A more likely model accepts the 1 630 m.y. age as approximately the age of a real event, either the original emplacement of the alkali granitoid or its remobilization or metamorphism, but considers the 1 260 m.y. alignment to be fortuitous, arising from the increase in Rb:Sr ratio upon weathering due to preferential loss of Sr (Bottino and Fullagar, 1968; Dasch, 1969). This model would be more convincing if the points on the lower 'isochron' were less well aligned.

A possible explanation for alignment of points along the lower isochron is the preferential leaching of radiogenic strontium relative to primary strontium, as has been observed in micas (Faure and Powell, 1972, p. 103). Radiogenic strontium, metastably situated in weathered K-feldspar may have been leached in preference to strontium stably situated in less-weathered plagioclase.

If all secondary radiogenic strontium were removed during weathering about 1 260 m.y. ago the strontium isotope ratio could be reduced to the level of the original, perhaps Archaean, emplacement. Under sedimentary cover since that time, the system evolved, generating a distribution resembling an isochron. Thus the apparent date may approximate the date of a period of weathering, with an initial ratio below that of the parent rocks.

Of the two isochrons, the older is by far the more reliable, as it contains the freshest samples of quartz syenite. The age of 1 630 m.y. is in broad agreement with radiometric ages of granitic rocks from the Gascoyne Province (Williams and others, 1978; de Laeter, 1976). The age is slightly younger than the indicated age of the Earaheedy Group sediments (1 700–1 800 m.y.), and of K–Ar ages on glauconite from the Earaheedy Group of 1 690–1 680 m.y. (Preiss and others, 1975; Butt and others, 1977), and could represent the age of formation of the ring structure.

ORIGIN OF THE STRUCTURE

EVIDENCE OF SHOCK METAMORPHISM

Several lines of evidence indicate that rocks within the core and the ring syncline were subjected to shock metamorphism, and hence the structure probably formed as the result of cryptoexplosive activity.

Shatter cones (Fig. 5A) are sparsely scattered through the granular iron-formation within a few hundred metres of the granitic core, but only rarely are they well developed. They

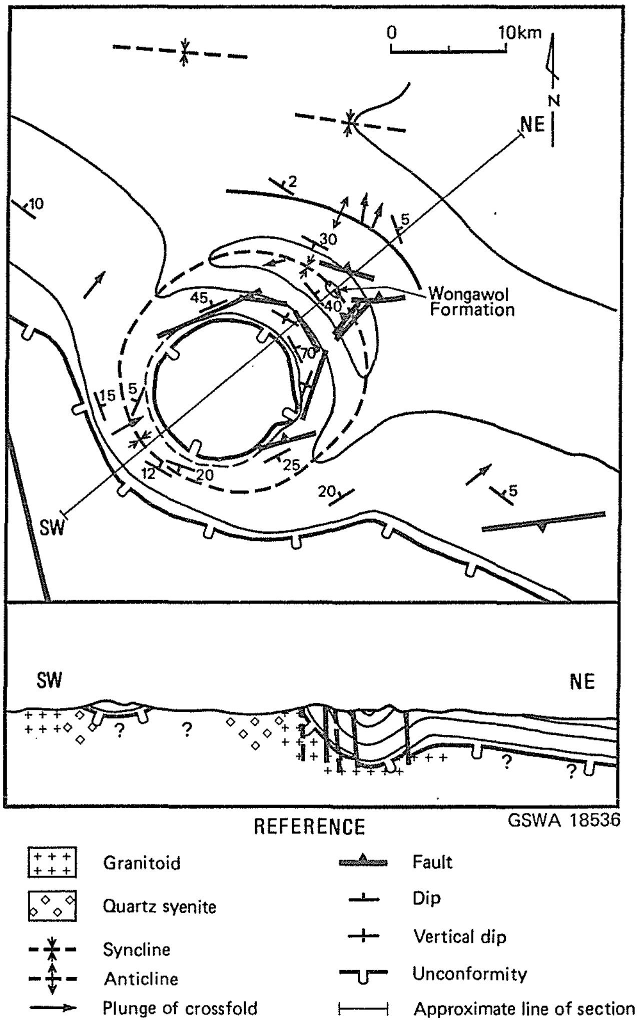


Figure 3 Structural sketch and diagrammatic cross section.

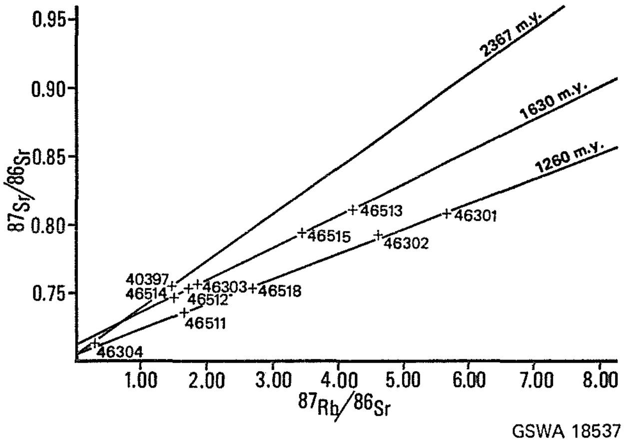


Figure 4 Isotopic data and reference isochrons, Teague Ring Structure.

range in length from a few centimetres to 150 mm and have apical angles of between 30° and 50°. A single shatter cone has been found in the quartz syenite (J. Ferguson, pers. comm.).

Deformation lamellae in quartz occur only in the granitic rocks of the core, not the quartz syenite. The lamellae show characteristics of the 'decorated' type (Carter, 1968) and are formed by lines of small fluid-filled inclusions. Commonly at least two sets are present, and these either overlap or form a chevron pattern (Fig. 5B and C).

Very small (less than 1 mm thick) pseudotachylite veins cut the granite and syenite. The veins consist of brecciated quartz and feldspar fragments in a devitrified glassy matrix. In the same thin sections plagioclase crystals are shattered and twin lamellae disrupted.

TERRESTRIAL OR EXTRATERRESTRIAL ORIGIN?

The features described in the previous section are generally taken as evidence of shock metamorphism produced by a cryptoexplosion. Circular structures produced by such events have been described from numerous parts of the world, and the Teague Ring Structure has features in common with many of them, particularly those in Precambrian terrains, for example the Vredefort Dome, South Africa (Dietz, 1961) and the Carswell Structure, Canada (Currie, 1969). For summaries see Robertson and Grieve (1975), and French and Short (1968).

The origin of such structures has been the subject of much debate. In its most basic terms, this debate centres around whether the structures formed as the result of meteorite impact (extraterrestrial) or an explosive event within the crust (terrestrial). The proponents of meteorite impact point to experimental evidence which suggests that the high strain rates of shock metamorphism cannot be produced by known processes within the crust. Their opponents rely on the empirical observations that many of the so-called impact structures lie on pre-existing structures, or contain features such as thermal metamorphism or igneous intrusions which are related to the origin of the structure but which predate the shock event; thus the event is not random, as required by the impact theory (Currie, 1969; Snyder and Gederman, 1965; Bucher, 1963; Sage, 1978).

In this context it is noted that the Teague Ring Structure does not appear to have been a random event. It lies astride the presently exposed line of unconformity at the base of the Earaheedy Group—which may form a hingeline related to the formation of the Wiluna Arch (Bunting and others, 1977). The plane of symmetry of the structure is perpendicular to the dominant fold direction and regional strike (and hence parallel to the major stress direction). The core contains quartz syenite (an unusual rock type in the Yilgarn Block) that pre-dated the shock metamorphism. Finally, the structure lies on a prominent aeromagnetic lineament which trends 060° and which coincides with a second possible shock metamorphic structure some 260 km to the southwest. Although this evidence is not conclusive, taken in conjunction with similar evidence for other structures elsewhere in the world, there is sufficient doubt about the viability of the impact theory to suggest that a terrestrial mechanism may be involved.

The nature of a terrestrial mechanism for cryptoexplosive features remains a problem. Numerous workers have shown that volcanic, tectonic or diapiric activities by themselves cannot produce the strain rates required for shock metamorphism. However, many of the Precambrian examples show a coincidence between the formation of a circular shock structure and alkaline magmatic activity (Currie, 1971; Sage, 1978), and it seems feasible that volatile pressures during alkaline magmatism could be sufficiently high to create the required explosion. Schreyer (1978, unpubl.) has suggested that an explosion of a dry, carbon dioxide-rich volatile phase in an alkaline magma caused the Vredefort Dome in South Africa. With this in mind, it is interesting to note that the syenitic rocks in the core of the Teague Ring Structure contain fresh pyroxene, and only minor primary hydrated minerals.

CONCLUSIONS AND SUMMARY

The Teague Ring Structure has many features that are characteristic of cryptoexplosive circular structures elsewhere in the world, but as in many of these structures the evidence for the nature and cause of the explosion is inconclusive. The presence of shatter cones, deformation lamellae and pseudotachylite veins could be taken as evidence of a meteorite impact, whereas the sketchy empirical evidence for a non-random origin would require the invocation of a terrestrial cause, such as a volatile explosion in an alkaline magma. The question of origin remains open, and indeed may remain open for many years; however, there are some significant observations on the Teague structure which are either pertinent to, or put constraints on, its origin. They are as follows:

1. In common with many other Precambrian circular structures, the core contains alkaline rocks, in this case pyroxene-quartz syenite.
2. The quartz syenite intrudes granitoid rocks which are in turn unconformable beneath Early Proterozoic rocks of the Nabberu Basin.
3. Of the two possible isochrons obtained from the quartz syenite, the older at 1 630 m.y. is most likely to have geological significance, though it may not represent the age of original emplacement of the

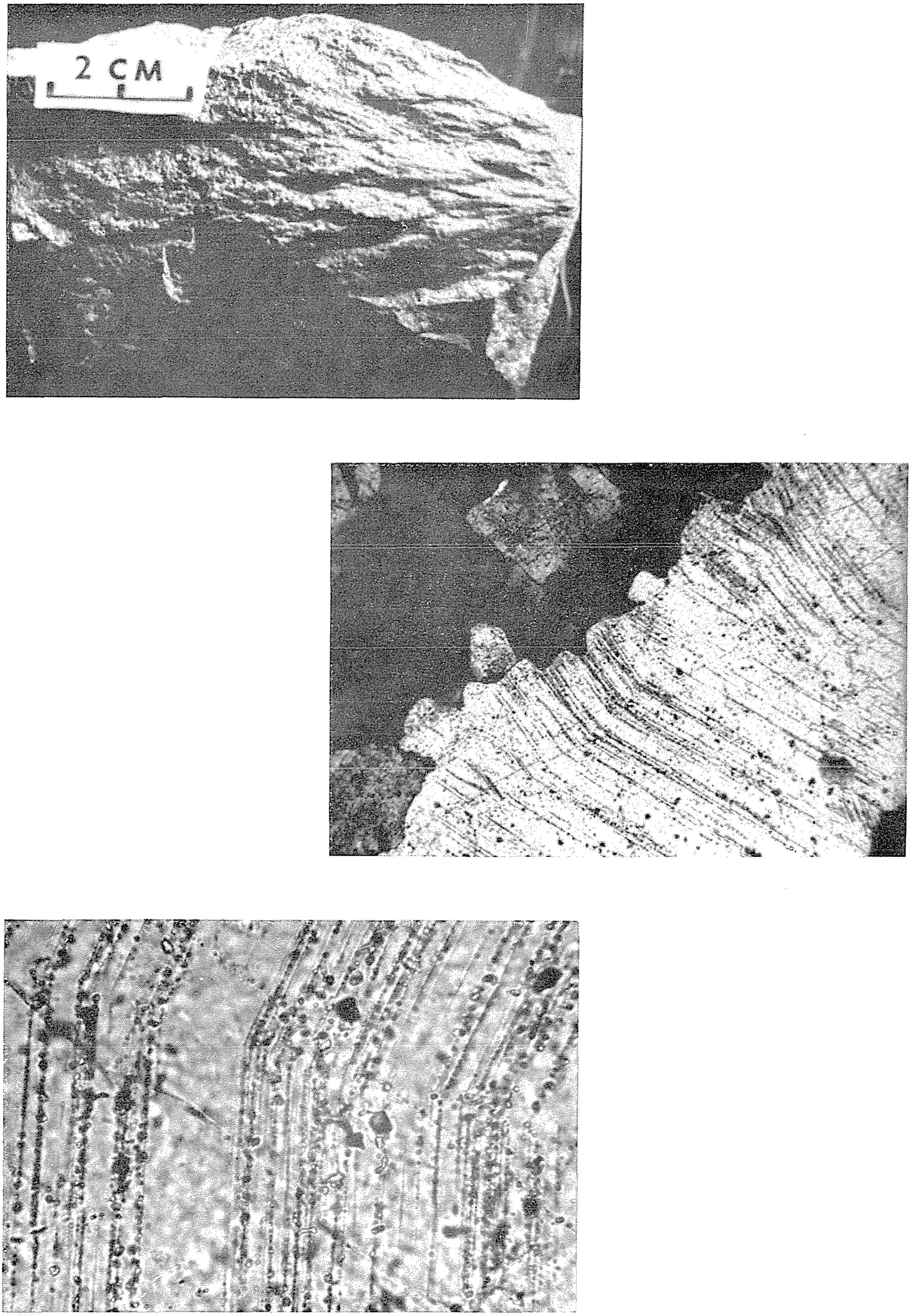


Figure 5 Shock metamorphic features:

(A) Shatter cones in granular iron-formation.

(B) Decorated deformation lamellae in quartz in leucogranite from the core of the structure. Field of view is about 1 mm.

(C) Detail from B showing fluid inclusions.

pluton. This date is younger than the presumed age of the overlying sediments and could conceivably be the time of formation of the structure.

4. As neither circular structures nor syenitic rocks are common in the northeastern Yilgarn Block, their association in the Teague Ring Structure suggests that they may be genetically related. Pseudotachylite veins and a shatter cone in the quartz syenite indicate that the quartz syenite was in place prior to shock metamorphism, and therefore could not be a result of the shock. Thus the structure seems likely to have been formed by a series of terrestrial events culminating in an explosion.
5. The physical meaning of the younger possible isochron at 1 260 m.y. is not clear, but it may record a period of alteration or weathering.

ACKNOWLEDGEMENTS

A structure such as this has produced much debate, and we are indebted to the large number of people with whom we have discussed the problem. In particular, John Bunting would like to thank D. C. Gellatly, W. Schreyer, J. Ferguson, C. Arndt, P. Dunn and numerous colleagues in the Geological Survey of Western Australia. D. C. Gellatly brought to our attention the existence of shatter cones in the iron-formation. The authors are also grateful to Mr D. J. Hosie of the Department of Physics, Western Australian Institute of Technology, for technical assistance during the project.

REFERENCES

Bottino, M. L., and Fullagar, P. D., 1968, The effects of weathering on whole-rock Rb-Sr ages of granitic rocks: Amer. Jour. Sci. v. 266, p. 661–670.

Bucher, W. H., 1963, Cryptoexplosion structures caused from without or from within the Earth ("astroblemes" or "geoblemes"?): Amer. Jour. Sci. v. 261, p. 597–649.

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., and Williams, S. J., 1979, Sir Samuel, W.A.: West. Australia Geol. Survey 1:250 000 Geological Series Explan. Notes.

Butler, H., 1974, The Lake Teague ring structure, Western Australia: an astrobleme?: Search v. 5, p. 534–536.

Butt, C. R. M., Davis, C. E. S., and Horwitz, R. C., 1977, Killara Copper Prospect: progress report: Australia CSIRO, I.R. 829 (unpublished).

Carter, N. L., 1968, Dynamic deformation of quartz, *in* French, B. M., and Short, N. M. (Eds), Shock metamorphism of natural materials: Mono Book Corp., Baltimore, p. 453–474.

Currie, K. L., 1969, Geological notes on the Carswell circular structure, Saskatchewan: Canada Geol. Survey Pap. 67–32.

——— 1971, Origin of igneous rocks associated with shock metamorphism as suggested by geochemical investigations of Canadian craters: Jour. Geophys. Research v. 76, p. 5575–5585.

Dasch, E. J., 1969, Strontium isotopes in weathering profiles, deep-sea sediments and sedimentary rocks: Geochim. et Cosmochim. Acta v. 33, p. 1521–1552.

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 Lewis, J. D., 1978, The ages of the syenitic rocks of the Fitzgerald Peaks, near Norseman: West. Australia Geol. Survey Ann. Rept 1977, p. 56–60.

Dietz, R. S., 1961, Vredefort ring structure: meteorite impact scar?: Jour. Geol. v. 69, p. 499–516.

Elias, M., and Bunting, J. A., 1978, Explanatory notes on the Wiluna 1:250 000 Geological Sheet: West. Australia Geol. Survey Rec. 1978/10.

Faure, G., and Powell, J. L., 1972, Strontium isotope geology: Berlin, Springer-Verlag, 188p.

French, B. M., and Short, N. M. (Eds), 1968, Shock metamorphism of natural materials: Mono Book Corp., Baltimore.

Hall, W. D. M., Goode, A. D. T., Bunting, J. A., and Commander, D. P., 1977, Stratigraphic terminology of the Earaheedy Group, Nabberu Basin: West. Australia Geol. Survey Ann. Rept 1976, p. 40–43.

Horwitz, R. C., 1975, Provisional geological map at 1:2 500 000 of the north-east margin of the Yilgarn Block, Western Australia: Australia CSIRO Mineral Research Lab. Rept F.P.10.

Lewis, J. D., Rosman, K. R. J., and de Laeter, J. R., 1975, The age and metamorphic effects of the Black Range dolerite dyke: West. Australia Geol. Survey Ann. Rept 1974, p. 80–88.

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 Rept 9, p. 111–137.

Preiss, W. V., Jackson, M. J., Page, R. W., and Compston, W., 1975, Regional geology, stromatolite biostratigraphy and isotopic data bearing on the age of a Precambrian sequence near Lake Carnegie, Western Australia: Australian Geol. Convention, 1st, Adelaide, 1975, Abstr. p. 92–93.

Robertson, P. B., and Grieve, R. A. F., 1975, Impact structures in Canada: their recognition and characteristics: Roy. Astronomical Soc. Canada Jour. v. 69, p. 1–21.

Sage, R. P., 1978, Diatremes and shock features in Precambrian rocks of the Slate Islands, northwestern Lake Superior: Geol. Soc. America Bull. v. 89, p. 1529–40.

Schreyer, W., 1978, The Vredefort Dome, South Africa: an astrobleme or an internal explosion structure?: Abstr. of lecture, Geol. Soc. Australia (West. Australia Div.) Monthly Notes, May, 1978, (unpublished).

Snyder, F. G., and Gederman, P. E., 1965, Explosive igneous activity along an Illinois-Missouri-Kansas axis: Amer. Jour. Sci. v. 263, p. 465–493.

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.

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.

SUMMARY OF THE PRECAMBRIAN STRATIGRAPHY OF WESTERN AUSTRALIA

by R. D. Gee

ABSTRACT

An updated stratigraphic table is presented which places lithostratigraphic units for each tectonic unit of Western Australia in a chronometric time scale. The Archaean-Proterozoic boundary should be revised to 2·5 b.y. from the figure of 2·4 b.y. previously adopted by the Geological Survey. Some geochronological control now exists on all major Proterozoic sedimentary sequences, and some inter-regional correlations are indicated by the tabulation. A major sedimentary cycle commenced 1·1 b.y. ago. Stratigraphic continuity before 1·1 b.y. is obscured by orogenic activity, but these older sequences are inherently of restricted extent.

INTRODUCTION

At appropriate times, this survey publishes summaries of the Precambrian stratigraphy of Western Australia, incorporating recent advances in geology and geochronology (Horwitz, 1968; Gee, 1974). This report is another in this series, and comes at a time when initial geological mapping of the State at a scale of 1:250 000 has just been completed. It also follows closely a period of accelerated geochronological enquiry into the Precambrian, much of which has been specifically directed at the broad stratigraphic framework of the State.

Most of the major sedimentary sequences have now been identified, and some geochronological data exist on most of

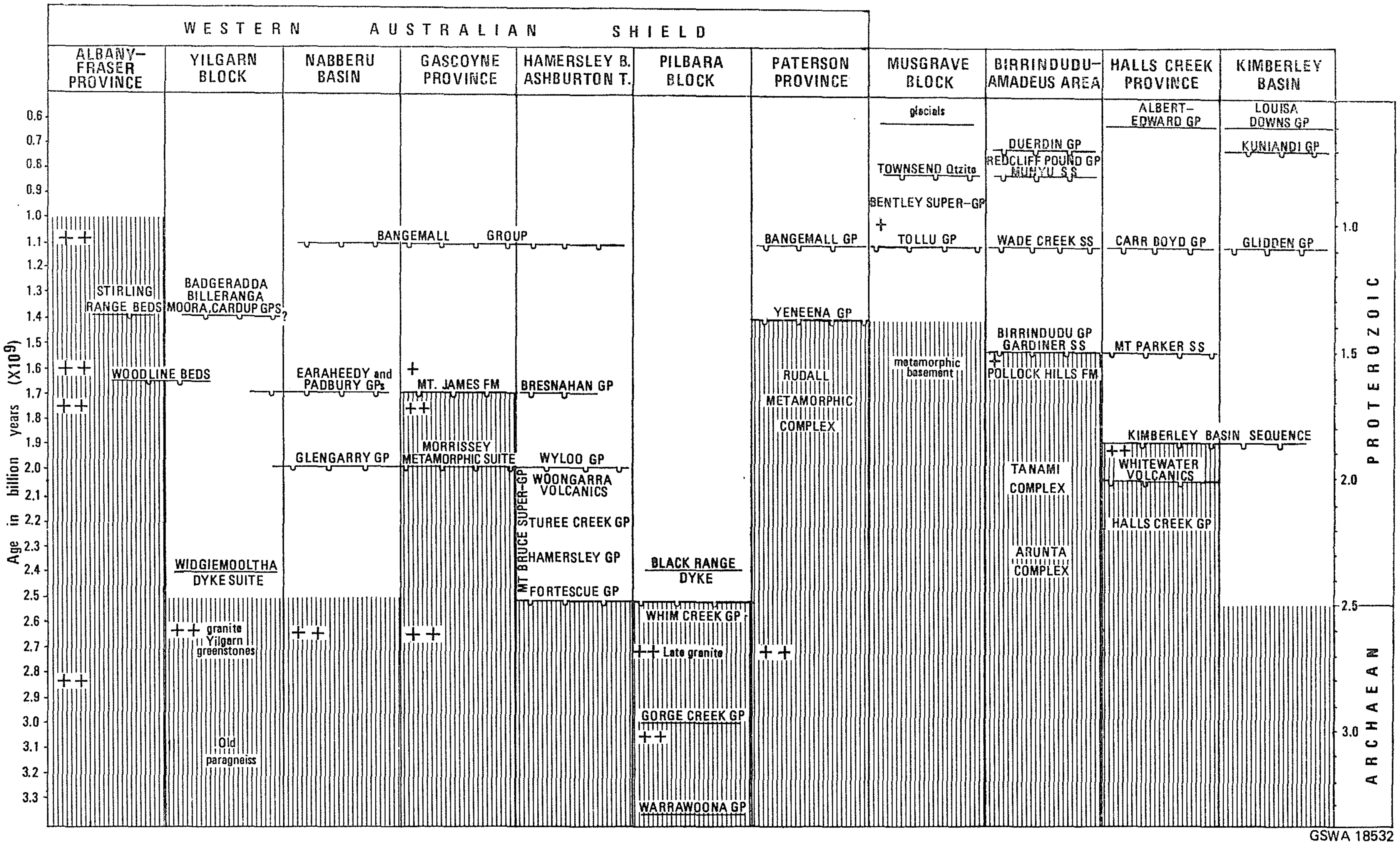


Figure 1 Summary chart of the Precambrian stratigraphy of Western Australia. Unconformities shown in conventional manner. Crosses indicate granite emplacement. Shaded area represents metamorphic/plutonic terrains that form basement to overlying cover sequences.

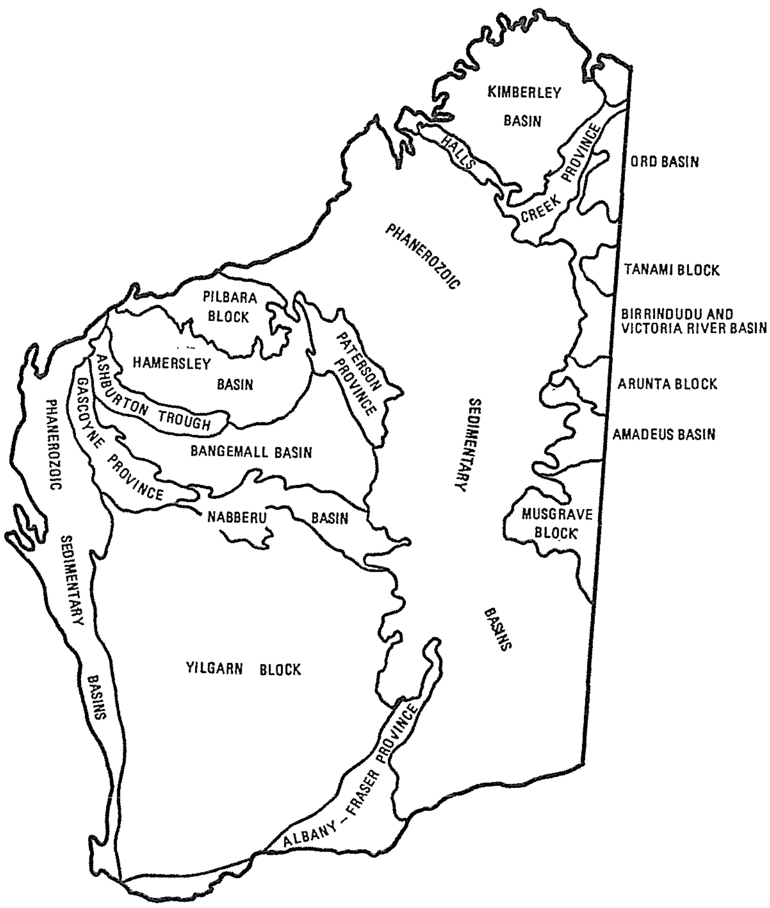


Figure 2 Distribution of Precambrian tectonic units referred to in Figure 1.

the major tectonic units. Consequently it is now possible to present a synthesis which is more solidly based than those of previous years. On the accompanying chart (Fig. 1) the major lithostratigraphic units (e.g. supergroup, group, etc.) that occur within the main tectonic units (Fig. 2) are arranged in a time scale of billions of years. For most rock sequences, the positions in the time scale are set by the relationships they hold to magmatic or metamorphic events for which geochronological data exist. This chart summarises the stratigraphy as it is presently understood, and only the more stratigraphically significant controls are referred to in the text. A more comprehensive review of the contribution of geochronology to the geology of Western Australia has been given by de Laeter and Trendall (1979).

The chart is based on a collation by the Australian Working Group (K. A. Plumb, R. D. Gee and B. R. Thomson) of the Subcommission on Precambrian Stratigraphy. The Australia-wide correlation chart, which will be presented elsewhere, is part of an international enquiry into establishing a widely acceptable global subdivision of the Precambrian.

In 1977 a new decay constant of $1{\cdot}42 \times 10^{-11}$ year $^{-1}$ for ^{87}Rb came into general use in place of the previously accepted figure of 1·39. For precise comparative purposes all Rb–Sr dates should be multiplied by a factor of 1·39/1·42 or 0·979. Whereas this change is significant in that it brings the Rb–Sr dates more closely into correspondence with other systems, and may also be important in resolving relationships in detailed studies, it has no effect on the broad-scale stratigraphy described here. As this paper is not intended to be a summary of geochronology of the State, Rb–Sr determinations prior to 1977 (which represent the vast bulk of the data) have not been corrected to the new constant. Furthermore, as a convention actual ages are quoted in millions of years, without showing the errors at the 95% confidence level, and where ages are used in a broad stratigraphic context, they are quoted in billions of years, rounded to one decimal place. In the compilation of Plumb and others which attempts to examine more precisely the field and geochronological relationships, the Rb–Sr ages will be corrected to the new constant.

SUBDIVISION OF THE PRECAMBRIAN

In Western Australia (Trendall, 1975), the approach to Proterozoic stratigraphy is the integration of isotopic dating and regional geology, rather than the use of chronostratigraphic (time-rock) terms tied to the geological record. This Survey has used a subdivision of the Precambrian time into Archaean and Proterozoic eons, the latter being subdivided into three eras called Lower, Middle and Upper Proterozoic, with time boundaries of 1 640 and 860 m.y. The concept of division of geological time, rather than of the geological record is consistent with the recent recommendations (James, 1978) of the Subcommission on Precambrian Stratigraphy, and the subdivisions of the Proterozoic have found use in broad-scale descriptions, especially where geochronological control has been lacking. But as more such data have become available the subdivisions have been found to have progressively less correspondence with the actual geological record, and have consequently declined in usefulness.

THE ARCHAEAN-PROTEROZOIC BOUNDARY

Since 1967, this Survey has used 2 400 m.y. as a convenient figure that separates the Archaean and Proterozoic rocks. This figure corresponds closely to the indicated age of dolerite dykes in both Archaean cratons. Moreover, this time plane was consistent with the belief that the age of the Mount Bruce Supergroup, which overlies the Archaean Pilbara Block, was in the range of 2 200 to 2 000 m.y. However, with the recognition that the Woongarra Volcanics (ca. 2 000 m.y., Compston and Arriens, 1968) are intrusive rather than extrusive (de Laeter and others, 1974, p. 91), there ceased to be any firm control on the age of the Hamersley Group. The only evidence bearing on its age became a poorly fitted Rb-Sr isochron of about 2 200 m.y. on a dolerite sill possibly contaminated by its wall rock (de Laeter and others, 1974), and an age of 2 329 m.y. on the Black Range dyke (Lewis and others, 1975), for which no field relationship with the Proterozoic rocks has been demonstrated.

Some suggestion for an appreciably older age of the Hamersley Basin sequence is suggested by an isochron of ca. 2 600 m.y. (Hickman and de Laeter, 1977) on sediments at the base of the sequence. More recently W. Compston and A. F. Trendall (pers. comm.) have obtained a U-Pb age of 2 496 m.y. on volcanogenic zircon from a stratigraphic position near the middle of the Hamersley Group, which is underlain by at least 2 km of sediment and volcanics. Therefore, it seems that the Archaean-Proterozoic boundary would be better placed at an older date.

Coincidentally, and independently from these developments, the Subcommission on Precambrian Stratigraphy in 1978 recommended 2 500 m.y. as the time plane that best separates the contrasting Archaean and Proterozoic terrains in most regions of the world. As an interim measure, this Survey now endorses this time boundary, as it is compatible with current knowledge in Western Australia, although it needs to be stressed that this boundary could be further adjusted in the light of continuing studies in the circum-Pilbara region.

Not surprisingly, the 2 500 m.y. boundary is inconsistent with some data. Rb-Sr dates in the range 2 330 to 2 366 m.y. have been obtained (de Laeter and Sylvester, pers. comm.) from volcanic and intrusive material in the Whim Creek Group which is unconformably overlain by the basal units of the Fortescue Group, which according to evidence present in this paper, could be about 2 500 m.y. old. Temporal and spatial relationships between these two rock sequences need to be resolved before any further refinement of the Archaean-Proterozoic boundary can be contemplated.

ARCHAEAN STRATIGRAPHY

PILBARA BLOCK

Hickman (in prep.) has erected a regionally extensive strati graphy for the Pilbara Block, consisting of the Warrawoona and Gorge Creek Groups. An important U-Pb age of 3 450 m.y. on zircon extracted from dacite (Pidgeon, 1978) is the only direct date for the Warrawoona Group, and makes these rocks the oldest in Australia.

A lower limit on the Gorge Creek Group is given by granite ages of about 3·0–2·9 b.y. (Compston and Arriens, 1968; de Laeter and others, 1975; and Oversby, 1976), some of which were emplaced into the Warrawoona Group before the overlying Gorge Creek Group sedimentation.

As previously mentioned, the more localised late Archaean volcanic sequence (Whim Creek Group) in the West Pilbara gives ages as young as 2·3 b.y. These ages are problematical and contribute to the present uncertainties on the age of the Archaean-Proterozoic boundary.

YILGARN BLOCK

Paragneiss and high-grade schist interfoliated with granitic gneiss that give ages around 3·0 b.y. (Arriens, 1971), are the oldest rocks in the Yilgarn Block. Gee, (1979a) considered that these metasediments are part of an ancient marine-shelf-type sequence that pre-dates the volcanogenic rocks in the greenstone belts.

At present, there is a lack of direct data on the age of the Yilgarn Block greenstones. Most are older than a widespread granite emplacement event at 2·6–2·7 b.y. (Arriens, 1971), and geological evidence (Gee, 1979a) suggests they evolved over a short period of time (ca. ?100 m.y.) which overlapped the period of granite emplacement. It is tentatively concluded that the greenstones are about 2·8–2·7 b.y. old, an age supported by a Rb-Sr date of 2 718 m.y. (Cooper and others, 1978) on gabbro that is probably co-magmatic with stratigraphically low mafic volcanics.

PROTEROZOIC STRATIGRAPHY

HAMERSLEY BASIN—MOUNT BRUCE SUPERGROUP

Trendall (1979) revised the Mount Bruce Supergroup to include the Fortescue, Hamersley and Turee Creek Groups and to exclude the Wyloo Group. Reference to the uncertainty of the age of the Mount Bruce Supergroup has previously been made, but it is probably between 2·6 and 2·0 b.y. The older limit is provisionally accepted as the age of younger granite in the Pilbara Block (de Laeter and others, 1975), the emplacement of which is probably the last craton-forming event in the basement. The younger limit is the age of the Woongarra Volcanics (Compston and Arriens, 1968; Arriens, 1975).

ASHBURTON TROUGH

The Wyloo Group, at its base, contains clasts that can be matched with the Woongarra Volcanics (Trendall, 1979), and the group is affected by granite plutonism and regional metamorphism which produced an orogenic climax at about 1·7–1·8 b.y. (de Laeter, 1976; Williams and others, 1978; Leggo and others, 1965).

NABBERU BASIN

The Glengarry Group in the western part of the Nabberu Basin is a thick geosynclinal sequence occurring in a trough along the northern margin of the Yilgarn Block (Gee, 1979b). It unconformably overlies the Archaean (2.5 b.y.) and participated in the orogeny in the Gascoyne Province (1·7–1·8 b.y.). A broad lithological similarity exists with the Wyloo Group, and Gee (1979a) has proposed that together these two thick trough sequences form the Capricorn Orogen, the oldest recognizable geosyncline in the Western Australian Shield.

In the eastern part and in synclines in the western part of the Nabberu Basin, the Glengarry Group is unconformably overlain by the Earaheedy and Padbury Groups respectively. Both these younger sequences contain granular iron-formation, which is a basis for their correlation. Bunting and others (1977) discussed the age constraints of the Earaheedy Group, and favoured an age of about 1·7 b.y., based on regional considerations and available K-Ar and Rb-Sr isotopic dates on glauconite (Preiss and others, 1975; Horwitz, 1975).

PATERSON PROVINCE—YENEENA GROUP

The Yeneena Group unconformably overlies the Rudall Metamorphic Complex, and is unconformably overlain by the Bangemall Group. Provisional Rb-Sr data (R. J. Chin and J. R. de Laeter, pers. comm.) indicate an age of about 1·4 b.y. for the metamorphic basement. Sedimentation is placed between 1·4 b.y. and the age of the Bangemall Group, of 1·1 b.y.

Some stratigraphic revision in this area (P. C. Muhling and A. T. Brakel, pers. comm.) has incorporated units of the "Manganese Group" into the Yeneena Group, the remainder being incorporated into the Bangemall Group. Likewise, the Waltha Woora Beds in the Robertson area are now variably apportioned either to the Yeneena Group or to the Bangemall Group.

BANGEMALL BASIN—BANGEMALL GROUP

The Bangemall Group is an extensive intracratonic sedimentary sequence which overlies with striking unconformity all the Proterozoic sequences referred to previously. It now incorporates much of the "Manganese Group", and some strata previously assigned to the Waltha Woora Beds. P. C. Muhling and A. T. Brakel (pers. comm.) correlate the Uaroo Group (van de Graaff and others, 1977) with the Bangemall Group.

Rb-Sr data on shale and felsite (Compston and Arriens, 1968) give an age of about 1 080 m.y., and an extrusive rhyolite (Gee and others, 1976) gives an age of 1 096 m.y. The unconformity below the Bangemall Group is placed at 1·1 b.y.

SEDIMENTARY SEQUENCES OF UNCERTAIN AGE

A number of isolated sequences occur in a stratigraphic position unconformably between the Wyloo Group (or the Morrissey Metamorphic Suite, its metamorphic equivalent) and the Bangemall Group. These include the Mount Minnie and Bresnahan Groups (Daniels, 1975), the Mount James Formation (Williams and others, 1979), various basement inliers in the Bangemall Basin (Muhling and others, 1978), and the Mount Leake Sandstone (Gee, 1979b). These sequences are located in the time scale according to the known broad geological constraints.

No recent work has been undertaken on dating the outliers of Proterozoic rocks scattered around the periphery of the Yilgarn Block. Allocation of these sequences (Cardup, Moora, Billeranga and Badgeradda Groups, and Mount Barren, Stirling Range and Woodline Beds) in the time scale is based mainly on the review of Low (1975).

MUSGRAVE BLOCK

A metamorphic basement recording ages around 1·4 b.y. is overlain by a felsic volcanic complex with related subvolcanic granites (Tollu Group) registering an age of 1 060 m.y. (Compston and Nesbitt, 1967). This is overlain by a marine shelf sequence called the Bentley Supergroup, which probably has a comparable age to that of the Bangemall Group.

Unconformably overlying all these rocks is a prominent orthoquartzite marker called the Townsend Quartzite, which is now generally correlated with the Heavitree Quartzite at the base of the Amadeus Basin sequence. It is therefore considered to be about 0·8 b.y. old.

AMADEUS—VICTORIA RIVER—BIRRINDUDU BASINS

Considerable remapping has been undertaken in this area by BMR and joint BMR-GSWA parties, and has resulted in a revised stratigraphy which is embodied in the bulletin by Blake and others (1980). Most of the previous stratigraphic problems stem from difficulties in correlating sandstone formations at the base of major sequences that rest unconformably on metamorphic basement blocks.

The basis for stratigraphic synthesis is now the correlation of the Heavitree Quartzite (correlated with the Townsend Quartzite) with the Munyu Sandstone at the base of the Redcliffe Pound Group. This correlation identifies an extensive sequence, including that of the Amadeus Basin, as a major platform cover anologous to, but marginally younger than, the Bangemall Group in the Western Australian Shield.

Below this major cover sequence, and lying unconformably above the metamorphic basement, is the Birrindudu Group and related sequences in the Birrindudu Basin. The basal sandstone (Gardiner Sandstone) of the Birrindudu Group records K-Ar glauconite ages of around 1 500 m.y. (Page and others, 1976). The Gardiner Sandstone is correlated with the Mount Parker Sandstone, which lies unconformably above metamorphic rocks along the eastern flank of the Halls Creek Province.

KIMBERLEY BASIN AND HALLS CREEK PROVINCE

Recent advances in the understanding of the Precambrian stratigraphy of the Kimberley region are outlined in Plumb and Gemuts (1976). Most significant is the revision of the age of the Whitewater Volcanics from 1 788 m.y. (Dow and Gemuts, 1969) to at least 1 850–1 880 m.y. (contemporaneous with porphyries and granites of this age), and possibly to as old as 1 940 m.y. (Bennett and Gellatly, 1970).

This revision would make the age of the overlying Kimberley Basin sequence consistent with Bofinger's (1967) dates of 1 800 m.y. on the Hart Dolerite, and 1 807 m.y. on the Carson Volcanics.

Another change is the plausible reinterpretation by Page (1976) of the Bofinger (1967) data on the Halls Creek Group. Page considered these basement rocks to be between 2 200 and 1 960 m.y. old, and, therefore, not Archaean.

CONCLUDING REMARKS

Some evidence for inter-regional correlations emerges from the chart (Fig. 1). Also shown, by grey shading on the chart is the extent of the metamorphic terrains. These areas act as stable cratonic basement upon which the sedimentary cover sequences were deposited. It is evident that the younger sequences are far more extensive than the older, and they seem to offer the best possibility of stratigraphically based correlations.

Most conspicuous are the widespread cover sequences of about 1·1 b.y., seen both in the Western Australian Shield and the Precambrian areas east of the Phanerozoic divide. In this latter area it marks the beginning of a period of long-continued stable-shelf-type sedimentation persisting up to the Cambrian, without the interruption of major orogenies.

The older Proterozoic sequences are of a more basinal or trough nature. Correlation of these older, more restricted sequences is made difficult by their partial involvement in orogenic belts, such as the Capricorn Orogen and the Paterson Province. The degree of actual contemporaneity of sedimentation in the Western Australian Shield at about 1·6–1·7 b.y. is uncertain, but the alignment of stratigraphic units at this level, as shown on the chart, offers the possibility of future correlation at this and lower stratigraphic levels in the complex Capricorn Orogen between the two Archaean cratons.

The oldest and most restricted sequence in the Western Australian Shield is the unique Mount Bruce Supergroup, which does not appear to have any correlation outside the Hamersley Basin. Its depositional extent seems to be confined to a basement which is the oldest and most thoroughly stabilised part of the Shield, the outcropping part of which is represented by the Pilbara Block. One of the more interesting problems in the Proterozoic geology of Western Australia is the palaeogeographic reconstruction in the interval 2·5–2·0 b.y., particularly as to what geological processes operated away from the Hamersley Basin while the Mount Bruce Supergroup was being deposited. At present there is no evidence bearing on this question.

REFERENCES

Arriens, P. A., 1971, The Archaean geochronology of Australia: Geol. Soc. Australia Special Publication No. 3, p. 11–24.

——— 1975, Geochronological studies of some Proterozoic rocks in Australia: Geol. Soc. Australia, 1st Aust. geol. convention, Adelaide, Abstracts Proterozoic geology, p. 63.

Bennett, R., and Gellatly, D. C., 1970, Rb-Sr age determinations of some rocks from the West Kimberley region, Western Australia: Australia Bur. Mineral Resources, Rec. 1970/20 (unpublished).

Blake, D. H., Hodgson, I. M., and Muhling, P. C., 1980, Geology of the Granites—Tanami Region, Northern Territory and Western Australia: Australia Bur. Mineral Resources, Bull. 197.

Bofinger, V. M., 1967, Geochronology in the East Kimberley areas of Western Australia: Australian National University, Ph.D. Thesis.

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.

Compston, W., and Arriens, P. A., 1968, The Precambrian geochronology of Australia: Canadian Journal of Earth Sciences, v. 5, p. 561–583.

Compston, W., and Nesbitt, R. W., 1967, Isotopic age of the Tollu Volcanics, Western Australia: Geol. Soc. Australia Jour., v. 14, p. 235–238.

Cooper, J. A., Nesbitt, R. W., Platt, J. P. and Mortimer, G. E., 1978, Crustal development in the Agnew region, W.A., as shown by Rb/Sr isotopic and geochemical studies: Precambrian Research, v. 7 (i), p. 31–59.

Daniels, J. L., 1975, Bresnahan and Mount Minnie Basins, *in* Geology of Western Australia: West. Australia Geol. Survey, Mem. 2, p. 143–146.

Dow, D. B., and Gemuts, I., 1969, Geology of the Kimberley Region, Western Australia: The East Kimberley: Australia Bur. Mineral Resources, Bull. 106.

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., Lewis, J. D., and Blockley, J. G., 1975, Granite ages within the Shaw Batholith of the Pilbara Block: West. Australia Geol. Survey Ann. Rept 1974, p. 73–79.

de Laeter, J. R., Peers, R., and Trendall, A. F., 1974, Petrography, chemical composition, and geochronology of two dolerite sills from the Precambrian Weeli Wolli Formation, Hamersley Group: West. Australia Geol. Survey Ann. Rept 1973, p. 82–91.

de Laeter, J. R., and Trendall, A. F., 1979, The contribution of geochronology to Precambrian studies in Western Australia: Royal Soc. West. Australia Jour., v. 62, p. 21–31.

Gee, R. D., 1974, Recent progress on the Precambrian stratigraphy of Western Australia: West. Australia Geol. Survey Ann. Rept 1973, p. 50–53.

Gee, R. D., 1979a, Structure and tectonic style of the Western Australian Shield: Tectonophysics, v. 59, p. 327–369.

——— 1979b, The geology of the Peak Hill area: West. Australia Geol. Survey Ann. Rept 1978, p. 55–62.

Gee, R. D., de Laeter, J. R., and Drake, J. R., 1976, Geology and geochronology of altered rhyolite from the lower part of the Bangemall Group near Tangadee, Western Australia: West. Australia Geol. Survey Ann. Rept 1975, p. 126–130.

Hickman, A. H., in prep., Geology of the Pilbara Block and its environs: West. Australia Geol. Survey Bull. 127.

Hickman, A. H., and de Laeter, J. R., 1977, Depositional environment and age of a shale within the Hardey Sandstone of the Fortescue Group: West. Australia Geol. Survey Ann. Rept 1976, p. 62–68.

Horwitz, R. C., 1968, Provisional subdivisions of the Precambrian in Western Australia: West. Australia Geol. Survey Ann. Rept 1967, p. 44.

——— 1975, Provisional geological map at 1:2 500 000 of the North-East margin of the Yilgarn Block, Western Australia: Australia CSIRO Minerals Research Laboratories Rept No. FP.10.

James, H. L., 1978, Subdivision of the Precambrian—a brief review and a report on recent decisions by the Subcommission on Precambrian Stratigraphy: Precambrian Research, v. 7, p. 193–204.

Leggo, P. J., Compston, W., and Trendall, A. F., 1965, Radiometric ages of some Precambrian rocks from the Northwest Division of Western Australia: Geol. Soc. Australia Jour., v. 12, p. 53–65.

Lewis, J. D., Rosman, K. J. R., and de Laeter, J. R., 1975, The age and metamorphic effects of the Black Range dolerite dyke: West. Australia Geol. Survey Ann. Rept 1974, p. 80–88.

Low, G. H., 1975, Proterozoic rocks on or adjoining the Yilgarn Block, *in* Geology of Western Australia: West. Australia Geol. Survey, Mem. 2, p. 71–81.

Muhling, P. C., Brakel, A. T., and Davidson, A. W., 1978, Mount Egerton, Western Australia: West. Australia Geol. Survey 1:250 000 Geol. Series explan. notes.

Oversby, V. M., 1976, Isotopic ages and geochemistry of Archaean acid igneous rocks from the Pilbara, Western Australia: Geochimica et Cosmochimica Acta, v. 40, p. 817–829.

Page, R. W., 1976, Reinterpretation of isotopic ages for the Halls Creek Mobile Zone, northwestern Australia: Australia Bur. Mineral Resources Jour. Aust. Geol. Geophys., v. 1, p. 79–81.

Page, R. W., Blake, D. H., and Mahon, M. W., 1976, Geochronology and related aspects of acid volcanics associated with granites and other Proterozoic rocks in the Granites—Tanami region, northwestern Australia: Australia Bur. Mineral Resources Jour. Aust. Geol. Geophys., v. 1, p. 1–13.

Plumb, K. A., and Gemuts, I., 1976, Precambrian geology of the Kimberley Region, Western Australia: 25th International Geological Congress, Excursion Guide 44C.

Pidgeon, R. T., 1978, 3 450 m.y. old volcanics in the Archaean layered greenstone succession of the Pilbara Block, Western Australia: Earth and Planetary Science Letters, v. 37, p. 421–428.

Preiss, W. V., Jackson, M. J., Page, R. W., and Compston, W., 1975, Regional geology, stromatolite biostratigraphy and isotopic data bearing on the age of a Precambrian sequence near Lake Carnegie, Western Australia: Geol. Soc. Australia, 1st Aust. geol. convention, Abstracts Proterozoic geology, p. 92–93.

Trendall, A. F., 1975, Introduction, *in* Geology of Western Australia: West. Australia Geol. Survey, Mem. 2, p. 25–32.

——— 1979, A revision of the Mount Bruce Supergroup: West. Australia Geol. Survey Ann. Rept 1978, p. 63–71.

van de Graaff, W. J. E., Denman, P. D., Hocking, R. M., and Baxter, J. L., 1977, Explanatory notes on the Ningaloo-Yanrey 1:250 000 geological sheet, Western Australia: West. Australia Geol. Survey Rec. 1977/9 (unpublished).

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. 50–60.

Williams, S. J., Williams, I. R., Chin, R. J., Muhling, P. C., and Hocking, R. M., 1979, Explanatory notes on the Mount Phillips 1:250 000 geological sheet, Western Australia: West. Australia Geol. Survey Rec. 1978/13.

THE DARLING FAULT: DIAMOND DRILLING RESULTS AT HARRISONS COPPER PROSPECT

by J. L. Baxter and J. L. Harris*

ABSTRACT

Diamond drilling of a geochemical anomaly for copper at Harrisons Prospect, 25 km northeast of Mingenew, (lat. 29°05′S, long. 115°37′E) by Amoco Minerals Australia Company indicates that:

(a) the Darling Fault plane is curved, and the dip ranges from 80° west near the surface to 52° west at a depth of less than 100 m;

(b) the mineralization is sub-economic with intersections averaging 0·2% Cu over a drilled distance of 30 m;

(c) mylonites in the Archaean gneissic rocks east of the fault predate development of the Darling Fault;

(d) the Darling Fault was a locus for brittle fracture in Permian and possibly Proterozoic times.

INTRODUCTION

The Darling Fault, a major structural feature in the earth's crust, was intersected in core drilling at Harrisons copper prospect (lat. 29°05′S, long. 115°37′E) by Amoco Minerals Australia Company (Amoco). The prospect is 25 km northeast of Mingenew, and 320 km north of Perth (Fig. 1).

Malachite in a silicified breccia in Archaean rocks cropping out in a steep-flowing tributary of the Lockier River, was first reported by Mr. G. W. Harrison in 1961. In 1976 the Harrison Syndicate conducted a limited exploration programme including percussion drilling. Chalcopyrite mineralization (maximum 2·3% Cu) over a drilled width of 65 m was intersected in one hole. Amoco, under a joint-venture agreement, carried out a systematic programme of exploration on the prospect during 1977. Work included: low-level colour aerial photography; airborne magnetometry and spectrometry; gridding; geological mapping; stream-sediment, soil, and rock-chip geochemistry; ground magnetics; gradient-array I.P.; and percussion-diamond drilling. Amoco's exploration programme culminated in the drilling of six combined percussion and diamond drill-holes at three locations to test a coincident soil, stream-sediment and rock-chip geochemical anomaly related to brecciated Archaean rocks immediately east of the Darling Fault. Although the mineralization encountered is sub-economic, (intersections averaged only 0·2% Cu over 30 m) the drilling provided a rare opportunity to study the Darling Fault.

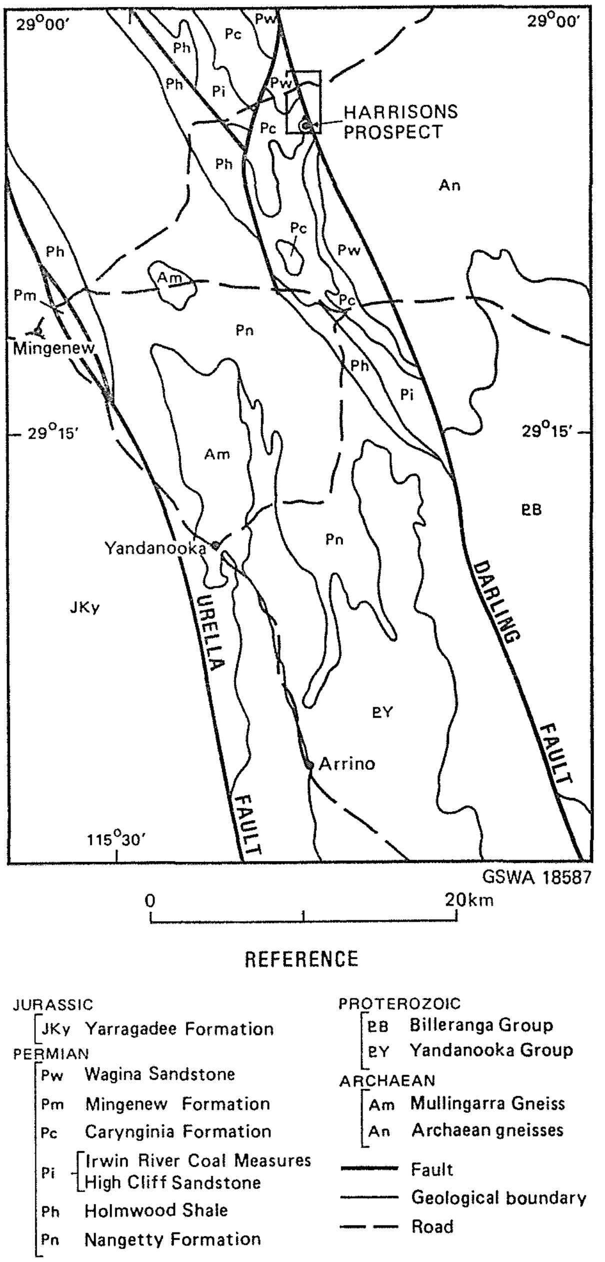
* Amoco Minerals Australia Company

TECTONIC SETTING OF THE DARLING FAULT

The Darling Fault is a normal fault, which can be traced at the surface and by geophysical methods for about 1 000 km along the western side of the Yilgarn Block. The fault forms the eastern limit of a more extensive fracture system in the Perth Basin.

Playford and others (1976) have described all data previously collected on the fault. The early history of the fault is uncertain. However, from evidence outside this area Playford and others (1976) postulated that a transcurrent fault developed along or close to the line of the present Darling Fault during the Proterozoic or early Palaeozoic and that normal faulting began later, possibly during the Silurian. In the Three Springs-Mingenew area, Proterozoic sediments have been deposited on either side of the fault. East of the fault plane, less than 1 km thickness of sediment is preserved; whereas, on the western or down-thrown side, in the Irwin Sub-basin, more than 5 km is preserved. Baxter and Lipple (in press), suggest that the fault may have acted as a growth fault during the Proterozoic. Playford and others (1976) and Hocking (1979) suggest similar activity on the fault during the Silurian, when more than 3 km of Tumblagooda Sandstone was deposited in the Coolcalalaya Sub-basin. There is no evidence of thick sedimentation in the Irwin Sub-basin after the close of the Permian, and it is probable that major movement along the fault ceased in this area during the early Mesozoic. The most prominent phase of the Darling Fault's history is seen further south. It took place between the Middle Triassic and Early Cretaceous, when movement on the Darling and Urella Faults created deep troughs during development of the Perth Basin, into which up to 15 km of sediments were deposited. Major movement on the fault ceased in the Neocomian (Early Cretaceous) (Playford and others, 1976).

Mylonite zones occur throughout the Yilgarn Block; several are located near its western and northern margins. Elias and Williams, (1977), Wilde and Low, (1978a), Wilson (1958) and Wilde and Low (1978b) interpret the mylonitization along the western margin of the Yilgarn Block as being due to a Precambrian event which may have been a forerunner of the Darling Fault, and Wilde and Low (1978b) suggest that the present position of the fault is controlled by this Precambrian event. Lister and Price (1978) in a study of the mylonite fabrics, and Wilson (1958) in a regional analysis of the south-western Yilgarn Block, conclude that compression, represented



igure 1 Regional geology and locality of Harrisons prospect, Mingenew.

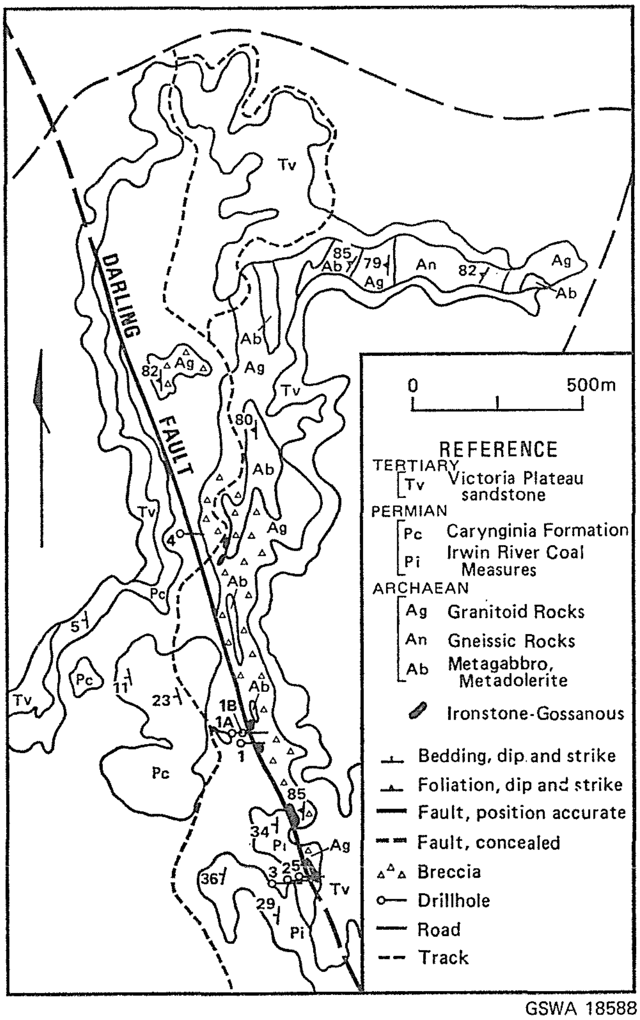


Figure 2 Surface geology at Harrisons prospect (see Fig. 1 for location).

by either transcurrent or reverse faulting, pre-dated the development of the Darling Fault. The transcurrent movement must precede the normal faulting in the Irwin Sub-basin.

GEOLOGICAL SETTING OF HARRISONS PROSPECT

Harrisons Prospect is located on the Darling Fault where the Irwin Sub-basin is faulted against the Yilgarn Block. Locally the Irwin Sub-basin contains Permian and ?Eocene sediments. The Permian sequence is restricted to the west side of the Darling Fault; whereas, the flat-lying ?Eocene Victoria Plateau Sandstone unconformably overlies both the Archaean gneisses and granitoids east of the fault, and the Permian succession west of the fault (Fig. 2). All the rock units are weathered and lateritized at the top of the breakaway exposures, but fresh rock is exposed in most of the creeks.

Archaean rocks

Diverse lithologies characterize the Archaean rock suite east of the fault. Medium- to coarse-grained granitoid and pegmatite underlie approximately half of the area investigated. The granitoids have intruded a gneissic suite which includes banded iron-formation, chert, meta-argillite, laminated pyritic graphitic schist, medium- to coarse-grained metagabbro and fine-grained mafic to ultramafic rocks. The suite is metamorphosed to lower amphibolite facies. The gneissic rocks have a predominantly north-northeasterly mineral foliation parallel to layering. On a regional scale the granitoids tend to be sub-parallel to the gneissic foliation but locally transgress the gneissosity. Generally, foliation in the granitoids is less intense than in the gneisses.

Mylonites: Laminated mylonitic rocks, characterized by deformation lamellae in quartz, and phyllitic fabric in quartz-mica rocks, occur within the granitoid and gneissic terrain east of the Darling Fault. It is generally accepted that the dominant mechanism for development of mylonites is dynamic recrystallization (Bell and Etheridge, 1973, 1976; White, 1977; Etheridge and Wilkie, 1978), and that most microstructures in the mylonites reflect a combination of dynamic recovery and recrystallization processes. Quartz ribbons, which possibly represent higher pressure deformation zones (Bossiere and Vauchez, 1978) in the granitoid host rocks, (Fig. 4 and 5) commonly have new, generally unstrained grains formed at their boundaries. Quartz-phyllite, with fine-grained mica supporting deformed quartz grains, is associated with the predominantly granitoid mylonite. (Fig. 6, 7 and 8). Passive veins formed after mylonization developed incipiently at first (Fig. 6) but finally replaced the micaceous groundmass of the mylonite, leaving the quartz grains almost intact (Fig. 7). The last stage in development of the mylonites was a spaced solution cleavage reflected in opaque clay trails (Fig. 5, 8). The presence of both crystal-plastic and solution fabrics in the mylonites indicates heterogeneous deformation pre-dating brittle fracture and mineralization.

Permian rocks

The Permian succession includes continental and marine sandstones, carbonaceous beds and siltstones. It appears that the contact between the Caryngina Formation and the Irwin River Coal Measures occurs within the lease. Exposed on the west side of the breakaway are silty sandstones, siltstones and sandstones, which are correlated with the Caryngina Formation. South of 5 100E, 50 950N, sandstone and

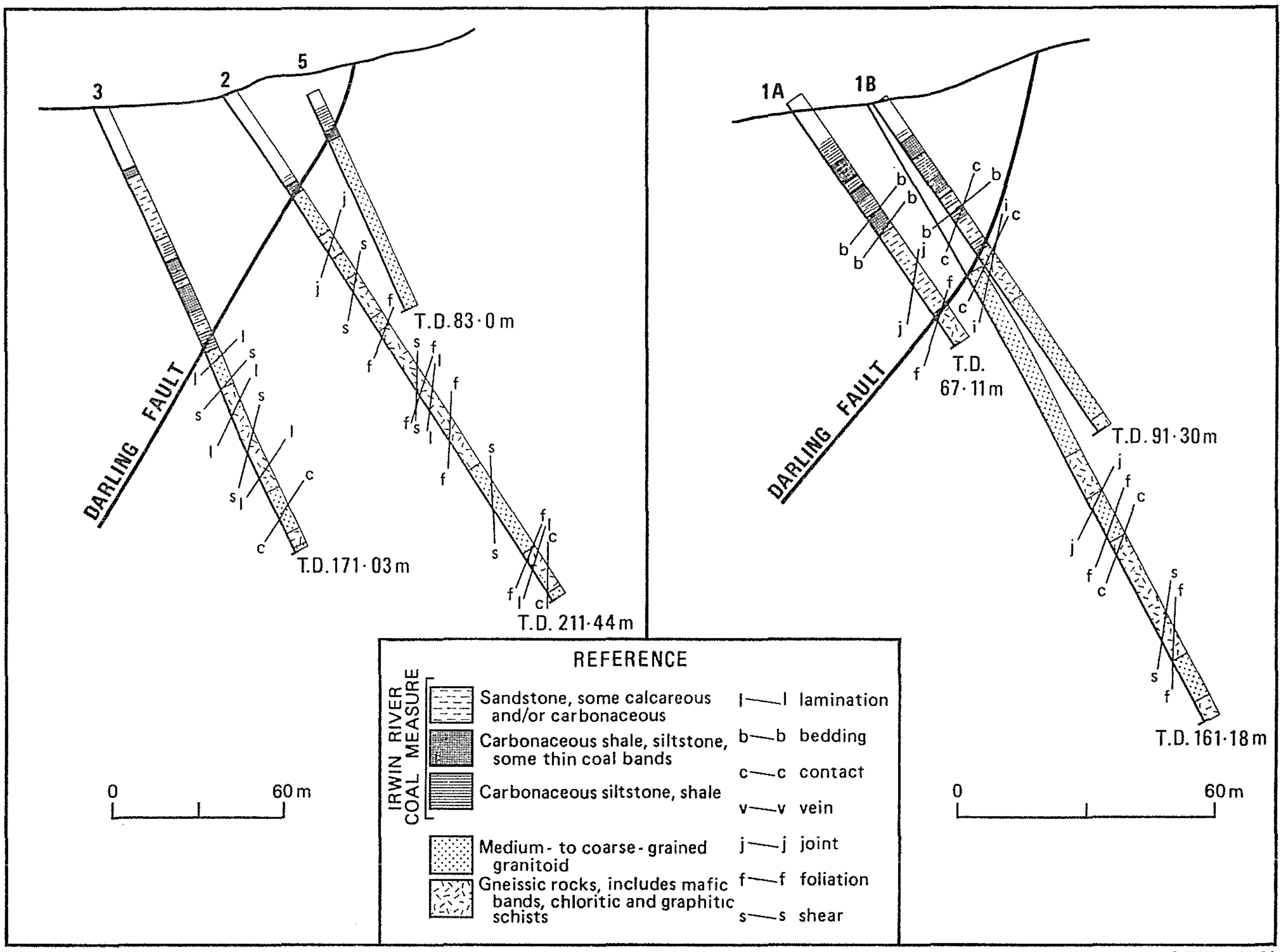


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Figure 3 Cross-sections of drilled sections at Harrisons prospect, showing the projected dip of the Darling Fault.

carbonaceous deposits containing an assemblage of palynomorphs that can be assigned to the *Acanthotriletes* assemblage of Segroves (1970) (Backhouse, 1978) probably represent the Early Permian Irwin River Coal Measures. Baryte crystals and small amounts of pyrite have been identified in the Permian sediments. Adjacent to the Darling Fault, calcite-filled joints occur in the Permian rocks.

The Darling Fault at Harrisons prospect

The Archaean rocks adjacent to the Darling Fault are mylonitized, and secondary quartz growth is common in bands throughout most lithologies. Remobilization of this quartz into veins occurs in the gneissic rocks. The mylonitization predates brecciation and gouge associated with the Darling Fault. The breccias extend up to 150 m from the fault plane, and fractures in them have been filled by fine-grained quartz. The gouge is between 0·15 and 0·30 m wide and is restricted to the fault plane. Quartz veins containing chlorite pervade the breccia zone, and are more prominent adjacent to the fault plane.

Unmetamorphosed feldspathic sandstone dykes occur within the breccia zone (Fig. 9). They are up to 0·30 m wide and up to 5 m from the fault plane, but are common within a metre of the plane. The dykes have been emplaced in the brecciated zone. They show no signs of metasomatic effects, post-date brecciation and cementation of the Archaean rocks, and are probably derived from sandstone members of the Permian succession, which they resemble lithologically.

Dip of the fault plane: Playford and others (1976) have reported dips (estimated from seismic data) on the Darling Fault in the southern part of the Perth Basin to be between 50° and 80° and tending to become steeper toward the south. The faulted contact between the Irwin River Coal Measures and the Yilgarn Block was intersected in each of the six holes drilled in this investigation. All holes were drilled on a bearing of 090° with declinations between 55 and 65°E. The contact was cored in two holes, 1A and 1B, with virtually 100% recovery. The dip data are summarized in Figure 3. When allowance is made for the 340° strike of the fault, the true dip of the fault on these two sections is 52° and 62° respectively. In constructing the cross-section care was taken to compensate for slight off-sets in positions of the drill holes in relation to the sections presented.

Exposure of the fault plane at the surface is discontinuous. However, its position at the surface can usually be determined to within a few metres. If the drill intersections of the fault are projected upward the predicted fault would be further east than where it is exposed. From this it is assumed that the fault plane is curved in the manner shown in Figure 3 and has a westerly dip of approximately 80 degrees close to the surface.

Mineralization

Chalcopyrite mineralization, disseminated in late-stage quartz-chlorite veinlets in the breccia zone over a down-hole interval of 30 to 60 m, contains an average of 0·2% copper. The style of mineralization resembles that described by Phillips (1972). Pyrite occurs in the veins, but, except where located in graphitic schist or pink coarse-grained granitoid, it is a minor component of the mineralization. The granitoid contains up to 5% sulphide, mainly as pyrite, and has low copper values.

The average grade of mineralization is independent of rock type. Brecciation and mineralization decrease eastward from the fault contact and are cut off sharply at the fault. Copper contents of the Permian sediments are in the range 20 to 30 ppm whereas the Archaean suite generally contains 1 000 to 3 000 ppm alongside the fault plane.

CONCLUSIONS

The diamond drilling of the Darling Fault has provided an insight into the dip of the fault plane and the development of the fault. It also gave further information on the only known base-metal mineralization within the Darling Fault zone.

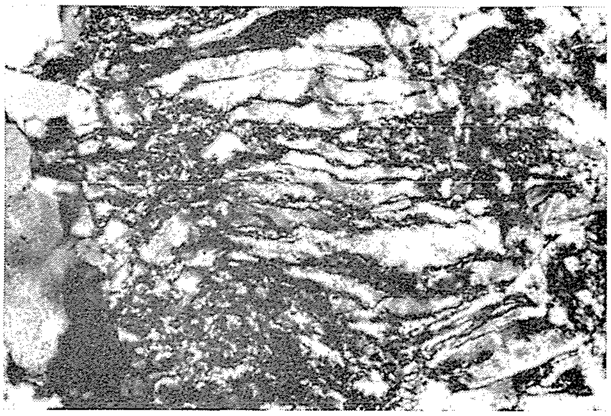

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Figure 4 Deformation lamellae with flattened quartz ribbons having new grains developed at the ribbon boundaries (crossed nicols). 44402A.

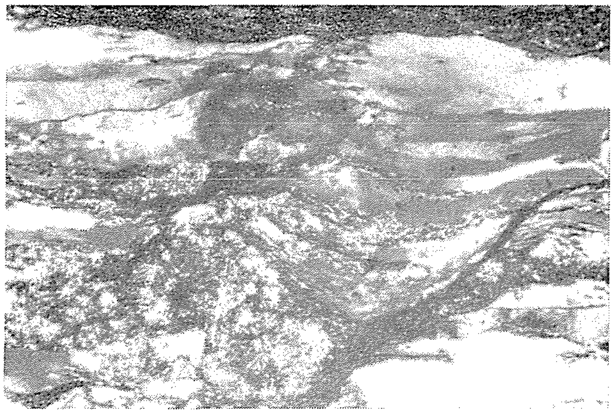

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Figure 5 Necking of quartz ribbons with new subgrains at the ribbon boundaries (crossed nicols). 44402E.

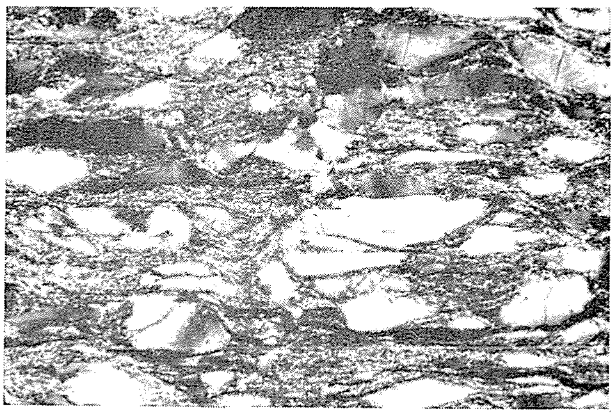

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Figure 6 Initial development of passive quartz veins in a quartz phyllite (crossed nicols). 44402A.

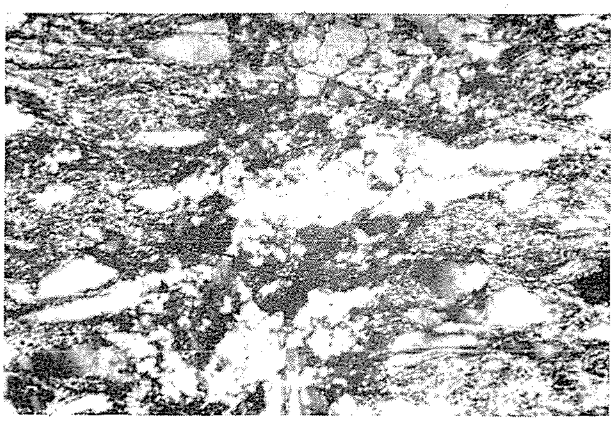

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Figure 7 Final development of passive quartz veins in a quartz phyllite (crossed nicols). 44402B.

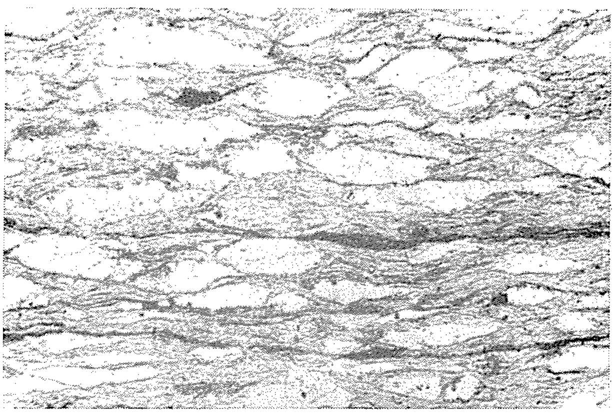

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Figure 8 Quartz phyllite with solution effects parallel to mylonite fabric (plane-polarized light). 44402B.

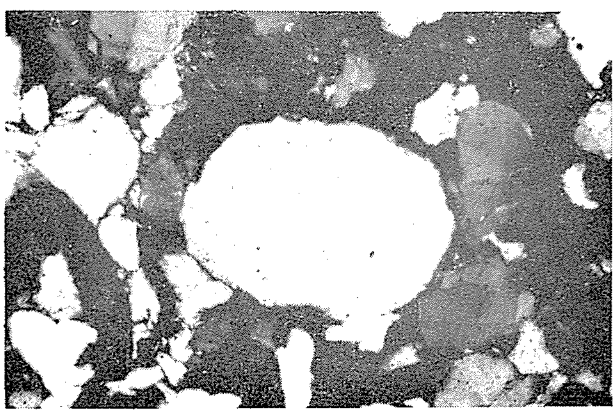

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Figure 9 Rounded unstrained quartz grain in a sandstone dyke (crossed nicols). 44403A.

It has been demonstrated that the fault plane has a relatively shallow dip at shallow depth, 52° to 62°, and is curviplanar with dips of about 80° near the surface in this area.

The Darling Fault plane contains a gouge which has been developed by grain-size reduction and mechanical reorientation of chloritic footwall material.

Mylonitization of the Archaean rocks east of the fault predates brecciation and mineralization. The mylonites have developed in a variety of rocks and contain well-developed crystal-plastic deformation and solution fabrics.

The hydrothermal fluids which introduced copper, silica and sulphur into the breccia to the east of the fault also chloritized the host rock. In view of the lack of mineralization in the sandstone dykes the process must pre-date their development. A likely source for the solutions is the Proterozoic Yandanooka Group, which underlies the Permian succession in the Irwin Sub-basin. Activity on the Darling Fault deposition of the volcanogenic wackes of the Yandanooka Group may have induced hydraulic fracturing and metasomatism of the relatively brittle mylonite zone adjacent to the fault plane. This requires a tensional stress regime.

It is apparent from these drilling results that the Darling Fault was initiated as a normal fault, developed under tension. It seems possible that movement was related to development of an asymmetric basin against the Darling Fault during deposition of the Yandanooka Group. Subsequent to the Proterozoic Era there is no record of deposition or deformation until the Permian Period. However, north of this area up to 3 000 m of Silurian sediments, (the Tumblagooda Sandstone) were deposited into a trough, bounded on the east by the Darling Fault. Permian activity on the fault is suggested by sandstone dykes of probable Permian age adjacent to the fault. There is no evidence of movement of fault bounded sedimentation in the area since the displacement of the Late Permian Wagina Sandstone.

REFERENCES

Backhouse, J., 1978, Palynology of a bore hole at Harrisons, copper prospect: West. Australia Geol. Survey Palynology Rept 57/1978, (unpublished).

Baxter, J. L. and Lipple, S. L., (in press), Explanatory notes on the Perenjori 1:250 000 geological sheet, W.A.: West. Australian Geol. Survey Rec. 1978/16.

Bell, T. H. and Etheridge, M. A., 1973, Microstructures of mylonites and their descriptive terminology: Lithos, 6, p. 337–349.

Bell, T. H. and Etheridge, M. A., 1976, The deformation and recrystallization of quartz in a mylonite zone, Central Australia: Tectonophysics, v. 32, p. 235–267.

Bossiere, G. and Vauchez, A., 1978, Deformation by ductile shear of a granite in the western Great Kabylia, Algeria: Tectonophysics, v. 51, p. 57–81.

Dennis, J. G., 1967, International Tectonic Dictionary: AAPG Mem. 7.

Elias, M. and Williams, S., 1977, Explanatory notes on the Robinson Range 1:250 000 geological sheet, W.A.: West. Australia Geol. Survey Rec. 1977/6.

Etheridge, M. A. and Wilkie, J. C., 1979, Grainsize reduction grain boundary sliding and the flow strength of mylonites: Tectonophysics, v. 58, p. 159–178.

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. for 1978, p. 40–44.

Lister, G. S. and Price, G. P., 1978, Fabric development in a quartz-feldspar mylonite: Tectonophysics v. 49, p. 37–78.

Phillips, W. J., 1972, Hydraulic fracturing and mineralization: Geol. Soc. London Jour. v. 128, p. 337–360.

Playford, P. E., Cockbain, A. E. and Low, G. H., 1976, The Geology of the Perth Basin, W.A.: West Australia Geol. Survey Bull. 124.

Segroves, K. L., 1970, The sequence of palynological assemblages in the Permian of the Perth Basin, Western Australia. A. Plantae: Gondwana Symposium, 2nd, South Africa, 1970, Proceedings & Papers p. 511–529.

White, S., 1977, Geological significance of recovery and recrystallization processes in quartz: Tectonophysics, v. 39, p. 143–170.

Wilde, S. A. and Low, G. H., 1978a, Perth, W.A.: West. Australia Geol. Survey 1:250 000 Geol. Series Explan. Notes.

Wilde, S. A. and Low, G. H., 1978b, Explanatory Notes on the PinjarraWestern Australia 1:250 000 Geological Sheet: West. Australia Geol. Survey Rec. 1978/5.

Wilson, A. F., 1958, Advances in the knowledge of the structure and petrology of the Precambrian rocks of south-western Australia: Royal Soc. West. Australia. Jour. v. 41, p. 57–83.

TWO "ANOMALOUS" ISOCHRONS FROM THE VICINITY OF NEWMAN

by J. G. Blockley, A. F. Trendall, J. R. de Laeter* and W. G. Libby

ABSTRACT

Two isochrons from the Newman area, one obtained on pillow lava from the Jeerinah Formation, and the other on granite unconformably underlying the Jeerinah Formation, give ages younger than those that could be expected from other geochronological evidence from the Mount Bruce Supergroup.

The age of 1 487 ± 305 m.y. obtained from the Jeerinah Formation lava is interpreted as reflecting a metamorphic event. The age of 2 235 ± 54 m.y. from the granite sample is considered to possibly reflect the time of uplift of the Sylvania Dome.

INTRODUCTION

In recent years the continuing Rb-Sr geochronology programme being conducted jointly by the Geological Survey of Western Australia and the Western Australian Institute of Technology has included studies of material collected from two sites near the iron-ore mining town of Newman, in the north west of Western Australia.

The first study was an attempt to date the Proterozoic Fortescue Group by determining the age of pillow basalt occurring in the Jeerinah Formation at the top of the group. The second was aimed at obtaining the age of a granite from the Sylvania Dome and thereby determining also a maximum age for the unconformably overlying Jeerinah Formation.

Both studies produced well-aligned isochrons. However, neither the age indicated for the basalt, nor that indicated for the granite are consistent with other geochronological evidence, if they are interpreted simply as the ages of extrusion and emplacement respectively.

Both are therefore regarded as being anomalous. The purpose of this paper is to record the analytical results and to suggest possible explanations for them. At present, no single hypothesis to account for either "age" is completely satisfactory.

REGIONAL GEOLOGICAL SETTING

Newman is situated near the southeastern edge of the Proterozoic Hamersley Basin, close to the northern edge of the Sylvania Dome, an inlier of presumed Archaean rocks (Fig. 1). The Jeerinah Formation is part of the Hamersley Basin succession. It constitutes the uppermost unit of the Fortescue Group, which in turn is the lowermost group in the Mount Bruce Supergroup (MacLeod and others, 1962; Trendall, 1979). A column showing formal stratigraphic units mentioned in this paper appears in Figure 2.

The lower part of the Fortescue Group is missing near Newman—shale of the Jeerinah Formation rests unconformably on granitic rocks of the Sylvania Dome. The granitic rocks have not been mapped in detail, but near Newman consist of strongly foliated biotite adamellite and massive to

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weakly foliated alkali granite. By analogy with the geologically similar Pilbara Block we would expect these to represent older and younger periods of granite emplacement respectively.

The structure near Newman is complex. Rocks of the Mount Bruce Supergroup form a series of asymmetric folds overturned to the north, so that the south limb of each syncline is near vertical and the north limb subhorizontal (Kneeshaw, 1975). The whole structure is cut by major faults. The Sylvannia Dome is affected by the faults and reticulated by dolerite dykes of several ages.

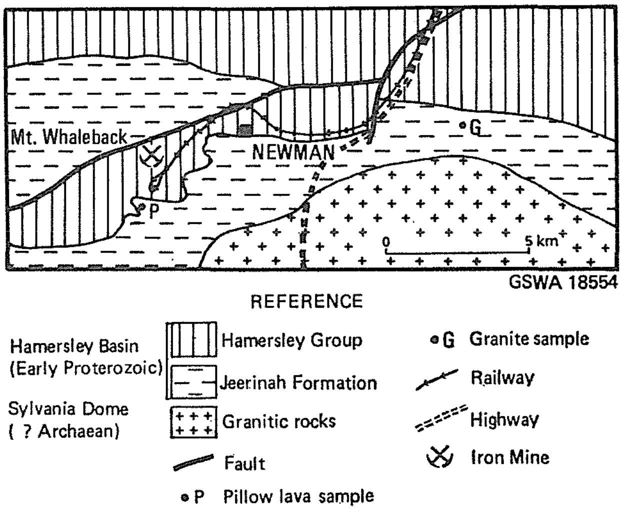


Figure 1 Plan of Newman area showing main geological units and sample localities.

MATERIAL ANALYZED

JEERINAH FORMATION BASALT

Field relationships

Samples of pillow basalt (30596 A–E) were collected from a ballast quarry 9 km southwest of Newman (Fig. 1). The quarry lies in the south limb of a syncline, so that the basalt, of which some 20 m stratigraphic thickness is exposed, is subhorizontal and not evidently deformed. The pillows range in exposed cross-sectional diameter between about 0·4 and 1·3 m, and their shapes clearly indicate that the sequence is right-way-up (Fig. 3A). Just south of the quarry the basal part of the Marra Mamba Iron Formation is exposed, dipping south-southwest at about 20°. There is thus little doubt that the basalt lies in the upper part of the Jeerinah Formation. It evidently represents part of the mafic material mapped and described by Daniels and MacLeod (1965) (who did not have the benefit of excavated exposures) as thick, persistent and concordant sills of dolerite.

Petrography

Although the samples collected were the freshest available, all appeared bleached, aphanitic and structureless. The generally close spacing of joints made it impossible to obtain evidently fresh material. In spite of their unpromising macroscopic appearance the samples show no sign of recent weathering when observed in thin section. A close mesh of albite platelets up to 0·5 mm long is intimately intergrown with finer felted fibres of almost colourless amphibole, locally and patchily clouded with a dust of scattered sphene. A lesser proportion of pale chlorite also contributes to the groundmass, and subhedral grains of clinozoisite up to 1 mm across are evenly distributed through the rock.

GRANITE

Field relationships

Samples 54917A–G come from a bulldozed costean in a small inlier of the alkali granite exposed about 15 km east of Newman, apparently at a local high point in the basement relative to the surrounding Jeerinah Formation. Except for 54917F, which is of a cross-cutting aplite dyke, the samples are all of coarse-grained alkali granite. A prominent bed of podded chert a few metres above the granite/Jeerinah Formation contact has been identified elsewhere in the eastern Hamersley Basin at a position some 400 to 500 m below the top of the formation.

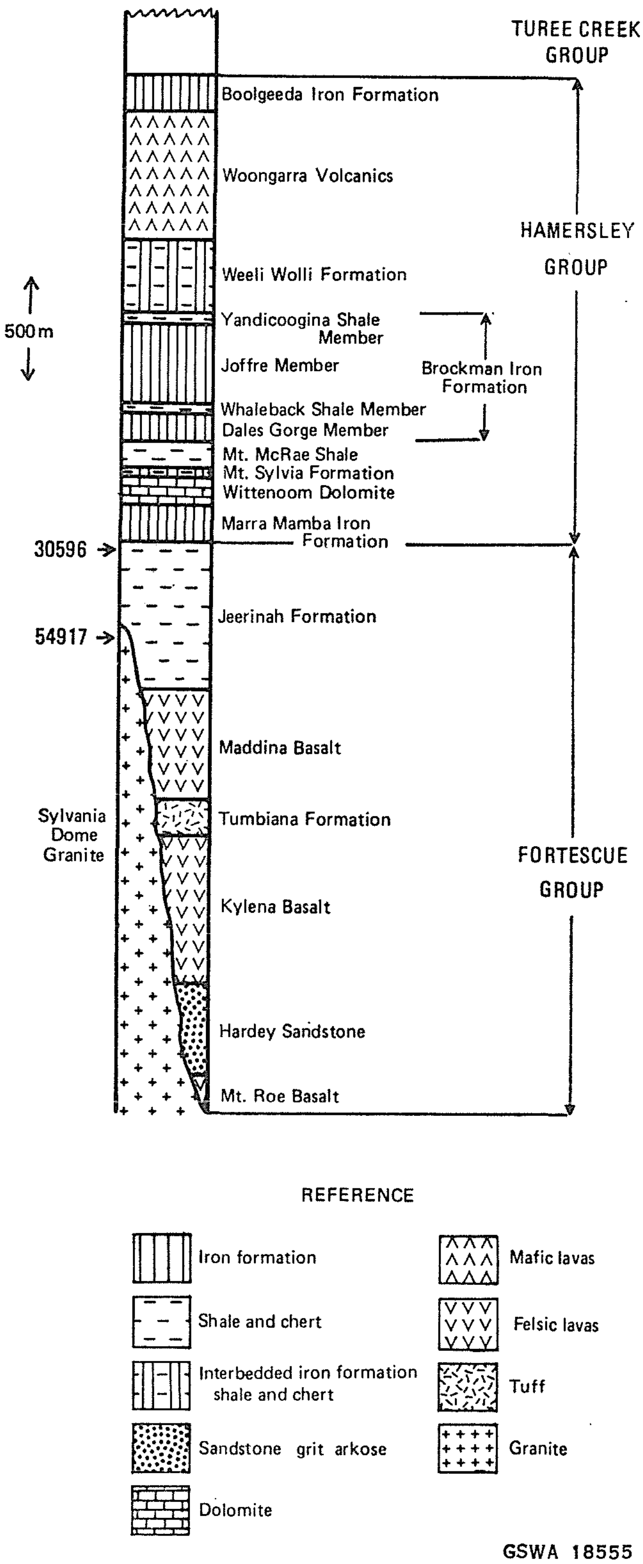


Figure 2 Stratigraphic column of Mount Bruce Supergroup (as redefined by Trendall, 1979) showing formations and members referred to in text. Principal lithologies only of each unit are indicated in the legend.

Near the granite, the shale, chert, and tuff beds of the Jeerinah Formation strike easterly and dip 30 to 40 degrees south. Converging chert beds indicate that there is a general thinning of the units towards the granite. However, the podded chert mentioned above is appreciably thickened and contorted near the granite, suggesting that it has slumped, or has been involved in local folding.

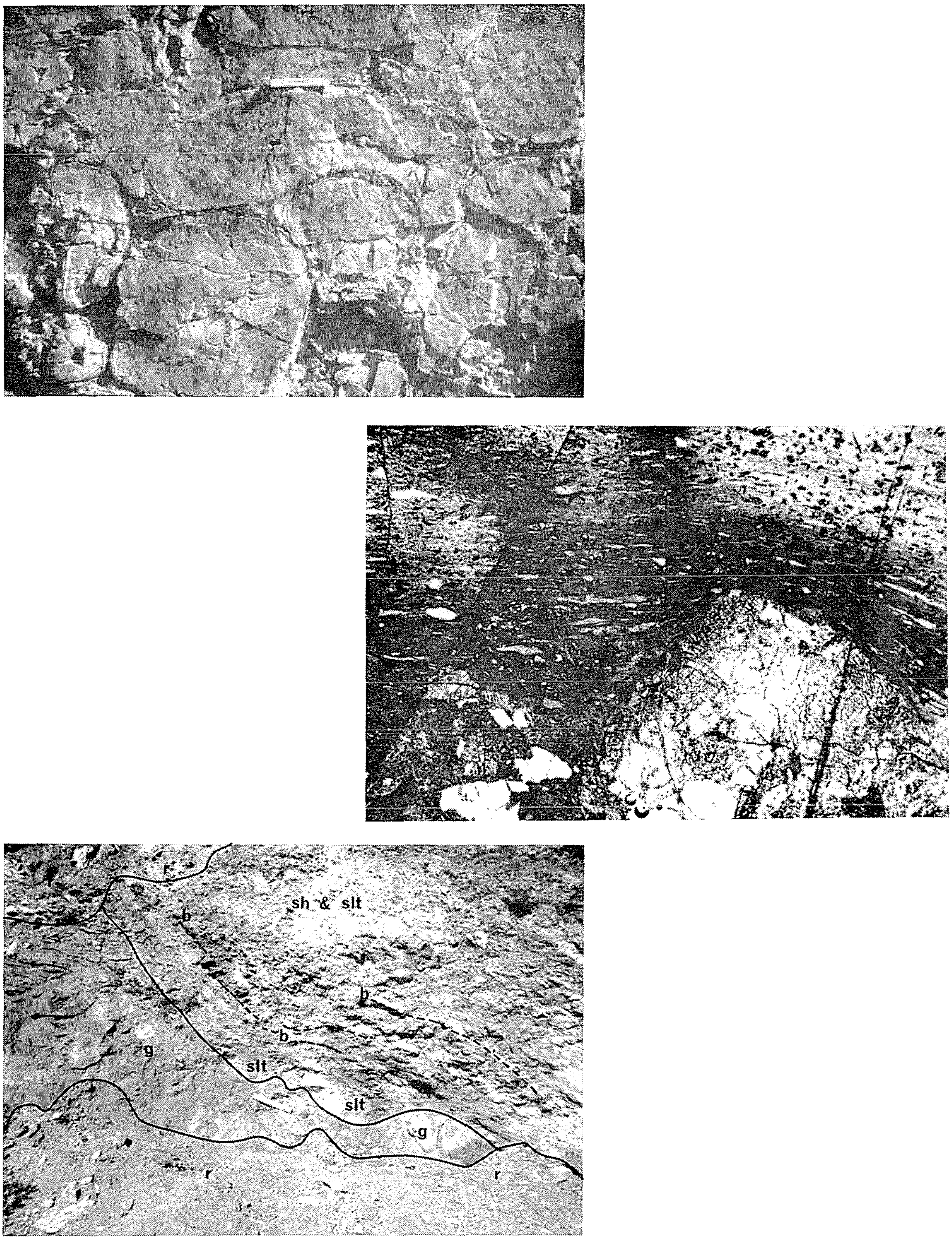


Figure 3 (A) Photograph of pillows in ballast quarry 9 km southwest of Newman. This pillow lava, in the upper part of the Jeerinah Formation, gives an anomalous Rb-Sr age of 1 487 m.y. The scale is 250 mm long.

(B) Photomicrograph of part of the shale/granite contact (see Fig. 3C) 15 km east of Newman. The shale laminations show compaction over a protruding phenocryst in the granite. The dark colour near the contact and along fractures is due to iron staining. The black rods of leucoxene after ilmenite are prominent in the upper right-hand corner. Lenticular clear patches, probably representing original mud pellets, show progressive deformation towards the contact. The prominent line near the right hand edge is a scratch on the slide (plane polarized light). GSWA 51757A x16·5.

(C) Photograph showing shale/granite contact at the site of sample 54917. Generally the bedding of the shale is parallel to the contact, but there are some irregularities in the granite surface. Hollows in this surface are filled with poorly bedded siltstone. The scale is 250 mm long. Letter symbols are as follows: r = rubble; g = granite; slt = siltstone; sh = shale; and b = bedding.

The shale/granite contact

The contact between the granite and Jeerinah Formation shale is well exposed in the costean. Apart from minor irregularities in the surface of the granite, the contact is parallel to the bedding of the shale (Fig. 3C). There is no decrease in grain size of the granite at the contact and no apparent contact metamorphic effects in the shale. No veins of granitic material cut the shale and there are no xenoliths of shale in the granite. Hollows in the granite contain slightly coarser silty material, but no well-defined basal arkose or conglomerate is present.

From this mainly negative field evidence it was concluded that the contact is an unconformity. However, as a further check for possible contact metamorphic effects in the shale, a number of thin sections were cut from across the contact and at varying distances from the granite. Sections cut through the contact show that the granite has been considerably altered, with much of the feldspar being destroyed; however, there is no suggestion of fine-grained chilling effects, and bedding seems to be draped over projecting grains in the granite (Fig. 3B). These factors confirm that the shale is in depositional contact with the granite.

Shale in contact with the granite is an almost cryptocrystalline mixture of phyllosilicates (probably sericite), dusty limonite, and presumed quartzofeldspathic minerals. Elongate pods, defined by their relative freedom from dusty iron-oxide, range from 0·15 mm to 1·0 mm long and are strongly oriented parallel to the contact with the granite. The pods probably represent clasts in the primary sediment. Within a few centimetres of the contact the degree of flattening of the pods increases with proximity to the contact.

Ilmenite, replaced largely by leucoxene, occurring as fine-grained stubby rods much coarser than the matrix, is very abundant in samples within a few centimetres of the contact with the granite, and in some samples at a greater distance. The rods have a weak preferred orientation parallel to the granite contact. Very fine phyllosilicates wrap around the ends of ilmenite grains. As the orientation of the ilmenite is much weaker than the orientation of the clasts, the ilmenite probably post-dates the clasts but predates the final deformation of the rock.

The possibility of the ilmenite being a contact-metamorphic mineral is discounted both on the textural evidence cited above, and the low metamorphic grade of the rock as a whole. Data presented by Best and Weiss (1964) indicated that in pelitic rocks contact-metamorphic ilmenite is associated with sillimanite and cordierite. Neither of these minerals was observed in the shale.

Petrography of the granite

The granite is a quartz-albite-microcline rock with microcline rather more abundant than quartz and albite. Mafic minerals have been replaced by very fine aggregates of chlorite and/or biotite. Relict shapes of the mafic aggregates indicate that amphibole as well as biotite was present. Apatite and zircon are the primary accessories, apatite being particularly prominent. Opaque and quasi-opaque minerals are mainly or wholly secondary and probably have replaced sphene.

The rock is coarse, hypidiomorphic inequigranular. Feldspars range from coarse to very coarse. Albite and, less perfectly, microcline, are euhedral against coarsely recrystallized quartz. Rarely, euhedral microcline forms sheaths around a euhedral core of albite. More commonly, euhedral albite grains are scattered in the larger microperthitic microcline grains. All feldspars are clouded with minute inclusions, perhaps in part chlorite. Epidote was not identified. Deformation and recrystallization are mild, limited mainly to quartz, though there are a few healed fractures in most samples, and feldspar has been substantially fragmented and recrystallized in one sample. Amphibole in a rock of this composition together with abundant apatite suggests that the granite has alkaline affinities.

A medium-grained, even-textured granophyric aplite cuts the granite. Much of the aplite is a vermicular intergrowth of quartz and feldspar around plagioclase and microcline grains. Mafic material present as biotite is rare.

EXPERIMENTAL PROCEDURES

The experimental procedures for Rb/Sr analyses used in this study were essentially the same as those described by Lewis and others (1975). 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 9·375 2. The value of $1·42 \times 10^{-11}$ 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, was well as the calculated $^{87}Rb/^{86}Sr$ ratios are given in Table 1. Errors accompanying the data are at the 95 per cent confidence level. The Rb and Sr concentrations in each sample 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.

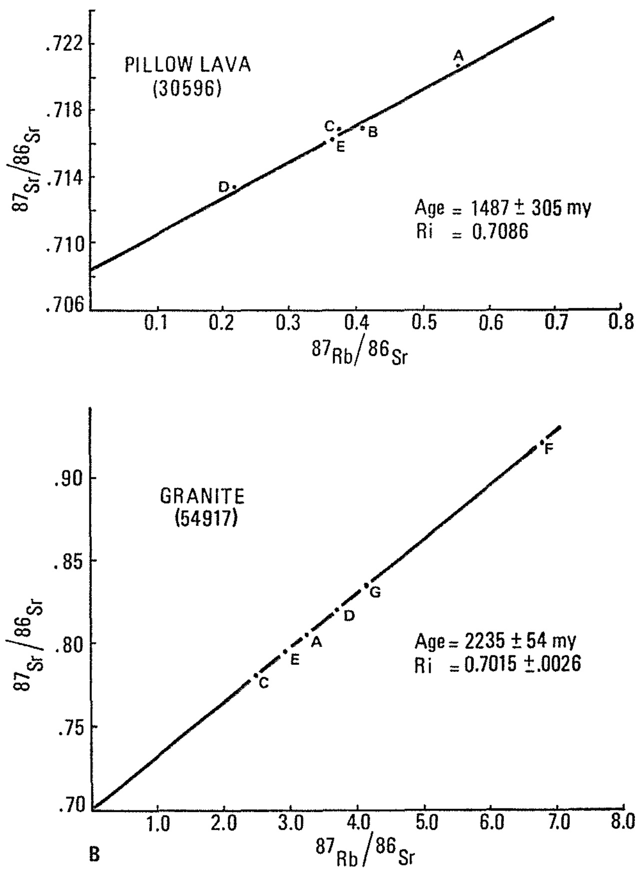
The data listed in Table 1 have been regressed using the least-squares programme of McIntyre and others (1966). The age and initial ratio of the alkali granite are 2 235 $\pm$ 54 m.y. and 0·701 5 $\pm$ 0·002 6 respectively. The mean square of the weighted deviates (MSWD) is 0·45, which indicates that the variations are within the range of experimental errors. The age and initial ratio of the Jeerinah lava are 1 487 $\pm$ 305 m.y. and 0·708 6 $\pm$ 0·001 7 respectively. The MSWD is 0·66, which is again within the range of experimental errors, the large range of possible error in age being due to the fact that only five samples with a limited range in Rb/Sr were available for analysis.

DISCUSSION

SIGNIFICANCE OF GRANITE AGE

The well-fitting isochron obtained from the granite samples would seem to support earlier estimates that deposition of the Mount Bruce Supergroup began at about 2 300 m.y. BP (Geol. Survey of Western Australia, 1975, p. 31). A discussion of the geochronological evidence for this estimate is given by Trendall and de Laeter (1972).

However, there is a body of later evidence which suggests that all components of the Mount Bruce Supergroup (as re-defined by Trendall, 1979) are appreciably older than 2 300 m.y. Such evidence includes: a Rb-Sr age of about 2 600 m.y. for shale from the Hardey Sandstone (Hickman and de



GSWA 18557

Figure 4 Isochrons from the Newman area.

(A) Five samples of pillow lava from near the top of the Jeerinah Formation (Samples 30596 A-D).

(B) Six samples of granite and cross-cutting aplite (F) from granite of the Sylvania Dome unconformably underlying the Jeerinah Formation (Samples 54917 A-F).

As discussed in the text, neither isochron is regarded as giving the primary igneous ages of the samples.

TABLE 1. ANALYTICAL DATA FOR JEERINAH PILLOW LAVA AND SYLVANIA DOME GRANITE

Sample	Rb (ppm)	Sr (ppm)	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
Jeerinah pillow lava					
30596 D	9	124	0·075 6 ± 0·000 8	0·219 ± 0·002	0·713 37 ± 0·000 21
30596 E	15	112	0·127 ± 0·002	0·367 ± 0·004	0·716 32 ± 0·000 25
30596 C	14	105	0·129 ± 0·002	0·373 ± 0·004	0·716 85 ± 0·000 28
30596 B	14	100	0·142 ± 0·002	0·410 ± 0·005	0·717 07 ± 0·000 24
30596 A	10	52	0·192 ± 0·003	0·555 ± 0·006	0·720 59 ± 0·000 19
Sylvania Dome granite					
54917 C	170	200	0·86 ± 0·01	2·50 ± 0·03	0·782 15 ± 0·000
54917 E	195	195	1·01 ± 0·02	2·94 ± 0·04	0·796 34 ± 0·000
54917 A	190	170	1·12 ± 0·02	3·26 ± 0·04	0·805 96 ± 0·000
54917 D	190	150	1·27 ± 0·02	3·71 ± 0·05	0·821 68 ± 0·000
54917 G	190	135	1·42 ± 0·02	4·15 ± 0·05	0·835 29 ± 0·000
54917 F	170	75	2·30 ± 0·03	6·78 ± 0·09	0·919 98 ± 0·000

Laeter, 1977); a model lead age of about 2 700 m.y. from galena in a vein cutting the Kylena Basalt (Richards, 1977); a U-Pb age of 2 490 m.y. on zircons from the Dales Gorge Member of the Brockman Iron Formation (Compston and others, in prep.); an age of about 2 350 m.y. for intrusive dolerite within the Weeli Wolli Formation (Trendall and de Laeter, in prep.); and a minimum age of 2 400 m.y. for the Woongarra Volcanics (Compston and others, in prep.).

If this more recent geochronology is accepted, then the isochron obtained from the granite samples cannot be interpreted simply as the age of intrusion, giving the maximum age of the Jeerinah Formation. Other possible explanations for what appears to be a geologically significant isochron are therefore examined in turn.

1. The granite actually intrudes the Jeerinah Formation.

   The field and petrographic evidence described previously makes an intrusive relationship between granite and the Jeerinah Formation very unlikely.

2. The shale resting on the granite is not part of the Jeerinah Formation.

   The distinctive podded chert band forming part of the succession near the contact has been identified elsewhere in the eastern Hamersley Basin, where it is undoubtedly part of the Jeerinah Formation.

3. The isochron gives the age of metamorphism of the granite. Calculations using the relationship defining the $^{87}Sr/^{86}Sr$ ratio (Faure and Powell, 1972, p. 12) and assuming an average $^{87}Rb/^{86}Sr$ ratio of 3·0 for the granite give a crustal residence time of 35 m.y. for R_i = 0·701 5, or 95 m.y. for R_i = 0·704 1 (i.e. 0·701 5 + 0·002 6). In either case the original (intrusive) age of the granite is still too young to be compatible with other geochronological results summarized above.

4. Sr isotopes in the granite have equilibrated with Proterozoic water of the Hamersley Basin.

   Although apparently fresh, the granite samples come from only a few metres below the unconformity. They have sufficient granulation of grain boundaries to suggest that they *may* have been permeated by water at the time when the Jeerinah Formation was deposited. It is possible that the Sr isotopes in the granite attained equilibrium with those in the permeating basin water. Veizer (1975) indicated that the $^{87}Sr/^{86}Sr$ ratio at about 2 235 m.y. BP was in the order of 0·702 0 to 0·703 5, figures not inconsistent with the R_i of 0·701 5 ± 0·002 6 found in the granite.

   If this hypothesis is correct, then the isochron gives the time at which the uplift of the Sylvania Dome led to final dewatering of the Hamersley Basin sediments in this area, allowing the granite to dry out and the isotopes to lose mobility.

SIGNIFICANCE OF BASALT AGE

For the reasons already given, the isochron age of 1 487 ± 305 m.y. obtained from the basalt samples certainly cannot be accepted as an extrusive age. An extensive regional "event" at about 1 700 m.y., during which Sr isotopes were redistributed, is well established elsewhere in an about the Hamersley Basin (Leggo and others, 1964; Trendall and de Laeter, 1972; Compston and others, in prep.; Trendall and de Laeter, in prep.), and this event has already been reported in the Newman area (Linley, 1975). It presumably corresponds with a period of metamorphism and folding, possibly related to the Ashburton Fold Belt (Gee, 1979). At present we accept the basalt isochron as an expression of this event.

ACKNOWLEDGEMENTS

We are pleased to acknowledge the co-operation of Mr. B. Willis and Mr. M. Kneeshaw of Mount Newman Mining Company Pty Ltd, who drew attention to the two exposures, made available a company bulldozer to assist with the sampling of the granite, and provided maps to help our geological interpretation of the geochronological results.

REFERENCES

Best, M. G., and Weiss, L. E., 1964, Mineralogical relations in some pelitic hornfelses from the southern Sierra Nevada, California: American Mineralogist v. 49, p. 1240–1266.

Compston, W., Trendall, A. F., Williams, I. R., Foster, J., and Arriens, P. A., in prep., A reassessment of the age of the Hamersley Group.

Daniels, J. L., and MacLeod, W. B., 1965, Newman, W. A.: West Australia Geol. Survey 1:250 000 Geol. Series Explan. Notes.

Faure, G., and Powell, J. L., 1972, Strontium Isotope Geology: Berlin, Springer-Verlag.

Gee, R. D., 1979, Structure and tectonic style of the Western Australian Shield: Tectonophysics v. 58, p. 327–369.

Geological Survey of Western Australia, 1975, Geology of Western Australia: West. Australia Geol. Survey Mem. 2.

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. Survey Ann. Rept. 1976, p. 62–68.

Kneeshaw, M., 1975, Mt. Whaleback iron orebody, Hamersley Iron Province; *in* Knight, C. L., (ed.) Economic Geology of Australia and Papua New Guinea, I. Metals: Australasian Inst. Mining and Metallurgy Mon. 5, p. 910–916.

Leggo, P. J., Compston, W., and Trendall, A. F., 1965, Radiometric ages of some Precambrian rocks from the Northwest Division of Western Australia: Geol. Soc. Australia Jour. v. 12, p. 53–66.

Lewis, J. D., Rosman, K. R. M., and de Laeter, J. R., 1975, The age and metamorphic effects of the Black Range dolerite dyke: West. Australia Geol. Survey Ann. Rept. 1974, p. 80–88.

Linley, J. G., 1975, Genesis of the Mount Whaleback iron ore deposit: Univ, Adelaide, Ph.D. thesis (unpublished).

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.

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.

Richards, J. R., 1977, Lead isotopes and ages of galenas from the Pilbara Region, Western Australia: Geol. Soc. Australia Jour. v. 24(8), p. 465–473.

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.

Trendall, A. F., 1979, A revision of the Mount Bruce Supergroup: West Australia Geol. Survey Ann. Rept. 1978, p. 63–71.

Trendall, A. F., and de Laeter, J. R., 1972, Apparent age and origin of black procellanite of the Joffre Member: West. Australia Geol. Survey Ann. Rept. 1971, p. 68–74.

——— in prep, A Revised age for dolerite sills of the Weeli Wolli Formation.

Veizer, J., 1975, $^{87}Sr/^{86}Sr$ evolution of seawater during geologic history and its significance as an index of crustal evolution; *in* Windley, B. F., (ed.), The Early History of the Earth: John Wiley and Sons, London.

Rb-Sr DATING OF GRANITIC ROCKS IN THE PEMBERTON AREA

by K. J. R. Rosman*, S. A. Wilde, W. G. Libby and J. R. de Laeter*

ABSTRACT

Rubidium-strontium isotope analysis of 37 samples from 7 localities in the Manjimup-Northcliffe-Walpole area of south-western Western Australia confirm the westward extension of the Proterozoic Albany-Fraser Province. In the vicinity of Northcliffe, the Proterozoic belt is at least 50 km wide and may extend farther northward. Model dates suggest that the Proterozoic rocks are primitive; that is, they were not derived within the crust from Archaean precursors.

INTRODUCTION

The Albany-Fraser Province is a Proterozoic mobile belt which extends around the southern margin of the Archaean Yilgarn Block. The Fraser Range section of the province, northeast of Ravensthorpe, has been the subject of several regional geochronological studies (Wilson and others, 1960; Arriens and Lambert, 1969; and Bunting and others, 1976). In the Albany area, several studies (Wilson and others, 1960; Turek and Stephenson, 1966; and Stephenson and others, 1977) have established the presence of Proterozoic rocks; however, their extension to the west and north has been in doubt. This doubt prompted the present reconnaissance study of the western sector of the province.

SAMPLES

Collection

A suite of samples was collected from each of seven areas, roughly constituting a north-south traverse of the suspected westward extension of the Albany-Fraser Province (Fig. 1). Each suite was assigned a number, and each sample within the suite was assigned a letter suffix. The location of each suite together with a brief description is shown in Table 1.

Suites 55810 to 55815 are outcrop samples collected by one of the authors (S.A.W.) in 1978. Sample 54161 F consists of a single diamond drill core segment, from Planet Mining Co. Drillhole DDH 14.

Co-ordinates of localities mentioned in the text are based on the 10 000 yard transverse mercator grid and were taken from the Pemberton (SI 50–10) 1:250 000 sheet.

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Description

Suite 55810: This suite of samples was collected from the Gibralter Quartz Monzonite (Walker, 1977; Wilde and Walker, 1979) which forms a discontinuous, curvilinear belt up to 100 km long (Fig. 1). The main sample site was 1·5 km northeast of Grevillea Fire Tower (4327 7916). The rock is variable, consisting chiefly of fine-grained quartz monzonite with scattered amphibolite xenoliths, and diffuse areas of coarse-grained material with scattered megacrysts of hornblende. There are also areas which are more gneissic. Sample 55810 F was collected 4·7 km east of Palgarup (4212 7760) from the south-west continuation of the quartz monzonite. The rock is even-grained with a strong lineation and weaker foliation.

Several samples have deep, dusky-green clinopyroxene, probably aegirine-rich, either as solitary grains or cores in mafic knots. These, together with microcline megacrysts, may antedate a prominent deformation event during which the other major minerals (feldspar, quartz, biotite and hornblende) were recrystallized. Garnet is present in sample 55810 E, which also has abundant clinopyroxene, very coarse sphene and prominent apatite.

Suite 55811: Poorly exposed migmatic rocks extend from Northcliffe northeast toward Quininup. They are inter-developed with granitic gneisses of uncertain affinities, which also outcrop further west.

The sample site was a creek bed, exhumed by the bursting of an earth dam, alongside the Wheatley Coast Road, 12·4 km north-northeast of Northcliffe (4162 7363). The earliest phase present is a fine- to medium-grained augen gneiss that varies from a compositionally layered variety to a more homogeneous variety with a streaky foliation. The gneiss is cut by veins and larger, more irregular, areas of even-grained adamellite. Veins of pegmatite, commonly bearing garnet, cut both the gneiss and the adamellite.

Under the microscope, protomylonitization obscures the distinct contrast between gneissic and isotropic phases observed in the field. Typically, abundant feldspar porphyroclasts are set in crystal-plastically deformed mortar, mainly quartz defining a flaser structure. Garnet, hastingsitic hornblende, together with failure of plagioclase to degrade from andesine, all suggest deformation at elevated temperature.

TABLE 1. LOCATION AND BRIEF DESCRIPTION OF SAMPLES

Sample Number	Locality Name	Location		Grid	Notes on individual samples
		Lat.	Long.		
54161	Yornup diamond corehole	34°05′	116°11′	4212 7760	*GNEISS* Biotite amphibolite
55810	Grevillea Fire Tower	34°04′	116°19′	4327 7916 (4212 7760)	*GIBRALTER QUARTZ MONZONITE* A. Typical fine-grained phase B. Fine-grained, leuco., gneissic variety C. Med. to coarse grained with hbld. megacrysts D. Coarse grained, marginal to gneiss E. Coarse grained, marginal to gneiss
55811	Northcliffe	34°32′	116°09′ 30″	4162 7363	*MIGMATITE* A. Fine-grained, compositionally layered gneiss with feldspar augen B. Mesocratic foliated adamellite with mafic schlieren C. Streaky augen gneiss D. Late pegmatite with clasts of earlier material E. Adamellite, coarser than B F. Late pegmatite
55812	Mount Chudalup	34°45′	116°04′	4076 7089	*ADAMELLITE* A–D & F. Typical E. Slightly weathered
55813	Windy Harbour	34°50′	116°01′	4005 6981	*GRANULITE* A. Melanocratic gneiss with lighter layers B. Ultramafic boudins in lighter material C. Leucrocratic felsic gneiss D. Pyroxene granulite E. Leucocratic granulite F. Leucocratic granulite G. Interlayered leucocratic/melanocratic gneiss
55814	Wainbup	34°47′	116°17′	4267 7007	*ADAMELLITE* A, D. Typical adamellite B, C. Adamellite with leucocratic veins E. Coarser adamellite F. Gneissic adamellite G. Strongly gneissic adamellite
55815	Walpole	34°57′	116°35′	4576 6865	*PORPHYRITIC GRANITE* A, D. Typical deformed porphyritic granite B, E. Mafic-rich variety C. Fine-grained variety

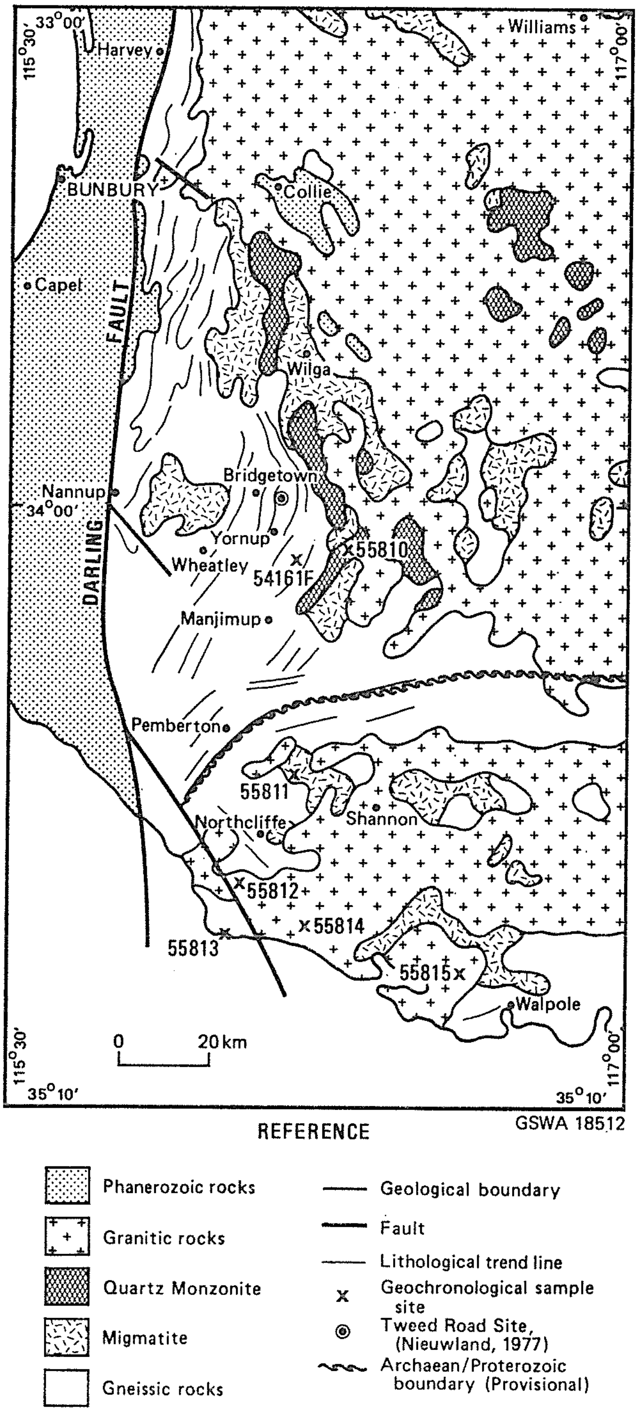

Figure 1 Sample localities and regional geology.

Suite 55812: Irregular areas of even-grained adamellite are associated with high-grade rocks of charnokitic affinity, granulite facies gneisses, and porphyritic granite south of Northcliffe. They are exposed as tree-covered knolls protruding from the coastal plain.

The sample site (4076 7089), where fresh rock had been exposed by blasting, is 1·2 km north-northwest of Mount Chudalup. The rock is a medium-grained, hornblende-bearing adamellite with a moderately strong cataclastic fabric.

Principal minerals are biotite, hornblende, quartz, microcline and calcic oligoclase. Deformed feldspar and mafic minerals are set in a mortar of quartz and shredded biotite.

Suite 55813: Granulite facies rocks are sporadically exposed between Windy Harbour and Mount Chudalup. The samples were collected from the foreshore at Windy Harbour (4005 6981). Units of felsic and mafic granulite are interlayered and there are also lenses and boudins of ultramafic composition, rich in both ortho- and clinopyroxene. Veins of orthopyroxene traverse the units, especially in the eastern parts of the exposure.

The mafic and ultramafic assemblages contain hornblende, clinopyroxene, hypersthene and plagioclase (samples 55813 A, B, and D). The intermediate phases (samples 55813 C and E) have quartz, oligoclase and hypersthene, with less biotite and minor microcline. Sample 55813 C contains quartz, oligoclase and perthite and is free of mafic minerals. Sample 55813 E is composed primarily of oligoclase antiperthite with quartz, about 5% hypersthene and very minor biotite.

Suite 55814: Even-grained adamellite is subordinate to the dominant porphyritic varieties in a large granitic area east of Northcliffe (Figure 1).

The even-grained adamellite was sampled from an exposure 24·5 km east of Windy Harbour (4267 7007) that was blasted during construction of Chesapeake Road.

Porphyroclasts of microcline and subordinate sodic oligoclase are set in a recrystallized, mylonitic, medium-grained matrix of quartz, feldspar, biotite, muscovite, and epidote.

Suite 55815: A body of coarse, even-grained to porphyritic granite forms an isolated area west of Walpole (Fig. 1). The porphyritic granite was sampled from blasted material along the South Coast Highway, 14·8 km west-northwest of Walpole (4576 6865).

All samples show some degree of cataclastic deformation, with slight rounding of microcline megacrysts and thorough recrystallization of quartz. Allanite is conspicuous in some samples and fluorite is abundant in samples 55815A and B.

Sample 54161*F:* The material was obtained from Planet Metals drill hole number DDH Y14 (4212 7760) sunk to test a nickel prospect near Yornup. The core was collected between 132·84 m and 133·22 m (depth from surface).

The rock is a medium-grained biotite amphibolite with minor quartz.

EXPERIMENTAL PROCEDURES

The experimental procedures used in this study were essentially the same as those described by Lewis and others (1975). 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

The measured Rb/Sr and $^{87}Sr/^{86}Sr$ ratios as well as the calculated $^{87}Rb/^{86}Sr$ ratios are shown in Table 2. Errors accompanying the data are at the 95% confidence level. The Rb and Sr concentrations in each sample are also listed. However, these concentrations are only accurate to ± 7% 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 2 have been regressed using the least-squares programme of McIntyre and others (1966). The results of regression, based on a decay constant of 1·42 x 10^{-11} yr^{-1} (Steiger and Jäger, 1977), are shown in Table 3 together with model dates for each suite based on an assumed $^{87}Sr/^{86}Sr$ initial ratio of 0·700.

DISCUSSION

The only previous geochronological data directly applicable to this study is a date of 2 838 ± 200 m.y. obtained by Nieuwland (written communication, 1977) from layered gneiss at Tweed Road, 5 km southeast of Bridgetown (Fig. 1).

Five of the seven localities sampled in the present study provide useful geochronological data, although the small range in isotopic ratios creates large uncertainties in results obtained by the isochron "method". The two remaining localities fail to provide data which can be readily interpreted; plotted points from suite 55813 (Windy Harbour) are extremely scattered and 54161 F (Yornup drillcore) is an isolated sample with a low $^{87}Rb/^{86}Sr$ ratio.

Isochrons (Fig. 2) from suites 55811, 55812, 55814, and 55815 yield dates which range from 733 m.y. to 1 289 m.y., with little indication of progressive increase in age across the province (Fig. 1 and Table 3). However, model dates in Table 3 (calculated to mean $^{87}Rb/^{86}Sr$ and $^{87}Sr/^{86}Sr$ values for each suite) range less widely and show a systematic decrease from suite 55810 in the north to suite 55815 in the south. This gradient is consistent with southward decreasing dates within the Fraser Range section of the Albany-Fraser Province described by Bunting and others (1976). The assumed initial ratio of 0·700 assures that model dates generated are close to maximum ages if the system is geochemically closed. This analysis of maximum model dates strongly suggests that these rocks were not derived from Archaean precursors. Such a hypothesis would have to involve either the introduction of Rb into, or the selective removal of radiogenic Sr from, an immense volume of crust, or both.

TABLE 2. ANALYTICAL DATA FOR WHOLE ROCK SAMPLES FROM THE PEMBERTON SHEET

Sample	Rb (ppm)	Sr (ppm)	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
55810—					
B	79	700	0·113 ± 0·002	0·327 ± 0·004	0·715 15 ± 0·000 42
F	89	712	0·125 ± 0·002	0·362 ± 0·004	0·715 32 ± 0·000 12
E	130	1 000	0·129 ± 0·002	0·373 ± 0·004	0·715 32 ± 0·000 28
A	105	786	0·135 ± 0·002	0·391 ± 0·004	0·714 20 ± 0·000 15
D	127	768	0·166 ± 0·002	0·481 ± 0·005	0·719 43 ± 0·000 56
C	133	785	0·169 ± 0·002	0·489 ± 0·005	0·719 90 ± 0·000 31
55811—					
C	185	170	1·09 ± 0·01	3·17 ± 0·04	0·774 80 ± 0·000 19
B	238	216	1·09 ± 0·01	3·18 ± 0·04	0·765 25 ± 0·000 19
A	210	148	1·42 ± 0·02	4·13 ± 0·05	0·786 00 ± 0·000 19
D	328	205	1·59 ± 0·02	4·64 ± 0·05	0·795 05 ± 0·000 48
E	253	145	1·74 ± 0·02	5·09 ± 0·06	0·800 30 ± 0·000 27
55812—					
E	175	241	0·724 ± 0·008	2·10 ± 0·03	0·745 28 ± 0·000 29
A	180	225	0·796 ± 0·008	2·31 ± 0·03	0·749 96 ± 0·000 19
B	181	216	0·836 ± 0·009	2·43 ± 0·03	0·751 17 ± 0·000 20
F	177	235	0·843 ± 0·009	2·45 ± 0·03	0·751 22 ± 0·000 50
C	187	215	0·871 ± 0·009	2·53 ± 0·03	0·753 27 ± 0·000 25
D	196	217	0·903 ± 0·009	2·62 ± 0·03	0·755 53 ± 0·000 54
55813—					
D	1·5	250	0·006 ± 0·000 1	0·017 4 ± 0·000 5	0·707 86 ± 0·000 28
A	3·4	162	0·019 ± 0·000 2	0·055 ± 0·001	0·726 90 ± 0·000 31
E	33	300	0 108 ± 0·001	0·313 ± 0·004	0·726 17 ± 0 000·80
F	33	292	0·111 ± 0·001	0·322 ± 0·004	0·727 00 ± 0·000 32
G	35	230	0·153 ± 0·002	0·444 ± 0·005	0·744 49 ± 0·000 21
C	120	201	0·599 ± 0·007	1·75 ± 0·02	0·785 35 ± 0·000 80
B	30	36	0·835 ± 0·009	2·43 ± 0·03	0·754 78 ± 0·000 67
55814—					
A	221	166	1·33 ± 0·02	3·87 ± 0·04	0·775 11 ± 0·000 35
D	238	161	1·48 ± 0·02	4·33 ± 0·05	0·782 24 ± 0·000 72
E	226	149	1·52 ± 0·02	4·42 ± 0·05	0·783 74 ± 0·000 20
G	226	148	1·53 ± 0·02	4·45 ± 0·05	0·784 94 ± 0·000 24
B	235	152	1·54 ± 0·02	4·48 ± 0·05	0·782 67 ± 0·000 37
F	229	145	1·59 ± 0·02	4·64 ± 0·05	0·788 27 ± 0·000 33
C	256	152	1·69 ± 0·02	4·93 ± 0·05	0·790 26 ± 0·000 18
55815—					
C	344	148	2·32 ± 0·03	6·78 ± 0·07	0·827 17 ± 0·000 25
A	334	133	2·52 ± 0·03	7·37 ± 0·08	0·833 73 ± 0·000 25
D	361	142	2·55 ± 0·03	7·46 ± 0·08	0·833 79 ± 0·000 25
B	363	137	2·65 ± 0·03	7·77 ± 0·08	0·838 00 ± 0·000 39
–	375	135	2·78 ± 0·03	8·15 ± 0·09	0·840 59 ± 0·000 89
:4161—					
F	8·5	410	0·021 ± 0·001	0·061 ± 0·000 8	0·706 50 ± 0·000 24

TABLE 3. PEMBERTON GEOCHRONOLOGY

	Regression age	Ri	Model	Model age	Assumed Ri
54161 F	....	....	....	....	....
55810	2 327 ± 1 624	·703 0 ± ·009 2	3	2 828	·700
55811	944 ± 246	·731 6 ± ·014	3	1 454	·700
55812	1 289 ± 258	·706 6 ± ·008 6	3	1 478	·700
55813	....	....	....	....	....
55814	1 047 ± 266	·717 3 ± ·016	2	1 316	·700
55815	733 ± 107	·756 2 ± ·010	2	1 252	·700

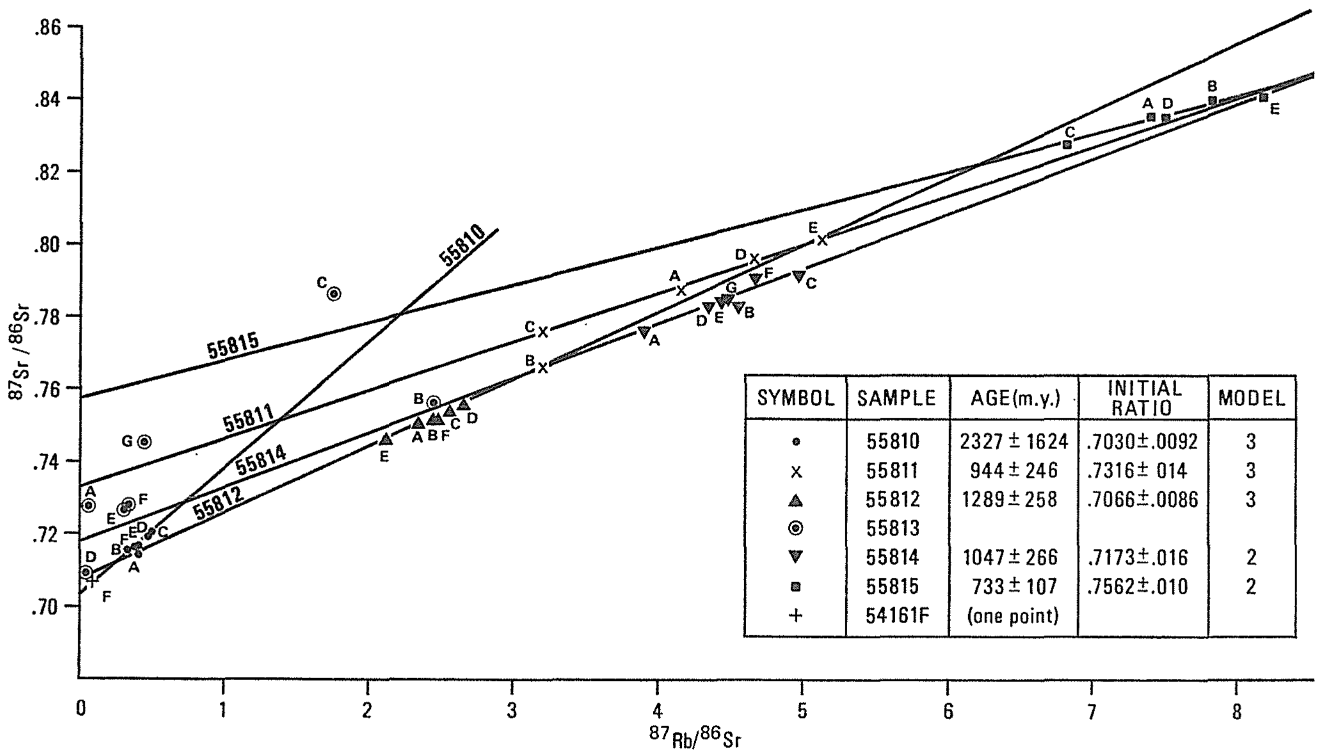

Figure 2 Isochron plot of 37 whole-rock Rb-Sr analyses from the Pemberton map sheet.

It seems likely that suite 55810 (Gibralter Quartz Monzonite) from near Grevillea Fire Tower is Archaean. The model date is well within the Archaean, the sample site is near the better controlled Archaean site of Nieuwland (written communication, 1977), the site is within the area of north-south regional structural trends characteristic of the Archaean Yilgarn Block, and the isochron regression, though Early Proterozoic, includes Archaean dates well within the error limits.

Even assuming an Archaean age for the rocks at Grevillea Fire Tower, the location of the Archaean-Proterozoic boundary is not closely defined by isotopic dating. The location of the boundary shown on Figure 1 is the best current estimate based on geological and structural controls that are consistent with the Rb-Sr geochronology.

CONCLUSIONS

The reconnaissance Rb-Sr geochronological study in the Manjimup-Northcliffe-Walpole area has demonstrated that the Proterozoic Albany-Fraser Province extends westward from Albany at least to within 20 km of Pemberton and has a north-south extent of more than 50 km.

The lack of evidence for Archaean precursors, combined with the apparent high initial $^{87}Sr/^{86}Sr$ ratios of some rocks suggest that the area had a complex Proterozoic history. This history includes a period of gneissification, formation of migmatite, and emplacement of even-grained and porphyritic granitic rocks.

A fuller evaluation of geochronological and geological data will accompany the report from further studies, now in progress, which are aimed at more precisely defining both the nature and position of the Archaean-Proterozoic boundary.

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REFERENCES

Arriens, P. A. and Lambert, I. B., 1969, On the age and strontium isotope geochemistry of granulite-facies rocks from the Fraser Range, Western Australia, and the Musgrove Ranges, Central Australia: Geol. Soc. Australia Spec. Pub. No. 2, p. 377–388.

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 for 1975, p. 117–126.

Lewis, J. D., Rosman, K. J. R., and de Laeter, J. R., 1975, The age and metamorphic effects of the Black Range dolerite dyke: West. Australia Geol. Survey Ann. Rept. 1974, p. 80–88.

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.

Stephenson, N. C. N., Russell, T. G., Stubbs, D., amd Kalocsai, G. I. Z., 1977, Potassium-argon ages of hornblendes from the Precambrian gneisses from the south coast of Western Australia: Royal Soc. of West. Australia Jour. v. 59, p. 105–109.

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. 449–458.

Walker, I. W., 1978, Hornblende-bearing granitoids of quartz-monzonite affinity from the southwest of the Yilgarn Block: West. Australia Geol. Survey Ann. Rept. for 1977, p. 44–49.

Wilde, S. A. and Walker, I. R., 1979, Explanatory notes on the Collie 1:250 000 geological sheet, Western Australia: West. Australia Geol. Survey Rec., 1979/11.

Wilson, A. F., Compston, W., Jeffery, P. M. and Riley, G. H., 1960, Radioactive ages from the Precambrian rocks in Australia: Jour. Geol. Soc. Australia, v. 6, pp. 179–195.

PERMIAN AMMONOIDS FROM THE CARNARVON BASIN – A REVIEW

by A. E. Cockbain

ABSTRACT

Permian ammonoids are known from the following units in the Carnarvon Basin (listed in ascending order): Callytharra Formation (*Metalegoceras* n. sp. Glenister and Furnish, *Mescalites* sp., *Svetlanoceras irwinense*); Wooramel Group—Cordalia Sandstone (*Pseudoschistoceras simile*), Billidee Formation (*Neocrimites* sp., *Bamyaniceras* sp.); Byro Group—Coyrie Formation (*P. simile*, *Neocrimites* sp., *Bamyaniceras* n. sp. Glenister and Furnish), Mallens Sandstone (*Bamyaniceras* sp.), Bulgadoo Shale, Quinnanie Shale and Wandagee Formation (*Bamyaniceras australe*), Nalbia Sandstone (*B. australe*, *Paragastrioceras wandageense*, *Daubichites goochi*); Kennedy Group—Coolkilya Sandstone (*D. goochi*, *Agathiceras applanatum Popanoceras* sp. indet. Glenister and Furnish). On the basis of the ammonoids the Callytharra Formation is Sterlitamakian (late Sakmarian), the Wooramel Group and Byro Group up to the Nalbia Sandstone are Baigendzhinian (mid Artinskian), and the Nalbia Sandstone to Coolkilya Sandstone are Roadian (late Artinskian or early Kungurian). All the ammonoid-bearing units are Early Permian in age.

INTRODUCTION

Ammonoids have been accorded a high value in the study of Permian stratigraphical palaeontology. It is unfortunate, therefore, that so few are known from Australia. In the eastern states about 60 specimens belonging to 2 genera are known, while in Western Australia, apart from the several hundred *Juresanites jacksoni* from the Holmwood Shale of the Perth Basin, only about 100 specimens belonging to 12 genera have been reported.

Some 40 specimens in 10 genera occur in the Carnarvon Basin. Nearly all have been described in 3 publications (Teichert, 1942, 1944, Glenister and Furnish, 1961) and their stratigraphical distribution has been documented by (among others) Glenister and Furnish (1961) and Condon (1967). However, because of different interpretations of the stratigraphy, particularly those of Teichert (e.g. 1957) and Condon (e.g. 1954) it is uncertain what formations some of the ammonoids came from. Now that the Geological Survey has completed the remapping of the basin it is an appropriate time to review the stratigraphical distribution of the Permian ammonoids, report some new records, and assess the age of the units in the light of these data. The stratigraphic nomenclature used follows the recent revision of Hocking and others (1980).

PERMIAN STAGE NAMES

There has been little uniformity in naming the major subdivisions of the Permian. Ross and Ross (1979) give a useful outline of Permian stratigraphical palaeontology. The accompanying table (Table 1) is an attempt to summarise and compare several of the more recently proposed schemes. The Geological Survey currently uses the subdivision of McWhae and others (1958). However, a more detailed subdivision for the Lower Permian (the part with which this paper is concerned) is needed and I follow Furnish (1973) with the substitution of Baigendzhinian in place of Leonardian for the middle substage of the Artinskian. The major difference between this scheme and that currently adopted by the Survey (see Table 1) is in the abandonment of the Kungurian Stage; early Kungurian rocks are here called Roadian and placed in the late Artinskian. The status of the Kungurian Stage is the subject of considerable debate (see, for example, Waterhouse, 1976). Ross and Ross (1979) refer to the "Kungurian facies" and point out that many of the Kungurian evaporite beds in the Urals may prove to be Artinskian, Ufimian or Kazanian in age. The few Kungurian ammonoids are similar to those of the Artinskian (Glenister and Furnish, 1961).

TABLE 1. COMPARISON OF VARIOUS SUBDIVISIONS OF THE PERMIAN

<table>
<tr><th>McWHAE AND OTHERS 1958 AND CURRENT GSWA USAGE</th><th colspan="2">GLENISTER AND FURNISH, 1961</th><th>MOORE, 1965 NORTH AMERICA</th><th>MOORE, 1965 EUROPE</th><th colspan="2">NASSICHUK AND OTHERS, 1965</th><th colspan="2">FURNISH, 1973</th><th colspan="2">WATERHOUSE, 1976</th><th>DICKENS, 1976</th><th>ROSS AND ROSS, 1979</th></tr>
<tr><td>TRIASSIC</td><td colspan="2">TRIASSIC</td><td>TRIASSIC</td><td>TRIASSIC</td><td colspan="2">TRIASSIC</td><td colspan="2">TRIASSIC</td><td rowspan="3">DORASHAMIAN</td><td>GRIESBACHIAN</td><td>TRIASSIC</td><td>TRIASSIC</td></tr>
<tr><td rowspan="4">TATARIAN</td><td colspan="2" rowspan="4">DZHULFIAN</td><td rowspan="4">OCHOAN</td><td rowspan="4">TATARIAN</td><td colspan="2" rowspan="4">DZHULFIAN</td><td rowspan="4">DZHULFIAN</td><td>CHANGHSINGIAN</td><td>OGBINAN</td><td rowspan="4">TATARIAN</td><td rowspan="4">DZHULFIAN</td></tr>
<tr><td rowspan="2">CHHIDRUAN</td><td>VEDIAN</td></tr>
<tr><td rowspan="3">DJULFIAN</td><td rowspan="2">BAISALIAN</td></tr>
<tr><td>ARAKSIAN</td></tr>
<tr><td rowspan="3">KAZANIAN</td><td rowspan="7">GUADALUPIAN</td><td rowspan="3">CAPITANIAN</td><td rowspan="7">GUADALUPIAN</td><td rowspan="3">KAZANIAN</td><td rowspan="6">GUADALUPIAN</td><td rowspan="3">CAPITANIAN</td><td rowspan="6">GUADALUPIAN</td><td>AMARASSIAN</td><td>URUSHTENIAN</td><td rowspan="3">KAZANIAN</td><td rowspan="6">KAZANIAN</td></tr>
<tr><td rowspan="2">CAPITANIAN</td><td rowspan="2">PUNJABIAN</td><td>CHHIDRUAN</td></tr>
<tr><td>KALABAGHIAN</td></tr>
<tr><td rowspan="4">KUNGURIAN</td><td rowspan="4">WORDIAN</td><td rowspan="4">KUNGURIAN</td><td rowspan="3">WORDIAN</td><td rowspan="3">WORDIAN</td><td rowspan="2">KAZANIAN</td><td>SOSNOVIAN</td><td rowspan="2">UFIMIAN</td></tr>
<tr><td>KALINOVIAN</td></tr>
<tr><td rowspan="2">KUNGURIAN</td><td>IRENIAN</td><td rowspan="2">KUNGURIAN</td></tr>
<tr><td rowspan="4">ARTINSKIAN</td><td>Not Named</td><td rowspan="4">ARTINSKIAN</td><td>ROADIAN</td><td>FILIPPOVIAN</td><td rowspan="4">ARTINSKIAN</td></tr>
<tr><td rowspan="3">ARTINSKIAN</td><td rowspan="3">ARTINSKIAN</td><td rowspan="2">BAIGENDZHINIAN</td><td rowspan="3">LEONARDIAN</td><td rowspan="3">ARTINSKIAN</td><td rowspan="2">BAIGENDZHINIAN</td><td rowspan="2">LEONARDIAN</td><td rowspan="2">BAIGENDZINIAN</td><td>KRASNOUFIMIAN</td><td rowspan="3">ARTINSKIAN</td></tr>
<tr><td>SARGINIAN</td></tr>
<tr><td>AKTASTINIAN</td><td>AKTASTINIAN</td><td>AKTASTINIAN</td><td rowspan="3">SAKMARIAN</td><td>AKTASTINIAN</td></tr>
<tr><td rowspan="5">SAKMARIAN</td><td colspan="2" rowspan="2">SAKMARIAN</td><td rowspan="5">WOLFCAMPIAN</td><td rowspan="5">SAKMARIAN</td><td rowspan="2">SAKMARIAN</td><td>STERLITAMAKIAN</td><td rowspan="5">SAKMARIAN</td><td>STERLITAMAKIAN</td><td>STERLITAMAKIAN</td><td rowspan="5">SAKMARIAN</td><td rowspan="2">SAKMARIAN</td></tr>
<tr><td>TASTUBIAN</td><td>TASTUBIAN</td><td>TASTUBIAN</td></tr>
<tr><td colspan="2" rowspan="3">ASSELIAN</td><td colspan="2" rowspan="3">ASSELIAN</td><td rowspan="3">ASSELIAN</td><td rowspan="3">ASSELIAN</td><td>KURMAIAN</td><td rowspan="3">ASSELIAN</td></tr>
<tr><td>USKALIKIAN</td></tr>
<tr><td>SURENAN</td></tr>
</table>

Where the columns are vertically subdivided the units shown are stages and substages except in the Furnish, 1973 column where series and stages are shown.
Thick horizontal line marks boundary between Lower and Upper Permian except in the Waterhouse, 1976 column where Lower, Middle and Upper Permian are indicated.

GSWA 18464

TABLE 2. STRATIGRAPHIC DISTRIBUTION OF PERMIAN AMMONOIDS OF THE CARNARVON BASIN

STRATIGRAPHIC UNIT		*Mescalites* sp.	*Svetlanoceras irwinense* (Teichert and Glenister), 1952	*Metalegoceras* n.sp. Glenister and Furnish, 1961	*Pseudoschistoceras simile* Teichert, 1944	*Neocrimites* sp.	*Bamyaniceras* sp.	*Bamyaniceras* n.sp. (Glenister and Furnish), 1961	*Bamyaniceras australe* (Teichert), 1942	*Paragastrioceras wandageense* Teichert, 1942	*Daubichites goochi* (Teichert), 1942	*Agathiceras applanatum* Teichert, 1944	*Popanoceras* sp. indet. Glenister and Furnish, 1961	AGE SUBSTAGE
KENNEDY GROUP (PART)	COOLKILYA SANDSTONE										UWA 20504–07 35777	UWA 21451	CPC 1775	ROADIAN
BYRO GROUP	BAKER FORMATION													
	NALBIA SANDSTONE								UWA 20145	UWA 20142	UWA 20507*			
	WANDAGEE FORMATION								CPC 1763 F21628 UWA 20144 a,b 20509,10					BAIGENDZHINIAN
	QUINNANIE SHALE								UWA 23237					
	CUNDLEGO FORMATION													
	BULGADOO SHALE								CPC 1764 F21629 A–D					
	MALLENS SANDSTONE						×							
	COYRIE FORMATION				UWA 21326–29 21440 39097,98	CPC 1777		CPC 1765 F21627 GSWA F11077/1						
WOORAMEL GROUP	BILLIDEE FORMATION					CPC 1776	×							
	MOOGOOLOO SANDSTONE													
	CORDALIA SANDSTONE				GSWA F10163									
	CALLYTHARRA FORMATION	×	×	CPC 1770										STERLITAMAKIAN

* Teichert (1942) recorded this as *Pseudoschistoceras* sp.

GSWA 18465

UWA University of Western Australia Geology Department specimen number
CPC Bureau of Mineral Resources Commonwealth Palaeontological Collection
GSWA Geological Survey of Western Australia specimen number

STRATIGRAPHICAL DISTRIBUTION IN THE CARNARVON BASIN

The stratigraphical distribution of Permian ammonoids in the Carnarvon Basin is summarized in Table 2. Distribution details and remarks on the age significance of the species (where appropriate) are given below. The genera are dealt with in alphabetical order. Specimen numbers are those of the University of Western Australia Geology Department (UWA), the Bureau of Mineral Resources Commonwealth Palaeontological Collection (CPC) and the Geological Survey of Western Australia (GSWA).

Agathiceras applanatum Teichert

1944 *Agathiceras applanatum* Teichert: p. 85, pl. 17 figs. 6, 7, text fig. 1.
1961 *Agathiceras applanatum* Teichert; Glenister and Furnish: p. 696, pl. 80 figs. 6, 7, text fig. 5A.

OCCURRENCE

Coolkilya Sandstone. UWA 21451 (the only known specimen) came from "... 300 yards [274 m] east of the mouth of the southeastern gully of Wandagee Hill (23°50½'S, 114°27½'E) ... about 90 feet [27 m] below the top of the Coolkilya Greywacke (Teichert, 1952, p. 130), where it is associated with *Pseudogastrioceras goochi*" (Glenister and Furnish, 1961, p. 697).

REMARKS

A long ranging genus with limited biostratigraphical value.

Bamyaniceras australe (Teichert)

1942 *Propinacoceras australe* Teichert: p. 224, pl. 35 figs. 2–7, text fig. 3C.
1961 *Propinacoceras australe* Teichert; Glenister and Furnish: p. 691, pl. 78 figs. 6–13, text fig. 3A.

OCCURRENCE

1. Nalbia Sandstone. UWA 20145 (holotype) came from the "... same horizon as *Helicoprion davisii* and *Paragastrioceras wandageense* (Teichert, 1952, p. 130), on the west limb of the syncline north of Wandagee Hill, 1 475 yards [1 349 m] north of the Wandagee-Minilya road ..." (Glenister and Furnish, 1961, p. 693). As discussed under *P. wandageense* this locality is in the Nalbia Sandstone.

2. Wandagee Formation. UWA 20144 a, b, 20509, 20510 from the Wandagee Formation, "... east limb of syncline exposed along the Minilya River west of Coolkilya Pool ... also ... 1 1/3 miles [2·1 km] south of Coolkilya Pool, just south of an important E.W. fault" (Teichert, 1942, p. 226). CPC 1763, F21628 from "1·5 miles [2·4 km] on a bearing of 52° from Curdamuda Well and 2·6 miles [4·2 km] on a bearing of 278° from Cundlego Well, at 23°44'06"S, 114°24'49"E ..." respectively "... approximately 300 feet [91 m] above the base and ... 190 feet [58 m] above the base of the Wandagee Formation" (Glenister and Furnish, 1961, p. 693).

3. Quinnanie Shale. UWA 23237 "... from the Quinnanie Shale near Coolkilya Pool on the south bank of the Minilya River" (Glenister and Furnish, 1961, p. 693).

4. Bulgadoo Shale. CPC 1764 "... from 136 feet [42 m] below the top of the Bulgadoo Shale at a point 2·0 miles [3·2 km] on a bearing of 151° from Donnelly's Well at 24°05'03"S, 115°05'36"E" (Glenister and Furnish, 1961, p. 693). CPC F21629A-D "... from near the base of the Bulgadoo Shale ... 7·6 miles [12·2 km] on a bearing of 231° from Moogooloo Trig (K58), at 23°38'42"S, 114°38'33"E" (Glenister and Furnish, 1961, p. 693).

The species is also known from the Liveringa Formation (Canning Basin).

REMARKS

Glenister and Furnish (1961, p. 693) included the species in the *Propinacoceras knighti* group. According to Glenister (pers. comm. 1979) "... true *Propinacoceras* is exclusively Wordian, and ... the homeomorphic group of *P. knighti* is confined to the Artinskian (through Roadian) ... All Australian occurrences formerly referred to *Propinacoceras* should now be assigned to *Bamyaniceras*" (Termier and Termier, 1970). *B. australe* is the commonest Permian ammonoid in the Carnarvon Basin.

Bamyaniceras n. sp. (Glenister and Furnish)

1961 *Propinacoceras* n. sp. Glenister and Furnish: p. 694, pl. 78 figs. 14, 15, text fig. 4.

OCCURRENCE

Coyrie Formation. CPC 1765 and F21627 are from the same locality as the Coyrie Formation *Neocrimites* (i.e. 24°06′06″S, 115°08′04″E). GSWA F11077/1 came from float collected below the outcrop of the carbonaceous shale near the base of the Coyrie Formation at 25°06′10″S, 115°08′45″E.

Bamyaniceras sp.

OCCURRENCE

1. Billidee Formation. Condon (1954, p. 62) recorded *Propinacoceras* from a unit labelled "75 feet [23 m] of soft dark-grey laminated coarse-grained siltstone" from what is now the upper part of the type section of the Billidee Formation (see Condon, 1967, fig. 79 wherein the record is repeated). Condon (1967, p. 97) also lists the genus from "4½ miles [7·2 km] west of Moogooree homestead and ½ mile [0·8 km] north of the Moogooree/Donnellys Well road" in the Billidee Formation.

2. Mallens Sandstone. Dickins (1956) identified *Propinoceras* sp. ind. (sic) from the "Bogadi Greywacke" (now called Mallens Sandstone, see Hocking and others (1980)) from "4 3/8 miles [7·0 km] on a bearing of 059° from Keogh Hill, near base". Condon (1967, p. 152) also gave this record and adopted the same erroneous spelling.

Daubichites goochi (Teichert)

1942 *Pseudogastrioceras goochi* Teichert: p. 227, pl. 35 figs. 12–16.
1942 *Pseudogastrioceras* sp. Teichert: p. 229, pl. 35 fig. 8 (see Glenister and Furnish, 1961, p. 721).
?1960 *Pseudogastrioceras fortieri* Harker *in* Harker and Thorsteinsson: p. 75, pl. 24 figs. 3–5, pl. 25 figs. 1–3 (see Nassichuk, 1970, p. 84)
1961 *Pseudogastrioceras goochi* Teichert; Glenister and Furnish: p. 719, pl. 84 figs. 1–4, pl. 85 figs. 1, 2, 5–7, text figs. 14A–C.
1970 *Daubichites goochi* (Teichert); Nassichuk: p. 82.

OCCURRENCE

1. Coolkilya Sandstone. UWA 20504 (holotype) came from "Somewhat above the basal beds (approximately *Thamnopora-Cleiothyridina* zone) of the *Linoproductus* stage of the Wandagee series, near mouth of northeastern gully of Wandagee Hill, on fence dividing Shed and Mundagan Paddocks, Wandagee Station" (Teichert, 1942, p. 228). Glenister and Furnish (1961, p. 721) pointed out that the holotype came from about 107 m above the base of the Coolkilya Sandstone (sensu Teichert, 1952). Other specimens (UWA 20505, 20506, 35777) came from the holotype horizon and higher; the highest specimen occurred about 27 m below the top of the formation and was associated with *Agathiceras applanatum* (Glenister and Furnish, 1961, p. 722).

2. Nalbia Sandstone. Glenister and Furnish (1961, p. 721) assumed that the holotype was the lowest known specimen of *D. goochi*. However, UWA 20507, which is the *Pseudogastrioceras* sp. of Teichert (1942) was placed in *D. goochi* by Glenister and Furnish. The specimen came from the same horizon as *Paragastrioceras wandageense* which is considered to be in the Nalbia Sandstone (see below).

The species is also known from the Lightjack Member of the Liveringa Formation (Canning Basin).

REMARKS

Glenister and Furnish (1961, p. 721) considered this species to be close to *Pseudogastrioceras roadense* from the Guadalupian. However, Nassichuk (1970) placed *goochi* in the genus *Daubichites* and suggested that it is possibly conspecific with *D. fortieri* from the Assistance Formation (Canada) which is Filippovian (i.e. Roadian) in age (see Waterhouse, 1976, p. 126; Nassichuk and others, 1965, p. 3). While *Daubichites* is currently known only from the late Early Permian (Roadian), *Pseudogastrioceras* is Dzhulfian in age (Nassichuk, 1970).

Mescalites sp.

OCCURRENCE

Callytharra Formation. The specimens came from G. A. Thomas' locality S662 from which *Svetlanoceras irwinense* (see below) is also recorded.

REMARKS

W. M. Furnish, who identified the specimens states (in correspondence to G. A. Thomas, 1976) "The second species in S662 is a gonioloboceratid, belonging in a family that characterizes the Upper Pennsylvanian, but is represented in the Permian by a single genus, *Mescalites* (Furnish & Glenister, 1971, Smithsonian Contribution to Paleobiology 3, p. 301–312). Previously, *Mescalites* was known only through the type species *M. discoidale* from the Bursum Formation of New Mexico. We are fairly confident of an Asselian age for the ammonoid bed in the Bursum. However, the Australian specimens differ in several respects from *M. discoidale* and are not conspecific with it: they may even warrant a new genus. Consequently, they cannot be utilized for age refinement".

Metalegoceras n. sp. Glenister and Furnish

1954 cf. *Metalegoceras:* Condon: p. 52.
1954 *Metalegoceras* cf. *M. clarkei* Miller; Thomas and Dickins: p. 219.
1961 *Metalegoceras* n. sp. Glenister and Furnish: p. 709, pl. 83 fig. 9, text fig. 9.
1973 *Metalegoceras* n. sp. Glenister and Furnish; Glenister and others: p. 1040.

OCCURRENCE

Callytharra Formation. The only known specimen (CPC 1770) came from ". . . near the base of the Callytharra Formation . . . (24°31′23″S, 115°18′20″E) approximately 8 miles [13 km] from Lyons River Homestead on a bearing of 344°, and 3·6 miles [5·8 km] from Mead's Bore on a bearing of 112°" (Glenister and Furnish, 1961, p. 709).

REMARKS

Glenister and others (1973) remark that the specimen can be related to the late Sakmarian *Metalegoceras australe* and possibly to the Artinskian genus *Sverdrupites.*

Neocrimites sp. Glenister and Furnish

1961 *Neocrimites* sp. Glenister and Furnish: p. 729, pl. 83 figs. 7, 8, pl. 86 figs, 4, 5, text fig. 16B.

OCCURRENCE

1. Coyrie Formation. CPC 1777 came from ". . . 4·95 miles [8·0 km] on a bearing of 119° from Donnelly's Well and 4·7 miles [7·6 km] on a bearing of 236° from Moogooree Homestead, at 24°06′06″S, 115°08′04″E . . . 485 feet [148 m] above the base of the Coyrie Formation" (Glenister and Furnish, 1961, p. 730). This is the same locality from which *Propinacoceras* n. sp. Glenister and Furnish (1961) was recorded. Coyrie Formation as used by Glenister and Furnish was the unit erected by Condon in 1954, the lower part of which was subsequently separated as the Billidee Formation. A level ". . . 485 feet [148 m] above the base of the Coyrie . . ." corresponds to somewhere within the ". . . 145 feet [44 m] thin-bedded soft dark siltstone . . ." of Condon (1967, fig. 102) which is the unit containing *Propinacoceras* in Condon (1954, p. 61) and is near the base of the Coyrie Formation as presently recognized.

2. Billidee Formation. CPC 1776 came from "2 000 feet [610 m] north of the Mt Sandiman Woolshed (24°23′22″S, 115°16′44″E) . . . Coyrie Formation, at about one-third the outcrop width from the base of the unit" (Glenister and Furnish, 1961, p. 730). This is presumably the same record as Condon's (1967, p. 97) "Ammonoidea (Glenister, 1961): *Neocrinites* sp." (sic) from "Five hundred yards [457 m] north of Mount Sandiman woolshed". This outcrop is now mapped as Billidee Formation (Condon, 1967, p. 97).

REMARKS

Glenister and Furnish (1961, Table 3) show the genus as not being recorded from pre-Baigendzhinian strata.

Paragastrioceras wandageense Teichert

1942 *Paragastrioceras wandageense* Teichert: p. 226, pl. 35 figs. 9, 10.
1961 *Paragastrioceras wandageense* Teichert; Glenister and Furnish: p. 713, pl. 84 figs. 5–7, text fig. 10A.

OCCURRENCE

Nalbia Sandstone. UWA 20142—the holotype and only extant specimen (a second one recorded by Teichert having been subsequently lost according to Glenister and Furnish (1961, p. 714))—came from "Two hundred yards [183 m] north of Wandagee-Minilya Road, west side of syncline, north of Wandagee Hill. In lower part of the *Linoproductus* stage of the Wandagee series, at approximately the same horizon as *Helicoprion davisii*" (Teichert, 1942, p. 227). Glenister and Furnish (1961, p. 714) argued that the holotype came from the lower part of the Coolkilya Sandstone, however, Condon (1954, p. 87) considered the outcrop to belong to the Nalbia Sandstone and recent mapping by the Survey confirms this interpretation. There is no reason to believe that *P. wandageense* occurs in the Baker Formation as implied by Condon (1967, p. 184).

REMARKS

The genus is not known in post-Artinskian strata (Ross and Ross, 1979).

Popanoceras sp. indet. Glenister and Furnish

1961 *Popanoceras* sp. indet. Glenister and Furnish: p. 725, pl. 83 fig. 10.

OCCURRENCE

Coolkilya Sandstone. CPC 1775 came from "0·45 miles [724 m] on a bearing of 103° from Wandagee Hill Trigonometrical Station, at 23°50′02″S, 114°27′05″E . . . 230 feet [70 m] below the top of the Coolkilya Greywacke as this formation is defined by Condon (1954) . . ." (Glenister and Furnish, 1961, p. 725).

REMARKS

The specimen is poorly preserved, although Glenister and Furnish (1961, p. 725) suggest ". . . relationship with advanced species of *Popanoceras* . . .". The genus is not recorded from post-Artinskian strata (Nassichuk, 1970).

Pseudoschistoceras simile Teichert

1944 *Pseudoschistoceras simile* Teichert: p. 88, pl. 17 figs. 1–5, text fig. 4.
1961 *Pseudoschistoceras simile* Teichert: Glenister and Furnish; p. 711, pl. 83 figs. 1–6, text fig. 8F.

OCCURRENCE

1. Coyrie Formation. UWA 21326 (holotype), 21327, 21328, 21329, 21440, 39097, 39098 all came from ". . . mud flat ¼ to ½ mile [400–800 m] south of Barrabiddy Dam, Wandagee Station" (Teichert, 1944, p. 89); 23°57′S, 114°31′E (Glenister and Furnish, 1961, p. 712). The formation at this locality was considered by Teichert (1944) and Glenister and Furnish (1961) to be the Barrabiddy Member of the Bulgadoo Shale. However, Condon (1967, p. 131) argued that, following the drilling of the nearby Quail 1 well, the unit was more likely to be Coyrie Formation. Recent mapping supports this (R. M. Hocking, pers. comm. 1979).

2. Cordalia Sandstone. GSWA F10163 came from the type section of the Cordalia Sandstone, northeast of Round Hill at 23°21′00″S, 114°39′00″E.

REMARKS

According to Teichert (144, p. 84) "The accompanying fauna gives no definite clue, and deductions as regards the possible age . . . can only be made with great reservations". On the other hand, Glenister and Furnish (1961, p. 687) point out that "The only species of *Pseudoschistoceras* known from outside of Australia is *P. gigas* (Smith), which occurs in the Baigendzhinian Bitauni beds of Timor". They go on to say that *P. simile* has a more advanced suture than the Timor species. It should be noted that Waterhouse (1976) considers the brachiopods from the Bitauni beds to indicate a post-Baigendzhinian age while acknowledging that ammonoid workers prefer a Baigendzhinian age (by contrast, earlier he (Waterhouse, 1970) raised the possibility that the beds could be lower Artinskian). The balance of evidence suggests that *P. simile* is no older than Baigendzhinian.

Svetlanoceras irwinense (Teichert and Glenister)

1952 *Uraloceras irwinense* Teichert and Glenister: p. 21, pl. 4 figs. 2–7.
1961 *Uraloceras irwinense* Teichert and Glenister; Glenister and Furnish: p. 715, pl. 84 figs. 8–11, text figs. 11A, 12.
1976 *Uraloceras* (*Svetlanoceras*) *irwinense* Teichert and Glenister; Thomas: p. 319.

OCCURRENCE

Callytharra Formation. The species came from G. A. Thomas' locality S662 which is 8·2 km on a bearing of 225° from Coondoo Outcamp, Bidgemia station (lat. 23°52′39″S, long. 115°31′20″E). This outcrop is in the lower part of the formation (G. A. Thomas, pers. comm. 1979).

The species was previously known only from the Holmwood Shale in the Perth Basin.

REMARKS

The species was identified by G. A. Thomas. W. M. Furn ish who also examined the material, states (in correspondence to G. A. Thomas, 1976) "By itself, *S. irwinense* indicates only a Sakmarian (Asselian-Sterlitamakian) assignment".

AGE SIGNIFICANCE

The oldest ammonoid-bearing formation in the Carnarvon Basin is the Callytharra Formation, from the lower part of which *Mescalites* sp., *Metalegoceras* n. sp. and *Svetlanoceras irwinense* are recorded. Of these species, *Mescalites* sp. is of unknown significance, *Metalegoceras* n. sp. is ". . . compatible with either a late Sakmarian or an Artinskian age" (Glenister and Furnish, 1961, p. 686) while *S. irwinense* suggests a Sakmarian age for the formation.

Previous workers have taken the abundant brachiopods and molluscs in the Callytharra Formation to indicate a correlation with the Nura Nura Member of the Poole Sandstone (Canning Basin) which Teichert (1942) and Thomas and Dickins (1954) considered to be early Artinskian on the basis of the ammonoids. However, Glenister and Furnish (1961, p. 686) pointed out that the presence of advanced *Propopanoceras* (*P. ruzhencevi*) means that the Nura Nura Member can be no younger than late Sakmarian (Sterlitamakian). Condon (1967) accepted an Artinskian age for the Callytharra Formation following Teichert (1942) and Thomas and Dickins (1954), while more recent authors (e.g. Playford and others, 1975) have followed Glenister and Furnish in considering the unit to be late Sakmarian. Webster (1977) has recently stated that the formation is Artinskian without giving any reasons.

The presence of *S. irwinense* and *Metalegoceras* n. sp. in the lower part of the Callytharra Formation now provides direct evidence for a late Sakmarian age for at least part of the unit.

The overlying Cordalia Sandstone, the basal formation of the Wooramel Group, contains *Pseudoschistoceras simile*, which it is argued above, suggests an age no older than Baigendzhinian (mid Artinskian). *Neocrimites* sp. from the Billidee Formation suggests a Baigendzhinian age for this the uppermost formation of the Wooramel Group. Hence the Wooramel Group as a whole is Baigendzhinian. Consequently, the unconformity between the Callytharra Formation and the Wooramel Group (van de Graaff and others, 1977) may represent the Aktastinian (early Artinskian). Contrary to this interpretation, Waterhouse (1976) believes the Wooramel Group itself to be Aktastinian, mainly on the evidence of the brachiopods.

Brachiopod and molluscan faunas in the Wooramel Group are best developed in:

1. The Jimba Jimba Calcarenite Member of the Billidee Formation (Condon, 1967),
2. shelly horizons within the Billidee Formation (R. M. Hocking, pers. comm.; see Cockbain, 1979); and
3. the "basal siltstone member of the One Gum Formation" (Konecki and others, 1958). This unit also occurs in B.M.R.8 (Mount Madeline) borehole (Dickins, *in* Mercer, 1967, p. 17) where Condon (1967) considers it to correlate with the Jimba Jimba Calcarenite Member. Stratigraphically it occurs above a sandstone ("Nunnery") and below a siltstone ("One Gum") and hence is in an equivalent position to the Jimba Jimba Calcarenite Member.

The faunas from all these horizons in the Wooramel Group are essentially the same and are very similar to that of the Callytharra Formation. Although Dickins (1963) established two faunal stages in the Callytharra–Wooramel sequence—Stage B from the Callytharra Formation and Stage C from the Wooramel Group—both Runnegar (1969) and Waterhouse (1970) recognize only one fauna at this level, Runnegar's Fauna II and Waterhouse's *Stepanoviella-Taeniothaerus* fauna. Dickins (1963, p. 20) admitted that his Stage C was "... marked by the absence rather than the presence of a marine fauna". The *Stepanoviella-Taeniothaerus* fauna occurs in the Callytharra Formation, the Wooramel Group, and the Nura Nura Member as well as in the Beckett and Fossil Cliff Members of the Holmwood Shale (Perth Basin). Ammonoids from these units range in age from Tastubian (mid Sakmarian, Beckett Member) to Baigendzhinian (mid Artinskian, Billidee Formation at the top of the Wooramel Group). From this it can be concluded that the *Stepanoviella-Taeniothaerus* fauna has a fairly long time range and occurs at a number of shelly horizons, often of limited extent, and hence cannot be used for detailed biostratigraphic correlation.

Most of the Byro Group, with *Neocrimites* and *Bamyaniceras australe*, is Baigendzhinian (mid Artinskian). The Nalbia Sandstone contains *Daubichites goochi* which suggests a Roadian (late Artinskian) age. The highest ammonoid-bearing unit, the Coolkilya Sandstone, contains *Agathiceras applanatum*, *Popanoceras* sp. indet. and *D. goochi*. Glenister and Furnish (1961, p. 725) considered the horizon from which *Popanoceras* came to be of early Guadalupian (Late Permian) age and they believed their Lower-Upper Permian boundary to lie between the uppermost bed with *Paragastrioceras* and the lowest occurrence of *goochi*. However, with the revision of the ammonoid occurrences presented here and the assignment of *goochi* to the early Permian genus *Daubichites*, it seems that the whole of the Coolkilya Sandstone is Lower Permian—a possibility forseen by Glenister and Furnish (1961, p. 688).

CONCLUSIONS

A reassessment of the stratigraphical distribution of Permian ammonoids in the Carnarvon Basin shows that only Early Permian species are present. The oldest ammonoid-bearing unit, the Callytharra Formation, is Sterlitamakian (late Sakmarian) and the overlying Wooramel Group is Baigendzhinian (mid Artinskian). The unconformity between the two units may represent all or part of the Aktastinian. The Byro Group is Baigendzhinian up to the Nalbia Sandstone which, together with the Coolkilya Sandstone of the Kennedy Group, is Roadian (late Artinskian). The age of the pre-Callytharra and post-Coolkilya beds cannot be established on the basis of ammonoids.

ACKNOWLEDGEMENTS

I thank G. A. Thomas for allowing me to include his new records from the Callytharra Formation and W. M. Furnish for his comments on *Svetlanoceras irwinense* and *Mescalites* sp.; B. F. Glenister for confirming my identification of *P.*

simile from the Cordalia Sandstone and for reading the manuscript and suggesting several improvements; J. M. Dickins for reading the manuscript.

REFERENCES

Cockbain, A. E., 1979, More Permian samples from the Carnarvon Basin: West. Australia Geol. Survey Palaeont. Rept. No. 22/1979 (unpublished).

Condon, M. A., 1954, Progress report on the stratigraphy and structure of the Carnarvon Basin, Western Australia: Australia Bur. Mineral Resources Rept. 15.

——— 1967, The geology of the Carnarvon Basin, Western Australia, Part II: Permian stratigraphy: Australia Bur. Mineral Resources Bull. 77.

Dickins, J. M., 1956, The Permian marine macrofossils of the Wooramel and Byro Groups of the Wooramel River area, Western Australia: Australia Bur. Mineral Resources Rec. 1956/113 (unpublished).

——— 1963, Permian pelecypods and gastropods from Western Australia: Australia Bur. Mineral Resources Bull. 63.

——— 1976, Correlation chart for the Permian System of Australia: Australia Bur. Mineral Resources Bull. 156B.

Furnish, W. M., 1976, Permian stage names, *in* The Permian and Triassic Systems and their mutual boundary: Canadian Soc. Petroleum Geologists Mem. 2, p. 522–548.

Glenister, B. F., and Furnish, W. M., 1961, The Permian ammonoids of Australia: Jour. Paleontology, v. 35, p. 673–736.

Glenister, B. F., Windle, D. L., Jr., and Furnish, W. M., 1973, Australasian Metalegoceratidae (Lower Permian ammonoids): Jour. Paleontology, v. 47, p. 1031–1043.

Harker, P., and Thorsteinsson, R., 1960, Permian rocks and faunas of Grinnell Peninsula, Arctic Archipelago: Canada Geol. Survey Mem. 309.

Hocking, R. M., Moore, P., and Moors, H. T., 1980, Modified stratigraphic nomenclature and concepts in the Palaeozoic of the Carnarvon Basin, Western Australia: West. Australia Geol. Survey, Ann Rept. 1979, p. 51–52.

Konecki, M. C., Dickins, J. M., and Quinlan, T., 1958, The geology of the coastal area between the lower Gascoyne and Murchison Rivers, Western Australia: Australia Bur. Mineral Resources Rept. 37.

McWhae, J. R. H., Playford, P. E., Lindner, A. W., Glenister, B. F., and Balme, B. E., 1958, The stratigraphy of Western Australia: Geol. Soc. Australia Jour., v. 4, pt. 2.

Mercer, C. R., 1967, Completion report BMR 8, Mount Madeline and 9, Daurie Creek, Byro Basin, Western Australia: Australia Bur. Mineral Resources Rept. 108.

Moore, R. C., 1965, Editorial preface, Treatise on invertebrate paleontology: Part H, Brachiopoda: Geol. Soc. America and Univ. Kansas Press.

Nassichuk, W. W., 1970, Permian ammonoids from Devon and Melville Islands, Canadian Arctic Archipelago: Jour. Paleontology, v. 44, p. 77–97.

Nassichuk, W. W., Furnish, W. M., and Glenister, B. F., 1965, The Permian ammonoids of Arctic Canada: Canada Geol. Survey Bull. 131.

Playford, P. E., Cope, R. N., Cockbain, A. E., Low, G. H., and Lowry, D. C., 1975, Phanerozoic: West. Australia Geol. Survey Mem. 2, p. 223–433.

Ross, C. A., and Ross, J. R. P., 1979, Permian: Treatise on invertebrate paleontology: Part A, Introduction: Geol. Soc. America and Univ. Kansas Press, p. A291–350.

Runnegar, B. N., 1969, The Permian faunal succession in eastern Australia: Geol. Soc. Australia Spec. Publ. 2, p. 73–98.

Teichert, C., 1942, Permian ammonoids from Western Australia: Jour. Paleontology, v. 16, p. 221–232.

——— 1944, Two new ammonoids from the Permian of Western Australia: Jour. Paleontology, v. 18, p. 83–89.

——— 1957, Notes on the geology of the Carnarvon (Northwest) Basin, Western Australia: Royal Soc. West. Australia Jour., v. 40, p. 65–72.

Termier, H., and Termier, G., 1970, Ammonoids de l'Artinskien (Zygarien) dans la montaigne de Bamyan (Afghanistan): Soc. Geol. Nord Annales v. 90, p. 93–100.

Thomas, G. A., 1976, Faunal evidence of climatic change in the Early Permian of the Carnarvon Basin, Western Australia: Internat. Geol. Cong., 25th, Sydney 1976, Abstracts, v. 1, p. 318–319.

Thomas, G. A., and Dickins, J. M., 1954, Correlation and age of the marine Permian formations of Western Australia: Australian Jour. Sci., v. 16, p. 219–223.

van de Graaff, W. J. E., Hocking, R. M., and Denman, P. D., 1977, Revised stratigraphic nomenclature and interpretations in the east-central Carnarvon Basin, W.A.: West. Australia Geol. Survey Ann. Rept. 1976, p. 37–39.

Waterhouse, J. B., 1970, Gondwanan occurrences of the upper Paleozoic brachiopod *Stepanoviella*: Jour. Paleontology, v. 44, p. 37–50.

——— 1976, World correlations for the Permian marine faunas: Univ. Queensland Papers Dept. Geology v. 7, no. 2.

Webster, G. D., 1977, New Permian crinoid fauna from Callytharra Springs, Western Australia: Geol. Soc. America Abstracts with programs, v. 9, p. 524–525.

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DIVISION V

Report of the Director of The Petroleum Branch for the Year 1979

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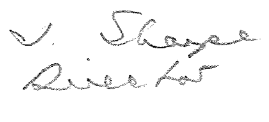
Under Secretary for Mines:

I hereby submit my Annual Report for the Petroleum Branch for 1979.



PETROLEUM TENEMENTS

Status on 31*st December* 1979 (Figure 1, Table I–IV)

Petroleum tenements current on the 31st December 1979 total 35 onshore and 45 offshore. These cover areas of 217 870 square kilometres and 691 845 square kilometres respectively. The area still available for application onshore and offshore combined is 1·05 million square kilometres. At the end of the year there were a total of 41 applications (35 onshore and 6 offshore) being processed.

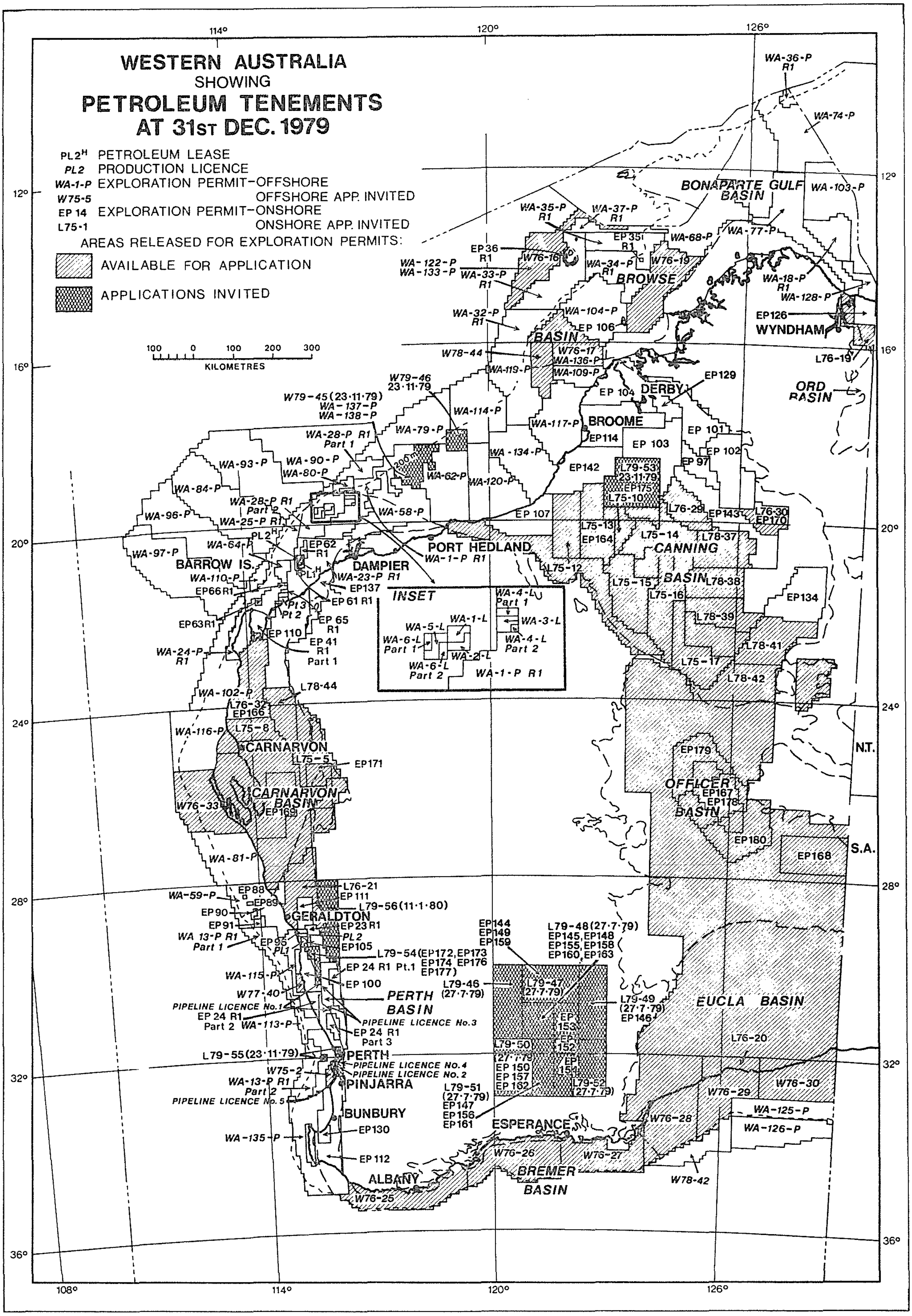


Figure 1 Petroleum Tenements on 31st December, 1979.

TABLE I

PETROLEUM TENEMENTS UNDER THE PETROLEUM (SUBMERGED LANDS) ACT, 1967

A. EXPLORATION PERMITS

Number	No. of Graticular Sections	Expiry Date	Registered Holder or Applicant
WA-1-P			
R 1	178	14/11/79	Woodside Oil Ltd, Woodside Petroleum Development Pty Ltd, Mid-Eastern Oil Ltd, North West Shelf Development Pty Ltd, B.P. Petroleum Development Aust. Pty Ltd, California Asiatic Oil Co.
WA-13-P			
R 1 Part 1	110 } 194	29/8/79	West Australian Petroleum Pty Limited
R 1 Part 2	84		
WA-18-P			
R 1	105	16/4/80	Australian Aquitaine Petroleum Pty Ltd
WA-23-P			
R 1	199	3/10/79	
WA-24-P			
R 1	104	17/10/79	West Australian Petroleum Pty Limited
WA-25-P			
R 1	128	16/10/79	
WA-28-P			
R 1 Part 1	52 } 178	24/3/80	
R 1 Part 2	126		
WA-32-P			
R 1	100	2/7/80	Woodside Oil Ltd, Woodside Petroleum Development Pty Ltd, Mid-Eastern Oil Ltd, North West Shelf Development Pty Ltd, B.P. Petroleum Development Aust. Pty Ltd, California Asiatic Oil Co.
WA-33-P			
R 1	194	18/5/80	
WA-34-P			
R 1	149	2/7/80	Woodside Oil Ltd, Woodside Petroleum Development Pty Ltd, Mid-Eastern Oil Ltd, North West Shelf Development Pty Ltd, California Asiatic Oil Co.
WA-35-P			
R 1	123	2/7/80	
WA-36-P			
R 1	18	18/5/80	Woodside Oil Ltd, Woodside Petroleum Development Pty Ltd, Shell Development (Aust) Pty Ltd, Mid-Eastern Oil Ltd, North West Shelf Development Pty Ltd, B.P. Petroleum Development Aust. Pty Ltd.
WA-37-P			
R 1	59	2/6/80	
WA-58-P	222	11/7/82	Western Energy Pty Ltd, Stirling Petroleum N.L.
WA-59-P	190	18/6/82	Esso Exploration & Production Aust. Inc., Western Mining Corp. Ltd.
WA-62-P	226	7/3/83	Oxoco-International Inc., Peyto Exploration Inc., Voyager Petroleums Ltd, Australian Oil & Gas Corp. Ltd, Bridge Oil Ltd, Endeavour Resources Ltd, A.A.R. Ltd, Offshore Oil N.L.
WA-64-P	22	28/2/83	Offshore Oil N.L., Southern Cross Exploration N.L., Hallmark Minerals N.L.
WA-68-P	249	7/3/83	Oxoco-International Inc., Peyto Exploration Inc., Voyager Petroleums Ltd, Bridge Oil Ltd.
WA-74-P	253	24/6/83	Pelsart Oil N.L.
WA-77-P	254	1/8/83	Magnet Metals Ltd, Jeerinah Mining Pty Ltd, Sundance Resources (Cayman) Ltd, Crux (International) Ltd, Scorpio Petroleum Ltd, Pluto Petroleum Ltd.
WA-79-P	235	1/8/83	Getty Oil Development Co. Ltd, Hematite Petroleum Pty Ltd, The Shell Co. of Aust. Ltd, Continental Oil Co. of Aust. Ltd.
WA-80-P	16	6/10/83	Otter Exploration N.L., Target Petroleum N.L., Endeavour Oil Co. N.L., Timor Oil Ltd, Spargo's Exploration N.L., Alkane Exploration (Terrigal) N.L.
WA-81-P	249	13/10/83	Continental Oil Co. of Aust. Ltd, General Crude Oil Co., International Ltd.
WA-84-P	400	18/11/83	Mobil Oil Aust. Ltd, Phillips Aust. Oil Co., Australian Gulf Oil Co., M.I.M. Investments Pty Ltd, B.P. Petroleum Development Aust. Pty Ltd.
WA-90-P	400	18/11/83	Woodside Petroleum Development Pty Ltd, Woodside Oil Ltd, Mid-Eastern Oil Ltd, B.P. Petroleum Development Aust. Pty Ltd, California Asiatic Oil Co., The Shell Co. of Aust. Ltd, Hematite Petroleum Pty Ltd.
WA-93-P	400	18/11/83	Hudbay Oil (Aust) Ltd, Canadian Superior Oil International Ltd, Pan Canadian Petroleum Ltd, Australian Oil and Gas Corp. Ltd.
WA-96-P	400	18/11/83	Esso Exploration and Production Aust. Inc., Hematite Petroleum Pty Ltd.
WA-97-P	400	18/11/83	
WA-102-P	234	15/3/84	Canada North West Land Ltd, Star Oil & Gas Ltd, Oakwood Petroleums Ltd, Cultus Pacific N.L.
WA-103-P	247	29/12/83	Natomas of West. Aust. Inc., Wainoco International Inc., Bonaparte Petroleum Ltd, Petro Energy Ltd, Lennard Oil N.L., White Pine Mining Pty Ltd.
WA-104-P	242	7/3/84	Oberon Oil Pty Ltd,
WA-109-P	75	4/7/84	Esso Exploration and Production Aust. Inc.
WA-110-P	25	24/7/84	Cultus Pacific N.L., C.N.W. Oil (Aust) Pty Ltd, Oakwood Petroleums Ltd., Star Oil & Gas Ltd.
WA-113-P	44	22/9/84	Haoma Gold Mines N.L.
WA-114-P	239	3/1/85	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.
WA-115-P	14	9/11/84	Geometals Oil Exploration Pty Ltd.
WA-116-P	250	9/11/84	
WA-117-P	248	15/11/84	Pursuit Exploration Pty. Ltd.
WA-119-P	227	28/5/85	Weaver Australia Oil & Gas Corporation
WA-120-P	250	28/5/85	
WA-122-P	202	Appln	Oil and Minerals Quest N.L., Consolidated Gold Mining Areas N.L., Seleka Mining and Investments Ltd, Oklahoma Crude Pty Ltd, Coldstream Crude Oil and Gas Pty Ltd.
WA-125-P	162	8/8/85	Esso Exploration and Production Aust. Inc., Hematite Petroleum Pty Ltd,
WA-126-P	230	8/8/85	
WA-128-P	54	7/8/85	Cultus Oil and Gas Pty Ltd, York Resources N.L., Archean Investments Ltd, C.N.W. Oil (Aust) Pty Ltd.
WA-133-P	202	Appln	Otter Exploration N.L., Pegasus Oil & Gas N.L., Eyre Petroleum Pty Ltd, Laredef Pty Ltd.

TABLE I—*continued*

PETROLEUM TENEMENTS UNDER THE PETROLEUM (SUBMERGED LANDS) ACT, 1967—*continued*

A. EXPLORATION PERMITS—*continued*

Number	No. of Graticular Sections	Expiry Date	Registered Holder or Applicant
WA–134–P	247	13/11/85	Chapman Oil of Australia Inc., Wainoco International Inc.
WA–135–P	231	13/11/85	
WA–136–P	173	Appln	Conex Oil Exploration N.L., Geometals Oil Exploration Pty Ltd.
WA–137–P	84	Appln	B.P. Petroleum Development Aust. Pty Ltd, A.A.R. Ltd, Australian Oil & Gas Corp. Ltd, 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,
WA–138–P	84	Appln	Cultus Pacific N.L., York Resources N.L., Archean Oil Ltd, Marlin Oil N.L., Brunswick Oil N.L., Attock Australia Petroleum Pty Ltd, Metramar Minerals Ltd.

B. PRODUCTION LICENCES

Number	No. of Graticular Sections	Expiry Date	Registered Holder or Applicant
WA–1–L	5	Appln	Woodside Oil Ltd, Woodside Petroleum Development Pty Ltd, Mid-Eastern Oil Ltd, North West Shelf Development Pty Ltd, B.P. Petroleum Development Aust. Pty Ltd, California Asiatic Oil Co.
WA–2–L	4	Appln	
WA–3–L	5	Appln	
WA–4–L	4	Appln	
WA–5–L	5	Appln	
WA–6–L	4	Appln	

TABLE II

PETROLEUM TENEMENTS UNDER THE PETROLEUM ACT, 1936

PETROLEUM LEASES

Number	Area km_2	Expiry Date	Holder
1H	259	9/2/88	West Australian Petroleum Pty Limited
2H	259	9/2/88	

TABLE III

PETROLEUM TENEMENTS UNDER THE PETROLEUM ACT, 1967

A. EXPLORATION PERMITS

Number	No. of Graticular Sections	Expiry Date	Registered Holder or Applicant
EP 23			
R 1	33	6/8/80	West Australian Petroleum Pty Limited
EP 24			
R 1 Part 1	39 } 85	6/8/80	
R 1 Part 2	24		
R 1 Part 3	22		
EP 35			
R 1	1	15/4/81	Woodside Oil Ltd, Woodside Petroleum Development Pty Ltd, Mid-Eastern Oil Ltd, North West Shelf Development Pty Ltd, B.P. Petroleum Development Aust. Pty Ltd, California Asiatic Oil Co.
EP 36			
R 1	1	15/4/81	
EP 41			
R 1 Part 1	102 } 106	18/7/81	West Australian Petroleum Pty Limited
R 1 Part 2	1		
R 1 Part 3	3		
EP 61			
R 1	4	19/9/81	West Australian Petroleum Pty Limited
EP 62			
R 1	8	19/9/81	
EP 63			
R 1	4	19/9/81	
EP 65			
R 1	2	19/9/81	
EP 66			
R 1	1	19/9/81	

TABLE III—*continued*

PETROLEUM TENEMENTS UNDER THE PETROLEUM ACT, 1967—*continued*

A. EXPLORATION PERMITS—*continued*

Number	No. of Graticular Sections	Expiry Date	Registered Holder or Applicant
EP 88	1	18/6/81	Esso Exploration & Production Aust. Inc., Western Mining Corp. Ltd.
EP 89	2	18/6/81	
EP 90	4	18/6/81	
EP 91	7	18/6/81	
EP 96	3	3/11/81	X.L.X. N.L.
EP 97	64	16/9/81	Whitestone Petroleum Aust. Ltd, Amax Iron Ore Corp., Pennzoil Producing Aust. Ltd, Australian Consolidated Minerals Ltd, Yom Oil Ltd.
EP 100	163	3/10/82	Agha-Jahri Exploration Co., Strata Oil N. L., Landshare Investments 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.
EP 101	172	24/6/82	Whitestone Petroleum Aust. Ltd, Amax Iron Ore Corp., Pennzoil Producing Aust. Ltd, Australian Consolidated Minerals Ltd, Australian Occidental Petroleum Inc., Vamgas Ltd, Yom Oil Ltd.
EP 102	200	24/6/82	Whitestone Petroleum Aust. Ltd, Amax Iron Ore Corp., Pennzoil Producing Aust. Ltd, Australian Consolidated Minerals Ltd, Yom Oil Ltd.
EP 103	184	22/8/82	Whitestone Petroleum Aust. Ltd, Yom Oil Ltd.
EP 104	199	31/8/82	Esso Exploration & Production Aust. Inc.
EP 105	4	29/11/82	Colgas Inc.
EP 106	1	7/3/83	Oberon Oil Pty Ltd.
EP107....	146	30/6/83	Era South Pacific Pty Ltd, Era West. Aust. Inc., E.S.P. Explorations Pty Ltd, Cambridge Royalty Co., Cambridge Petroleum Royalties Ltd, North West Mining N.L.
EP 110	200	3/8/83	Samantha Mines Pty Ltd, Otter Exploration N.L., Onslow Oil & Gas Exploration Pty Ltd.
EP 111	42	21/10/83	Jervois Sulphates (N.T.) Ltd.
EP 112	135	29/4/84	Weaver Australia Oil & Gas Corporation
EP 114	196	22/7/84	Swan Resources Ltd, Eagle Corp Ltd.
EP 126	123	17/8/84	Australian Aquitaine Petroleum Pty Ltd, Alliance Petroleum International Ltd, Vamgas Ltd, Western Mining Corp. Ltd.
EP 129	123	7/8/84	Home Oil Aust. Ltd, Occidental Exploration & Production Co., Alberta Eastern Gas (1978) Ltd, Vamgas Ltd.
EP 130	18	22/8/84	Mesa Australia Ltd, Western Mining Corp. Ltd, Offshore Oil N.L., Monarch Petroleum N.L., Whicher Oil N.L.
EP 134	200	22/7/84	Mobil Oil Aust. Ltd.
EP 137	72	22/7/84	J. O. Clough & Son Pty Ltd, Avon Engineering Pty Ltd.
EP 142	200	10/10/84	Chapman Oil of Australia Inc., Wainoco International Inc.
EP 143	198	20/9/84	Western Mining Corp. Ltd.
EP 144	180	Appln	Magnum Minerals Pty Ltd, Openpit Mining & Exploration Pty Ltd.
EP 145	180	Appln	
EP 146	180	Appln	
EP 147	192	Appln	Dampier Mining Co. Ltd.
EP 148	180	Appln	
EP 149	180	Appln	
EP 150	192	Appln	
EP 152	160	Appln	Esso Exploration & Production Aust Inc.
EP 153	80	Appln	
EP 154	80	Appln	
EP 155	180	Appln	Swan Resources Ltd.
EP 156	192	Appln	
EP 157	192	Appln	
EP 158	180	Appln	CSR Ltd.
EP 159	180	Appln	Uranium Consolidated N.L., Uranium Prospecting Evaluation Services Pty Ltd, Pacific Exploration Consultants Pty Ltd.
EP 160	180	Appln	
EP 161	192	Appln	
EP 162	192	Appln	Consolidated Gold Mining Areas N.L., Kia Ora Gold Corp N.L., Uranium & Nickel Exploration N.L., Nickel & Mineral Search N.L., Oak Ridge Petroleum Pty Ltd.
EP 163	180	Appln	Ferrovanadium Corp. N.L., Kemple Mines N.L., Reynolds Diversified Corp., Antarctic Petroleum Pty Ltd, Lefroy Oil N.L.
EP 164	172	Appln	Willara Petroleum Pty Ltd, Medcon Petroleum Ltd, Brunswick Oil N.L., Pontella Nominees Pty Ltd.
EP 166	200	Appln	Winthrop Investments Ltd, Monarch Petroleum N.L., Meda Petroleum N.L., Geotechnics (Aust.) Pty Ltd.
EP 167	197	Appln	Terrex Resources N.L., Oil & Minerals Quest N.L., Zanex Ltd, Capital Oil Corp. Ltd, Mincorp Ltd.
EP 168	200	Appln	
EP 169	182	Appln	Eagle Corp. Ltd, Pan Continental Mining Ltd, Elvet Exploration Pty Ltd, Tully Nominees Pty Ltd.
EP 170	83	Appln	Oil Company of Aust. N.L., Offshore Oil N.L., E.S.P. Interior Pty Ltd, Pan Pacific Petroleum N.L., Strata Petroleum Pty Ltd.
EP 171	96	Appln	Eagle Corporation Ltd.
EP 172	32	Appln	Getty Oil Development Co. Ltd, Mesa Aust. Ltd, Offshore Oil N.L., Basin Oil N.L.
EP 173	32	Appln	Leighton Mining N.L., Metals & Energy Minerals N.L., Cultus Pacific N.L., York Resources N.L., Brunswick Oil N.L., Archean Oil Ltd, Longreach Oil Ltd, Hartogen Explorations Pty Ltd, Cluff Oil (Aust) N.L.

TABLE III—*continued*

PETROLEUM TENEMENTS UNDER THE PETROLEUM ACT, 1967—*continued*

A. EXPLORATION PERMITS—*continued*

Number	No. of Graticular Sections	Expiry Date	Registered Holder or Applicant
EP 174	32	Appln	Australian Aquitaine Petroleum Pty Ltd, Alcoa of Australia Ltd, Alliance Minerals Aust. N.L.
EP 175	193	Appln	Getty Oil Development Co. Ltd, Union Texas Aust. Inc., Alliance Petroleum International Ltd.
EP 176	32	Appln	Strata Oil N.L., Griffin Coal Mining Co. Ltd, Carless, Capel & Leonard Ltd, Dan Allen Hughes & Dudley Joe Hughes, Pan Pacific Petroleum N.L.
EP 177	32	Appln	Magnet Metals Ltd, Mid-East Minerals N.L., Parika Pty Ltd, Stirling Petroleum N.L.
EP 178	200	Appln	The Shell Co. of Aust. Ltd.
EP 179	200	Appln	
EP 180	200	Appln	

B. PRODUCTION LICENCES

PL 1	5	24/10/92	West Australian Petroleum Pty Limited
PL 2	4	24/10/92	

TABLE IV

PETROLEUM TENEMENTS UNDER THE PETROLEUM PIPELINES ACT, 1969

PIPELINE LICENCES

Number	Date of Expiry of Current Term	Registered Holder or Applicant
1	1/12/91	California Asiatic Oil Co., Texaco Overseas Petroleum Co., Shell Development (Aust) Pty Ltd, Ampol Exploration Ltd.
2	1/12/91	
3	1/12/91	
4	1/12/91	
5	1/12/91	

Offshore Tenement Activity (Figure 2, Tables V and VII)

Although only three areas were advertised during 1979 there were 21 new applications for 15 areas in Western Australian waters. Eight permits covering 126 430 square kilometres were granted and by the end of the year the total number of offshore exploration permits and the area covered by these were 45 permits and 691 845 square kilometres respectively. Ten applications were unsuccessful and at 31st December there were 6 applications being processed.

TABLE V

DEALINGS UNDER THE PETROLEUM (SUBMERGED LANDS) ACT, 1967, DURING 1979

(a) ADVERTISEMENTS (SECTION 20)

Area Number	Basin	Date Gazetted	Closing Date	No. of Blocks	Area (km²)
"Closing Date" Section 20(1)					
W79–45....	Canning	27/7/79	23/11/79	84	6 810
W79–46....	Canning	27/7/79	23/11/79	36	2 930
			Total		9 740
"No Closing Date" Section 20(3)					
W78–44....	Canning-Browse	9/11/79	....	80	6 560
			Total		6 560

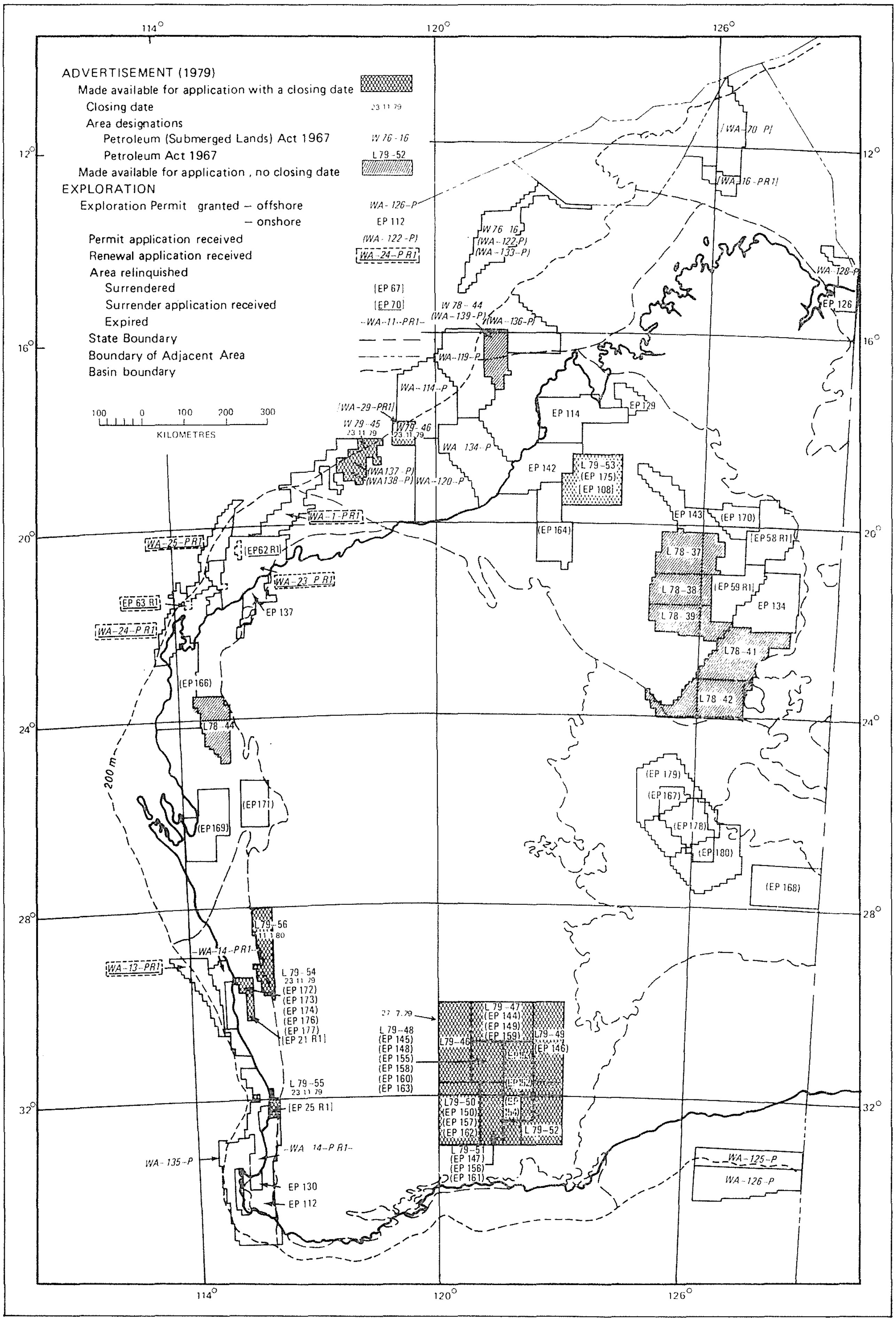


Figure 2 Petroleum Tenement Dealings during 1979

TABLE V—*continued*

DEALINGS UNDER THE PETROLEUM (SUBMERGED LANDS) ACT, 1967, DURING 1979—*continued*

(b) EXPLORATION PERMIT APPLICATIONS AND GRANTS (SECTIONS 21 AND 22)

Application or Permit Number	Area Number	Applicant	Date Received	Basin	No. of Blocks	Area (km²)	Status	Operative Date
WA-114-P	W76-10	Era *et al*	30/6/78	Canning	239	19 500	Granted	4/1/79
WA-118-P	W76-17 (part)	Conex *et al*	28/9/78	Browse	173	14 220	Withdrawn	28/5/79
WA-119-P	W76-11	Weaver	11/1/79	Canning-Browse	227	18 500	Granted	29/5/79
WA-120-P	W76-13	Weaver	11/1/79	Canning	250	20 205	Granted	29/5/79
WA-121-P	W76-11	Iona Nominees	23/1/79	Canning-Browse	227	18 500	Refused	22/5/79
WA-122-P	W76-16	Oil and Minerals Quest N.L. *et al*	16/3/79	Browse	202	16 760	Pending	....
WA-123-P	W76-19	Ferrovanadium Corp. N.L. *et al*	16/3/79	Browse	233	19 280	Refused	21/9/79
WA-124-P	W76-33	Kemple Mines N.L. *et al*	16/3/79	Carnarvon	248	19 100	Refused	21/9/79
WA-125-P	W76-29 (part) W76-30 (part)	Esso *et al*	30/3/79	Eucla	40 122	2 880 8 775	Granted	9/8/79
WA-126-P	W78-42 (part)	Esso *et al*	30/3/79	Eucla	230	16 350	Granted	9/8/79
WA-127-P	W78-43	Genoa *et al*	30/3/79	Bonaparte	54	3 730	Refused	31/8/79
WA-128-P	W78-43	CNW *et al*	30/3/79	Bonaparte	54	3 730	Granted	8/8/79
WA-129-P	W76-29 W76-30 W78-42	Otter *et al*	30/3/79	Eucla	24 98 212	1 725 6 900 15 075	Refused	30/7/79
WA-130-P	W78-43	Siberia *et al*	30/3/79	Bonaparte	54	3 730	Refused	31/7/79
WA-131-P	W78-44	Australis *et al*	30/3/79	Canning	80	6 560	Refused	20/9/79
WA-132-P	W76-17 (part)	P.A. Development	11/4/79	Browse	173	14 230	Refused	20/12/79
WA-133-P	W76-16	Otter	20/4/79	Browse	202	16 760	Pending	....
WA-134-P	W76-14	Chapman Oil of Aust. Inc.	7/5/79	Canning	247	20 050	Granted	14/11/79
WA-135-P	W75-1	Chapman Oil of Aust. Inc.	7/5/79	Perth	231	16 440	Granted	14/11/79
WA-136-P	W76-17 (part)	Conex Oil Exploration *et al*	8/5/79	Browse	173	14 220	Pending	....
WA-137-P	W79-45	BP Petroleum Development *et al*	22/11/79	Canning	84	6 810	Pending	....
WA-138-P	W79-45	Cultus Pacific N.L. *et al*	22/11/79	Canning	84	6 810	Pending	....
WA-139-P	W78-44	Oil and Minerals Quest *et al*	18/12/79	Canning-Browse	80	6 560	Pending	....

Note: For full title of Registered Holders or Applicants, refer Table I.

(c) ACCESS AUTHORITIES AND CONSENTS (SECTION 112)

Number	Applicant	Basin or Area of Survey	Permit or Area requiring Access Authority
AA66SL	Woodside *et al*	North West Shelf	WA-93-P
AA67SL	Oxoco	Canning	WA-29-P
AA68SL	Woodside *et al*	North West Shelf	WA-25-P, WA-93-P
AA69SL	Magnet	Bonaparte	WA-103-P
AA70SL	Western Energy	North West Shelf	WA-1-P
AA71SL	Continental Oil	Carnarvon	Vacant
AA72SL	Esso *et al*	Exmouth Plateau	WA-84-P
AA73SL	Woodside *et al*	North West Shelf	WA-58-P, WA-23-P, WA-28-P, WA-25-P, WA-93-P and vacant areas
AA74SL	Magnet *et al*	Bonaparte	Vacant
AA75SL	Getty *et al*	North West Shelf	Vacant
AA76SL	Phillips *et al*	Exmouth Plateau	WA-93-P, WA-25-P, WA-96-P
AA77SL	Esso *et al*	Eucla	Vacant
AA78SL	CNW *et al*	Carnarvon	WA-116-P
AA79SL	Geometals	Carnarvon	WA-102-P

(d) EXPLORATION PERMIT SURRENDERS (SECTION 104)

Permit Number	Basin	Permittee	Date Surrender (Gazetted)	No. of Blocks and Area (km²)	
				Original	Surrendered
WA-19-P R1	Bonaparte	Alliance	17/11/78	49 (4 060)	49 (4 060)
WA-29-P R1	Canning	WPD— Part 1 Part 2	23/2/79	36 (9 735) 84	36 (9 735) 84
WA-16-P R1	Bonaparte	Arco	31/8/79	40 (3 340)	40 (3 340)
WA-70-P	Bonaparte	Getty	21/12/79	251 (21 060)	251 (21 060)

TABLE V—*continued*

DEALINGS UNDER THE PETROLEUM (SUBMERGED LANDS) ACT, 1967, DURING 1979—*continued*

(e) EXPLORATION PERMIT EXPIRIES AND RENEWALS (SECTION 30)

Permit Number	Basin	Permittee	No. of Blocks	First Term Expiry Date	Status	No. of Blocks Renewed	Area
WA-1-P R1	Carnarvon	Woodside *et al*	178	14/11/79	Pending	84	6 750
WA-13-P R1	Perth	Wapet	194	29/8/79	Pending	35	2 545
WA-14-P R1	Perth	Wapet	198	29/8/79	Expired	....	....
WA-23-P R1	Carnarvon	Wapet	199	3/10/79	Pending	4	320
WA-24-P R1	Carnarvon	Wapet	104	17/10/79	Pending	52	4 125
WA-25-P R1	Carnarvon	Wapet	128	16/10/79	Pending	64	5 125
						Total Area	18 865

Onshore Tenement Activity (Figure 2, Table VI and VII)

Onshore tenement activity increased markedly during 1979. During the year seventeen areas were advertised and all but seven of these have attracted applications to explore for petroleum. There was a total of 69 applications registered for 30 areas in 1979. Competition was particularly keen for the new oil shale areas in the Eastern Goldfields and in the Perth Basin east of Geraldton.

Nine permits were granted during the year and as of 31st December there were 35 applications for 16 areas being processed. The permits granted in 1979 cover 88 030 square kilometres and those being processed relate to a total area of 204 575 square kilometres. Twenty three applications were unsuccessful and three were withdrawn.

At the end of the year 35 exploration permits covering an area of 217 870 square kilometres were held by exploration companies.

TABLE VI

DEALINGS UNDER THE PETROLEUM ACT, 1967, DURING 1979

(a) ADVERTISEMENTS (SECTION 30)

Area Number	Basin	Date Gazetted	Closing Date	No. of Blocks	Area (km²)
"Closing date" (Section 30(1))					
L79-46	Eastern Goldfields	30/3/79	27/7/79	180	13 270
L79-47	Eastern Goldfields	30/3/79	27/7/79	180	13 270
L79-48	Eastern Goldfields	30/3/79	27/7/79	180	13 270
L79-49	Eastern Goldfields	30/3/79	27/7/79	180	13 270
L79-50	Eastern Goldfields	30/3/79	27/7/79	192	13 930
L79-51	Eastern Goldfields	30/3/79	27/7/79	192	13 930
L79-52	Eastern Goldfields	30/3/79	27/7/79	192	13 930
L79-53	Canning	27/7/79	23/11/79	193	15 620
L79-54	Perth	27/7/79	23/11/79	32	380
L79-55	Perth	27/7/79	23/11/79	36	2 620
L79-56	Perth	7/9/79	11/1/80	109	8 170
			Total	....	123 660
"No Closing date" (Section 30(3))					
L78-37	Canning	20/7/79	....	166	13 315
L78-38	Canning	20/7/79	....	132	10 535
L78-39	Canning	20/7/79	....	141	11 195
L78-41	Canning	20/7/79	....	200	15 825
L78-42	Canning	20/7/79	....	200	15 710
L78-44	Carnarvon	20/7/79	....	118	9 200
			Total	....	75 780

(b) EXPLORATION PERMIT APPLICATIONS, GRANTS AND WITHDRAWALS (SECTION 31 AND 32)

Application or Permit Number	Area Number	Applicant	Date Application	Basin	No. of Blocks	Area (km²)	Status	Operative Date
EP 136	L78-36	Carr Boyd *et al*	6/4/79	Canning	43	3 510	Refused	3/8/79
EP 137	L78-45	J. O. Clough *et al*	6/4/79	Carnarvon	72	5 730	Granted	23/7/79
EP 138	L78-45	Stowport	6/4/79	Carnarvon	72	5 730	Refused	10/7/79
EP 139	L78-45	Archean Investments *et al*	6/4/79	Carnarvon	72	5 730	Refused	10/7/79
EP 140	L78-36	Acquis	6/4/79	Canning	43	3 510	Rejected	11/6/79
EP 141	L78-43	Acquis	6/4/79	Perth	18	1 285	Rejected	11/6/79
EP 142	L75-9	Chapman Oil of Australia	14/5/79	Canning	200	16 190	Granted	11/10/79
EP 143	L76-29	Western Mining	24/7/79	Canning	80	6 520	Granted	21/9/79
	L76-30				171	9 410	Granted	21/9/79
EP 144	L79-47	Magnum Minerals *et al*	27/7/79	Eastern Goldfields	180	13 270	Pending	....
EP 145	L79-48	Magnum Minerals *et al*	27/7/79	Eastern Goldfields	180	13 270	Pending	....
EP 146	L79-49	Magnum Minerals *et al*	27/7/79	Eastern Goldfields	180	13 270	Pending	....
EP 147	L79-51	Dampier Mining Co. Ltd	27/7/79	Eastern Goldfields	192	13 930	Pending	....
EP 148	L79-48	Dampier Mining Co. Ltd	27/7/79	Eastern Goldfields	180	13 270	Pending	....

TABLE VI—*continued*

DEALINGS UNDER THE PETROLEUM ACT, 1967, DURING 1979—*continued*

(b) EXPLORATION PERMIT APPLICATIONS, GRANTS AND WITHDRAWALS (SECTION 31 AND 32)—*continued*

Application or Permit Number	Area Number	Applicant	Date Application	Basin	No. of Blocks	Area (km²)	Status	Operative Date
EP 149	L79–47	Dampier Mining Co. Ltd	27/7/79	Eastern Goldfields	180	13 270	Pending	....
EP 150	L79–50	Dampier Mining Co. Ltd	27/7/79	Eastern Goldfields	192	13 930	Pending	....
EP 151	L79–46	Griffin Coal Mining Corp.	27/7/79	Eastern Goldfields	180	13 270	Withdrawn	5/9/79
EP 152	L79–48, 51 & 52 (part)	Esso	27/7/79	Eastern Goldfields	160	11 690	Pending	....
EP 153	L79–48 (part)	Esso	27/7/79	Eastern Goldfields	80	5 870	Pending	....
EP 154	L79–51 (part)	Esso	27/7/70	Eastern Goldfields	80	5 800	Pending	....
EP 155	L79–48	Swan Resources Ltd	27/7/79	Eastern Goldfields	180	13 270	Pending	....
EP 156	L79–51	Swan Resources Ltd	27/7/79	Eastern Goldfields	192	13 930	Pending	....
EP 60	....	Wapet	4/3/70	Carnarvon	2	....	Withdrawn	14/9/79
EP 64	....	Wapet	4/3/79	Carnarvon	1	....	Withdrawn	14/9/79
EP 112	L76–23	Weaver Aust. Oil & Gas Corp.	11/1/79	Perth	135	9 600	Granted	30/4/79
EP 113	L76–25	Weaver Aust. Oil & Gas Corp.	11/1/79	Canning	196	15 970	Refused	17/7/79
EP 114	L76–25	Swan Resources *et al*	13/2/79	Canning	196	15 970	Granted	23/7/79
EP 115	L76–32	Unigas *et al*	2/3/79	Carnarvon	200	15 700	Refused	18/8/79
EP 116	L76–21 (part)	Siberia Nickel *et al*	16/3/79	Perth	168	12 690	Refused	21/7/79
EP 117	L76–32	Western Queen *et al*	16/3/79	Carnarvon	200	15 700	Refused	18/8/79
EP 118	L76–25	Satima *et al*	22/3/79	Canning	196	15 970	Refused	17/7/79
EP 119	L76–25	Ferrovanadium *et al*	26/3/79	Canning	196	15 970	Refused	17/7/79
EP 120	L76–19	Kemple Mines *et al*	30/3/79	Bonaparte	76	6 260	Refused	8/8/79
EP 121	L76–23	Reynolds Diversified *et al*	30/3/79	Perth	135	9 600	Refused	30/4/79
EP 122	L78–35	Forsayth *et al*	30/3/79	Bonaparte	47	3 880	Refused	8/8/79
EP 123	L78–43	International Mining Corp. *et al*	4/4/79	Perth	18	1 285	Refused	20/8/79
EP 124	L78–45	Offshore Oil N.L. *et al*	4/4/79	Carnarvon	72	5 730	Refused	10/7/79
EP 125	L78–36	Esso Exploration	5/4/79	Perth	43	3 510	Refused	3/8/79
EP 126	L78–35	Australian Aquitaine *et al*	5/4/79	Bonaparte	47	3 880	Granted	18/8/79
EP 127	L75–9 (part)	Medcon *et al*	5/4/79	Canning	197	16 210	Refused	21/9/79
EP 128	L78–43	Weaver Oil & Gas Corp.	5/4/79	Perth	18	1 285	Refused	20/8/79
EP 129	L78–36	Home Oil *et al*	5/4/79	Canning	43	3 510	Granted	8/8/79
EP 130	L78–43	Mesa Australia *et al*	5/4/79	Perth	18	1 285	Granted	23/8/79
EP 131	L78–43	Alcoa of Australia	6/4/79	Perth	18	1 285	Refused	20/8/79
EP 132	L78–43	Australian Aquitaine *et al*	6/4/79	Perth	18	1 285	Refused	20/8/79
EP 133	L78–36	Mobil	6/4/79	Canning	43	3 510	Refused	3/8/79
EP 134	L78–40	Mobil	6/4/79	Canning	200	15 935	Granted	23/7/79
EP 135	L78–36	Lennard Oil *et al*	6/4/79	Perth	43	3 510	Refused	3/8/79
EP 157	L79–50	Swan Resources Ltd	27/7/79	Eastern Goldfields	192	13 930	Pending	....
EP 158	L79–48	CSR	27/7/79	Eastern Goldfields	180	13 270	Pending	....
EP 159	L79–47	Uranium Consolidated N.L. *et al*	27/7/79	Eastern Goldfields	180	13 270	Pending	....
EP 160	L79–48	Uranium Consolidated N.L. *et al*	27/7/79	Eastern Goldfields	180	13 270	Pending	....
EP 161	L79–51	Uranium Consolidated N.L. *et al*	27/7/79	Eastern Goldfields	192	13 930	Pending	....
EP 162	L79–50	Consolidated Gold Mining *et al*	27/7/79	Eastern Goldfields	192	13 930	Pending	....
EP 163	L79–48	Ferrovanadium Corp. N.L. *et al*	27/7/79	Eastern Goldfields	180	13 270	Pending	....
EP 164	L75–13	Willara Petroleum Pty Ltd *et al*	23/8/79	Canning	172	13 840	Pending	....
EP 165	L76–30	Oil Co. of Australia *et al*	29/8/79	Canning	200	16 060	Refused	21/9/79
EP 166	L67–52	Monarch Petroleum *et al*	21/9/79	Carnarvon	200	15 700	Pending	....
EP 167	Unlisted	Terrex Resources N. L. *et al*	10/10/79	Officer	197	15 370	Pending	....
EP 168	Unlisted	Terrex Resources N.L. *et al*	10/10/79	Officer	200	15 200	Pending	....
EP 169	Unlisted	Eagle Corp. *et al*	19/10/79	Carnarvon	182	14 000	Pending	....
EP 170	L76–30 (part)	Oil Co. of Australia *et al*	24/10/79	Canning	83	6 650	Pending	....
EP 171	L75–5 (part) plus	Eagle Corp.	21/11/79	Carnarvon	96	7 400	Pending	....
EP 172	L79–54	Getty *et al*	21/11/79	Perth	32	2 380	Pending	....
EP 173	L79–54	Leighton *et al*	22/11/79	Perth	32	2 380	Pending	....
EP 174	L79–54	Australian Aquitaine *et al*	23/11/79	Perth	32	2 380	Pending	....
EP 175	L79–53	Getty *et al*	23/11/79	Canning	193	15 620	Pending	....
EP 176	L79–54	Strata Oil N.L. *et al*	23/11/79	Perth	32	2 380	Pending	....
EP 177	L79–54	Magnet *et al*	23/11/79	Perth	32	2 380	Pending	....
EP 178	Unlisted	Shell Co.	6/12/79	Officer	200	15 375	Pending	....
EP 179	Unlisted	Shell Co.	6/12/79	Officer	200	15 480	Pending	....
EP 180	Unlisted	Shell Co.	6/12/79	Officer	200	15 260	Pending	....

Note: For full title of Registered Holders and or Applicants, refer Table II.

TABLE VI—*continued*

DEALINGS UNDER THE PETROLEUM ACT, 1967, DURING 1979—*continued*

(c) ACCESS AUTHORITIES (SECTION 106)

Number	Applicant	Basin or Area of Survey	Permit or Area Requiring Access Authority
AA 7	Exploration Geophysics *et al*	Perth	Vacant Area
AA 8	XLX N.L.	Perth	EP 111
AA 9	Mesa *et al*	Perth	EP 112

(d) EXPLORATION PERMIT SURRENDERS (SECTION 98)

Permit Number	Basin	Permittee	Date Surrender (Gazetted)	No. of Blocks		Area (km²)
				Original	Surrendered	
EP 108	Canning	Houston Oil and Minerals	12/4/79	193	193	15 620
EP 21 R1	Perth	Wapet	23/2/79	32	32	2 380
EP 25 R1	Perth	Wapet	23/2/79	36	36	2 620
EP 58 R1	Canning	AAR	5/10/79	150	150	12 070
EP 59 R1	Canning	AAR	5/10/79	139	139	11 075
EP 62 R1	Carnarvon	Wapet	Pending	8	....	....
EP 63 R1	Carnarvon	Wapet	Pending	4	....	....

TABLE VII

SUMMARY COMPARISON OF EXPLORATION PERMIT DEALINGS

(1978–1979)

	1978		1979	
	No.	Area (km²)	No.	Area (km²)
Areas Advertised—				
Onshore	11	106 120	17	199 440
Offshore....	4	37 450	3	16 300
Totals	15	143 570	20	215 740
Permits Granted—				
Onshore	4	30 805	9	88 030
Offshore....	8	90 460	8	126 430
Totals	12	121 265	17	214 460
Permit Applications (pending at year end)—				
Onshore	0	....	35	204 575
Offshore....	2	33 730	6	44 350
Totals	2	33 730	41	248 925
Permits Held				
Onshore	31	173 540	35	217 870
Offshore....	41	614 280	45	691 845
Totals	72	787 820	80	909 715
Permits Surrendered (includes those pending at year end—one being a partial surrender)—				
Onshore....	6	9 600	7	44 440
Offshore	1	4 060	3	34 135
Totals	7	13 660	10	78 575
Second Renewals (pending at year end)—				
Onshore....	....	....	....	....
Offshore	....	....	5	18 865*
Totals	....	....	5	18 865
Permits Expired—				
Onshore....	....	....	....	....
Offshore	....	....	1	14 460
Totals	....	....	1	14 460

* 1st renewal area—77 595 km².

PETROLEUM APPRAISAL AND DEVELOPMENT

Barrow Island Field (Table VIII, Figure 3)

(Operator—West Australian Petroleum Pty Limited)

West Australian Petroleum Pty Limited continued their programme of development and infill drilling on Barrow Island with the T-32 rig throughout 1979. A total of 41 wells were drilled.

In the southern Five-spot area of the Windalia Main Pool, 24 infill wells were drilled and completed as producers. One injector was also drilled and B-16M was deepened to below the original objective Windalia Sand. Production was established in this well from a section of the Muderong Shale not previously tested. A water disposal well was also drilled in the B Block.

In the gas cap area of the Windalia pool i.e. in the L and Q blocks, two pilot wells were drilled. The production performance from these showed that viscous fracture stimulation fluid and a high sand concentration together with water flood repressuring had improved oil production. An additional 5 development wells were then drilled, 3 being producers and 2 injectors. A Windalia discovery well F-72, was drilled in an area down-thrown from the main pool and also put on production.

Six Gearle wells were drilled to further evaluate the potential of resistivity anomalies in the Gearle Siltstone which is oil productive in 3 of 4 wells drilled prior to 1979. Evaluation, testing and stimulation of the 1979 Gearle wells is not complete but the results to date have been disappointing and only L-32G is oil productive.

A second Ideco H-35 well servicing rig was commissioned for routine well servicing, well repairs and stimulation. The Cooper rig was set aside for standby purposes. Work over operations on six wells to investigate casing failures from external corrosion was initiated during the year. Pilot cathodic protection schemes were also undertaken and the effectiveness of cathodic protection in protecting casing from further corrosion was being evaluated.

Continued efforts were directed towards computer modelling of the Windalia reservoir. Preliminary results of the conversion of producing wells to injection indicate that this has been beneficial for waterflood sweep and oil recovery. There were no conversions in 1979.

The status of the 574 wells drilled on Barrow Island to the end of 1979 is shown in Table VIII and on Figure 3. Of these, there are 515 wells which are completed in respect to the Windalia Sand Member which is the principal reservoir on the island. This includes 4 wells which are cased but not currently perforated plus one well completed in the water leg for observation.

Dongara, Mondarra and Yardarino Fields (Figure 4)

(Operator—West Australian Petroleum Pty Limited)

The Mondarra No. 2 gas well was production tested in November and it is now planned to run a flow line to the No. 1 location and bring No. 2 on stream in 1980.

The Dongara No. 10 and Yardarino No. 1 oil wells remained on full production throughout the year. The Dongara No. 8 oil well was transferred from partial to full production in July because of the difficulty of "re-starting" due to pressure decline. The increased production necessitated round the clock trucking from Dongara.

An attempt to put Dongara No. 17 oil well on production was made in January but again due to reservoir pressure decline continuous production could not be maintained. A workover for this well is planned for 1980.

The average daily production of oil from the Dongara Field during 1979 was 41·38 m^3 compared to 27·27 m^3 for 1978.

TABLE VIII

BARROW ISLAND FIELD

WELL COMPLETION STATUS BY RESERVOIRS on 31st DECEMBER 1979

Horizon/Pools	On Production Method F.	P.	G.L.	On Injection	Shut-in Pro-ducers‡	In-jectors	Mis-cellaneous§	Abandoned ‖	Total
Tertiary—									
Carbonates*	....	....	....	8	1	....	....	....	9
Lower Cretaceous—									
Gearle	1	2	1	....	6	....	1	....	11
Windalia Radiolarite	....	....	....	....	1	....	....	....	1
Windalia Sand—									
Main Pool, Waterflood†	6	189	83	151	30	43	1	1	504
Non-Waterflood	....	1	....	....	....	....	....	....	1
North Pool	....	1	....	....	....	....	....	1	2
South Pool	....	....	....	....	3	....	1	....	4
Other	....	....	1	....	3	....	2	2	8
Muderong	....	4	2	....	3	....	....	....	9
Flacourt (Salt Water Source)	3	....	3	....	3	....	....	1	10
5 500 ft Sand	....	....	....	....	1	....	....	....	1
6 200 ft Sand	....	....	....	....	1	....	....	....	1
Upper Jurassic—									
6 600 ft Sand	....	....	....	....	2	....	....	....	2
6 700 ft Sand	1	1	....	....	3	....	....	....	5
Other "Jurassic"	1	....	....	....	....	....	1	1	3
Middle Jurassic	....	....	....	....	3	....	....	....	3
Total	12	198	90	159	60	43	6	6	574

NOTES:

* Includes salt water disposal.

† B-36 Production historically included with main pool.

‡ 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 water leg for observation.

‖ Abandoned wells are fully plugged and abandoned.

¶ F = Natural Flow, P = Pumping, GL = Gaslift

General—Recompleted wells are included in Horizon/Pool of current completion.

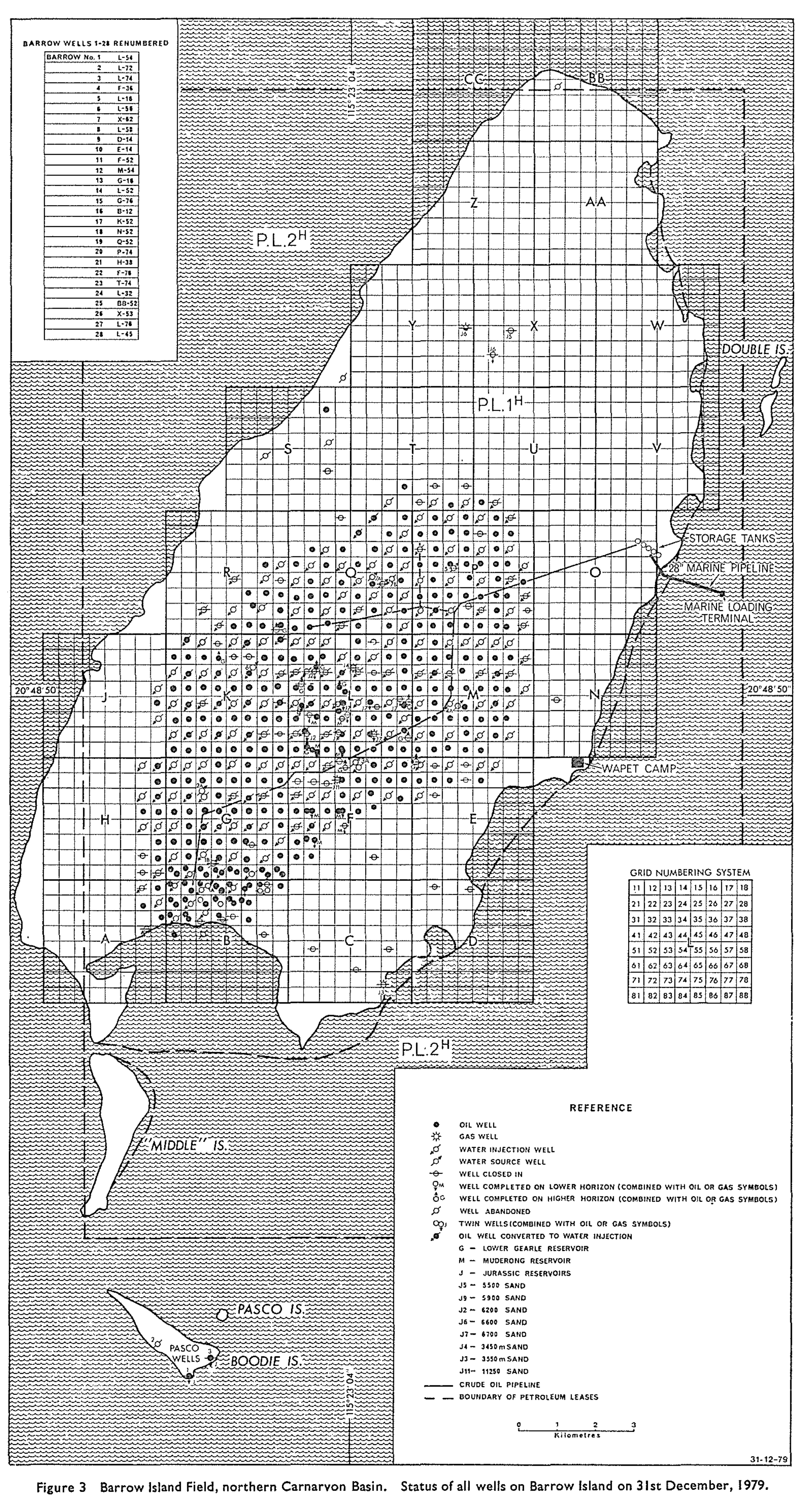


Figure 3 Barrow Island Field, northern Carnarvon Basin. Status of all wells on Barrow Island on 31st December, 1979.

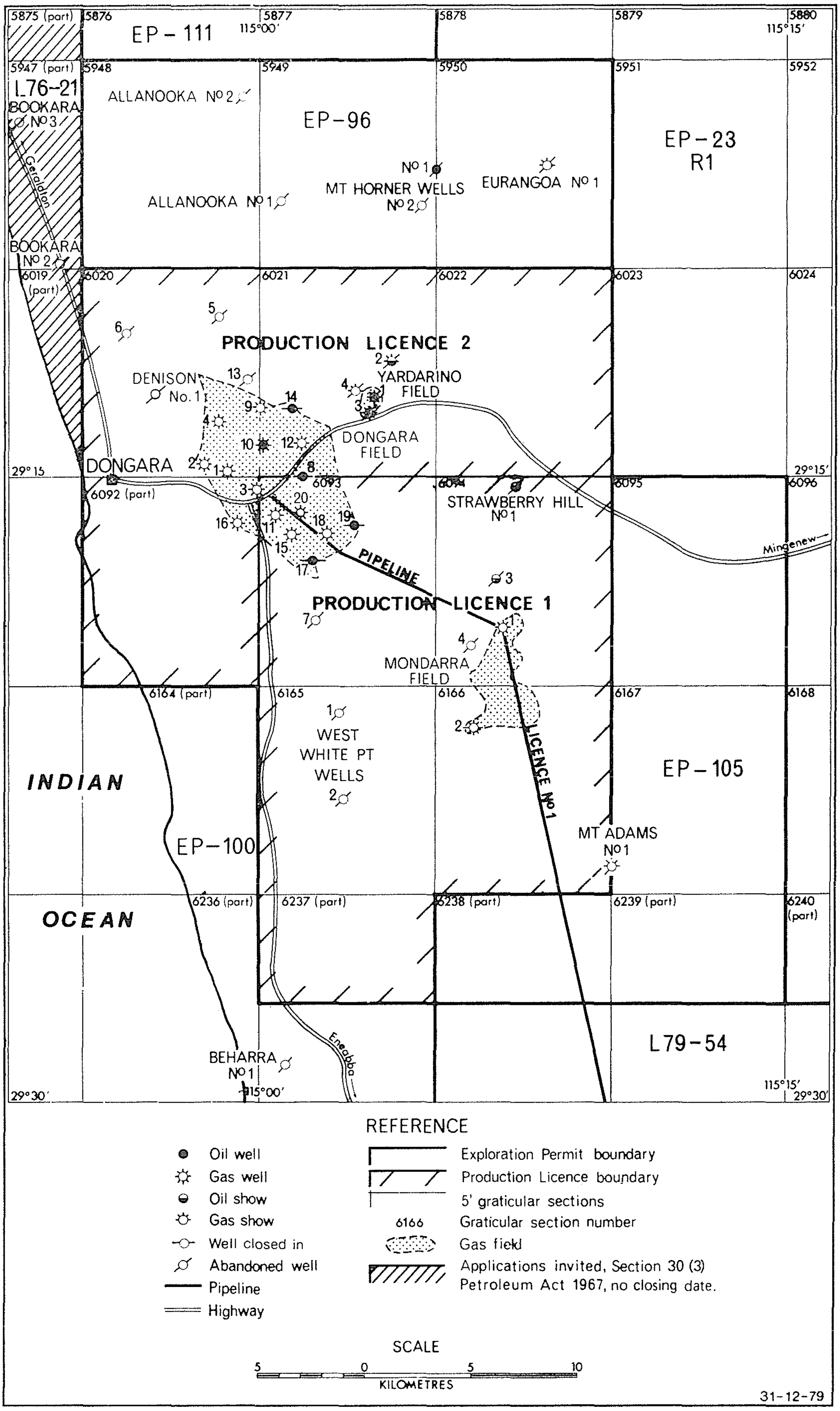


Figure 4 Dongara area, northern Perth Basin. Status of petroleum tenements and wells on 31st December 1979

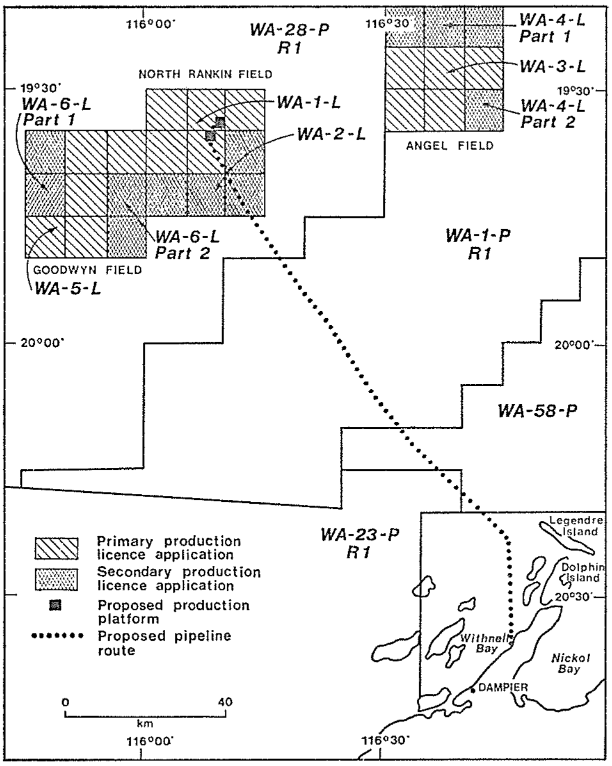


Figure 5 Angel, North Rankin and Goodwyn field locations showing the proposed pipeline route to Withnell Bay.

North Rankin and Goodwyn Fields (Figure 5)

(Operator—Woodside Petroleum Development Ltd)

All major technical studies for the planning and definition phase of the North West Shelf Natural Gas Project were completed during 1979.

The proposed development consists of:

(a) An offshore production platform to be established on the North Rankin gas field in time to begin production initially to supply pipeline gas to Western Australian markets in September, 1984.

(b) A second platform to be in production on the North Rankin gas field in 1986, lifting total gas production to the level required to sustain exports of liquefied natural gas (LNG).

(c) A third production platform to be established on the Goodwyn gas field during the early 1990's.

(d) A pipeline approximately one metre in diameter to carry both gas and liquids from the production platforms to the coast at Withnell Bay 10 km north of Dampier, (Figure 5). The 135 km long pipeline will be buried beneath the sea floor.

(e) A processing plant at Withnell Bay which will produce four products at the following average annual production rate:
1. Sales gas for Western Australia—151 x 10^{15} joules ($10·9$ x $10^6 m^3$ per day)
2. Condensate—$1·4$ x 10^6 tonnes
3. Liquefied Petroleum Gas (LPG)—$0·63$ x 10^6 tonnes
4. Liquefied Natural Gas (LNG)—6 x 10^6 tonnes

(f) Storage and shipping facilities for LNG, condensate and LPG.

(g) Accommodation and amenities for employees in both the construction and production phases and the other infrastructure items required to support a complex industrial operation in a remote area.

(h) A fleet of specialised carriers to transport the LNG to markets.

The Commonwealth Government has issued an export licence which covers the proposed export of LNG. Substantial quantities of condensate and LPG will be extracted from the gas prior to sale.

After comprehensive studies of the impact of the project on the environment, a draft Environmental Impact Statement and Environmental Review and Management Programme was presented to the State Government in May and also made available for public comment. A final environmental impact statement was submitted in July.

A comprehensive agreement between the Participants and the Government of Western Australia which provides the framework under which the project will operate was signed and subsequently ratified as an Act of the Western Australian Parliament in December, 1979.

PETROLEUM PRODUCTION

Barrow Island Field (Tables IX, X and XII, Figures 6 and 7)

The total production of petroleum during 1979 from Barrow Island is shown in Table IX.

Associated gas produced with the crude oil has no direct market outlet at Barrow Island. About 15% of associated gas (12 885 $10^3 m^3$) is used as field fuel and the remainder is processed for the extraction of plant products such as LPG and natural gasoline. The natural gasoline is blended with the crude oil for sale and the LPG is either sold as LPG to markets in the north-west of the State, or blended with the crude oil. A small amount (285 m^3 or 7% of LPG production) is used as vehicle fuel on Barrow Island.

During the year, the infill and development wells drilled in the 1978-79 programme contributed nearly 120 000 m^3 of crude oil or about 8% of the Barrow Island oil production for the year. The potential effect of the additional production in slowing down the decline in Barrow Island Field production was lost because during several months of the year production had to be curtailed due to the lack of available tankers to offload stored production.

For example production in September averaged 2 020 m^3 per day as compared with 4 954 m^3 per day in January when no curtailment was required and 3 843 m^3 per day in December when partial curtailment of production was required.

A breakdown of annual and cumulative production for the reservoirs of the Barrow Island Field is shown in Table IX. Annual production of crude oil from the commencement of commercial production in 1967 is shown in Figure 6 and the cumulative production of liquids and water injected is shown in Figure 7. It can be seen that at the end of 1979 the total amount of water injected exceeds the total amount of oil and water produced; the difference is due largely to the volume of gas produced from the reservoir.

Total royalty paid on Barrow Island crude oil sales during 1979 was $3 621 638, an increase of $142 267 or 4% over 1978. When the difference in production between 1978 and 1979 is taken into account, the royalty per cubic metre of sales has risen from $1·92/m³ in 1978 to $2·58/m³ in 1979 or an increase of 34%.

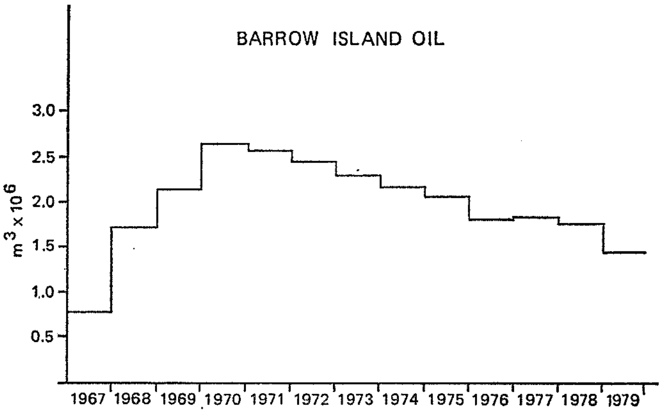


Figure 6 Barrow Island Field (Petroleum Lease 1H). Yearly production of crude oil from 1967 to 31st December, 1979.

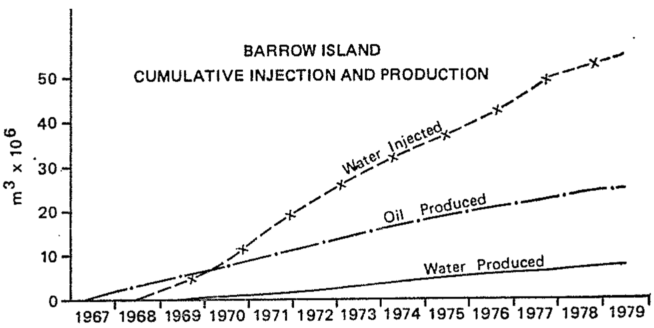


Figure 7 Barrow Island Field. Windalia Reservoir, cumulative production of oil and water and cumulative water injected from 1967 to 31st December, 1979

TABLE IX
BARROW ISLAND FIELD, PETROLEUM PRODUCTION DURING 1979

Reservoir	Production for year 1979					Cumulative Production				
	Oil (m³)	Natural Gasoline (m³)	Liquefied Petroleum Gasoline (m³)	Gas (10³m³)	Water (m³)	Oil (m³)	Natural Gasoline (m³)	Liquefied Petroleum Gasoline (m³)	Gas (10³m³)	Water (m³)
Lower Gearle	14 309	....	....	3 421·4	1 595	53 969	....	....	9 296·3	2 788
Windalia	1 421 840	4 914	3 949	78 473·3	685 454	25 094 116	31 115	30 365	2 132 053·1	7 489 073
Muderong	5 040	....	....	954·0	6 151	235 707	....	....	37 447·2	86 203
Jurassic 5 900'	2 440	....	....	242·0	1 223	2 440	....	....	242·0	1 223
Jurassic 6 600'	2 100	....	....	461·9	16 330	79 025	....	....	24 427·1	169 804
Jurassic 6 700'	7 746	....	....	1 426·0	15 585	236 107	....	....	128 678·5	121 877
Total	1 453 475	4 914	3 949	84 978·6	726 338	25 701 364	31 115	30 365	2 332 144·2	7 870 968
Cumulative totals for oil reservoirs not producing in 1979						9 135	....	....	80 925·8	19 707
Cumulative totals for gas reservoirs not producing in 1979						3 698 (condensate)	....	....	48 407·7	16 618
Total Production to 31/12/79						25 714 197	31 115	30 365	2 461 477·7	7 907 293

Water Injected during 1979 — 3 134 424 m³ Cumulative water injected — 56 199 286 m³

TABLE X

BARROW ISLAND FIELD, OIL AND GAS DISPOSAL DURING 1979

	Oil (m^3)	Natural Gasoline (m^3)	Liquefied Petroleum Gas (m^3)	Gas (10^3m^3)
Total Production	1 453 475	4 914	3 949	84 978·6
Field Fuel	....	....	†285	12 885·3
Sales	*1 405 769	....	2 709	....

Royalty paid on petroleum sales during 1979 = $A 3 621 637.65

* Oil sales include all natural gasoline produced and 783 m^3 L.P.G.

† Vehicle fuel.

Dongara, Mondarra and Yardarino Fields (Table XI, XII and Figure 8)

Table XI shows the petroleum production from the northern Perth Basin fields during 1979 together with the cumulative production since commercial production began in October 1971.

Gas production averaged 2 340 10^3m^3 per day during 1979 from the Dongara, Mondarra and Yardarino fields. Annual production since 1971 is shown in Figure 8 and it is estimated that about 50% of the probable reserves of the northern Perth Basin gas fields has been produced.

The royalty paid on petroleum production from the northern Perth Basin fields during 1979 was $1 050 355, an increase of $165 255 or 19% over 1978.

The 1979 production of petroleum and cumulative production for all fields to date is shown in Table XII.

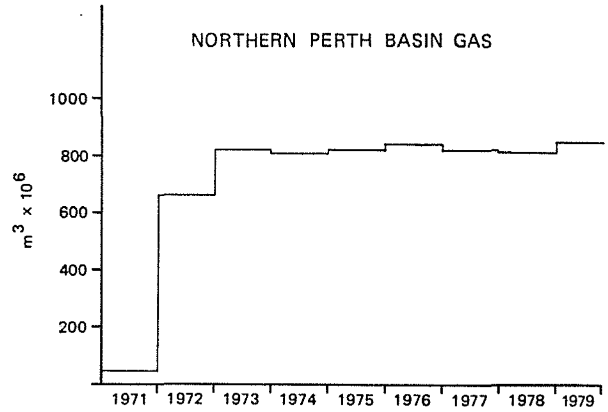


Figure 8 Northern Perth Basin. Yearly production of gas between 1971 and 31st December, 1979.

PETROLEUM RESERVES

The total recoverable petroleum reserves of the State at the end of 1979 are estimated with a 25% probability to be at least 16·1 10^6m^3 of crude oil, 54·6 10^6m^3 of condensate, 29·4 10^6m^3 of LPG and 435·5 10^9m^3 of natural gas. There have been a number of revisions to reserves during 1979 as better information came to hand and better reserves estimation techniques can be used as a result. The most significant variation to reserves have occurred as a result of the decision by the North West Shelf joint venturers to extract the LPG (propane and butane) from produced gas as separate products from LNG (liquefied natural gas).

During 1979 the drilling of Pueblo No. 1 in the Carnarvon Basin and Brecknock No. 1 in the Browse Basin lead to discoveries which resulted in an increase in the States petroleum resources. The economic viability of these discoveries will require further evaluation before they can be regarded as economic reserves. The details of reserves as at 31st December 1979 are set out in Table XIII.

PETROLEUM PIPELINES

Dongara to Pinjarra Natural Gas Pipeline

(Operator—West Australian Natural Gas Pty Ltd)

A total of 1 388 work proposals from Government Department and Instrumentalities, and other parties, were processed during 1979.

There were no encroachments on the Dongara to Pinjarra pipeline during the year.

PETROLEUM INDUSTRY ACCIDENTS

Refer Table XIV and Figure 9.

Staff

The staff of the Petroleum Branch during 1979 were as follows:—

A. J. Sharp—Director, Petroleum Branch (Level 6)
A. H. Pippet—Senior Petroleum Engineer (Level 5)
P. H. J. Hammett—Petroleum Engineer (Level 4)
D. N. Smith—Production Geologist (Level 4)
S. P. Willmott—Reservoir Engineer (Level 4)
I. D'Mello—Technical Assistant (G–VII–1)
F. Kleinman—Secretary/Stenographer (C–III–2)

TABLE XI

DONGARA, MONDARRA AND YARDARINO FIELDS, PETROLEUM PRODUCTION DURING 1979

Field	Number of producing wells at 31/12/1979	Production for year 1979				Cumulative production			
		Gas (10^3m^3)	Condensate (m^3)	Oil (m^3)	Water (m^3)	Gas (10^3m^3)	Condensate (m^3)	Oil (m^3)	Water (m^3)
Dongara	13	791 678·0	2 755·3	14 670·5	12 945·0	5 947 519·4	26 966·6	52 754·2	40 754·3
Mondarra	1	41 935·3	299·6	....	721·3	444 610·5	6 063·2	....	3 717·0
Yardarino	1	20 517·3	....	431·2	795·5	25 106·0	....	566·6	910·3
Total	15	854 130·6	3 054·9	15 101·7	14 461·8	6 417 235·9	33 029·8	53 320·8	45 381·6

Total gas sold in 1979 = 836 175·4 10^3m^3
Total condensate sold 1979 = 3 048·8 m^3
Total oil sold in 1979 = 14 965·4 m^3

Royalties:		
Gas	$	997 695.28
Oil	$	44 683.09
Condensate	$	7 976.85
Total royalties paid		$1 050 355.22

NOTES:

1. Metric standard conditions for both gas and oil are 15°C and 101·325 kPa.
2. Does not include 3 467 10^3m^3 used in testing prior to production for commerce.
3. Volumetric figures rounded.

TABLE XII

SUMMARY OF PRODUCTION TO 31st DECEMBER 1979

	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)	
	1979	Cumulative	1979	Cumulative	1979	Cumulative	1979	Cumulative
Carnarvon Basin—								
Barrow Island	1·453	25·701	0·085	2·332	0·004	0·030	0·005	0·031
Other	....	0·011	....	0·132	....	....	....	0·004
Perth Basin—								
Dongara	0·015	0·053	0·792	5·951	....	....	0·003	0·027
Mondarra	....	....	0·042	0·445	....	....	neg.	0·006
Yardarino	<0·001	0·001	0·021	0·026	....	....	....	....
Other	....	....	....	0·062	....	....	....	0·003
Total	1·469	25·766	0·939	8·948	0·004	0·030	0·008	0·071

TABLE XIII

SUMMARY OE IDENTIFIED RECOVERABLE PETROLEUM RESERVES AT 31st DECEMBER 1979

Field	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	12·06	14·48	0·55	0·62	0·09	0·09	0·07	0·07
Perth Basin—								
Dongara	0·27	0·27	5·24	5·24	....	....	0·02	0·02
Mondarra	....	....	0·12	1·10	....	....	neg	0·01
Yardarino	neg	neg	0·02	0·02	....	....	....	....
Total	....	14·76	....	6·99	....	0·09	....	0·11
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	....	....	2·26	2·99
West Tryal Rocks	....	....	8·25	58·94	....	....	0·55	3·94
Total	....	1·35	....	428·50	....	29·30	....	54·50
Total Reserves	....	16·11	....	435·49	....	29·39	....	54·61

P1 probability > 75%
P2 probability > 25%

TABLE XIV

ACCIDENT STATISTICS RELATING TO THE PETROLEUM EXPLORATION, PRODUCTION AND PIPELINE INDUSTRY DURING 1979

PETROLEUM INDUSTRY CATEGORIES

	Drilling Activities		Barrow Island Oil-field	Dongara Gas-field	Natural Gas Trans-mission Pipeline	Total
	Onshore	Offshore				
NATURE OF INJURY	NUMBER OF INJURIES					
Head	....	8	6	....	....	14
Eye	....	11	11	....	....	22
Trunk	....	27	17	....	....	44
Arm	....	13	4	....	....	17
Hand	....	26	16	....	....	42
Leg	1	17	11	....	....	29
Foot	2	14	10	....	....	26
Occupational diseases	....	....	....	....	....	....
Other injuries and shock	....	....	2	....	....	2

TABLE XIV—*continued*

ACCIDENT STATISTICS RELATING TO THE PETROLEUM EXPLORATION, PRODUCTION AND PIPELINE INDUSTRY DURING 1979—*continued*

PETROLEUM INDUSTRY CATEGORIES—*continued*

	Drilling Activities		Barrow Island Oil-field	Dongara Gas-field	Natural Gas Trans-mission Pipeline	Totals
	Onshore	Offshore				
AGENCY OF INJURY	**NUMBER OF INJURIES**					
Machinery in operation	....	13	9	1	....	23
Vehicles	....	....	4	....	....	4
Tools—hand	....	8	7	....	....	15
Tools—power	....	4	1	....	....	5
Manual handling	....	10	11	....	....	21
Harmful contacts	....	8	8	....	....	16
Persons falling or striking	....	37	12	1	....	50
Objects flying or falling	....	27	19	1	....	47
Other	....	2	5	....	....	7
MAGNITUDE OF INJURY	**NUMBER OF ACCIDENTS**					
Minor	2	62	64	....	....	128
Serious	1	41	15	....	....	57
Fatal	....	....	....	....	....	....
TIME FACTOR	**EXPOSURE TIME AND TIME LOST**					
Thousands of manhours exposure	34 032	1 491 964	427 887	14 742	27 593	1 996 218
Manhours lost*	496	16 192	4 848	....	....	21 536

* A nominal 8 hour day is assumed.

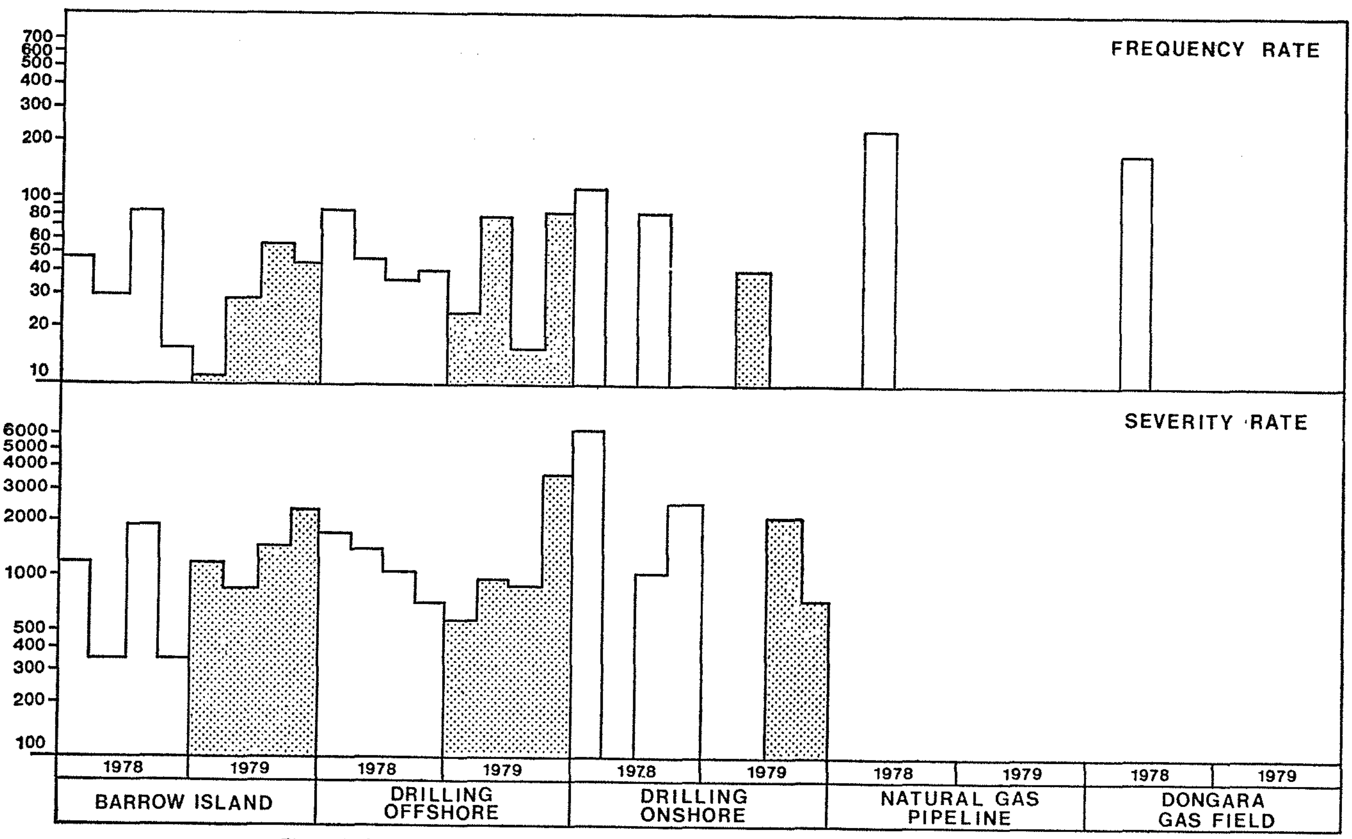


Figure 9 Serious injuries in the petroleum exploration and pipeline industry during 1978 and 1979. Frequency and severity rate.

DIVISION VI

Report of the Superintendent Surveys and Mapping for the Year 1979

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, 1979.

STAFF

During the year, all vacancies with one exception were filled and we were fortunate in being able to convert 16 professional positions on the attached list into establishment items. Although this has not increased the total staff, it has ensured that when vacancies do occur they will be filled by advertising and not by attached officers, thereby reducing the staff.

	Occupied	Attached	Vacant	Total
Professional	71	....	....	71
General	29	....	....	29
Technical	6	....	....	6
Clerical	10	1	1	12
Trainee	3	....	....	3
				121

Although this represents a full staff compliment, all areas were under heavy pressure to maintain programmes. Despite the usual high response from staff members, work loads accumulated due to sheer volume. The Mapping Branch felt the full impact of the Commonwealth's withdrawal of funds the previous year for printing of 1:250 000 maps and heavy overtime programmes were necessary to meet the demand. An indication of the increased demand in just one area only can be seen in the 1:250 000 geological map section where 27 map sheets were in progress during the year as against 12 sheets as recently as 1976.

Other geological work was just as heavy including Urban geology maps, maps and diagrams for publications and a revised edition of the State Geological map.

The Public Plans Branch were called upon to provide additional service in all areas in response to a strong and increasing interest in mining activity, particularly in gold and diamonds. The small counter staff found it difficult to cope with map sales that doubled in number and two and a half times in value compared to the previous year. There is no indication of any slackening of interest.

Other effects of this mining interest were to require more and more base plans to be prepared at larger scales to adequately show tenements.

Although the number of tenements surveyed were less than previously due to a reduction in the survey vote, other work previously neglected was attended to and further work on extension of computer applications was carried out.

A more detailed report of each Branch follows.

SURVEY BRANCH

Surveys of mining tenements during the 1979 calendar year were carried out by 28 Licensed Surveyors attached to 21 individual practices. See Fig. 1.

Survey work completed is summarised as follows:—

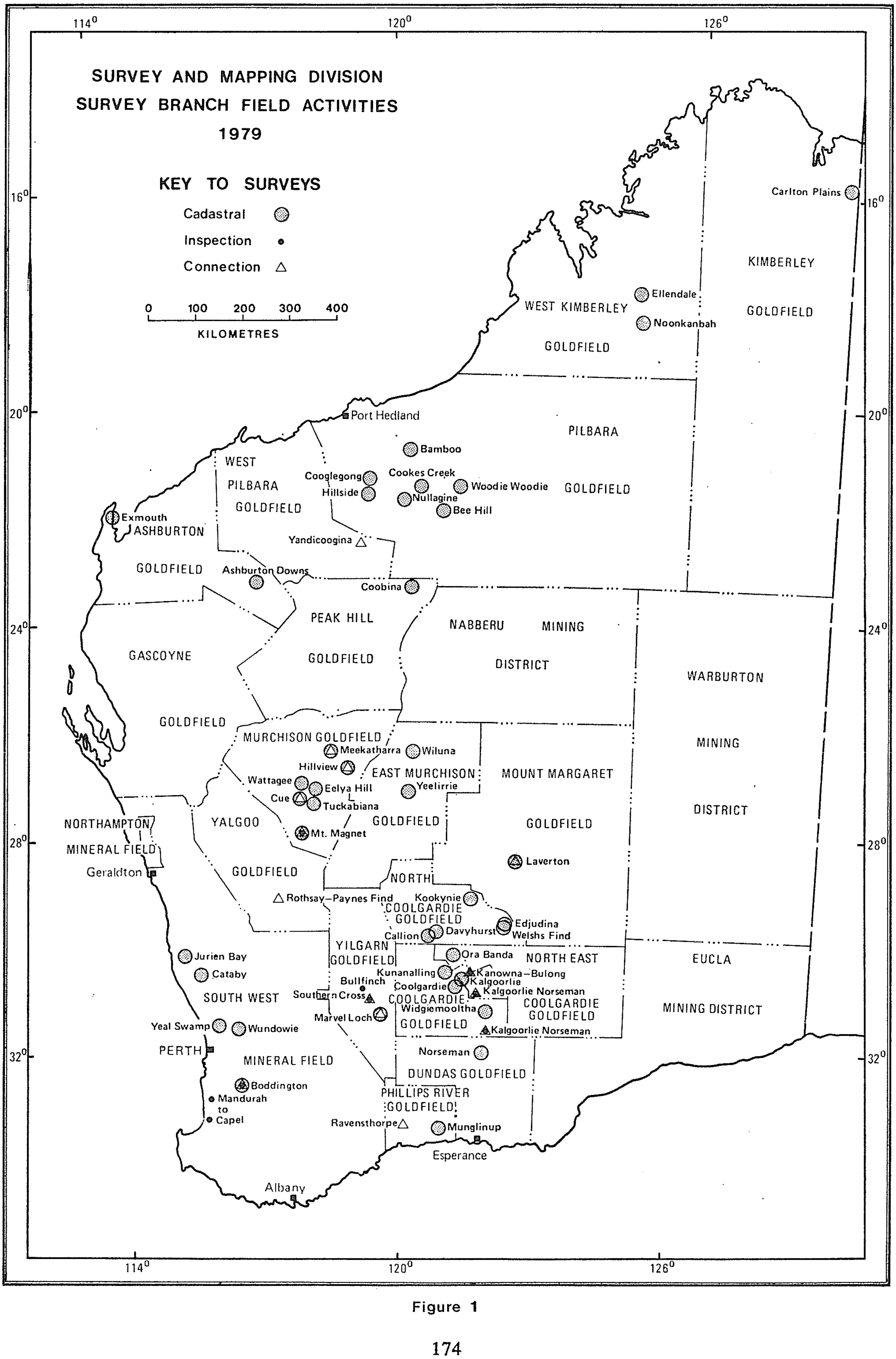
	1979 Average Area (64·92 ha)	1978 (95·83 ha)
No. of Tenements surveyed	742 ($405)	1 259 ($453)
No. of Field Books lodged	167	217
Total Boundary Line Run	1 329 km	2 891 km
Traverse Line Run	162 km	185 km
Total Area Delineated by Survey	47 747 ha	122 153 ha
Distance travelled in positioning	74 611 km	62 540 km
Total value of Cadastral surveys	$300 423	$570 897
Total value of Geodetic surveys	$103 182	$ 52 466
Total value of Special surveys	$ 5 542	$ 42 735
Total Expenditure	$409 147	$666 098

The work performed by individual Practitioners is itemised in the following table:—

Company	Surveyor(s)	No. of Surveys	Area Surveyed (ha)
Ranieri, Bateman & Assoc.	J. S. Ranieri G. Bateman	95	10 904
D. F. V. Wilson	D. F. V. Wilson C. Gulaptis	22	2 620
Fisher-Lewis	M. M. Fisher E. J. Still	79	671
McGay Surveys	D. J. McGay	87	7 259
J. Zuideveld & Assoc.	J. Zuideveld	59	3 777
K. R. Maguire	K. R. Maguire	41	4 254
Markey, Campbell & Thomson Pty. Ltd.	T. L. Markey W. N. Thomson	28	2 381
A. R. Williams & Assoc.	A. R. Williams R. G. Beardman	20	2 335
K. M. Edwards	K. M. Edwards	32	2 783
Hille & Thompson	P. J. Hille A. G. Thompson M. W. Hatch	57	6 275
McKimmie, Jamieson & Partners Pty. Ltd.	G. S. Chignell	18	1 852
F. R. Rodda	F. R. Rodda	....	....
A. K. King & Co.	A. K. King C. Parker	29	745
P. D. Heyhoe	P. D. Heyhoe	63	502
R. G. Agnew	R. G. Agnew	46	397
K. F. Paterson & Assoc.	K. F. Paterson	32	254
Byrne & Associates	G. G. Bateman C. Gulaptis	19	127
Warren F. Johnson (W.A.) Pty. Ltd.	K. D. Bartlett	4	484
I. M. Gordon	I. M. Gordon	10	58
G. C. Callaghan	G. C. Callaghan	....	....
Associated Surveys Pty. Ltd.	G. Nolan	1	69
21	28	742	47 747

The considerable difference in number of tenements surveyed and the expenditure on cadastral survey with 1978 figures is the result of several factors. A large number of surveys completed during 1979 were lodged too late in the year to be included in 1979 statistics. Scheduling of surveys after the 1st July, 1979 was curtailed as it was not known until late August the amount which would be allocated for carrying out Mines Department Surveys.

The average area of tenements has reduced to 64·92 ha (95·83 ha in 1978) reflecting the increased interest in gold and survey of Gold Mining Leases and a large group of smaller than



SURVEY AND MAPPING DIVISION
SURVEY BRANCH FIELD ACTIVITIES
1979
KEY TO SURVEYS
Cadastral
Inspection
Connection
0 100 200 300 400
KILOMETRES
114°
120°
126°
16°
20°
24°
28°
32°
Carlton Plains
KIMBERLEY
GOLDFIELD
Ellendale
Noonkanbah
WEST KIMBERLEY
GOLDFIELD
Port Hedland
PILBARA
GOLDFIELD
Bamboo
Cookes Creek
Woodie Woodie
Nullagine
Bee Hill
Cooglegong
Hillside
WEST
PILBARA
GOLDFIELD
Exmouth
ASHBURTON
GOLDFIELD
Yandicoogina
Ashburton Downs
Coobina
PEAK HILL
GOLDFIELD
NABBERU MINING
DISTRICT
GASCOYNE
GOLDFIELD
WARBURTON
MINING
DISTRICT
MURCHISON GOLDFIELD
Meekatharra
Wiluna
Hillview
Wattagee
Eelya Hill
Cue
Tuckabiana
EAST MURCHISON
GOLDFIELD
Yeelirrie
MOUNT MARGARET
GOLDFIELD
NORTHAMPTON
MINERAL FIELD
Geraldton
YALGOO
GOLDFIELD
Mt. Magnet
Laverton
NORTH
COOLGARDIE
GOLDFIELD
Rothsay-Paynes Find
Kookynie
Edjudina
Welshs Find
Callion
Davyhurst
YILGARN
GOLDFIELD
Ora Banda
NORTH EAST
COOLGARDIE
GOLDFIELD
EUCLA
MINING DISTRICT
Jurien Bay
Cataby
Kunanalling
Kanowna-Bulong
Bullfinch
Coolgardie
Kalgoorlie
Kalgoorlie Norseman
SOUTH WEST
Southern Cross
COOLGARDIE
GOLDFIELD
Widgiemooltha
Marvel Loch
Kalgoorlie Norseman
Yeal Swamp
Wundowie
PERTH
Norseman
MINERAL FIELD
DUNDAS GOLDFIELD
Boddington
Mandurah
to
Capel
PHILLIPS RIVER
GOLDFIELD
Ravensthorpe
Munglinup
Esperance
Albany

Figure 1

average Mineral Claims for manganese in the Pilbara. On expenditure per kilometre basis the cost 1978–79 has increased from $184.52 per km to $201.42 per km a 9% increase. The higher expenditure on Geodetic Surveys reflects the need for co-ordination of present and future mapping and recording in areas of continuing mining interest.

Survey Dispute

A dispute between a surveyor carrying out Mines Department instructions and an aboriginal community managing a pastoral station in the Kimberley was eventually amicable settled by this Department's Administration taking a firm stand with the matter.

Photogrammetric Surveys

Photogrammetric Survey of Mineral Claims in the Ellendale area followed with some standard survey adjustment of area has now been completed.

The Pannawonica sections of the photogrammetric survey of ML 248SA has been completed by the contractor and lodged with the Mines Department. No new photogrammetric surveys were undertaken.

Field Inspections

Mt. Magnet control survey to help with reconnaissance and planning.

Control reconnaissance in the Kalgoorlie-Norseman area.

Reconnaissance of Southern Cross-Bullfinch control extensions and check of terrain and vegetation loadings.

Inspection of a point control venture between Alwest and this Department in an area North West of Boddington.

Field Levelling

Further extensions of levelling to bore holes for the G.S.W.A. in their investigations of the underground reservoir in the area from north of Bunbury south to Capel has been carried out during several levelling operations by Surveys Branch staff.

Control Projects and Co-ordinate Traversing and standard Plans Resulting therefrom.

Projects	NS (km)	EW (km)	Stations	Length of Traverse (km)	Points co-ordinated
Proceeding—					
Cue	70	90	....	1 076	1 316
Meekatharra	85	35	....	1 420	2 384
Kanowna-Bulong	Re measure of eastern section		....	....	....
Ravensthorpe	20	33	....	183	262
Yandecoogina (TR Boundaries)	....	....	....	....	....
New Projects—					
Mt. Magnet	140	60	15	....	....
Rothsay-Paynes Find	74	112	12	....	....
Hillview	10	25	1	....	....
Kalgoorlie-Norseman	200	70	16	....	....
Laverton (ext)	137	96	4	789 (2 540 total)	1 140 (3 011 total)
Collie	12	16	....	368	976
Southern Cross	50	30	10	....	....
Boddington	14	15	5	....	....
Ravensthorpe	10	21	3	....	....

New Standard Plans	1: 50 000	1: 10 000
Youanmi	4	2
Narndee	3	....
Gullewa	3	....
Golden Grove	5	....
Barrambie	4	4
Pannawonica	1	....
Minmeroora	1	....
Jimmawurrada	1	....
Koongie	1	....
Angelo	1	....
Halls Creek	1	....
Forrestania	7	....

Petroleum Section

There has been unprecedented upsurge in Permit applications both onshore and offshore which has lead to much increase in the work load for preparation of technical descriptions and plans and updating of records for the staff in the area.

Whilst the need to list all reserves affected by new onshore permits has been eased by drawing the applicants attention to the possible presence of reserves at the "offer" stage, a considerable time has been spent listing reserves affected by applications for wells and seismic surveys.

A new State Map at 1:2 500 000 as an index to petroleum tenements has been prepared to replace the smaller scale 1:4 000 000 previously maintained so that Petroleum Exploration areas may be better presented.

Computer Services Section

The Officer in Charge of the Computer Services Section has been reclassified from Level 1A to Level 2 of 25/8/78 giving recognition to his ability and the need for the section.

Normal support services have been maintained as follows:—

Survey accounts.

Annual update of the G.S.W.A. petroleum wells computer file.

Assisting branch staff in operating computer programmes for geodetic computing and traversing.

Supervision of material to be added to the CADMAPS system.

Computer operating costs were $2 389.

Special Projects—"Mindust" Programme

The system for the recording and processing of dust sampling was made operational late in August.

Future involvement is for such data processing officer to be available to key in data as it becomes available and a programmer to supervise data input and check each processing run.

Digitisation

Investigations into applications of digitisation for the capture of records has proceeded and a test programme for digitising and replotting from this data has been developed.

A digitisation project over a pilot area of mining tenements is to proceed to evaluate the scope and factors affecting recording of information by this method.

Automatic Plotting

Two programmes have been developed to automatically produce base sheets with the geographic graticule plotted on Clarke 1858 Spheriod. The plots are produced on the Xynetics flat bed plotter at the M.R.D. Corresponding AMG plots showing horizontal control are produced using the Lands Department CADMAPS data base.

Computer Equipment

An additional C.R.T. terminal was housed in the Computer Services Section specifically to process Mindust samples.

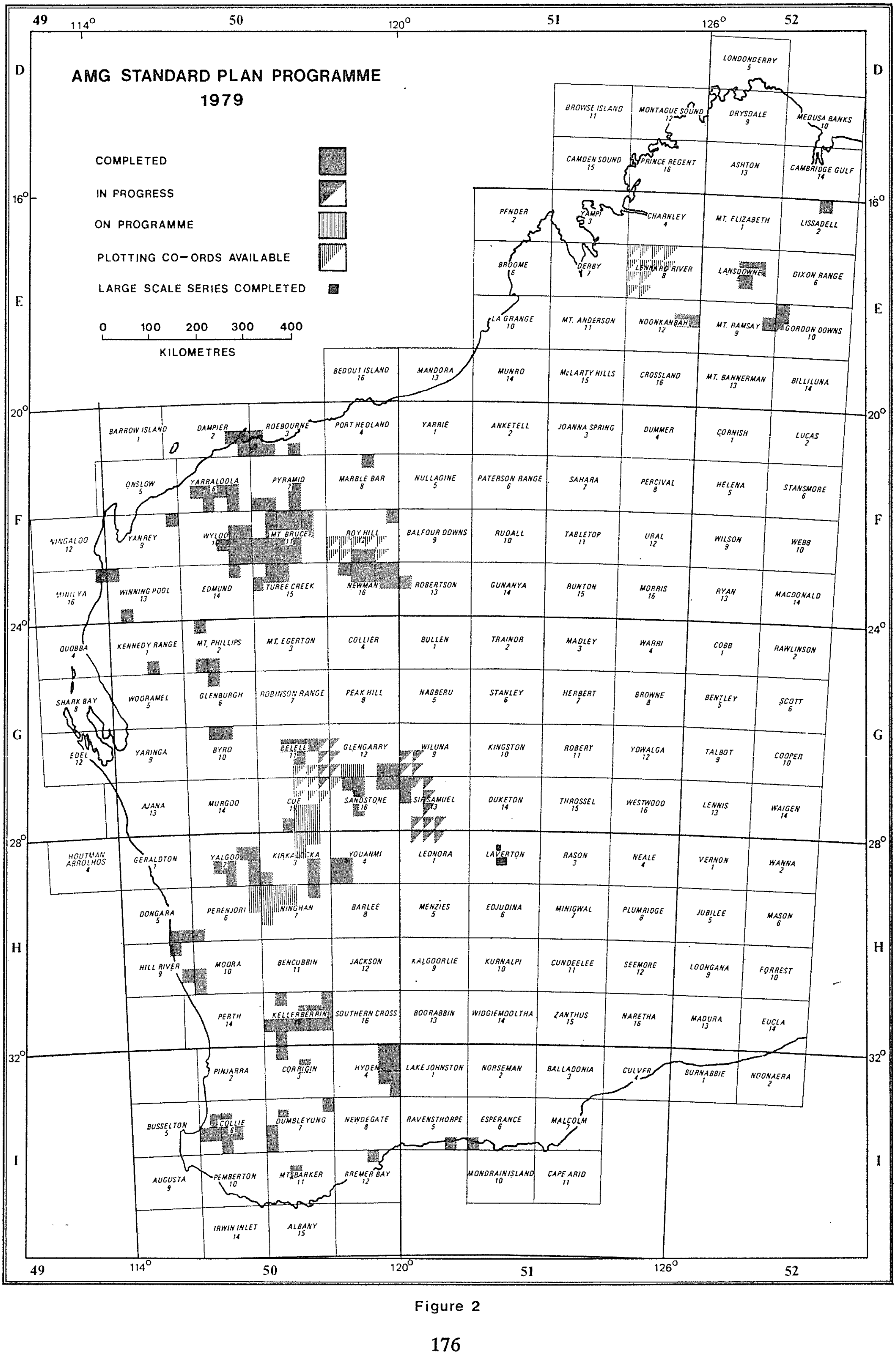
All available computer lines between the PDP 11/40 Computer and Mineral House are now in use.

Housing of Computer Staff and Equipment

As has been previously reported the space allocated for this important function is neither sufficient nor suitably placed and every effort to house this area in better circumstances should be made.

Survey Regulations

A committee met regularly to redraft the Survey Regulations that apply to Mines Department Surveys, in line with the new Mining Act. The aim was to update, clarify and condense the existing regulations. A draft was prepared and approved and is presently before the Institution of Surveyors and the Land Surveyors Licensing Board for comment.



AMG STANDARD PLAN PROGRAMME
1979
COMPLETED
IN PROGRESS
ON PROGRAMME
PLOTTING CO-ORDS AVAILABLE
LARGE SCALE SERIES 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
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 2

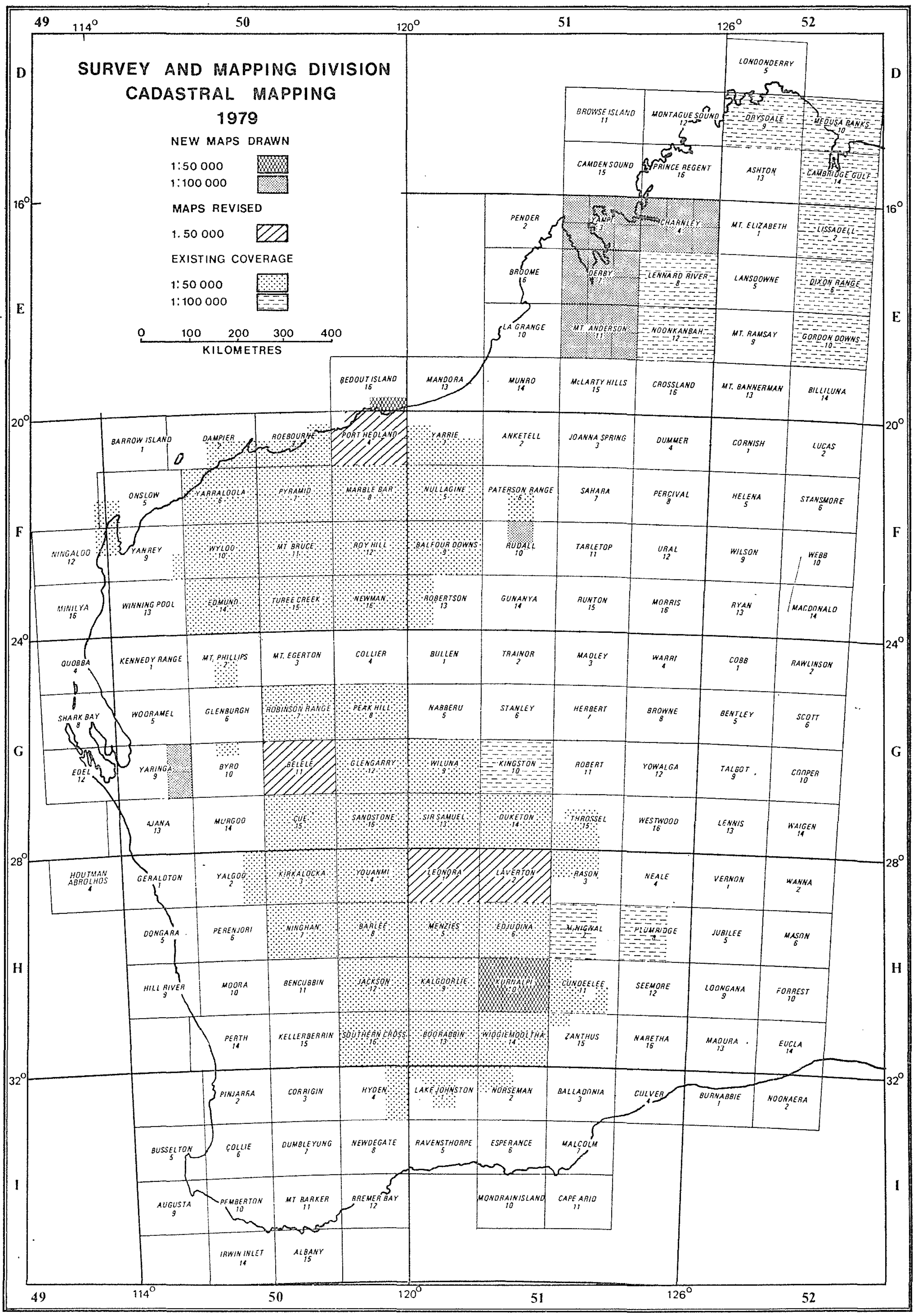


Figure 3

95816—(12)

MAPPING BRANCH

Cadastral Mapping Section

In response to diamond exploration in the West Kimberley, 25 new maps at a scale of 1:100 000 were completed on the AMG covering the Mt. Anderson, Derby, Yampi and Charnley areas.

At a scale of 1:50 000, 3 AMG sheets were completed at Bedout Island in the Pilbara and 48 sheets in the Eastern Goldfields at Laverton and Kurnalpi.

Revision of existing maps continued with a total of 72 sheets being updated at the scale of 1:50 000 in the areas of Leonora, Belele, and Port Hedland. See Fig. 3.

Geological Mapping

1:250 000 Series

The heavy regional mapping programme of the previous year was even more evident with a total of 27 sheets in various stages of production. The figures were made up of 18 first edition sheets of:—

Nullagine
Pinjarra
Ningaloo-Yanrey
Robinson Range
Rudall
Kingston
Trainor
Bullen
Gunanya
Onslow
Collier
Quobba
Wiluna
Southern Cross
Glengarry
Moora
Nabberu
Stanley

and 9 preliminary editions of:—

Yarrie
Port Hedland
Paterson Range
Mt. Phillips
Yaringa
Kirkalocka
Perenjori
Ninghan
Collie

Limited funds allowed only 1 first edition map of Marble Bar to be printed by the Government Printer. A further 4 first edition maps, Mt. Egerton, Sir Samuel, Duketon and Perth were printed by contract.

Project Mapping

Coloured maps of the Copper Bulletin, Tin Bulletin and Meckering Bulletin are all awaiting publication. Coloured plates for the Geology of the Pilbara Block Bulletin and the Geology of the Bangemall Basin Bulletin are in production.

1:50 000 Urban Geology Series

The only sheet printed during the year was the coloured edition of Pinjarra. Karratha, Nickol Bay, Pt. Samson and Baynton are awaiting printing. Dampier and Roebourne are in progress and should be ready for printing early in the new year.

State Maps

The State Geological map was published as a 150th anniversary edition. The revised State Map and gazetteer with bathymetric and hypsometric tinting was prepared for publishing.

Geological Publications

The fair drawing of 500 separate black and white figures for the publication of Bulletins, Report Series, Records, Explanatory Notes and Pamphlets was maintained at a high standard. The figures for the Pilbara Bulletin were completed, whilst the drafting for the comprehensive Nickel Bulletin was commenced. The Carnarvon Basin project was brought to a conclusion. Other publications were prepared for the Petroleum Branch and the Chemical Laboratories. As usual the section was under pressure for many drawings that were done as visual aids for 35 mm slides and overhead transparencies for lectures, local, interstate and overseas. The graphics and display work has increased immensely in this section.

Reprographic Section

This section again embraced a wide range of skills and processes. They met the many demands made upon them from all sources, through co-operation and an overtime programme. The number of items of work on the process camera and the printing down frames, was in excess of 4 000.

Colour developing and printing has expanded since the acquisition of a new colour print processor, so much so that over 4 450 prints were processed for many branches of the Department and an increased number of 35 mm coloured slides were photographed or copied.

Colour proofing and masking for multi-coloured reproduction increased with the expansion of geological mapping.

The plan printing section again came under heavy demand with the increase in mineral activity. This area provided a continuous service to all Branches and the public counter. Over 44 300 plans were printed, 2 572 plans were mounted and 385 booklets were bound, giving an overall total of some 47 257 items from this section.

PUBLIC PLANS BRANCH

The increase in mining activity was particularly felt in this Branch. Applications for all tenements averaged almost 1 000 a month to give a total of 11 266. See figs. 4, 5.

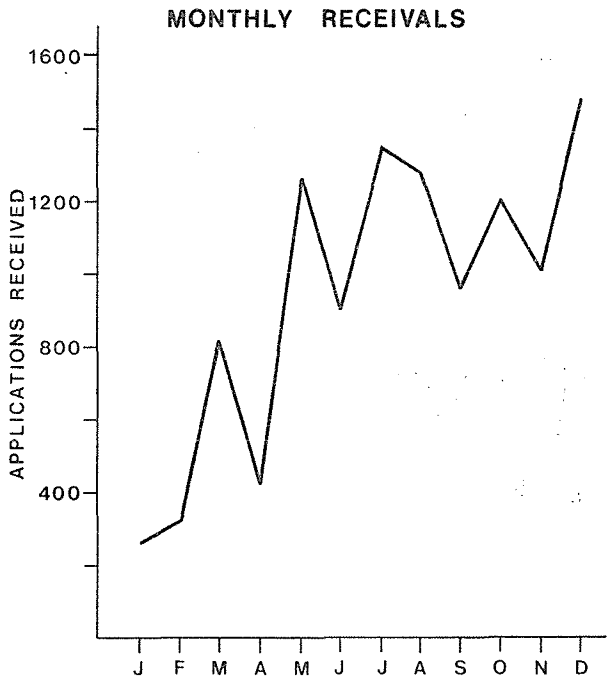


Figure 4

Applications for Tempory Reserves numbered 727 almost 300 more than 1978.

Coal	228
Gold	27
Iron	30
Other (including diamonds and uranium)	442
	727

Temporary Reserves approved during the year numbered 467.

Coal	116
Gold	15
Iron	37
Other (including diamonds and uranium)	299
	467

The involved processing required for these reserves placed a heavy burden on the staff.

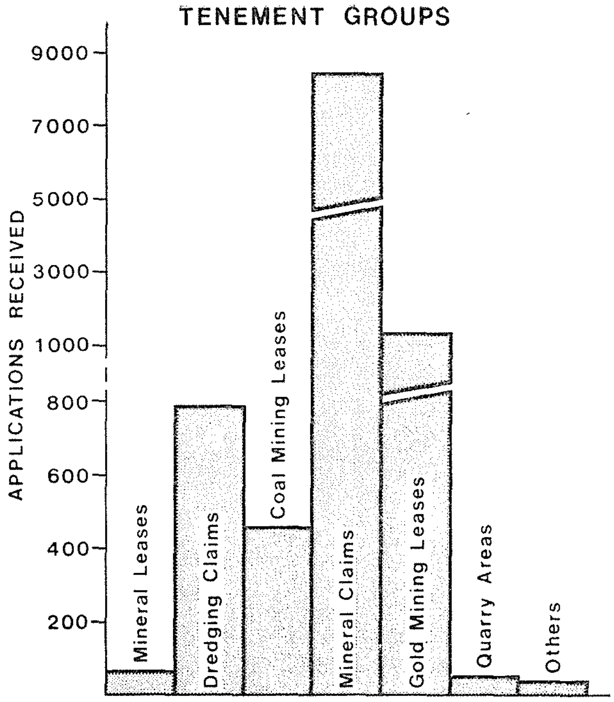


Figure 5

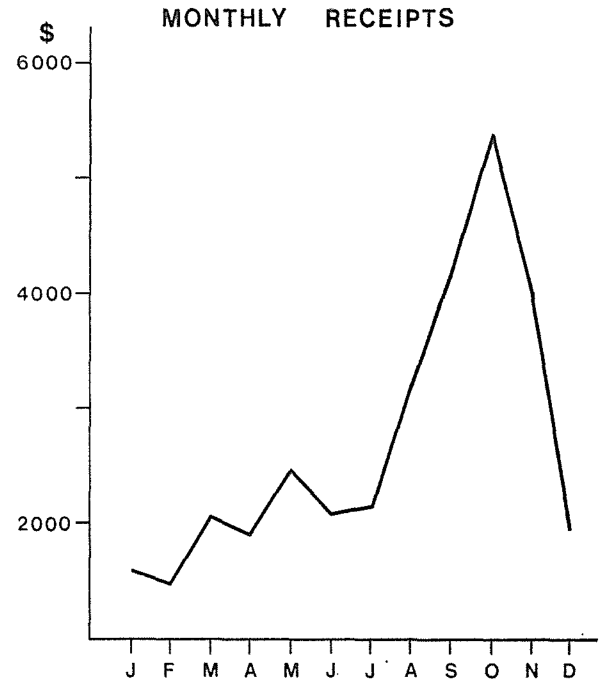


Figure 7

Map sales almost doubled in number (26 460) See Fig. 6 and two and a half times in value ($32 498) See Fig. 7 from the previous year.

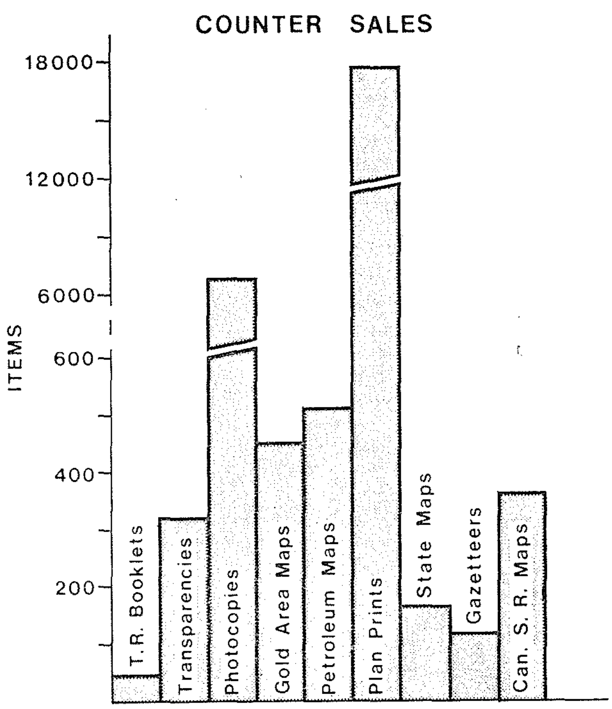


Figure 6

Counter staff were severely pressed and often had to be reinforced with Drafting personnel.

Despite this, public plans were maintained in Perth and the Outstations and new plans introduced where necessary to cope with the increase in applications. The numbers of public plans and other associated survey documents registered and in use with the Department are listed below.

	Current	Obsolete
Public Plans		
1:1 000 000 index series	14	82
1:1 000 000 temporary reserve series	14	39
1:1 000 000 petroleum series	33	31
1:250 000 public plans	108	332
1:100 000	76	70
1:50 000 and 1:25 000	1 157	2 241
Large Scale Series	6	15
Lands old series (imperial)	183	821
Mines old series (miscellaneous)	21	474
Lands old series (TM)	14	182
Old index sheets	....	137
Petroleum map (M175)	1	66
	1 627	4 480
Standard Plans		
Old projection (20 chains)	583	84
Transverse Mercator	212	9
Australian Map Grid—		
1:50 000	163	21
1:25 000	29	....
1:10 000	18	....
Provisional (all scales)	368	2
	1 373	116
Field Books		
Cadastral surveys	5 695	
Survey Plans		
Diagrams (imperial)	59 880	
Diagrams (metric)	6 800	
Original Plans—		
(imperial)	286	
(metric)	413	
	67 379	

W. R. MOORE,
Superintendent, Surveys and Mapping.

CONTENTS

DIVISION VII

Government Chemical Laboratories Annual Report—1979

UNDER SECRETARY FOR MINES

I have pleasure in presenting the summarised 85th Annual Report of the operations of the Government Chemical Laboratories for the year ended 31 December 1979.

ADMINISTRATION

The Laboratories consist of seven Divisions, the Kalgoorlie Metallurgical Laboratory, the Library and a centralised office under the control of the Director (Government Analyst, Chemist and Mineralogist) located as follows:

Perth, 30 Plain Street

- Director—R. C. Gorman, B.Sc., F.R.A.C.I., M.A.I.A.S.
- Deputy Director—H. C. Hughes, B.Sc., F.R.A.C.I., M.A.I.A.S.
- Agricultural Chemistry Division—J. Jago, B.Sc., A.R.A.C.I., Chief of Division.
- Food and Industrial Hygiene Division—F. E. Uren, A.P.T.C.Chem., A.R.A.C.I., Chief of Division.
- Forensic Chemistry Division—V. J. McLinden, A.P.T.C.Chem., A.R.A.C.I., Chief of Division.
- Industrial Chemistry Division—E. B. J. Smith, B.Sc., D.Phil., M.A.I.A.S., A.R.I.C., A.R.A.C.I., A.P.I.A., Chief of Division.
- Mineral Division—D. Burns, B.A., B.Sc., F.R.A.C.I., Chief of Division.
- Water Division—N. Platell, B.Sc., A.R.A.C.I., Chief of Division.
- Library—J. Bryant, B.Sc., Dip.Ed., Dip.Lib., Librarian.
- Office—A. D. W. Kinghorn, B.A., Senior Clerk.

Bentley, Catherine Street

- Engineering Chemistry Division—B. A. Goodheart, B.Sc., M.I.E.Aust., A.R.A.C.I., A.M.Aust., I.M.M., Chief of Division.

Kalgoorlie, MacDonald Street

- Kalgoorlie Metallurgical Laboratory—A. Mykytiuk, A.I.T.Met., W.A.S.M., Officer in Charge.

STAFF

The establishment of the Laboratories including three long term temporary officers now consists of the following officers:

Professional Division	83
General Division	49
Clerical Division	12
Wages Staff	2
Total	146

Staff increases during the year included two professional officers, one for the Food and Industrial Hygiene Division and one for the Engineering Chemistry Division and two laboratory technicians for the Forensic Chemistry Division. Another temporary laboratory technician was obtained for 12 months for work for the State Housing Commission on utilisation of Pindan soils for brick making in the north-west of the State.

Again staff have to be complimented on their efficiency, effort and dedication during the year, without such efforts the increased work load could not have been handled.

COMMITTEES

Various staff members served during the year on the following statutory, *ad hoc* or inter-departmental committees:

- Ecology of the Ord Dam Sub-committee.
- Environmentally Hazardous Chemicals Committee.
- Fluoridation of Public Water Supplies Advisory Committee.
- Food and Drug Advisory Committee.
- Food Analysis Sub-committee of National Health and Medical Research Council.
- Forensic Science Co-ordinating Group.
- Government Paint Committee.
- Investigating Panel of the W.A. Post Secondary Education Commission on Re-accreditation of the W.A.I.T. Chemistry Course.
- Laboratory Safety Committee of the Industrial Foundation for Accident Prevention.
- Laporte Effluent Disposal, Environmental and Hydrogeological Sub-committees.
- Laporte Industrial Factory Agreement Review Committee.
- Lupin Technology Committee.
- Medical Fitness in Relation to Driving, Sub-committee on Back-calculation of Blood Alcohol Levels.
- Mineral Processing and Manufacturing Sub-committee of C.S.I.R.O. State Committee.
- National Association of Testing Authorities:
  - Chemical Registration Committee; and
  - W.A. State Committee.

TABLE 1

SOURCE AND ALLOCATION OF WORK—1979

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—									
Agricultural Department	22 631	....	1 485	18	....	....	....	100	24 234
Agricultural Protection Board	....	....	44	13	....	....	....	....	57
Conservation and Environment Department	....	....	....	....	....	....	....	24	24
Consumer Affairs Bureau	....	....	10	....	22	....	....	....	32
Department of Corrections	....	....	....	51	....	....	....	....	51
Education Department	24	....	....	....	....	....	....	....	24
Fisheries and Wildlife Department	....	....	36	....	....	....	....	20	56
Geological Survey	....	15	....	....	....	....	437	....	452
Government Chemical Laboratories	20	232	40	30	2	....	321	....	645
Government Employees Housing Authority	....	....	....	....	4	....	....	....	4
Government Stores	....	....	84	....	....	....	....	....	84
Harbour and Lights Department	....	....	....	5	2	....	....	....	7
Hospitals	....	....	39	....	....	....	....	....	39
Industrial Development Department	....	....	....	....	....	....	....	40	40
Labour and Industry Department	....	....	173	....	1	....	....	....	174
Leschenault Inlet Management Authority	....	....	....	....	....	....	....	96	96
Main Roads Department	....	....	....	....	38	....	34	10	82
Metropolitan Water Board	....	....	142	....	11	....	28	1 563	1 744
Mines Department	....	....	144	4	....	26	678	297	1 149
Office of the North West	....	5	....	....	2	....	....	....	7
Peel Inlet Management Authority	....	....	....	....	....	....	....	92	92
Police Department	....	....	13	2 345	1	26	90	....	2 475
Public Health Department	45	....	1 752	29	8	....	1 712	139	3 685
Public Service Board	....	....	....	....	2	....	....	....	2
Public Works Department	....	....	152	....	13	1	16	5 411	5 593
Road Traffic Authority	....	....	....	1 413	....	....	51	....	1 464
Small Claims Tribunal	....	....	....	....	4	....	....	....	4
State Energy Commission	....	....	....	....	2	....	....	....	2
State Housing Commission	....	....	....	....	1	....	....	....	1
Swan River Management Authority	....	....	....	....	....	....	....	325	325
Tender Board	....	....	....	....	171	....	....	....	171
Various Authorities	13	....	7	....	....	....	32	20	72
PUBLIC—									
Free	....	....	....	....	....	5	30	....	35
Pay	1 246	123	32	905	28	1 465	477	626	4 902
Total	23 979	375	4 153	4 813	312	1 523	3 906	8 763	47 824

Oils Committee of the Government Tender Board.

Paints Advisory Committee of the Government Tender Board.

Pesticides Registration Committee.

Poisons Advisory Committee.

Scientific Advisory Committee under the Clean Air Act; and

- Fluoridation Sub-committee.
- Incinerator Sub-committee.

Standards Association of Australia:

- Iron Ores Committee.
- Iron Ore Chemical Analysis Committee.
- Heavy Mineral Sands Chemical Analysis Committee.
- Laboratory Glassware and Related Apparatus Committee.

State Advisory Committee to Australian Coal Industry Research Laboratories on Collie Coal Mining Research.

Swan River Management Authority, Industrial and Biological Committees.

Veterinary Preparations and Animal Feeding Stuffs Advisory Committee.

Waste Disposal Technical Committee.

Water Purity Advisory Committee.

Water Quality Criteria, E.P.A. Marine and Estuarine Working Group.

Many of these committees required an appreciable amount of effort and time being spent by staff, to be able to play a useful and constructive role in the operation of these committees.

ACCOMMODATION

It is a pleasure to record that after many years of requesting, funding has now been approved for the initial stage of air-conditioning of the Laboratories. Construction will commence in 1980 and it is expected by the summer of 1980–81 that many areas will get relief from the summer heat which is exacerbated by the heat output of laboratory apparatus such as ovens, hot plates, etc.

A number of minor alterations and additions to improve the accommodation in the office and several Divisions was commenced late in the year. Approval has also been received for funding of the extensions to the pilot plant at the Engineering Chemistry Division at Bentley after a six year waiting period. This will be a very welcome addition when completed in 1980.

Approval of funding for reconstruction of the Kalgoorlie Metallurgical Laboratory was not received this year. It is hoped that this will occur in 1980 so that construction can fit in with the proposed School of Mines extensions of which the Kalgoorlie Metallurgical Laboratory rebuilding has been designed as an integral part.

There is a pressing need by several Divisions on the Plain Street site for further laboratory space. A decision on future expansion on the present site by construction of a two to three storey building on the Hay Street frontage is becoming more urgent.

EQUIPMENT

Limited funds for purchase of apparatus has again been a major problem this year. The delays in approval of major equipment costing over $5 000, obtained through the Equipment Purchase and Replacement Committee continue to be disappointing. The inflationary increases in cost of scientific equipment far exceeds the normal inflation rate and hence any allowance for inflation by Treasury in our allocation does not cover such increase. The result being that our ability to purchase even minor apparatus is greatly affected.

We were able during the year to obtain the following major items of equipment: a Leco induction furnace, a Varian Model 275D atomic absorption spectrophotometer, a tensile tester and a pilot scale air classifier. Approval for eight requested major items of equipment for purchase in 1979–80 has not yet been received.

There is an increasing use by three Divisions of electron probe and electron microscope facilities at W.A.I.T., State Health Laboratories and C.S.I.R.O. While the opportunity to use these facilities is greatly appreciated, the inconvenience and time involved is becoming a nuisance. There is a need for ourselves to obtain such equipment in the near future.

LIBRARY

During the year 3 100 items were added to the library collection. The growth of the library continues to be restricted by lack of storage space. A financial and usage review of library journal costs and usage together with the availability of journals via the inter-library loan system resulted in the cancellation of 10 journal subscription titles and the addition of only one new one during the year.

GENERAL

The pattern of past recent years continued in that there were appreciable increases in demands on our services during 1979. There was a further increase in sample receivals of

15 per cent over that of 1978. Since 1970 there has been an increase of 130 per cent in sample receivals, whereas in the same period there has been a far from commensurate staff increase of only 22 per cent.

The greatest increases in work loads have been from the Department of Agriculture but increased emphasis on dust samples for environmental and occupational health aspects from the Public Health Department and State Mining Engineer and increased case loads in the physical evidence section of the Forensic Chemistry Division have also been significant.

Towards the end of the year the doping control tests of race horses was taken over for the West Australian Turf Club, this work was previously done in Sydney. All doping control in sport in this State is now done in these Laboratories. An additional technician was specially obtained for this work, his salary and expenses will be covered by the charges made. This has meant that beside providing a better service to the Turf Club, money for this work stays in the State and one more person is employed locally.

The Kalgoorlie Metallurgical Laboratory was brought under the professional direction of the Engineering Chemistry Division during the year thus more closely co-ordinating the two groups, which operate in similar areas.

With the growth of groundwater treatment plants there has been an increasing need by the Metropolitan Water Board for their own on site chemists. This has resulted in a decrease of work submitted by the Board to us, however this decrease has been more than made up by the increasing emphasis by the Public Works Department on monitoring effluents and their effects on water supplies under the Rights in Water and Irrigation Act.

One of the extra curricular activities that was of great value this year was the Royal Australian Chemical Institute's Fifth Australian Symposium on Analytical Chemistry held at the University of Western Australia in August.

The Deputy Director Mr. H. C. Hughes was Chairman of the organising committee and Mr. B. Codling was Secretary. This highly successful symposium was of considerable benefit in the contact it brought with international experts from the U.K., U.S.A. and Rumania as well as with Australian authorities, in areas of direct concern to the Laboratories such as forensic science, water quality, modern instrumentation and automation, standardisation and laboratory safety. A number of papers and posters were presented by staff members, which were well presented and received; these reflected very favourably on the professional standing of the staff involved.

In the 1978 report I commented on the effect that staff and funding restrictions were having on our efficiency in view of the greatly increased demands on our services. As a result of this the Public Service Board have agreed that a review of our staffing and funding should be made. It has been proposed to the Board that this review should have wide terms of reference and review our function, inter-departmental relationships, building and site requirements as well as staffing and funding requirements. The Board has agreed to this and a review will occur in 1980. Such a review has become essential to be able to make any long term planning possible, instead of as at present of having to react to *ad hoc* requests by Departments, without their support to the Public Service Board and Treasury for the necessary staff and funds to carry out such requests. The review is welcomed as a possible means of overcoming or at least mitigating the many problems we have been facing through increased work loads.

Again this year there have been many interesting topical and controversial problems as well as areas where we have assisted industry, these have included such things as sewage plant odours, 2,4,5-T and dioxin, Laporte effluent disposal, Burswood Island rubbish disposal site, water quality, asbestosis, diatomite, attapulgite, gold and many others. These are referred to in greater detail in the following reports of Divisions.

The overall numbers of samples and sources of work received in 1979 is given in Table 1.

R. C. GORMAN,
Director, Government Chemical Laboratories.

AGRICULTURAL CHEMISTRY DIVISION

GENERAL

The variety of work was similar to that of the previous year. The general increase in numbers of samples received re-emphasised the need for further efforts aimed at increasing efficiency. To this end the actions outlined in the 1977 Annual Report were supported by the creation in the Division of a study group of senior officers which is involved in setting research priorities. The purpose is to co-ordinate ideas for improving analytical procedures. However it is difficult to fully utilise personal efforts and progress in the face of financial restrictions which severely limit the acquisition of vital modern equipment. Plans for alterations to the older part of the Division were finalised but design of new fume cupboards suitable for use with perchloric acid was not completed.

CONFERENCES, WORKSHOPS AND TALKS

B. J. Codling (Secretary) and L. A. Plues-Foster were members of the organising committee Analytical Group, Royal Australian Chemical Institute which presented the successful Fifth Australian Symposium in Analytical Chemistry held at University of W.A. in August.

N. L. Wilson presented a paper titled "Rapid Determination of low levels of Erucic Acid in Rapeseed" at the Symposium.

The Chief of Division attended meetings of the Lupinseed Technology Committee and also helped present a case to the Food Science and Technology Committee of the National Health and Medical Research Council for the acceptance of W.A. sweet lupinseed for human consumption.

P. E. Wilson participated in an inter-operator study on the determination of heavy metals in marine tissue in Hobart in February organised by the Commonwealth Department of Science and the Environment.

PUBLICATIONS

P. E. Wilson was author of a paper entitled "A Venturi Sampler for Aspirating Small Sample Volumes in Atomic Absorption Spectroscopy" which was published in Atomic Absorption Newsletter Vol. 18, 115, 1979.

NATURE OF WORK

Table 2 shows the numbers, nature and sources of samples received. It also shows that the Division is unique in the Laboratories in that its work originates almost entirely from one client department. Compared with the previous year there were increases in numbers of samples of soils, wheat plants, clover, pasture, cauliflower and decreases in lupins, animal bones and tomato leaves.

TABLE 2

AGRICULTURAL CHEMISTRY DIVISION

	Department of Agriculture	Government Chemical Laboratories	Education Department	Public Health Department	Other Departments	Pay	Total
Animal Tissue	666	....	....	....	....	....	666
Cereal	5 705	....	4	....	....	18	5 727
Fertilizer	181	....	....	....	5	9	195
Horticulture	1 307	....	....	....	....	....	1 307
Miscellaneous	400	20	....	45	1	17	483
Pasture and Stock Food	3 206	....	20	....	....	95	3 321
Soil	11 166	....	....	....	7	1 107	12 280
Total	22 631	20	24	45	13	1 246	23 979

TABLE 3

SAMPLES RECEIVED 1975–1979

Year	1975	1976	1977	1978	1979
Receivals	11 120	13 803	16 765	19 122	23 979
In hand 31 December	6 313	7 281	8 158	5 005	7 352
Output....	13 183	11 835	15 888	22 275	21 632

The total receivals (23 979) is 25 per cent higher than 1978. Output (21 632) was similar to 1978 leaving 7 352 samples in hand at 31 December. Table 3 shows these details for previous years, and indicates that the amount of work can be expected to steadily increase in the future.

Work completed and for which reports were issued is summarised below.

PLANT SECTION

Sample receivals increased by 41 per cent over 1978 (6 864 to 9 713). Analyses requested increased from 2·0 to 2·6 per sample giving an increase of 80 per cent in analyses requested (13 957 to 25 127).

Automatic Analysis

Results from a four channel autoanalyser obtained by manual chart reading were compared with those obtained by on-line data collection by computer. The on-line system was proven satisfactory and was adopted for routine use.

Increased demand for the determination of total and inorganic sulphur in pasture plants led to the successful modification of an automated continuous flow turbidimetric procedure, previously used for soil extracts, to handle this type of sample.

Plant Material

Priority was given to samples from Kununurra to enable Department of Agriculture Research Station staff to review experimental programmes and meet their schedules of growing two crops per year. Nitrogen, phosphorus and zinc were analysed in tissues of rice, maize, sugar-cane, soy beans and sorghum to follow fertilizer uptake.

Wheat grain and tops again provided a large part of the work. Nitrogen determination was required on material from trials harvested in 1978 comparing responses to various sources of fertilizer nitrogen and methods of application.

A tissue test for nitrogen status of wheat crops required analysis of tissues for nitrate and total nitrogen at progressive stages of growth. Analyses for phosphorus allowed total phosphorus uptake by the crop to be used as an alternative to grain yield as a means of comparing relative effectiveness of fertilizers and methods of application.

Lupin plants and seed were examined for calcium, phosphorus and manganese to check nutrient ratios in areas where superphosphate appeared to induce split-seededness. A large number of nitrogen and potassium analyses were completed for trials studying fertilizer movement and availability to lupins, clover and wheat. Crude protein content of lupin was compared with other legumes such as vetches, beans and peas and was generally higher.

Cobalt in lupinseed submitted by a farmer from Coorow was unusually low and approaching the concentration (0·005 ppm) quoted as giving vegetative yield response to cobalt fertilizer.

Clover and pasture samples required a wide range of work. Nitrogen, phosphorus and potassium content of samples from fertilizer trials was handled by automated procedures, but there was also a demand for sulphur and proximate analyses of introduced and native species used for grazing in the south or north of the State. Other less usual analyses were oxalates in saltbush and soluble carbohydrates and lignin in mulga leaves. Comparison of our current procedure for determining acid-detergent fibre in pastures, with a method used by Irish workers, gave similar results. The latter method offered no advantages.

Cauliflower export marketing was hindered by discoloration of curd and cracking of stems. Analyses of various parts of affected and unaffected plants were made for boron and molybdenum to identify suspected nutrient imbalance. Levels were normal and further work was directed to the possibility of calcium and magnesium deficiencies induced by high rates of nitrogen and potassium fertilizers.

Cauliflower leaves were analysed for total nitrogen and nitrate at progressive growth stages in trials aimed at establishing optimum requirements of nitrogen fertilizer and evaluation of local fertilizer and management practices. A good correlation between leaf nitrate level and yield of reject cauliflower was obtained. Maximum yield of good quality curd corresponded to a level of 0·26 per cent nitrate and a value of 21 for the ratio (Total $N-NO_3/N$): (NO_3/N) in the leaf at the third sampling date.

The crude alkaloid content of three samples of Uniharvest lupinseed was within the low range usually found in sweet narrow-leafed lupinseed grown in W.A. Barley and oat grains were analysed for the Grain Pool to assist with marketing. Grapevine leaves from a study at Frankland River were analysed for major and minor elements to complete data for fixing optimum nutrient levels. Cabbage leaves were analysed for eight elements to follow effects of different irrigation methods and rates of water application at Medina Research Station. Apple and other fruit tree leaves were monitored for up to eight nutrients.

Feeding Stuffs

Poultry feeds from experiments studying the effects of calcium and phosphorus on eggshell strength needed a close check on chemical composition. Up to thirteen ingredients used in formulating the rations and the actual rations as fed were given prompt analysis throughout the trials.

Mixed feeds or feed ingredients for teaching purposes at Agricultural High Schools were received from the Education Department. Feedlot trials at Kununurra using sugar-cane as a basic feed, required extensive analysis including all major and trace element nutrients for meatmeal and rice bran additives.

Advice was given on the quality of meatmeal produced by W.A. firms to assist in registration of the materials for sale in compliance with the Veterinary Preparations and Animal Feeding Stuffs Act.

Urea content of a ration prepared from cereal grain and urea was less than the allowed maximum of 3 per cent and therefore unlikely to be the cause of a serious problem of infertility in stud rams.

A fish meal prepared from waste from Albany fisheries was sold as a protein source for pig feeds and claimed to be high in lysine. Crude protein content was similar to that of meatmeal but lysine was higher although less than in imported fish meals.

Dried pig swill is produced as a potential stock food following the prohibition of feeding raw swill. Proximate analysis, major and trace element and amino acid contents indicated that the material could prove a valuable feed source. Levels of heavy metals were low, in contrast to samples examined in previous years from other sources. Determination of cadmium and lead caused some difficulties because of the presence of relatively larger amounts of iron.

Development of a method for estimating vitamin A content of poultry and pig feeds was initiated following an expression of interest by researchers in that area. Results obtained from a preliminary trial using the colourimetric Carr-Price procedure were unsatisfactory, but were sufficient to give qualitative evidence that a feed, from an enquiry in which vitamin A liver deficiency was diagnosed, was low in vitamin A. Confirmation that a vitamin pre-mix may have been omitted from the feed was obtained by high pressure liquid chromatography. The latter technique offers a better means of carrying out analyses of all vitamins and until this instrumentation is available to us work has been suspended.

Mincemeat

A total of 391 samples of beef meat either minced or in cores were analysed for moisture and fat to provide reference chemical data for trials aimed at establishing a rapid physical method for estimation of carcass fat. Early results comparing carcasses of five different breeds and different slaughtering dates did not appear to follow expected changes in fatness. Some time was devoted to reviewing methods of determination of fat as alternatives for the gravimetric solvent extraction now in use.

Fertilizers and Manures

Certificates of Analysis were issued for 102 samples examined out of 114 received under the new Fertilizers Act 1977. Of the samples completed 19 per cent were deficient in one or more constituents. This was a marked improvement on the position which prevailed under the old Act when about 40 per cent of samples examined could be expected to fail to comply with guaranteed composition.

Some mixed fertilizers containing nitrogen as nitrate gave lower values for nitrogen than expected when using a salicylic acid reduction step. This was thought to have been due to high levels of chloride in the sample. Checks using either Devarda's alloy or chromium metal as reductant confirmed the original results.

A number of fertilizers used in experiments which had produced inexplicable yield results were shown to be incorrect mixtures. Others were contaminated, incorrectly labelled or unmarked and stressed the need for proper care in taking, identifying and preserving of samples.

Analysis of a pelleted form of mono-calcium phosphate used as a sulphur-free phosphorus source in field trials revealed a discrepancy in the Official Methods of Analysis of the Association of Official Analytical Chemists, U.S.A., for determination of water-soluble phosphorus, in materials containing non-ortho forms of phosphate, by the molybdo-vanadate method. The pelletising and curing procedure converted some phosphate to the non-ortho form, which, although soluble in water did not react with the molybdo-vanadate reagent, giving a low result for water soluble phosphorus. The publishers of the methods were advised, with a recommendation that an acid hydrolysis step be included in the procedure to convert all water soluble phosphorus to the ortho form before the final colour development stage.

Incinerated sewage sludge from Bunbury had less fertilizer value than unburnt sludge. It had a high pH (9·5) and about 60 per cent was insoluble in acid.

Granules of superphosphate remaining on the surface of trial plots at the end of the growing season contained phosphorus and sulphur in amounts similar to granules recovered from pot trials conducted several years ago. The sulphur was probably present as anhydrite and gypsum. The relative insolubility of the granules may indicate an advantage of superphosphate as a sulphur source in some leaching situations.

A soil conditioner prepared from municipal waste by the Auckland City Council was examined for the Perth City Council which expressed interest in this form of rubbish recycling and use of the material for landscaping. It had a composition close to similar material from New Zealand evaluated in 1970 for the Department of Agriculture.

SOIL SECTION

About two thirds of the work came from on-going studies referred to in last year's Annual Report, with projects investigating the fate of potassium, phosphorus and sulphur fertilizers contributing about 6 000 samples of topsoils and subsoils for analysis. Samples from new investigations related to a tissue test for nitrogen in wheat, a survey of bowling greens, problems with market garden soils and classification of soil types selected for new trial sites.

Soil Testing

Requests by farmers for soil testing for copper, potassium and phosphorus numbered 1 107, a further steady increase over the previous year. The tests, although approved only for cereal and pasture production, are tending to attract field advisers seeking supporting evidence for diagnosis of nutritional problems with vegetables, fruit trees and turf grasses. Agricultural High Schools and Research Station staff are also making increasing use of soil tests because the patchwork effects of fertilizers from various trials run within a paddock makes calculation of a fertilizer history difficult.

Deficiencies in instructions for sampling issued to farmers by the Department of Agriculture were conveyed to that Department. Analytical work showed that sampling in spring instead of autumn made little difference to soil test results. This means that farmers can obtain early advice on fertilizer requirements and the pressure on deliveries of fertilizers can be spread over a longer period.

A proposal for the Section to provide free soil tests for farmers with properties affected by drought did not eventuate. A small number of samples were dealt with before an offer was made by C.S.B.P. and Farmers Ltd., to undertake the service.

North-west

Samples from Ord River experiments, as with plant materials, were given priority to allow time for adjustments in schedules where necessary. Most analyses entailed monitoring of soil nitrogen, phosphorus and zinc levels in trials on rice, maize, soy beans, sugar-cane and sunflower.

The use of 0·005M sulphuric acid as an extractant for phosphorus gave results similar to extraction with 0·5M sodium bicarbonate and it was recommended that its use be terminated. Total nitrogen, ammonia and nitrate were determined in samples from trials measuring effects of incorporating rice straw into the soil, and response to different rates of nitrogen fertilizer.

Topsoils from the final sampling of a survey of the Ashburton Catchment were analysed for total soluble salts, extractable phosphorus and total nitrogen. The attempt to relate these parameters to vegetation patterns and areas susceptible to overgrazing was not assisted by these analyses and indicates the danger in attempting to use chemical data from topsoils in understanding the distribution of deep rooted species.

Carnarvon soils were analysed to follow movement of fertilizers applied to improve capsicum yields and in an investigation of the Gascoyne River offstream storage of water. Boron was high in water soluble extracts of samples from Meekatharra where boron toxicity in plants is well known. The adviser at Derby submitted samples for assistance in establishing vegetable gardens at Gogo, Udialla, Christmas Creek, Fox River and in the town.

Advice was given to the Office of the North West on the unsuitability of a calcareous muck soil for horticultural purposes.

Sulphur

Sampling in the second year of a project to establish optimum rates and methods of utilizing sulphate fertilizers maintained a heavy commitment in this line of work.

Results of monitoring fertilized plots at three depths at regular intervals gave results similar to those obtained in the first year of the project, and confirmed the leaching of sulphate from topsoils at all sites. At some sites there was an accumulation of sulphate at depth.

The automated turbidimetric procedure used for measuring sulphate in 0·01M $Ca(H_2PO_4)_2$ extracts of the samples was improved by adapting the autosampler to twin-probe operation and altering the position of the colorimeter flow cell. These modifications resulted in less baseline drift and less signal noise at concentrations of sulphate near one part per million in the soil.

Although work in the previous year showed that mineralisation of soil sulphur to sulphate was not important relative to quantities of sulphate added as fertilizer, an attempt was made to measure mineralisation in samples from unfertilized plots on a range of soil types and at different times of the year. Results obtained by extraction of soil in the field immediately after sampling were compared with corresponding sub-samples which were analysed after a period of air drying and storage. With the exception of one soil type mineralisation could not be detected.

Nitrogen

Investigation of a tissue test for nitrogen in cereals, to enable prediction of response to subsequent nitrogen fertilizer applications on wheat belt soils, was commenced. Total soil nitrogen, ammonia and nitrate were estimated in samples taken at the same time as plant tissue samples. Results correlated with fertilizer treatment.

These and other trials looking at effects of tillage methods, sources of nitrogen on incidence of take-all disease in wheat, rates of nitrogen fertilizer on wheat yield and nitrogen fixation by legumes, required a large number of total nitrogen analyses. A semi-micro Kjeldahl method using a colorimetric step for estimation of ammonia was proved suitable for routine work.

Potassium

The fate of potassium fertilizers applied at different times to lupins and wheat and different sources of potassium on sub-clover was followed as in previous seasons by estimation of potassium extractable in 0·1M HCl at five depths in a range of soils and rainfall situations.

It would be preferable to use 0·5M $NaHCO_3$ as extractant for potassium especially when extractable phosphorus is also required. A micro sample valve described in Trace and Environment Section overcame difficulties of analysis by atomic absorption spectroscopy which had led to rejection of this extractant for estimation of "available" potassium. When tested in automated mode with soil extracts it prevented build-up of salts in the nebulizer system and gave excellent accuracy and precision. It offers the possibility of a dual automated system for phosphorus and potassium soil tests.

Copper

The use of extractant solutions for measuring the copper status of samples from field trials comparing the effects of nitrogen, phosphorus and sulphur fertilizers on copper uptake by cereals, was extended. Values for copper and zinc obtained on acid soils using 0·005M DTPA (diethylenetriaminepenta-acetic acid), which has already proved useful for calcareous soils, were about one third those using 0·2M ammonium oxalate. While ammonium oxalate has proved a useful extractant for investigations in W.A., DTPA is used more widely as a multi-element complexing agent for soil fertility work. Further investigation of its use is planned.

Analysis of copper in soils treated with fertilizer in pot trials to study the effects of crop residues, soil type and time after application on the availability of copper to the wheat plant was continued.

Comparison of 0·2M ammonium oxalate extractable copper, in soil samples from pots cropped with wheat to exhaustion of copper, showed no change between samples taken before the first and third sowings, for Dongara calcareous soil.

Newdegate soil showed only a slight reduction in extractable copper over the same period. However analysis of the wheat plant parts (tops, young leaves, grain) showed that copper availability, as measured by copper concentration in dry matter, decreased markedly with time for both soils. For Newdegate soil the decrease was less marked in the grain, but for Dongara soil the availability of copper was reduced to the extent that grain was produced at the highest rate of added copper only. It seems therefore that, if the pot trial reflects the field situation, 0·2M ammonium oxalate may not be the most suitable extractant for accurately measuring copper status of soils at the low levels where deficiencies occur in W.A. and that investigation of the use of DTPA as recommended in our Annual Report for 1977 or other extractants is justified.

A second pot trial tested the effects of added organic matter and incubation on copper availability to wheat plants of copper fertilizer added at different rates. At high rates of copper addition, extractable copper decreased as organic matter addition increased. A period of incubation before seeding further decreased extractable copper. At lower rates of added copper the ammonium oxalate test did not distinguish between different levels of available copper caused by either added fertilizer or added organic matter. Incubation did not have marked effect on concentrations of copper in the wheat plants. In a separate trial, comparing the effects of soil sterilization on availability of copper, there was very little difference between extractable copper in sterilized or unsterilized pots.

Market Gardens

Market garden soils examined in connection with poor growth of celery, lettuce and silver beet had levels of nutrients about 10 to 100 times greater than normal. Up to 1 300 ppm potassium, 400 ppm copper and 2 000 ppm phosphorus were found. This and concentrations of one per cent phosphorus in leaf dry matter indicated excessive use of fertilizers. Total soluble salts were also generally high and were due in some cases to sulphate which could have been derived from either fertilizer residues or from oxidation of sulphides in peaty soils near swamps.

Bowling Greens

Top soils from a survey of general condition and nematode infestation of turf grass on metropolitan and country bowling greens were analysed for phosphorus and potassium by soil test methods. Some samples indicated unnecessary use of fertilizers by over enthusiastic greenkeepers.

Erosion Losses

Measurement of loss in productivity due to wind erosion of topsoil was continued at three sites by attempting to relate loss in yield to nutrient losses. Nitrogen, phosphorus and organic carbon in the top 4 mm of soil and at depths to 300 mm were measured to provide base data for checking restoration of fertility after simulated erosion. At a Wongan Hills site topsoil loosened by grazing animals was sampled prior to cyclone Alby in April 1978. The nitrogen content of the loosened material indicated that 30 to 40 kg nitrogen per ha could be lost by erosion of a layer 5 mm deep.

Miscellaneous

Organic carbon determination by a modified Walkley/Black procedure was introduced on a routine basis as a rapid alternative to the slower total carbon method. The ratio Walkley/Black carbon: total carbon was shown to be dependent on soil type. The "total" method must therefore be retained for a number of long term trials, commenced several years earlier, until organic carbon data is complete.

Calcium levels in cleared and uncleared soils from the Albany-Esperance region were assessed in relation to poor seed production and viability of clover. There was no consistent relationship between exchangeable calcium and superphosphate history.

Adsorption isotherm data were obtained for phosphorus and sulphur on soils selected for nutrient leaching studies.

A survey of nutrient status of potato soils in the Manjimup district was commenced and indicated a big variation in fertility levels, extractable phosphorus ranging 3 to 130 ppm and potassium 32 to 350 ppm.

Comprehensive background chemical data were supplied before establishing trials to study methods of regeneration of poor clover stands. Low values for extractable phosphorus and potassium were good indicators of poor areas of clover on the Wellington Dam catchment.

A Technicon InfraAlyzer which employs a non-destructive infra-red reflectance principle, was tested for suitability for soil analysis. Instrument readout correlated quite well with conventional analysis for organic carbon and nitrogen, indicating some further investigation is justified.

TRACE AND ENVIRONMENT SECTION

Activities mainly involved investigations into the trace element and fluoride content of animal tissues, plant samples and fatty acid composition of oilseeds. The Section continued to be involved with the work of the Plant and Soil Sections through research and development into automatic analyser systems and methodology for determination of amino acids.

A simple rotary loop valve capable of injecting microlitre sample aliquots into the nebulizer system of an atomic absorption spectrophotometer was designed and tested. The work arose from problems with analysis of soil extractants having high solids content such as 0·5M sodium bicarbonate. These solutions cause difficulties when conventional aspiration techniques are used. The system virtually eliminated build-up of salts in the spectrometer burner and shows promise of rapid sample throughput with automated equipment.

Copper in Wheat

Over 2 000 samples of leaves from field trials at different locations in the State and from pot trials were analysed to provide data for the study of availability of copper fertilizers and the effects of high analysis nitrogen and phosphorus fertilizers on copper uptake.

Because of the unusually low levels of copper involved in many of the samples, the effects of reported interferences by calcium in the determination of copper by atomic absorption spectroscopy were checked. Results appeared to confirm those of other workers but the findings were not conclusive and further work is needed. Two samples of wheat straw containing less than one ppm copper were checked in an inter-laboratory study which showed good agreement between our results and those obtained at University of W.A. and Murdoch University.

Trace Elements in Porcine Tissues

Kidney, liver, muscle, spleen and testes were analysed for calcium, cadmium, cobalt, copper, iron, magnesium, manganese, lead and zinc to evaluate the possibility of elements other than fluoride being involved in the development of kidney lesions in pigs fed high levels of rock phosphate as a feed supplement. Analytical work was almost completed and interpretation of the data is pending.

Fluoride

A feed metabolism trial designed to compare the effects of fluoride from different sources added to the diet of pigs produced samples of feed, faeces, urine, blood and bones. Analysis for fluoride showed that fluoride distribution in the feed mixes was uneven despite care in the addition of ingredients, and that mixing problems noted previously had not been solved. Faeces from pigs which received calcium fluoride contained more fluoride than from animals which received rock phosphate or sodium fluoride.

Excretion of fluoride in urine and concentration of fluoride in blood was greatest for animals which received sodium fluoride and least for those which received calcium fluoride. The overall picture was that uptake of fluoride was related to the solubility of the source. The method for determination of fluoride by ion electrode in 3·2M nitric acid extracts of samples was satisfactorily applied to all samples in this exercise and speeded up the analytical work considerably.

The results of the above trial were responsible for a proposal to use finely powdered alumina as a feed additive when rock phosphate was used as a supplement to complex fluoride and decrease problems associated with its uptake by the body

A comparison of the relative effectiveness of alumina and a soluble aluminium salt was made in the laboratory. Alumina was found to be far less effective in complexing fluoride in conditions which would be expected to prevail in a pig stomach. It was recommended that if the idea was pursued by trials with animals a soluble aluminium salt be included as a treatment for comparison. Fluorosis in guinea pigs used as test animals developed again as bone malformations and a feed sample was found to be high in fluoride content. A previous recommendation to test batches of feed before use was adopted as a result of this occurrence. Data for fluoride balance studies undertaken by the Department of Public Health were provided by examination of fired and unfired portions of bricks produced at a metropolitan brickworks. Analytical data from thirty samples indicated that more than 85 per cent of the fluoride in brick clay was released during firing, in confirmation of work done over several years on this problem.

Vine leaves from a property adjacent to the works were analysed for fluoride to confirm visual symptoms of damage by gaseous emissions and to assist in assessing the efficiency of scrubbing devices in reducing ground level concentrations of atmospheric fluoride near the works.

Cobalt

Fertilizing of pastures with cobalt and copper fortified fertilizer has been carried out in the Gingin district for many years. A survey of the concentrations of these two elements in livers of animals grazing in the area was initiated as part of a study of the economics of continued application of these elements following a sharp rise in the cost of cobalt sulphate. Livers analysed had normal levels of cobalt indicating that current fertilizer applications are not wasteful of this material. Cobalt in human urine and blood was sufficiently above normal levels to indicate uptake by a person working in an area where trace elements were being handled.

Molybdenum

There was increased call for determination of molybdenum in clover based pastures in the Bunbury area for diagnosis of difficulties with maintenance of dry matter production. Other samples concerned problems in vegetable production mainly cauliflowers. The purchase of a 40 mm micro-cell for the spectrophotometer will simplify analysis since it will allow extraction of the molybdenum-dithiol complex into a smaller volume of solvent, giving a lower limit of detection.

Environmental

Apart from the work related to fluoride emissions from brickworks, samples of vegetation growing in the vicinity of waste liquid ponds at Kwinana were analysed for copper, iron, manganese, nickel and zinc. There were no marked differences in the concentrations of these metals in healthy or unhealthy plants showing stress symptoms indicating that seepage or air-borne dust from the ponds was not responsible.

Oilseeds

The erucic acid content of oil from rapeseed samples submitted by growers for quality certification under the Department of Agriculture's Seed Certification Scheme was determined on a regular basis. All the samples examined were below the maximum limit of 1·5 per cent of erucic acid in the oil. It was necessary to use a relatively large sample (30 g) for expression of the oil used for analysis, to minimise sample variability. Precision of the analysis was shown to be affected both by the presence of foreign seeds such as wild turnip and variations of erucic acid content with size of the rapeseed itself. A manuscript which describes the rapid analytical method and sampling problems was prepared for publication.

Other samples of pedigree rapeseed were analysed for fatty acid composition to provide plant breeders with information on variety characteristics.

Erucic acid content of lupinseed was determined in connection with unexplained fertility effects on ewes fed lupinseed near mating time. Fatty acids, in particular those related to erucic acid, affect ovarian activity and it was thought that differences in lamb drop might be accounted for by differences in fatty acid composition and content of the seed used for feeding. This was not the case, as analyses were virtually identical and erucic acid levels in the seed were low.

Linoleic acid content and linoleic:oleic acid ratios were determined in sunflower seeds from trials in the south-west and at Kununurra. Sunflower seeds marketed through a Pool at Kununurra were submitted by the Grain Pool for estimation of oil content.

J. JAGO,
Chief, Agricultural Chemistry Division.

ENGINEERING CHEMISTRY DIVISION

An organisational change effected early in the year was the incorporation of the Kalgoorlie Metallurgical Laboratory as a section of the Engineering Chemistry Division.

The amalgamation was made to promote efficiency and co-ordination between the two groups, which operate in similar areas of activity. The Kalgoorlie Metallurgical Laboratory has been carrying out assay and investigational work with the general aim of assisting the mineral industry of the Eastern Goldfields area for a period of the order of 50 years. In recent years there has been increasing scope for the Kalgoorlie Laboratory to adopt a wider role and to undertake general project work. The incorporation within the Engineering Chemistry Division is aimed to assist this transition.

Stimulated in part by the amalgamation, a review of some aspects of the operations of the Division was commenced late in the year. The review is especially aimed at defining methods of identifying the State's mineral processing problems and of setting priorities for research programmes. The worth of forming an Advisory Group to assist the achieving of these objectives and to aid information transfer to and from the Division is under consideration.

During 1979, the Division continued to undertake projects within the following main categories.

(1) Investigations requested by industry and individuals.
(2) Testwork undertaken for Government Departments.
(3) Research programmes initiated by the Division.
(4) Technical Studies and Advisory Service for Government and the Public.

CONTRACT INVESTIGATIONS

There was a consistent demand from industrial and mining companies for a wide variety of testwork. The results of these sponsored (company paid) investigations, which were carried out at both laboratory and pilot plant level, remain confidential to the client and only brief general background descriptions can be released in this report.

Processing of Vanadium Ores

Over a period of several years the Division has assisted a local company to develop a process for recovery of vanadium from a titaniferous magnetite deposit. The company is now constructing a commercial plant and this will come on stream during the first half of 1980. The research programmes have been directed towards evaluation of most phases of the metallurgical flowsheet. In 1979, the main emphasis was on examination of the pelletising characteristics of the primary ore.

Laboratory scale testing to optimise flux and moisture levels was followed by proving runs in a pilot scale disc pelletising unit. The 1 metre diameter, stainless steel disc pelletiser had recently been fabricated within the Division and was capable of production rates of the order of 100 kg of pellets per hour. Several tonnes of head material were processed and roasting and leach extraction tests were carried out in conjunction with the pelletising trials.

Zircon Beneficiation

A test programme that commenced late in 1978 and was aimed at evaluating a novel process for zircon upgrading was continued during the year at the request of a prominent mineral sands mining company.

In general, the zircon concentrates produced from the W.A. coastal deposits encounter marketing difficulties in time of over-supply because of the presence of minor impurities. These impurities influence the surface colour and appearance of the individual grains.

Several batches of zircon head material were roasted in the pilot rotary kiln over a range of conditions and with varying levels of additive. The products were generally of enhanced quality and confirmed that the prospective treatment method held promise for commercial application.

Form-coke Manufacture

The practical requirements for briquetting various carbonaceous materials such as Collie coal char and wood charcoal have been established by extensive previous investigations carried out by the Division. Much of this work was aimed at producing a substitute coke from Collie coal for foundry use or for use as a metallurgical fuel-reductant for primary metal production.

A local company which requires a supplementary fuel for its metallurgical operations involved the Division in further testing during 1979. The objective of the work was to produce carbonaceous briquettes from coal char and charcoal with the aid of organic binders.

Diatomite

The consumption of diatomite for filter aid usage is increasing and currently most of the material used in Australia is imported. Some years ago, in recognition of this, the Division commenced a research programme to establish the potential for treating lower grade diatomite bearing material from coastal swamp areas of W.A. to produce a refined high grade product capable of meeting the stringent filtration use specifications.

The background knowledge gained in this broad study was put to further use during 1979 when a local mining company requested processing trials on material obtained from deposits north of Perth. More recently the same company has announced its intention of constructing a commercial plant of 5 000 tonne per annum capacity at Geraldton to produce high grade diatomite products. The results of the testwork will be directly correlatable and will be used for the design of the large scale plant.

The early phases of the test programme have confirmed that extreme care is necessary when mining local diatomite deposits. If the localised pockets of diatomite which contain high levels of impurities are mined along with the better grade material, then it is very difficult to produce a high grade end product.

Work also continued to assist another company, which is developing an insecticide with a diatomite base for use in eradication of grain weevil and other grain storage pests.

Attapulgite Clay

A company which established an industrial scale attapulgite processing plant at Geraldton towards the end of 1979 consulted the Division and then requested a test programme to explore various possible treatment methods that may be usable for production of refined grades of product capable of wider market applications.

The programme will continue in 1980.

Micaceous Hematite

The micaceous hematite employed in Australia as a special purpose paint pigment is commonly imported from Europe. On receiving a request from a geologist, material from a Western Australian deposit was examined for its potential to be processed to a product comparable with imported material.

De-oiling of Chemical Grains

A Kwinana based company which imports a granular chemical reagent for use in its process requested assistance in defining a method for removal of the mixed fuel-diesel oil coating, which was applied to the grains prior to shipping to avoid agglomeration. The coating caused operating difficulties in later processing but was found to be readily removable by a roasting method under conditions determined by the test programme.

Fluidised Bed Cooler

A small project aimed at establishing design criteria and heat transfer characteristics for a fluid-bed heat exchanger unit was carried out in collaboration with consulting engineers and on request from a mineral sand mining company.

Miscellaneous

Other projects carried out for various clients included gravity concentration tests on gold tailings; determination of grinding indices for ilmenite; assessment of drying and carbonising characteristics of green jarrah and karri timbers; analysis of various fuels such as coal and charcoal.

PROJECTS FOR OTHER DEPARTMENTS

Soil Stabilisation for Brick Making

Dating from mid 1975 extensive testwork has been carried out in conjunction with the Office of Regional Administration and the North West and in collaboration with Mr. C. A. P. Boundy to establish the practicality of using indigenous soils as a building construction material in the northern parts of the State. A type of soil prevalent in the North West, termed "Pindan", was researched in the earlier work and emphasis placed upon the formulation of pressed cement and lime stabilised bricks which were hardened by a simple open air curing process. Bricks made by this method were subsequently successfully incorporated into the construction of an experimental house at Broome.

The scope of the testwork done in 1979 was broadened to determine the properties and the response to stabilisation of a wide range of soil types from the northern part of the State. This is aimed to culminate in the formulation of criteria relating soil properties to response to stabilisation. The possible utilisation of stabilised soil in load bearing applications and in other building applications was also under study. The majority of soils from areas centred on Broome, Derby, Fitzroy Crossing and Pandanus Park have thus far shown favourable response to stabilisation, yielding compacts of unconfined compression strengths of between 20 to 30 MPa, but those from Wyndham and Kununurra have, by comparison, not responded as well. This research will continue into next year.

Further basic testwork with Pindan type soils has shown that stabilisation with bitumen emulsion at levels of between 5 and 7 per cent results in compacts of improved water resistance properties but with little enhancement of strength above that of self stabilised soil.

A special $30 000 grant made available by the Government in the middle of the year enabled the acquisition of important test equipment, including a mechanical press and proving rings for evaluation of unconfined compression strength of test compacts, and the 12 month appointment of a specialist technician to assist with the testwork.

Geochronology

The Geological Survey branch of the Mines Department is evaluating rock and mineral age determinations by methods based on radioactive decay and one of the more recent variations of method requires the pre-concentration of zircon grains from the material under test.

The Division undertook to explore the possibility of concentrating the zircon constituency in porphyritic granite rocks to aid the Survey's geochronology programme.

The beneficiation method perfected incorporated stages of crushing, grinding, gravity concentration (Wilfley table), heavy liquid separation and induced roll magnetic separation.

Twenty grams of zircon concentrate was produced from 65 kilograms of granite and was subsequently found to be satisfactory for the age determination procedures.

INTRA-DIVISION PROJECTS

Briquetting of Coal

A Federal Government grant of $7 000 was approved by the National Energy Research Development and Demonstration Council (N.E.R.D.D.C.) for a project related to the briquetting of Collie coal. The Division has a long history of association with this topic both in active research and development and in maintaining an advisory service to local industry.

The preparation of a coke substitute from the non-coking Collie coal involves as a first step the carbonisation of the coal to form "char". This process can be carried out in a number of ways and the briquetting characteristics of the char are influenced by the carbonisation techniques.

The Division's earlier work (1950–1960) had resulted in the adoption of a vertical rinsing-gas retort as the carbonising unit. The design incorporated an indirectly heated section which precluded contact between char and gases containing carbon dioxide at temperatures above 600°C. The resultant char was a particularly satisfactory briquetting stock. Subsequent industrial work prepared char by other means and it was noted that char prepared in a rotary kiln yielded weaker briquettes and char prepared in an internally heated experimental vertical retort yielded strong briquettes.

Hence the Division proposed an investigation of the effect of temperature and carbon dioxide on the briquetting characteristics of Collie coal char and this project received N.E.R.D.D.C. support.

Three samples of coal from different seams at Collie viz. Hebe, Neath and Wyvern, were used. Char was prepared in the rotating stainless steel pot kiln designed and fabricated in the Division. The kiln was heated by insertion in an electrically heated, controlled temperature furnace and the atmosphere in the kiln was either nitrogen or carbon dioxide fed continuously from cylinders. To avoid fouling the kiln with tar etc., the coal was first carbonised in saggars at 600°C. Subsequently this low temperature char was carbonised in the pot kiln at 850°C and 1 150°C in carbon dioxide and nitrogen (separately). These various char samples were made into briquettes using a petroleum bitumen as binder. The briquettes were matured in an oxidising atmosphere at 250°C and carbonised at 600°C. The compressive strengths of the briquettes were determined in a hydraulic press and were accepted as the criterion of satisfaction. In extreme cases where the char had been severely affected it was not possible to form a briquette with the amount of binder used for this programme.

Carbonisation at high temperature in carbon dioxide had an adverse effect on the briquetting characteristics. This was not unpredictable as the Boudouard reaction at this temperature was expected to affect the surface characteristics of the char. Chars prepared at a similar temperature in nitrogen yielded satisfactory briquettes. Physical examination of the chars was undertaken in an attempt to clarify the phenomenon. X-ray diffraction, scanning electron microscopy, surface area measurements and porosity measurements have been included in the examination which is almost completed. No significant differences have yet been observed which are adequate to account for the different briquetting characteristics.

The final report to N.E.R.D.D.C. will be made early in 1980. It is likely that the Division will extend the investigation to encompass the fluid bed production of char for briquetting as this method may have some commercial significance.

Zircon Cleaning

In recent years, the Division has assisted several mineral sands mining companies to evaluate potential methods for upgrading the quality of zircon concentrates to "premium" grade by removal of deleterious surface coatings and other minor impurities. Some sponsored work along this theme continued in 1979 and has been reported earlier. Interpretation of the results of these earlier test programmes in order to make effective overall comparisons of the efficacy of the various treatment methods is difficult because of the variation in head samples supplied and due to the specific process problems of individual companies. Accordingly a Departmental investigation was initiated to try to establish the most efficient and economical method of treating W.A. zircon concentrates.

Concentrates from three operating companies were subjected to beneficiation by roasting (with and without additives) and acid leaching under varying conditions and the degree of response gauged mainly by measurement of the increase in reflectance and reduction of the iron content of the zircon concentrate.

When processed in the "as received" condition the three concentrates generally responded poorly to the various methods of beneficiation, whereas prior removal of the magnetic fraction led to a much higher quality product.

Earlier work by the Mineral Division has indicated that the inherent pink colouration of zircon grains was due to traces of manganese which has been raised in valence from Mn^{2+} to Mn^{3+} by radiation. These further tests have confirmed that this colouration can be eliminated by heating and that this colour removal contributes to the improved reflectance of the zircon in any method which includes roasting of the grains at temperatures of the order of 300–600°C.

Assessment of the results was in progress at year end. Preliminary findings are that three different methods of treatment may be generally effective in producing high grade products. The selection of the most suitable method will be influenced by the total cost of installing and operating the various treatment circuits which will need to incorporate the use of moderately hazardous reagents and are subject to high corrosion factors and are also energy intensive.

Treatment of Oxidised Copper Ores

Recent dramatic increases in the price of refined copper metal have encouraged producers to re-assess deposits and deferred projects which, as recently as one year ago, were considered uneconomic. While projects aimed at exploiting massive sulphide deposits take some four to six years for construction and therefore are unlikely to proceed unless long term favourable conditions are apparent, small deposits can be quickly brought on line to take advantage of the high copper prices.

Some of the modestly sized copper oxide deposits of Western Australia have been reviewed and subjected to test programmes in the light of improved methods of extraction and changing economic conditions over the past several years. This Departmental project has culminated in 1979 in the preparation of a Report of Investigations (No. 22) titled "Potential for Exploitation of the Oxidised Copper Ores in Western Australia" and this report will be released shortly.

This publication examines the major known oxidised copper deposits in Western Australia in terms of past development, mineralogy and amenability to beneficiation. Copper extraction methods have been reviewed and some assessed for potential application to various types of deposit.

Small, localised deposits of high grade oxide ore will probably continue to be exploited at the "shoestring" level by a simple beneficiation circuit and the sale of the concentrate. However, future deposits outside the capability of the independent operator are likely to be treated hydrometallurgically rather than by physical beneficiation or pyrometallurgical methods.

For ores containing low acid consuming gangue constituents such as those occuring at Whim Creek and Mons Cupri, sulphuric acid leaching followed by cementation or solvent extraction/electro-winning to recover the copper appears the best prospect for a return on investment. The presence of high acid consuming gangue minerals (Thaduna deposit is typical) can be nullified by leaching in basic media. In times of high copper prices both acidic and basic leaching routes have been shown to be economically attractive.

Diatomite Processing

When time permitted some further testing was done in continuation of the Division's long standing programme aimed at utilisation of the diatomite deposits of W.A.

In August, Chemist and Research Officer R. V. Field presented a paper titled "Processing and Potential Utilisation of Variable Grade Western Australian Diatomite Deposits" to the Annual Conference of the Australasian Institute of Mining and Metallurgy.

The main findings presented in the paper were that local diatomites vary considerably in quality and that the degree to which they can be upgraded by hydro or pneumatic cyclone separator circuitry and the yield of useful product are influenced by the proportion of impurities and by the size, type and degree of fragmentation of the contained diatoms.

In general the better quality head materials can be upgraded by straight and flux calcination and associated processing to the equivalent of premium grade imported products.

Spherical Agglomeration

The increasing use of slurry pipelines for the transport of coal has prompted consideration of using pipelines as a medium for beneficiation. De-ashing of fine coals by violent agitation with light oils in which the fine coal particles are selectively agglomerated has also been advocated.

While Western Australia's only coal production comes from the low ash deposits of the Collie field, other potential coal reserves are known to carry considerable ash content.

There also may be a local need to beneficiate other carbonaceous materials such as charcoals and blast furnace dust. Thus it was deemed appropriate to seek some familiarity with the agglomerating method and a brief appraisal was made using blast furnace dust from the Wundowie operations as the head material.

The initial objective of using oils to spherically agglomerate the charcoal and thus allow its separation by screening has not been achieved. However, the results have shown that low ash-high carbon products can be produced by the separation of two immiscible layers. Further work would ascertain the characteristics required by an oil for the efficient recovery of charcoal but this work will not proceed until further potential applications can be established.

Coal Catalogue

Over a period of many years these Laboratories have maintained an active interest in research into the characteristics and utilisation of Western Australian coals. In practical terms this effort has been directed mainly at coal from Collie as this was and is the only commercially developed source of coal in the State.

During the 1960's, in common with many other laboratories throughout the world, it was not possible to justify the resources needed to maintain a major research effort in the halcyon days when cheap oil was supplanting coal. At that stage important research themes, (mainly directed at the briquetting and gasification of Collie coal) had been completed and because the technology of burning Collie coal was adequately catered for in the then State Electricity Commission, active interest in coal research declined.

In recent years the position has again changed radically with Collie coal re-assuming a position of extreme importance in the State's energy resources and accordingly many enquiries on its properties and utilisation are being received by the Division.

So that the knowledge gained during the many years of research should be readily available, in 1979 the Division began the compilation of a complete record of the data acquired. As the information is widely spread, the task is formidable and will continue in 1980.

The Division has maintained an information bank and a lively interest in coal and fuel matters generally. Many enquiries have been received from industry about coal and fuel matters and advice has been freely given.

Mineral Economics

The appointment of a Research Officer in August to carry out specialised cost engineering and general feasibility studies on the metallurgical processes under test or review added an important new dimension to the work of the Division.

By the end of the year, studies that had commenced along this theme included:

(i) Cost analysis of the production of briquettes from Collie coal char;

(ii) An update of the economic potential for gold recovery by using chloridising roast techniques (study motivated by escalation in market value of gold);

(iii) Processes and costs for reactivation of activated carbon (review stimulated by increasing use of carbon-in-pulp method for gold recovery);

(iv) A "State of the Art" review and cost analysis for the Division's test programmes on the potential for beneficiating the primary Banded Iron Formation of the Hamersley Basin to a high grade iron resource.

BUILDINGS

Notification of the allocation of funds to enable extension of the main pilot plant was received late in the year. These improvements had been requested each year since 1973. Construction is scheduled to commence early in 1980 and will provide approximately 150 square metres of additional working space and enable the permanent mounting of much equipment including flotation circuitry, wet gravity and classification rigs together with the transfer and installation of equipment from another Division to form an integrated crushing and grinding system.

EQUIPMENT

A Varian Techtron model AA 275D Atomic Absorption Spectrophotometer was acquired during the year to enable "on site" process control analysis.

A 1 metre diameter double whizzer type mechanical air separator was received in December and this will be used for separation and classification of fine powders. The unit will have an immediate application in the diatomite project.

The 5 x 0·35 metre rotary kiln is the key piece of equipment in many of the Division's test programmes and during the year the kiln was relined with high duty refractory and other improvements were made.

CONSULTATIVE AND ADVISORY

Many requests were received for advice on matters relevant to the activities of the Division. Frequent requests for information came from Companies and the general public and assistance was given to other Government Departments.

The Division continued to be involved in Committee and other representational activities. A considerable time commitment is made by the Senior Officers who serve on these Committees, for example—the Scientific Advisory Committee which serves the Air Pollution Control Council, the Committee formulated to assist Collie coal mining research and the Committee planning capital works expansion on the Kalgoorlie School of Mines campus.

GENERAL

Assistant Chief Mr. L. J. Brennan attended the inaugural Conference of the Australian Institute of Energy which was held in Newcastle in February.

Research Officer R. E. Marshall attended the 5th Analytical Symposium of the Royal Australian Chemical Institute in Perth in August and Messrs. B. Goodheart, R. Field and J. George attended the Annual Conference of the Australian Institute of Mining and Metallurgy in Perth earlier in August.

The Chief of Division, B. Goodheart made several visits to operating mineral processing plants and R. E. Marshall made a 7 day inspection tour of the Eastern Goldfields nickel operations in September.

B. A. GOODHEART,
Chief, Engineering Chemistry Division.

FOOD AND INDUSTRIAL HYGIENE DIVISION

GENERAL

The Division has seen increases in the number of samples received this year for industrial hygiene examination and for miscellaneous samples. There has been a decrease in the number of food samples received. Last year the Fisheries and Wildlife Department conducted a survey of fish from the Great Australian Bight for mercury content and this accounted for over 1 000 samples. A similar survey was not conducted this year, because of this there has been a 13 per cent reduction in the total number of samples received compared with last year.

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 4.

CONFERENCES AND WORKSHOPS

The Department of Science and the Environment, Marine Branch held two workshops which members of this Division attended. Mr. M. B. Rowe attended the workshop on Hydrocarbons in Marine Tissue held in Melbourne and Mr. D. E. Fleming the workshop on Trace Metals in Marine Tissue held in Hobart. Mr. Fleming, subsequent to the Hobart workshop attended the Conference of Scientific Officers and Engineers Engaged in Occupational Health held in Sydney.

The Ninth Residues Conference was held in Perth this year. Messrs. L. P. Conti, G. E. Ebell and J. H. Genovese attended all the sessions while other members of the Division attended selected sessions. Messrs. Fleming and G. A. Taylor attended the Fifth Analytical Chemistry Conference of the Royal Australian Chemical Institute which was held in Perth. Members of the Division presented three posters at the poster sessions on:

1. "Simultaneous Determination of 2,4- and 2,6-Diisocyanatotoluene (TDI) and 3,3'-Dichloro-4, 4'-diaminodiphenylmethane (MOCA)", Messrs. Genovese, Taylor, Ebell and Fleming.
2. "Determination of Alkyl Mercury in Fish", Messrs. D. L. N. Collett, Fleming and Taylor.
3. "Determination of Cobalt, Copper, Lead, Nickel and Zinc in Whole Blood by Atomic Absorption Spectrophotometry", Mr. Fleming.

Messrs. Ebell and Genovese attended a one day symposium in Perth on "Agriculture in the Environment in Western Australia" at which Mr. Ebell presented a paper on "Pesticide Behaviour and Persistence in Agriculture and the Environment".

FOODS

Officers of the Division have co-operated with Officers of the Fruit Section of the Horticultural Division, Department of Agriculture on investigations of two long standing problems associated with apple storage. The problems "bitter pit" and "superficial scald" can be treated with the application of calcium salts and diphenylamine respectively. This year a satisfactory mixed dip containing both calcium and diphenylamine has been developed but further work will be required next year to perfect some of the dipping techniques. It is pleasing to note that the use of the dipping solution based on our advice has practically eliminated the rejection of exported fruit at the point of sale.

A large number of fish and other marine foods were regularly checked for their mercury content. The majority of these samples were low in mercury content but it was noted that fish described as red snapper frequently exceeded the 0·5 mg/kg of mercury set in the Food and Drug Regulations.

Only four samples of shark were received this year and each of the sharks exceeded the 0·5 mg/kg level.

Four samples of forktail catfish (Arius Sp.) from Lake Argyle all had mercury levels above 0·5 mg/kg. This resulted in 32 samples of fish muscle being received from the various species of fish found in Lake Argyle. All three fish described as long tom (Strongylura kreffti) and five of the 21 fork-tail catfish had mercury levels above 0·5 mg/kg.

Three samples taken from black marlin caught at Exmouth had mercury levels from 1·9 to 2·8 mg/kg.

All of the 49 samples of tripe received complied with the Food and Drug Regulations with respect to pH.

Two samples of paddy rice contaminated with grain-sorghum from the Ord Irrigation Area were examined for aflatoxins with negative result.

There has been some concern over the sodium intake of children fed with infant formula milk powders. Of the samples received, three stated the sodium concentration of the made up formulation. In the laboratory when made up with distilled water two had a sodium concentration in excess of that stated, but if the formulations were made up with Perth tap water all three would exceed the sodium concentration stated on the label.

During the year a number of samples of coconut which are imported from the Philippines contained sulphur dioxide. Some years ago there was similar trouble but those samples also contained methyl bromide residues. During this year no methyl bromide residues were detected but when the food dye Amaranth (C.I. 15980) was added to the coconut the samples containing sulphur dioxide, the dye rapidly faded to a yellow colour.

TABLE

FOOD AND INDUSTRIAL HYGIENE DIVISION

	Department of Agriculture	Agriculture Protection Board	Bureau of Consumer Affairs	Government Chemical Laboratories	Department of Labour and Industry	Fisheries & Wildlife Department	Government Stores	Hospitals	Metropolitan Water Board	Mines Department	Pay	Police Department	Public Health Department	Public Works Department	Other	Total
FOOD—																
Apple	240	....	....	....	....	....	....	....	....	....	....	....	1	....	....	241
Apple dip	91	....	....	....	....	....	....	....	....	....	....	....	....	....	....	91
Bananas	14	....	....	....	....	....	....	....	....	....	....	....	....	....	....	14
Beer	....	....	....	....	....	....	....	....	....	....	....	....	11	....	....	11
Coconut	....	....	....	....	....	....	....	....	....	....	....	....	130	....	....	130
Crabmeat	....	....	....	....	....	....	....	....	....	....	....	....	17	....	....	17
Fish and fish products	....	....	....	....	....	3	....	....	....	....	2	....	509	....	....	514
Fruit juice	....	....	....	....	....	....	....	....	....	....	....	....	23	....	....	23
Honey	2	....	....	....	....	....	....	....	....	....	....	....	9	....	....	11
Liquor	....	....	....	....	....	....	....	....	....	....	....	....	25	....	....	25
Milk	44	....	....	2	....	....	....	....	....	....	....	....	10	....	....	56
Mussels	....	....	....	....	....	....	....	....	....	....	....	....	63	....	....	63
Octopus	....	....	....	....	....	....	....	....	....	....	....	....	12	....	....	12
Oysters	....	....	....	....	....	....	....	....	....	....	....	....	19	....	....	19
Pears	17	....	....	....	....	....	....	....	....	....	....	....	....	....	....	17
Rice	13	....	....	....	....	....	....	....	....	....	....	....	....	2	....	15
Sausages	....	....	....	....	....	....	....	....	....	....	....	....	10	....	....	10
Scallops	....	....	....	....	....	....	....	....	....	....	....	....	13	....	....	13
Squid	....	....	....	....	....	....	....	....	....	....	....	....	30	....	....	30
Sweets	....	....	....	....	....	....	....	....	....	....	....	....	18	....	....	18
Tomatoes	8	....	....	....	....	....	....	....	....	....	....	....	3	....	....	11
Tripe	....	....	....	....	....	....	....	....	....	....	....	....	49	....	....	49
Vegetables	....	....	....	....	....	....	....	....	....	....	....	....	19	....	....	19
Various	13	....	....	2	....	1	....	1	....	....	....	....	98	....	1	116
INDUSTRIAL HYGIENE																
Air	....	....	....	6	....	....	....	....	10	33	....	....	215	....	....	264
Blood	....	....	....	....	....	....	....	3	....	1	....	....	7	....	....	11
Charcoal tubes	....	....	....	....	....	....	....	....	....	22	....	....	10	....	....	32
Filters	....	....	....	....	....	....	....	....	....	....	....	....	51	....	....	51
Inspection and investigations	....	....	....	....	1	....	....	1	....	12	1	....	10	....	....	25
Urine	....	....	....	....	172	....	....	3	2	59	16	....	30	24	....	306
Various	....	....	....	....	....	....	....	....	....	15	....	....	15	....	....	30
MISCELLANEOUS—																
Air	149	....	....	....	....	....	....	....	....	....	....	2	....	....	....	151
Animal tissue and fat	8	34	....	....	....	....	....	....	....	....	....	....	6	....	....	48
Animal tox	12	....	....	....	....	....	....	....	....	....	1	....	....	....	....	13
Fish tissue	....	....	....	2	....	32	....	....	....	....	....	....	....	....	....	34
Pesticides	48	2	....	5	....	....	....	....	1	....	3	3	22	3	....	87
Soil	3	....	....	....	....	....	....	....	....	....	....	....	83	23	....	109
Specimen from patients	....	....	....	....	....	....	....	28	....	....	3	....	133	....	....	164
Surgical dressings	....	....	....	....	....	....	84	....	....	....	....	....	....	....	....	84
Water	3	....	1	10	....	....	....	....	120	....	3	....	14	94	6	251
Wool	793	....	....	....	....	....	....	....	....	....	....	....	....	....	....	793
Various	27	8	9	13	....	....	....	3	9	2	3	8	87	6	....	175
Total	1 485	44	10	40	173	36	84	39	142	144	32	13	1 752	152	7	4 153

A box containing the broken fragments of two soft drink bottles was submitted for examination. The story accompanying the sample was that one bottle had exploded in a crate and a fragment of the exploding bottle had struck the other bottle causing it to break. The fragments were pieced together and showed the impact marks at the same height on both bottles. The shape, position and angle of the fractures indicated that the bottles broke on impact with each other.

Cans of marmalade were examined following a complaint that there was a dark "oil like" substance near the surface of the jam. The lid was the only area inside the can which was not lacquered. The dark material was caused by the acids of the marmalade attacking the tin plate and iron of the can to form the dark mass.

Throughout the year the Public Health Department have submitted a number of samples of mussels taken from Cockburn Sound for cadmium determination. The Food and Drug Regulations level for cadmium in foods is 5·5 mg/kg. The majority of the mussel samples were below 2 mg/kg.

INDUSTRIAL HYGIENE

This year 306 biological specimens were examined from workers to measure their exposure to industrial chemical hazards. Of these samples 227 were urine samples from workers to monitor their uptake of lead. Workers with a normal level of up to 80 μg/L accounted for 56 per cent of these samples, those with an acceptable level of 90–150 μg/L accounted for 27 per cent and those with greater than 150 μg/L, an excessive level, for 17 per cent.

Blood, hair and urine samples for mercury accounted for a further 52 analyses. In most of these samples mercury was found at very low concentrations, but one sample of hair from a mine gold room worker had a high mercury content. This sample confirmed this worker's prolonged exposure to high mercury concentrations.

Apart from the biological samples examined for lead and mercury other samples were examined for arsenic, cobalt, 2, 4-D, fluorine, manganese, thallium and zinc.

During the year several "on the spot" inspections and samples were taken from various laboratories and industrial situations.

A mineral research laboratory was visited and samples of air for acetone and tetrabromoethane were taken. This laboratory had been the subject of several adverse reports on previous visits, with respect to handling of these materials. It is pleasing to note that conditions with respect to the two vapours have vastly improved. Another mineral research laboratory which uses quantities of acetone, bromoform and hydrochloric acid was visited. The acetone and hydrochloric acid levels in the air were satisfactory but the levels of bromoform were excessive. The face velocity of the fume cupboards was found to be well below that recommended by British Standard 3202:1959. Recommendations were made that bromoform be handled only in fume cupboards and that the face velocity of the fume cupboards should be increased.

Mercury in air was determined in samples from a mine gold room, a technical school, two dental therapy schools and a hospital laboratory. The mercury levels in some of the mine gold room airs were excessive but in all the other cases the mercury level was satisfactory.

Anaesthetic gas levels were measured at the Murdoch University Veterinary School operating theatre and Repatriation General Hospital operating theatres. Generally the gas levels in the air were satisfactory although at Repatriation General Hospital several leaking connections in the anaesthetic equipment detected by our inspection, had to be rectified.

At the request of the Occupational Health Division of Public Health an officer of this Division visited three senior high schools to report on their handling of chemicals and ventilation in the respective science laboratories. The report made recommendations on fume cupboards, substitution of less toxic reagents for those in use, safe storage of chemicals, proper labelling of toxic and carcinogenic chemicals and general laboratory safety.

In the extensions to King Edward Memorial Hospital several hundred outlets for compressed gases were installed. This Division was requested to check that each outlet was correctly labelled and on the purity of the gas at that outlet. All the outlets were true to label but one outlet of compressed oxygen was found to be contaminated with a small quantity of hydro-carbon. After purging of the gas line the quality of the oxygen was found to be satisfactory.

Samples of diesel exhaust fumes taken from diesel engines working in a mine development area at Kalgoorlie were found to be satisfactory with respect to carbon monoxide and oxides of nitrogen.

A series of samples were taken from the ethylene oxide fumigation area of a hospital. Ethylene oxide decay times for several plastic packages containing surgical articles showed that most of the articles can be used 18 hours after fumigation.

Air samples collected in charcoal tubes from a north west mine railway workshop showed that air in the vicinity of the degreasing plant had excessive levels of tetrachloroethylene and trichloroethylene.

An exudate removed from a capacitor of an electrically operated mechanical shovel used on an iron ore mine was submitted for P.C.B's. No P.C.B's were found in the sample.

At a factory first aid post a nurse treated a worker with a proprietary eye irrigant but the irrigant caused such intense pain to the eyes that the worker had to be hospitalised for treatment. Our examination showed the irrigant used contained approximately 70 per cent ethanol and a small quantity of methyl salicylate. This concentration of ethanol would certainly be responsible for the stinging of the eyes. Neither ethanol nor methyl salicylate were stated ingredients of the eye irrigant. It has not been established how the ethanol and methyl salicylate came to be in the bottle.

Nine visits were made to the waterfront during the year to investigate spillages or complaints of odours. None of the spillages or complaints were of a serious nature.

SPECIMENS FROM PATIENTS

There has been a slight increase in the number of samples submitted by private medical practitioners and hospitals but there has been a 30 per cent increase in the number of analyses carried out. These samples were taken to assist in the patient's diagnosis.

Table 5 lists the analyses which were carried out on these samples.

TABLE 5

SPECIMENS FROM PATIENTS—ANALYSES

Analysis	Number
Arsenic	85
2,4-D	19
Lead	65
Mercury	60
2,4,5-T	16
Thallium	33
*Various	47

* Includes boron, bromides, cadmium, chromium, cobalt, copper, DDT, dieldrin, fluorine, glyphosate and polychlorinated biphenyls.

PESTICIDES

There has been an increase in the number of soil samples from building sites submitted to check that the soil has been correctly treated against termites. In the majority of cases the amount of pesticide present indicates that the treatment could not have been carried out in accordance with Australian Standard 2057:1977. Soil Treatment for Protection Against Subterranean Termites. While the Standard does not give a level in soil it is possible to calculate from the recommended rate of application and field moisture holding capacity, levels of pesticides that would be expected in correctly treated soils. For a sandy soil sampled to a depth of 62·5 mm (2·5 inches) the amount of pesticide expected from an application of 5·3 L/m^2 of an 0·5 per cent of pesticide would be 265 mg/kg.

Five rotenone based sheep dips formulations were submitted by the Department of Agriculture. Two of the formulations were very low in rotenone content.

Pesticide and Trihalomethane Residues

Trihalomethanes are not pesticides but their analysis is very similar to that of organochlorine pesticides and are therefore conveniently grouped with pesticides. When water is chlorinated trihalomethanes are frequently the end product of the chlorination of organic matter within the water. Trichloromethanes were first analysed by the Division this year and the Metropolitan Water Board submitted 60 samples in connection with their survey of the effects of chlorination on water supplies.

Table 6 gives a summary of the major types of samples received this year for pesticide and trihalomethane residues.

TABLE 6

PESTICIDE AND TRIHALOMETHANE RESIDUE ANALYSES

Sample	Number
Air	149
Animal tissue and blood	47
Bananas	14
Coconut	130
Dairy products	44
Foods	33
Pasture and stockfood	9
Rice plants and grain	13
Soils—	
Agricultural	26
Termite treatment	76
Vegetables	30
Waters	242
Wool	793

For several years hormone damage to tomato plants has been observed in the Geraldton area and 2,4-D was the prime suspect as the cause of this damage. This year the Department of Agriculture after consulting the Public Health Department, Bureau of Meteorology and this Division undertook a series of weekly air samples from various points in the area to monitor the 2,4-D in the air. Because of the poor seasonal conditions the amount of 2,4-D used by farmers in the surrounding district was not as high as in normal years. As the isopropyl ester is not used locally, we advised the Department of Agriculture to have a quantity of the ester made for experimental purposes, as the specific ester could then be detected and not confused with others applied in the area. Unfortunately, a shift in the wind after the application of the ester meant that the ester did not carry to the sampling points. It is anticipated that the monitoring programme will be continued. In this years sampling the Division reported 2,4-D levels down to 0·01 μg/m^3 but in future samples we will be reporting to 0·001 μg/m^3.

At the request of the Police samples of soil and leaves were taken from around two dying trees. It was suspected that the trees had been poisoned. The butyl ester of 2,4,5-T was found in all the samples.

There has been a very large increase in the number of samples of fleece submitted by the Department of Agriculture in connection with dipping and jetting of sheep with various pesticides for lice and blowfly control. The experiments to date have shown that the hand wand application places more pesticide in the fleece than the automatic jetting race. The minimum concentration of pesticide in the fleece to prevent blowfly strike has yet to be determined. We anticipate that further work in this area will continue next year.

ANIMAL TOXICOLOGY

Four swallows were examined for organochlorine pesticides following a large number of deaths in the Bunbury area of these birds. No toxic concentration of organochlorines were detected.

After being dipped with a diazinon based dip a number of sheep died. Only samples of the fleece were submitted for diazinon content. These samples showed higher concentrations of diazinon than those submitted in connection with jetting race experiments.

In another dipping mishap samples of liver and kidney were submitted. These samples showed elevated levels of ethyl fenthion (Lucijet).

Samples from the stomach contents of four dogs when examined had ethyl fenthion present in concentrations indicating that this compound could have caused the death of the dogs. Some farmers bait a dead sheep carcass with ethyl fenthion to control crows but if a dog should eat the bait it is invariably fatal to the dog.

MISCELLANEOUS

The death of a diver using a petrol driven compressed air supply on board a boat led to this Division conducting tests for oxygen, carbon dioxide and carbon monoxide on the air supply after it had been running under simulated conditions of the accident. The oxygen and carbon dioxide concentrations were normal but the carbon monoxide concentration was elevated to a level where if that air were continuously breathed for about one hour the diver would be in danger. It was noted that the air intake of the compressor was very close to the exhaust of the petrol engine.

The purchaser of a "home brew kit" when examining the large plastic container of the kit found it to contain some fluid. When the fluid touched his hand it imparted a tingling sensation and portion of the skin of the hand turned white. The liquid was drained from the container and submitted by the Bureau of Consumer Affairs for chemical examination. The liquid was identified as a solution of hydrogen peroxide. It appears that the container had previously been used to store hydrogen peroxide but it had not been properly cleansed before being incorporated as part of the "home brew" kit.

A workman applying a proprietary sodium hypochlorite solution to a water supply noticed that the liquid had an acrid rather than a chlorine odour. He immediately ceased adding the liquid. A sample of the liquid was submitted by the Metropolitan Water Board for identification. The liquid was identified as concentrated hydrochloric acid which also contained a quantity of phenols.

The emergency power unit at a large hospital was powered by a gas turbine engine. After having little service the gas turbine failed due to a deposit build up on the blades. The failure was blamed on the fuel oil. When examined the fuel oil complied with the manufacturer's specification for ash, Conradson carbon residue and distillation range, the parameters likely to cause a build up of a deposit on the blades.

The Public Health Department submitted six chemical toilet preparations. Three failed to pass the requirements of British Standard 2893:1957 in that their flash point was below 150°F. One of the failed samples claimed on its label a formaldehyde concentration of 35 per cent w/v but only 7·4 per cent w/v was found.

The Medical Supply and Equipment Section of the Government Stores Branch submitted 84 samples of surgical dressings in connection with their tenders for these items. It was noted that the general quality of the tendered samples did not meet the appropriate standard of the British Pharmaceutical Codex.

Eighty-two high volume dust filters collected from the Perth City area were examined for α benzpyrene. Forty of the filters had been stored for about three years before being submitted for examination and no α benzpyrene was detected in these samples. However, filters which were more recent contained small amounts of α benzpyrene.

A series of tests for objectionable odours on air from the Shenton Park waste water treatment plant were conducted for the Metropolitan Water Board. Traces of hydrogen sulphide and methanethiol were detected in the main sewer air but chemical tests on samples of air from the treatment plant did not show any compounds likely to cause the odour. In the literature in connection with this work we found a very wide range of odour thresholds for skatole and no data for indole. Using an odour panel we concluded that the threshold of odour for skatole was 0·000 4 μL/L and for indole 0·005 μL/L. Tests carried out showed that all the individual complaints suggested in the literature as likely to cause such odours could be detected by gas chromatography at or below their individual odour thresholds.

F. E. UREN,
Chief, Food and Industrial Hygiene Division.

FORENSIC CHEMISTRY DIVISION

The major function of the Forensic Chemistry Division is to provide a scientific service to the Police, making use of the benefits of modern scientific equipment, knowledge and expertise. This is done by way of advice and consultation, by chemical and physical examination of exhibits and by research and investigation. The overall aim is to assist the Police to prevent crime, to apprehend the criminal and to bring the criminal to justice using scientific evidence to effect a successful prosecution and equally importantly to prevent innocent persons of being wrongfully charged.

Over the last decade science has provided a wide range of equipment and techniques which can be directed at the solving of crime and to the production of valuable evidence which is used in the courts. Whilst every effort is made to incorporate such advances into the fight against crime, our efforts have been severely curtailed by financial restrictions.

The 1970's saw the drug problem arise from its infancy to its current problem level. The latter half of the 1970's also saw the Division's involvement in the examination of physical evidence increase dramatically. Both of these areas of the Division's activities have aggravated the already restricted staff numbers situation not only by the amount of laboratory work involved but also by the increased time spent by chemists giving expert evidence in the courts. The staff of the Division was involved in more than seventy court cases both in the city and country centres. The time involved in these cases ranged from one hour to two days.

A laboratory technician was acquired by the Division late in 1979, not to cope with the increased Police Department workload but to assist with analysis in connection with the doping control programme carried out by the Western Australian Turf Club. The acceptance of the work from the W.A.T.C. now means that all analysis in connection with doping control programmes in sport in this State are now handled by the Forensic Chemistry Division. This work is complementary to the toxicology and drug work and provides chemists with the experience to detect drugs at therapeutic levels as compared to overdose concentrations.

The source and type of samples received in 1979 are shown in Table 7.

TABLE 7

FORENSIC CHEMISTRY DIVISION

	Agriculture Department	Agriculture Protection Board	Government Chemical Laboratories	Department of Corrections	Greyhound Racing Control Board	Pay	Police Department	Public Health Department	Road Traffic Authority	Western Australian Trotting Association	Western Australian Turf Club	Other	Total
BAITS	....	13	....	....	....	4	7	3	....	....	....	....	27
BLOOD & URINE ALCOHOL—													
Sobriety	....	....	....	....	....	....	....	....	1 005	....	....	....	1 005
Traffic Deaths	....	....	....	....	....	....	4	....	402	....	....	....	406
CRIMINAL INVESTIGATION	....	....	....	....	....	....	533	6	4	....	....	4	547
DOPING CONTROL IN SPORT—													
Greyhounds	....	....	....	....	278	....	....	....	....	....	....	....	278
Horses	....	....	2	....	....	8	....	....	....	565	34	....	609
DRUGS	....	....	13	1	....	1	880	5	1	....	....	....	901
MISCELLANEOUS—													
Maritime pollution	....	....	....	....	....	....	45	....	....	....	....	5	50
Specimens from prisoners or patients	....	....	3	50	....	3	....	5	....	....	....	....	61
Various	4	....	6	....	....	1	....	6	....	....	....	....	17
TOXICOLOGY—													
Animal	14	....	6	....	....	11	17	3	....	....	....	....	51
Human	....	....	....	....	....	....	859	1	1	....	....	....	861
Total	18	13	30	51	278	28	2 345	29	1 413	565	34	9	4 813

TOXICOLOGY

Exhibits were received from 303 cases of sudden death which were the subject of Police investigation. Of this number 198 cases were submitted for examination of poisons and/or drugs.

In 61 of these cases no evidence of any poison or drug was established, and in the remaining cases the presence of at least one drug or poisonous substance was detected. The concentrations of drugs detected in some cases made their toxicological significances uncertain.

Details of drugs and poisons are listed in Table 8.

TABLE 8

DRUG AND POISON CASES

Drug or Poison	No. of Positive Identifications
Carbon monoxide	35
Pentobarbitone	14
Paracetamol	10
Amitriptyline	8
Nortriptyline	8
Diazepam	6
Oxazepam	6
Phenytoin	6
Propoxyphene	6
Amylobarbitone	5
Doxepin	5
Lignocaine	5
Methanol	5
Trichloroethanol	5
Morphine	4
Various*	48

* Chlorpromazine, benzodiazepine metabolites, pethidine, pheniramine, salicylic acid (3 each). Carbamazepine, chlordiazepoxide, methadone, quinalbarbitone (2 each). Acetone, biperiden, butobarbitone, carbromal, chloroquine, digoxin, codeine, glutethimide, freon 11, methylphenidate, malathion, natural gas, valproic acid, naproxen, phenobarbitone, phenol, nor-chlorcyclizine, methapyrilene, salicylamide, ritalinic acid, toluene, thioridazine, zinc, trifluoperazine, theophylline (1 each).

In 36 per cent of cases received alcohol was detected, and in 60 cases the concentration of alcohol was such that it caused or contributed to the cause of death. For instance, in 9 cases out of 29 involving firearm deaths and in 5 cases out of 14 cases of drowning, alcohol was present in the blood.

The pattern of drugs and poisons detected in 1979 was similar to that found in 1978. Of note was a decrease in the number of deaths associated with propoxyphene (down from 15 in 1977 to 10 in 1978 to 6 in 1979) and an increase in the number of deaths associated with pentobarbitone (14 in 1979 compared to 8 in both 1977 and 1978).

During the year new analytical methods for barbiturates, benzodiazepines, tricyclic anti-depressants, strychnine and morphine have been developed. These methods utilise the HP 5992A gas chromatograph-mass spectrometer operating in the selected ion monitoring mode (GC-MS-SIM) for the detection procedure. The GC-MS-SIM allows for the extremely sensitive and specific detection of drugs. The need for the system was exemplified in a recent case involving the death of a young woman from a narcotic overdose.

The GC-MS-SIM enabled an accurate analysis to be made for morphine at injection sites which were located at the left wrist, the left elbow and the right elbow. The quantities of morphine which were found at these sites were 2, 3 and 73 micrograms respectively. The detection of morphine at this level would have been impossible without the GC-MS-SIM.

The results of the analyses, together with the result of analysis of a syringe involved, meant that the statement given by a second party, who had previously been charged with manslaughter, could be corroborated. This led to the manslaughter charge being withdrawn.

DOPING CONTROL IN SPORT

An increase of 36 per cent in the samples analysed for the Western Australian Trotting Association and the Greyhound Racing Control Board was brought about by the extended surveillance by the W.A.T.A. at country centres, the newly adopted policy of the W.A.T.A. in taking a blood sample when a urine sample is not forthcoming and by the establishment of the new greyhound track at Mandurah.

Drugs detected during the year were, caffeine together with its associated metabolites, lignocaine, phenylbutazone and metoclopramide, which accounted for a total of seven positive reports. In addition, the detection of theobromine in a number of horse urines was traced to the use of Wynn's diuretic balls.

The acceptance of the doping control work for the Western Australian Turf Club, which formerly was done by the Australian Jockey Club at Randwick, now means that the Forensic Chemistry Division is one of Australia's major centres for the analysis of drugs in connection with sport.

BLOOD ALCOHOLS (TRAFFIC ACT)

Blood samples are taken under the Road Traffic Act from persons who choose to submit a blood sample in preference to, or in addition to a Breathalyzer test. After a decline in the last two years when Breathalyzers were introduced to more of the less populous country districts, the number of samples received this year has shown a 21 per cent increase over 1978.

The frequency of the levels of alcohol in the blood samples received in 1979 calculated to the time of the offence are shown in Table 9. The table shows that 90 per cent of the bloods had an alcohol level in excess of 0·08 per cent while 60 per cent were greater than 0·015 per cent.

TABLE 9

TRAFFIC ACT—BLOOD ALCOHOL LEVELS

Alcohol per cent	No. of Cases	Per cent of Cases
less than 0·050	46	4·6
0·050–0·079	65	6·5
0·080–0·099	63	6·3
0·100–0·149	231	23·0
0·150–0·199	288	28·6
0·200–0·249	195	19·4
0·250–0·299	87	8·6
more than 0·299	30	3·0
Total	1 005	100·0

There is a need to have blood and/or urine samples taken from persons who show signs of intoxication but who have nil or very low breath test blood alcohol readings. Police officers continue to report an increasing incidence of apparently drug affected drivers, but without the power to take samples, little progress can be made in assessing the seriousness of this problem or in being able to do something about it.

BLOOD ALCOHOL (TRAFFIC DEATHS)

Results of the analysis of blood and urine samples for alcohol continue to show that alcohol is a major contributor to the cause of traffic deaths.

Table 10 shows the distribution of alcohol in the bloods of drivers, passengers, pedestrians and motor cyclists. These figures apply only to samples received at the laboratory. In some instances blood samples cannot be obtained and in the case of small children no samples are submitted.

TABLE 10

TRAFFIC DEATHS—BLOOD ALCOHOL LEVELS

Alcohol per cent	Motor Vehicle Drivers	Passengers	Pedestrians	Motor Cycle Riders
not detected	42	32	16	8
less than 0·05	7	2	2	2
0·050–0·079	1	2	1	1
0·080–0·099	2	3	....	2
0·100–0·149	9	7	2	3
0·150–0·199	15	6	3	6
0·200–0·249	13	5	1	3
0·250–0·299	5	1	1	....
more than 0·299	2	2	4	....
Total	96	60	30	25

The figures reveal that 48 per cent of drivers of motor vehicles and 56 per cent of riders of motor cycles who were killed in traffic accidents had blood alcohol levels in excess of 0·08 per cent.

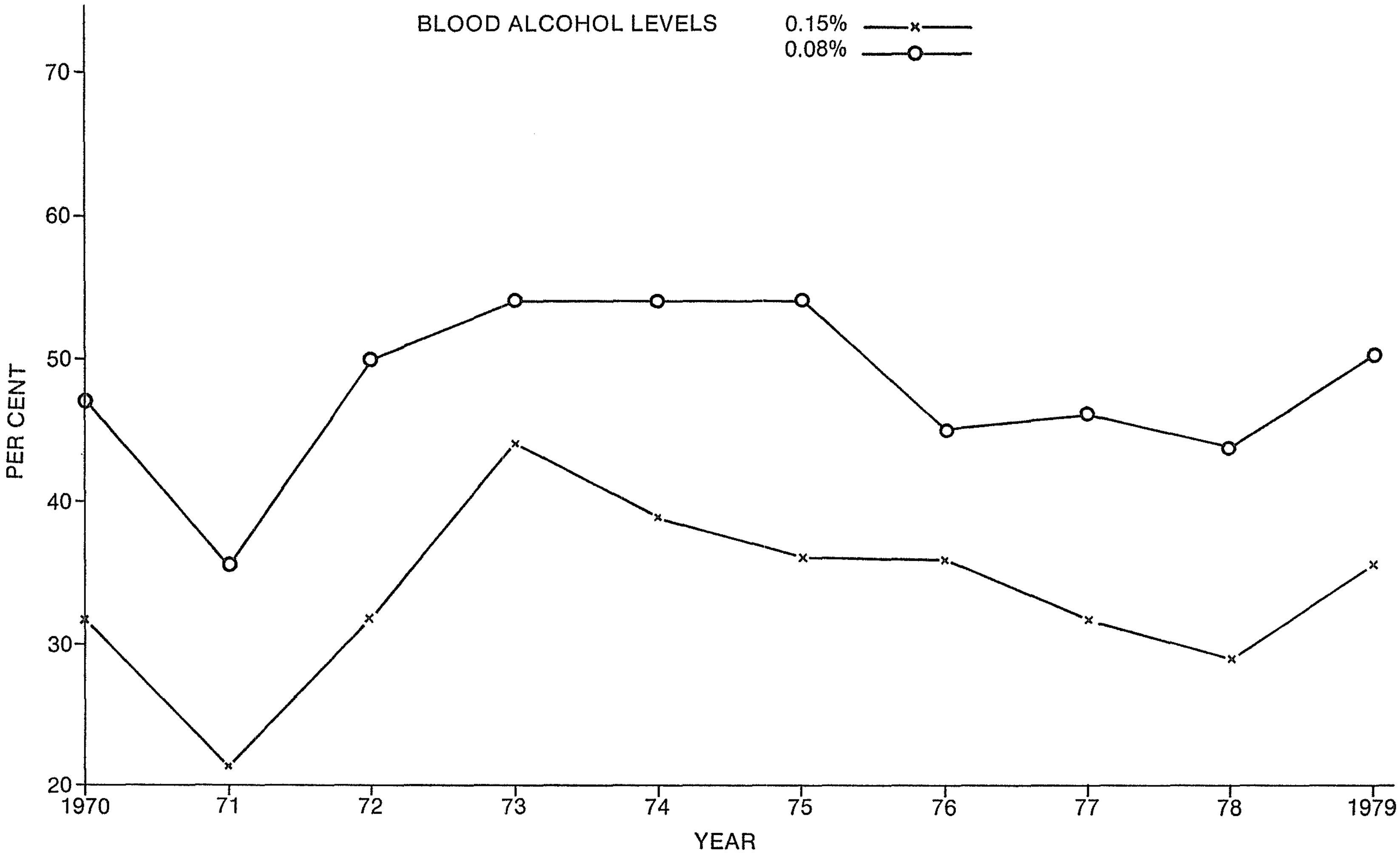
Blood alcohol levels of 0·15 per cent or more were found in 36 per cent of the drivers and 36 per cent of the motor cycle riders.

If these figures were those of an extraordinary year then they would be cause for considerable concern. However, Fig. 1 shows a similar trend was maintained throughout the 1970's. On average over the decade, 34 per cent of drivers of motor vehicles including motor cycles involved in fatal accidents had blood alcohol levels greater than 0·15 per cent and 48 per cent had levels in excess of 0·08 per cent.

The continuing high level of involvement of such high levels of blood alcohol in drivers involved in fatal accidents, shows that current road traffic regulations and education are making little impact on this problem.

FIGURE 1

DRIVERS OF MOTOR VEHICLES INVOLVED IN FATAL ACCIDENTS 1970-1979



DRUGS

Two hundred and six cases comprising 901 exhibits were received for the identification of drugs and suspected drugs. The exhibits were submitted by the C.I.B. Drug Squad in the majority of cases.

Details of drug cases are listed in Table 11.

TABLE 11

DRUGS—POLICE DRUG SQUAD

Type of Drug	No. of positive Identifications
Cannabis and/or products	128
Heroin	21
Bromo-dimethoxyamphetamine	17
Morphine	7
Cocaine	4
Pentazocine	3
Methaqualone	3
Methadone	2
Pethidine	2
Barbiturates	2
Codeine	2
Various*	19

* Opium, ephedrine, lignocaine, oxazepam, L.S.D., diazepam, dihydrocodeine, fentanyl, droperidol, phenoperidine, chloroquine, omnopon, chlordiazepoxide, strychnine, dextromoramide, normethadone, ethyl morphine, yohimbine, atropine (1 each).

The above figures represent an increase of 40 per cent in case numbers and a fifty per cent increase in positive identifications compared to 1978.

Three trends in the number of positive identifications which occurred in 1979 are worthy of note. These are an eightfold increase in the number of bromo-dimethoxyamphetamine cases, from 2 in 1978 to 17 in 1979, a twofold increase in cannabis and/or cannabis products (from 54 to 128) and a decrease of 60 per cent in the number of identifications of heroin (from 58 to 21).

The reasons for the increases in bromo-dimethoxyamphetamine and cannabis are unclear, however the decrease in the heroin figure does appear to reflect the general decrease in the availability of the drug, brought about by the increased efforts and efficiency of the police and narcotic control authorities, both in Australia and overseas.

Bromo-dimethoxyamphetamine a psychotomimetic or hallucinogenic drug which first appeared in 1976 and then reappeared in 1978 was previously detected in small quantities in isolated cases, however in 1979 not only has the frequency increased eightfold but also the size of seizures encountered has multiplied. In five separate seizures of the drug, the quantities involved were 100, 200, 200, 2 050 and 3 545 separate "trips" or doses of the drug.

For 3 months from December 1978 to February 1979 the Division quantitatively analysed all seizures for the information of the Australian Royal Commission of Inquiry into Drugs. The results of the analyses are as follows:

- Cannabis—tetrahydrocannabinol content—average 0·8 per cent, range 0·4–4·3 per cent
- Cannabis resin—tetrahydrocannabinol content—average 17 per cent, range 11–22 per cent
- Heroin—diacetylmorphine content—average 21 per cent, range 8–45 per cent
- Cocaine—average 100 per cent
- Bromo-dimethoxyamphetamine—0·5 mg per dose

CRIMINAL INVESTIGATION

Chemical and physical examination of exhibits collected from scenes of crimes and accidents is undertaken in this Division as an aid to police enquiries and to provide court evidence. The number of cases received during 1979 continued along the upward trend of recent years. These cases are summarised in Tables 12 and 13.

TABLE 12

CRIMINAL CASES 1979

Type of Exhibit	No. of Cases
Flammable liquids (including fire debris)	58
Paint and paint flakes	23
Blood and urine	33
Explosive and incendiary residues	5
Clothing	8
Fibres	7
Food and drink	8
Gunshot residues	7
Miscellaneous	21

Table 12 summarises the range of exhibits received and Table 13 summarises the matters which gave rise to their submission for examination.

TABLE 13

CATEGORY OF OFFENCE OR INCIDENT

	No. of Cases
Arson and fires	58
Hit-run traffic	16
Stealing	6
Armed holdup	5
Sex offences	34
Murder	7
Wilful damage	12
Assaults and woundings	2
Unclassified	14

As can be seen from the above tables, the investigation of suspicious fires accounts for a considerable proportion of exhibit receivals. The increase in sample numbers during 1979 was largely due to the investigation of such incidents. Of the 58 cases involving debris from fires, 25 were found to have some fire accelerant present. Of these, 13 contained petrol, 7 contained kerosine, 2 contained diesoline and 1 each contained methylated spirits, mineral turpentine and an unidentified hydrocarbon mixture. It would appear from these figures that arson is an increasing problem and is a cause for concern. This trend is in line with the experience of overseas countries although not on the same scale. New York City, for example, has about 55 000 building fires per year. Motives for committing arson are many and include vandalism, revenge, insurance, pyromania and murder or attempted murder. Each of these motives were represented in the cases examined during the year.

The next biggest group of specimens received, as in previous years, was paint and paint flakes. These items were received in respect of a variety of offences such as hit-run traffic cases, theft, murder and wilful damage. Paint flakes frequently cross transfer during criminal activity and they can provide good evidence as to the identity of the criminal.

A greater number of cases involving firearms were investigated during 1979. Five armed holdup cases were received involving a variety of physical evidence and seven cases involving shootings were examined for gunshot residues. Of these shootings, two involved handguns, two involved shotguns and the remainder involved rifles. A typical case concerning gunshot residue analysis involved the determination of firing distance and the angle of the shot. These determinations were made by measurement of the distribution of primer compounds (lead and barium) around the bullet holes.

Of the explosions investigated during the year, only one involved high explosives (gelignite) and the remaining four were low order improvised mixtures.

Exhibits from thirty-two cases of alleged rape were received for blood alcohol estimation. Of these 15 were negative, six had a blood alcohol concentration of between 0·03 and 0·08 per cent, five were between 0·08 and 0·15 per cent and six were greater than 0·15 per cent.

1979 saw a greatly expanded use of Scanning Electron Microscopy (S.E.M.) for criminalistic samples. This was facilitated by an arrangement with the W.A.I.T. Physics Department and C.S.I.R.O. The technique has been particularly helpful in cases involving gunshot residues, fibres, paint, metals, incendiary reaction products, glasses and paper. Co-operation with the W.A.I.T. staff has enabled the S.E.M. to be applied to, and to extend the project on the collection of data on glass samples. Scanning Electron Microscopy is a technique ideally suited to the solution of many forensic problems and its application will continue to grow in this Division.

The 1970's have seen in W.A. a transformation of scant and disorganised forensic chemistry services into a significant and organised service. The rate of increase in sample receivals is limited as a result of restrictions on staff numbers, equipment and facilities necessary to continue the growth of services. At a time when the crime rate is rising, it is essential that investment in criminalistics be made in order that the Police Force has the necessary laboratory back up.

MARITIME POLLUTION

Fifty samples of oil from fourteen oil spill occurrences were analysed this year.

Of these, four samples resulting from beach and ocean pollution of Trigg, Geraldton and Dampier were examined to determine whether the samples of oil were of ocean-going vessel origin. The other incidents involved comparison of the polluting oil with that from possible offending vessels. Of these ten cases, it was established that in nine cases the spill was confirmed to have originated from the suspect vessel.

The types of oil encountered in pollution incidents include diesoline, residual fuel oils and crude oils.

A surprising feature in connection with the work is the apparent leniency shown by the Courts towards offenders. The low fines inflicted on the offenders do not reflect the gravity of the offence which carries a maximum fine of $50 000.

CONFERENCES—PAPERS

The Division was strongly represented at each of the following which were held in Perth:

Fifth Australian Symposium on Analytical Chemistry

Annual Conference of Forensic Toxicologists

Annual Conference on Illicit Drugs

The following papers were presented at the Fifth Australian Symposium on Analytical Chemistry:

N. T. Campbell "Applications of Gas Chromatography-Mass Spectrometry in Forensic Analysis".

N. T. Campbell and A. M. Stenhouse "A Screening Procedure for the Identification of Drugs in Blood and Urine with Potential Application to Traffic Offenders".

B. F. Lynch and J. M. Challinor "Analysis of Oils in Marine Pollution".

B. F. Lynch and J. M. Challinor "Chemical Analysis of Bomb Scene Debris".

B. F. Lynch and J. M. Challinor "Forensic Examination of Paints".

Two papers were read at the Australian National Symposium on Forensic Sciences in Adelaide:

R. C. Hansson and A. M. Stenhouse "The Elucidation of Unknown Compounds in Horse and Dog Urines".

V. J. McLinden "Problems Involved in any Legislation against the Drug Affected Driver".

V. J. McLINDEN,
Chief, Forensic Chemistry Division.

INDUSTRIAL CHEMISTRY DIVISION

The Division has continued to receive enquiries and to carry out work covering a wide range of subjects from Government, private industry and the general public. Work was carried out for sixteen other Government Departments and Instrumentalities during the year in addition to work for industry.

Dr. Smith and Mr. Kippo both delivered lectures to the Know Your Plastics series organised by the Plastics Institute of Australia and Mr. Kippo also gave a lecture to the Oil and Colour Chemists Association.

Dr. Smith attended the Annual Convention of the Oil and Colour Chemists Association held in Victoria and Mr. McKinnon attended the Annual Conference of the Institution of Chemical Engineers held in New South Wales.

Dr. Smith was also a member of several judging panels of the Industrial Design Council and acted as an assessor of three paint testing laboratories for the National Association of Testing Authorities.

MATERIALS TESTING

Paint

Work was completed on the paint tender and results reported to the Tender Board.

Two samples of locally made paint being used at one of the hospitals were submitted with the complaint that they differed in quality. Tests showed that both were very similar and compared well with results obtained in previous years on the same brand of paint.

The Main Roads Department is developing road signs based on the Australian Standard. There has been some difficulty in achieving the specified specular gloss. The specular gloss of a number of samples submitted during the year was measured at 60° and 85° angles. Some sample panels were supplied and others were prepared by the Division.

A detailed report on the painting of weathered cement roof tiles was prepared for State Housing Commission. It was largely based on information supplied by commercial firms and provided an analysis of the claims made. A specification for surface preparation was also included.

Failure of paint on the walls of new extensions to Harvey Hospital was investigated. Two types of failure in the alkyd coatings were identified. One was caused by water splashing adjacent to shower recesses and hand basins. The other failure, which occurred randomly, was found to be caused by high alkalinity in the cement render which attacked the alkyd resin binder.

A number of other more minor investigations were also carried out. These included faulty results obtained with one of the car glazing systems in two cases (the glaze was found to be a silicone wax polish); a problem with the clear protective coating on one of the mineral specimens on the Supreme Court Gardens obelisk caused by the instability of the mineral to weathering; identification of some coatings for Public Health Department; identification of some paints used at the new Canning Vale prison for compliance with specification; fire testing of a synthetic fibre paint spray booth filter fabric.

Building Materials

Several carpet complaints were investigated for the Bureau of Consumer Affairs and Small Claims Tribunal. Some of the complaints were: staining of carpet after steam cleaning; shag pile carpet for excessive fibre loss; discoloration of a shag pile carpet in heavy wear areas; poor rubbing fastness of a carpet dyed a very deep shade; identification of pile fibre composition; crushing of carpet pile.

A recently installed carpet at the State Energy Commission was showing apparent fading in trafficked areas. The cause was found to be a physical loss of dyestuff from the carpet fibres, no doubt caused by faulty dyeing. The abrasion resistance of the acrylic pile was good.

Vinyl flooring samples were tested in particular for Government Employees Housing Authority. Colour fading in another sample submitted by Bureau of Consumer Affairs was again shown to be alkali attack on one of the pigments and caused by lime picked up from damp concrete.

Two further samples of concrete underlay were tested according to previously reported methods and both were found to be satisfactory.

Two samples of sandwich panels were submitted for fire testing by Department of Health and Medical Services. The panels consisted of a rigid polyurethane foam core with fibreglass reinforced plastic facings. One set of panels was claimed to have a fire retardant grade of FRP. Both types of panels were tested under the conditions of AS1530 Part 3 "Early Fire Hazard Test of Materials". Both performed similarly, catching fire readily, burning vigorously and evolving large volumes of smoke. Because of this, only one panel of each set of six was tested. The foam itself was found to be a fire retardant grade under the conditions of the particular test used for that purpose, but this was of no help in the primary test.

Other minor matters dealt with included: abrasion resistance testing of ceramic tiles; corrosion of stainless steel sinks by sodium hypochlorite in some hospitals because the wrong grade of stainless steel was used; use of stearic acid as a flux when lead burning old to old and new to old lead; apparent disappearance of the aluminium film in window heat reflective sheeting possibly caused by filiform corrosion.

Analysis and testing of the products selected for the Floor and Wall Maintenance Products Tender were completed.

Plastics and Rubber

Main Roads Department submitted during the year a number of samples of rubber tyre buffings supplied by tyre retreaders for determination of natural and synthetic rubber content.

The Water Board submitted at various times samples of rubber fittings for identification of the rubber. Most were natural rubber, but one sample was EPDM synthetic rubber. Also submitted were plastic jumper valves found to be made from acetal with the washer being nitrile rubber.

Assistance was given to the Small Claims Tribunal concerning a damaged fibreglass reinforced plastic swimming pool. A hearing at the site was attended and expert advice provided. Subsequently, the thickness of the walls and base of the pool was measured using an ultrasonic thickness gauge. The mean readings along two levels of the walls and one traverse of the floor were found to be below the minimum specified by the fibreglass reinforced plastic swimming pool standard, AS1838.

Public Health Department submitted a plastic back-pack pressure sprayer which had burst in use. It was known that the unit had been stored for a considerable time in the open. The tank of the unit was high density polyethylene and as expected the exterior surface was severely photo-oxidised and the material was embrittled. Tensile tests comparing material from a new tank with samples cut from the burst tank showed that the latter was significantly weaker. Such tanks should always carry a warning statement that they must be stored under cover at all times when not in use.

Another sample which had failed for a similar reason was submitted by the Bureau of Consumer Affairs. In this case the product was a plastic car window blind made in Taiwan. The owner had complained of a pungent smell when opening the car particularly after it had been standing in the sun. This smell started to appear about two months after the blinds were fitted and after six months some damage had also occurred. The blind material was found to be a triple laminate of polypropylene film and the damaged areas were severely photo-oxidised and brittle. Although the odour could not be positively identified because of its very low concentration (the nose is a very sensitive detector) it was probably caused by acetic acid which is a primary photo-decomposition product of polypropylene. This product is an example of an imported line which is not suitable for Australian conditions.

Samples of 8 inch diameter rigid PVC pipe, stub flange and pipe adhesive were submitted by Public Works Department. During a pressure test the stub flange had blown off the pipe end and injured the operator. Examination showed that the pipe was just outside the requirements of the Australian rigid PVC pipe standard for outside diameter and ovality. The adhesive had also been applied unevenly. Such a combination would have produced a weak joint.

In relining old corroded concrete sewer mains the Water Board use short lengths of rigid PVC pipe which are pushed through the main from one manhole to the next, the joints being bonded on site with an epoxy adhesive. The adhesive being used was found to cure too quickly producing a hard, relatively brittle bond which was cracking sometimes during the lining operation. A slower curing more flexible epoxy adhesive had been obtained. Samples of both were submitted for tensile shear tests on the adhesive joint, particularly after exposure to hydrogen sulphide. Samples of lap joints using rigid PVC sheet prepared with both adhesives were exposed for one month to an atmosphere saturated with water and hydrogen sulphide. Tensile shear strength test results were then compared with the results obtained from a similar number of control samples which had been stored in the laboratory. It was found that joints made with the original adhesive did suffer a significant fall in shear strength after the exposure whereas the second product did not.

Other investigations included: determination of resin/glass ratio in samples of fibreglass reinforced plastics from boats; discoloration of a vinyl car roof cover caused by severe photo-degradation; fire testing of synthetic fibre filling for toys; cause of cracking in a plastic fuel tank from a lawn mower; safety of disposable plastic cigarette lighters and possible risk of explosion and fire; fire tests on pillow materials; damage to a car seat cover possibly caused by a protective spray.

Miscellaneous

Analyses of the products selected for the 1978 detergent tender were completed. Tenders for 1979 were assessed and recommendations made.

Three more lots of termite bait based on the insecticide Mirex were prepared for the Office of Regional Administration and the North West for further experiments on the control of Mastotermes. The formulations were varied by using different types of sawdust and in some cases with additives which might act as attractants.

Some tests were applied to samples of charcoal thought to be Skylab debris. The material was found to be fully carbonised and pyrolysis did not detect any organic material and no conclusions could be reached.

At the request of the Fire Brigades Board a report was prepared on the static electricity hazards of clothing with particular reference to their 90 per cent nylon work shirts. It was concluded that the nylon shirts should be replaced by polyester/cotton shirts.

An all too frequent cause of kitchen fires is the overheating of cooking oils. As a result of a complaint concerning a particular brand of polyunsaturated vegetable oil catching fire the Bureau of Consumer Affairs submitted a sample of the oil together with a sample of refined dripping for comparison. As this is a safety matter and both the Consumer Products Safety Committee and the National Safety Council were involved a number of experiments were carried out to investigate the thermal behaviour of the two products.

In the original statement of complaint the freshly purchased blended vegetable oil was placed in an aluminium saucepan—1¼ pints of oil in a 4 pint saucepan—and heated over a gas burner until it was smoking hot, whereupon it ignited. The lid was immediately put on the pan and the gas turned off. After about two minutes the lid was removed and the oil ignited again. After replacing the lid the pan was taken outside. After a further five minutes approximately the lid was again removed but the oil did not ignite. However, on pouring the hot oil into a larger container it ignited again causing severe burns to one leg and hand.

To study the thermal behaviour of the samples, closed cup flash points were determined and also smoke points, boiling points and self ignition temperatures. The last three determinations were made in a saucepan over a gas flame to approximate to the conditions to be expected in a kitchen. The following results were obtained.

	Closed Cup Flash Point	Smoke Point	Boiling Point	Self Ignition Temperature
	°C	°C	°C	°C
Dripping	210	214	345	360
Vegetable Oil	225	255	348	348

The values obtained for the closed cup flash point and self ignition temperature are quite normal and fall within the range of values expected of oils and fats.

After self ignition occurred the lid was immediately placed on the pan. The lid was removed after two minutes when both materials immediately re-ignited. After four minutes the dripping re-ignited, but not the vegetable oil. However, after replacing the lid a small explosion was heard in the vegetable oil saucepan indicating that ignition had occurred.

The time taken to cool to various temperatures after the self ignition test was also measured. After 5 minutes the temperatures had fallen to 300°C, after 15–16 minutes to 200°C and after about 35 minutes to 100°C. Rate of fall of temperature would no doubt have been faster if the pans had been taken outside.

Closed cup flash points were also determined on the oils after thermal treatments and the following results were obtained.

	Closed Cup Flash Point, °C		
	(1)	(2)	(3)
Dripping	210	210	190
Vegetable Oil	225	230	215

Where (1) refers to fresh oil, (2) refers to oil after heating at 300°C for one hour, and (3) refers to oil after the self ignition test.

The conclusion is the obvious one that this complaint was an example of gross overheating of the oil. Oil heated to the self ignition temperature is likely to have a lowered flash point thus increasing the danger of re-ignition if not handled carefully.

ASSISTANCE TO INDUSTRY

Fire tests on four types of panels and carpet tiles to AS1530 Part 3 "Early Fire Hazard Test of Materials" were carried out for local firms.

Blockage in a copper pipe in an air conditioning plant was found to be caused by an alkyd resin probably dissolved by the refrigerant liquid from a painted area in another part of the system.

Electrical contactors were failing to break contact when switched off. The cause was found to be an undercured epoxy embedding resin which melted and bonded the contacts together. Contactors with fully cured epoxy resin behaved normally.

Two samples of sisal baling twine were tested for tensile strength and concentration of rotproofing agent. One sample was rotproofed evenly with copper naphthenate and had a satisfactory breaking strain. The other sample had been rotproofed with a mixture of a green dye with pentachlorphenol. Treatment was uneven and where the green colour was absent very little pentachlorphenol was present and breaking strain was low.

A number of samples of painted steel panels were exposed for 500 hours in the salt spray cabinet for comparison of the several paint systems used.

Removal of vulcanised rubber from conveyor belt with cable reinforcement was investigated for a mining company. When repairing breaks, the old rubber must be removed prior to splicing and recoating with rubber. Solvents were found to be unsatisfactory. The simplest method was the use of a low temperature burn off with a batswing flame used for paint removal, at the same time scrubbing with a wire brush.

CONSULTATIVE

As usual a wide range of enquiries was received from all sections of the community, Government Departments and Instrumentalities, industry, commerce and the public. A selection is given below:

Urea-formaldehyde foam and its use for home insulation.

Toxicity of methyl ethyl ketone peroxide and its effect on the eyes.

Growth of mould on cardboard boxes after shrink wrapping.

Exterior durability of acrylic sheet and other plastic materials.

Problems with swimming pool paints and control of water quality (a perennial request.)

Production of smoke for aerodynamic testing.

Manufacture of fibreglass reinforced plastics tanks.

Use of plastics in contact with food.

Use of thiourea as a gold complexing agent.

Use of chlorhexidine as an antiseptic in wineries.

Removal of graffiti.

Foam filling of tyres.

Anti-vandal window glazing.

Safe handling of solvents and specialty chemicals used in laundries.

Production of lightweight concrete.

Use of corrosion inhibitors in wet blast cleaning of steel.

Toxicity of materials used in polyurethane rubber processing.

Manufacture of a special 2,4-D ester.

Recycling scrap plastics.

Cracking of reinforced concrete caused by corrosion of reinforcing rods.

Production of methane and alcohol on farms.

Use of PTFE powder in floor polishes.

Use of plastics in conveyor rollers.

Possible local manufacture of PVC windows.

Peeling of paint from ceilings.

E. B. J. SMITH,
Chief, Industrial Chemistry Division.

KALGOORLIE METALLURGICAL LABORATORY

GENERAL

This section continued to supply metallurgical and analytical services to the public and Government Departments in the Goldfields region. Its services were very much in demand as indicated by a substantial 88 per cent increase in sample receivals and resulting work load in 1979.

The sharp increase in the price of gold and services to the Custom Mill in Kalgoorlie were major reasons for the higher workload.

The favourable gold price has initiated many feasibility programs in the Goldfields which should progress to the gold production stage in 1980. The laboratory has provided continued assistance to small operations throughout the year and a high demand for its services is expected in 1980.

METALLURGICAL INVESTIGATIONS

Contract confidential reports were carried out on a range of metallurgical beneficiation studies.

Custom Milling Plant

The laboratory performed two functions for the North Kalgurli Custom Milling Plant. Firstly potential ores were tested to determine if the ore was of a refractory nature. Standard tests were developed to simulate the plant treatment circuit. Some details on amalgamation recoveries, cyanidation times and settling properties were established. Secondly the ore parcels treated at the plant were tested to establish gold recoveries that formed the basis of payment to Custom Plant clients. These tests were carried out in duplicate and required a high debree of accuracy.

Tailing Retreatment

A large number of gold tailing deposit samples were submitted to establish the gold extraction, lime and cyanide requirements and make some recommendation on the method of treatment. A number of mine waters were also examined for suitability in treatment processes.

Small tailing retreatment plants were established during the year and some efficiency appraisal investigations were undertaken.

Although vat leaching and zinc box precipitation of gold is still the most common method of a small operator, developments using charcoal in pulp and air agitation continued, leading to the establishment of a charcoal stripping plant in Kalgoorlie.

Investigation at this laboratory covered both methods of tailing retreatment with emphasis being placed on correct tailing deposit sampling methods and an understanding of the role of lime in a cyanidation circuit.

Ore Beneficiations

A number of mining companies and prospecting syndicates submitted ore samples to establish the suitability for a particular method of treatment.

A refractory ore was investigated in detail and results confirmed that flotation and roasting were a necessary part of the flowsheet that would result in a satisfactory gold recovery.

Coarse ore leaching of a number of gold ores was undertaken on a laboratory scale. The ores varied from 25 to 3 mm in top size. Results were variable depending on the size of ore, porosity of the ore and the nature of the gold present. Semi-porous clayey ores with fine gold present gave best results. The coarse ore leaching of low grade open-cut ores is a highly likely development in the 1980's if ores with the right properties can be located and the treatment technology, well established overseas, tested and modified to suit local conditions.

ANALYTICAL SERVICES

Support services to metallurgical investigations increased substantially this year. A high demand for gold analysis by both fire assaying and atomic absorption was experienced. Gold determination by atomic absorption was restricted to solutions and mainly used in the determination of gold recovery rates.

Public assay requests on gold bullions and umpire sampling were met on demand. The high workload from metallurgical investigations reduced the capacity for meeting all assaying requests on demand. A number of requests for a large number of assays were not accepted.

During the year 77 gold bullions were analysed and a standard method for the estimation of gold in specimens developed. In the second half of this year the gold in 66 specimens was estimated.

SERVICES TO OTHER DEPARTMENTS

A small volume of samples were received from the Gold Stealing Detection Staff and the State Battery. In general all requests were given a high priority.

ADVISORY AND CONSULTATIVE

Advisory services to the mining public on treatment problems and operating techniques continued throughout the year. An inspection of a number of operating plants was undertaken by the Officer In Charge and the Chief of the Engineering Chemistry Division (Mr. B. A. Goodheart) in November.

A. MYKYTIUK,
Officer In Charge, Kalgoorlie Metallurgical Laboratory.

MINERAL DIVISION

GENERAL

With the exception of the Geological Survey, client Departments generally increased their sample submissions this year, although the overall number of samples is approximately the same as last year.

The main increase has been in relation to air pollution and occupational hygiene where it amounted to 20 per cent. Since this work is largely quantitative mineralogical assessment of dusts, it has resulted in an appreciable increase in the mineralogical content of the Division's work. The pressure of this and forensic mineralogical work has led to a decline in mineralogical recording and attention to the mineral collections.

Work undertaken for the Geological Survey has not declined as the sample receivals would suggest because many samples from a field excursion late in 1978 have been handled this year.

Details of sample receivals is shown in Table 14.

contained no phosphate but contained elemental sulphur with quartz and calcite; material from near a glass works which was shown to have indigenous origin as did dust accumulated on an air conditioner filter.

Association was found between settled dusts and that produced at a saw milling plant, a terrazo grinding operation, a brickworks flue and a mica plant.

An examination was made of size grading of paper waste dust from the Government Printing Office to assist design of a disposal system.

Instruction was given to a chemist from a cement works, to assist the firm in assessing the origin of dusts which are in part from works and part indigenous.

HAZARDS TO HEALTH

Examinations under this heading represent 26 per cent of all samples received and are mainly concerned with dust in air at work sites.

TABLE 14

MINERAL DIVISION

	Geological Survey	Government Chemical Laboratories	Main Roads Department	Metropolitan Water Board	Mines Department	Police Department	Public Health Department	Public Works Department	Road Traffic Authority	Other	Public: Pay	Public: Concession	Public: Free	Total
Building Materials	....	....	24	....	....	....	7	10	....	4	27	....	....	72
Dusts	....	11	....	....	589	....	1 615	2	....	4	20	....	....	2 241
Forensic Examinations	....	....	....	....	....	90	....	....	....	....	....	....	....	90
Geochemistry	102	....	....	....	....	....	....	....	....	....	....	1	....	103
Mineral Identifications	43	90	....	....	2	....	69	....	....	3	76	30	5	318
Water Main Pipes	....	....	....	23	....	....	....	....	....	....	....	....	....	23
Miscellaneous	....	9	3	5	6	....	18	2	....	18	16	....	....	77
Ores and Minerals—														
Clay	....	....	....	....	....	....	....	2	....	....	11	....	....	13
Gold	19	....	....	....	55	....	....	....	....	....	168	64	24	330
Iron	73	28	....	....	....	....	....	....	....	....	....	....	....	101
Lead	3	5	....	....	14	....	....	....	....	....	21	....	....	43
Limestone	33	....	....	....	....	....	....	....	....	....	....	....	....	33
Zircon	....	178	....	....	....	....	....	....	....	....	8	....	....	186
Various	6	....	3	....	12	....	3	....	....	3	28	....	1	56
Silicate Rocks	158	....	....	....	....	....	....	....	....	....	4	....	....	162
Pyrometry	....	....	4	....	....	....	....	....	51	....	3	....	....	58
Total	437	321	34	28	678	90	1 712	16	51	32	382	95	30	3 906

Investigational work for and participation in technical committees of the Australian Standards Association have continued in the fields of iron ore and bauxite, and commenced with heavy mineral sands. Co-operation with this latter work is also undertaken with the W.A. Chamber of Mines.

AIR POLLUTION

Samples associated with air pollution increased and represented 46 per cent of all samples received. Approximately 500 air samples were examined for lead. These were mainly from a continuation of Public Health Department monitoring of fluctuations at a stationary site in Murray Street Perth, but included a scan which was made in the Munster area, and a new program of high volume sampling in the centre city block and on the eastern outskirts. Also, a comparison was made of the lead content of air breathed by Road Traffic Authority Officers on bicycles, in cars, and in offices, the averages of the results which are well below the T.L.V. of 150 $\mu g/m^3$ were $7 \cdot 1$, $4 \cdot 4$ and $2 \cdot 8$ $\mu g/m^3$ respectively.

The remaining 830 samples were dusts of varying types from Public Health Department monitoring and investigations of complaints.

The dust monitoring samples examined were from the following localities with respect to the associated industries or problems: Cape Lambert and Port Hedland—iron ore; Kalgoorlie—gold mining and dumps; Munster and Rivervale—cement; Naval Base—alumina; North Fremantle—talc; Bunbury, East Perth and South Fremantle—coal fired power generation; Kwinana—general dust deposition; Maylands—coal fired brickworks; and Calista—steel mill.

Dusts sampled as a result of complaints were of many types. Soot smuts from boiler flues, which are acid due to their sulphur content, were found responsible for staining and paint attack on fibre glass boats and cars. In another instance, where a nearby boiler stack was suspect, the deposit on a roof was found to be non-related organic matter of fungal origin.

Other cases where the suspect source has been shown not to be implicated, have been at Hamilton Hill where calcite and quartz were indigenous and cement works material less than 1 per cent; at Kwinana where suspect phosphate material

Free Silica

Quantitative estimation of the quartz (free silica) content of dusts, which defines the maximum permissible concentration of the dust in a work area, were made on samples submitted by the State Mining Engineer and the Public Health Department.

Many of these were from quarrying operations at Boulder, Byford, Cardup, Cranbook, Gelorup, Gosnells, Herne Hill, Maddington, Meckering, Merredin and Wungong Dam.

Free silica monitoring of mine dusts was from iron ore operations at Goldsworthy—Shay Gap, Koolan and Cockatoo Islands, Koolyanobbing, Newman and Robe River and also of dust from nickel mines at Kambalda, Agnew and Redross, and gold mines at Mt. Charlotte, Telfer, Frances Furness, Sorby Hills and generally around Kalgoorlie. The heavy sands plants at Capel and Bunbury, baryte mining operations at North Pole, clay residues from Chandler and mining operations at Moolyella and Pilgangoora were included. Free silica was also estimated in dusts from plants in the Metropolitan Area subject to the Mines Regulation Act. These were associated with glass and refractories manufacture and with sand blasting operations.

The dust capturing characteristics of several sampling cyclones and impact samplers were studied relative to the distribution of respirable and non respirable dust at various parts of the instruments.

Lead

Lead dust associated with gold assaying was examined from several gold mines. Also the distribution of lead was determined in tailings from an old lead mine, which were being used as land fill.

Other Metals

Estimation of various other metals in dusts for comparison with tolerance limits included nickel, cobalt and manganese from mining operations and zinc from galvanising operations.

Asbestos

Concern relating to the publicised hazard of asbestos inhalation caused an increase in air sampling activity initiated by unions and employers. A survey for Telecom continued for several months.

Continuing monitoring by the Public Health Department included brake lining works where chrysotile concentrations up to 18 fibres/ml were measured, although that figure was an isolated instance.

A survey of various atmosphere sites in Wittenoom both in and out of doors was concluded. This showed an overall average of 0·031 fibres/ml of crocidolite with considerable variation between sites. Dusts taken from an air conditioner unit filter at Wittenoom was shown to contain 2 per cent crocidolite.

A similar atmosphere survey conducted in Perth gave an overall average concentration of 0·002 fibres/ml with many samples showing no asbestos fibres. Because of the extreme fineness of the fibres it was not practical to determine the percentage of asbestos types in these samples but usage in the Metropolitan area, as assessed by observation of fibrous material and dusts over several years, indicates a high preponderance of non crocidolite types.

Since a threshold limit value of 0·2 fibres per ml has been set for crocidolite and the National Health and Medical Research Council limit for amosite and chrysotile is 2 fibres/ml the hazard in Perth streets is obviously considerably less than that represented by the Wittenoom figure.

Air samples during an operation of sawing asbestos sheet contained approximately 6 fibres/ml.

Several large organisations in the mining and transport industries, which were involved in plant changes requiring the removal of asbestos insulation, made arrangements to conduct their own air sampling and evaluation programs. Officers from three organisations were instructed in the technique of asbestos fibre counting.

A large number of fibrous materials were examined to assess their potential for forming asbestos fibres in the atmosphere. Samples from domestic situations constituted 24 per cent of the total.

Amosite was present in 34 per cent and chrysotile in 24 per cent of samples. One sample submitted by the Department of Labour contained 80 per cent crocidolite. The remaining samples had no asbestos fibre content. The fibrous content of these consisted of organic and cellulose fibre, rockwool or fibre glass, although others contained only gypsum and vermiculite. Calcium carbonate was the most common cementing agent in those materials containing asbestos and often other materials were admixed including rockwool, cotton fibre, portland cement and diatomite.

Dust from two air conditioner filters each contained approximately 5 per cent amosite but these were from situations in which asbestos could be expected.

Air delivered by ten different types of hair dryer was examined because of the possible use of asbestos as insulation. Only one yielded a measurable amount of asbestos (chrysotile) fibre.

Samples of masonry filling (spackling) compounds were found to contain no asbestos fibres.

Asbestos fibres in samples of beer, wine and soft drink were of an acceptable level but the wine showed a wide range between bottles indicating an inconsistency in filtering, possibly associated with change of filter media.

Personal air samples from an insulation firm were examined to check the concentration of fibre—glass fibres. The microscopic characteristics of these fibres were recorded.

Other Dusts

Irritation suffered by workers at a foundry using a charge of low silica pig iron, ferrovanadium and soda ash was shown to be unrelated to the dust sampled. This consisted of 80 per cent of graphite.

Samples from mineral sands waste dumps in the Geraldton area were examined for potential health risks. No free acidity or significant radioactivity was detected in the samples. Advice was given that the radioactivity of large masses of material, as in the dumps, could only be checked by examination on site.

GEOCHEMISTRY

Although receivals this year totalled 158 for summation analyses, the greater part of the years work was on 632 samples involving 14 300 determinations from the 1978 field excursion to the Pilbara region. This involved major element analyses for differentiation of magma masses in batholiths at Mt. Edgar and Corunna Downs, and trace elements to assess their potential for mineralisation.

Data from X-ray fluorescence analysis and from conventional analyses are combined by a computer program to show associations and produce scatter diagrams available to the Geological Survey through a direct computer link.

Other rocks in support of regional mapping include a suite for the explanatory notes to the Winning Pool sheet.

Also examined were galena and host rocks from Sweetwater Well in the Nabberu Basin. A newly discovered gossan on the Newdegate sheet was examined for economic potential.

Soils from Mt. Saddleback were examined for trace metals to determine the genesis of the weathering profile in relation to bauxite mining.

ECONOMIC ASSESSMENTS

Evaluation of the economic potential of known deposits was made of several materials which included gold.

Gold

Fifty six samples were examined from Government sources mainly concerned with assessing a claim for mining assistance and with umpire assay of State Battery samples. The great majority of samples were examined for the public and consisted of 26 ores including smelter slag, and nuggets of which the largest contained 130 oz troy of gold.

Because of the increasing price of gold throughout the year several bullion samples were analysed for people who wished to know the value of metal which they owned, without selling it immediately.

The interest caused by the increasing price of gold, and the consequent burgeoning popularity of metal detectors in gold prospecting, resulted in the submission of 131 nuggets for estimation of gold content.

Because of a premium above the quoted metal price which was being paid for nuggets with collector appeal, the finders were anxious for an estimate of the gold content without damage to the specimen.

The mass of metal in a nugget can be calculated from the following formula.

$$\text{Mass of metal} = \frac{SG_M\,(M_N - V_N\,SG_{Ga})}{SG_M - SG_{Ga}}$$

Where SG_M = specific gravity of metal
SG_{Ga} = specific gravity of gangue
M_N = mass of nugget in grams
V_N = volume of nugget in cubic centimetres

When the SG of the metal is taken as 19·3 (gold) and that of the gangue is 2·67 (quartz) this formula becomes:

$$\text{Mass of gold} = 1{\cdot}16\ M_N - 3{\cdot}09\ V_N \text{ grams}$$

Hence quite appreciable errors can occur in estimating the gold content of a nugget if the specific gravity of the metal is less than 19·3 due to the presence of silver or other metals and if the gangue has a specific gravity different to that of quartz. An estimate of the gangue S.G. can be made by inspection of the minerals present, but no non-destructive estimation can be made of the S.G. of the metal. Additional errors can occur if there are air or gas inclusions as bubbles or pores in either the gold or the gangue.

Some of the possible variations are illustrated in Table 15 which compares the determined specific gravity of artificial alloys and actual nuggets with their calculated specific gravity.

TABLE 15

SPECIFIC GRAVITY OF GOLD/SILVER ALLOY AND NUGGETS

Gold per cent	Silver per cent	Specific Gravity Found	Specific Gravity Calculated
Alloys—			
100	0	19·3	19·3
91·6	8·4	18·1	18·1
75	25	16·0	16·0
50	50	13·6	13·6
0	100	10·5	10·5
Nuggets—			
76·8	23·0	14·7	16·2
89·4	10·5	15·8	17·8
93·3	6·6	16·6	18·4
96·5	3·5	17·2	18·7
93·2	6·7	18·0	18·3
99·5	0·6	18·9	19·2

While this table does not illustrate the effect of varying specific gravities of the gangue it does illustrate the effects of apparent inclusion of gas bubbles in the nuggets, as in all cases the found specific gravities are lower than that expected from their composition.

Other gold bearing materials examined included a scheelite concentrate taken from an old dump which contained a surprising 1930 g/tonne of gold, and rejects from a Wilfley table, after removal of the gold concentrate, which assayed 83·6 g/tonne.

Investigations included a cyanide leach extraction test of dump material using mine-site water; examination of products from a plant using collection of gold by carbon absorption; investigation of lumps forming under the mercury of battery plates.

Tantalite

A dispute before the Wardens Court regarding development of a tantalite claim resulted in comprehensive sampling and analysis of the deposit.

Miscellaneous assessments included diatomite and peat from Wallumbeenup swamp, iron ores from Ministerial Leases, limesands from Ledge Point, limestones from Lake Joondalup and Cape Lambert.

MINERALOGY

General

The majority of mineralogical examinations consisted of quantitative estimates of the mineral content of rocks, to supplement chemical analyses in the study of the geochemistry of rock masses. These include the study of the variation of carbonate geochemistry in the Nabberu Basin.

Other mineral identifications in connection with geological mapping have been of common minerals in unusual habit. Electron microprobe studies have been made of laterites to determine, from the relationship of metal elements, whether they were gossans.

Mineralogical work associated with the Wungong Dam was concerned with deep erosion observed in gullies in the borrow area. This soil was distinguished by a substantial proportion of montmorillonoid.

Diamond prospecting produced requests for identification of mineral grains with particular reference to garnet species. Samples ranged from river sands to percussion drillings. Heavy minerals consistent with high grade metamorphism were identified from Ajana.

Other heavy minerals which aroused interest include baryte occurring in tin-jig concentrates at Pinga, a partially metamict zircon with inclusions of faintly greenish-coloured xenotime from the old MC 35 at Warda Warra, and chromite from east of Bridgetown. The quoted high market price for tantalic oxide created some interest in tantalum minerals and specimens were examined of tanteuxenite from Hillside, and a columbite of SG 5·676 from Mukinbudin.

Examinations were made of several mineral assemblages reputed to have activated metal detectors. The detector response was often due to magnetic minerals such as magnetite or to faulty operation of the equipment.

Metals detected were generally not naturally occurring with the lead—tin alloy solder being more common.

Metalliferous minerals included a suite of specimens representing various ore bodies at the MC 38 silver mine at Kununurra. Specimens from the Rose Dam, Mt. Pleasant north of Kalgoorlie, site contained native copper and native silver together with sulphide and oxidised copper minerals. Specimens from Coppin Pool contained cerussite, pyromorphite and malachite and from north of Boodarockin aurichalcite (blue copper zinc carbonate) with oxidised copper minerals.

Other occurrences of interest include fine grained graphite from Marvel Loch; pyrite nodules from north of Millstream with a baryte—quartz nucleus; diatomite from the Nanson-Nabawa road; and an altered dolerite from the Chittering Avon valleys suspected to be jade. Its uneven hardness make it unsuitable for carving.

An interesting deposit in a cave overhang at Cape Le Grand National Park proved to be an interlayered structure of opal and iron oxides with intergrowth of gypsum.

Clays causing difficulties in the mineral concentration operations of a mineral sands company were identified to assist in overcoming the problem. Other clays representing various deposits in the Walkaway area were examined for illite concentration and advice was given re early-firing cracking of pottery.

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	
Anatase	Mitchell Plateau
North West	
Tapiolite	Yinnietharra
Murchison	
*Dumortierite	Golden Grove
Anatase	Day Dawn
Micaceous Hematite	Peak Hill
Almandine	Yandanooka
South West	
Chromite	Bridgetown
Columbite—tantalite	Mukinbudin
Marcasite	Greenbushes
Hollandite	Greenbushes
Apatite nodules	Thornlie
Uvarovite	Bullfinch
Central	
Native Copper	Mt. Pleasant
Eucla	
Cassiterite	Norseman
Scheelite	Norseman
Columbite—Tantalite	Norseman

* First occurrence recorded in W.A.

Mineral Collections

The Mineral Division collection now incorporating the Simpson Collection, numbers 11 268 specimens.

In 1979, 73 specimens were added of which 51 represent localities in Western Australia with 17 specimens from overseas and 5 from Eastern States localities, added in donated suites. Specimens of interest received from overseas localities were donated by the Geological Survey of W.A. from their suite of African kimberlites. Another donation was of kimberlite rocks and indicator minerals from South Australia, Victoria and Western Australia.

Samples of significant mineral occurrences from the leases of exploration and mining companies operating in Western Australia are sought and donations would be welcomed.

METALS AND ALLOYS

Ball pane hammers which had been involved in accidents, wherein chips from the faces caused injury, were examined for the Department of Labour. They were advised that chemical composition was not the dominant factor in the behaviour of the metals. The chipping of the surface was not attributable to the metal characteristics although they were slightly harder than specified.

Stainless steel from a sink was shown to be of unsuitable composition for its use where active chlorine was present, 316 stainless steel was specified.

Surgical scissors from considerable stocks held by the Government Stores Department were examined to decide whether their failure was due to a manufacturing fault. Non-destructive testing by X-ray and ultrasonic techniques was not practical for these items. The steel had the composition of a general cutlery steel. Examination of surfaces and shafts fractured in use and experimentally, indicated that the faulty scissors had carried cracks for a considerable time before breaking, and that incipient cracking had been caused by stamping identifying numbers into the cold metal of the shaft.

Engine core plugs submitted by the Bureau of Consumer Affairs were examined for corrosion products which may have indicated the nature of the attack causing penetration pitting. No evidence could be drawn from these products but it was shown that the composition of the plugs was of a nature which, due to experience, had long ceased to be recommended by the manufacturer.

A case before the Small Claims Tribunal involved corrosion of an electric stove. Examination of the corrosion product (rust) was made to determine whether it was normal or contained features which would suggest accelerated corrosion due to spillage. It was found to contain a constituent of cleaning products.

FORENSIC EXAMINATIONS

In two instances of murder in which the victim's body was dragged across the ground, mineralogical evidence was produced to deduce the events which took place. In one, scrapings from under the victim's finger nails were related to the area from which the body was dragged. In the other, the presence of slag globules in a suspect's car was related to an area through which the body was dragged.

In an attempted rape case, soil from the victim's home and various items of clothing were compared with that from the scene.

A small smear of paint on a rock supposedly used as a murder weapon was characterised as to the type of pigment present. A range of paints was then examined and the tint of the unknown paint was related to a specific type from one manufacturer. Paint smears on various items of clothing and at various sites were compared.

Samples of lapidary prase and chrysoprase were examined in connection with alleged theft from a mineral claim. Samples suspected as stolen were seized from a lapidary in Melbourne. Examination showed no comparison with reference samples from the claim.

In a complicated case involving suspect stolen gold bearing ore, samples from 5 different sites, were compared including a stockpile awaiting treatment at a State Battery, and a stockpile on the complainant's gold mining lease. Mineralogical examination and assays for gold and silver supported the contention that at least some of the ore from the Battery had come from the complainant's stockpile.

The question of the distance at which a shot was fired was critical in one case from which blood stained clothing with a bullet hole was examined. The concentration of barium and lead at various diameters from the hole was measured and compared with the pattern on cloths into which bullets had been fired from measured distances. It was established that there was a strong correlation between firing distance and lead intensity and no correlation between firing distance and barium intensity.

BUILDING MATERIALS

Concrete and Aggregates

Aggregates for use in concrete bridges and culverts for the Main Roads Department formed the biggest group examined, since local stone is chosen because of cost, and the fact that in many instances they have not been put to this use before These were checked for potential reactivity with the alkali of cement and mineralogical examination to detect the presence of deleterious materials.

Aggregates for road surfacing were also examined and for this use metallurgical blast furnace slag was tested. A quality control check was made on bituminous concrete purchased by the Main Roads Department, because physical properties suggested that it did not conform to specifications.

This was confirmed in a number of instances. Free lime concentrations varied over a large range.

Concrete masonry blocks were examined to determine their potential to produce efflorescence, which is related to the content of free lime and to porosity. A difference was indicated between autoclaved blocks with a free lime content less than 0·1 per cent, which showed no efflorescence, and some cured without autoclaving which had a free lime content of 0·31–0·82 per cent and showed slight efflorescence.

The possibility of using concrete blocks, for the construction of open fire places associated with aboriginal housing, was examined. A loss of strength followed by spalling from 300–600°C was expected and a recommendation was made for the use of aluminous cement—blast furnace slag as a mix for the fire place bricks.

Deteriorated concrete was found in a country water tank when emptied for routine cleaning. It occurred at a single level indicating a break in pouring of the concrete. Cavities were filled with coarsely crystalline calcite which had caused some deterioration. Patching of friable areas was recommended.

Faulty concrete flooring at a country ambulance brigade headquarters was shown to be due to the underlying earth fill which was mine rubble. Reaction of sulphides in this caused crystallisation of goslarite ($ZnSO_4$ $7H_2O$) which lifted and cracked the floor.

Another concrete floor at a hospital deteriorated causing lumps under PVC floor tiles. These were initially attributed to faulty adhesive but were shown to be due to particles of expansive aggregate close to the surface of the concrete. The aggregate, which contained particles which expanded to amorphous potassium aluminium silicate, came from a quarry in the Darling Scarp. Advice re treatment was given. Failure of reinforced concrete in structural columns of a building was not due to added calcium chloride but a reflection of the density of the concrete in relation to its environment close to the sea.

Assistance was sought by a local government authority to determine the cause of cracking of concrete slabs laid in a mortar bed over concrete in the vehicle bearing portion of a paved area. Examination of used and comparable unused slabs, original materials, the mortar bed, and the exudation in the cracks lead to the conclusion that the problem arose from a weakness of design which allowed the mortar to become the drainage strata for water flushings which were administered daily. The pumping action of passing traffic produced fluctuating pressure and this together with weakness and excess permeability of the mortar caused leaching and lack of support for the concrete slabs.

An investigation of a method of separation from blended cements of the components, portland cement, blast furnace slag and pulverised fuel ash, was undertaken on behalf of the industry because of interest aroused by a visiting lecturer in cement technology.

The suggestion that furfural could be used was followed up and it was established that, in fact, the method quoted was one of gravity separation using heavy liquids.

Other Building Materials

There has been a continuation into this year of problems earlier experienced with "drumming" plaster. While mixes less rich in cement than specified were noted, lack of adhesion of the plaster was attributed to technique which allowed absorption of moisture from the mortar before setting.

Examination was made of wall plaster from an old building of historic interest at Wonnerup, so that authentic repairs could be made.

The association of insects with a number of instances of fretting of mortar from between the lower courses of brickwork brought suggestions that the insects were eating the mortar. The fretting could be explained by several factors such as friability, porosity and weakness of the mortar, together with lack of adhesion. The presence of the insects was probably due to them sheltering in the recesses.

Staining noted on the metal of an insulation board—mini strip ceiling at a school was shown to consist of mono-basic ammonium phosphate.

Ammonium phosphate is used as a fire-proofing agent in fibre board. Water from a roof leak extracted the phosphate from the sheet and deposited it on the metal. Advice on removal of the efflorescence was given.

For industry, absorption tests were made on special bricks and brick samples dried in a newly installed furnace at a brick manufacturing establishment, to ascertain the efficiency of the new furnace.

WATER PIPE EXAMINATIONS

Further batches of water-main pipes were submitted by the Metropolitan Water Board for leaching and dye penetration tests to assess possible deterioration in service.

In addition to cement-asbestos pipes which had been in use for periods from 5 to 15 years, samples of reinforced concrete pipes and cement lined steel pipes have been tested.

The leaching pattern of cement asbestos pipes shows a graded leaching of the lime from the inner surface of the pipe to a depth of 6–8 mm over a period of approximately 15 years service. Pipes examined have varied from 12–25 mm in thickness. Only a limited number of cement-lined steel pipes have been examined but these have shown an apparent increase in the lime content at a point 4–5 mm from the inner surface of the pipe.

Difficulty in producing representative samples of reinforced concrete pipes due to the size and unevenness of the aggregate used in their construction, has limited the interpretation that can be placed on the chemical analyses, but is largely overcome by the use of very large samples.

Deposits which have hindered the functioning of some Metropolitan Water Board pumps in the Mirrabooka area were found to be mainly composed of hydrated aluminium compounds which were soluble in sodium hydroxide solutions. Sections of new pipes which had been treated with sodium hydroxide were examined to assess possible damage by the alkaline treatment.

PYROMETRY

Facilities for calibration of mercury in glass thermometers were upgraded by the acquisition of a standard temperature bridge and platinum resistance thermometer to replace standard mercury in glass thermometers of considerable age. Thermometers for use with the Breathalyzer were routinely calibrated. A set of electronic temperature sensors was calibrated for a private firm.

MISCELLANEOUS EXAMINATIONS

The event of "Skylab" material falling over Esperance brought a request for urgent examination to decide whether the finder would be sent to America to collect a prize for the first material delivered there within a time limit. The examination was necessary because earlier hoax material was submitted. It was anticipated that exotic space age material would be readily identifiable as such. The charred material submitted consisted of almost pure carbon. On structural characteristics an estimate of the probable genuineness of the material was made and the finder was sent to America. N.A.S.A. later confirmed the origin of the material and the prize was paid.

Failure of standby storage batteries from the Fire Brigade Board, and from the navigational lights of Bunbury harbour were investigated and found to be due to incorrect charging procedures.

A series of tests on prilled ammonium nitrate was made to assess the possibility of using spent lubricating oil as a replacement of diesel fuel in the mixing of AMFO explosive. This use was intended as an energy conservation and economy measure. A used oil component up to 50 per cent by volume gave satisfactory absorption.

An investigation of the mercury halo technique of metal prospecting included a study of the distribution of 13 elements in selected sulphide minerals, and of the physical separation of sulphide minerals. Investigations have also been made of chemical methods which will be applicable to this investigation. This work is proceeding.

PILOT PLANT PRODUCTS

Activities of the Engineering Chemistry Division produced products from various stages of their experimental programs which were examined along with head samples so that mass balances could be obtained.

The material examined included—upgraded zircon, processed diatomite, copper ore leachates, granular potassium chloride and briquettes of roasted Collie coal char.

COMPUTING ACTIVITIES

Automatic operation of the X-ray fluorescence spectrometer under computer control has largely been successful. Periods of up to six hours unattended operation are now possible, depending on the types of analysis required. However, intermittent equipment malfunction has required the modification of control programs to recognise any hiatus in operation and to alert the operator.

Work in storing, on the computer, operational parameters for all types of analysis is progressing.

Data manipulation and reporting programmes have been refined to the point where data generated for routine samples (e.g. GSWA) is stored on the computer in report form and is available for interpretation and data reduction processes without the need for manual transcription of results.

Due to the continued lack of formal computer personnel, Divisional staff have once again been involved to a large extent with the operation and maintenance of the computer system. Examples of such involvement are:

Weekly "backup" copying procedures to duplicate the programs/data comprising the total computer system such that the failure of a particular module of the computer does not entail complete loss of the data stored therein.

Preparation and collation of computer estimates for the Department and also in completing various questionnaires for governmental computer bodies.

Operation of the Departmental Computer Users Group and membership of the Computer Advisory Committee.

Programming advice and assistance to other Divisions and Branches of the Department in particular to GSWA, with modifications to programs purchased externally, and writing of other programs for geochemical interpretation of data.

Also advice in areas of selection and commissioning of computer related equipment (e.g. plotter, digitizer, visual display units etc.).

Operation and maintenance of operating system soft ware including the introduction of new versions of such programmes.

An in-service computer course was devised and presented by Divisional staff. This course was designed to promote awareness of the potential and use of the local computer system.

D. BURNS,
Chief, Mineral Division.

WATER DIVISION

GENERAL

The anticipated improvements in analytical efficiency and investigational output due to sub-division of the Water Division into three sections during 1978 has not been fully realised. There has however been improvement, as is reflected in sample and publication output. Interfacing of automated analytical equipment with the computer has not been completed, although the necessary equipment to effect this, is on order. The software required for such interfacing is at an advanced stage of development by ourselves.

There has been an increased demand from both the Government and private sector for consultation and advice, mainly in the water treatment area. Factors creating this demand include general overall water shortages and publications generated by the Division, associated with iron stain prevention and the use of bore water in swimming pools.

Attendance and activity associated with various committees has also continued to be a significant Divisional function. Three of the main committees, namely the Laporte Effluent Sand Dune Disposal and Pipeline to Sea Disposal sub-committees and the Public Health Department Waste Disposal Technical Committee, have necessitated a considerable amount of written comment involving literature search both in relation to previous analytical results and theoretical aspects.

Table 16 lists the samples received in 1979.

TABLE 16—WATER DIVISION

	Agriculture Department	Dept. of Conservation and Environment	Department of Industrial Development	Dept. of Fisheries and Wildlife	Leschenault Inlet Management Authority	Main Roads Department	Metropolitan Water Board	Mines Department	Pay	Peel Inlet Management Authority	Public Health Department	Public Works Department	Swan River Management Authority	Other	TOTAL
Corrosion and Deposits	....	....	....	....	....	....	2	....	7	....	4	4	....	1	18
Effluents	....	10	22	....	....	....	....	....	21	....	2	243	9	....	307
Environmental monitoring—															
Leschenault Inlet	....	....	....	....	96	....	....	....	....	....	....	....	....	....	96
Peel Inlet	....	....	....	....	....	....	....	....	....	92	....	....	....	....	92
Swan River	....	....	....	....	....	....	....	....	....	....	....	....	225	....	225
Investigations	....	....	....	....	....	....	....	....	....	....	1	2	....	1	4
Miscellaneous	....	....	....	....	....	....	1	....	2	....	3	1	....	1	8
Waters—															
Fluoridated	....	....	....	....	....	....	688	....	....	....	....	806	....	....	1 494
Network Survey	....	....	....	....	....	....	....	....	....	....	....	1 711	....	....	1 711
General	100	14	18	20	....	10	872	297	596	....	129	2 644	91	17	4 808
TOTAL	100	24	40	20	96	10	1 563	297	626	92	139	5 411	325	20	8 763

TABLE 17

SAMPLE SOURCE 1970–79

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
M.W.B.	2 049	2 231	2 305	2 286	2 677	2 816	2 619	2 225	1 471	1 563
P.W.D.	1 926	1 725	1 840	1 942	1 707	1 951	2 581	2 713	4 828	5 411
Total receivals	5 279	5 375	5 535	5 582	6 113	6 435	6 592	7 184	7 697	8 763

Sample Source

Sample receivals have increased by over 1 000 on 1978 which is equivalent to about 14 per cent. This is the ninth successive year where sample receivals have shown an increase in number. Of these samples about 1 700 were handled in the environmental section and approximately 1 700 in the automated network section leaving the balance of nearly 5 400 in the water and treatment section.

Table 17 indicates that of the two major Government Departments providing the bulk of these samples there has been a dramatic change in their proportional representation of the total received since about 1977. The sample receival from the Metropolitan Water Board was slightly higher than that from the Public Works Department between 1970 and 1976, but in 1977 the change occurred; until now in 1979 the Public Works Department provided 62 per cent of the samples compared to 18 per cent from the Metropolitan Water Board. This reduction in Metropolitan Water Board numbers has been brought about by the establishment of their separate laboratory and the increase in Public Works Department numbers has been caused by the influx of the Australian Water Resources Council network survey monitoring, increases due to the "Rights in Water and Irrigation Act" effluent samples and the more frequent monitoring of country town water supplies.

Papers and Publications

The following papers and publications were prepared during the year.

1. "Destratification experience in Western Australia" by P. N. Jack was presented at a joint U.S.A.-Australia seminar on "Destratification of Reservoirs" in Melbourne.
2. "The determination of Uranium in water by absorption on cellulose phosphate paper and X-ray fluorescence readout was presented by R. Schulz at the 5th Australian Symposium on Analytical Chemistry in Perth.
3. "An historical outline of corrosion and its prevention in the Mundaring/Kalgoorlie pipeline" was presented by P. N. Jack at the 19th Australasian Corrosion Conference in Perth.
4. "Water quality monitoring of the Peel Inlet/Harvey Estuary system" by R. Schulz was published as Report of Investigation No. 21.
5. A pamphlet on the use of bore water in swimming pools by N. Platell was published as an Information Bulletin.

Conference/Seminar Attendance

The following conferences were attended during the year by Divisional staff. Those interstate had only one attendee whereas those in Perth usually had multiple attendees.

Joint U.S.A./Australian Seminar on reservoir destratification in Melbourne.

Eighth Federal A.W.W.A. Convention in Gold Coast, Queensland.

Fifth Australian Symposium on Analytical Chemistry in Perth.

Nineteenth Australasian Corrosion Association Conference in Perth.

Equipment

Because of drastic curtailment of fund availability for equipment, no equipment of value greater than $5 000 had been purchased during the 1978/79 financial year and the current outlook for ordering of such equipment during the 1979/80 financial year is remote. An organic carbon analyser, essential for full evaluation of organic effluents and associated contaminated waters, is valued at $19 000 and appears to be an unlikely aquisition prior to the 1980/81 financial year.

There has also been severe reduction of funds available for lower priced equipment. Apart from a fluoride electrode, the only other equipment ordered in 1979 for the current financial year has been in association with interfacing of automated equipment to the computer.

The lack of funding for equipment can only lead to a downgrading of the services available within the Division.

WATER SUPPLIES

Salinity of Hills Catchment Dams

A list of the annual average chloride levels for surface samples from the major hills catchment dams between the years 1960–1979, which are used for drinking supplies, is given in Table 18. Based on rainfall recordings at Perth, 1979 was the driest year for the period of interest, but the average chloride levels of most dams have not deteriorated during 1979. For 1979, only one of the source supplies, namely South Dandalup, displayed its maximum average value over the period of interest.

TABLE 18

ANNUAL AVERAGE CHLORINITY OF HILLS CATCHMENT DAMS 1960–1979

Chloride, Cl*

mg/L

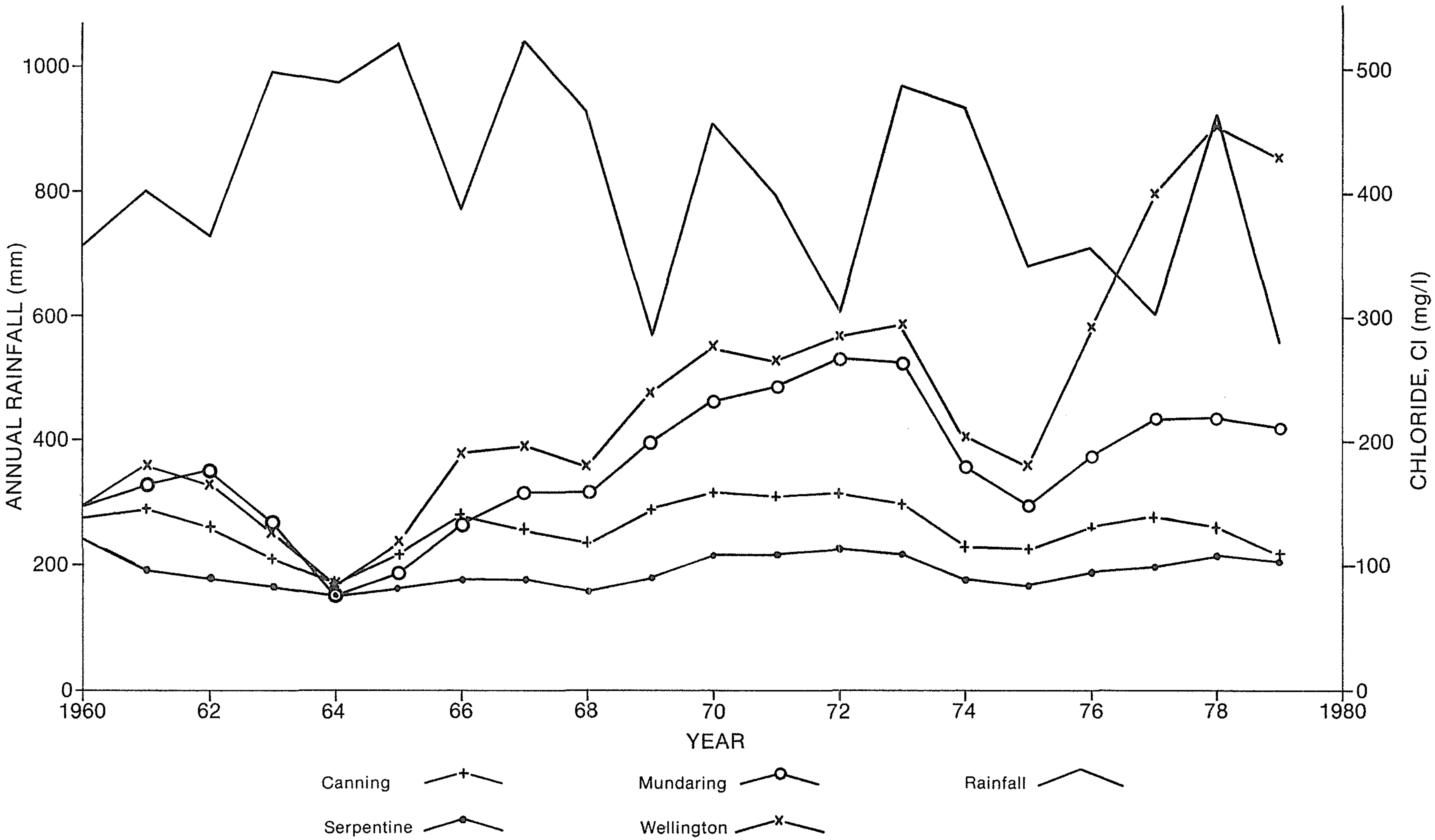
Year	Rainfall (Perth)	Canning	Churchmans	Mundaring	North Dandalup	Serpentine	South Dandalup	Victoria	Wellington	Wungong
	mm									
1960	717	135	....	145	....	120	....	....	205	....
1961	820	145	....	165	....	95	....	....	180	....
1962	731	135	....	175	....	90	....	....	165	....
1963	995	105	....	130	....	85	....	....	125	....
1964	976	85	....	75	....	75	....	....	85	....
1965	1 042	110	....	95	....	80	....	....	120	....
1966	774	140	....	135	....	90	....	....	190	....
1967	1 038	130	....	160	....	90	....	....	195	....
1968	931	120	....	160	....	80	....	....	180	....
1969	574	145	....	200	....	90	....	....	240	....
1970	909	160	65	235	....	110	....	140	275	85
1971	799	155	60	245	80	110	....	135	265	80
1972	611	160	65	270	85	115	....	140	285	90
1973	974	150	60	265	65	110	....	125	295	75
1974	938	115	60	180	65	90	....	105	205	75
1975	682	115	60	150	75	85	75	110	180	80
1976	713	130	65	190	85	95	80	135	295	85
1977	608	140	70	220	90	100	85	120	400	95
1978	923	130	65	220	110	110	85	110	455	95
1979	560	110	65	215	105	105	90	125	430	90

* Conversion factor for Cl to total dissolved solids (by evaporation at 180°C)

1·85 for Wellington Dam
2·0 for all others

FIGURE 2

SALINITY VARIATION OF MAJOR HILLS RESERVOIRS 1960-1979



The salinity level at Wellington dam has improved slightly, possibly due to bottom flushing, but it is still the supply with the major concern because of the possible implications in relation to both domestic and irrigation situations. Factors other than rainfall are obviously affecting the high salinity level in Wellington dam and the amount of clearing is considered to be the main causative agent.

Figure 2 is a plot of time against the annual average chloride levels of the longer established hills reservoirs, as well as the average rainfall. There is some inverse correlation between chloride and rainfall, provided a time lag of up to several years is applied. A constant time lag factor is due to runoff occurring only after a significant contribution to the annual average has been made (January to May). A variable time lag depends on the proportion of that year's runoff being held in the dam, which in turn is dependent on the quantity and quality of overflow or flushing.

Fluoridated Water Supplies

A list of the average fluoride levels for 1979 for the fluoridated water supplies throughout the State is given in Table 19, together with the intended level. With the exception of the supplies from the Mundaring-Goldfields, Albany and Esperance which are slightly underdosed, all other supplies have been maintained at the intended level. Fluoridation of the Broome Water Supply, which naturally contained only 0·1–0·2 mg/L of fluoride commenced in the latter part of 1979. Because of Broome's higher mean maximum temperature the intended fluoride level is lower.

TABLE 19

FLUORIDATED TOWN SUPPLIES

Supply	No. of Samples	Fluoride, F mg/L mean	Fluoride, F mg/L intended
Perth/Metropolitan	674	0·82	0·8 ± 0·1
Mundaring/Goldfields	85	0·61	0·8 ± 0·1
Wellington/Comprehensive	87	0·83	0·8 ± 0·1
Albany	171	0·67	0·9 ± 0·1
Broome	11	0·65	0·7 ± 0·1
Collie	144	0·70	0·8 ± 0·1
Esperance	99	0·76	0·9 ± 0·1
Geraldton	87	0·78	0·8 ± 0·1
Manjimup	79	0·85	0·9 ± 0·1

Sodium Hazard

Sodium levels on all reticulated supplies are currently being regularly monitored. Several hundred samples from reticulated supplies and private household supplies at the six country centres of Katanning, Manjimup, Merredin, Narrogin, Northam and Pinjarra have been analysed for the University of W.A. Department of Medicine to establish the relationship, if any, between blood pressure levels and sodium levels in the drinking supply. The sodium levels in the reticulated supplies varied between 32 and 229 mg/L and those in the private households varied from 1 to 670 mg/L. Although a press release in relation to this study indicated that a range of sodium levels in drinking water from 34 mg/L at Manjimup to 220 mg/L at Katanning produced no significant differences in blood pressures of 13 year olds, a final published report by the Department of Medicine on the study has not been released.

Treatment of Supplies

Apart from regular monitoring of all country town water supplies a number of on site visits or joint projects were arranged to resolve a number of problems. These included:

1. Australind—The proposed raw water supply containing 30 mg/L of iron and 1·0 mg/L of manganese was not amenable to the normal aeration, alkali addition and coagulation/flocculation procedure for effective iron and manganese removal. An additional oxidant besides aeration was required. Chlorine was not as effective as potassium permanganate. The final recommendation was aeration, followed by hydrolime at about 80 mg/L to give a pH of about 7·5, followed about 5 minutes later with 2 mg/L of potassium permanganate. This gave a product water quality of 0·10 mg/L of iron and 0·02 mg/L of manganese.
2. Geraldton—A spate of complaints of earthy odours and tastes from the reticulated supply in Geraldton led to an examination of deposits in the pipelines and organic growths in the uncovered summit tank at Allanooka. "Synedra spp", a taste producing type of algae was identified in the pipeline deposits and another taste producing type "Peridinium spp" was the predominant species in the summit tank. Storage of the sample from the summit tank at ambient temperature in the laboratory produced strong earthy odours. Recommendations included covering the tank or dosing with algicides such as chlorine or copper sulphate.
3. Wagerup—Laboratory trials for colour removal from a raw surface water for a major industrial undertaking, showed that alum dosing at 15 mg/L or less, followed by sand filtration after several minutes detention was capable of reducing colour levels from 40 to less than 10 units. Higher colour levels than 40 could persist in the raw water supply for several months of the year and higher alum dosages would be expected to cope. Backwash frequency could be excessive for this short period but would be preferable to constructing a clarification unit.
4. Perth—The recently installed iron removal plant at the Queen Elizabeth II Centre—incorporated a rapid multi media filter after aeration instead of the medium rate sand filter recommended from laboratory trials. The plant performance suffered and a product water with less than 0·2 mg/L of iron could not be obtained with the holding time available between aeration and filtration. Although increased holding time improved the performance of the multi media filter, such a facility was not available. A caustic soda or hydrolime dose of 5 to 10 mg/L immediately after aeration was recommended as a means to give the desired performance with the available plant.
5. Canning dam—A uniform dark green to black deposit in the tunnel section of the main line from Canning dam was shown to be of organic origin due to manganese bacterial growths. Two separate conditions appeared to have triggered the growth. The first was the occurrence of higher levels of manganese in the dam water, increasing from a normal $< 0{\cdot}02$ to 0·10 mg/L during a period when the dam was less than half full; the second was due to inadequate chlorination during periods of discontinuity of flow through the tunnel. As the manganese level had subsequently reverted to its previous level of 0·02 mg/L, breakpoint chlorination was recommended for removal of the manganese bacterial growths.

ENVIRONMENTAL

Rights in Water and Irrigation Act

Activity in this area has increased during 1979, until there are now almost one hundred separate industries (primary and secondary), for which the effluent quality and its effect on surface streams or underground aquifers is being regularly monitored. These industries cover a wide scope of activity and undersirable components in each are widely variable.

At one particular site, where preliminary examination of the supposed uncontaminated aquifer was being undertaken prior to discharge into a lagoon of a comparitively innocuous effluent, it was revealed that the aquifer was already contaminated at high levels with an organic pollutant from another source. The B.O.D. at one selected depth interval was several thousand mg/L.

Laporte Effluent

The frequency of analysis of the liquids contained in the two main aquifers beneath the dune disposal area was reduced during 1979 from that carried out in 1978. Vibro core soil samples submitted in late 1978 did not give the quantitative support for iron immobilisation within the dune system as anticipated. The samples submitted were subsequently shown to be unsuitable for such a quantitative assessment. Attempts to confirm the 95 per cent immobilisation of iron, as predicted in our 1976 Report, have to date been unsuccessful with soil sampling.

Laboratory experimentation using Laporte effluent with surplus pure limestone showed that after a period of 3 months in an artificial atmosphere of carbon dioxide, there was little or no immobilisation of iron. The theoretical ratio of iron to calcium (based on carbonate solubility products) remaining in solution of approximately 1/100 did not eventuate. Actual ratios were approximately 10/1 and suggests that the ratio is dependent on other constants within the system. This aspect has led to some alteration of the suggested iron immobilisation mechanism in the final report on sand dune disposal. Bacterial oxidation and cation exchange are now suggested to be possible "immobilisers" of iron.

Discussions and written comments to the authors of the two final reports on sand dune disposal have been a time consuming activity.

Estuarine Monitoring

Of the three estuarine systems currently being monitored at quarterly intervals, the Swan and Canning river system and that at the Peel Inlet/Harvey Estuary have undergone some changes, both in relation to sites and interpretation of the data obtained.

1. Swan/Canning—The new monitoring programme mentioned in the 1978 Annual Report commenced as planned. The new sites included 37 major natural streams and artificial drains, and 24 river sites, 6 of which have been selected for depth studies.

The heavy metal input study is intended for completion at the end of 12 months in April 1980. From the results to date for the drains and tributaries, copper and zinc levels, although well below 96 hr LC_{50} values for the most sensitive aquatic creatures, were in many instances above the objective levels (usually based on a 0·01 application factor). With the exception of copper all other metals in the main waterbody were below objective levels. Combining contaminant level with flowrates suggested that the main metal contributors to the Swan river are the King William Street and Belmont main drains and to the Canning river, it is the Southern river.

The results to date also suggest that the main nutrient sources to the Swan river are from King William Street drain, Ellen brook and the Claisebrook drain: and to the Canning river, it is the Southern river.

2. Peel Inlet/Harvey Estuary—Two additional sites were included during 1978, one being to monitor the effects of a proposed intensive primary industry near the Serpentine river.

A report of Investigation, No. 21 covering water quality monitoring of the above estuarine system between 1972 and 1978 has been published. Salinity levels had remained fairly constant since a previous survey by C.S.I.R.O. about twenty years earlier despite the construction of dam sites on the Serpentine and Murray (via the Dandalup) river during the intervening period. Phosphorus levels had increased significantly during the same period.

Waste Disposal Sites

Regular monitoring of the Hertha Road and Jones Street sites for waste disposal and the Gnangara pine plantation for liquid waste disposal continues. There were interesting developments at the Brockway and proposed Burswood Island refuse disposal sites.

Brockway Tip: The most significant inorganic nitrogen contamination of an aquifer adjacent to a refuse disposal site is occurring here. Contouring of inorganic nitrogen levels suggest that the contamination could emanate mostly from evaporative lagoon seepage at the nearby sewage plant where the material being evaporated has a very high nitrogen level.

Burswood Island: Samples taken from the groundwater beneath the previously used tip site at Burswood Island showed values for ammonia nitrogen between 15 and 150 mg/L. These levels are very similar to previously recorded results from other tip sites. Based on ammonia levels in the "neat" leachate and the volumes formed from a pilot plant at Hertha Road, it was possible to calculate the additional effect of reusing the site, on the waters of the Swan river. It was calculated that it could increase the existing inorganic nitrogen level o the Swan river water by from 0·05 to 0·10 mg/L. This increase was considered to be adequate to move the water status from one of comparative safety to one of doubtful quality in relation to eutrophication. Such evidence as this was instrumental in delaying or preventing the use of Burswood Island for such rubbish disposal purposes.

Fertiliser Application to Del Park and Jarrahdale

A survey of streams in these areas immediately after rainfall following aerial spraying of ammonium phosphate fertilisers into newly forrested areas associated with bauxite mining activity, indicated that levels of inorganic nitrogen and phosphorus were similar to control areas. This indicates that initially at least, no increase in stream nutrients would result.

Catchment Activity and Nutrient Loading

Approximately 500 samples have been received as part of a nutrient investigation programme aimed at assessing typical nutrient loads from two catchments on the Coastal plain and from a representative range of forrested and agricultural catchments in the Darling Range. Eleven stations on the Murray River Basin have been sampled up to three times per week for ammonia, nitrate, kjeldahl nitrogen, and orthophosphate and total phosphorus.

MISCELLANEOUS

Seepage from Concrete Walls of Dams

Seepage water through the concrete of the Canning dam wall has been regularly analysed for the past several decades, without a great deal of interpretation other than noting the constancy of the analyses. Of recent years seepage water samples have also been received from concrete walls at Victoria reservoir and Harvey dam. Because chemical analysis had not been related to flow rate most of the previous interpretation was based on the analytical result (seepage water from comparatively unleached concrete has high levels of sodium and calcium hydroxide).

Current interpretation at Canning dam, based on flow rate, suggests that despite the high ratio of sodium to calcium a significant portion of the concrete has been leached. If all of this had been leached from a specific area (such as the rock face to concrete contact) then there might be cause for concern. Core samples of concrete between the wall tunnel and the rock base are intended for examination in 1980.

Organic growths in the seepage water at pH of 12 could not be identified. Despite some similar features to cellular algae they were presumed to be of bacterial origin, because of the lack of sunlight.

Open Elements in Jugs

Resultant water after boiling in a jug with an open element had levels of copper, nickel and zinc each of the order of 10 to 20 mg/L. Continuous drinking of such a water would constitute a health hazard, but the cause of the problem, namely loose connections or badly corroded wire elements, usually leads to rapid failure and replacement, with a high probability that the problem will not immediately recur. Such open elements are not recommended.

Toxic Inhibitors in Primary Heating Water

Analysis and inspection of the primary and secondary hot water in a multi-storey building showed that incorrect safety installation procedures had allowed water from the primary circuit, containing several hundred mg/L of hexavalent chromium to gain access to the secondary or domestic hot water at levels up to 4 mg/L of hexavalent chromium. Excessive additions of hexavalent chromium had been required to maintain the intended primary water concentration, just prior to the observance of a pale yellow colour in the domestic hot water.

Disruption of the Concrete Surface of Swimming Pools

Excessive use of sodium bisulphate for pH correction in a swimming pool water had caused the sulphate level to exceed 600 mg/L, and sulphate attack was considered responsible for the "lumpiness" observed in the pools concrete surface. The client was advised to resort to hydrochloric acid for pH correction, but it was nevertheless considered unusual for sodium bisulphate pH correction to raise the sulphate to such a level.

Hot Water Storage Vessel Corrosion

Advice is frequently requested for the best types of units available. Currently the two most popular materials used for constructing mains pressure hot water storage vessels are:

(i) Steel lined with temperature resistant glass and protected with a magnesium anode;

(ii) Stainless steel (Austenitic—316).

Both of these types of units are currently given a 5 year guarantee by some of their respective manufacturers against water of a specified quality. Waters in the metropolitan area and most reticulated country supplies comply with this quality.

The shortcomings of both these types of units were amplified in the 1977 annual report, but this has now been complicated by the fact that both units have had their guarantees against corrosion increased to 5 years. An additional shortcoming of the magnesium protected glass lined steel is maintenance of iron levels below 0·004 per cent in the magnesium anode. Levels in excess of this can cause rapid magnesium corrosion and hydrogen gas evolution with subsequent safety hazards.

There are still many unanswered questions in relation to the preferred material. Inspection of two stainless steel units which were removed from service in the metro area after periods of service close to that of the current guarantee exhibited no obvious signs of stress or any other attack.

Corroded Aluminium Fins on Chiller Unit at Wickham

After interpretation of the analyses of the fins the corrosion was considered to be due to salt from either evaporation of flush cleaning water, settling of evaporated salt from sea mist spray or from adjacent wind blown soil. Recommendations included air blowing for cleaning but if water had to be used at least the final rinse should be with distilled or rain water.

Porous Concrete Pipes for Drainage

These pipes, with lower ratios of cement than that normally used for concrete, had prematurely failed in drainage situations where free carbon dioxide levels were hgih. The client was advised to check all drainage water for carbon dioxide prior to using this material. Initially the pipe should not be used in situations where carbon dioxide exceeded 100 mg/L but this was only an interim measure to be modified after performance could be related to carbon dioxide levels.

Minimum Salts in Evaporative Cooling Water

The Metropolitan Water Board was advised not to impose a restriction to maintain total salts in evaporative cooling tower waters above 3 000 mg/L. The problems associated with such a restriction, in relation to both scaling and corrosion, did not seem to justify the approximate 0·1 per cent saving in the average total Perth consumption, particularly as leakage and lawn irrigation already accounted for about 50 per cent of consumption.

N. PLATELL,
Chief, Water Division.

95816—(14)

DIVISION VIII

Annual Report of the Chief Inspector of Explosives, for the Year 1979

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, 1979.

LEGISLATION

The main legislative action to affect this Branch throughout the year was a proclamation of the Explosives and Dangerous Goods Act Amendment Act, 1978, as published in the *Government Gazette,* dated August 31, 1979. The Amendment Act will now permit the declaration of any substance, considered by the Minister to be a danger to public safety, as "dangerous goods", and may allow the regulation of these dangerous goods with respect to classification, marking storage, carriage and sale, as is required.

Also, the Amendment Act formally changed the title of the Chief Inspector of Explosives to the Chief Inspector of Explosives and Dangerous Goods, thereby recognising the extensive role the Branch must take in the administration and control of dangerous goods generally.

A number of amendments were made to the Flammable Liquids Regulations, 1967, effective from their publication in the *Government Gazette* dated August 31, 1979, affecting a total of thirty-seven regulations, together with the necessary changes to alter the classification of the three subclasses of flammable liquids to 3.1, 3.2 and 3.3, throughout the regulations.

There was only one addition to the list of Authorised Explosives throughout the year, viz:

Class 1.4F

(0348) Bird Frite Cracker Cartridges (x)

and work is proceeding on the authorisation for use in Western Australia of several others. Approval was given for an amendment to the authorised definition of the explosive "Iregel".

STAFF

On November 1, Inspector of Explosives, Mr D Basanovic, having reached the mandatory age limit, retired from the Public Service after almost ten years with the Branch. Mr J. Hanley, formerly of the Transport Commission, was appointed one month later as a replacement Inspector.

It is with considerable sadness that I record the death of Mr F. F. Allsop, Chief Inspector of Explosives, 1948-1968, on May 25, 1979. His funeral was attended by members and ex-members of the Explosives Inspectorate.

At December 31, the staff of the Explosives and Dangerous Goods Branch totalled 22 and consisted of:

- Clerical—6.
- Inspectorate—8.
- Reserve Security—8.

MANUFACTURE OF EXPLOSIVES

Inspections of the main manufacturing plants were made at various intervals throughout the year and operators advised on safety precautions. Final approval of new bulk ammonium nitrate storage depots on the minesites at Pannawonica, Paraburdoo and Tom Price were granted after the Inspectorate had ensured that all safety requirements were being maintained. Trans-shipment facilities for bulk ammonium nitrate prills from rail to road vehicles were noted as being satisfactorily operational at Dalwallinu, Kalgoorlie and Narngulu.

Approval was given for the manufacture of slurry explosives at Collie where a mobile slurry mixing and loading unit was installed for down the hole delivery to the open-cut coal mines. The support facility for this unit was temporarily installed on a mine site pending negotiations between this Department and the Forests Department for the lease of suitable land for explosive manufacturing and storage purposes.

The overall manufacture of nitrate based explosives at licensed plants showed a substantial decrease throughout the year, when compared with figures for previous years. A breakdown of these explosives and a comparison with the previous year is as follows.

	1978 (tonnes)	1979 (tonnes)
ANFO	66 392	59 071
Al/ANFO	775	—
Water Gel	1 759	2 309
	68 926	61 380

Although industrial unrest within the various companies mining iron ore in the Pilbara region caused a reduced usage of explosives, the major reason for this year's lower total of manufactured nitrate explosives was an improvement of blasting techniques through more effective use of stemming for large diameter blastholes.

IMPORT AND USAGE OF EXPLOSIVES

The current year's importation and overall use of explosives showed an increase of almost 40% over the previous year. Albeit, the use of cartridged nitrate explosives showed a decrease of 36%, however, the use of nitroglycerine based explosives increased by 77%. It would appear that the less sensitive nitrate explosives are losing favour with the users of small diameter cartridged explosives in Western Australia.

The usage of explosives continued to be closely watched by the Inspectorate and records of sales were randomly checked to ensure that persons purchasing explosives were legally entitled to use them. Similarly, the use of fireworks was closely watched and excellent control was exercised by the issue of permits, totalling forty-three 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 8% over the previous year. Once again, significant increases occurred in the number of Licences to Manufacture a Blasting Agent and of Shotfirer's Permits. A major proportion of Shotfirers are also applying for a Licence to Manufacture a Blasting Agent.

A comparison of the number of licences and permits issued for explosives during the past two years is shown below.

Licences	1978	1979
Import	8	7
Explosives Manufacture	11	7
Blasting Agent Manufacture	354	402
Storage—Mode A	33	36
Storage—Mode B	12	11
Magazine Type One (1 000 kg)	96	116
Magazine Type Two (5 000 kg)	46	45
Magazine Type Three (greater than 5 000 kg)	72	88
Sell	39	35
Convey	39	50
Total Licences	710	797
Permits		
Shotfirer's	1 146	1 231
Fireworks Display	41	43
Entry Permit for Explosives	39	37
Total Licences and Permits	1 936	2 108

Of the 1 231 Shotfierer's Permits issued throughout the year, 209 were to newly qualified permit holders. Forty-four of these new permit holders were from a total number of fifty-one candidates who were examined without having attended a comprehensive training course.

A total of nine training courses for Shotfirers were conducted by the Explosives Inspectorate for 196 trainees. Seventy-one of these attended the three evening courses and the remainder were government or local authority employees who attended one of the six in-service courses. Forty-two candidates withdrew from the courses before the examination and a further twenty-two failed the examination.

Forty-eight candidates attended four additional courses run at Pinjarra and South Hedland by instructors who are not officers from this Branch. Thirty-three of these candidates were successful in obtaining Permits. The use of "outside" lecturers is a worthwhile support for the training system, enabling more courses to be conducted in rural areas without a consequent strain on the resources of the Branch.

As a result of several requests from farming areas, two one day training sessions were held for farmers in the south-west. These field day type courses were strictly limited in content to the safe and effective use of those explosives a farmer may need for land clearing. No examination was held and no attempt was made to give comprehensive instructions on all aspects of explosives use. Within these limitations, the courses seemed to be very well received and of great benefit to the twenty-eight who attended.

EXPLOSIVES RESERVES

Woodman Point Explosives Reserve

Major companie storing or manufacturing explosives at the Woodman Point Explosives Reserves were advised of the proposed relocation by July 1982 to a new reserve area to be constructed within State Forest No. 70 at Baldivis. Planning of the new Baldivis Reserve area within the constraints of a $50 000.00 allocation from Treasury was commenced in close liaison with architectural staff of the Public Works Department.

Two incidents of illegal entry to the Reserve area occurred during the year. The first was when several magazines were broken into and two cases of explosives were stolen. The second occurred much later in the year when an amenities room and office on the Reserve was forcibly entered. A small sum of money and an electric calculator were stolen. Entry to the Reserve was made by cutting a hole in the corrugated iron boundary fence. These are the first such incidents since security at the Reserve was improved in 1976 and this speaks highly of the diligence of the watching staff.

An explosion at the Reserve resulted in the death of two men and the destruction of a building used for the preparation of "quick match" fuse. The building was illegally overstocked with fireworks pieces at the time of the explosion, albeit in preparation for a public display as part of the State's sesquicentenary celebrations, and the operator who was a most experienced and capable pyrotechnician was killed instantly. The other man, a Departmental watchman, immediately following the explosion suffered a heart attack from which he subsequently died.

A small fire was detected in the lunch room adjacent to the explosives manufacturing plant at Woodman Point Explosives Reserve. The fire had occurred because an electrical appliance had not been switched off. Arrangements have now been made to ensure that the master switch supplying the area is switched off at the close of daily operations.

The jetty at the Reserve was used only twice during the year to dispatch small quantities of explosives onto a licensed vessel used by a shotfirer for marine blasting. However, as in previous years, the Reserve continued to provide excellent service in the control of storage and manufacturing facilities and also in the checking of several thousand vehicle movements from the Reserve to distribute explosives to other parts of the State.

Other Explosives Reserves

- Operations at the Kalgoorlie Explosives Reserve continued at a steady rate through the year. Funds have been allocated towards providing a supply of water for fire protection at the Reserve and arrangements have been made with the local Public Works Department office to provide the connection into the main. The major company using the facilties at the Explosives Reserve was given approval to locate an office within the Reserve as a means of improving supervision at the manufacturing plant.
- A security fence was erected around the boundary of the Reserve at Geraldton.
- Negotiations are continuing for the gazettal of explosives reserves at Karratha and Collie.
- A major bush fire at Port Hedland threatened to encroach upon the explosives storage area and all road and rail traffic was halted until it was certain there was no further danger. Fortunately the fire-breaks around each magazine were quite adequate and the fire did not spread to any of the buildings.

Relocation of Woodman Point Explosives Reserve

As indicated above, planning for the relocation of the Woodman Point Reserve facilities is well under way. It is appropriate at this time to consider the history of the old Reserve, and to this end a request was made of Mr G. A. Greaves, Chief Inspector of Explosives, 1968-1974, who wrote the following historical account.

Woodman Point Explosives Reserve—An Historical Survey

Ammunition Dump, Magazine Reserve or Explosives Depot? The A Class Reserve at Woodman Point is vested in the Hon. Minister for Mines for the storage of explosives and efforts are now being made to move the magazine so that this land together with the Quarantine Station can be developed for the purposes of public recreation.

When James Stirling brought the first settlers to the Swan River Colony 150 years ago, it was from Cockburn Sound and Garden Island that he founded the new Colony. From a temporary settlement on Garden Island, numerous crossings were made to the mainland and the nearest landing place became known as Woodman Point. Thomas Woodman was the purser on H M S *Success* and his name was given to that point of land which separates Jervoise Bay from Owen Anchorage and which later became the site of the Quarantine Station. This is under Commonwealth administration and on its northern boundary it adjoins a State Explosives Reserve administered through the Department of Mines. For obvious reasons both the Quarantine Station and the Explosives Reserve are closed to the general public and the law prohibits any unauthorised person from entering or intruding on the clean sandy beaches of Cockburn Sound at these places. With so much industrial development in the Kwinana area there is only limited access to the beaches of Cockburn Sound and State planning authorities have long sought for public use, both the Quarantine area and the Explosives Reserve so that the land and the beaches might become available for public recreation and possibly for the attraction of tourists.

The Commonwealth has already indicated its willingness to select a new site for a Quarantine Station and to arrange for transfer of the land to the State Government. Relatively few migrants now arrive at Fremantle by ship and the old facilities have become outmoded in present day conditions. It also appears feasible and even desirable that an alternative site be found for the explosives magazine which have occupied the present Reserve since 1903. Woodman Point may therefore be on the threshold of major developments and instead of being a restricted area as it has been since the turn of the century it may soon be freely available for the recreation of the people of Western Australia. Progress may be slow since action is required from both the Commonwealth and the State Government and neither is likely to move rapidly on projects which involve considerable expenditure. Both, however, have accepted the proposals and the old Explosives Reserve will not remain for long on the site which it has already occupied for one half of Western Australia's recorded history.

The name of Woodman Point was always familiar to me from early childhood in Perth. Both my parents migrated to Western Australia with other family members on the Orient Line Steamship "Otway" which departed from Tilbury in the Port of London on 18th February, 1910. They paid £12.0.0 each for the voyage and were accommodated in 12 berth cabins with "bedding, cabin and table requirements provided by the ship". There was great disappointment on arrival at Fremantle when a Port doctor diagnosed a case of smallpox on board and all passengers for Fremantle were moved directly to the Quarantine Station where they spent some weeks at Government expense complaining about their misfortune. They continued for many years to recall this first experience of Australia and subsequently thought it to have been the best holiday of a lifetime. Woodman Point was therefore a familiar name to me. In later years I was to become actively associated with the Woodman Point Explosives Reserve as an officer in the Mines Department, and worked for many years in close proximity to what had been the first home in this State for my migrant parents.

It is recorded that in the early years of the Colony a sailor was killed by an explosion of gunpowder at Woodman Point; this probably occurred in the course of landing supplies from ships anchored in Cockburn Sound. Dynamite was not available until after 1870 and only very small quantities of explosives were used in Western Australia prior to 1890. Mining then created a demand and legislation was required to control the importation, storage and conveyance of explosives. An Explosives Substances Act was passed in 1892 followed by a more comprehensive Explosive Act in 1895 which remained in force as the only controlling legislation until 1961. Mining explosives were stored at first in the hulk of an old ship outside Fremantle and this was still in use for bulk storage when the Government Analyst and Chemist, Mr E. A. Mann became the first Inspector of Explosives in 1895. Magazines were then constructed on an area of land adjacent to the smelting works at Robb Jetty, otherwise known as Owen Anchorage. On this first Reserve, there were seventeen magazines owned by the importers of explosives and three owned by the Government which also provided an office and some housing for its employees.

At the turn of the century, mining had become a major industry in the State and explosives were essential tools in the underground workings. All supplies were imported by ship from overseas factories and had to pass through the Robb Jetty magazines before being conveyed by rail to the mines. Authorities in Fremantle therefore considered the Robb Jetty magazines to be uncomfortably close and claimed that they were a potential danger to the community. There were frequent complaints and in 1902 efforts were made to select an alternative site. The Chief Inspector, Mr E. A. Mann, together with a Lands Department surveyor, Mr Brockman, inspected a possible site at Bayswater "1½ miles from the Station" and another place near the railway line at Chidlow's Well. Then on 29th November, 1902, a meeting was held to discuss the matter with the eight importers of explosives. Mr H. Gregory was present as Minister for Mines, together with Mr E. A. Mann, Sir George Shenton, and other representatives. They discussed the sites proposed at Bayswater, Chidlow's, Guildford and at Case Point, which was said to be 13 miles south of Fremantle. The Minister then drew attention to Woodman Point and all agreed that it would be suitable if the land could be obtained. It was at that time leased by the Fremantle Race Club, which had installed some improvements, but which held no title to the land. Sir George Shenton commented at the meeting that "there was a racecourse there but perfectly useless because the sand was so deep ..... there was a fence and a kind of stand but it was knee-deep in sand and used only about twice a year for the cabmen's races ..... an awful place."

Mr Mann inspected the Woodman Point racecourse on 6th December, 1902 and appears to have approved of it as a site for the magazines since he wrote to the trustee of the racing club, Mr J. J. Higham, MLA and requested a surrender of the lease. The reply came from three trustees, J. J. Higham, E. Soloman and R. H. Holmes and demanded £1,000 to cover the cost of the improvements. The Minister for Mines then offered only £600 or "he would proceed with an inland site" but after further discussion it appears that £1,000 was actually paid as recompense for the improvements and the surrender of a 99 year lease. No great haste was shown to move to the new area and in June 1903 the Surveyor-General, Mr Harry Johnston, instructed an officer called Mr Wigglesworth to "hurry the matter on". Within a month from that time the air was shattered by the explosion of a detonator magazine at Owen Anchorage There was general alarm in South Fremantle and Beaconsfield; the blast was heard and felt for several miles toward Perth, and the event, which undoutedly did much to hurry Mr Wigglesworth, will be remembered by some people to this day. The magazine exploded at 7.10 p.m. on 15th June, 1903 and it was soon known that it had caused the instantaneous death of a duty watchman named Thomas Whelan. Whelan, a man of 28, had resided with his wife and one child at the Magazine Reserve. In the course of his patrol duties he suspected there was something wrong at the detonator magazine and requested assistance from two labourers, Archibald Turner and Francis Duff, who were camped nearby while employed on the erection of Copley's meat freezing works. Together they returned to the magazine where Whelan bravely proceeded alone to investigate the trouble. Whelan had started to force an entry when he shouted to his friends to run fast and as they did so the magazine exploded and he was blown to pieces. In the next few weeks there were exhaustive enquiries and a lengthy inquest was held on the tragedy. The Coroner's finding was inconclusive and although circumstances indicated that some personal grievances were involved, no person was held to be actually responsible for Whelan's death. The explosion, however, did much to strengthen the feelings of Fremantle residents and it did indeed "hurry on" the plans for moving the magazines to Woodman Point.

In August of 1903, the new Reserve was surveyed by Surveyor Reilly of Rockingham and by September the fencing and staff quarters had been erected. Some of these original quarters are still in existence as is also an office and telephone room erected at an additional cost of £30. By January of 1904, the magazine buildings were moved from Owen Anchorage and re-erected within the new Reserve where they still stand, having served the needs of the mining industry for 75 year on the present site. Although an equal number of new magazines have been added in that time, many of the old-style structures continue to be used at the present time.

The Woodman Point Explosives Reserve has fulfilled its purpose to the mining industry of Western Australia and before long the area of nearly 121 hectares (300 acres) with its clean shelved beach front may be open to the public for general recreation. In this respect it will follow the fate of similar old established magazine reserves in other States which have already succumbed to the demands of urban development. Bantry Bay was closed a few years ago in Sydney; the Altona Reserve in Melbourne has gone, and explosives are no longer stored in the old historic magazines of Hobart.

It is now more than a century since Alfred Nobel succeeded in controlling the explosive power of nitroglycerine which had been known since it was first made by an Italian chemist called Sobrero in 1846. Nobel produced the first dynamites, blasting gelatine and detonators at a time when explosives were urgently needed throughout the world for railroad construction. These were the explosives used in Western Australia when the mining industry boomed in the nineties of last century and for many years all supplies were imported from the Nobel factories at Ardeer in Scotland. Ships off-loaded their hazardous cargo outside the harbour into lighters which conveyed the explosives to an isolated jetty at the Explosives Reserve. They were then conveyed to magazines in rail waggons drawn by horses. After the long voyage and a passage through the heat of the tropics there was often some deterioration of the explosive mixtures so it was necessary to hold them in magazines while sampling, testing and strict inspections were carried out. When approved for release they were loaded directly from magazines into rail vans and conveyed by rail to the mining centres throughout the State. It was not until the thirties of this century that the Deer Park factory in Melbourne was able to supply all of the explosives needed in this State. Certain special products and devices continue to be manufactured overseas even to this day.

In later years the horses at Woodman Point were replaced by tractors which hauled the rail vans within the area. Explosives from the Melbourne factory were carried in small motor vessels which could berth at the jetty and discharge cargoes of 200 to 300 tons directly to the rail vans which were then towed by tractor to the magazine. There was only one roadway providing vehicle access from the main gate to the jetty. This road was formerly Marmion Road which had been closed and included in the Reserve in 1903. The extension of the standard gauge railway to Robb Jetty spelled doom for the old system of conveying explosives. Shipments declined and supplies were railed directly to Kalgoorlie and Robb Jetty. At both places it was necessary to use road transport for further conveyance to magazines. More roadways were therefore required within the Reserve, which had operated for over 60 years with only narrow gauge rail access from jetty to the magazines. The jetty is actually outside the Reserv area and is under control of the Fremantle Port Authority. Since there are now no explosives arriving by ship there is no purpose in maintaining the jetty as the Authority had done for so long.

Explosives too have changed in recent years; until 1960 they were all sensitised with nitroglycerine in varying amounts and were basically only improved variations of the original types developed by Nobel in the last century. Then came the porous prill form of ammonium nitrate which could be mixed with a combustible liquid at the mine site and this new development in the sixties greatly reduced the consumption of conventional dynamite mixtures. Western Australia now has a chemical plant at Kwinana for production of blasting grade ammonium nitrate and vast quantities of it are used in the Pilbara and other mining fields, while the State's consumption of nitroglycerine explosives remains at about the same level as it was before. One can only conjecture what explosives would have been used to blast iron ore in Western Australia had the mine development occurred ten or fifteen years earlier. Probably there would have been, somewhere in this State, one of the largest dynamite factories in the world. With ammonium nitrate it is possible to formulate powerful but relatively insensitive explosives and prepare the mixtures on mobile equipment at the blasting site.

The Woodman Point Reserve has served the mining industry through many eventful year and the little ships from Melbourne delivered their dangerous cargo after many a stormy voyage across the Bight. One ship, the "Blythe Star" however, came to grief after arrival at Woodman Point and with its full cargo still on board. On 30th June 1965 it was blown ashore by a severe storm and badly damaged by the rough seas. In the calm weather which followed, all cargo had to be removed from the vessel before it could be refloated. The adjacent area was then littered with some 300 tons of dynamite explosives which remained exposed to the weather for about four weeks before a massive operation was organised for their safe removal and destruction. Another emergency occurred in the summer of 1972 when a fire swept through the southern portion of the Reserve; some old magazine buildings were located in the danger area and were saved only by the utmost efforts of the patrol staff on duty at the time. The loss by fire of any one of those magazines would have ended in an explosion much greater than that produced by the small detonator magazine which was destroyed in 1903.

After 75 years the old Explosives Reserve is near the end of its useful life and what was once the scene of the cabmen's races will in future years become a playground for boating, fishing and general beach recreation. What Sir George Shenton described as "an awful place" has now become a very choice piece of real estate. There are still some patches of the original native flora which have remained undisturbed for 75 years and one hopes that these, together with some of the original tuart trees, will escape destruction when the magazines fall and development is commenced.

INSPECTORAL ACTIVITIES

Explosives Security

Approximately $1\frac{3}{8}$ tonnes of explosives and 6 800 detonators were collected by the Inspectorate from twenty-six different locations throughout the State. As in previous years, the majority of the explosives were returned to Woodman Point Explosives Reserve where they were destroyed by the Magazine Staff, but in some cases the explosives were too sensitive to be transported and were destroyed at a nearby safe place. A small quantity of deteriorated or outdated marine distress signals were also disposed of at Woodman Point. One batch of flares was collected from a disused mine shaft with the assistance of the Mines Inspectorate and the local Police.

Fourteen instances of theft involving explosives were reported. Seven of the thefts were from mines or quarries in the Kalgoorlie or Geraldton areas. Action was taken by the Mines Inspectorate following the Kalgoorlie incidents and by this Branch at Geraldton where there were also two thefts from licensed Shotfirers. In all cases storage conditions have either been upgraded or the storage discontinued.

A part filled packet of detonators was stolen from a farmer's vehicle when it was left unattended in a country town. The farmer was subsequently reprimanded for his failure to provide secure storage conditions for his explosives.

Approximately twenty railway fog signals were stolen from a security shed in the Perth metropolitan area. Such thefts are usually the work of children and action has been commenced by this Branch to generally improve the operations involving these signals.

Enquiries are continuing into the circumstances surrounding the loss of approximately two kilograms of explosives from a sealed railway van. The explosives were loaded into the van in New South Wales and the van was then sealed. The loss was discovered when the receiving agents broke the seal to unload the consignment.

Explosives Storage and Use

Three hundred and fifty magazines and licensed stores were inspected and some were required to make modifications to improve the standard of security. With the printing of a new Australian Standard for magazine construction, the general policy is to upgrade magazines to this standard throughout the State.

Several incidents were investigated at civil construction sites where explosives had been used improperly and legal proceedings were instituted against three persons. All three subsequently pleaded guilty and were duly fined.

Analysis and Testing

Examination of explosive products and ancillary equipment was continued throughout the year. Chemical analysis of porous prill ammonium nitrate samples showed that the required basic standards for the product were being maintained by the local manufacturer. Field tests were also carried out to confirm that the sensitivity of ANFO prepared from ammonium nitrate prills made to a new formulation had not significantly varied. Following tests at Woodman Point Explosives Reserve it was found that the sensitivity of the product was only marginally less than the product marketed for many years.

Several explosive devices were examined by the Branch officers to assess their suitability for public use. Two of the devices were designed to be projected from a shotgun so they would function approximately 100 metres from the operator. "Bird Frite" cartridges, as the name suggests, are intended for bird control—particularly on farms or airports. The second device "Fireball cartridge" is an incendiary device for remote ignition of fires by forestry personnel. Both devices have been approved for use in Western Australia subject to similar restrictions to those which apply to blasting explosives.

A distress signal "Dial-a-Star" was also tested and approved for general sale to persons over the age of eighteen years on condition that they be used only for distress purposes.

A shipment of 160 Nichimen photo electric circuit testers was examined for maximum current output. All were found satisfactory and given approval for use in accordance with Section 7.35 (2) of the Mines Regulation Act, Regulations, 1976. A further circuit meter, the University Graham Meter W4-E11, was submitted for examination and was subsequently granted general approval for testing electrical firing circuits in Western Australia.

Multi-channel exploders which have been used on several occasions in recent years to initiate massive underground pillar blasts, have been modified by the manufacturer to overcome early problems. The new version has received tentative approval for the next twelve months so that performance in the field can be evaluated. Additionally, several private individuals requested approval for the use of a military exploder manufactured about 1941. This was an Australian Army Mark VII rackbar exploder which was approved following the fitting of a suitable safety key.

The routine testing of imported nitroglycerine explosives continued throughout the year, together with the random sampling and testing of all safety fuse passing through the Woodman Point Explosives Reserve. The Abel Heat Test was conducted on 442 samples of nitroglycerine explosives and 51 samples of safety fuse were tested for burning rates and cross ignition. All samples were found to be satisfactory.

Flammable Liquids and Gases Inspections

As in previous years, flammable liquids inspections dominated the activities of the Branch with some 6 000 inspections of premises and vehicles. Particular attention continued to be given to self service operations at the ninety-five such service stations now licensed in Western Australia. Licences were issued for 5 200 premises to store flammable liquids.

The storage of swimming pool chlorinating agents at service stations was again checked at the beginning of summer. Very few problems were found, these consisting of overstocking, usually of large containers and storing chemicals too close to fuels. No problem was experienced in getting proprietors to render their storages safe.

Routine inspections in several rural areas revealed the presence of numerous tanks fabricated from glass reinforced plastics (GRP) being used to store flammable liquids. None of the known manufacturers of these tanks was working to an approved standard and consequently each has been told that GRP tanks are not approved for the storage of flammable liquids in Western Australia. Several enquiriies have been made through the Australian Institute of Petroleum and the Plastics Institute of Australia to resolve this problem and set an acceptable standard for construction.

The supervision of comprehensive fire drills at several major fuel terminals continued through 1979 and no major faults were found with any of the systems inspected. Generally, there has been an excellent response to the Branch's requirements for fire fighting facilities in tank depots, resulting in an improved standard throughout Western Australia.

Regulations for LP Gas are as yet only in the draft form, nevertheless the storage of LP Gas is making increasing demands on the time of the already hard pressed inspectoral staff. Location plans were submitted for examination for more than forty new tank installations and on site inspections were made of most of these.

Many additional inspections were made of existing tank and cylinder storage facilities in connection with the proposed LP Gas regulations.

Miscellaneous Dangerous Goods

- Comprehensive advice was requested on the storage of dangerous goods by the licensees of premises already storing flammable liquids.
- Several inspections were made at a metropolitan hospital site to advise on the location of a new storage tank for liquefied oxygen.
- The Metropolitan Water Board was advised on building construction and location for the storage of chlorine in one tonne cylinders at a proposed local distribution centre.
- A major petroleum exploration company was advised on the safe storage and handling of a wide range of packaged and bulk dangerous goods associated with their drilling operations.
- Several enquiries were received concerning the storage and transportation of hydrogen peroxide. A company intending to transfer bulk hydrogen peroxide through Western Australia requested and was given advice on recommended safety precautions. Subsequently preliminary work was done towards preparing a specification for the conveyance of hydrogen peroxide by tanker vehicle.
- Westrail were advised on training policies for staff who may become involved in handling dangerous goods and of safety requirements for a proposed distribution of LP Gas from rail tankers at various country centres.
- 46 kg 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

The total number of inspections was marginally lower than then previous year, 6 494 as against 6 636, as indicated in the following summary of inspections:

	1978	1979
Explosives—		
magazines, etc.	214	351
vehicles	28	24
use	21	20
destruction	23	22
Licence to Manufacture a Blasting Agent	58	78
Flammable Liquids—		
licensed and exempt premises	5 580	5 462
advice	238	224
vehicles	474	313
Total	6 636	6 494

ACCIDENTS AND OUTRAGES

Explosives

Section 55 of the Explosives and Dangerous Goods Act requires that any accident involving explosives or dangerous goods shall be reported to the Chief Inspector. All such incidents, totalling eight throughout 1979, were investigated by the Branch Inspectorate.

- A man prospecting for gold lost a hand and sustained injuries to his face and eyes when a stick of gelignite exploded prematurely. It was not possible to determine the cause of the explosion.
- A boy was slightly injured when a detonator exploded after he connected it to a torch battery.
- A young man lost two fingers and part of a thumb when a fireworks piece functioned prematurely at an illegal fireworks display held as part of a rodeo. The person responsible for the display was subsequently prosecuted for breach of the Explosives Regulations.
- Assistance was given to the Police following the detonation of a bomb at a suburban shopping complex. As the incident was obviously a criminal act all investigatory work was conducted by the Police who subsequently arrested the perpetrator.
- Three young men were injured when approximately sixty plain detonators exploded. The sixty detonators were the remainder of a packet of 100 which were being used to cap pre-cut lengths of safety fuse intended for the following day's blasting. In the absence of any conclusive proof of the cause of the explosion, the shotfirers in charge of the operation were reprimanded for failing to ensure the operators were adequately supervised.
- An accident which occurred late in December 1978 was reported to the Branch and investigated during 1979. No one was injured but flyrock was thrown onto the roof of adjoining premises when an overcharged shot was fired. The shotfirer and his employer (the local municipal authority) were warned to take more care when firing future shots otherwise their licence would be revoked.
- An explosion which resulted in the death of two men occurred in a concrete building at the Woodman Point Explosives Reserve. The building which was located outside the security area of the Reserve, was used for the preparation of display fireworks. The cause of the explosion could not be determined.
- Three youths were arrested after they used explosives they had stolen to damage road signs and a minesite battery.

Flammable Liquids

It is not always possible for the Inspectorate to attend at the scene of all accidents involving flammable liquids. Fires at service stations during refuelling operations are often extinguished and cleaned up before any report is made. It is usual to rely on oil company or Police reports for information on these incidents. Fifteen accidents involving flammable liquids were reported during the year, six of which were investigated in detail by the Inspectorate. As in previous years, the vast majority of the accidents resulted from ignorance of the properties of flammable liquids rather than a wilful disregard of safety precautions.

- A boy died as a result of burns received when a quantity of thinners he was carrying caught fire. The boy had taken some thinners in an open plastic container to light an incinerator. No one saw the fire start but it is believed the thinners was ignited prematurely when the boy operated an electronic type cigarette lighter he had been loaned to light the incinerator.

- In two incidents similar to each other, youths were burned when flammable solvents used to wash engine parts ignited when they attempted to light cigarettes.
- A man was burned when a petrol drum exploded while he was welding it.
- A twin engined light aircraft was destroyed by fire when full drums of aviation fuel ignited soon after they were placed by the wing mounted fuel tanks. The drums were all open, ready for decanting into the fuel tanks and the fumes are believed to have been ignited when the pilot started his motor car intending to shift it to use the headlights to illuminate the filling operation.
- A man was burned when trying to light a kerosine fuelled pressure lamp. The investigating officers found the filler cap on the lamp had not been replaced before attempting to light the lamp. The can of fuel had also been left open on the table adjacent to where the lamp was at the time of the fire. The victim was reported to have been affected by alcohol at the time of the accident.
- Some months after installation, a buried fibreglass tank collapsed when full of fuel. Arrangements were made with the local fuel agent to pump the fuel out of the tank using approved equipment and the situation was rendered safe without the occurrence of a fire. The tank had not been constructed to an approved standard nor installed in an approved manner. As all parties concerned had incurred considerable inconvenience, the storage was in an isolated area and litigation was proposed between the involved parties, no legal action was taken by the Branch.
- A man was burned when petrol sprayed out of a twenty litre jerry can onto his clothes and was ignited from an adjacent spark ignition motor. The jerry can had been standing in the sun and was being moved to a cooler position when the vapour pressure forced the cap open and petrol sprayed out.
- A fire at a service station resulted in damage to the buildings on the premises. The fire started less than one hour after the building had closed down after the day's trading and is believed to have originated from some electrical equipment in the office. All flammable liquids on the site were stored in accordance with the regulations and did not become involved in the blaze.
- A fire was reported as a result of a static discharge during the refuelling of a late model Ford car which was fitted with a polythene petrol tank. As a result of this and several other similar fires throughout Australia, Ford are recalling several models of their vehicles for modification. It is believed the fires occurred when unearthed fuel delivery hoses were used.
- A man died following an explosion and fire in an elevated tank used to supply fuel to a hotel boiler. An extensive investigation and full report was made by the Branch Inspectorate, but as this fatality is currently the subject of a Coroner's inquiry, no further details can be provided at this time.
- A semi-trailer and its attached fuel tanks were badly damaged when the trailer parted from the prime mover and overturned on an isolated section of country road. No fire resulted and no persons were injured in the accident which resulted in the destruction of two of the vehicle's three 6.8 kilolitre tanks and the loss of twenty kilolitres of petrol and distillate.
- A fire occurred during the filling of a 4.5 kilolitre, two compartment tank, mounted on a truck. The cause of the fire was believed to be a static electricity discharge from a PVC fill pipe which was being used contrary to the requirements of the regulations. The fire was extinguished using the portable extinguishers located on the adjacent drum storage ramp.
- Two vehicles were destroyed in separate accidents during refuelling operations at service stations. A driveway attendant was injured at one site. In both cases, petrol vapours ignited and the source of ignition was almost certainly the pilot light of an LP Gas powered refrigerator which had been left on contrary to the manufacturers recommendations. Several other such incidents were also reported to inspectors during the year but none of these could be confirmed.

Other Dangerous Goods

Because of the absence of any other dangerous goods investigating authority, the Branch professional officers are requested to assist at incidents which may in fact be beyond the ambit of the Explosives and Dangerous Goods Act. Several such incidents occurred during 1979.

- Advice and assistance were given to the Emergency Services following a fire which occurred when hydrogen peroxide leaked from a pump onto dry grass. The fire spread to an area in which twenty, 50 litre drums of hydrogen peroxide were stored and several of these drums exploded.
- An explosion occurred in a ship under construction when a welding arc was struck at the open end of a pipe leading into a compartment intended to be used as a fuel tank. No fuel had been introduced into the tank or the pipe prior to the explosion and it is believed that flammable gas had accumulated in the tank. The origin of the gas could not be ascertained but is thought to be either LPG from a leaking cylinder supplying a cutting torch or hydrogen formed from a reaction between the zinc galvanising on the tank and the alkaline soap solution used as a leak detector.
- An accident involving swimming pool chemicals was investigated. Two youths sustained face and eye injuries when a mixture of fuel and chlorinating agent exploded as they ignited it. In previous years youths have been charged by the Police for breach of section 19 of the Explosives and Dangerous Goods Act for mixing these substances. In this instance, no charges were laid.
- Assistance was requested by and given to the Department of Labour and Industry Inspectorate to determine the cause of a flash ignition which severely burned a worker preparing phenolic formaldehyde casting resin. A revised mixing procedure was recommended which minimised the evolution of flammable vapours and removed sources of ignition.

COMMITTEES, PUBLICATIONS AND LECTURES

- The Inspectorate participated in the activities of several committees which required interstate travel:
  - SAA Committee ME/17—Road Tankers for Conveyance of Hazardous Chemicals.
  - AAPMA Working Group on explosives transport by sea.
  - ATAC Advisory Committee on the Transport of Dangerous Goods.
  - AIP Seminar on Road Tanker Emergency Services.
  - 15th Annual Conference of Chief Inspectors of Explosives.
- A paper entitled "Flammable Liquids Hazards", written by the Chief Inspector as an address to the Oil and Colour Chemists Association was published in the August 1979 edition of Chemistry in Australia.
- Training exercises and associated lectures were conducted by the Deputy Chief Inspector as part of the training of WA Police Bomb Squad Personnel.
- The Inspector and Research Officer and an Inspector of Explosives, Mr W. Gildare, conducted shotfiring training courses throughout the year.
- The Acting Senior Inspector of Explosives, Mr R. K. Douglas, addressed a conference for Territory Managers of a major oil company and discussed general aspects of the Flammable Liquids Regulations.

CONCLUSION

Once again the members of the Explosives and Dangerous Goods Branch were more than fully occupied in the pursuit of their duties in maintaining the provisions of the Explosives and Dangerous Goods Act and Regulations throughout the year.

The Branch has continued to maintain an excellent rapport with other Departments and Branches of the Department of Mines to whom my gratitude is hereby extended for the assistance given throughout the year.

H. DOUGLAS,
Chief Inspector of
Explosives and Dangerous Goods.

DIVISION IX

Report of Superintendent, Mine Workers' Relief Act, and Chairman, Miners' Phthisis Board 1979

Under Secretary for Mines

Annual Report 1979—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, 1979.

2. *General*

The State Public Health Department, under arrangements made with this Department, continued the periodical examination of mine workers throughout the year.

3. *Mine Workers' Relief Act*

3.1 TOTAL EXAMINATIONS

The examinations made under the Mine Workers' Relief Act during the year totalled 3 712 and compared with 5 788 for the previous year; a decrease of 2 076. The results of examinations are as follows:—

Normal	3 517
Silicosis early, previously normal	10
Silicosis early, previously silicosis early	171
Silicosis advanced, previously normal	....
Silicosis advanced, previously silicosis early	....
Silicosis advanced, previously silicosis advanced	6
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	3
Asbestosis advanced, previously normal	....
Asbestosis advanced, previously asbestosis early	1
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	3 712

The 1979 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.

3.2 ANALYSES OF EXAMINATIONS

In explanation of the examination figures, I desire to make the following comments:—

3.2.1 NORMAL, ETC.

These numbered 3 517 or 94.61% of the men examined and include men having first class lives or suffering from fibrosis only. The figures for the previous year being 6 719 or 97.05% of the men examined.

3.2.2 EARLY SILICOSIS

These numbered 181 of which 10 were new cases and 171 had previously been reported; the figures for 1978 being 174 and 17 respectively. Early silicotics represent 4.88% of the men examined, the percentage for the previous year was 2.75%.

3.2.3 ADVANCED SILICOSIS

There were 6 cases reported, all of which had been previously reported as Advanced Silicosis. Advanced silicotics represent 0.16% of the men examined, the percentage for the previous year being .07%.

3.2.4 EARLY ASBESTOSIS

There were 3 cases of Early Asbestosis reported.

3.2.5 ADVANCED ASBESTOSIS

There was 1 case that advanced from Early Asbestosis during the year.

3.2.6 SILICOSIS–ASBESTOSIS

Four (4) cases of Early Silicosis-Asbestosis were reported during the year. This category represents 0.11% of the men examined.

4. *Mines Regulation Act*

4.1 TOTAL EXAMINATIONS

Examinations under the Mines Regulation Act totalled 4 163. There was a decrease of 2 760 under this Act in 1979, as compared with 1978.

Of the total 4 163 examined, 3 655 were new applicants and 387 were re-examinees. In addition, Provisional Certificates were issued to 121 persons in isolated country areas.

4.2 ANALYSES OF EXAMINATIONS

Particulars of examinations are as follows:—

4.2.1 NEW APPLICANTS

Normal	3 655
Silicosis early	....
Silicosis early with tuberculosis	....
Tuberculosis	....
Other conditions	....
Total	3 655

4.2.2 RE-EXAMINEES

Normal	387
Silicosis early	....
Silicosis early with tuberculosis	....
Tuberculosis	....
Other conditions	....
Total	387

These men had previously been examined and some were in the industry prior to this examination.

4.3 HEALTH CERTIFICATES ISSUED TO NEW APPLICANTS AND RE-EXAMINEES

The following health certificates were issued under the Mines Regulation Act:—

Initial Certificates (Form 2)	4 163
Temporary Rejection Certificates (Form 3)	....
Rejection Certificates (Form 4)	....
Re-Admission Certificates (Form 5)	....
Special Certificates (Form 9)	....
Total	4 163

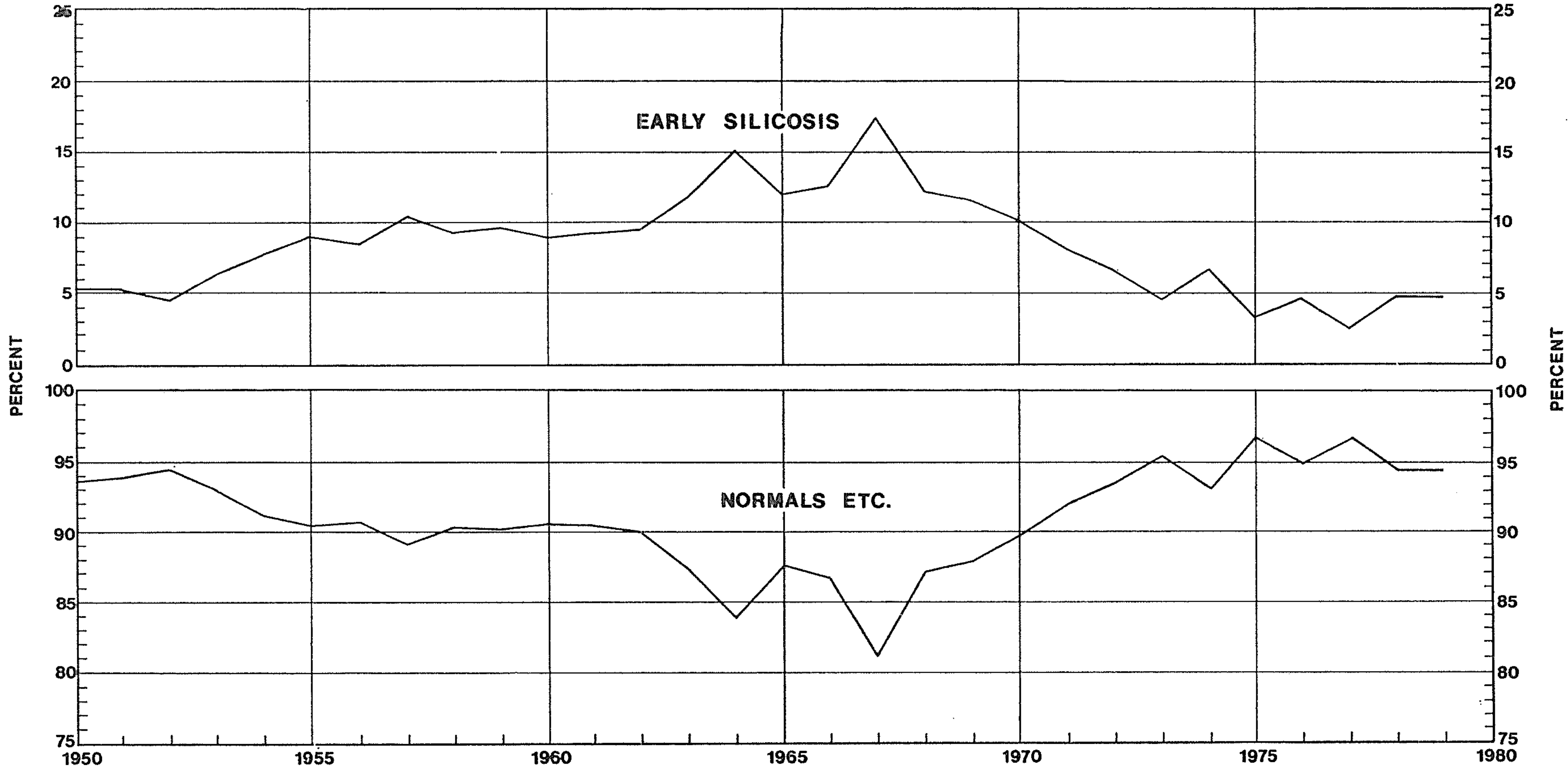
5. MINERS' PHTHISIS ACT

The amount of compensation paid during the year was $4 087·40 compared with $4 964·57 for the previous year.

The number of beneficiaries under the Act as on 31/12/1979 was 20, being 2 ex-miners and 18 widows.

R. S. THOMPSON
Superintendent Mine Workers' Relief Act
and
Chairman, Miners' Phthisis Board

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

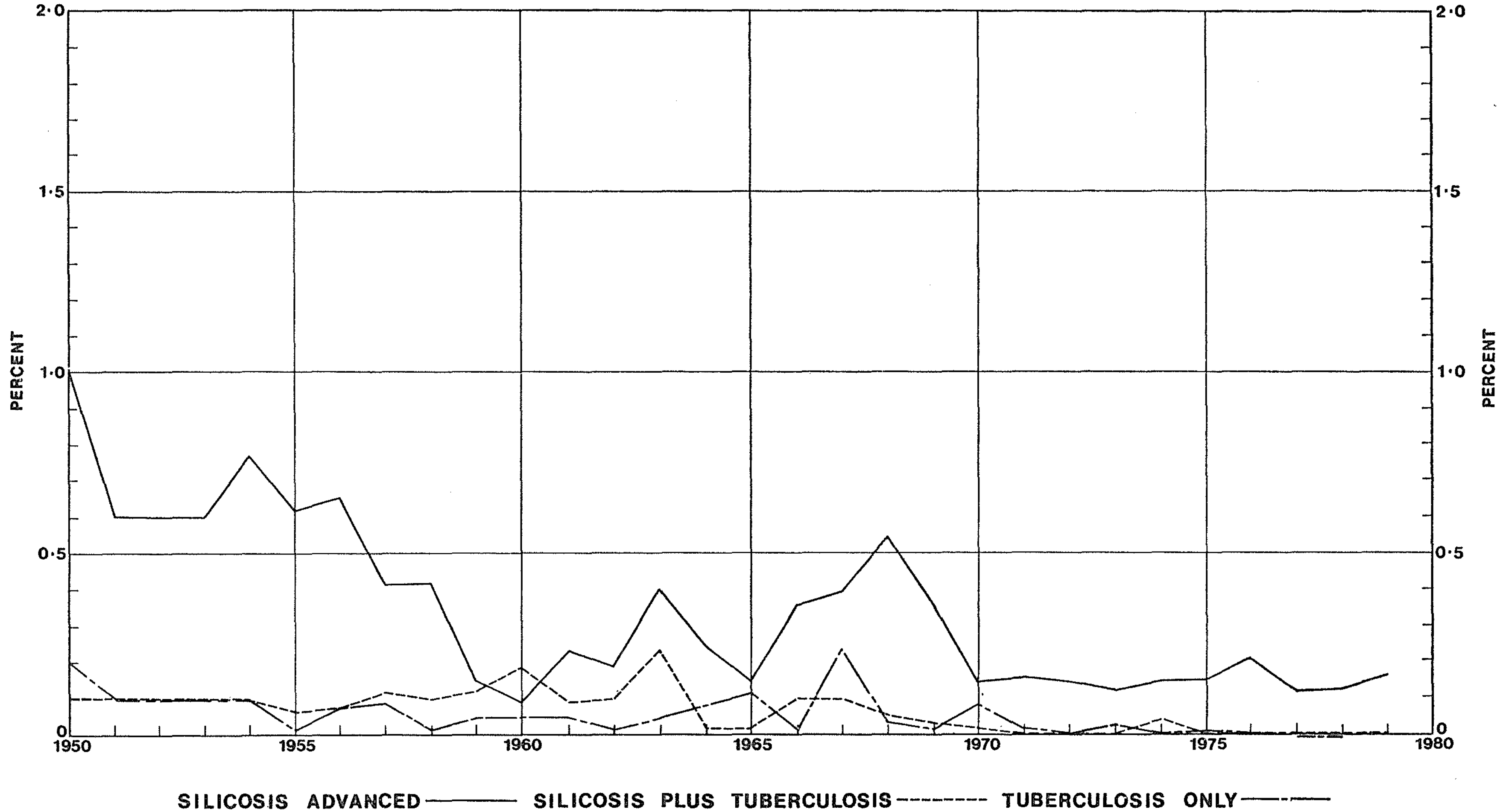


TABLE SHOWING RESULTS OF PERIODICAL EXAMINATION OF MINE WORKERS FROM INCEPTION OF EXAMINATIONS (1925)

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

MINING STATISTICS
to 31st December, 1979

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TABLE I

PRODUCTION OF GOLD AND SILVER AS REPORTED TO THE MINES DEPARTMENT DURING 1979

(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 1979					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
Kununarra	M.C. 80/4936	Costeo, P.	....	....	13·00	·028	....	....	....	13·00	·028	....

Pilbara Goldfield

MARBLE BAR DISTRICT

Mining Centre	Number of Lease	Registered Name of Company or Lease	Total for 1979					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
Bamboo Creek	G.M.L. 45/1203	Mt. Prophecy	....	....	306·00	·271	....	....	....	6 366·76	86·438	....
Elsie Creek	D.C. 45/1059	Edwards, M. R.	....	·122	....	....	....	....	·122	....	....	....
Marble Bar	G.M.L. 45/1450	Betty Boo	....	....	65·00	·072	....	·027	....	1 504·00	3·163	....
	1487	Charger	....	....	178·00	·511	....	·292	....	1 730·00	3·903	....
	1536	Charlie	....	....	8·00	·250	....	....	....	8·00	·250	....
	1529	Halleys Comet	....	....	....	15·381	1·654	....	....	6 462·06	319·480	34·958
	1209	Ironclad	....	....	100·00	·109	....	....	....	2 231·23	4·252	·006
	1551	Jo Jo Again	....	....	21·00	·024	....	....	....	21·00	·024	....
	1545	Ned Kelly	....	....	12·00	·351	....	....	....	12·00	·351	....
	1547	Shanon Mine	....	....	3·00	·205	....	....	....	3·00	·205	....
	1333	White Angel	....	....	113·00	·096	....	....	....	113·00	·096	....
		Sundry Claims	·154	....	80·00	·065	....	2·240	8·552	23 017·00	407·946	·341
Telfer	1421 etc.	Newmont Proprietary Limited	....	....	439 510·00	5 292·037	3·023	....	....	1 168 209·00	16 725·388	141·776
Western Shaw	1583	Dons Delight	....	....	3·00	·029	....	....	....	3·00	·029	....
		L.T.T. 45/28 (2663H) Lever, L.	....	....	....	·022	....	....	....	....	·022	....

NULLAGINE DISTRICT

Mining Centre	Number of Lease	Registered Name of Company or Lease	Alluvial	Dollied and Specimens	Ore treated	Gold therefrom	Silver	Alluvial	Dollied and Specimens	Ore treated	Gold therefrom	Silver
Nullagine	G.M.L. 46/401	Lucky Star	....	....	30·00	·424	....	....	....	36·00	·604	....

Peak Hill Goldfield

Mining Centre	Number of Lease	Registered Name of Company or Lease	Alluvial	Dollied and Specimens	Ore treated	Gold therefrom	Silver	Alluvial	Dollied and Specimens	Ore treated	Gold therefrom	Silver
Peak Hill	G.M.L. 52/653	McWilliams Submarine	....	....	313·00	1·237	....	....	....	313·00	1·237	....
	609	Morning Star	....	3·127	....	....	....	·250	3·939	....	·038	....
	610	North Star	....	4·367	....	....	....	·260	4·744	2 072·00	1·745	....

East Murchison Goldfield

BLACK RANGE DISTRICT

Mining Centre	Number of Lease	Registered Name of Company or Lease	Alluvial	Dollied and Specimens	Ore treated	Gold therefrom	Silver	Alluvial	Dollied and Specimens	Ore treated	Gold therefrom	Silver
Barrambie	G.M.L. 57/1117	Scheelite Leases	....	....	65·00	·622	....	....	....	2 042·77	37·928	·610
Sandstone		Sundry Claims	....	....	176·00	·131	....	1·464	44·200	16 873·17	216·516	....

Murchison Goldfield

CUE DISTRICT

Tuckabianna	G.M.L. 40/2459	Davo	....	....	255·00	·482	....	....	....	255·00	·482	....

MEEKATHARRA DISTRICT

Gabanintha		Sundry Claims	·174	....	....	....	....	·696	4·947	5 478·02	93·932	·114
Meekatharra	G.M.L. 51/2247	Fishers	....	....	590·00	·959	....	....	....	590·00	·959	....
	2244	Gloria Jean	....	....	447·00	2·986	....	....	....	687·00	4·163	....
	2015	Haveluck	....	....	340·00	·621	....	....	....	18 491·51	35·422	....
	2139	Ingliston Gold Mine	....	....	870·00	24·762	....	....	....	2 934·00	91·138	....
Yaloginda	2050	Bluebird	....	....	873·00	·601	....	....	....	1 236·49	·791	....
		State Battery—Meekatharra	....	....	....	*3·546	....	....	....	196·10	*917·207	*·782
		L.T.T. 51/51 (2792H) Schmidt, L. G.	....	·076	....	*·582	....	....	·076	....	*·582	....

MOUNT MAGNET DISTRICT

Lennonville	G.M.L. 58/1885	Contura, D.	....	....	84·00	·062	....	....	....	84·00	·062	....
Mt. Magnet	1701	Alison	....	....	290·00	1·006	....	....	....	1 560·00	5·366	....
	1708	Gay Parisian	....	....	787·00	1·215	....	....	....	907·00	1·411	....
	1475	Morning Star North	....	....	20·00	·122	....	....	....	31·94	·375	....
	1702	Veronica	....	....	1 200·00	2·529	....	....	....	1 200·00	2·529	....
	1749	Windbag East	....	....	300·00	·103	....	....	....	300·00	·103	....
		Sundry Claims	....	2·155	....	....	....	5·103	86·085	64 731·00	944·510	·918

Yalgoo Goldfield

Goodingnow	G.M.L. 59/1357	Ark Gold Mine	....	....	113·00	1·738	....	....	·388	4 230·41	118·680	....
	1242	Carnation	....	....	120·00	1·476	....	....	....	1 089·78	9·317	....
	1390	Galah	....	....	52·00	·072	....	....	....	52·00	·072	....
	1244	Sweet William Extended	....	....	8·00	·104	....	....	....	113·48	·699	....
Rothsay	1347	Bonnie Venture North	....	....	50·00	·049	....	....	....	50·00	·049	....
		L.T.T. 59/31 (2909H) M. & S. Mining	....	....	....	*4·611	....	....	....	....	*4·611	....

Mt. Margaret Goldfield

MOUNT MORGANS DISTRICT

Redcastle	G.M.L. 39/689	Lady Susan	....	....	250·00	·292	....	....	....	1 648·00	3·896	....

MOUNT MALCOLM DISTRICT

Diorite	G.M.L. 37/1974	Puzzle	....	....	280·00	2·073	....	....	....	362·88	2·791	....
Lake Darlot	2101	Goat Show	....	....	1·00	·078	....	....	....	1·00	·078	....
Leonora	2076	Bannockburn	....	....	230·00	·161	....	....	....	230·00	·161	....
	2065	British King	....	....	532·00	8·179	....	....	....	1 338·00	21·843	....
	2077	Garden	....	....	55·00	·276	....	....	....	55·00	·276	....
	2063	Gwalia West	....	....	203·00	·317	....	....	....	203·00	·317	....
	2084	Harbour Lights	....	....	614·00	·968	....	....	....	614·00	·968	....
	1888	Healeys Hope	....	....	314·00	2·965	....	....	....	637·83	6·613	....
	2083	Heartbreak	....	....	183·00	1·136	....	....	....	183·00	1·136	....
	2015	Island	....	....	435·00	1·476	....	....	....	1 982·72	15·599	....
	2041	Naroona	....	....	145·00	·508	....	....	....	195·00	·740	....
	(2058)	Picnic	....	....	272·00	·332	....	....	....	1 042·00	1·742	....
	1762	Sons of Gwalia	....	·042	891·00	1·152	....	....	·718	10 410·07	25·791	....
	1860	Tower Hill	....	....	171·00	·409	....	....	....	6 860·61	15·972	....
	1906	Two Glads	....	....	254·00	3·422	....	....	....	8 998·28	59·960	....
	2099	Vicki	....	....	155·00	·192	....	....	....	155·00	·192	....
	2036	Victor	....	....	8·00	·051	....	....	....	43·00	·242	....
		Sundry Claims	·408	·211	140·00	·317	·036	1·615	12·422	26 507·52	421·931	·869
		State Battery—Leonora	....	....	....	*10·400	*·832	....	....	92·46	*117·690	*4·249

Table I.—*Production of Gold and Silver from all sources, etc.*—continued.

Mt. Margaret Goldfield—cont.

MOUNT MARGARET DISTRICT

Mining Centre	Number of Lease	Registered Name of Company or Lease	Total for 1979: Alluvial kg	Total for 1979: Dollied and Specimens kg	Total for 1979: Ore treated Tonnes	Total for 1979: Gold therefrom kg	Total for 1979: 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
Burtville	G.M.L. 38/2810	Aye Bee West	....	....	66·00	·088	....	....	....	66·00	·088	....
	2567	Boomerang	....	....	36·00	·534	....	....	....	623·27	1·594	·114
Erlistoun	2854	Terringo	....	....	14·00	·045	....	....	....	14·00	·045	....
Laverton	2756	Banker	....	....	10·00	·015	....	....	....	10·00	·015	....
	2679	Bulldog	....	....	602·00	·597	....	....	....	1 593·67	1·491	....
	2851	Childe Harold	....	....	100·00	·126	....	....	....	100·00	·126	....
	2818	Craiggiemore South	....	....	1 461·00	2·757	....	....	....	1 911·00	3·221	....
	2799	Ida, H.	....	....	300·00	·238	....	....	....	300·00	·238	....
	2867	North	....	....	190·00	·395	....	....	....	190·00	·395	....
	2866	South	....	....	110·00	·271	....	....	....	110·00	·271	....
	2836	Tempest	....	....	613·00	1·649	....	....	....	613·00	1·649	....
		Sundry Claims	....	·325	297·00	·516	....	6·705	46·759	18 321·38	290·071	....
		L.T.T. 38/61 (2709H) Hopkins & Crocker	....	....	....	*·094	....	....	....	....	*·094	....

North Coolgardie Goldfield

MENZIES DISTRICT

Mining Centre	Number of Lease	Registered Name of Company or Lease	Total for 1979: Alluvial kg	Total for 1979: Dollied and Specimens kg	Total for 1979: Ore treated Tonnes	Total for 1979: Gold therefrom kg	Total for 1979: 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. 29/6026	Long Wait	....	....	31·00	·568	....	....	....	31·00	·568	....
Menzies	5815	Espacia	....	....	505·00	2·458	....	....	....	4 565·00	21·692	....
	5799	First Hit	....	....	184·00	·247	....	....	....	1 179·32	5·634	....
		Sundry Claims	....	....	3·00	·014	....	1·769	19·490	44 045·69	828·953	25·311
Mt. Ida	6000	Corida	....	....	159·00	1·426	....	....	....	159·00	1·426	....
		State Battery—Menzies	....	....	....	*1·076	·177	....	·237	20·32	*138·219	35·644
		L.T.T. 29/15 (2139H) Yundaga Mining Syndicate	....	7·532	....	*6·830	....	....	7·532	....	*6·830	....
		L.T.T. 29/56 (2824H) Woosnam, G.	....	....	....	*·203	....	....	....	....	*·203	....

ULARRING DISTRICT

Mining Centre	Number of Lease	Registered Name of Company or Lease	Total for 1979: Alluvial kg	Total for 1979: Dollied and Specimens kg	Total for 1979: Ore treated Tonnes	Total for 1979: Gold therefrom kg	Total for 1979: 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. 30/1338	Jacks Find Gold Mine	·798	....	....	....	....	·798	....	....	....	....
	1333	Makai	....	....	24·00	·080	....	....	....	55·00	·233	....
	1336	Whaihi	....	....	40·00	·064	....	....	....	40·00	·064	....
Morleys	1221	Emerald	....	....	152·00	·832	....	....	....	661·00	4·515	....
	(1089)	Paramount	....	....	612·00	2·583	....	....	·046	5 399·47	122·117	....
Mulline	1340	Little Willee	....	....	1 026·00	3·563	....	....	....	1 687·00	5·930	....

NIAGARA DISTRICT

Mining Centre	Number of Lease	Registered Name of Company or Lease	Total for 1979: Alluvial kg	Total for 1979: Dollied and Specimens kg	Total for 1979: Ore treated Tonnes	Total for 1979: Gold therefrom kg	Total for 1979: 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
Niagara	G.M.L. 40/1031	Gladstone	....	1·028	....	....	....	....	1·028	....	....	....
		L.T.T. 40/31 (2335H etc.) Bright, J.	....	....	....	*·643	....	....	....	....	*·643	....

YERILLA DISTRICT

Mining Centre	Number of Lease	Registered Name of Company or Lease	Total for 1979: Alluvial kg	Total for 1979: Dollied and Specimens kg	Total for 1979: Ore treated Tonnes	Total for 1979: Gold therefrom kg	Total for 1979: 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
Yarri		Black Rooster	....	....	428·00	·910	....	....	....	428·00	·910	....
	G.M.L. 31/1474	Cindy	....	....	303·00	·785	....	....	....	303·00	·785	....
	1320	Margaret	....	....	1 062·00	2·649	....	....	....	5 820·15	43·939	·010
	1465	Wallaby	....	·141	....	....	....	....	·141	....	....	....
		State Battery—Yarri	....	....	....	*·496	*·115	....	....	280·94	*294·008	*1·148

95816—(15)

Broad Arrow Goldfield

Bardoc	....	Sundry Claims	....	....	76·00	·203	....	1·709	37·887	20 140·17	268·333	....
Black Flag	G.M.L. 24/2462	King Edward	....	....	28·00	·041	....	....	....	28·00	·041	....
Broad Arrow	2455	Bellbird	....	....	70·00	·630	....	....	....	70·00	·630	....
	2346	Sunday Eve	....	1·408	32·00	·260	....	....	1·408	408·37	9·855	....
Ora Banda	2270 } 2290 }	Gimlet South Leases	....	....	2 479·00	3·760	....	....	....	79 271·56	223·475	5·120
	2484	Old Ora Banda	....	....	52·00	·463	....	....	....	52·00	·463	....
	2300	Sleeping Beauty	....	....	648·00	2·939	....	....	....	6 846·96	41·695	·035
	2463	Three Boys	....	....	76·00	·089	....	....	....	76·00	·089	....
		Sundry Claims	....	....	26·00	·296	....	....	15·034	18 967·93	165·873	....
Paddington	2339	Paddington Consols South	....	....	135·00	·219	....	....	....	450·57	5·418	....
		State Battery—Ora Banda	....	....	....	*1·105	*·609	....	....	130·10	892·098	3·976
		L.T.T. 24/50 (1872H) Harford, Savage & Stewart	....	*20·913	....	*2·087	*·337	....	*78·861	....	*2·087	*·337

North-East Coolgardie Goldfield

KANOWNA DISTRICT

Gindalbie	....	Sundry Claims	....	....	73·00	·144	....	....	22·286	6 197·41	103·961	....
Kanowna	G.M.L. 27/1586	Kanowna Red Hill	....	....	260·00	·405	....	....	....	10 511·68	47·636	·060
	1709	Unknown	....	....	103·00	·181	....	....	....	103·00	·181	....

KURNALPI DISTRICT

Karonie	G.M.L. 28/490	Brownie's Mine	....	....	29·00	·144	....	....	....	29·00	·144	....
	492	Rowe's Find	....	....	60·00	·286	....	....	....	125·00	·651	....
Kurnalpi	503	Tuppence	....	....	259·00	·820	....	....	....	259·00	·820	....
Mulgabbie	507	Casurina	....	....	104·00	·542	....	....	....	104·00	·542	....

East Coolgardie Goldfield.

EAST COOLGARDIE DISTRICT

Binduli	G.M.L. 26/7040	Rising Son	....	1·371	98·00	3·726	....	....	1·371	98·00	3·726	....
Boorara	6658	Waterfall	....	....	46·00	·261	....	....	·088	584·34	6·577	....
Boulder	(5815)	Great Boulder No. 1 South	....	·015	....	....	....	....	·065	6·00	·446	·045
	5345 etc.	Kalgoorlie Lake View Pty. Ltd.	....	....	....	81·027	15·342	....	....	1 108 024·40	6 516·076	2 373·135
		Prior to transfer to present holders	....	....	....	....	....	....	26·700	62 162 730·32	732 838·733	106 492·417
	6663	Kalgoorlie Lake View Pty. Ltd.	....	....	620·00	4·943	....	....	....	2 847·00	17·614	....
	6896	Kalgoorlie Lake View Pty. Ltd.	....	....	186·00	·342	....	....	....	1 067·00	2·707	....
	7124	Kalgoorlie Lake View Pty. Ltd.	....	·367	1 382·00	5·637	....	....	·367	2 474·00	8·187	....
	6897	Kalgoorlie Lake View Pty. Ltd.	....	....	687·00	5·445	....	....	....	7 334·00	30·054	....
	6905	Kalgoorlie Lake View Pty. Ltd.	....	....	169·00	·625	....	....	....	3 577·00	7·866	....
	6593	Kalgoorlie Lake View Pty. Ltd.	....	....	1 502·00	10·882	....	....	....	4 400·00	26·441	....
	6665	North Kalgurli Gold Mines	....	....	1 911·00	12·023	....	....	....	1 911·00	12·023	....
	6869	North Kalgurli Gold Mines	....	....	1 585·00	3·420	....	....	....	1 981·00	4·346	....
	7007	North Kalgurli Gold Mines	....	....	3 633·00	5·320	....	....	....	3 633·00	5·320	....
Hampton Plains	S.L. 31	Clements, S.	....	....	82·00	·054	....	....	....	82·00	·054	....
	P.P.L. 488, Loc. 48	Lethlean, L.	....	....	8·00	·104	....	....	....	34·59	1·521	....
	S.L. 1	Hampton Areas Aust. Pty. Ltd.	....	....	10 185·00	7·616	....	....	....	10 185·00	7·616	....
	P.P.L. 222, Loc. 48	Phillips, J. W.	....	....	152·00	·185	....	....	....	352·00	·470	....
	S.L. 24, Loc. 48	Trinidad, B.	....	....	98·00	·209	....	....	....	670·00	1·217	....
Kalgoorlie	G.M.L. 26/6848	Golden Dream	....	....	246·00	·283	....	....	....	1 378·76	2·705	....
	6563 etc.	Kalgoorlie Lake View Pty. Ltd. (Mt. Charlotte)	....	....	716 791·00	3 307·804	655·722	....	....	4 200 683·38	17 848·236	2 262·953
		Prior to transfer to present holders	....	....	....	....	....	....	·178	4 947 601·36	21 751·229	5·336
	6485	Maritana Hill	....	....	1 643·00	6·630	....	....	....	10 136·95	31·092	....
	6991	Taroya	....	....	1 413·00	2·201	....	....	....	2 903·00	3·820	....
		Sundry Claims	....	....	88·00	·315	....	7·229	35·073	65 337·85	731·383	·006
Wombola	6844	Daisy Gold Mine	....	....	336·00	5·587	....	....	1·756	30 645·00	874·051	27·519
	6912	Dry Mount North	....	....	15·00	·024	....	....	....	30·00	·078	....
	7148	Hammer and Tap	....	....	61·00	·224	....	....	....	61·00	·224	....
	6635	Hodad	....	....	52·00	·093	....	....	....	4 020·26	19·849	1·611

Table I.—*Production of Gold and Silver from all sources, etc.*—continued.

Mining Centre	Number of Lease	Registered Name of Company or Lease	Total for 1979 Alluvial kg	Total for 1979 Dollied and Specimens kg	Total for 1979 Ore treated Tonnes	Total for 1979 Gold therefrom kg	Total for 1979 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
		East Coolgardie Goldfield—cont.										
		EAST COOLGARDIE DISTRICT—cont.										
	6487	Leslie	....	....	17·00	·064	....	....	....	1 199·60	15·983	·036
	6614	Logans Gold Mine	....	....	359·00	·627	....	....	5·227	8 599·20	47·902	·039
	6877	Lurgan	....	·032	41·00	·202	....	....	·342	746·00	5·775	....
	7176	Marice	....	....	20·00	·085	....	....	....	20·00	·085	....
	7166	Marko	....	....	50·00	·253	....	....	....	50·00	·253	....
	6676	Rosemary	....	....	62·00	·090	....	....	....	1 045·00	11·847	....
		Sundry Claims	....	....	278·00	·912	....	....	22·459	30 637·31	491·273	·006
		State Battery—Kalgoorlie	....	....	....	*9·844	*1·245	....	....	396·97	*1 336·948	*27·018
		BULONG DISTRICT										
Bulong	G.M.L. 25/1393	Judith	....	·636	37·00	·221	....	....	·636	37·00	·221	....
		Coolgardie Goldfield.										
		COOLGARDIE DISTRICT										
Bonnievale	G.M.L. 15/6151	Melva Maie	....	....	96·00	1·603	....	....	·084	1 461·38	11·043	....
	6465	Mystery	....	....	66·00	·249	....	....	....	66·00	·249	....
	6380	Oshkosh	....	....	42·00	·031	....	....	....	61·00	·054	....
	5890	Rayjax	....	....	14·00	·373	....	....	1·416	2 066·09	61·340	·159
Bulla Bulling	6278	Pool Mans Wealth	....	....	20·00	·164	....	....	....	234·00	1·107	....
Burbanks	6381	Belgium Queen	....	....	296·00	·148	....	....	....	383·00	·770	....
	6225	Glenloth	....	....	134·00	·570	....	....	....	175·00	·807	....
	6267	Grosmont	....	....	605·00	1·399	....	....	....	3 970·00	8·286	....
	6217	Lady Robinson	....	....	302·00	·493	....	....	....	378·41	·619	....
		Sundry Claims	....	....	12·00	·038	....	1·712	15·475	20 130·74	299·249	·030
Coolgardie	6049	Central Tindals	....	....	603·00	·874	....	....	....	891·56	1·372	....
	6026	Cyanide North	....	....	250·00	·256	....	....	....	286·83	·456	....
	6362	De Profundis	....	1·336	....	....	....	....	1·336	....	....	....
	6282	Doreen Rose	....	....	383·00	·559	....	....	....	1 364·26	2·619	....
	6422	Dorothys	....	....	145·00	·174	....	....	....	145·00	·174	....
	6132	Ellen Jean	....	....	74·00	·093	....	....	....	74·00	·093	....
	6059	Empress	....	....	70·00	·250	....	....	....	526·00	1·181	....
	6337	Golden Hope	....	....	326·00	·177	....	....	....	431·00	·453	....
	6425	Heather Bell	....	....	528·00	·703	....	....	....	528·00	·703	....
	6350	Hennessy	....	....	38·00	·104	....	....	....	169·00	·205	....
	6193	Marlene	....	....	47·00	·041	....	....	....	217·70	·144	....
	6154	Monkani	....	....	310·00	·461	....	....	....	15 909·92	21·698	....
	6374	New Prosperity	....	....	97·00	·090	....	....	....	97·00	·090	....
	6394	Phyllis	....	....	305·00	·538	....	....	....	305·00	·538	....
	6195	Rose Hill	....	....	168·00	·155	....	....	....	1 286·04	·962	....
	6427	Sunshine	....	....	30·00	·096	....	....	....	30·00	·096	....
	6176	Three Mile	....	....	80·00	·016	....	·140	2·259	1 458·15	1·904	....
	6184	Three Mile Extended	....	·278	69·00	·121	....	....	·278	69·00	·121	....
	6144	Tindals South	....	....	614·00	·773	....	....	....	1 692·00	2·470	....
	6346	Worked Out	....	....	122·00	·840	....	....	....	211·00	1·367	....
		Sundry Claims	....	·002	401·00	2·257	....	7·375	95·780	94 904·12	948·087	·059
Gibraltar	6341	Reform	....	....	390·00	·554	....	....	....	763·00	1·200	....
Hampton Plains	P.P.L. 484, Loc. 59	McIlree, G.	....	....	648·00	2·108	....	....	....	2 461·63	6·011	....
	S.L. 36	Hampton Areas Pty. Ltd.	....	....	274·00	·529	....	....	....	274·00	·529	....
	S.L. 24	Trinidad, B.	....	....	180·00	·236	....	....	....	180·00	·236	....
	S.L. 33	Turich & Kennedy	....	....	14·00	·062	....	....	....	14·00	·062	....
	S.L. 29	Waters, L. K.	....	....	26·00	·081	....	....	....	67·00	·267	....
	S.L. 37	Waters, A.	....	....	46·00	·093	....	....	....	46·00	·093	....

Coolgardie Goldfield—cont.

COOLGARDIE DISTRICT—cont.

Higginsville	G.M.L. 15/5647	Fair Play Gold Mine	....	....	....	1 123·00	2·798	....	·131	1·950	42 367·04	120·055	·001
	6469	Gibsyn	....	....	....	40·00	·189	....	....	....	40·00	·189	....
	6061	Two Boys	....	....	....	70·00	·311	....	....	9·074	4 362·64	36·728	....
		Sundry Claims	....	....	....	46·00	·190	....	....	5·824	4 170·34	63·084	....
Kambalda	6161	Elizabeth Ellis	....	....	....	25·00	·080	....	....	....	25·00	·080	....
	6426	St. Barbara	....	....	....	119·00	·489	....	....	....	119·00	·489	....
	M.L. 152 etc.	Western Mining Corporation	....	....	....	....	228·583	379·090	....	22·003	32·00	573·989	1 650·217
		Sundry Claims	....	....	....	702·00	2·039	....	....	....	906·50	3·011	....
Logans Find		Sundry Claims	....	....	....	9·00	·031	....	·214	17·157	3 634·64	113·812	1·409
Wannaway	G.M.L.(15/6406)	Try Again	....	....	....	390·00	·621	....	....	....	390·00	·621	....
Widgiemooltha	6344	Host Group	....	....	·099	599·00	5·517	....	....	·995	2 429·89	23·401	....
		State Battery—Coolgardie	....	....	....	....	*·793	*·019	....	....	783·38	*1 353·216	*1·109
		L.T.T. 15/83 (2825H) Szalay, P.	....	....	....	....	*·018	....	....	....	....	*·018	....

KUNANALLING DISTRICT

Carbine	G.M.L. 16/1082	Hawkins Find	....	....	....	860·00	1·192	....	....	·270	4 849·00	9·734	·065
	1162	Second Go	....	....	....	64·00	·204	....	....	....	64·00	·204	....
		Sundry Claims	....	....	....	23·00	·104	....	4·238	3·487	7 190·04	76·190	....
Dunnsville	1128	Min Min Revisited	....	....	·157	....	....	....	....	1·425	4·00	·234	....
	1126	Wealth of Nations	....	....	....	312·00	1·042	....	....	....	312·00	1·042	....
Kintore	1059	New Haven	....	....	....	573·00	2·522	....	....	·367	4 989·57	20·319	·011
Kunanalling	1052	Catherwood	....	....	....	368·00	·357	....	....	....	2 650·30	3·077	....
	1111	Goldfarmer	....	....	....	665·00	·685	....	....	....	1 123·00	1·211	....
	1134	Last Chance	....	....	....	51·00	·263	....	....	·254	157·00	·679	....
	1203	Monica's Find	....	....	....	95·00	·187	....	....	....	95·00	·187	....
		Sundry Claims	....	....	....	174·00	1·533	....	6·735	30·928	18 552·66	324·148	·674

Yilgarn Goldfield.

Bullfinch	G.M.L. 77/4933	Golden Triangle	....	....	....	31·00	·179	....	....	....	31·00	·179	....
	4607	Open Cut	....	....	....	226·00	·269	....	....	·400	890·49	2·466	....
		Sundry Claims	....	....	·004	274·00	·417	....	·263	1·745	8 392·48	135·670	·755
Corinthian	4826	Corinthian South	....	....	....	302·00	1·142	....	....	....	605·00	2·145	....
Eenuin	4825	Lucky Jim	....	....	....	10·00	·104	....	....	....	10·00	·104	....
Greenmount	4829	Electrum	....	....	....	156·00	·790	....	....	....	343·00	1·450	....
	4888	Greenmount	....	....	....	103·00	·156	....	....	....	103·00	·156	....
	4962	McCosker	....	....	....	617·00	1·489	....	....	....	617·00	1·489	....
Hopes Hill	4801	Hopes Hill	....	....	....	52·00	·076	....	....	....	52·00	·076	....
Kennyville	4802	Dorothy Leslie	....	....	....	195·00	·273	....	....	....	577·00	·691	....
	4852	Victoria	....	....	·871	....	....	....	....	1·129	5 545·58	37·521	·066
Marvel Loch	4434	Cornwall	....	....	....	24·00	·084	....	....	....	18 255·23	77·366	16·426
	4814	Frances Firness	....	....	1·888	5 075·00	17·138	·065	....	21·998	36 265·43	411·488	12·899
	4630	New Marvel Loch	....	....	·073	....	....	....	....	·073	....	....	....
	4035	Undaunted	....	....	....	285·00	2·899	....	....	....	1 372·17	6·845	·012
		Sundry Claims	....	....	....	102·00	·426	....	·353	25·172	39 874·05	435·224	2·675
Mt. Jackson	(4725)	Numeralla	....	....	....	292·00	·596	....	....	....	481·00	1·639	....
Mt. Palmer	4250	Palmerston	....	....	....	585·00	3·676	....	·063	·052	2 254·26	11·076	·059
Parkers Range	4508	Buffalo	....	....	....	470·00	·851	....	....	·322	2 049·50	8·879	·175
	4717	Centipede	....	....	....	209·00	·502	....	....	....	209·00	·502	....
	4621	Dollar	....	....	....	35·00	·213	....	....	·114	328·18	2·205	....
	4864	Apache	....	....	....	55·00	·130	....	....	....	55·00	·130	....
	4626	The Australia	....	....	·121	....	....	....	....	·781	242·00	1·159	....
Southern Cross	4634	Frasers	....	....	....	288·00	·898	....	....	195·626	9 302·58	171·423	....
	4639	Golden Pig	....	....	·022	303·00	·207	....	....	·022	357·00	·222	....
	4752	Holy Well	....	....	....	193·00	·213	....	....	....	644·00	1·039	....
	4871	New Find	....	....	....	75·00	·092	....	....	....	75·00	·092	....
	4638	Three Boys South	....	....	....	28·00	·095	....	....	....	80·00	·190	....
Westonia	4744	Pius Sheila	....	....	32·628	....	....	....	....	32·628	....	....	....
		State Battery—Marvel Loch	....	....	....	....	*3·598	*3·144	....	....	149·36	*196·851	*96·319
		L.T.T. 77/152 (2620H) Gould, R. A.	....	....	·214	....	....	....	....	·214	....	....	....
		L.T.T. 77/162 (2770H) Buck, N. G.	....	....	·137	....	....	....	....	·137	....	....	....

Table I—*Production of Gold and Silver from all sources, etc.*—continued

Mining Centre	Number of Lease	Registered Name of Company or Lease	Total for 1979					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
Dundas Goldfield												
Dundas	G.M.L. 63/2054	Abbotshall	....	....	60·00	·102	....	....	....	437·97	1·102	·014
	2332	Dundas Queen	....	....	50·00	·033	....	....	....	50·00	·033	....
Norseman	1936 etc.	Central Norseman Gold Corpn. N.L.	....	....	136 687·00	2 260·762	757·332	....	....	6 178 089·18	87 145·279	55 552·198
	2364	Narweena	....	....	41·00	·091	....	....	....	41·00	·091	....
		Sundry Claims	....	....	118·00	·192	....	32·739	112·653	51 105·01	705·495	7·623
Peninsula	2319	Peninsula	....	·251	406·00	4·957	....	....	·251	754·00	5·459	....
		State Battery—Norseman	....	....	....	*6·009	*·090	....	....	434·76	*836·651	*37·093
Phillips River Goldfield												
Kundip	G.M.L. 74/277	Western Gem	....	....	179·00	3·950	....	....	....	992·33	13·453	·001

TABLE II

Production of Gold and Silver from all Sources, showing in kilograms the output as reported to the Mines Department during the year 1979.

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		....	....	....	....	....	....	....	....	13·00	·028	·028	....
Pilbara	Marble Bar	·154	·122	440 399·00	5 309·423	5 309·699	4·677	·154	·122	440 429·00	5 309·847	5 310·123	4·677
	Nullagine	....	....	30·00	·424	·424	....						
West Pilbara		....	....	....	....	....	....	....	....	....	....	....	....
Ashburton		....	....	....	....	....	....	....	....	....	....	....	....
Gascoyne		....	....	....	....	....	....	....	....	....	....	....	....
Peak Hill		....	....	....	....	....	....	....	7·494	313·00	1·237	8·731	....
East Murchison	Lawlers	....	....	....	....	....	....						
	Wiluna	....	....	....	....	....	....	....	....	241·00	·753	·753	....
	Black Range	....	....	241·00	·753	·753	....						
Murchison	Cue	....	....	255·00	·482	·482	....						
	Meekatharra	·174	·076	3 120·00	34·057	34·307	....	·174	2·231	6 056·00	39·576	41·981	....
	Day Dawn	....	....	....	....	....	....						
	Mt. Magnet	....	2·155	2 681·00	5·037	7·192	....						
Yalgoo		....	....	....	....	....	....	....	....	343·00	8·050	8·050	....
Mt. Margaret	Mt. Morgans	....	....	250·00	·292	·292	....					·050	....
	Mt. Malcolm	·408	·253	4 883·00	34·412	35·073	·868	·408	·578	8 932·00	42·029	43·015	·868
	Mt. Margaret	....	·325	3 799·00	7·325	7·650	....						
North Coolgardie	Menzies	....	7·532	882·00	12·822	20·354	·177						
	Ularring	·798	....	1 854·00	7·122	7·920	....	·798	8·701	4 529·00	25·427	34·926	·292
	Niagara	....	1·028	....	·643	1·671	....						
	Yerilla	....	·141	1 793·00	4·840	4·981	·115						
Broad Arrow		....	....	....	....	....	....	....	22·321	3 622·00	12·092	34·413	·946
North East Coolgardie	Kanowna	....	....	436·00	·730	·730	....	....	....	888·00	2·522	2·522	....
	Kurnalpi	....	....	452·00	1·792	1·792	....						
East Coolgardie	East Coolgardie	....	1·785	743 816·00	3 477·057	3 478·842	672·309	....	2·421	743 853·00	3 477·278	3 479·699	672·309
	Bulong	....	·636	37·00	·221	·857	....						
Coolgardie	Coolgardie	....	1·715	10 948·00	258·968	260·683	379·109	....	1·872	14 133·00	267·057	268·929	379·109
	Kunanalling	....	·157	3 185·00	8·089	8·246	....						
Yilgarn		....	....	....	....	....	....	....	35·958	9 985·00	36·513	72·471	3·209
Dundas		....	....	....	....	....	....	....	·251	137 362·00	2 272·146	2 272·397	757·422
Phillips River		....	....	....	....	....	....	....	....	179·00	3·950	3·950	....
South West Mineral Field		....	....	....	....	....	....	....	....	....	....	....	....
Northampton Mineral Field		....	....	....	....	....	....	....	....	....	....	....	....
State Generally		....	....	....	....	....	....	....	....	....	....	....	....
Outside Proclaimed Goldfield		....	....	....	....	....	....	....	....	....	....	....	....
Total		....	....	....	....	....	....	1·534	81·949	1 370 878·00	11 498·505	11 581·988	1 818·832

TABLE III

Return showing total production reported to the Mines Department to 31st December, 1979.

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	....	....	....	....	....	....	....	282·614	94·412	23 312·89	537·869	914·895	4·005
Pilbara	Marble Bar	488·119	143·241	1 538 845·97	27 447·020	28 078·380	1 199·924	815·190	233·939	1 739 019·92	32 387·087	33 436·216	1 233·544
	Nullagine	327·071	90·698	200 173·95	4 940·067	5 357·836	33·620						
West Pilbara	....	....	....	....	....	....	....	201·871	11·655	25 300·54	759·720	973·246	59·432
Ashburton	....	....	....	....	....	....	....	288·283	15·006	6 916·33	90·617	393·906	1 305·455
Gascoyne	....	....	....	....	....	....	....	21·725	6·956	4 271·21	201·731	230·412	3·973
Peak Hill	....	....	....	....	....	....	....	105·882	180·700	799 282·12	10 045·920	10 332·502	118·009
East Murchison	Lawlers	221·544	73·823	2 055 242·12	25 750·138	26 045·505	848·153	280·939	691·665	12 833 916·81	113 737·401	114 710·005	1 876·336
	Wiluna	7·355	39·007	9 016 082·65	58 236·403	58 282·765	321·060						
	Black Range	52·040	578·835	1 762 592·04	29 750·860	30 381·735	707·123						
Murchison	Cue	160·036	285·097	6 926 629·34	43 662·433	44 107·566	8 548·605	802 527	1 864·742	15 802 034·67	188 986·455	191 653·724	16 343·740
	Meekatharra	457·601	584·121	2 395 899·85	40 959.261	42 000·983	164·191						
	Day Dawn	102·381	353·886	2 070 709·73	42 792·490	43 248·757	5 270·404						
	Mt. Magnet	82·509	641·638	4 408 795·75	61 572·271	62 296·418	2 360·540						
Yalgoo	....	....	....	....	....	....	....	56·477	102·155	456 061·04	8 295·054	8 453·686	47·372
Mt. Margaret	Mt. Morgans	111·191	292·443	1 241 107·67	22 339·838	22 743·472	181·374	367·171	1 104·971	11 745 804·70	154 807·195	156 279·337	8 178·653
	Mt. Malcolm	126·960	521·249	7 928 226·88	95 936·572	96 584·781	5 938·518						
	Mt. Margaret	129·020	291·279	2 576 470·15	36 530·785	36 951·084	2 058·761						
North Coolgardie	Menzies	52·773	226·771	1 994 043·83	44 684·482	44 964·026	1 222·148	151·921	630·780	3 819 336·17	80 681·501	81 464·202	2 260·169
	Ularring	4·831	227·341	553 343·43	13 955·461	14 187·633	693·202						
	Niagara	53·451	57·745	961 070·06	16 446·787	16 557·983	177·793						
	Yerilla	40·866	118·923	310 878·85	5 594·771	5 754·560	167·026						
Broad Arrow	....	....	....	....	....	....	....	684·367	966·387	1 489 121·55	23 655·544	25 306·298	186·742
North East Coolgardie	Kanowna	3 314·052	424·792	1 058 842·73	19 656·643	23 395·487	94·903	3 713·342	683·713	1 075 076·10	20 259·075	24 656·130	95·298
	Kurnalpi	399·290	258·921	16 233·37	602·432	1 260·643	·395						
East Coolgardie	East Coolgardie	1 049·527	1 305·392	108 303 814·18	1 240 222·141	1 242 577·060	209 755·866	1 901·934	1 805·860	108 499 555·69	1 244 392·406	1 248 100·200	209 758·983
	Bulong	852·407	500·468	195 741·51	4 170·265	5 523·140	3·117						
Coolgardie	Coolgardie	546·114	724·800	3 138 133·37	48 981·305	50 252·219	3 344·901	593·450	917·412	3 529 145·35	56 937·362	58 448·224	3 369·022
	Kunanalling	47·336	192·612	391 011·98	7 956·057	8 196·005	24·121						
Yilgarn	....	....	....	....	....	....	....	69·348	440·525	8 484 174·37	76 699·762	77 209·635	6 751·552
Dundas	....	....	....	....	....	....	....	70·176	520·134	8 260 092·26	117 434·076	118 024·386	68 555·508
Phillips River	....	....	....	....	....	....	....	18·883	25·608	133 775·68	3 922·263	3 966·754	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	....	....	....	....	....	....	....	37·351	38·447	27·43	321·902	397·700	1 015·922
Outside Proclaimed Goldfield	....	....	....	....	....	....	....	....	....	....	....	....	39·177
Total	....	....	....	....	....	....	....	10 473·229	10 337·348	178 731 294·23	2 134 231·510	2 155 042·087	325 048·528

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
	361 479·224	1 840 932·130	2 202 411·354	1 441 576 390

	1978	1979
	$A	$A
Estimated Mint value of above production	1 157 736 289	1 172 052 737
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	169 536 371	264 344 449
Estimated Total	$A1 332 451 864	$A1 441 576 390
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 361 975 371	$A1 471 099 897

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 1979

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 (W.A.) Ltd	1 447 101	....	154 839 807
M.L. 70/1SA	.... South West	.... Alcoa of Australia (W.A.) Ltd	2 498 344	....	267 322 808
			3 945 445	....	(*l*) 422 162 615
		BARYTES			
M.L. 45/1522	.... Pilbara	.... Dresser Minerals International Inc.	34 658	....	(*b*) 482 235
		BUILDING STONE			
		Quartz			
M.C. 70/1921	.... South West	.... Cutts, J. E.	644	....	644
M.C. 70/2110	.... South West	.... Snowstone Pty. Ltd.	1 030	....	46 350
			1 674	....	(*a*) (*c*) 46 994
		Quartzite			
M.C.'s 70/1158–9	.... South West	.... House R. P.	1 135	....	(*a*) (*c*) 13 775
		Spongolite			
M.C. 70/726	.... South West	.... Universal Milling Co. Pty. Ltd.	152	....	(*a*) (*c*) 2 268
		CLAYS			
		Cement Clay			
M.C. 70/788	.... South West	.... Bell Bros. Pty. Ltd.	21 348	....	(*a*) (*c*) 53 369

TABLE V.—*Quantity and Value of Minerals, other than Gold, Reported during the Year 1979—continued*

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonne	Metallic Content	Value $A
		Fire Clay			
M.C. 70/435	.... South West	.... Midland Brick Co. Pty. Ltd.	1 213	....	182
M.C. 70/436–7	.... South West	.... Midland Brick Co. Pty. Ltd.	257 459	....	37 091
M.C. 70/304 etc.	.... South West	.... Clackline Refractories Ltd.	6 176	....	12 266
M.C.'s 70/522–3	.... South West	.... Bridge, J. S.	122 120	....	122 120
			386 968	....	(*a*) (*c*) 171 659
		White Clay—Ball Clay			
M.C. 70/109	.... South West	.... Bristile Ltd.	619	....	(*a*) (*c*) 7 428
		Kaolin			
M.C. 70/247, 605	.... South West	.... Universal Milling Pty. Ltd.	827	....	(*a*) (*c*) 4 960
		Attapulgite (Fullers Earth)			
M.C. 70/16369	.... South West	.... Malina Holdings Ltd.	10 067	....	(*a*) (*c*) 181 206
		COAL			
C.M.L. 12/448 etc.	Collie	.... Griffin Coal Mining Co. Ltd.	1 269 521	....	21 519 686
C.M.L. 12/437 etc.	Collie	.... Western Collieries Ltd.	1 465 709	....	22 888 194
			2 735 230	....	(*e*) 44 407 880
		COBALT (Metallic by-product of Nickel Mining)			
				Cobalt Tonne	
M.L. 15/152 etc.	.... Coolgardie	.... Western Mining Corporation	....	182·092	1 553 804
M.L. 38/255 SA	.... Mt. Margaret	.... Agnew Mining Co. Pty. Ltd.	....	33·770	1 106 824
			....	215·862	2 660 628
		COPPER (Metallic by-product of Nickel Mining)			
				Copper Tonne	
M.L. 15/152 etc.	.... Coolgardie	.... Western Mining Corporation	....	1 452·468	1 875 015
M.L. 38/255 SA	.... Mt. Margaret	.... Agnew Mining Co. Ltd.	....	288·340	381·461
			....	1 740·808	2 256 476
		EMERALDS			
				Carats	
M.L. 20/116 .... M.C. 20/2131	.... Murchison	.... Bellairs, R. D.	....	1 205	7 230
		FELSPAR			
M.C. 70/2110	.... South West	.... Snowstone Pty. Ltd.	1 545	....	77 300
M.C. 59/5800, 5987	Yalgoo	.... Chandilla Exploration and Investments Pty. Ltd.	379	....	5 699
			1 924	....	(*a*) 82 999
		GLASS SAND			
M.C. 70/1191	.... South West	.... Silicon Quarries Pty. Ltd.	159 979	....	393 548
M.C. 70/417–8 etc.	South West	.... Australian Glass Manufacturers	23 884	....	31 740
M.C. 70/1076	.... South West	.... Ready Mix Group (W.A.)	94 228	....	N.A.
			278 091	....	(*c*) 425 288
		DOLOMITE			
M.C. 77/60	.... Yilgarn	.... Read, J. E., P. S. & B. J.	585	....	(*a*) 3 510
		GYPSUM			
M.C. 77/50 etc.	.... Yilgarn	.... H. B. Brady Pty. Ltd.	23 929	....	58 881
M.C. 77/9 etc.	.... Yilgarn	.... W.A. Plaster Mills	27 695	....	95 346
M.C. 70/15466 etc.	South West	.... Swan Portland Cement Ltd.	13 986	....	213 606
M.C. 70/611, 616 etc.	South West	.... Gypsum Industries of Aust. Pty. Ltd.	10 772	....	19 214
M.C. 70/1115–6	.... South West	.... McAndrew, R. W.	868	....	1 736
M.C. 9/43, 49, 50	.... Gascoyne	.... Agnew Clough Ltd.	165 960	....	578 000
			243 210	....	(*a*) 966 783
			Plaster of Paris reported as manufactuerd during the year—35 436 tonnes from 52 270 tonnes by Two (2) Companies.		
		GARNET SANDS			
M.C. 70/11563	.... South West	.... Target Minerals N.L.	42	....	(*b*) 3 480

TABLE V.—*Quantity and Value of Minerals, other than Gold, Reported during the Year* 1979—*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	85 051	54 181	(*c*)(*d*) 4 767 928
		Ore Railed to Kwinana		Av. Assay Fe%	
M.L. 77/2 SA	Yilgarn	Dampier Mining Co. Ltd.	*1 338 356	63·00	(*n*) 9 864 759
		Ore Shipped Interstate			
M.L. 4/10 etc.	West Kimberley	Dampier Mining Co. Ltd.	222 319	68·01	(*b*) 1 529 871
M.L. 52/244 SA	Peak Hill	Mt. Newman Mining Co. Ltd.	6 979 411	64·00	(*b*) 68 754 298
		Ore Exported Overseas			
M.L. 4/10 etc.	West Kimberley	Dampier Mining Co. Ltd.	839 731	68·60	(*b*) 10 531 875
M.L. 4/50 etc.	West Kimberley	Dampier Mining Co. Ltd.	2 366 304	66·82	(*b*) 30 999 173
M.L. 52/244 SA	Peak Hill	Mt. Newman Mining Co. Ltd.	23 600 402	63·00	(*b*) 284 189 916
M.L. 47/4 SA	West Pilbara	Hamersley Iron Pty. Ltd.	27 391 309	63·61	(*b*) 335 105 770
T.R. 2401H	West Pilbara	Cliffs W.A. Mining Co. Pty. Ltd.	9 514 800	59·09	(*b*) 88 468 937
M.L. 45/235 SA	Pilbara	Goldsworthy Mining Ltd.	6 689 032	63·08	(*b*)86 630 595
			78 941 664	....	916 075 194
		* Includes 273 597 tonnes shipped interstate			
		PELLETS (Exported Overseas)			
M.L. 47/4SA	West Pilbara	Hamersley Iron Pty. Ltd.	1 768 407	63·36	(*b*) 34 664 677
T.R. 2401H	West Pilbara	Cliffs W.A. Mining Co. Pty. Ltd.	4 461 911	62·60	(*b*) 88 854 302
			6 230 318	....	123 518 979
		* LIMESTONE (For Building, Burning and Agricultural Purposes)			
M.C. 70/1662	South West	Bell Bros. Pty. Ltd.	25 065	....	22 056
M.C. 70/684, 728	South West	Bell Bros. Pty. Ltd.	1 000	....	880
M.C. 70/1290	South West	Bellombra V.	6 181	....	17 637
M.C. 70/1755	South West	Cockburn Cement Ltd.	12 000	....	12 000
M.C. 70/713	South West	General Bulldozing Co. Pty. Ltd.	2 973	....	2 973
M.C. 70/1093	South West	Piper Walker Pty. Ltd.	163	....	163
M.C. 70/709	South West	Snader, R.	21 747	....	10 722
M.C. 70/2734–5	South West	Swan Portland Cement Ltd.	37 859	....	126 976
M.C. 70/1660	South West	Swan Portland Cement Ltd.	306 199	....	1 038 244
M.C. 70/989	South West	W.A. Limestone Co. Pty. Ltd.	46 200	....	115 500
M.C. 70/17025	South West	Wolfe, S. H.	330	....	1 400
M.L. 47/267, 277	West Pilbara	Hamersley Iron Pty. Ltd.	35 798	....	27 597
M.L. 47/513	West Pilbara	Specified Services Pty. Ltd.	3 081	....	3 081
	South West	†Unspecified Producers	181 000	....	181 000
			679 596	....	(*c*) 1 560 229

* 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.	1 379	47·5	24 149
M.L. 52/65	Peak Hill	Dampier Mining Co. Pty. Ltd.	16	47·0	278
			1 395	....	(*b*) 24 427
		MICA			
M.C. 45/7145, 8416	Pilbara	Pilbara Mica Corporation Ltd.	310	....	(*b*) 65 773
		MINERAL BEACH SANDS			
		Ilmenite (g)		Av. Assay TiO_2 %	
M.C. 70/619 etc.	South West	Westralian Sands Ltd.	157 575	55·16	
M.C. 70/746 etc.	South West	Cable Sands Pty. Ltd.	119 630	55·72	
Sussex Loc. 7	South West	Cable Sands Pty. Ltd.	5 100	64·60	
M.C. 70/389	South West	Western Mineral Sands Pty. Ltd.	220 776	54·00	
M.C. 70/516	South West	Western Titanium Ltd.	302 494	54·60	
M.C. 70/7002	South West	Western Titanium Ltd.	23 616	59·40	
M.C. 70/7556	South West	Jennings Mining Ltd.	52 022	59·03	
M.C. 70/7062	South West	Allied Eneabba Pty. Ltd.	201 631	60·71	
			1 082 844		(*b*)27 699 090
		Upgraded Ilmenite (*g*)			
M.C. 70/516	South West	Western Titanium Ltd.	60 442	92·50	

TABLE V.—*Quantity and Value of Minerals, other than Gold, Reported during the Year* 1979—*continued*

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonne	Metallic Content	Value $A
		Rutile (*g*) (*h*)		Ti02 Tonnes	
M.C. 70/7556	South West	Jennings Mining Pty. Ltd.	17 362	16 587	4 834 145
M.C. 70/7062	South West	Allied Eneabba Pty. Ltd.	53 263	51 129	10 482 232
M.C. 70/7002	South West	Western Titanium Ltd.	23 198	22 258	4 507 555
M.C. 70/15565–9	South West	W.M.C. Mineral Sands Ltd.	528	507	63 360
			94 351	90 481	(*b*) 19 887 292
		Leucoxene (*g*) (*h*)		Ti02 Tonnes	
M.C. 70/619 etc.	South West	Westralian Sands Ltd.	14 685	13 219	1 978 721
M.C. 70/516	South West	Western Titanium Ltd.	9 005	7 997	1 133 326
M.C. 70/746	South West	Cable Sands Pty. Ltd.	5 256	4 617	773 054
Sussex Loc. 7	South West	Cable Sands Pty. Ltd.	250	217	34 750
			29 196	26 050	(*b*) 3 919 851
		Monazite (*g*) (*h*)		Th02 Units	
M.C. 70/516	South West	Western Titanium Ltd.	1 591	9 613	323 664
M.C. 70/619 etc.	South West	Westralian Sands Ltd.	2 307	14 838	472 855
M.C. 70/746 etc.	South West	Cable Sands Pty. Ltd.	735	4 722	192 765
Sussex Loc. 7	South West	Cable Sands Pty. Ltd.	33	201	8 613
M.C. 70/7062	South West	Allied Eneabba Pty. Ltd.	12 290	78 087	2 954 810
M.C. 70/7556	South West	Jennings Mining Ltd.	396	2 574	80 564
			17 352	110 035	(*b*) 4 033 271
		Zircon (*g*) (*h*)		Zr02 Tonnes	
M.C. 70/619 etc.	South West	Westralian Sands Ltd.	50 928	33 144	2 967 983
M.C. 70/746 etc.	South West	Cable Sands Pty. Ltd.	18 742	12 242	918 484
Sussex Loc. 7	South West	Cable Sands Pty. Ltd.	510	334	12 752
M.C. 70/516	South West	Western Titanium Ltd.	14 943	9 856	757 064
M.C. 70/7062	South West	Allied Eneabba Pty. Ltd.	157 766	104 422	8 808 865
M.C. 70/7556	South West	Jennings Mining Ltd.	17 290	11 373	841 929
M.C. 70/7002	South West	Western Titanium Ltd.	73 268	48 700	3 544 163
M.C. 70/5565–9	South West	W.M.C. Mineral Sands Ltd.	3 750	2 475	69 312
			337 197	222 546	(*b*) 17 920 552
		Xenotime (*g*) (*h*)		Y203 kg	
M.C. 70/516	South West	Western Titanium Ltd.	44	13 200	(*b*) 53 990
		NICKEL CONCENTRATES		Av. Assay. Ni%	
M.L. 15/152 etc.	Coolgardie	Western Mining Corporation	337 962	12·64	189 713 958
M.L. 38/255 SA	Mt. Margaret	Agnew Mining Co. Pty. Ltd.	58 693	10·79	18 233 728
M.L. 15/336	Coolgardie	Selcast Exploration Ltd.	12 482	16·50	9 440 647
M.L. 38/32, 35	Mt. Margaret	Windarra Nickel Mines Pty. Ltd.	3 964	9·50	893 634
			413 101	....	(*o*) 218 281 967
		NICKEL ORE		Av. Assay Ni%	
M.C. 15/1288 M.L. 15/248	Coolgardie	Metals Exploration N.L.	66 018	3·67	(*c*) 9 022 227
		PALLADIUM (*h*) (Metallic by-product of Nickel Mining)		kg	
M.L. 15/152 etc.	Coolgardie	Western Mining Corporation	....	213·888	625 772
		PLATINUM (*h*) (Metallic by-product of Nickel Mining)			
M.L. 15/152 etc.	Coolgardie	Western Mining Corporation	....	85·880	862 865
		OCHRE			
M.C. 20/26, 29	Murchison	Universal Milling Co. Pty. Ltd.	222	....	(*a*) 3 772
		PETROLEUM Crude Oil	kilolitres		
1H	Ashburton	West Australian Petroleum Pty. Ltd.	1 405 765	....	(*m*) 140 166 826
Lic. 1	South West	West Australian Petroleum Pty. Ltd.	14 965	....	(*q*) 820 535
			1 420 730	....	140 987 361
		Natural Gas	$m^3 10^3$		
Lic. 1	South West	West Australian Petroleum Pty. Ltd.	836 175	....	(*p*) 19 953 906
		Condensate	Tonne		
Lic. 1	South West	West Australian Petroleum Pty. Ltd.	2 368	....	N.A.

TABLE V.—*Quantity and Value of Minerals, other than Gold, Reported during the Year* 1979—*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.	3 934 794	....	(*b*) 28 444 382
		SEMI PRECIOUS STONES			
		Amethyst	kg		
M.C. 9/444, 256	Gascoyne	Soklich, F.	1 243	....	6 165
		Chrysoprase			
M.C. 69/965	Outside proclaimed	Irrunijtju Community Inc.	1 000	....	2 000
		Moss Opal			
M.C. 63/60	Dundas	Soklich, F.	2 442	....	1 155
		Chalcedony			
M.C. 9/498, 884	Gascoyne	Soklich, F.	90	....	100
M.C. 9/1921	Gascoyne	Butler, R. G. & A. W.	198	....	180
			....	....	9 600
		TALC			
M.L.70/433	South West	Three Springs Talc Pty. Ltd.	70 059	....	N.A.
M.L. 52/190	Peak Hill	Westside Mines N.L.	40 300	....	N.A.
			110 359		
		SILVER	kg		
		By-Product of Gold Mining	1 815·580	....	355 027
		By-Product of Nickel Mining	41·070	....	19 941
			1 856·650	....	374 968
		TANTO-COLUMBITE ORES AND CONCENTRATES (*g*) (*h*)			
				TA205 Units	
M.L. 1/657 etc.	Greenbushes	Greenbushes Tin N.L.	107·50	4 675	4 864 634
M.C. 59/5799 etc.	Yalgoo	Chandilla Exploration and Investments Pty. Ltd.	·14	6	5 352
M.C. 45/920, D.C. 45/755	Pilbara	Pilgan Mining Pty. Ltd.	41·55	138	1 054 901
M.C. 45/107 etc., D.C. 45/553	Pilbara	Goldrim Mining Australia Ltd.	11·75	603	1 091 906
M.C. 45/668 etc.	Pilbara	Endeavour Resources Ltd.	11·06	216	437 276
			172·00	5 638	(*b*) 7 454 069
		TIN CONCENTRATES		Sn Tonnes	
M.L. 1/657 etc.	Greenbushes	Greenbushes Tin N.L.	533·66	386·13	5 906 941
M.C. 45/668 etc.	Pilbara	Endeavour Resources Ltd.	121·64	85·56	1 199 664
M.C. 45/107 etc. D.C. 45/553	Pilbara	Goldrim Mining Australia Ltd.	11·21	8·30	114 160
M.C. 45/672, 700	Pilbara	Hart, D. N. & L. E.	1·74	1·19	14 124
M.C. 45/920 D.C. 45/755	Pilbara	Pilgan Mining Pty. Ltd.	26·65	7·99	307 342
			694·90	489·17	(*b*) 7 542 231

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, 1978, 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)	"	21 853 426	1 986 947 355
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	"	63 693	2 040 815
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	"	44 525	843 093
Quartzite	"	14 146	91 280
Sandstone	"	681	4 020
Sandstone (Donnybrook)	"	84	3 486
Slate	"	239	2 115
Spongolite	"	4 345	49 215
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	"	700 702	1 415 725
Fireclay	"	2 925 086	2 250 936
Fullers Earth	"	10 534	185 027
White Clay—Ball Clay	"	33 305	241 677
Kaolin	"	10 532	52 709
Coal	"	57 845 860	291 610 982
Cobalt (Metallic By-Product Nickel Mining)	"	2 025	8 945 005
Copper (Metallic By-Product Nickel Mining)	"	13 283	12 612 835
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	35 165	31 579
Emeralds	grams	1 407	11 149
Emery	tonne	21	750
Felspar	"	78 961	727 360
Fergusonite	kg	300	783
Gadolinite	tonne	1	224
Garnet Sands	"	685	49 254
Glass Sand	"	1 948 131	1 668 793
Glauconite (*h*)	"	6 571	300 769
Gold (Mint and Export)	kg	2 202 411	1 441 576 390
Graphite	tonne	156	2 608
Gypsum	"	2 624 514	7 076 627
Iron Ore—			
Pig Iron Recovered	tonne	1 234 936	72 758 408
Ore Exported	"	726 141 839	6 140 691 001
Pellets Exported	"	50 804 178	747 431 822
Locally Used Ore	"	27 857 686	205 091 481
For Flux	"	58 996	74 096
Jarosite	"	10	75
Kyanite	"	4 283	43 562
Lead Ores and Concentrates	"	489 720	10 636 394
Limestone	"	14 545 677	17 480 658
Lithium Ores—			
Petalite	"	8 042	124 123
Spodumene	"	108	3 627
Magnesite	"	60 376	1 075 116
Manganese—			
Metallurgical Grade	"	1 931 666	41 477 775

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	,,	2 926	82 778
Mineral Beach Sands—			
Ilmenite Concentrates	,,	12 023 121	180 114 322
Monazite Concentrates	,,	67 756	11 138 075
Rutile	,,	445 402	85 458 529
Leucoxene	,,	151 784	15 175 822
Zircon	,,	1 413 485	79 129 538
Xenotime	,,	307	311 739
Crude Concentrates	,,	158	1 553
Molybdenite	,,	79	1 730
Nickel Concentrates	,,	3 713 433	1 535 103 188
Nickel Ore	,,	696 133	52 144 652
Ochre—			
Red	,,	13 877	273 448
Yellow	,,	455	5 956
Peat	,,	4 052	62 633
Petroleum (Crude Oil)	kl	25 661 248	610 375 157
(Natural Gas)	$m^3 10^3$	6 464 954	78 675 611
(Condensate)	tonne	27 695	N.A.
Palladium (By-Product Nickel Mining)	kg	1 294	2 592 033
Platinum (By-Product Nickel Mining)	kg	562	2 964 503
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	32 806 209	167 363 643
Semi Precious Stones—			
Amethyst	kg	28 721	30 248
Beryl (Coloured)	,,	91	100
Chalcedony	,,	89 123	39 501
Chrysoprase	,,	123 552	125 642
Dravite	,,	8 640	15 594
Green Beryl	,,	50	629
Magnesite	,,	5 073	2 780
Moss Opal	,,	117 001	50 034
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	,,	807	3 228
Tiger Eye Opal	,,	20 447	14 412
Topaz (Blue)	,,	3	4
Tourmaline	,,	1 035	2 124
Sillimanite	tonne	2	26
Silver (*c*)	kg	431 315	9 947 153
Soapstone	tonne	574	3 856
Talc	,,	755 915	(g) 4 719 452
Tanto/Columbite Ores and Concentrates	,,	2 848	19 721 640
Tin	tonne	36 006	53 897 023
Tungsten Ore and Concentrates—			
Scheelite	,,	172	144 532
Wolfram	,,	310	125 810
Vermiculite	,,	4 481	47 331
Zinc (Metallic By-Product) (*d*)	,,	2 934	(j)
Zinc Ore (Fertiliser)	,,	20	200
Total Value to 31st December, 1979	....		$A13 979 381 904

(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 Statistical 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 1978 and 1979.†

Company	1978			1979		
	Above	Under	Total	Above	Under	Total
*Gold—						
Central Norseman Gold Corporation N.L.	146	66	212	133	68	201
Kalgoorlie Lake View Pty. Ltd. (Mt. Charlotte)	31	144	175	28	138	166
Mulga Mines Ltd.	66	24	90	....	....	....
Newmont Pty. Ltd. (Telfer Project)	93	....	93	95	....	95
All Other Operators	255	135	390	345	189	534
State Average	591	369	960	601	395	996
Alumina (from Bauxite)—						
Alcoa of Australia (W.A.) Ltd.	2 804	....	2 804	2 947	....	2 947
Coal—						
Griffin Coal Mining Co. Ltd.	269	....	269	276	....	276
Western Collieries Ltd.	282	319	601	300	320	620
Iron Ore—						
Cliffs Western Australian Mining Co. Pty. Ltd.	364	....	364	393	....	393
Dampier Mining Co. Ltd.	583	....	583	623	....	623
Goldsworthy Mining Ltd.	812	....	812	762	....	762
Hamersley Iron Pty. Ltd.	2 073	....	2 073	2 136	....	2 136
Mt. Newman Mining Co. Pty. Ltd.	1 309	....	1 309	1 510	....	1 510
Wundowie Iron & Steel	10	....	10	11	....	11
Mineral Beach Sands—						
Allied Eneabba Pty. Ltd.	200	....	200	192	....	192
Cable Sands Pty. Ltd.	62	....	62	67	....	67
Jennings Mining Ltd.	107	....	107	73	....	73
Western Mineral Sands Pty. Ltd.	30	....	30	....	....	....
Westralian Sands Ltd.	100	....	100	....	....	....
W.S.L. Group	....	....	....	126	....	126
Western Titanium Ltd.	237	....	237	234	....	234
Nickel—						
Anaconda Australia Inc.	14	59	73	....	....	....
Agnew Mining Co. Pty. Ltd.	....	....	....	166	46	212
Metals Exploration N.L.	88	86	174	81	81	162
Selcast Mining Corporation	36	69	105	14	70	84
Western Mining Corporation	552	643	1 195	604	669	1 273
Windarra Nickel Mines Pty. Ltd.	135	66	201	....	....	....
Petroleum—Crude Oil—						
West Australian Petroleum Pty. Ltd.	102	....	102	106	....	106
Salt—						
Dampier Salt Limited	179	....	179	171	....	171
Lefroy Salt Co.	12	....	12	3	....	3
Leslie Salt Co.	39	....	39	47	....	47
Texada Mines Pty. Ltd.	170	....	170	....	....	....
All Other Minerals	295	....	295	374	2	376
State Total—Other than Gold	10 864	1 242	12 106	11 216	1 188	12 404

* For details of individual years prior to 1967—see Annual Report for 1966 or previous reports.

† Effective workers only and totally excluding non-workers for any reason whatsoever.

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Excavation for Wungong Dam
prior to embankment construction