DEPARTMENT OF MINES ANNUAL REPORT 1977

Department of Mines
ANNUAL REPORT
1977

REPORT OF THE
DEPARTMENT *of* MINES
WESTERN AUSTRALIA
FOR THE YEAR 1977

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

WILLIAM C. BROWN, Government Printer, Western Australia

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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 1977, *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, 1978.

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WESTERN AUSTRALIA

Report of the Department of Mines for the Year 1977

DIVISION I

PART 1—GENERAL REMARKS

The Honourable the Minister for Mines

I have the honour to submit for your information a report on the Mining Industry for 1977.

The estimated value of the mineral output of Western Australia (including gold, coal and petroleum) for the year was $1 698·49 million, an increase of 14 per cent over the previous year and an all-time record. This increase was due mainly to higher prices for iron ore, increased production and price for gold, and increased production of alumina, petroleum, ilmenite and rutile.

To the end of 1977 the progressive value of the mineral production of the State from 1886 amounted to $10 122 million.

Iron ore exports which commenced in 1966, contributed $5 096 million which is over half the progressive total.

ROYALTIES

Royalty revenue during the year amounted to $54·496 million, an increase of $7·843 million over the figure for 1976. Iron ore royalties amounted to 84 per cent of the total. Full details are contained in Table 2 of Part 2 of this report.

IRON ORE

The quantity of iron ore for local use and export fell marginally from 85·6 million tonnes in 1976 to 83·6 million tonnes in 1977. This decline is a repercussion of the recession in world demand for steel which is now affecting iron ore suppliers.

ALUMINA

Alcoa of Australia (W.A.) Limited continued to increase production of alumina from bauxite mined at Jarrahdale and Del Park and fed to the company's refineries at Kwinana and Pinjarra. Production increased from 3·1 million tonnes in 1976 to 3·4 million tonnes in 1977, the latter having an estimated value of $276·5 million.

NICKEL

The total value of nickel in concentrates, briquettes and powder amounted to an estimated $248·3 million in 1977 compared with $228·3 million in 1976. This increase was due to higher prices and not to increased production which was marginally down on 1976; nickel concentrates and nickel ore production being down 1 902 tonnes and 1 795 tonnes respectively.

PETROLEUM
(Crude Oil and Natural Gas)

Sales of crude oil for Barrow Island during 1977 totalled 11·7 million barrels valued at $46·6 million compared with 11·2 million barrels valued at $30·9 million in 1976.

Although the quantity increase was only small the large increase in value was brought about by the Commonwealth Government introducing as from the 17th August, 1977 a two tier pricing system as the first step toward pricing local crude oil at world parity.

Under the system producers will receive the import parity price determined by the Commonwealth Government every six months for a specified part of their production. In respect of Barrow Island production the import parity price was $13·00/barrel as from 17th August, 1977 and this price applied to a specified proportion of production with the balance of production being at $2.88 per barrel.

The Dongara and Mondarra gas field supplied a total 813·7 million cubic metres of natural gas valued at $14·7 million to sales outlets at Perth-Fremantle-Kwinana-Pinjarra areas.

Interest in petroleum exploration showed an increase both on and off-shore and programmes costing hundreds of millions of dollars over the next five or six years have been approved. There was a marked increase in the amount of drilling during 1977 and the length of marine seismic surveys more than doubled, being 5 994 km as compared to 2 599 km in 1976.

GOLD

The estimated value of gold received at the Perth Mint during 1977 was $42 572 837, an increase of $17 001 909 compared with the 1976 figure. The quantity of gold received was 9 827 kg, an increase of 2 561 kg over the 1976 figure.

The weighted average price obtained for Western Australian gold as recorded by the Department of Mines for 1977 computed to $134.75 per fine ounce (troy) as against $109.46 for 1976.

Throughout the year the world market price of gold maintained a steady increase which is reflected in the above value and this should revive and stimulate interest in gold mining.

Newmont Proprietary Limited commenced production from Telfer during the year and contributed 4 155 kg of gold to the above total of 9 827 kg.

Details of gold production reported to the Department as distinct from that received at the Mint are set out in Table 1 of Part 2 of this report. The quantity of auriferous ore treated during the year was 1 071 980 tonnes compared with 951 028 tonnes in 1976, and the average number of persons engaged in gold mining fell from 1 153 in 1976 to 871 in 1977.

COAL

Coal production from the Collie Coal Field during the year showed an increase of 89 279 tonnes over that for 1976.

Figures for the last three years were:—

	1975	1976	1977
Tonnes	2 113 979	2 268 727	2 358 006
Total Value	$15 073 668	$20 613 647	$23 172 093
Average Value per Tonne	$7.130 5	$9.022 2	$9.826 9
Average Effective Workers	836	860	862
Proportion of Deep Mined Coal	26·08%	24·34%	22.82%

OTHER MINERALS

Other minerals to yield over a million dollars for the year were: Salt $26·1 million, Ilmenite $22·2 million, Rutile $18·9 million, Zircon $9·1 million, Leucoxene $1·1 million, Tin Concentrates $4·3 million, Tanto/Columbite $2·1 million, Limestone $1·2 million, Copper (by-product of Nickel Mining) $1·7 million; while Pig Iron valued at $3·9 million was produced by the Wundowie Iron and Steel Industry.

OUTLOOK

The mining industry of Western Australia came through 1977 very admirably despite the difficulties experienced because of the depressed state of world prices for most metals and world wide cutbacks in demand for iron ore and nickel products because of oversupply. These difficulties seem

certain to carry through into the first half of 1978, however every endeavour is being made by the Government and the various companies to ensure that the State will hold its place in world markets.

A really bright note for the year was the rising price of gold which shows every indication of reaching a level where it should be feasible to re-open mines on the Golden Mile and other centres. This should also stimulate interest in prospecting throughout the State.

The world energy crisis has caused world wide attention to be focused on the potential of the State to provide coal, petroleum and uranium, and an immediate advantage has been the increased level of exploration activity for these minerals during 1977.

The extensive and varied mineral resources of the State afford the opportunities for expansion and I am confident the mining industry will continue to grow and contribute to the welfare of Western Australia.

PART 2—COMPARATIVE STATISTICS

TABLE 1

SUMMARY

Mineral Production: Quantity, Value, Persons Engaged

	1976	1977		Variation
IRON ORE—				
Tonnes	85 572 799	**83 562 287**	—	2 010 512
Value ($A)	$845 993 361	**$955 013 963**	+	$109 020 602
Persons Engaged	4 813	**5 209**	+	396
ALUMINA—				
Tonnes	3 120 057	**3 456 987**	+	336 930
*Value ($A)	$249 604 540	**$276 558 960**	+	$26 954 420
Persons Engaged	2 367	**2 594**	+	227
NICKEL—				
Tonnes (Ore and Concentrates)	530 826	**527 129**	—	3 697
Value ($A)	$228 832 749	**$248 371 821**	+	$19 539 072
Persons Engaged	2 489	**2 333**	—	156
PETROLEUM—CRUDE OIL—				
Barrels	11 197 157	**11 772 990**	+	575 833
†Value ($A)	$30 915 627	**$46 600 648**	+	$15 685 021
Persons Engaged	104	**101**	—	3
GOLD—				
Reported to Department (Mine Production)—				
Ore Treated (Tonnes)	951 028	**1 071 980**	+	120 952
Gold (Kilograms)	7 091	**10 747**	+	3 656
Average Grade (grams per tonne)	7·5	**10·00**	+	2·5
Persons Engaged	1 153	**871**	—	282
Mint and Export (Realised Production)—				
Gold (Kilograms)	7 266	**9 827**	+	2 561
Estimated Value ($A) (including Overseas Gold Sales Premium)	$25 570 928	**$42 572 837**	+	$17 001 909
COAL—				
Tonnes	2 268 727	**2 358 006**	+	89 279
Value ($A)	$20 613 647	**$23 172 093**	+	$2 558 446
Persons Engaged	860	**862**	+	2
MINERAL BEACH SANDS—				
Tonnes	1 157 497	**1 408 293**	+	250 796
Value ($A)	$46 976 589	**$52 122 978**	+	$5 146 389
Persons Engaged	944	**872**	—	72
OTHER MINERALS—				
Value ($A)	$42 241 108	**$54 626 160**	+	$12 385 052
Persons Engaged	616	754	+	138
TOTAL ALL MINERALS—				
Value ($A)	$1 490 644 549	**$1 699 039 460**	+	$208 394 911
Persons Engaged	13 346	13 596	+	250

* 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 Industries Assistance Commission for Barrow Island crude oil at Kwinana.

TABLE 1 (*a*)

Quantity and Value of Minerals other than Gold and Silver produced during 1976 *and* 1977
Western Australia

Mineral	1976		1977		Increase or Decrease for Year Compared with 1975	
	Quantity	Value	Quantity	Value	Quantity	Value
	Tonnes	$	Tonnes	$	Tonnes	$
Alumina (from Bauxite)	3 120 057	249 604 540	**3 456 987**	**276 558 960**	+ 336 930	+ 26 954 420
Antimony	309	379 660	**836**	**999 228**	+ 527	+ 619 568
Barytes	12 099	1 330 890	**7 117**	**87 450**	— 4 982	— 1 303 440
Building Stone (Quartzite)	524	6 630	**730**	**7 670**	+ 206	+ 1 040
(Quartz)	4 091	81 482	**4 388**	**141 414**	+ 297	+ 59 932
(Spongolite)	57	828	**17**	**253**	— 40	— 575
Clays (Bentonite)	564	5 076	**147**	**1 470**	— 417	— 3 606
(Cement Clay)	46 265	115 002	**28 390**	**70 969**	— 17 875	— 44 033
(Fire Clay)	222 523	141 436	**263 707**	**100 096**	+ 41 184	— 41 340
(White Clay—Ball Clay)	555	6 552	**323**	**3 230**	— 232	— 3 322
(Kaolin)	524	5 144	**482**	**3 800**	— 42	— 1 344
Coal	2 268 728	20 613 647	**2 358 006**	**23 172 093**	+ 89 278	+ 2 558 246
Cobalt (By-product of Nickel Mining)	195	594 014	**201**	**712 884**	+ 6	+ 118 870
Copper (By-product of Nickel Mining)	1 420	1 337 683	**1 831**	**1 734 785**	+ 411	+ 397 102
Copper Ore and Concentrates	6 200	910 000	....	....	— 6 200	— 910 000
Diatomaceous Earth	....	....	**20**	**500**	+ 20	+ 500
	Carats		Carats		Carats	
Emeralds (cut)	....	....	**13 830**	**12 182**	+ 13 830	+ 12 182
	Grams		Grams		Grams	
Emeralds (rough, uncut)	....	....	**739**	**5 803**	+ 739	+ 5 803
	Tonnes		Tonnes		Tonnes	
Felspar	498	14 840	**645**	**16 055**	+ 147	+ 1 215
Garnet Sands	....	....	**164**	**12 300**	+ 164	+ 12 300
Glass Sand	109 543	75 661	**137 181**	**73 131**	+ 27 638	— 2 530
Gypsum	122 377	323 146	**105 102**	**282 038**	— 17 275	— 41 108
Iron Ore (Pig Iron Recovered)	56 521	4 931 874	**45 090**	**3 903 976**	— 11 431	— 1 027 898
(Exported and locally used)	79 942 758	746 070 201	**77 858 409**	**837 805 531**	— 2 084 349	+ 91 735 330
(Pellets)	5 630 041	94 991 286	**5 658 788**	**113 304 456**	+ 28 747	+ 18 313 170
Limestone	705 031	1 078 919	**769 868**	**1 182 051**	+ 64 837	+ 103 132
Magnesite	....	....	**23 906**	**637 449**	+ 23 906	+ 637 449
Manganese (Metallurgical Grade)	....	....	**2 267**	**39 663**	+ 2 267	+ 39 663
Mica	1 850	7 400	....	....	— 1 850	— 7 400
Mineral Beach Sands (Ilmenite)	937 271	16 795 059	**1 201 884**	**22 210 438**	+ 264 613	+ 5 415 379
(Monazite)	2 286	394 578	**5 150**	**828 921**	+ 2 864	+ 434 343
(Rutile)	83 584	15 963 819	**89 873**	**18 920 888**	+ 6 289	+ 2 957 069
(Leucoxene)	9 066	1 332 859	**7 106**	**1 058 892**	— 1 960	— 273 967
(Zircon)	125 242	12 457 553	**104 280**	**9 103 839**	— 20 962	— 3 353 714
(Xenotime)	48	32 721	....	....	— 48	— 32 721
Nickel Concentrates	457 490	222 787 660	**455 588**	**241 322 717**	— 1 902	+ 18 535 007
Nickel Ore	73 336	6 045 089	**71 541**	**7 049 104**	— 1 795	+ 1 004 015
Ochre	1 025	17 214	**42**	**717**	— 983	— 16 497
	kg		kg		kg	
Palladium (By-product of Nickel Mining)	247	301 930	**298**	**499 599**	+ 51	+ 197 669
Platinum (By-product of Nickel Mining)	98	394 553	**115**	**527 666**	+ 17	+ 133 113
Ruthenium (By-product of Nickel Mining)	14	23 046	**7**	**13 073**	— 7	— 9 973
	bbls		bbls		bbls	
Petroleum—Crude Oil (barrels)	11 197 157	30 915 627	**11 772 990**	**46 600 648**	+ 575 833	+ 15 685 021
	$m^3 10^3$		$m^3 10^3$		$m^3 10^3$	
Natural Gas ($m^3 10^3$)	832 621	7 661 819	**813 787**	**14 707 822**	— 18 834	+ 7 046 003
	Tonnes		Tonnes		Tonnes	
Condensate	2 949	N.A.	**2 816**	**N.A.**	— 133	N.A.
Salt	3 714 164	23 323 839	**3 705 476**	**26 138 310**	— 8 688	+ 2 814 471
	kg		kg		kg	
Semi-precious Stones	5 099	3 382	**42 293**	**24 374**	+ 37 194	+ 20 992
	Tonnes		Tonnes		Tonnes	
Talc	65 270	N.A.	**90 466**	**N.A.**	+ 25 196	N.A.
Tanto/Columbite Ores and Concentrates	118	1 348 307	**157**	**2 124 638**	+ 39	+ 776 331
Tin Concentrates	602	2 462 252	**636**	**4 273 832**	+ 34	+ 1 811 580
Vermiculite	....	....	**716**	**7 160**	+ 716	+ 7 160
		1 464 887 218		**1 656 282 075**		+ 191 394 857

TABLE 1 (*b*)

Quantity and Value of Gold and Silver received at the Perth Mint during the years 1976 *and* 1977

Mineral	1976		1977		Increase or Decrease for Year Compared with 1976	
	Quantity	Value	Quantity	Value	Quantity	Value
	kg	$	kg	$	kg	$
Gold	*7 266·138	†25 570 928	***9 827·184**	**†42 572 837**	+ 2 561·046	+ †17 001 909
Silver	*2 110·045	186 403	***2 087·975**	**184 548**	— 22·070	— 1 855
Total		25 757 331		**42 757 385**		+ 17 000 054
Grand Total		1 490 644 549		**1 699 039 460**		+ 208 394 911

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

TABLE 2

ROYALTIES

Mineral	Royalty Collected		Increase or Decrease Compared with 1976
	1976	1977	
Alumina	985 182.24	**1 379 403.03**	+ 394 220.79
Amethyst	.42	**1.85**	+ 1.43
Antimony	....	**191.95**	+ 191.95
Barytes	595.40	**350.39**	+ 245.01
Bentonite	28.20	**7.23**	— 20.97
Building Stone	378.75	**534.22**	+ 155.47
Chalcedony	5.21	**21.18**	+ 15.97
Clay	12 333.59	**15 791.10**	+ 3 457.51
Coal	51 702.31	**58 616.05**	+ 6 913.74
Cobalt	2 962.62	**3 705.89**	+ 743.27
Diatomaceous Earth	....	**3.00**	+ 3.00
Emeralds	12.83	**120.52**	+ 107.69
Felspar	26.39	**19.35**	— 7.04
Glass Sand	3 825.97	**13 973.28**	+ 10 147.31
Gold	....	**1.00**	+ 1.00
Green Beryl	1·05	....	— 1.05
Gypsum	5 137.57	**6 237.57**	+ 1 100.00
Ilmenite	208 234.48	**346 333.25**	+ 138 098.77
Iron Ore	40 713 012.43	**45 887 023.66**	+ 5 174 011.23
Leucoxene	6 183.09	**31 073.39**	+ 24 890.30
Limestone	23 564.48	**25 350.43**	+ 1 785.95
Magnesite	....	**3 529.28**	+ 3 529.28
Manganese	....	**358.50**	+ 358.50
Mica	69.13	....	— 69.13
Monazite	2 506.77	**17 842.00**	+ 15 335.23
Moss Opal	8.98	**31.40**	+ 22.42
Natural Gas	467 245.88	**726 742.96**	+ 259 497.08
Natural Gas-Condensate	5 522.33	**2 916.38**	— 2 605.95
Nickel	2 205 454.82	**3 264 079.02**	+ 1 058 624.20
Ochre	10.16	**.75**	— 9.41
Oil (Crude)	1 330 900.55	**1 847 891.28**	+ 516 990.73
Opal	....	**10.59**	+ 10.59
Palladium	644.57	**1 161.60**	+ 517.03
Platinum	886.60	**1 208.42**	+ 321.82
Ruthenium	59.45	**30.73**	— 28.72
Rutile	206 106.28	**412 304.50**	+ 206 198.22
Salt	241 404.34	**220 123.59**	— 21 280.75
Talc	5 709.29	**7 443.90**	+ 1 734.61
Tiger Eye	....	**8.50**	+ 8.50
Tanto-Columbite	5 281.07	**11 310.20**	+ 6 029.13
Tin	132.98	**116.35**	— 16.63
Vermiculite	....	**35.80**	+ 35.80
Xenotime	156.92	**67.46**	— 89.46
Zircon	167 475.92	**210 164.41**	+ 42 688.49
Total	46 652 763.07	**54 496 135.96**	+ 7 843 372.89

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	
	1976	**1977**	1976	**1977**	1976	**1977**
	kg	kg	Per cent	Per cent	grams	grams
Kimberley	....	....	....	....	....	....
West Kimberley	....	....	....	....	....	....
Pilbara	163·942	**4 986·356**	2·31	**46·53**	10·1	**15·4**
West Pilbara	....	....	....	....	....	....
Ashburton	....	....	....	....	....	....
Gascoyne	....	....	....	....	....	....
Peak Hill	4·315	....	·06	....	3·6	....
East Murchison	12·276	**2·600**	·17	**·02**	107·6	**26·3**
Murchison	54·627	**43·962**	·77	**·41**	13·0	**10·9**
Yalgoo	10·229	**·443**	·15	....	14·1	**4·9**
Mount Margaret	41·839	**34·624**	·59	**·32**	5·7	**6·9**
North Coolgardie	24·430	**23·609**	·35	**·22**	11·1	**5·8**
Broad Arrow	39·160	**13·624**	·55	**·13**	29·2	**3·2**
North-East Coolgardie	2·081	**·652**	·03	**·01**	7·0	**4·1**
East Coolgardie	3 493·554	**2 515·104**	49·32	**23·47**	4·6	**4·5**
Coolgardie	104·921	**127·102**	1·48	**1·19**	7·5	**14·9**
Yilgarn	87·613	**57·692**	1·24	**·54**	11·0	**16·9**
Dundas	3 044·941	**2 908·503**	42·98	**27·14**	22·1	**18·7**
Phillips River	....	**2·211**	....	**·02**	....	**30·3**
South West Mineral Field	....	....	....	....	....	....
State Generally	....	....	....	....	....	....
	7 083·928	**10 716·482**	100·00	**100·00**	7·4	**10·0**

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

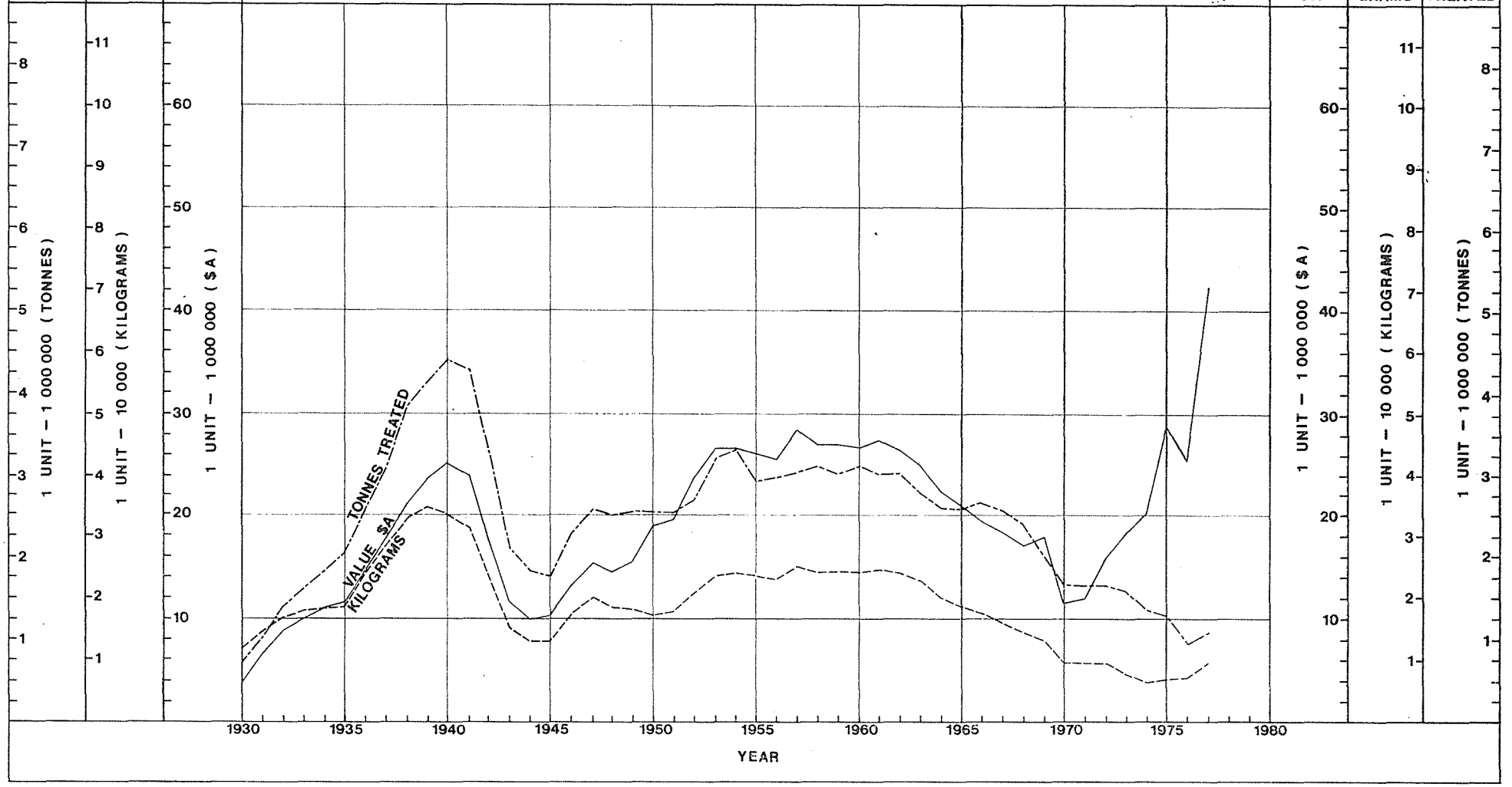
TABLE 4

Total Coal Output from Collie River Mineral Field, 1976 *and* 1977, *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
1976	552 292	6 960 615	120	328	....	....	1 684	1 233
1977	538 028	8 050 325	124	323	....	....	1 666	1 204
Open Cut Mining—								
1976	1 716 435	13 653 032	....	....	412	4 176	....	....
1977	1 819 978	15 121 768	....	....	415	4 385	....	....
Totals—								In All Mines
1976	2 268 727	20 613 647	120	328	412	....	....	2 641
1977	2 358 006	23 172 093	124	323	415	....	....	2 735

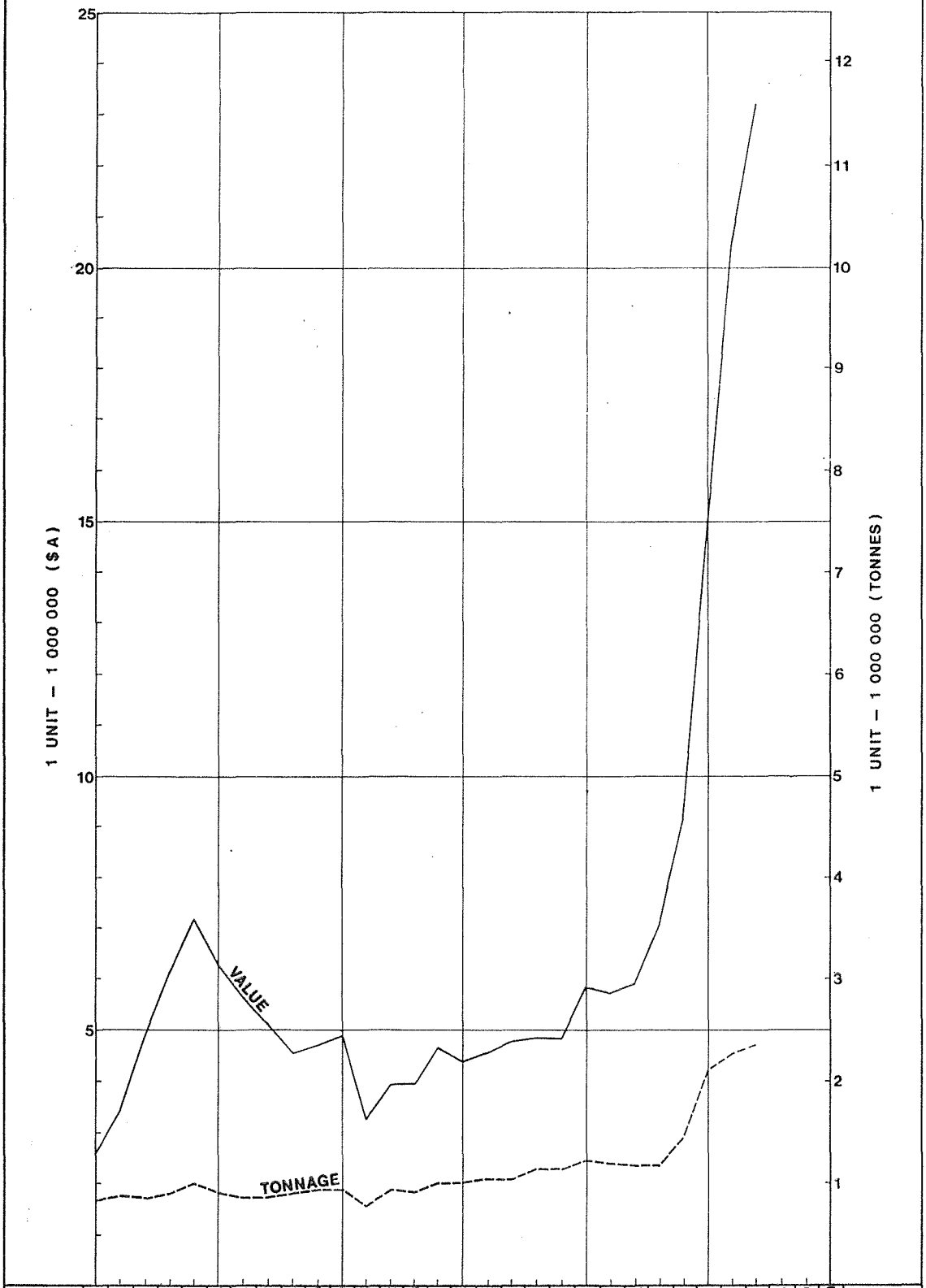
DIAGRAM OF GOLD OUTPUT

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



GRAPH OF COAL OUTPUT

SHOWING QUANTITIES AND VALUES AS REPORTED TO DEPT. OF MINES



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

GRAPH OF TREND IN COAL OUTPUT

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

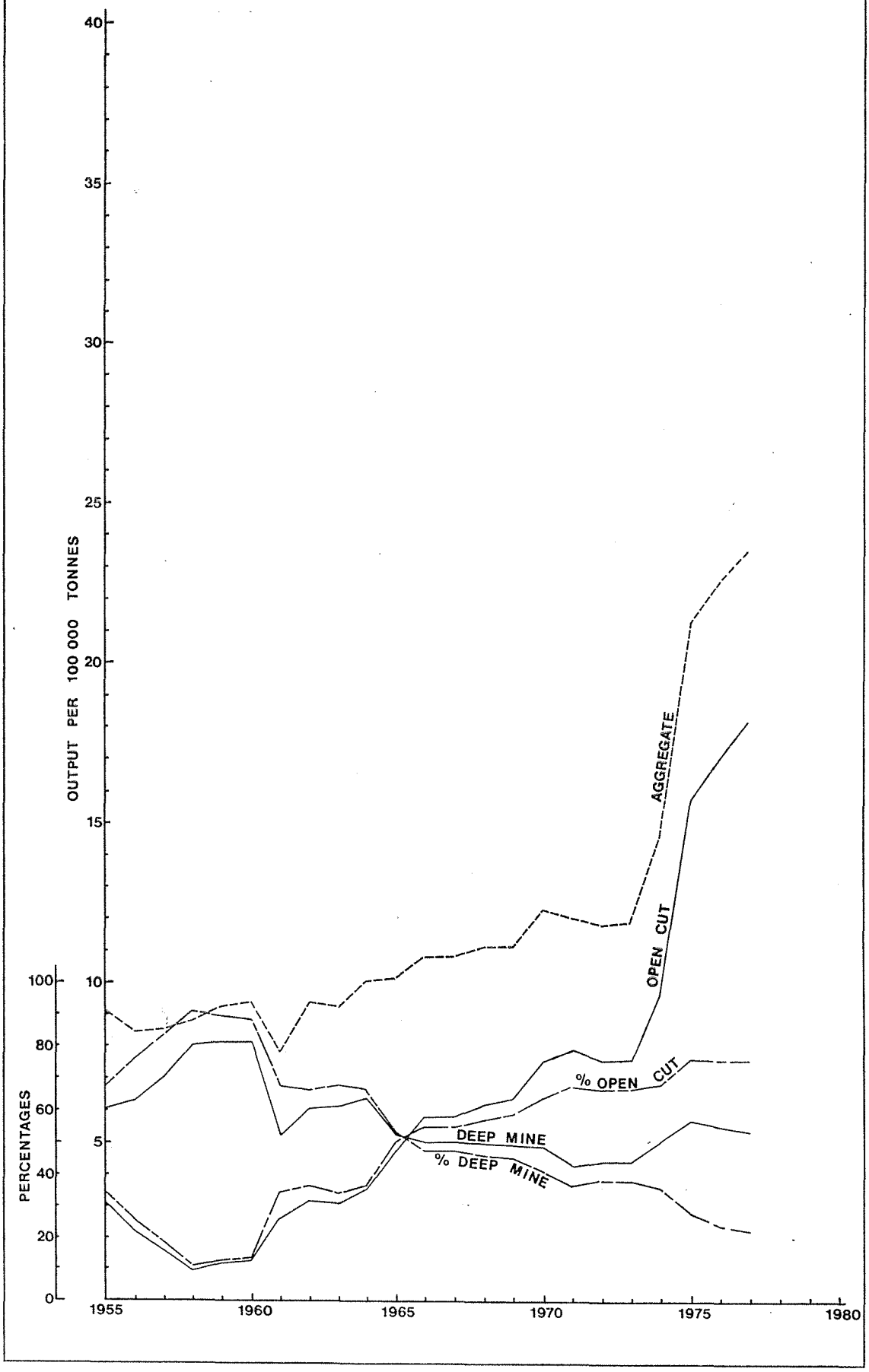


TABLE 5

MINING ACT, 1904

LEASES AND OTHER HOLDINGS UNDER VARIOUS ACTS RELATING TO MINING

Total Number and Area of Mining Tenements applied for during 1977 *and in force as at* 31*st December*, 1977 (*compared with* 1976)

	Applied for				In Force			
	1976		1977		1976		1977	
	No.	Hectares	No.	Hectares	No.	Hectares	No.	Hectares
Gold—								
Gold Mining Leases	232	1 851	315	2 630	2 321	18 642	1 918	17 878
Dredging Claims	....	....	....	....	4	395	4	395
Prospecting Areas	251	2 082	227	1 805	216	1 763	207	1 646
Temporary Reserves	42	4 908	....	....	45	5 227	11	1 269
Totals	525	8 841	542	4 435	2 586	26 027	2 140	21 188
Coal—								
Coal Mining Leases	134	16 201	1 719	202 773	130	15 076	146	16 431
Prospecting Areas	4	4 788	7	6 876	....	....	2	2 384
Temporary Reserves	....	....	3	59 950	3	3 922	5	63 774
Totals	138	20 989	1 729	269 599	133	18 998	153	82 589
Other Minerals—								
Mineral Leases	44	4 266	25	1 936	815	80 450	730	69 038
Dredging Claims	5	171	49	3 379	217	8 663	215	9 028
Mineral Claims	6 483	726 492	3 657	408 944	11 163	1 137 588	13 264	1 370 745
Prospecting Areas	25	193	10	85	22	192	9	69
Temporary Reserves	146	2 380 959	116	1 696 950	439	6 845 282	395	5 417 943
Totals	6 703	3 112 081	3 857	2 111 294	12 656	8 072 175	14 613	6 866 823
Other Holdings—								
Miners' Homestead Leases	....	....	....	....	306	12 575	320	13 911
Miscellaneous Leases	1	2	4	17	104	836	95	729
Residential Areas	....	....	....	....	49	18	44	15
Business Areas	1	1	1	1	15	6	16	7
Machinery Areas	2	1	2	7	28	47	25	35
Tailings Areas	....	....	....	....	25	40	25	40
Garden Areas	6	7	6	10	86	138	84	138
Quarrying Areas	30	273	46	411	178	1 504	208	1 667
Water Rights	5	30	3	6	106	314	95	5 793
Licenses to Treat Tailings	87	....	73	....	69	....	68	....
Totals	132	314	135	452	966	15 478	980	22 335
Grand Totals	7 498	3 142 225	6 263	2 385 780	16 341	8 132 678	17 886	6 992 935

TABLE 5 (*a*)

SPECIAL ACTS

Leases applied for during 1977 *and in force as at* 31*st December*, 1977 (*Compared with* 1976)

	Applied for				In Force			
	1976		1977		1976		1977	
	No.	Hectares	No.	Hectares	No.	Hectares	No.	Hectares
Bauxite	....	....	....	....	7	1 269 618.00	7	1 202 951.40
Iron	1	31 880.00	....	....	9	293 567.93	10	352 540.56
Salt	....	....	....	....	5	257 465.16	5	244 226.16
Totals	1	31 880.00	....	....	21	1 820 651.09	22	1 799 718.12

TABLE 5 (*b*)

PETROLEUM ACTS

Permits, Licenses and Leases applied for during 1977 *and in force as at* 31*st December,* 1977 (*Compared with* 1976)

Holding	Applied for				In Force			
	1976		**1977**		1976		**1977**	
	No.	Blocks	No.	Blocks	No.	Blocks	No.	Blocks
Onshore—								
Petroleum Act, 1967—								
Exploration Permits	11	96	**1**	**1 285**	31	1 219	**35**	**2 037**
Production Licenses	....	....	....	....	2	9	**2**	**9**
Petroleum Leases (Barrow Island)	....	....	....	....	1	8	**1**	**8**
Totals	11	96	**1**	**1 285**	34	1 236	**38**	**2 054**
Offshore—								
Petroleum (Submerged Lands) Act 1967—								
Exploration Permits	18	4 014	**32**	**9 170**	21	2 643	**34**	**6 550**
Production Licenses	....	....	**5**	**22**	....	....	....	....
Petroleum Leases (Barrow Marine)	....	....	....	....	1	12	**1**	**12**
Totals	18	4 014	**37**	**9 192**	22	2 655	**35**	**6 562**
Grand Totals	29	4 110	**38**	**10 477**	56	3 891	**73**	**8 616**

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

Holding	Applied for				In Force			
	1976		**1977**		1976		**1977**	
	No.	Km	No.	Km	No.	Km	No.	Km
Onshore—								
Petroleum Pipelines Act, 1969—								
Pipeline Licenses	....	....	....	....	5	444·9	**5**	**444·9**
Totals	....	....	....	....	5	444·9	**5**	**444·9**

TABLE 5 (*c*)

MINING ACT, 1904

Leases in Force as at 31st December, 1977 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	11	83·34	10	1 082·39	....	....	....	....
Broad Arrow	42	297·50	26	3 925·59	....	....	1	4·00
Bulong	31	261·03	1	9·68	....	....	....	....
Collie	....	....	63	6 967·83	....	....	....	....
(Private Property)	....	....	1	210·00	....	....	....	....
Coolgardie	139	1 026·59	371	41 560·77	22	752·26	3	11·72
Cue	33	279·83	1	41·18	4	450·43	....	....
Day Dawn	47	403·05	....	....	1	8·09	....	....
Dundas	476	4 220·71	....	....	17	485·12	....	....
East Coolgardie	98	3 027·41	4	351·50	60	1 322·28	57	489·01
Gascoyne	7	57·44	1	3·23	....	....	....	....
Greenbushes	....	....	75	3 966·00	6	169·00	....	....
Kanowna	54	427·07	5	221·34	12	3·75	....	....
Kimberley	2	18·70	....	....	....	....	....	....
Kunanalling	22	174·89	....	....	2	310·43	....	....
Kurnalpi	13	125·68	....	....	....	....	....	....
Lawlers	36	257·40	....	....	5	449·16	....	....
Marble Bar	163	1 391·49	61	7 035·47	....	....	12	87·67
Meekatharra	114	921·53	....	....	10	714·33	1	0·40
Menzies	48	381·04	1	28·73	7	299·43	....	....
Mount Magnet	113	807·63	....	....	....	....	....	....
Mount Malcolm	57	444·70	....	....	9	513·91	1	0·30
Mount Margaret	54	517·63	59	6 011·61	6	15·34	....	....
Mount Morgans	28	243·13	....	....	....	....	....	....
Niagara	4	29·82	....	....	1	8·09	....	....
Northampton	....	....	3	25·07	....	....	....	....
(Private Property)	....	....	....	....	....	....	....	....
Nullagine	23	166·25	....	....	2	8·89	2	19·42
Peak Hill	22	161·16	6	269·45	4	99·94	....	....
Phillips River	4	21·36	19	763·93	....	....	1	2·40
(Private Property)	....	....	14	1 692·55	106	6 063·06	....	....
South West	....	....	31	3 098·38	....	....	....	....
(Private Property)	1	4·04	28	2 463·97	....	....	....	....
Ularring	23	177·38	....	....	....	....	....	....
West Kimberley	2	18·70	1	9·94	....	....	....	....
West Pilbara	12	109·82	20	483·91	3	14·15	10	91·00
Wiluna	4	38·70	22	2 648·60	17	1 569·16	2	1·20
Yalgoo	33	232·63	3	185·74	1	4·04	....	....
Yerilla	41	333·51	....	....	1	4·04	....	....
Yilgarn	142	1 043·52	10	945·71	24	366·51	5	21·89
(Private Property)	14	124·81	....	....	....	....	....	....
Outside Proclaimed	....	....	....	....	....	....	....	....
Totals	1 918	17 877·89	848	85 469·08	320	13 631·41	95	729·01

	No.	Hectares
Gold Mining Leases on Crown Land	1 903	17 749·04
Gold Mining Leases on Private Property	15	128·85
Mineral Leases on Crown Land	805	81 102·56
Mineral Leases on Private Property	43	4 366·52
Miner's Homestead Leases on Crown Land	320	13 631·41
Other Leases on Crown Land	95	729·01
Other Leases on Private Property	....	....

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TABLE 5 (*d*)

MINING ACT, 1904

Claims and Authorised Holdings in Force at 31st December, 1977 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	....	....	....	....	291	27 085·15	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Black Range	3	24·22	....	....	311	31 156·28	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Broad Arrow	21	164·52	....	....	96	10 491·10	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Bulong	....	40·87	....	....	56	6 480·70	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Collie	....	....	....	....	....	....	....	....	....	....	1	2·00	....	....	....	....	1	4·00	....	....
(Private Property)	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Coolgardie	62	491·70	....	....	476	48 586·50	4	1·60	....	....	....	....	....	....	7	12·12	32	269·38	4	27·37
Cue	4	16·73	....	....	366	40 195·83	1	0·1	....	....	1	2·02	....	....	....	....	1	9·71	....	....
Day Dawn	2	10·07	....	....	42	4 385·78	....	....	....	....	....	....	....	....	4	8·08	....	....	....	....
Dundas	5	43·69	....	....	290	25 832·04	....	....	....	....	....	....	1	2·02	....	....	3	24·27	2	4·85
(Private Property)	....	....	....	....	2	41·67	....	....	....	....	....	....	....	....	....	....	....	....	....	....
East Coolgardie	11	74·41	....	....	110	12 527·16	28	11·20	....	....	1	0·80	10	18·57	12	21·80	11	80·90	12	13·29
Gascoyne	....	....	2	165·91	215	20 048·68	....	....	....	....	....	....	....	....	....	....	3	27·51	....	....
Greenbushes	....	....	....	....	2	13·00	....	....	....	....	....	....	....	....	8	20·00	....	....	2	15·00
Kanowna	11	100·54	....	....	146	16 382·88	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Kimberley	....	....	....	....	1 127	128 221·65	....	....	....	....	....	....	....	....	4	5·24	12	84·05	....	....
Kunanalling	12	100·09	....	....	10	1 202·55	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Kurnalpi	4	38·84	....	....	152	17 583·10	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Lawlers	3	29·13	....	....	1 028	112 613·73	....	....	....	....	....	....	....	....	....	....	3	29·10	1	0·40
Marble Bar	4	33·98	197	7 338·63	989	95 799·00	1	0·20	2	0·80	8	12·21	1	20·2	19	32·71	47	330·98	27	5 659·59
Meekatharra	4	33·97	4	394·9	354	40 685·26	....	....	....	....	....	....	....	....	....	....	....	....	3	3·01
Menzies	3	19·41	....	....	233	25 362·52	....	....	....	....	....	....	....	....	1	0·40	....	....	....	....
Mount Magnet	10	92·16	....	....	131	15 192·23	....	....	....	....	....	....	....	....	7	3·70	....	....	3	1·00
Mount Malcolm	7	58·22	....	....	984	111 940·05	....	....	....	....	....	....	....	....	9	14·12	1	2·02	2	0·80
Mount Margaret	1	9·71	....	....	317	35 930·54	....	....	....	....	2	3·99	5	9·90	2	4·84	7	67·53	1	0·40
Mount Morgans	....	....	....	....	329	38 353·02	....	....	....	....	....	....	....	....	....	....	....	....	1	0·40
Niagara	3	24·26	....	....	182	21 421·47	....	....	....	....	1	1·00	....	....	....	....	2	11·73	3	2·40
Northampton	....	....	....	....	48	2 470·71	....	....	....	....	....	....	....	....	....	....	....	....	....	....
(Private Property)	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Nullagine	....	....	1	121·40	295	16 147·39	....	....	....	....	1	0·40	3	1·60	1	0·40	....	....	11	11·27
Peak Hill	1	9·71	....	....	180	17 597·58	....	....	1	0·40	3	5·02	2	3·30	2	3·97	7	67·9	2	8·53
Phillips River	1	0·75	....	....	202	20 482·79	....	....	....	....	1	0·8	....	....	....	....	1	2·0	....	....
(Private Property)	....	....	....	....	79	8 465·35	....	....	....	....	....	....	....	....	....	....	....	....	....	....
South West	3	2 393·17	12	1 267·13	487	39 053·67	....	....	....	....	....	....	....	....	....	....	1	3·0	....	....
(Private Property)	1	9·71	....	....	779	62 778·03	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Ularring	3	27·91	....	....	44	4 803·57	....	....	....	....	1	0·40	2	1·61	....	....	....	....	3	1·60
West Kimberley	1	9·6	1	120·0	432	48 039·20	....	....	1	0·40	2	4·04	....	....	....	....	16	114·56	2	19·42
West Pilbara	....	....	2	15·37	514	45 106·77	4	1·20	6	2·40	....	....	....	....	4	7·67	59	528·35	9	16·94
Wiluna	1	8·01	....	....	718	83 215·08	....	....	....	....	1	0·40	1	1·21	....	....	....	....	1	0·40
Yalgoo	10	76·69	....	....	698	76 384·83	....	....	6	2·40	....	....	....	....	....	....	....	....	....	....
Yerilla	1	4·85	....	....	261	30 246·34	....	....	....	....	....	....	....	....	....	....	....	....	5	4·82
Yilgarn	18	136·92	....	....	279	26 678·38	6	0·66	....	....	2	2·01	....	....	4	2·99	1	9·71	1	1·66
(Private Property)	2	14·56	....	....	6	554·44	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Outside Proclaimed	....	....	....	....	3	189·38	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Totals	218	4 098·94	219	9 423·34	13 264	1 370 745·40	44	14·96	16	6·40	25	35·09	25	40·23	84	138·04	208	1 666·70	95	5 793·15

TABLE 6

MEN EMPLOYED

Average number of Men employed in Mining during 1976 *and* 1977

Goldfield	District	Gold		Other Minerals		Total	
		1976	**1977**	1976	**1977**	1976	**1977**
Kimberley	....	....	....	....	....	....	....
West Kimberley	....	....	....	379	**413**	379	**413**
Pilbara	Marble Bar	19	**104**	....	**943**	....	**1 047**
	Nullagine	95	**94**	....	**96**	95	**190**
West Pilbara	....	....	....	2 397	**2 574**	2 397	**2 574**
Ashburton	....	....	....	104	**101**	104	**101**
Gascoyne	....	....	....	180	**176**	180	**176**
Peak Hill	....	18	....	1 204	**1 378**	1 222	**1 378**
East Murchison	Lawlers	....	....	....	....	....	....
	Wiluna	1	....	....	....	1	....
	Black Range	2	**5**	....	....	2	**5**
Murchison	Cue	7	**2**	2	**7**	9	**9**
	Meekatharra	26	**22**	....	....	26	**22**
	Day Dawn	5	....	....	....	5	....
	Mt. Magnet	16	**15**	....	....	16	**15**
Yalgoo	....	10	**10**	4	**5**	14	**15**
Mt. Margaret	Mt. Morgans	2	**3**	....	....	2	**3**
	Mt. Malcolm	28	**28**	....	....	28	**28**
	Mt. Margaret	5	**6**	403	**364**	408	**370**
North Coolgardie	Menzies	12	**22**	....	....	12	**22**
	Ularring	7	**17**	....	1	7	**18**
	Niagara	3	**2**	....	....	3	**2**
	Yerilla	4	**4**	....	....	4	**4**
Broad Arrow	....	16	**19**	82	**65**	98	**84**
North-East Coolgardie	Kanowna	2	**1**	....	....	2	**1**
	Kurnalpi	2	**2**	....	....	2	**2**
East Coolgardie	East Coolgardie	495	**200**	....	22	495	**222**
	Bulong	5	....	....	**2**	5	**2**
Coolgardie	Coolgardie	38	**52**	2 020	**1 896**	2 058	**1 948**
	Kunanalling	19	**7**	....	....	19	**7**
Yilgarn	....	105	**31**	149	**154**	254	**185**
Dundas	....	211	**223**	2	**2**	213	**225**
Phillips River	....	....	**2**	....	....	....	**2**
South-West Mineral Field	....	....	....	3 393	**3 553**	3 393	**3 553**
Northampton Mineral Field	....	....	....	....	....	....	....
Greenbushes Mineral Field	....	....	....	80	**111**	80	**111**
Outside Proclaimed Goldfield	....	....	....	....	....	....	....
Collie Coalfield	....	....	....	860	**862**	860	**862**
Total—All Minerals	....	1 153	**871**	12 193	**12 725**	13 346	**13 596**

	1976	**1977**
Minerals Other than Gold—		
Alumina (from Bauxite)	2 367	**2 594**
Antimony	....	**94**
Barytes	10	**6**
Building Stone	6	**6**
Clays	19	**17**
Coal	860	**862**
Copper Ore and Conc.	11	....
Diatomaceous Earth	....	**2**
Emeralds	....	**8**
Felspar	6	**4**
Garnet Sands	....	**2**
Glass Sand	11	**11**
Gypsum	8	**14**
Iron Ore	4 813	**5 209**
Limestone	22	**24**
Magnesite	....	**2**
Mica	2	....
Mineral Beach Sands	944	**872**
Nickel	2 489	**2 333**
Petroleum (Crude Oil)	104	**101**
(Natural Gas)	7	**9**
Salt	393	**383**
Semi Precious Stones	6	**18**
Talc	20	**23**
Tanto/Columbite	2	**3**
Tin	93	**128**
Total—Other Minerals	12 193	**12 725**

PART 3–STATE AID TO MINING

(A) STATE BATTERIES

At the end of the year there were 15 State Batteries including the Northampton Base Metal Plant.

From inception to the end of 1977, gold, silver, tungsten, lead, copper, tantalite and garnet ores to the value of $47 690 251 have been treated at the State Batteries. $45 435 987 came from 3 994 761 tonnes of gold ore, $487 852 from 85 368 tonnes of tin ore, $69 165 from 4 843·3 tonnes of tungsten ore, $1 561 534 from 71 207·2 tonnes of lead ore, $11 932 from 224·0 tonnes of copper ore, $96 046 from 3 120·8 tonnes of tantalite ore, $21 957 from 849 tonnes of garnet ore and silver valued at $5 778 recovered as a by product from the cyaniding of gold tailings.

During the year 44 205·95 tonnes of gold ores were crushed for 337·974 kilograms bullion, estimated to contain 286·433 kilograms fine gold equal to 6·47 grams per tonne. The average value of sands after amalgamation was 2·44 grams per tonne, making the average head value 8·91 grams per tonne. Cyanide plants produced 24·387 kilograms of fine gold, giving a total estimated production for the year of 310·82 kilograms of fine gold valued at $1 336 858.

The working expenditure for the year for all plants was $1 550 528 and the revenue was $173 462 giving a working loss of $1 377 066 which does not include depreciation, interest or Superannuation. Since the inception of State Batteries, the Capital expenditure has been $2 072 763 made up of $1 505 663 from General Loan Funds; $482 284 from Consolidated Revenue; $57 243 from Assistance to Gold Mining Industry; and $27 573 from Assistance to Metalliferous Mining.

Head Office expenditure including Workers Compensation, Insurance and Pay Roll Tax was $230 414 compared with $241 647 for 1976.

The actual expenditure from inception to the end of 1977 exceeds revenue by $12 849 668.

(B) PROSPECTING SCHEME

At the end of the year two men were in receipt of prospecting assistance as compared with one at the end of 1976.

Total expenditure for 1977 was $777.43 and refunds amounted to $77.50 in respect to sands payments.

There were no crushings by assisted prospectors during the year.

Progressive total figures since the inception of the scheme are:

Expenditure—$1 054 747
Refunds—$204 993
Ore Crushed—131 205 tonnes
Gold Won—1 813·062 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 exploration companies, the Branch has published a bulletin on the heavy-mineral-sands resources of the State, thus satisfying a long-felt need in the industry; and, in conjunction with the Bureau of Mineral Resources, has published an additional seventeen sheets of the 1:250 000 series geological maps.

Early in the year a series of public lectures on geological topics were held in Perth; these were well attended. Later in the year a three-day excursion and lecture series on the Robinson Range 1:250 000 geological sheet attracted many participants from the industry.

Final preparations were made towards the opening, in 1978, of a microfilm reading room; this is designed to make exploration data on former tenements more easily accessible to the mineral and petroleum exploration companies.

PART 4–GOVERNMENT CHEMICAL LABORATORIES

The wide range of functions of this Branch are indicated by the titles of its eight Divisions:

(1) Agricultural Chemistry
(2) Food and Industrial Hygiene
(3) Industrial Chemistry
(4) Mineral
(5) Toxicology and Drug
(6) Water
(7) Engineering Chemistry (Bentley)
(8) Metallurgical Laboratory (Kalgoorlie)

Various members of the staff serve on a number of Boards and Committees.

The summarized reports contained in Division VII of this report emphasize the range of subjects dealt with by the Laboratories. They also show their increasing involvement in ecological, environmental and consumer protection matters in addition to the more traditional subjects. Valuable assistance is also given to the police in such matters as forensic examinations and drug use problems, As a consequence of this, officers of the Laboratories are making fuller professional contribution to these fields rather than purely a service one of supplying analytical data. The greater involvement is resulting in greater job satisfaction besides providing a more valuable and useful scientific service to the State.

PART 5–EXPLOSIVES BRANCH

The functions of the Explosives Branch are to ensure that the quality of explosives and the modes of transport and storage of explosives and flammable liquids comply with statutory safety requirements.

Throughout the year a total of 685 licenses were issued for various purposes related to explosives, import, manufacture, storage and sale, and this represented a 5·4 per cent increase over licenses issued during 1976.

A total of 1 038 permits were also issued, which included 963 Shotfirers Permits, a rise of 212 on total permits issued during 1976.

Both general and professional officers of the Explosives Branch made more than 6 000 inspections during the year to give advice on the safe storage of flammable liquids at licensed and non-licensed premises throughout the State. A total of 5 117 licenses were issued for the storage of flammable liquids and 528 vehicles conveying flammable liquids in bulk were inspected.

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 and some 28 mine sites were visited by the mobile x-ray unit.

A total of 14 828 examinations were made under the Mine Workers' Relief Act and the Mines Regulations Act. Of the examinations under the Mines Regulations Act, 4 316 were new applicants and 3 098 were re-examinees.

Compensation under the Miners' Phthisis Act paid during the year was $4 950 compared with $4 964 in the previous year. The number of beneficiaries under the Act as at 31/12/1977 was 22 being 2 ex-miners and 20 widows.

PART 7–SURVEYS AND MAPPING BRANCH

The survey thrust of the Division has been two-pronged; towards completing cadastral surveys that are of importance; and completing such additional points of major connection to the standard geodetic survey as will provide a complete integrated network of survey control suitable for many purposes. Private surveyors have been used to accomplish field work in all occasions. Efforts are being used to make as much use as possible of computer aids in data handling.

Demand for cartographic preparation of maps and plans has increased, with many maps now awaiting printing. Photographic processing was in great demand with 11 063 items being processed. Microfilming of "M" series files continued with 50 being filmed.

A total of 6 613 tenement applications were processed, including 171 Temporary Reserves. Public demand for search of plans continued and $9 912 worth of plans were sold.

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 Division 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 1977

Under Secretary for Mines:

I hereby submit the 1977 Annual Report for the State Mining Engineer's Branch which is divided into the following sections:

Mineral and Metal Production, Accident Statistics and Mine Inspection—by J. M. Faichney, Mining Engineer-Principal Senior Inspector of Mines.

Metalliferous Mining Operations—

Port Hedland Inspectorate—by H. L. Burrows, Mining Engineer-Senior Inspector of Mines.

Perth Inspectorate—by G. J. Dodge, Mining Engineer-Senior Inspector of Mines.

Kalgoorlie Inspectorate—by I. W. Loxton, Mining Engineer-Senior Inspector of Mines.

Summary Report of Accident at the No. 1 Shaft of Agnew Mining Company Pty Ltd—27th April, 1977—by J. Jance, Mechanical Engineer-Special Inspector of Mines.

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

Drilling Operations—by D. A. Macpherson, Drilling Engineer.

Board of Examiners for Mine Managers and Undergound Supervisors—by W. J. Cahill, Secretary.

Board of Examiners for Quarry Manager's Certificates—by J. A. Suda, Secretary.

Ventilation Board—by J. A. Suda, Secretary.

MINERAL METAL AND COAL PRODUCTION

In Western Australia's mineral, metal and coal production for the 1977 calendar year, the value of iron ore production was again the highest at $951 109 987 followed by alumina at $276 558 960, then nickel ore and concentrates at $248 371 821, gold at $46 961 828, salt at $26 138 310, coal at $23 172 093 and ilmenite at $21 666 789. Further information on mineral metal and coal production and producers is given in separate reports by the Mining Engineer-Principal Senior Inspector of Mines and the Mining Engineer-Senior Inspectors of Mines for the Kalgoorlie, Port Hedland, and Perth Inspectorates respectively.

ACCIDENTS

There were 13 fatal and 685 serious accidents reported for the year compared with 11 fatal and 685 serious accidents reported for the previous year.

It is with regret that I report that five persons were killed in a winding accident at the No. 1 Shaft of the Agnew Mining Company Pty Ltd on 27th April, 1977 and this is covered by a summary report of the accident by J. Jance, Mechanical Engineer.

DRILLING OPERATIONS

During 1977 the Drilling Section was responsible for the drilling of 3 822 metres in 24 bores, the development of 87 aquifers in 79 bores and the testing of 30 aquifers in 26 bores.

The total metreage drilled was well below previous years partly because efforts were concentrated on developing and testing a backlog of existing bores and partly due to the closing down of one field unit because of personnel problems.

Exploratory drilling for water was carried out at Moora, Bunbury/Yoganup, Joondalup, Canning Basin and the Fortescue Valley. In addition drilling for groundwater sampling was carried out in the Manjimup woodchip area.

STAFF

Promotions—

Shenton, E. F. Mining Engineer-District Inspector of Mines	25/1/77
Sheppard, A., Mining Engineer-Special Inspector of Mines	13/5/77

Resignations—

Edlington, W. B., Mining Engineer-District Inspector of Mines	29/7/77
Diamantes, P. J., Mining Engineer-District Inspector of Mines	9/12/77
Rimes, J. M., Ventilation Officer	3/2/77
Linden, G. J., Ventilation Officer	3/3/77

Appointments—

Grose, F. T., Ventilation Officer	4/7/77
Cheah, Y. C., Ventilation Officer	18/7/77

A. Y. WILSON,
State Mining Engineer.

13th June, 1978

MINERAL AND METAL PRODUCTION ACCIDENT STATISTICS AND MINE INSPECTION

J. M. Faichney—Mining Engineer/Principal Senior Inspector of Mines

MINERAL AND METAL PRODUCTION

Production is shown in the following tables:

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

and is based on information obtained from various sources including the Statistical, and Mine Inspection, Sections of the Department.

Cobalt, copper metal, palladium, platinum, and ruthenium are by-products of nickel mining whilst silver is a by-product of both nickel and gold mining.

TABLE 1

Mineral and Metal Output (excluding Petroleum)

Mineral Production	1976		1977	
	Production	Value	Production	Value
	Tonne (t)	$A	Tonne (t)	$A
Alumina	3 120 057	249 604 540	3 456 987	276 558 960
Antimony	309·40	379 660	836	999 228
Barytes	12 099	1 330 890	7 117	21 750
Bentonite	564	5 076	147	1 470
Building stone	4 672	88 940	5 135	149 337
Clays	269 867	268 134	292 902	178 095
Coal	2 268 728	20 468 874	2 358 006	23 172 093
Cobalt	194·80	594 014	200·66	712 884
Copper—Metal	1 419·97	1 337 683	1 830·90	1 734 785
—Ore and Concentrates	6 200	910 000	....	....
Diatomaceous Earth	....	....	20	500
Emeralds—Carats (cut)	....	....	13 830	12 182
Emeralds (grams)	....	....	739	5 803
Felspar	498	14 840	645	16 055
Garnet Sand	....	....	164	12 300
Glass Sand	109 543	Not available	137 181	Not Available
Gold (kg)	7 091·42	23 644 412	10 747·37	46 961 828
Gypsum	122 377	323 146	105 102	282 038
Ilmenite (includes upgraded and reduced ilmenite)	937 271	16 795 059	1 164 299	21 666 789
Iron Ore	85 572 799	841 061 487	83 517 197	951 109 987
Iron Ore—Pig Iron	91 924	4 931 874	71 695	3 903 976
Leucoxene	9 065·20	1 332 859	7 106	1 058 892
Limestone	705 031	1 078 919	769 868	1 182 051
Magnesite	....	....	23 906	637 449
Manganese	....	....	2 267	39 663
Mica	1 850	7 400	....	....
Monazite	2 286	394 578	5 150	828 921
Nickel Ore and Concentrates	530 826	228 832 749	527 129	248 371 821
Ochre	1 025	17 214	42	717
Palladium (kg)	247·28	301 930	298·25	499 599
Platinum (kg)	98·21	394 553	114·89	527 666
Ruthenium (kg)	14·36	23 046	7·32	13 073
Rutile	83 584·40	15 963 819	89 873	18 920 888
Salt	3 714 164	23 323 839	3 705 476	26 138 310
Semi-precious Stones (kg)	5·10	3 382	42 293	24 374
Silver (kg)	2 110·05	186 403	2 087·98	184 548
Talc	65 270	Not available	90 466	Not Available
Tanto-Columbite	118·38	1 348 307	156·74	2 124 638
Tin Concentrate	602·02	2 462 252	636·39	4 273 832
Vermiculite	....	....	716	7 160
Xenotime	48	32 721	....	....
Zircon	125 242·46	12 457 553	104 280	9 103 839
Totals	....	1 449 920 153	....	1 641 437 501

NOTE: The value of the mineral and metal output is not complete as the value of some minerals or metals is not available for publication.

TABLE 2

Reported Mine Development

Mining District	Mine	Shaft Sinking (Metres)	Decline and Incline (Metres)	Driving and Cross Cutting (Metres)	Rising and Winzing (Metres)	Exploratory Drilling (Metres)	Total (Metres)
GOLD—							
East Coolgardie	Kalgoorlie Mining Associates	156	119	2 340	591	5 021	8 227
	Daisy Gold Mine	....	....	....	15	....	15
Dundas	Central Norseman Gold Corporation N.L.	....	....	1 603	503	17 225	19 331
North Coolgardie	Espacia Gold Mine	....	....	290	....	....	290
Pilbara	Mulga Mines Ltd.	....	442	164	132	184	922
Murchison	Ingliston Gold Mine	....	....	....	30	....	30
Yalgoo	Ark Gold Mine	....	....	15	....	....	15
	Totals on Gold Mines	156	561	4 412	1 271	22 430	28 830
NICKEL—							
Coolgardie	Western Mining Corporation Ltd. (Kambalda Nickel Operations)	432	4 888	14 638	3 748	72 655	96 361
	Anaconda Aust. Inc.	....	....	1 054	271	7 995	9 320
	Metals Exploration N.L.	58	....	1 073	778	2 984	4 893
	Selcast Exploration Ltd.	....	....	796	200	3 659	4 655
Broad Arrow	Western Mining Corporation Ltd. (Great Boulder Operations)	....	....	....	....	581	581
Mount Margaret	Western Mining Corporation Ltd. (Windarra Project)	....	524	1 676	732	18 143	21 075
East Murchison	Agnew Mining Co.	46	361	71	77	2 235	2 790
	Totals in Nickel Mines	536	5 773	19 308	5 806	108 252	139 675
SCHEELITE-WOLFRAM							
Yalgoo	Minefields Exploration	105	....	88	....	....	193
	Totals in Scheelite-Wolfram Mines	105	....	88	....	....	193

TABLE 3

Principal Gold Producers

Mine	1976			1977		
	Tonnes Treated	Yield Kilograms	Grams Per Tonne	Tonnes Treated	Yield + Kilograms	Grams Per Tonne
Kalgoorlie Lake View Pty. Ltd.	22 423	143·62	6·4	....	....	....
Kalgoorlie Lake View Pty. Ltd. (Mt. Charlotte)	713 647	2 891·75	4·0	549 717	2 354·62	4·3
Kalgoorlie Lake View Pty. Ltd.	....	*374·56	....	....	....	....
Central Norseman Gold Corporation N.L.	137 902	3 039·93	22·0	155 517	2 908·13	18·7
Mulga Mines Ltd.	15 164	146·19	9·6	30 669	532·88	17·4
Newmont Pty. Ltd.	....	....	....	293 087	4 433·18	15·1
Minor Producers	61 891	487·88	7·9	42 990	487·67	11·3
Total State Production	951 027	7 083·93	7·4	1 071 980	10 716·48	10·0

* From mill clean-up.

† Does not include alluvial or dollied gold.

NOTE: The calculated value of the gold produced in 1977 was $46 961 828 which includes $31 218 700 distributed by the Gold Producers Association from the sale of 8 712·62 kilograms of gold at an average premium of $3 214.24 per kilogram.

TABLE 4
Overseas Iron Ore Exports

Company	Sales Tonnes	Grade % Fe
Hamersley Iron Pty. Ltd.	31 638 476	63·31
Mt. Newman Mining Co. Pty. Ltd.	22 464 142	63·00
Cliffs W.A. Mining Co. Pty. Ltd.	12 486 576	58·77
Goldsworthy Mining Ltd.	6 396 175	63·16
Dampier Mining Co. Ltd.	2 544 498	67·68
Total	75 529 867	62·60

TABLE 5
Nickel Producers

Product and Producer	Centre	Quantity Tonnes	Grade % Ni	Value $
NICKEL CONCENTRATES				
Western Mining Corporation Ltd.	Kambalda	307 010	11·99	166 513 259
Western Mining Corporation Ltd. (Windarra)	Windarra	104 320	10·20	45 140 357
Western Mining Corporation Ltd. (Great Boulder)	Scotia	3 684	13·30	2 353 419
Western Mining Corporation Ltd. (Gt. Boulder)	Carr-Boyd Rocks	1 994	9·64	917 366
Selcast Exploration Ltd.	Emu Rock	16 754	17·10	11 993 728
Anaconda Australia Inc.	Redross	21 826	14·78	14 404 588
Total Concentrates		455 588	11·90	241 322 717
NICKEL ORE				
Metals Exploration N.L.	Nepean	71 544	3·29	7 049 104

DIAGRAM OF FATAL ACCIDENTS

SEGREGATED ACCORDING TO CLASS OF MINING

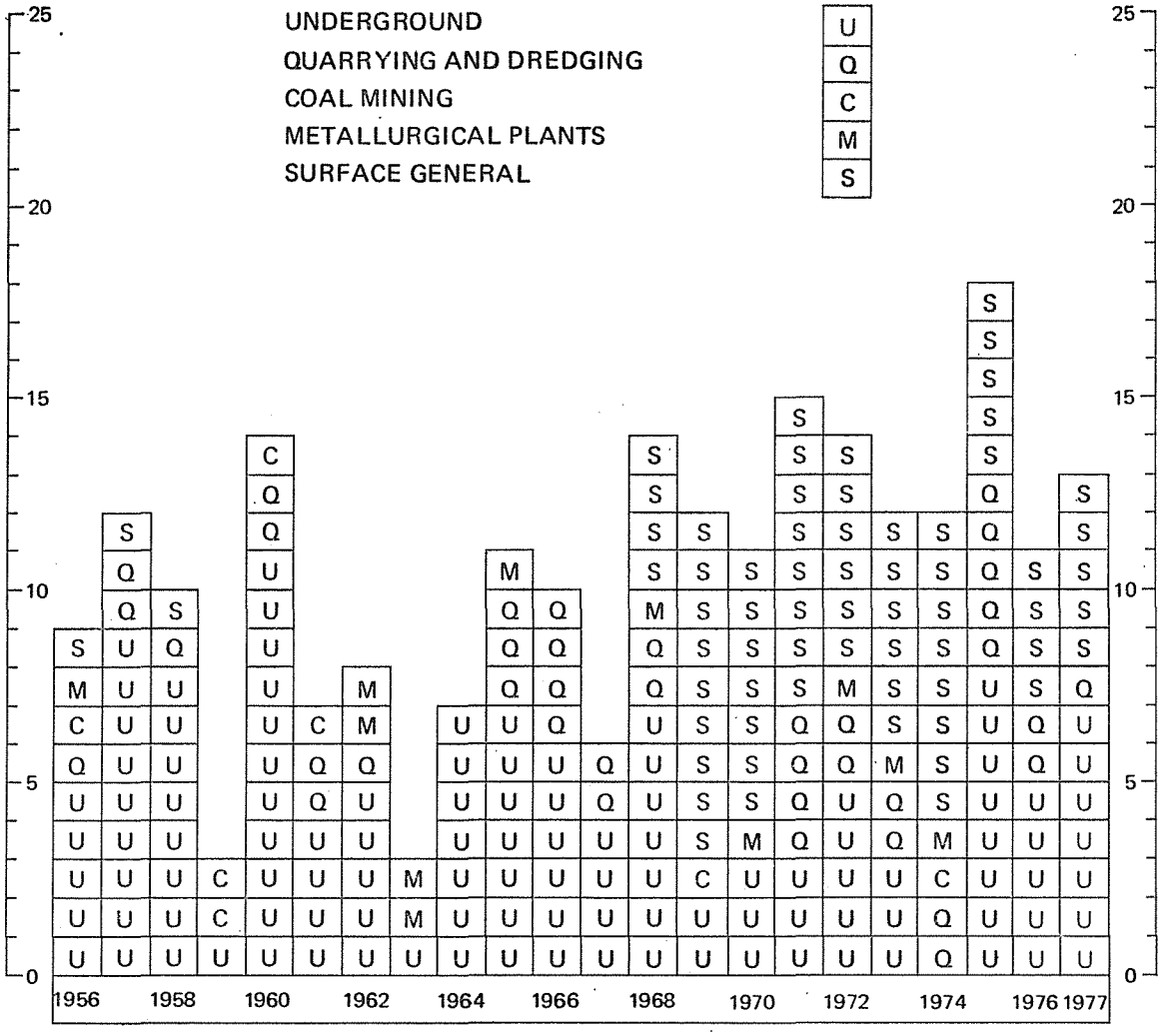

TABLE "A"
SERIOUS ACCIDENTS FOR 1977

Class of Accident	Pilbara	West Pilbara	Peak Hill	Gascoyne	Mount Margaret	East Coolgardie	Coolgardie	Dundas	South West	Greenbushes	Yilgarn	East Murchison	Broad Arrow	Collie	Total
Major Injuries (exclusive of fatal)—															
Fractures—															
Head	....	....	1	....	....	....	....	....	....	1	....	....	....	....	2
Shoulder	....	....	....	....	....	....	1	....	1	....	....	....	....	....	2
Arm	2	2	....	1	1	1	3	1	3	....	....	....	....	....	14
Hand	1	2	1	....	....	1	2	....	....	....	....	....	....	1	8
Spine	....	....	....	....	....	....	1	....	....	....	....	....	....	....	1
Rib	1	....	....	2	....	....	3	....	....	....	....	....	....	2	8
Pelvis	....	....	....	....	....	....	1	....	....	....	....	....	....	....	1
Thigh	....	....	....	....	1	....	2	....	....	....	....	....	....	....	3
Leg	....	2	....	1	....	....	3	....	2	....	....	....	....	....	8
Ankle	4	2	1	....	....	1	....	....	4	....	....	....	....	2	14
Foot	....	3	....	....	....	....	6	....	3	....	....	....	....	....	12
Amputations—															
Arm	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Hand	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Finger	3	1	2	....	1	1	3	....	5	....	....	....	....	....	16
Leg	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Foot	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Toe	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Loss of Eye	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Serious Internal	2	....	....	....	....	....	....	....	....	....	....	....	....	....	2
Hernia	3	....	....	....	....	....	4	....	5	....	....	....	....	....	12
Dislocations	....	2	....	....	....	1	....	....	1	....	....	....	....	....	4
Other Major	....	....	....	1	....	3	9	1	....	....	....	....	....	....	14
Total Major	16	14	5	5	3	8	38	2	24	1	....	....	....	5	121
Minor Injuries—															
Fractures—															
Finger	2	2	....	....	1	1	11	1	3	....	....	1	2	5	29
Toe	....	2	....	....	2	1	5	....	3	....	....	1	....	....	14
Head	2	2	....	....	1	2	5	....	1	....	....	1	2	1	17
Eyes	2	2	....	2	2	1	3	1	6	1	....	....	....	....	20
Shoulder	....	3	....	....	....	2	9	....	5	....	....	1	1	3	24
Arm	2	10	1	1	3	3	3	1	11	1	....	....	1	1	38
Hand	7	17	....	....	2	7	24	3	11	2	....	....	....	9	82
Back	9	27	9	3	5	13	36	3	17	2	....	....	3	26	153
Rib	....	2	....	....	....	....	1	....	1	....	....	....	....	....	4
Leg	9	31	3	1	....	2	21	....	13	....	2	....	....	2	84
Foot	3	6	1	....	3	2	8	3	22	....	1	1	2	3	55
Other Minor	4	2	....	....	....	7	12	2	9	....	....	....	2	6	44
Total Minor	40	106	14	7	19	41	138	14	102	6	3	5	13	56	564
Grand Total	56	120	19	12	22	49	176	16	126	7	3	5	13	61	685

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

TABLE "B"

ACCIDENTS SEGREGATED ACCORDING TO MINERAL MINED AND PROCESSED

Mineral	Men Employed	Accidents		
		Fatal	Serious	Minor
Bauxite (Alumina)	2 590	....	50	124
Coal	860	....	61	494
Gold	1 014	....	43	153
Ilmenite etc.	957	....	40	105
Iron	12 289	3	191	691
Nickel	3 339	8	257	695
Salt	378	1	16	70
Tin	145	....	7	24
Other Minerals	188	....	5	9
Rock Quarries	373	1	15	41
Totals	22 133	13	685	2 406

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	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Pilbara	....	....	....	1	....	....	....	....	....	1	....	54	....	56
West Pilbara	....	....	....	....	....	....	....	....	....	....	2	120	2	120
Ashburton	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Peak Hill	....	....	....	....	....	....	....	....	....	....	1	19	1	19
Gascoyne	....	....	....	....	....	....	....	....	....	....	1	12	1	12
Murchison	....	....	....	....	....	....	....	....	....	....	....	....	....	....
East Murchison	....	....	....	1	5	1	....	....	....	1	....	2	5	5
Yalgoo	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Northampton	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Mount Margaret	....	1	....	2	....	....	....	....	....	11	....	8	....	22
North Coolgardie	....	....	....	....	....	....	....	....	....	....	1	....	1	....
Broad Arrow	....	....	....	2	....	1	....	....	....	8	....	2	....	13
North East Coolgardie	....	....	....	....	....	....	....	....	....	....	....	....	....	....
East Coolgardie	....	....	....	2	....	2	....	....	....	8	....	37	....	49
Coolgardie	....	2	1	24	....	10	....	....	1	93	....	47	2	176
Yilgarn	....	....	....	....	....	....	....	....	....	....	....	3	....	3
Dundas	....	1	....	....	....	....	....	....	....	8	....	7	....	16
Phillips River	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Greenbushes	....	....	....	....	....	....	....	....	....	....	....	7	....	7
South West	....	1	....	....	....	....	....	....	....	....	1	125	1	126
Collie	....	....	....	1	....	....	....	....	....	43	....	17	....	61
Nabberu	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Warburton	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Eucla	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Total for 1977	....	5	1	33	5	14	....	....	1	173	6	460	13	685
Total for 1976	1	4	2	39	1	6	....	1	1	223	6	412	11	685

ACCIDENT STATISTICS

These statistics cover all classes of mining accidents associated with mineral and metal production as reported to the Mines Department.

There were 13 (11) fatal and 685 (685) serious accidents. (The figures for the previous year are shown in brackets.)

A diagram showing the fatal accidents segregated according to class of mining operation and extending over the past 20 years in included in this report. Other tabulations are:

Table A—the number of serious accidents segregated according to the nature of the injury and the mining district in which the accidents occurred.

Table B—the accidents (Fatal, Serious, Minor) are segregated according to the mineral mined and treated, and also indicates the number of men engaged in the mining of each mineral.

Table C—fatal and serious accidents are segregated according to cause and mining district in which they occurred.

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

Name and Occupation	Date	Mine	Details and Remarks
A. F. O'Dwyer (Miner)	13/1/77	Western Mining Corporation Ltd. (Kambalda Nickel Operations)—Silver Lake Mine	He was found at the bottom of an ore pass from a cut and fill stope. A rope attached to his safety belt was broken.
A. W. Schiff (Building construction supervisor)	29/3/77 Died 31/3/77	Texada Mines Pty. Ltd.	The utility vehicle he was driving behind a haulage truck collided with another utility travelling in the opposite direction.
P. Zekic (Miner)	27/4/77	Agnew Mining Company Pty. Ltd.—No. 1 Shaft	The men were in a kibble at the surface ready to be lowered underground when, due to a malfunction of the winding engine mechanism, the kibble was raised at excessive speed and crashed into a beam at the top of the skyshaft, causing the rope supporting the kibble to break and the kibble to plunge to the surface brace.
I. Lokas (Miner)	27/4/77		
R. W. Barclay (Miner)	27/4/77		
Z. Matovinovic (Miner)	27/4/77		
D. Miladinovic (Miner)	27/4/77		
C. K. Gibson (Truck driver)	29/4/77	The Readymix Group (W.A.)—Albany	A section of a steel bin fell on him whilst it was being lifted by a crane.
S. H. Moir (Miner)	30/4/77 Died 6/5/77	Western Mining Corporation Ltd. (Great Boulder Operations)	Assisting to move a reel of rope with a crane and the load moved and hit him on the neck and shoulder.
L. Tuytel (Truck driver)	4/5/77	Mt. Newman Mining Co. Pty. Ltd.—Mt. Whaleback	The 120 tonne truck he was reversing to tip load at waste dump went over the edge.
D. Fredd (Labourer)	14/7/77	Hamersley Iron Pty. Ltd.—Railway	Struck by train propelling on east track whilst track maintenance machines were working on west track of dual lines.
D. J. Wilkins (Track machine operator)	14/7/77		
J. Sundell (Miner)	26/10/77	Anaconda Aust. Inc.—Redross mine	Crushed by a fall of rock whilst barring down the back of the stope.

WINDING MACHINERY ACCIDENTS

Accidents involving winding machinery and the associated equipment were investigated. Action to repair the damage was taken. Brief details are:

Overwinds (3): The crosshead of a sinking kibble in which there were five men, crashed into a beam in the skyshaft of the No. 1 Shaft of Agnew Mining Co. Pty. Ltd. The rope attached to the kibble was broken and the kibble fell to the brace. Faults in the electronic winder control system and the absence of mechanical safeguards were the causes contributing to this accident.

An investigation into an overwind at the Durkin Shaft of Western Mining Corporation Ltd (Kambalda Nickel Operations) showed that the safety control circuit was not effective in a single gear operation. Whilst the second skip was being brought up to the chairing position at the surface, with the winder in single gear, the skip accelerated through the safety zone and into the skyshaft. The rope was detached and the skip suspended. It was necessary to cut the rope and replace the detaching hook assembly.

At the Scotia mine of Western Mining Corporation Ltd (Great Boulder Operations) the winder driver over-ran his mark whilst running the skip down to the No. 12 level prior to hoisting ore. The cage in the other compartment became suspended in the skyshaft. The detaching hook had to be replaced.

Cage/Skip Hang-ups (4): Three of these accidents occurred in shafts operated by Western Mining Corporation Ltd (Kambalda Nickel Operations).

Lengths of rail being brought to the surface in the Jan Shaft snagged in the shaft and dislodged the cage gates. There was no damage to the shaft but rope attachments and gates had to be changed.

Whilst ore was being hauled in the Durkin Shaft the door of the bottom dump skip opened and the ore was emptied down the shaft causing damage to the timbers. The skip and attachments were replaced.

The locking arm on the skip in the Silver Lake Shaft fouled the shaft timbers during ore haulage causing minor damage to the shaft. Inadequate clearance was considered to have been the cause of this accident.

An empty skip derailed whilst descending in the underlay Regent Shaft of Central Norseman Gold Corporation N.L. Two shaft centre legs and an axle of the skip were damaged. It is believed that a stone, which fell from the ascending skip and lodged between the rail and the wall, caused the derailment.

Miscellaneous (3): To facilitate inspection the rope attached to the skip on the Reward Shaft of Kalgoorlie Mining Associates was reeved with one end being secured in the skyshaft and the other end secured by wooden clamps at the collar of the shaft. Whilst in a slack rope condition the rope slipped through the clamps allowing the skip to drop 140 metres on to the pentice. Worn timber blocks in the clamps contributed to this incident. Minor damage resulted to the shaft but the skip and rope had to be replaced.

The sheave wheel assembly and pedestal bearing were replaced when the shaft on the head sheave broke adjacent to the bearing at the Otter Juan haulage shaft of Western Mining Corporation Ltd (K.N.O.).

During the sinking of the Jan Shaft of Western Mining Corporation Ltd (K.N.O.) the winding engine was used to remove formwork from the cured concrete in the shaft, and in one incident the formwork was allowed to fall to the bottom of the shaft. No-one was injured. The cause was attributed to inattentive driving of the winding engine.

Decline Accidents (4): Three of these accidents occurred in declines at the Kambalda Nickel Operations of Western Mining Corporation Ltd. Two were in the Hunt decline. The driver of an empty truck being driven down the decline found the vehicle pulling to one side. He stopped the vehicle and found that four bolts securing the steering rod bracket had sheared off. In the other accident an L.H.D. diesel engined loader tipped on to its side whilst dumping a load at an underground stockpile. The driver stated that he drove over a large rock whilst the bucket was being raised. No injuries resulted from either accident. The third accident occurred in the McMahon decline when a diesel engined jumbo drilling rig which was being driven down the decline accelerated and crashed into the wall. Foot brake failure was due to a fractured hydraulic line.

Seizure of the brakes due to excessive wear is believed to have been the main cause of an accident to a diesel engined Wigbus which was being driven down the decline at the Mt. Charlotte mine of Kalgoorlie Mining Associates. When the driver applied the brakes the bus slid into the wall of the decline No-one was injured.

PROSECUTIONS

Complaints for breaches of the Mines Regulation Act and Regulations were made with the following results:

A supervisor in charge of shaft sinking pleaded guilty to breaching regulations 15.25, 15.28 and 15.64 contrary to Section 30(3) of the Mines Regulation Act, 1946–1974. Section 30(3) provides that where an offence is proved to have been committed with the consent or connivance of, or to be attributable to any neglect on the part of the owner, agent, manager, or supervisor he as well as the person who committed the offence shall be guilty of the offence. He was fined a total of $60.00 with costs of $12.30.

Complaints were also laid against the shaft sinking contractors and four other persons for breaches of the regulations in the same incident but the hearings were adjourned until April 20th, 1978.

CERTIFICATES AND PERMITS

Certificates of Exemption: Nine certificates were granted under Section 46 of the Mines Regulation Act.

Sunday Labour Permits: Twelve permits were issued covering 21 shifts and involving a total of 111 men. The permits were granted in order to avoid loss of time in the subsequent working of the mine, and safety, and were given for: removing raise bore cuttings in a decline; installing electrical gear in a decline; installing pump and cables; replacing the ventilation duct in a decline; installing a pump column and to plug off an inflow of water; safety work on a sinking stage; installing electric cable in a shaft; concreting a plat and grizzly area; installing a loading station in a shaft; removing pentices from shafts; and to stabilise ground above steel sets in a decline.

Permits to Fire Outside Prescribed Times: Only one permit was issued and this was to the Agnew Mining Co. Pty Ltd during the sinking of the Main decline. It was conditional on the posting of warning notices to prevent persons entering the area and suitably dispelling the resulting blasting fumes.

Authorised Mine Surveyor's Certificates: The Survey Board issued 21 certificates during the year. Five of these were for initial certificates and the remainder were issued to those who were previously registered but sought authorisation under the new regulations as required by Regulation 10.4 of the Mines Regulation Act, 1946–1974. Certificates were issued as follows:

A. C. Cruickshank—Certificate No. 014.
D. M. Harken—Certificate No. 015.
J. E. Maisey—Certificate No. 016.
A. R. McGee—Certificate No. 017.
B. S. Patterson—Certificate No. 018.
K. J. Phillips—Certificate No. 019.
N. E. Rollo—Certificate No. 020.
P. M. Wreford—Certificate No. 021.
J. C. Argus—Certificate No. 022.
D. M. Attrill—Certificate No. 023.
J. L. Denison—Certificate No. 024.
J. M. Faichney—Certificate No. 025.
C. E. Ion—Certificate No. 026.
A. J. M. Knox—Certificate No. 027.
N. W. Lindfield—Certificate No. 028.
A. W. Ibbotson—Certificate No. 029.
A. V. Pegler—Certificate No. 030.
E. F. Shenton—Certificate No. 031.
E. G. Timoney—Certificate No. 032.
J. C. McDermott—Certificate No. 033.
K. R. Hales—Certificate No. 034.

Mine Inspection: The operations and details of metalliferous mining are contained in the reports of the Mining Engineers-Senior Inspector of Mines responsible for the Inspectorates based on Kalgoorlie, Port Hedland, and Perth. Coal mining is covered in the report of the Mining Engineer-Senior Inspector of Coal Mines based at Collie.

The working places on all mines were inspected in accordance with the requirements of the Mines Regulation Act and the frequency of inspections were generally similar to previous years.

A vacant position as a District Inspector of Mines in the Kalgoorlie Inspectorate has been difficult to fill whilst another position as a District Inspector at Port Hedland became vacant about the middle of the year and a replacement was not obtained until early 1978. Another District Inspector also resigned from the Branch late in the year.

The administration of the new mining regulations, introduced in 1976, has proceeded satisfactorily, although some minor problems have been raised. Some minor amendments may be necessary.

Ventilation: All mines, crushing and treatment plants throughout the State were inspected by the ventilation staff and determinations of dust concentrations by gravimetric methods and dust counts were made. Temperatures and humidity conditions, and ambient gas levels were checked at underground working places.

The mining regulations now require that the ventilation of the underground workings of a mine in which a diesel engine is used and in any other workings underground when required by the District Inspector shall be under the control and daily supervision of a Ventilation Officer appointed by the Registered Manager of a mine. The control and suppression of dust and contaminant emissions in quarries and surface mining operations, when required by the District Inspector of Mines, are also to be under the control and supervision of a Ventilation Officer. This requirement places the responsibility on the Registered Manager of the mine to provide adequate ventilation and the Branch's ventilation staff will collect dust samples measure temperatures etc. to check the results of sampling etc. undertaken by the Company's ventilation staff.

Both positional and personal dust sampling has been undertaken by the Branch's ventilation staff and a total of 1 166 gravimetric dust samples were collected from all sources. Thirty per cent of these samples exceeded the Threshhold Limit Value for the particular dust sampled. Four hundred and forty-eight konimeter samples were also taken, and most of these were in underground mines where diesel engined equipment was not in use. Twenty-five per cent of these samples had a count in excess of 300 particles per cubic centimetre.

Some of the hard rock mobile crushing plants being operated in country areas are now being provided with pressurised cabins from which the operators can control the crushing and screening units. The provision and use of water on these plants has also improved considerably. Wet screening of crushed rock with the recycling of water is increasing and is an effective method of reducing dust in crushing plants.

It is also becoming standard for vehicular equipment in quarries to be fitted with cabins and equipped with air conditioners which serve to pressurise the cabins and thereby minimise the amount of dust entering. Working conditions in hot harsh climates are also improved considerably.

Ventilation officers employed by the mining companies have been assisted by the Branch's staff and short one-day courses were conducted in Perth and Karratha to instruct in the techniques of gravimetric dust sampling, weighing, and the interpretation of results.

Fifty-three new permits for diesel engined equipment were issued in the Kalgoorlie inspectorate. Several new types of diesel engined equipment were introduced into underground mining operations and included a forklift, a compactor for sandfill, a hydraulic jumbo drilling rig, air compressors, a diamond drill, and a power pack for use with raise bore drills.

Routine sampling of the undiluted diesel exhaust gases for carbon monoxide and nitrous gases were undertaken by the Branch's Ventilation Officers. A total of 416 vehicles were tested and only 2·2 per cent had results in excess of 2 500 p.p.m. carbon monoxide and 3·6 per cent exceeded the limit of 2 000 p.p.m. allowed for oxides of nitrogen. However it was necessary to have many vehicles withdrawn from service and sent to the workshops due to poor maintenance. Operators are required to ensure that vehicles are kept fully roadworthy.

Generally both primary and secondary airflows in underground mines were found to be satisfactory but on two occasions, at separate mines, gross recirculation of the primary circuits occurred. Assistance was given by the Ventilation Officers to carry out extensive underground airflow surveys and suggest corrective action, and were instrumental in assisting to avert work stoppages.

In all underground mines using diesel engined equipment for development purposes management were instructed to ensure that ventilation dusting was maintained within 15 metres of the face. High dust counts were regularly recorded in areas where ducting was not kept up to the working area.

Attention has been given to the handling of cyanide, xanthate, litharge and to the working areas on mines where thallium, mercury, antimony and arsenic are used or encountered. Drums of cyanide are now opened by a pneumatic tool and a mechanical tipping device has been constructed at one mine. The use of extractor fans and ducting in sample preparation rooms where litharge is used and the incorporation of bins with bottom discharge for flux has minimised the exposure of employees to this dust hazard.

Nineteen persons were affected by fumes in 13 separate accidents, but fortunately none were fatal. Thirteen persons were affected by carbon monoxide created by blasting of explosives and from diesel engine exhaust fumes; three from sulphur dioxide; one by hydrogen cyanide; and two by hydrogen sulphide. All accidents were investigated.

GENERAL

Seven mine fires occurred and were investigated. Two were in disused shafts known as Mortys and Horsehoe No. 4 on the Golden Mile. The cause is not known. Two fires were on diesel engined vehicles in use underground at the Mt. Charlotte mine of Kalgoorlie Mining Associates. Grease on an exhaust pipe on a loader ignited in one incident and in the other a burst hydraulic hose caused oil to squirt onto the turbo charger of a truck, and ignite. Both of these fires were quickly extinguished and no damage resulted. A small fire occurred in the discharge piping and air receiver of the No. 4 compressor at Mt. Charlotte. The fire was confined to the discharge section of the compressor and was caused by a defective valve. A fire occurred on a loader at the Redross mine of Anaconda (Aust.) Inc. and caused considerable damage. It was attributed to an electrical fault but the area was

so badly damaged that the precise cause could not be determined. A fire on a loader in the McMahon decline of Western Mining Corporation Ltd (K.N.O.) was due to a burnt out seal in the pre-combustion chamber. The fire was quickly extinguished. These incidents accentuate the need for adequate fire precautions and the equipping of diesel engined vehicles with suitable fire extinguishers.

The portable Sprengnether Seismograph was used regularly throughout the year to measure ground vibrations from blasting. Recordings were made for the Metropolitan Water Board to ensure that blasting for trenches for water mains in the Hills area were not excessive to cause damage to adjacent residences, and again at Mullaloo where blasting took place for the ocean sewerage effluent outlet. Measurements were taken for Westrail from blasting in a quarry near Meckering, and blasting in the Muja Open Cut at Collie was monitored for Griffin Coal Mining Company Ltd. Complaints about blasting by the Readymix Group at Gelorup were also investigated and ground vibrations measured. Pillar blasts at the Mt. Charlotte mine of Kalgoorlie Mining Associates and the Windarra mine of Western Mining Corporation Ltd were also recorded. Complaints about blasting were also investigated without recourse to measurements as considerable information has been obtained over the past 15 years of experience with blasting and the resulting ground vibrations.

Most of the matters appertaining to rehabilitation of mined areas were referred to the Mining Engineer-District Inspector of Mines (Rehabilitation). The principal areas of activity were in mineral sands and tin mining but on occasions his attention was directed to the activities undertaken for bauxite, clay and natural sand, although the rehabilitation of bauxite areas is by negotiation between Alcoa of Aust. (W.A.) Ltd and the Forests Department, and the clay and sand pit operations are generally subject to conditions laid down by the respective local government authorities.

The mineral sands mining companies in the Stratham-Busselton area have contoured, covered with top soil and seeded a total of 117 hectares of ground and in addition have contoured a further 28 hectares, and seeded areas previously restored. Western Titanium Ltd have established excellent pastures and have created lakes and wetland settings which are attracting considerable wildlife. Rehabilitation of the areas mined by Westralian Sands Ltd in the Yoganup area is now progressing satisfactorily. Their programme did not commence until 1975. The mining operations of Cable Sands Pty Ltd at Stratham will be completed in 1978 and the rehabilitation of the area should be finalised soon after.

At Eneabba, Jennings Mining Ltd contoured, covered with top soil and seeded 70 hectares of restored ground during 1977 but were unfortunate when the wall of a tailings dam failed and permitted sand and slime to move downhill and cover a large area of rehabilitated ground. Allied Eneabba Pty Ltd contoured, covered with top soil and seeded 28·5 hectares of ground and contoured a further six hectares. This company is bound to restore the area with native plants but early efforts have been directed to the stabilisation of the restored areas with cereal crops. Trial plots have been established to monitor plant regeneration under varying conditions. Western Titanium Ltd have established trial plots in this area also.

Although the operations of W.M.C. Mineral Sands Ltd in the Jurien Bay area have ceased the rehabilitation work is continuing and 80 hectares were attended to in 1977 and will be continued until the property is acceptable to the owner.

Most of the mineral sands mining groups have appointed qualified agronomists to their staff to direct rehabilitation procedures.

Greenbushes Tin Ltd continued to rehabilitate current and previously mined areas in accordance with their agreement with the Government. A full time agronomist has been appointed to the company's staff and he has established a nursery to cultivate local as well as other suitable native plants.

METALLIFEROUS MINING OPERATIONS— PORT HEDLAND INSPECTORATE

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

Despite the news of a downturn in the mining industry generally and the reduction in demand for iron, little effect has been felt in this inspectorate over the year.

Increased employment has been reported from both the iron ore companies and the two gold mining companies, although late in the year it was announced that Mulga Mines Pty Limited's Blue Spec mine near Nullagine would cease operations early in 1978, thus about 110 men will lose their present jobs.

Total reported employment in the industry is just over 12 400. This figure does not include men employed in those companies which quarry blue metal for roads and railway ballast, and move their mobile plants on completion of relatively short term contracts.

It is estimated that a further 100 men are working in this extractive industry bringing the estimated total to 12 500 in the inspectorate.

EXPLORATION

Some hundreds of applications for mineral claims and other mining tenements were dealt with throughout the year, particularly in the Kimberley Goldfield where a number of international consortiums have been carrying out exploration programmes for some years. At least one party intends entering the secondary stage in 1978 and plans to build a small plant for further testing for minerals.

BARITE

Dresser Industries employed five men at the North Pole mine, but did not mine any ore. The camp was relocated to a site close to the deposits and extensions and alterations were made to the plant.

At the grinding mill in the wharf area in Port Hedland about 4 000 tonnes of barite was ground to a powder. Four thousand six hundred tonnes of ore was carted from the mine stockpiles to Port Hedland for this purpose. The company hope to receive large orders and recommence mining once the offshore drilling commences.

CRUSHED ROCK

Readymix Group (W.A.) completed quarrying and crushing 135 574 cubic metres of ballast for the Newman railroad at Quarry 6, Sandhill, then moved to Quarry 4, at Redmont where they completed quarrying and crushing a further 72 280 cubic metres of ballast for the railroad before ceasing operations in this inspectorate.

GOLD

Mulga Mines Pty Limited operated the Blue Spec mine near Nullagine throughout the year. Of the 38 804 tonnes of ore broken, 36 147 tonnes treated yielded 552·424 kilos of gold plus 930·5 tonnes of 60 per cent antimony concentrate.

Development completed consisted of: 442·5 metres of decline; 21·1 metres of driving; 142·5 metres of crosscutting; 31·3 metres of winzing and 100·4 metres of rising.

One hundred and eighty-four metres of exploration diamond drilling was completed.

This mine was the first in this area to employ females in the general workforce. Of the 91 employees, about 6 are young women. They have proved to be efficient in the treatment plant where one became a shift foreman.

A director stated that the mine would cease production early in 1978.

Near the end of the year, a large stock of bagged antimony concentrates remained on the surface as the company could not find a market.

Telfer Project of Newmont Pty Ltd. This mine is situated in desert country east of the Oakover River and is approximately 220 kilometres at 086°, from Nullagine near the Patterson Range, at latitude 21°45' S, longitude 122°13' E.

The portion of the ore body being worked is flat dipping. Quest Mining remove the overburden and the company follows through removing the ore.

A total of 7 746 550 tonnes of waste and ore was broken during the year and about 300 000 tonnes of ore treated.

The village has been completed and accommodates 39 staff members, 143 other employees plus the families of the married staff and employees.

The operation is similar to a quarry, the ore being hauled by trucks to a stockpile or directly fed into the bin at the primary crusher, while the overburden is hauled by truck to the waste dump.

A number of young women are employed as truck drivers and in the plant.

A decline in gold prospecting is noted, but there are still a number of men at various centres.

IRON

The iron ore industry is the mainstay of the area.

Figures from the five companies show: a rise of 1 115 in number of employees to a total of 11 747; a rise in total break of ore and waste of 24 780 000 tonnes to 181 572 000 tonnes.

Although the ore broken increased by 17 512 000 tonnes to 119 746 000, ore shipped fell slightly by 762 000 tonnes to 83 517 000 tonnes.

Production and Shipping (Million Tonne Units)

Company	Persons Employed	Ore Broken	Ore Shipped			Total
			Lump	Fines	Pellets	
Hamersley Iron	4 332	52 426	14 220	16 891	2 007	33 118
Mt. Newman	4 075	43 855	14 443	13 049	....	28 998*
C.R.R.I.A.	1 584	14 060	....	8 728	3 683	12 411
Goldsworthy Mining	1 349	6 814	3 130	3 263	....	6 393
Dampier Mining	407	2 591	229	2 368	....	2 597
Total	11 747	119 746	32 022	44 299	5 690	83 517

* Included in total for Mt. Newman Mining Co. Ltd. is 1 058 high grade plus 0 448 low grade "run of mine" ore (—30 mm).

Hamersley Iron Pty Limited. The mine sites at Tom Price and Paraburdoo are open cut and at each centre produce lump ore and fines which are railed 400 km to the port at Dampier where pellets are produced from the high grade fines.

Tom Price. Mining took place over 13 operating benches each of 15 metres in height; the major items of equipment being 8 x 9 m^3 shovels, five rotating drills, 3 ANFO pumper trucks for charging holes and 31 Haulpak trucks for carting.

The crushing and screening plant capacity is 25 million tonnes per annum.

Construction of a beneficiation plant is in progress. This will double the previous machinery when completed.

Paraburdoo. Mining took place over seven benches of 14 metres height, the major items of equipment being six x 9 m^3 shovels, three rotary drills, two ANFO pumper trucks and 14 x 150 tonne Haul trucks.

The treatment plant has a capacity of 17 million tonnes per annum.

Dampier. At the port, the stockpile at Parker Point has a capacity of 1·4 million tonnes and the berth can handle ships up to 130 000 DWT.

The newer facility at East Intercourse Island has stockpile capacity for $1{\cdot}6 \times 10^6$ tonnes and can accommodate ships up to 160 000 DWT. Stockpiles at Parker Point also cater for the 2·8 million tonne per annum capacity pellet plant.

Mt. Newman Mining Co Pty Limited. The ore is mined at Mt. Whaleback near Newman townsite. Drilling of the 15 metre benches is carried out using 14 Bucyrus Erie 60R drills and ANFO used for blasting and the broken material loaded by 20 shovels into 53 x 120 short ton and 17 x 200 short ton Haulpaks.

Low grade and waste material is hauled to different dumps while the ore passes through primary and secondary crushing before being railed 420 km to Port Hedland for tertiary crushing and screening at the plant at Nelson Point.

At Mt. Whaleback new plant installed included: 2 x P & H 2800 shovels; 4 x P & H 2100 B.L. lower carbodies and 1 x WABCO 120C Haulpak.

New developments included: an extensive programme of personal dust monitoring; substantial additions to the mine water reticulation system, and further testing of the bucket wheel excavator at Ore Body 29 and the shipment of bulk samples of special blended fines (85 per cent Mt. Whaleback and 15 per cent Marra Mamba).

In the Newman townsite 116 houses and 32 flats were completed and a further 48 houses commenced.

Surface development on the mine included 2 800 metres of new benches, 2 200 metres of ramps and 2 000 metres of haulroads.

At Nelson Point new plant and equipment included: a Fiat tractor for clean up in tunnels; fixed spray dust suppression system covering 60 per cent of the stockpile area; completed fitting of roll-over bars and air conditioning of mobile equipment; one Cat. 988 F.E.L. for track maintenance; one Speno Grinder for track maintenance, and three new ALCO locomotives for railroad operations.

One hundred and forty-two new houses were completed and 36 new flats commenced during the year.

Cliffs Robe River Associates. The ore is mined at Pannawonica and railed direct to Cape Lambert where all processing is carried out to produce pellets and fines.

The mine is single bench operation on mesa caps 20 metres or less in height. A new 2·9 km access road was formed to the 2400F mesa.

Work commenced during the year to upgrade all facilities from the mine to the shiploading to bring capacity up to 20 million tonnes per annum.

At Pannawonica townsite 11 houses and one nine-room single girl's quarters were completed and 35 houses and 36 single men's quarters commenced.

At Wickham nine 12-bedroom single men's quarters were completed and 35 houses commenced.

Goldsworthy Mining Limited. One open pit is operated at Goldsworthy and at Shay Gap centre a number of relatively small deposits at Shay Gap and Sunrise Hill.

Primary crushing is done at the two centres before the ore is railed to Finucane Island for secondary and tertiary crushing and shiploading.

Operations were seriously affected in April through railroad washouts as a result of cyclone "Leo" passing between Port Hedland and Goldsworthy.

At Goldsworthy, 575 metres of benches; 1 173 metres of ramps and 716 metres of haulroads were formed during the year.

At Shay Gap, 1 855 metres of benches, 1 968 metres of ramps and 1 020 metres of haulroads were formed.

New plant included one Cat D9 dozer and one Cat 988 front end loader.

A new 16 berth caravan park was opened at Goldsworthy.

Dampier Mining Company Limited. The company operates on Cockatoo and Koolan Islands in Yampi Sound.

Cockatoo Island. This orebody was the original one mined and has been almost mined over its length down to the high water level. The ore body is on the southerly shoreline and a feasibility study to determine a viable method to mine the ore below the sea level is at present being conducted.

Koolan Island has five known ore bodies of which two are currently being mined.

The main ore body is open cut on a 12 metre bench system and a new bench has been commenced at R.L. of 74 metres above sea level.

The Acacia orebody is developed on a 10 metre bench system.

Primary drilling is carried out by three rotary drills while percussion drills are used for secondary drilling.

Blasting is mainly with ANFO and Cordtex with non-electric firing.

Electric shovels, an hydraulic shovel and rubber tyred front end loaders dump into haulage vehicles.

The ore bin is crushed to —64 mm and stored in a 60 000 tonne ore bin.

New plant includes an RH 75 hydraulic shovel; two Euclid 85 ton dump trucks and two Dart D-600 front end loaders.

SALT

Reported production of salt totalled 3·135 million tonnes and shipments 3·145 million tonnes. Total number of employees is 276.

Texada Mines Pty Limited. operate on Lake McLeod North of Carnarvon, company employees living either in Carnarvon or at the minesite.

After treatment, the washed product is transported by road-trains 24 km to Cape Cuvier where it is stockpiled prior to shipment.

New conveyors have been erected at Cape Cuvier to increase stockpile capacity.

The radial stacker was dismantled and re-erected at the washplant site to facilitate increased stockpiling.

Dampier Salt Limited—Dampier. Operations continued throughout the year and in general conditions are similar to the other two operating companies.

Leslie Salt Co.—Port Hedland. The workforce remained the same as last year. Four new crystallizers were prepared during the year but to date only one is in use. A fourth washline was added during the year.

TIN

Production figures are not available but activity has been continuous near Moolyella where Pilbara Concentrates employ about 12 men.

At Spear Hill, the Challenger Mining Group Limited in a joint venture known as the Shaw River Tin Project under an option agreement with J. A. Johnston & Sons Pty Limited carried out exploration and trial production tests. They completed tests and left the area about the end of the year. Their future plans are unknown.

Several individual prospectors have been partly active during the year.

PERTH INSPECTORATE

Mining Engineer, G. J. Dodge Senior Inspector of Mines

Most mineral producers in the Perth Inspectorate are still being affected by the general slow down in mineral demand by the manufacturing countries. As a result, there has been a tendency to cut capital spending, production, and in many instances, the number of personnel employed. One mine, W.M.C. Mineral Sands at Jurien, ceased operations and placed the plant on care and maintenance. No new major mines commenced operations during the year.

ALUMINA

Alcoa of Australia (W.A.) Ltd. Alcoa's three mine sites produced 12 307 000 tonnes of bauxite from 138·05 hectares of land. The two refineries produced 3 470 000 tonnes of alumina or 11·4 per cent more than in 1976.

During 1975, Alcoa installed an Oxalate removal plant because of the detrimental effects of the sodium oxalate upon the chemical processes utilised in the extraction of the alumina. Sodium oxalate is formed by the chemical interaction of the caustic solutions and the organic material introduced with the bauxite.

The sodium oxalate was sent to the mud lakes but again caused problems when it returned with the liquor recovered from the lakes. To overcome this problem, a $500 000 furnace was under construction during the later part of 1977. Commencing early in 1978, sodium oxalate from the oxalate removal plant will be burned in the furnace to produce sodium carbonate. The carbonate will be dissolved in water and then causticised with lime to form sodium hydroxide which will be utilised in the process.

At Kwinana, salvage of caustic solution from mud lakes A, B and C to stop the pollution of the surrounding country and ground water was continued throughout the year. The method of removal is by the Eductor System.

1977 was the first full year of exports through Bunbury. Thirty-six vessels loaded 1·1 million tonnes of alumina from the company's shiploading complex.

Alcoa purchased land south of Waroona as the site for a new refinery to treat bauxite from the proposed Wagerup mine sites.

Design studies and an environmental impact statement were commenced during the year.

BUILDING STONE

Production of crushed aggregate for concrete and road building materials remained steady, relative to 1976 production. The 1976 upsurge in rail ballast requirements was maintained until the middle of the year, but then ceased altogether. This was replaced by a requirement for large armour stone and rock filling which will continue throughout 1978. An average of 220 persons were employed on these quarry sites throughout the year.

Avon Quarries—Northam. Operations continued throughout the year for a production of 10 700 m³ of crushed aggregate.

Bell Basic Industries Ltd. Bell's operated quarries at Maddington, Wungong and Yatupa.

Production from Maddington increased slightly to 742 000 tonnes of sized aggregates. The work force remained constant at 47 persons.

The Yatupa Quarry is on the banks of the Greenough River and approximately 30 km south east of Geraldton.

Armour stone for the Port Denison fishing harbour groyne is the only product removed from the site at present.

At Wungong, Bell's commenced production of some 800 000 m³ of rock fill for the construction of the Wungong Dam. A further 500 000 m³ of earth and clay is being excavated from borrow pits for blending with the rock. Bell's are subcontracting to John Holland (Constructions) Pty Ltd who are the contractor's for the construction of the dam.

Bruce Rock Shire Council. The council owned quarry at Bruce Rock operated during the summer to produce 7 400 m³ of crushed aggregate. The Shire maintains a stable workforce by utilising the quarry personnel on road construction and maintenance during the winter months.

Pioneer Concrete (W.A.) Pty Ltd. The Herne Hill and Walkaway quarries operated continuously throughout the year for a production of 824 000 tonnes of screened aggregate.

Pioneer commenced the construction of a new crushing and screening plant in the hills approximately five kilometres south of Byford. The plant is situated in a valley and will be completely hidden from the South West Highway. Production is expected to commence in March, 1978.

The Readymix Group (W.A.). Readymix operated quarries at Gosnells, Gelorup, Albany and Ejanding. The Ejanding quarry was opened up to fulfil a railway ballast contract and operated for approximately 5 months. The Gosnells and Gelorup quarries operated continuously, whereas the Albany quarry closed down in March after replenishing stockpiles.

CLAYS AND SHALES

The Midland Brick Company Pty Ltd continue to be the largest single producer of clay and shales. Their pits are located in the Toodyay, Herne Hill, Bullsbrook and Muchea districts. Production for the year was 690 343 cubic metres.

Other producers accounted for approximately 86 000 cubic metres. Average number of men employed in the industry is 65.

COPPER

At Golden Grove, the Electrolytic Zinc-Amax joint venture completed its diamond drilling programme at the end of June. No mining is likely until a considerable improvement occurs in the price of copper.

EMERALDS

Emerald Mines of W.A. This company was formed to reopen and mine emeralds from the Aga Khan Mine. A considerable quantity of money was spent de-watering the mine, repairing the shaft and setting up a small electric winder.

The plant had been modified and by the end of June all was in readiness for development mining to commence. At this stage, all underground work was ceased and had not recommenced by the end of the year.

Mr. R. Bellairs is still obtaining emeralds from surface workings and has reported the recovery of 13 830 carats for the year.

FELSPAR

Chandilla Exploration and Investments Pty Ltd produced 463 tonnes from Goodingnow in the Yalgoo District while Snowstone Pty Ltd produced 182 tonnes from their Mukinbudin quarry.

GARNET

Target Minerals N.L. This company has been conducting exploration and test work on garnet bearing sand dunes near Port Gregory. A trial parcel of 849 tonnes was treated at the Northampton State Battery for a recovery of 488 tonnes of garnet concentrates. Sample shipments have now been forwarded to potential buyers to determine market acceptability.

GOLD

Meekatharra District. The Meekatharra State Battery treated 3 063 tonnes of ore for a recovery of 42·503 kg of gold.

A five man syndicate is obtaining excellent recoveries from the "Ingliston Consols" on G.M.L. 51/2139. Seven hundred and twenty-five tonnes of ore were treated for a recovery of 37·431 kg of gold. Most of this ore came from a shoot above the No. 5 level, but this has now been worked out. The Syndicate then sank a 30 metre winze below the No. 5 level. High gold values persisted throughout its entire depth.

Open cut ore from the Haveluck, G.M.L. 50/2015 accounted for 1 202 tonnes which returned 2·348 kg of gold. Although this ore yielded only 1·95 grams per tonne, it is very oxidised and hence easy to mine and crush. It is also within a kilometre of the Battery.

Other parcels treated at the battery were 900 tonnes from the Halcyon (G.M.L. 50/2068) for a return of 1·597 kg and 230 tonnes from G.M.L. 55/2200 at Nannine for a return of 360 gms of gold.

Mount Magnet District. A small syndicate spent several months de-watering and refitting the shaft of the Empress Gold Mine. At the end of the year they had commenced winze sinking below the 76 m level.

Western Mining Corporation Ltd commenced a programme of geophysical surveying and diamond drilling on the Hill 50 Gold Mine leases.

Paynes Find. The Ark Gold Mine closed down during the year after an unsuccessful attempt to find new ore. At the 60 m horizon, a south drive penetrated 15 m along the shear zone without success. No ore was recovered from the mine during the year. Plans are in hand to re-open the mine during 1978.

GYPSUM

Gypsum Industries of Australia Pty Ltd produced 27 814 tonnes from Lake Cowcowing.

ILMENITE, LEUCOXENE, MONAZITE, RUTILE, XENOTIME AND ZIRCON

Most mineral sand miners experienced another difficult year. The apparent improvement indicated by the overall increase in mineral production over 1976 figures (227 000 tonnes) is not a true picture of the situation. This increase was primarily brought about by the Eneabba mines achieving design production early in the year. Plant expansions and improvements at some of the Capel mines during 1975/76 also resulted in higher outputs during the first half of 1977.

However, by mid 1977 a major over-supply, particularly of zircon, forced many companies to drastically cut production. Some 220 personnel were dismissed as a result of these cuts.

Capital expenditure was virtually restricted to completing projects commenced or planned in 1975/76.

By the end of 1977 ilmenite shipments were improving, but zircon stockpiles continued to grow. Most companies raised their mining cut off grade and where possible, mined low zircon ore.

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.	190	4·749	238 630	....	3 204	48 629	....	87 687	378 150
Cable Sands Pty. Ltd.	71	0·750	116 241	2 908	292	....	....	7 233	126 674
Jennings Mining Ltd.	204	3·841	139 568	....	....	36 313	....	21 951	197 832
*W.M.C. Mineral Sands Operation	40	....	....	....	....	3 770	....	2 790	6 560
Western Mineral Sands Pty. Ltd.	45	0·974	209 841	....	....	....	....	....	209 841
Westralian Sands Ltd.	116	1·034	113 110	9 322	2 744	....	....	20 915	146 091
Western Titanium Ltd. (Capel)	184	1·536	204 664	1 922	1 665	998	12	19 532	228 793
Western Titanium Ltd. (Eneabba)	170	2·130	31 877	....	....	20 913	....	29 666	82 456
	1 020	15·064	1 053 931	14 152	7 905	110 623	12	189 774	1 376 397

NOTE:—Minerals recovered from concentrates mined in 1976.

Allied Eneabba Pty Ltd. Production of 378 000 tonnes of minerals was achieved from the treatment of 4 749 000 tonnes of ore and the re-treatment of 10 000 tonnes of concentrates. This is an increase of 102 000 tonnes of mineral production over the previous year and is approaching the designed capacity of the plant. Whereas most companies have had to deliberately reduce production, Allied have endeavoured to achieve designed output as they are fortunate in having a firm market for their ilmenite production.

Towards the end of the year the company commenced construction of an additional zircon storage shed with a capacity of 62 000 tonnes.

Cable Sands Pty Ltd. From their Stratham and Wonnerup mine sites Cable's excavated and treated 750 000 tonnes of ore. Mineral production totalled 127 000 tonnes.

The Stratham ore body will be depleted during the first quarter of 1978. Development of a new mining operation at Ambergate, six kilometres south west of Busselton, has commenced. The Stratham wet plant will be re-located at Ambergate, but will be land based.

An ilmenite storage shed with a capacity of 35 000 tonnes was constructed at the Bunbury Treatment Plant. This will eliminate many of the problems being experienced as a result of stockpiling in the open.

Jennings Mining Ltd. The down turn in the mineral sands market forced the closure of the Dunal Plant during August. The throughput capacity of the Strand Plant was increased from 150 to 200 tonnes per hour to maintain the required production balance. Even so, at least 65 persons were dismissed as a result of the closure.

Jennings mined and treated 3 841 000 tonnes of ore and produced 198 000 tonnes of saleable minerals.

W.M.C. Mineral Sands Operation. Following the cessation of mining in late 1976, the treatment plants closed down on the 31st May, 1977 and were placed under care and maintenance.

During the five months of operations the company treated 68 562 tonnes of concentrates for a recovery of 3 770 tonnes of rutile and 2 790 tonnes of zircon.

A skeleton staff has been left in the area to maintain equipment and to continue with rehabilitation. All surplus equipment and housing has been sold.

Western Mineral Sands Pty Ltd. During 1977 mining reached the southern end of the ore body. A new mining pit was commenced just north of the dry plant. The dredge was put up for sale and the company has reverted to dry mining methods.

Self loading scrapers haul the sands to a receiving hopper from which they are fed into the wet screening system at a controlled rate. The "floating" wet plant has been modified to operate as a land based plant.

During the two month change over, stockpiled heavy mineral concentrates were used to maintain mineral production.

The company became a wholly owned subsidiary of Westralian Sands Ltd during 1977.

Westralian Sands Ltd. Westralian Sands continued to operate well below capacity with a production of 146 000 tonnes of minerals.

The oil fired burner on the heavy mineral concentrate dryer was replaced with a coal fired combustion chamber utilising Collie coal.

Westralian Sands Ltd announced a share merger which resulted in Western Mineral Sands and Ilmenite Pty Ltd becoming wholly owned subsidiaries of Westralian Sands. At the same time, Tioxide Australia Pty Ltd acquired 40 per cent of the issued capital of Westralian Sands. The merger is expected to benefit the company in the marketing and sale of its products.

Western Titanium Ltd (Capel). In July the company retrenched 42 employees and made some cut-backs in production. Even so, the previous year's figures were slightly exceeded with a recovery of 229 000 tonnes of minerals. Ore mined totalled 1 536 000 tonnes.

In the dry plant, the high tension cleaning circuit was upgraded by the addition of nine single pass, 250 mm, high tension rolls.

Ilmenite feed for the beneficiation plant is now railed from Eneabba. The existing coal unloading facility was upgraded by fitting an additional hopper and conveyor system, capable of handling 800 t.p.h., feeding a storage bin of 2 000 tonne capacity.

Western Titanium Ltd (Eneabba). The company is progressively changing over from its dozer/conveyor combination of mining and transportation to a scraper/pumping combination.

The original system proved completely inadequate to the task, primarily because of the inability of the system to handle the lateritic rock which occurs in the ore body. Self powered scrapers will load and haul the ore to a receiving hopper. From the hopper, it will be fed to a wet screening plant to wash and remove the rock. The sands will then be pumped to the wet plant.

The Geraldton storage silos were completed and are now fully operational.

During the year, the company mined 2 180 000 tonnes of ore and produced 82 000 tonnes of saleable minerals. The operation only produces sufficient ilmenite to meet the Capel Beneficiation Plant requirements. A "magnetics" concentrate containing the bulk of the ilmenite is stockpiled at the plant site and would require further separation for the production of ilmenite.

IRON

The declining market for pig iron was again reflected in a further drop in production by the two pig iron producers

Australian Iron and Steel. Pig iron production was 614 300 tonnes from the processing of 1 025 000 tonnes of iron ore. This represents a fall of 11½ per cent on the previous year's production. The number of personnel employed remained constant at 350.

Wundowie Iron and Steel. 45 248 tonnes of pig iron were produced from the processing of 72·861 tonnes of iron ore. This represents a fall of 22 per cent on the previous year's production.

An average of 62 persons were employed.

LEAD

No lead mining took place in the Perth Inspectorate during the year. However, a three man syndicate purchased the Mary Springs Lead Mine and completed de-watering operations.

NICKEL

Western Mining Corporation Ltd. Nickel production was cut drastically with only 16 700 tonnes being produced. This is only 55·5 per cent of the designed output of the refinery. By-products produced were:—ammonium sulphate 114 121 tonnes; copper sulphide 2 292 tonnes and mixed sulphides 960 tonnes.

The average number of persons employed fell by 29 to 444.

SALT

During the year the Perth Inspectorate was enlarged to include that portion of the Gascoyne Mining District below the 25° South Latitude. This has meant the inclusion of the Useless Loop Salt operation of J. O. Clough and Son Pty Ltd within the Perth Inspectorate.

J. O. Clough and Son Pty Ltd. The company commenced a general modernisation and upgrading of its facilities to improve the efficiency of the operation.

A new stacker and reclaim system is being installed which will more than double existing capacity. This will increase productivity by minimising the need to harvest salt during peak growth summer months.

The shiploading system is being modified to load at a rate of 1 200 tonnes/hour as against the present 700 tonnes/hour. New mining, pumping and power generation equipment has also been installed.

SAND

There are now 40 sand pits operating in the metropolitan area. Silica sand for export is still being mined by the Ready-mix Group and Silicon Quarries.

Sand pits which operate on a continuous basis outside the metropolitan area are located at Geraldton, Mandurah, Bunbury and Albany.

SCHEELITE-WOLFRAM

Minefields Exploration at Mt. Mulgine sank two exploration shafts being No's 2 and 3, to depths of 48·7 metres and 56·8 metres respectively. Lateral development of 51 metres from No. 2 shaft and 37 metres from No. 3 shaft was carried out to test the ore body and obtain sufficient ore to conduct metallurgical pilot plant studies.

A prospect on Yanget Station, east of Geraldton, produced 145 tonnes of wolfram ore from which 1·75 tonnes of concentrates were recovered at the Northampton State Battery.

At Dalgaranga, a small open pit was commenced on M.C. 59/4762 on a wolfram ore body. A small treatment plant is being erected on the site.

In the Melville area north of Yalgoo, prospecting over a number of claims produced 227 tonnes of scheelite ore from which 1·37 tonnes of concentrate were recovered.

TALC

Three Springs Talc Pty Ltd. The production of 62 500 tonnes of saleable talc was 22 per cent above the 1976 production. The company's stripping programme continued, resulting in a total of 158 000 tonnes of talc and waste being mined.

During the year a market for clean, washed fines was established. As a consequence a new wet screening section was added to the plant.

The wet screening has assisted in the suppression of dust and this, together with a new Mecal dust suppression system fitted at the crusher and picking belt end of the circuit, has resulted in a major reduction in dust concentration levels.

Westside Mines N.L. Westside excavated 117 000 tonnes of ore and waste and produced 44 300 tonnes of talc.

During the year a second pit was commenced approximately 400 metres south of the No. 1 pit and a number of modifications were again made to the plant.

The company also operates a small 1 000 tonne/annum grinding mill at North Fremantle. Talc is railed to the Fremantle plant where it is stockpiled prior to shipment. With the forthcoming closure of the Mullewa-Meekatharra railway, it is likely that shipments will commence through the Port of Geraldton.

TIN-TANTALITE

Greenbushes Tin N.L. continued with the development and mining of a large open pit along the main lode structure which was previously restricted from mining by the existence of the South West Highway.

The company did not renew the agreement with the contractor carrying out the mining when it expired on the 28th May and is now doing its own mining. A number of the contractor's vehicles were purchased by Greenbushes Tin and added to its own fleet. New equipment purchased by the company were four x 50 tonne Four Wheel Drive Payhaulers and two x 4 ½m³ Back Hoes.

Ore production totalled 1 173 000 m³ of which 1 129 000 m³ were treated. 403 000 m³ of waste stripping was also achieved. Tin/Tantalite concentrate production totalled 652·5 tonnes.

The average number of personnel employed increased by 25 to 126.

Warda Warra Mining Company Pty Ltd. This company has been formed to operate the tantalite ore body at Dalgaranga on M.C. 59/5052. The tantalite occurs in the weathered fraction of a siliceous pegmatite. The tantalite is concentrated using wet screening and a cone. 3 700 tonnes of ore were mined and treated for a recovery of 1 605 kg of Ta_2O_5 concentrate.

VANADIUM

Wundowie Iron and Steel are still conducting investigations into the possibility of mining the Coates Siding Vanadium deposit.

A small pilot plant to test the metallurgical aspects of the ore was erected at the company's Wundowie plant during the year.

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KALGOORLIE INSPECTORATE

I. W. Loxton
Mining Engineer/Senior Inspector of Mines

GENERAL

During the last few years the mining of nickel has become the dominant factor within the Kalgoorlie Inspectorate. Consequently with the downturn in the price of nickel, due mainly to over-supply, a cut-back in mining operations has occurred within the Inspectorate.

The year 1977 saw the closure of the Scotia and Carr Boyd nickel mines operated by the Great Boulder section of Western Mining Corporation Ltd. The Kambalda section also suspended operations at the Fisher decline and the Victor shaft sink after the pre-sink had been completed.

The price of gold rose quite substantially during the year, which has resulted in speculation that sections of the Fimiston leases may be re-opened. It has been estimated that the cost of such a venture would be in excess of $20 million, therefore before such a decision is made a great deal of preliminary work has to be done and the price of gold must remain at a satisfactory level.

Following 18 months of speculation as to the future of the Kalgoorlie School of Mines, the State Government announcement in October that the school would be retained in Kalgoorlie was warmly received by most sections of the community.

In October it was reported that a coal seam had been intercepted during drilling to find water for new road works on the Norseman-Esperance highway. However, further studies have revealed that the deposit is peat with a very high ash content.

The controversy over the planned construction of a uranium pilot plant near Kalgoorlie continued during the year even though a survey conducted amongst local residents revealed that the majority were in favour of the plant being located near Kalgoorlie. The plant would be so designed so that with a minimum of modifications it could be used to test other ores.

Following the multiple fatality at the Agnew No. 1 shaft of the Agnew Mining Company Ltd in April a mining enquiry into the accident resulted in charges of manslaughter being laid against four persons. These charges were later dropped because of a legal difficulty.

Kalgoorlie Mining Associates announced in May that $2·4 million would be spent on constructing a new flotation section and ball mill at the Oroya plant while a new crushing plant would be installed at the Mount Charlotte mine.

During the year it was decided to remove the wooden headframe on the original Baileys Reward lease as several inspections had revealed the headframe legs to be in a dangerous condition. Several proposals were studied to try and save the historic structure but were found not the be feasible.

Prospecting activity with respect to gold increased marginally during the year. The four Departmental mobile compressors which are hired out to prospectors for a nominal rental were in demand constantly throughout the year.

Mining and exploration activities which took place within the Kalgoorlie Inspectorate during 1977 are as follows:

ARSENIC

A small one-man operated pilot plant to extract arsenic trioxide from the tailings dumps of the Moonlight Wiluna gold mine was constructed during the year just west of the Wiluna townsite. To date, only a small tonnage of tailings has been treated.

AGGREGATE

The Readymix Group was quite active within the Inspectorate during the year. Their mobile crushing plant at Agnew crushed aggregate to supply the Agnew Mining Company with enough material for plant and road construction at the mine site.

South of Boulder their plant crushed continuously during the year stockpiling various sizes of aggregate to be used mainly for the production of concrete railway sleepers and rail ballast.

The Readymix Group were also successful in gaining a contract to crush rail ballast from the Commonwealth Railway Quarry at Karonie.

Meanwhile at Esperance, the group commenced wet rescreening of stockpiled aggregate in the latter part of the year. No production figures are available for publication from this Company.

The South Australian based Company, Quarry Industries, worked a quarry near Norseman for about four months during the year to produce approximately 38 000 tonnes of aggregate for the Main Roads Department. The Company has also opened a qyarru some six kilometres north of Kookynie where aggregate is being crushed and stockpiled to provide rail ballast for Westrail. To date, 122 000 tonnes of ballast has been stockpiled.

During 1977 the Boulder Shire crushing plant operated at low capacity and towards the end of the year ceased production altogether. The plant has now been taken over by Caddy Pty Ltd who will resume operations in the new year under the name of Kalgoorlie Quarries. Initially, rock will be obtained from mullock stockpiles at the Mount Charlotte mine.

BERYL

In the Riverina District west of Menzies a small recovery plant for the extraction of emeralds has been constructed. No details of production is available.

COPPER

Exploration in the Phillips River Mining District for copper was scaled down during the year. Union Miniere pulled out of the exploration syndicate with Hollandia following poor drilling results even though unofficial reports indicate that about one million tonnes of copper-gold ore was discovered by drilling at Kunduip.

Both Amax Exploration (Aust.) and C.R.A. Exploration Pty Ltd withdrew from the joint venture with Carr Boyd Minerals Ltd and Norseman Mining N.L. in the West River area, resulting in exploration coming to a standstill.

In the Teutonic Bore area of the Mount Margaret Mining District further drilling has been carried out on the Copper-Zinc-Silver deposit discovered by M.I.M. Holdings Ltd and Western Selcast. Ore reserves to date do not suggest a large scale mining opreation.

GRAPHITE

About 10 tonnes of material has been removed from the graphite deposit at Munglinup in the Phillips River Mining District for testing by the Government Metallurgical Laboratory in Kalgoorlie. Norseman Mining N.L. have taken an option over the deposit.

GYPSUM

There was no activity at the Norseman gypsum deposit, however Norseman Mining N.L. reported that negotiations were continuing with Australian interests who may wish to participate in the development of these deposits.

At Lake Brown and Lake Seabrook over 50 000 tonnes of gypsum was mined during the year.

GOLD

Although the price of gold rose substantially during the year, there was no marked progress made in developing new, nor re-opening former mines. General opinion amongst mining personnel is that the price of gold would have to stabilize at around $170–$180 (Aust.) before re-opening of the Fimiston mines could be considered.

In the East Coolgardie Mining District, Kalgoorlie Mining Associates' Mt. Charlotte operation was the main gold producer. This was supplemented by prospectors ore treated at the Kalgoorlie State Battery of which tributers at Fimiston and the Daisy Gold Mine at Mt. Monger were the chief contributors.

From the run down state of the Mt. Charlotte mine which existed at the close of 1976, Kalgoorlie Mining Associates have gradually increased production throughout the year to reach about 50 000 tonnes per month which is still below maximum output.

Development, which included shaft sinking, lateral development and declining was vigorously pursued to meet full rehabilitation. Major developments were the resumption of declining which has reached the 16 level, extension of the Man and Supply shaft from the nine to the 15 level and extension of the Reward haulage shaft from the 13 to the 14 level as part of the planned extension to the 17 level. A chamber has also been cut at the 15 level in preparation to transferring the crushing station from the 10 level to this horizon. The main production came from the 14 and 15 levels and was supplemented by ore containing appreciable amounts of fill material from old mill holes on the eight, 860 and nine levels.

The latter ore was screened at the surface and fines returned into the Southern Orebody void above the nine level up until December when the system was suspended. Development work was also commenced on the Southern Orebody at the 11, 13 and 14 levels.

On the surface, fill for the main stope was obtained solely from quarrying the north and east walls of the existing open cut. A crushing section is under construction to the south of the Reward Shaft, which when in operation during 1978, will make the K.O.T. plant at Fimiston redundant. The Oroya treatment plant was modified from a combination of straight cyanidation and flotation to 100 per cent flotation with cyanidation of only the flotation concentrate.

Five tribute parties working various open cuts on KMA's Fimiston leases treated 8 785 tonnes of ore at the Kalgoorlie State Battery for a recovery of 32·34 kg of bullion.

Outside of Kalgoorlie, the Daisy Gold Mine at Mt. Monger was the largest private producer in the East Coolgardie Goldfield. Operated by four men, it produced 19 960 grams of gold bullion from 568 tonnes. The ore was mined between the five and six levels and entailed some 15 metres of rise development work. Ore reserves are estimated at 2 000 tonnes with prospects for additional ore from proposed development on the four and six levels.

The Kalgoorlie State Battery was kept busy throughout the year and it was necessary to employ a third shift per day from May onwards to cope with the demand created by a large quantity of ore available from tributers at Fimiston.

The battery manager supplied the following statistics of the operation: Gross tonnes treated was 13 031 for 116·8 kg bullion made up of 8 785 tonnes for 32·34 kg from tributers; 4·246 tonnes for 43·05 kg from other prospectors; and 41·13 kg of bullion smelted for prospectors working cyanide plants in various localities.

No activity occurred at the North Kalgurli Mines Ltd during the year except for one tributer who took out a small crushing from an open cut for a very low return.

Kalgoorlie Southern Gold Mines N.L. completed some broadly spaced drilling on their leases to test the extent of concealed altered basalt and to prospect for gold mineralisation. Negative results and an adverse financial position could lead to liquidation in 1978.

Little gold mining activity was recorded in the East Murchison Mining District. The Scheelite Gold Mine at Barrambie was worked spasmodically and some small crushings were obtained.

At the Goanna Patch, parties of prospectors were reported to have had success in discovering appreciable amounts of alluvial gold with gold detectors. Soil from around previously known alluvial patches is spread out with a front end loader prior to scanning with detectors. A number of these instruments are being used in the Leonora area but no record of finds is available as the gold is being sold to private individuals at prices ranging from two to three times the value of gold content.

Part time prospectors operating in the Kundip area south of Ravensthorpe produced some gold ore which was crushed at the Marvel Loch Battery.

In the Dundas Mining District, Central Norseman Gold Corp. N.L. enjoyed a very profitable year as a result of maintained high grades of ore and increasing gold price. Ore was won from the Regent and North Royal shafts as well as from the washplant treating open cut ore from the North Royal open cut. At the Regent shaft, which contributes about 60 per cent of the ore milled, mining was carried out on most levels between the 15 and 32. Remnant mining and extensions of existing stopes provided most of the tonnage. Major development of the North Crown reef on the 22 and 25 levels was completed. Only a few small shoots were located and these were being tested by rising and sublevelling. The workforce at the Regent mine was approximately 50 men.

At the North Royal Shaft, high grade ore was mined from stopes on the 4 and 5 levels. Water has been pumped out to the seven level and reconditioning of the six level has commenced About 23 men are employed at this shaft.

Stockpiled ore from the North Royal Open cut No. 1 continued to be treated at the wash plant and contributed some 15 733 tonnes of ore for the Phoenix plant. At the end of the year, a start was made in excavating the No. 2 open cut which is situated just north of the shaft.

Diamond and percussion drilling metreage was increased from the previous year, which together with increased development, added some 100 000 tonnes to ore reserves to a figure of 493 300 tonnes of rour years production on current throughput. The Company pegged 27 gold mining leases during the year.

New plant installed at the mine included a 1·5 megawatt diesel alternator, Laytae drilling machine (radial), 30 tonnes weighbridge and a 1 200 c.f.m. compressor.

The State Battery at Norseman operated throughout the year treating mainly the Fairplay Gold Mine ore from Higginsville.

In the Mount Margaret Mining District, small amounts of gold are still being won from the Sons of Gwalia leases. Ore from these leases, together with ore mined by prospectors at various areas around Leonora have kept the State Battery at Leonora operating continuousy throughout the year.

The Fraser's and Marvel Loch Gold Mines in the Yilgarn Mining District remained closed during the year, however the Radio Treatment Plant treated 3 000 tonnes of tailings from the Francis Furness Mine and recovered 14·62 kg of gold.

Tailings at Evanston continue to be treated for gold.

At the Aspacia Gold Mine, north of Menzies, the south drive on the three level was stoped out and the ore was treated at the Menzies State Battery. Gold recovery was poor due to the high sulphide content in the ore.

A 90 metre crosscut from the main lode to the west lode was developed on the three level and a drive on the lode to the west shaft was advanced. The purpose being to prospect the west lode, reefs between the two lodes, and to improve the ventilation of the mine.

The ore block on the west lode was small but payable at 23·32 gms per tonne. The block was leading stoped and 2·5 metres of benching below the level was carried out. A prospect winze will be developed on the west lode to determine the economics of the ore block and the feasibility of sinking the shaft.

Two hundred metres of driving was completed during the year and 1 500 tonnes of ore broken. Of the 1 350 tonnes treated, 12 324 grams of gold was recovered, leaving reserves of over 20 000 tonnes yet to be mined.

The setting up of a plant to treat the tailings dumps at Yundaga has commenced and similar gold recovery attempts were made at Kookynie and Davyhurst.

A three man syndicate crushed several hundred tonnes of ore from the Porphyry gold mine during the year but values were very low and the syndicate has now disbanded.

The Grants Patch Tailings Lease in the Broad Arrow Mining District continued to employ three men and produced 37·32 kg of gold from 25 000 tonnes of tailings. The purchase of a R.B. 38 drag line greatly speeded up the recovery process. Some 20 000 tonnes of tailings still remain to be treated.

There was also some activity in the Ora Banda area at the Gimlet South and other leases within 16 km of the town.

IRON

Both Dampier Mining Pty Ltd and Agnew Clough Ltd continued to mine iron ore from their deposits at Koolyanobbing in the Yilgarn Mining District.

Figures supplied by Dampier Mining show that 1 454 000 tonnes averaging 61 per cent Fe was railed to Kwinana during 1977. Ore reserves have been increased and stand at approximately 180 million tonnes.

Agnew Clough Ltd mined approximately 100 000 tonnes of ore with 66 000 tonnes being railed to Wundowie. The decrease in production was due to a general downturn in the industry and the closure of one of the blast furnaces at Wundowie. A grade of 62 per cent Fe was maintained and mine men were employed.

A radial stacker at the Koolyanobbing rail siding used for stockpiling and blending lump ore was of great benefit to the blast furnaces operations at Wundowie.

MAGNESITE

Norseman Mining N.L. advised that further test work and feasibility studies continued but no active mining took place.

NICKEL

Western Mining Corporation Ltd continues to be the major producer of nickel in the State and during the year its Kambalda Nickel Operations produced 1 391 125 tonnes of broken ore. Ore reserves were slightly lower at 22 233 000 tonne @ 3·19 per cent Ni.

Production was obtained from four vertical shafts and five decline shafts using either ore skips or trackless equipment to transport the ore to the surface.

The Gibbs surface winze which extends from the surface to the seven level of the Durkin Shaft came into service during the year and levels have been developed at the two, three sub, three and four horizons. Some very rich ore has been encountered in this area.

Shaft sinking at the Long shaft continued throughout the year and reached the 13 level (approx. 700 metres below surface). The shaft is scheduled to a planned depth of 940 metres.

An Alamak S180 excavator was tried for normal shaft mucking but its performance was found to be inferior to the Cactus grab which has been used on most shaft sinking at Kambalda.

The Otter Juan ore body is still a major tonnage producer yielding some 30 000 tonnes per 28 day period. An underground crushing station sited at the 10 level crushes approximately 50 per cent of the abovementioned tonnage and the ore is then hauled to the surface by skips through a raise bored vertical shaft.

Shaft sinking has been completed at the Jan shaft and a pentice has been constructed at the 14 level.

Due to a downturn in the nickel industry, work was suspended at the Victor shaft after the presink, headframe, workshops, changerooms and winder installations had been completed.

Both the Carr Boyd Rocks and Scotia nickel mines closed down during the year. Production from Carr Boyd amounted to 29 853 tonnes with ore reserves of 55 800 tonnes while at Scotia some 57 000 tonnes were hoisted and ore reserves amounted to 160 000 tonnes.

Windarra Nickel Mines for which Western Mining Corporation are the operation managers, continued their open pit and underground mining during the year. Tonnes broken were:

(a) Underground—424 271

(b) Open Pit—562 446

Because of the limited ore available in the Western end of the open pit at South Windarra a decision was made to remove the overburden from the eastern pit to mine the low grade ore body.

Towards the end of the year underground production was severely restrained due to the failure of a mass blast which was scheduled to produce some 230 000 tonne of broken ore.

The Agnew Mining Company pursued an active development programme during the year but its activities were hampered by the tragic death of five men involved in the shaft sinking operations.

The 7·5 metre diameter fully lined concrete shaft has been sunk to a depth of 46 metres and is progressing very slowly. The delay in commissioning the equipment and winders due to the multiple fatality set the company back about four months in their schedule.

In conjunction with this, the water problems encountered in the shaft hindered the rate of sinking.

The decline heading reached 361 metres from the portal entrance. Steel sets were placed in the decline to hold up weak ground and the sets were shotcreted. As an extra safety measure, the sets were concreted for two metres above the floor of the decline in order to tie the sets together and protect them from being damaged by loaders. Ground conditions were improving with depth.

Driving north and south on the No. 1 shoot ore body has commenced on the R.L. 1443 level. The ore exposed is about three metres wide. It will be treated at the Agnew Mill in March, 1978. In the meantime, some ore is being transported to Kambalda.

Construction work on the concentrating plant and Leinster town site were well advanced at the close of the year. Work had also commenced at providing facilities at the rail head at Leonora to accept concentrates road hauled from the mine site.

Ore reserves at the Nepean mine of Metals Exploration N.L. increased to 337 000 tonne with a grade of 3·8 per cent nickel. Development work at the mine included the sinking of the shaft a further 58 metres to the 12 level (430 m) together with 1 073 metres of driving and 778 metres of rising. Production was down slightly on last year at 71 500 tonnes, however more nickel (2 318 tonnes) was produced.

At the Redross mine of Anaconda Australia Inc, the eight level was partially developed after ore handling facilities were established below this level.

The future of this mine is in doubt as development of the mine has not kept pace with production, with the result that most stoping blocks have or are approaching floor pillar height. Ore broken during the year amounted to 109 000 tonnes.

Selcast Exploration Ltd dispensed with labour intensive mining methods during the year with the result that production almost doubled on the 1976 figures. Ore broken amounted to 170 324 tonnes.

A major stope filling programme was completed towards the end of the year between the four and eight levels and work commenced on development of the ore body between the four and two levels. However, mining of this ore block will not commence until a rock mechanics study has been made.

Further engineering studies have been carried out during the year in the Forrestania area by the partners Amax and Amoco. Reports early in the year revealed that some rich assays were obtained from drilling of the Flying Fox area.

The Croesus plant of North Kalgurli Mines Ltd operated throughout the year treating nickel ore from mines operated by Anaconda Aust Inc and Selcast Exploration Ltd.

Closure of the Scotia and Carr Boyd Rocks mines in September was followed by the ceasation of nickel ore milling at the Fimiston plant of Western Mining Corporations Great Boulder Operations. Until closure, the plant treated 81 404 tonnes of nickel ore for a recovery of 7 953 tonnes of nickel-copper concentrates.

The crushing section of the plant is being periodically used to crush silica flux for the nickel smelter and up until the end of the year some 14 000 tonnes were crushed. The flux is being mined from a low grade, lateritic nickel deposit situated at Siberia some eighty kilometres north of Kalgoorlie.

During the year the WMC Nickel Smelter treated 302 653 tonnes of concentrate containing 34 772 tonnes of nickel and 2 913 tonnes of copper for a recovery, in matte form, of 46 608 tonnes containing 33 248 tonnes of nickel and 2 814 tonnes of copper. The results show an increase of 1 261 tonnes of nickel content when compared with the previous year's production.

Towards the latter part of the year, work commenced on the construction of a new flash furnace and associated auxilliary equipment which comprises electrostatic precipitator, air preheater, power generation and slag cleaning. This work is scheduled for completion in October, 1978. The construction of the new furnace was necessary to accommodate the treatment of additional concentrate when Agnew Mining Co Pty Ltd reaches the production stage. The furnace is designed to treat 450 000 tonnes per annum without the use of oxygen. This could be increased by a further 250 000 tonnes per annum by the use of oxygen, but additional oxygen generating capacity would be required. These modifications will make the original furnaces redundant but they could be converted to other base metal smelting if the need arose. The smelter employed an average of 337 personnel.

PEAT

A remarkable discovery of peat was made some 50 km south of Norseman by a drilling contractor whilst boring for water for the Main Roads Department. Australian Consolidated Minerals pegged the area and it was reported that evidence from seven drill holes suggests the occurrence of 50 million tonnes of peat. However, it has a 30 per cent ash content which detracts from its value. The deposit is said to be some 20 metres thick lying under six metres of overburden. Investigations are continuing.

SALT

The Lefroy Salt Company continued to harvest salt from its Lake Lefroy leases throughout the year. Due to drought conditions there was a problem with wind blown dust contaminating the salt.

Some 231 780 tonnes of salt were harvested while export of salt through Esperance amounted to 169 700 tonnes.

W.A. Salt Supply harvested some 4 000 tonnes of salt from the eastern end of Pink Lake at Esperance. Thirty hectares of ponds have been established and brine is pumped into these. Harvesting is done by grading the salt crust into windrows and using a salt harvester to load into trucks. The salt is used in the metro and south west areas of W.A. Four men are seasonally employed.

URANIUM

Uranium mining at W.M.C's Yeelirrie deposit was at a standstill. The Company reported that environmental, technical and financial studies of this deposit continued and that plans were completed for a small scale research plant for metallurgical testing of the ore which, subject to environmental and Governmental approvals, will be constructed near Kalgoorlie.

Several large companies entered the search for uranium in the Wiluna area and some drilling has been done.

VERMICULITE

Mineral Claim 74/1567 at Young River was not worked during the year. Sales of exfoliated and raw vermiculite were made from stockpiles formerly transported to Perth. Some 400 tonnes of ore are stockpiled at the minesite.

SUMMARY REPORT OF ACCIDENT AT THE No. 1 SHAFT OF AGNEW MINING COMPANY PTY LTD—27/4/1977

J. Jance
Mechanical Engineer/Special Inspector of Mines (Machinery)

The accident occurred at the Agnew mine which is located near the small town of Leinster, in the East Murchison Mining District, and is approximately 350 kilometres north of Kalgoorlie. The mine is to be operated by the Agnew Mining Co. Pty Ltd when development and site preparation has been completed.

The No. 1 shaft had been sunk previously to a depth of 40 metres and work was proceeding in preparation for continuing the shaft sinking. This included the installation and commissioning of the winding engine and associated equipment.

At approximately 5.00 a.m. on April 27th, five miners entered the shaft sinking kibble attached to the winding rope and told the braceman to signal to the winding engine driver to lower the kibble down the shaft. The braceman signalled to raise the kibble so that the shaft cover doors could be opened to allow it to enter the shaft. The kibble was raised about two metres and the doors opened. The signal was then given to lower the kibble down the shaft but when the driver applied power to the winding engine to lower the kibble it ascended at rapid speed up the skyshaft. The crosshead for the kibble struck the crashbeam near the top of the headframe and the impact resulted in the winding rope (38 mm diameter) breaking at approximately 300 mm back from the capel, and allowing the kibble to fall about 27 metres onto one of the open doors and the surface brace. The five men in the kibble were fatally injured. The winding engine driver was fortunate to escape injury as the rope whipped back onto the winding engine room causing damage to the roof.

DESCRIPTION OF WINDING ENGINE

The "winder" involved in the accident was a Fraser and Chalmers type and consisted of:

(i) Two cast-steel drums 3·35 metres diameter coupled through a clutch.

(ii) Reduction gearbox—ratio 1:8.

(iii) Two sets of brakes—gravity weight applied—pneumatically released post type acting on brake paths 3·66 metres diameter.

(iv) 1 138 kW Electric Motor 480 r.p.m. (G.E.C.).

(v) G.E.C. Mine Winder Controller.

(vi) Ward-Leonard Electrical System.

and was fitted with:

38 mm diameter wire rope 9 x 6/6 x 7/3 non-rotating flattened strand construction pre-formed R.H.L.L. with fibre core; Minimum Breaking Strength 1 000 kN.

WINDING ENGINE OPERATION

(1) Electronic System

This is a system in which the speed and direction of the motor, and therefore the "winder" itself, is controlled by varying and reversing the voltage output of the generator.

To achieve this, the generator field current is varied. The greater the field current, the higher the generator voltage will be and the faster the "winder" will go. To reverse the generator volts, the field current is reversed and the engine direction of rotation is reversed.

On this "winder" the current for the generator field is derived from a thyristor convertor which consists of two controlled rectifier bridges; one allows field current to be passed in one direction whilst the other passes current in the opposite direction. The selection of which is to operate is determined by the change-over logic module and, depending on the polarity of one of these input signals, the module selects which polarity is required for the generator field current and an output signal is given from the change-over logic module to inhibit the other bridge.

The system is so designed that only one inhibit signal is accepted at any one time so that if one of the inhibit outputs is switched on any other inhibit signal will be ignored until the operating inhibit signal is switched off. Under these circumstances when a wind is called for which requires the opposite signal in the thyristor convertor the field current will flow in the wrong direction and the motor will also rotate in the wrong direction.

(2) Back-up Protection Systems

The back-up protection systems are in the form of "positional" limit switches, generator field overload switches and a "mine winder controller".

The positional limit switches are designed to remove the power to the winder if a shaft conveyance enters a "prohibited" zone and apply the mechanical brakes to the drums to stop the "winder" before the conveyance strikes any permanent obstruction in the shaft.

The generator field overload switches also basically remove the power to the "winder" and cause the mechanical brakes to be applied should the field current become too high causing over-voltage on the generator and over-speed on the "winder".

The "mine winder controller" is a protective device for a winding engine; the main functions being:

(a) prevention of excessive winding speed in mid-shaft;

(b) enforcement of a progressive reduction in speed as the conveyances approach the end of their normal travel and thus prevent overwinding at a dangerous speed.

(c) provision of an end-of-trip gear which is brought into action when the conveyances are overwound.

Should the "winder" speed exceed the maximum allowable speed at any point in the shaft by more than 10 per cent of top speed then an overspeed contact will open, tripping the "winder" safety circuit and bringing the "winder" to rest under emergency braking conditions. A second contact on the position or distance measuring dial is also adjusted to trip the safety circuit should the conveyance pass beyond a maximum position in the shaft.

DETECTED FAULTS IN EQUIPMENT

(i) Electronic System

Tests carried out indicated that a fault existed in the change-over logic module K8006. All logic chips on this module functioned correctly except the "Pulse Stretcher" chip. It was found that the generator field current always went negative irrespective of the direction of movement of the winding engine driver's operating lever.

(ii) Mechanical Brakes

The brakes on the "loose" drum were inoperative and this drum was "clutched out" so that any winding performed was in "single gear".

The brakes on the driven drum were not adjusted satisfactorily. The clearance between the brake shoes and the brake path was approximately 15 mm at the time of the accident.

(iii) Back-up Protection Systems

The only back-up protection system which was commissioned at the time of the accident was the generator overload switch. This was found in "tripped" condition after the accident.

The "positional" limit switches were not installed and the "mine winder controller" was disconnected from the drum. It was also noted that the "mine winder controller" drive shaft, if connected, would be driven off the "loose" drum; this was considered to be a basic design fault.

FACTORS CONTRIBUTING TO ACCIDENT

The main factors which contributed to the accident are listed as follows:

(i) "Mine winder controller" disconnected.

(ii) "Positional" limit switches not installed.

(iii) Failure of electronic module.

(iv) Operating winder in "single gear" when hoisting men.

(v) Mechanical brakes incorrectly adjusted.

The winding engine should not have been used without the statutory approval of the Chief Inspector of Machinery. This approval is given only after an on-site inspection shows that all the safety requirements, relevant to winding engines, set out in the Mines Regulation Act and Inspection of Machinery Act, have been met.

It is recognised that random failures can occur in electronic modules of the type installed on this "winder" and it is for this reason that back-up safety devices are fitted to prevent accidents. The total system only becomes "fail-safe" if the back-up safety devices outlined in the regulations are fitted and properly commissioned.

COAL MINING

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

The coal industry at Collie achieved another record annual output of coal during 1977. The output of 2 358 005 tonnes was an increase of 89 274 tonnes or 3·93 per cent on the

previous year's output of 2 268 731 tonnes. Whilst the increase was only slightly over half of the 154 749 tonnes or 7·32 per cent increase achieved in 1976, the assured expectation is for greatly increased outputs to be produced in the coming years.

The proportion of underground mined coal again declined slightly from 24·34 to 22·82 per cent of the total output, produced from Western No. 2 Colliery. The two open cuts, Western No. 5 and Muja produced 77·18 per cent of the output.

The total value of the coal produced during 1977 was $23 172 093, an increase of $2 558 446 compared with the 1976 value of $20 613 647.

Western Collieries Limited Western No. 2 Mine

For the third year in succession, this colliery again produced over one half of a million tonnes of coal. The output of 538 029 tonnes was, however, the lowest annual output for the past three years and was 14 265 tonnes less than the 1976 output of 552 294 tonnes.

By the end of the year, the use of hand held scoops for coal loading was phased out completely. Following drilling and blasting off the solid, all coal is now loaded out from the face by diesel powered loaders. Three types of loader were in use: there were 23 Melroe Bobcats, four BHB Dirt Devils and two Eimco 911 LHD Units. The Bobcat and Dirt Devil Wheel Loaders which load directly on to chain conveyors in the face areas are very manoeuvreable in the confined spaces which are often experienced in relation to timbering. The Load Haul Dump Units eliminate the need for chain conveyors inbye of the belt conveyor systems but problems are experienced due to floor deterioration caused by constant travelling of the machines, particularly in dip drivages where wet and often soft floors prevail.

In addition to the 29 diesel powered loaders in use at the coal faces, the transport of supplies and personnel is mainly effected by diesel engined vehicles for which purposes there are two Wagner Supplies and Personnel Carriers, one BHB Mine Transporter and five Holder Tractors, giving a total of 37 diesel engined vehicles operating in the mine. All of these units are installed and operated under permit conditions which necessarily require appropriately high standards of ventilation.

The current workings of the mine, including the separate area in from the South East Entries, are very extensive and widespread. This is a concomitant of the cyclic mining systems wherein five men crews of composite miners are generally allocated with up to four places to each crew. The intermittent blasting of coal from the unsheared or solid faces throughout working shifts also necessitates that working places must be widespread to minimise pollution of the air circuits by shotfiring fumes.

Practically 284 tonnes of explosives were used to produce the output of 538 029 tonnes of coal. This was around 0·5 kg of explosives per tonne of coal produced.

The aggregate length of the belt conveyors installed and in use at the mine is approximately 12 kilometres.

Mine layouts which shall provide for greater concentration of work for a given output of coal, probably involving continuous mining methods in pre-drained areas, consistent with aims to improve the percentage recovery of coal are receiving attention and shall be complementary to important research and field trials work proposed to be undertaken at Collie by the Australian Coal Industries Research Laboratories Limited over a six year period.

This colliery which commenced production a quarter of a century ago, in 1952, produced a total quantity of 7 594 201 tonnes to the end of 1977. This was, by far, the greatest quantity of coal produced from a single underground colliery at Collie. The previous largest output from an underground mine at Collie was from the Proprietary Colliery which produced 4 871 842 tonnes over the 44 years period, 1911 to 1955.

Western Collieries Limited Western No. 5 Open Cut

The output of 717 491 tonnes was an increase of 7·70 per cent over the 1976 output of 616 164 tonnes.

In the early part of the year, mining was completed at the Wyvern Seam Excavation on the remaining exposed coal in No. 3 Bay. Coal production commenced from the Wyvern Seam in October, 1974 and was completed during March, 1977. An output of 413 010 tonnes of coal was won from this area where overburden removal amounted to 2 012 867 m³. The high wall was worked down to a depth of approximately 30 m over the seam which was approximately 4·5 m thick over a part of the area.

Current workings over the Neath and Cardiff Seams are generally in two separate groups of excavations, both of which extend over considerable areas. The Western No. 5 or Main Excavations are continuing as extensions to the original mining programme commenced in 1970 near the East bank of the South Branch of the Collie River. The Western No. 5A excavations where overburden removal commenced in October, 1976 are located to the North West of the Main Excavations and on the west side of the river, on the upthrow side of the fault which was previously intercepted on the downthrow side by Cardiff Colliery underground workings.

Considerable areas of the Cardiff and Neath Seams were exposed and won out in the Central—North portion of the Main Excavations and where, at the latter part of the year, work was progressing well on advancing the high wall by overburden removal to expose Cardiff Seam coal in the "C3" Block across part of the original bed of the river. Ultimately, development down dip in this area shall involve re-routing the river from the temporary diversion channel ahead of the workings, back through the mined out and back filled area to the rise side of then current workings. Systematically planned back filling was a feature of the work in this area.

Very good progress on overburden removal and coal extraction from the Cardiff and Neath Seams was evident at the Western No. 5A Excavations. Most of the coal output from this area was won on a broad front down from the exposed sub-crop line of the Cardiff Seam. Between the sub-crop lines of the Cardiff and Neath Seams, a wide strip of coal was exposed and partially won from the Neath Seam. The West end of these workings extend to the fault line which separates them from downthrown strata over the Cardiff Colliery underground workings.

Filling in of a void created by a major collapse which occurred 30 years ago over the Cardiff Colliery workings was carried out during the latter part of the year with overburden transported from the nearby open cut workings.

Bitumenising of the new coal haulage road from the area near the bridge over the permanent diversion channel to the crusher installation at Western No. 2 Mine was completed in February.

Rehabilitation planning and procedures received considerable attention by the Company, in liaison with the Forests and Agriculture Departments.

The Griffin Coal Mining Company Limited—Muja Open Cut

This colliery was again, the largest single coal producer on the field and, for the second year in succession, produced over one million tonnes of coal. The output of 1 102 485 tonnes was 52 212 tonnes more than the previous year's output of 1 050 273 tonnes.

The progress made at the North Extension Excavations where hydraulic excavators and face shovels commenced operations in the coal measures strata in February, following previous forward stripping of the Nakina Formation or Lake Beds strata was quite remarkable. The major fault which trends parallel with the East Extension Area High wall was exposed in these workings in which the Ate, Bellona and Ceres Seams were won from the downthrow side and the Delta, Diana, Eos and Flora Seams and most of the Galatea Seam were won on the upthrow side across the area. At the end of the period, the remaining Galatea Seam coal was being won and the Hebe Seam was being opened out across and down from the sub-crop line. There was an intensive application of heavy earth moving and haulage equipment at this area where the manifold problems encountered in working multiple seams in highly inclined, faulted, and water bearing strata were successfully encountered.

The Bucyrus Erie 200 W Walking Dragline continued on final shales removal from the top of the steeply dipping Hebe Seam at Block No. 7 during the first half of the year. As the 12 m thick coal seam had previously been mined in underground workings of the old Hebe Mine to a height of eight metres above the floor in this area, precautions were taken during final overburden removal and in coal winning to ensure that the work was carried out safely with only drilling equipment and light vehicles passing over the four metre thick coal over the workings. Most of the coal was won from this area by the end of the year.

Significant progress was made on forward stripping of top overburden down to the coal measures on Block No. 8 and on removal of laterite and some top overburden from East Section Panel No. 7.

A new borehole was put down and a submersible pump located over the No. 7 Left or deepest area of the old Hebe Mine workings as a part of the programme for de-watering ahead of the current open cut workings.

As most of the overburden removed from the mine was dumped on the surface, there was minimal back filling during the year.

Since this mine commenced production practically a quarter of a century ago in 1953 it has produced 11 027 455 tonnes of coal. This is 707 592 tonnes more than the combined total outputs of the other two operating mines at Collie.

A total quantity of 12 218 170 tonnes of coal have, through production from the Hebe Mine and Muja Open Cut, been won from the Muja Formation Basin.

General

There were 555 reported accidents of which 494 were minor and 61 were classified as serious where an employee was absent from work for two weeks or more. With 860 persons employed, the labour force in the industry was practically the same as that for the previous year. There were 323 persons in underground or predominantly underground occupations.

For the third successive year, over two million tonnes of coal were produced from the coalfield. The past three years' output of 6 740 717 tonnes amounted to 12·8 per cent of the total output of 52 707 126 tonnes produced during practically 79 years of mining, since 1898.

DRILLING OPERATIONS

D. A. Macpherson
Drilling Engineer

During 1977, the Drilling Section was responsible for the drilling of 3 822 metres in 24 bores, the development of 87 aquifers in 79 bores and the testing of 30 aquifers in 26 bores. The work was carried out by Departmental employees and equipment except for 2 shallow bores which were drilled by a private contractor.

The total metrage drilled is well below previous years, partly because of the emphasis on the developing and testing of a backlog of existing bores, and partly due to closing down one field unit because of personnel problems. During the year a fatal accident occurred on one of the rigs and this together with maintenance and modifications reduced progress on this unit.

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.

MOORA LINE

This job forms part of the State wide ground water investigation conducted by the Geological Survey of Western Australia, and is financed by the Department of Mines. The Moora Line commences at Moora and runs west to the coast.

The job is required to provide information on stratigraphy and ground water conditions to a projected depth of 762 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 side wall cores. This bore is then cased to bottom, cemented and perforated at two intervals, each perforated interval is isolated by packers and developed and airlifted to provide accurate water samples and water level measurements for the aquifers at the perforated intervals. Subsequent bores may be drilled at the same site to provide water quality and water level measurements for aquifers at other levels.

Drilling operations on this job by Departmental equipment were completed during 1977. A further deep bore of 1 200 metres may be required and if so will be carried out under contract in 1978/79. During 1977 drilling was completed at sites five, seven, eight and nine and two replacement bores drilled at site one. Development and testing was completed at sites one, three, five, six, seven and eight.

BUNBURY/YOGANUP

This job forms part of the State wide ground water investigation carried out by the Geological Survey of Western Australia and is financed by the Department of Mines. The work being done is in the Bunbury/Busselton areas.

The job is required to provide information on stratigraphy and ground water conditions to a projected depth of 1 100 metres at selected sites in the area. This is being effected by drilling one bore at each site to provide strata samples, geophysical bore logs and side wall cores. Each bore is then perforated and tested at various depths to provide accurate water samples, water level measurements and aquifer characteristics at various depths.

At the start of the year, development and testing on the previously drilled Quindalup Line Bore six was carried out. Five separate aquifers were investigated using explosive perforations to tap the aquifers and compression packers to isolate each aquifer for individual testing.

Automatic recording equipment was used to record the variables during the testing. The information collected was of a higher standard than is obtained by normal manual recording methods. Improvements are being made to the equipment and the techniques used.

JOONDALUP

This job forms part of the state wide ground water investigation conducted by the Geological Survey of Western Australia and is financed by the Department of Mines. The Joondalup Job lies in the area between Guilderton, Muchea, and the West Coast. The job is required to provide information on stratigraphy and ground water conditions to a projected depth of about 80 metres at selected sites in the area.

Work was continued on two special requirement sites early in 1977. The work at each of the special sites consists of drilling a bore to bedrock to provide strata samples and geophysical bore logs, followed by the construction of a screened bore to a selected depth to provide water quality and water level information from that depth. A third bore two metres deep is drilled at each site to provide water level information in the top soil layers of the area.

This job has now been completed.

BUNBURY (Shallow aquifers)

This job forms part of the State wide ground water investigation carried out by the Geological Survey of Western Australia and is financed by the Department of Mines. The work is being done in the Bunbury/Busselton area. The job is required to provide information on stratigraphy and ground water conditions to a projected depth of 100 metres at selected sites in the area. This is being done by drilling one bore at each site to target depth, to provide strata samples and geophysical bore logs. This 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.

Development work was carried out early in the year on bores that had been previously drilled. Further drilling is expected to be carried out on this job during 1978.

CANNING BASIN

This job forms part of the State wide ground water investigation conducted by the Geological Survey of Western Australia and is financed by the Department of Mines. The Canning Basin is a large sedimentary geological province extending from the De-Grey River along the coast past Broome and east towards the Northern Territory border. The job is required to provide information on stratigraphy and ground water conditions to bedrock over the whole basin. The work was commenced in the corner of the basin near the De-Grey River and the coast and is extending outwards from there.

The information is being obtained by drilling one bore at each site to bedrock to provide strata samples, geophysical bore logs and some cores. This bore is then screened at a selected depth, developed and tested. Subsequently bores are drilled at the same site to allow screening, developing and testing of aquifers at different depths. The bores are left in suitable condition for continuous water level measurement.

During 1977 further development work was carried out on 26 bores and testing on 21 bores. Automatic recording equipment was used to record the variables and some improvements in the use of the equipment were effected during the programme.

A replacement bore was constructed at site nine where previous attempts to reach target depth had failed. This completed all drilling work in the current programme for this job.

FORTESCUE VALLEY

This job forms part of the State wide ground water 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 ground water 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. The bore was screened and tested by airlifting. The bore was left in suitable condition for continuous water level measurement.

During 1977 a further eight bores were drilled, but the programme was not completed because the rig being used had to return to the workshop for extensive modification and repair. It is expected that further work will be carried out in 1978.

MANJIMUP WOODCHIP INDUSTRY

This job forms part of an investigation into the effects of logging for the Manjimup Woodchip Industry on the ground water regime in the area. The work is being carried out for an investigating committee and is financed by the Department of Mines. The work consists of drilling a bore by continuous coring hollow auger methods at each of a number of selected sites and completing the bores as water sampling and water level measurement points for long term recording of ground water variations in the area. At specially selected points coring is continued into bedrock by diamond drilling methods and casing cemented down to bedrock to provide information on water movements in the bedrock of the area.

The work was commenced early in 1976 and proceeded smoothly to completion except for a testing programme. This testing was carried out during 1977 on four of the bores. A series of "pumping out" and "pumping in" tests were carried out and variables recorded on automatic recording equipment. This work completed the current programme.

STAFF

On 20th September 1977, Mr. D. Thomas left the Section to join the Department of Tourism.

On the 18th November, 1977 Mr. B. Arney joined the staff as temporary General Assistant G.VII.1 to replace Mr. D. Thomas.

PLANT

During 1977 a new tractor was placed in service. This replaced an old Chamberlain tractor which had reached the end of its economic life.

The Mayhew 2000 rotary rig was sold during the year. Various other items of plant and equipment which had reached the end of their economic life were sold and where necessary replaced.

TABLE SHOWING WORK CARRIED OUT DURING YEAR ENDED 31/12/77

Place	Purpose	Type of Work	Done By	No. of Bores	No. of Aquifers	Meterage
Moora Line	Groundwater investigation	Rotary Drilling	Dept. of Mines	10	....	3 212
		Development	Dept. of Mines	13	17	....
		Cable Tool Drilling	Contractor	2	....	42
Bunbury/Yoganup	Groundwater investigation	Development	Dept. of Mines	1	5	....
		Testing	Dept. of Mines	1	5	....
Joondalup	Groundwater investigation	Rotary Drilling	Dept. of Mines	4	....	99
Bunbury (Shallow aquifers)	Groundwater investigation	Development	Dept. of Mines	39	39	....
Canning Basin	Groundwater investigation	Rotary Drilling	Dept. of Mines	1	....	224
		Development	Dept. of Mines	26	26	....
		Testing	Dept. of Mines	21	21	....
Fortescue Valley	Groundwater investigation	Rotary Drilling	Dept. of Mines	8	....	245
Manjimup	Investigation of the effects of logging on groundwater	Testing	Dept. of Mines	4	4	....
			TOTALS—			
			Drilling	24	....	3 822
			Developing	79	87	....
			Testing	26	30	....

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

W. J. Cahill—Secretary

Herewith I submit the Annual Report on the activities of the Board of Examiners for the year, 1977.

Mining Law Examination

The examination in Mining Law for Mine Manager's Certificates of Competency was held on April 4, 1977. Details of this examination are as follows:—

Entries	7
Admitted	6
Pass	3
Did not sit	2

The names of the successful candidates were:—

K. M. Hollands
D. R. Nicholls
J. G. Speed

Underground Supervisor's Examination

The above examination was held on September 5, 1977 and attracted applications from the following centres:—

Kalgoorlie	22
Norseman	3
Nullagine	4
Perth	1
Shay Gap	1
Windarra	8

The following number of applications were accepted:—

Kalgoorlie	21
Norseman	3
Nullagine (all subject to verification of experience and First Aid by 26/8/77)	4
Perth	1
Shay Gap	1
Windarra	7

Results were as follows:—

Passed	23
Failed	14

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

Kalgoorlie:
J. W. Astrand
R. G. Beaver
M. R. Covich
B. W. Ford
B. R. French
S. J. Howell
R. N. Howlett
M. F. Lorenz
K. O'Shea
J. E. Rowe (restricted to Western Mining Corporation, Kambalda Nickel Operations).
E. E. Shackleton
P. C. Teasdale

Norseman:
G. E. Sutton
M. A. Wilson
B. C. Lovely

Windarra:
L. G. Eeles
L. J. Eveille
C. P. Giles
T. W. Jackson
C. J. Turner

Agnew:
C. Cristopolous
E. A. A. Buehler (restricted to the Mining Operations of the Agnew Mining Co. Pty Ltd)

Perth:
K. Hollands

Shay Gap:
J. W. Barron

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 requests of various Mining Companies:—

Agnew:
T. L. B. Vandermerwe
J. Vrbic
(Both certificates—"Restricted to Shaft Sinking at the Agnew Nickel Project of the Agnew Mining Co. Pty Ltd".)
I. Djulic (Restricted to Shaft Sinking, tunnelling and decline mining at the Agnew Nickel Project of the Agnew Mining Co. Pty Ltd.)

Windarra:
E. S. Mein*

Kambalda:
S. J. Coughlan*
C. A. McIntyre*
(Both certificates—"Restricted to the Kambalda Nickel Operations of W.M.C.".)

*NOTE: These three persons were the holders of a degree in Mining and had passed the prescribed Mining Law examination for Mine Managers and produced evidence of the required 12 months practical experience.

Mine Manager's Certificates

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

A. Watson
R. J. Lloyd
G. J. Sauer
P. I. B. Pearce
A. Sheppard
J. McAllister
J. G. Speed

General

Three meetings were held during the year on March 10, July 21 and September 29, 1977.

Members of the Board visited Nullagine, Windarra and Anbew to carry out oral examinations for the Underground Supervisor's examinations.

As well as the general examination, quite a few applicants were examined orally, on request, and restricted certificates issued as a result.

BOARD OF EXAMINERS FOR QUARRY MANAGER'S CERTIFICATES

J. A. Suda—Secretary

EXAMINATIONS

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

QUARRY MANAGER'S CERTIFICATES OF COMPETENCY

The first examination in Mining Law was held on the 9th May, 1977 and seven entries were received and accepted.

Those successful in the examination were:—

Swann, R. C.
Seels, C.
McIntosh, J. L.
Pooley, R. H.

The second examination in Mining Law was held on the 3rd October, 1977 and eleven entries were received and accepted.

Those successful in the examination were:—

Alderson, J.
George, D.
Atkinson, G.
Jongen, P.
Mahalingham, S. S.
Gardiner, B.
King, S.
Sibbell, F.

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

Argus, J. C.
Grieve, B. L.
Seels, C. A.
Swann, R. C.
Stark, T. A.
Pooley, R. H.
Mahalingham, S. S.

RESTRICTED QUARRY MANAGER'S CERTIFICATES OF COMPETENCY

Examinations in Mining Law and Quarrying were held on the 3rd October, 1977 and nine entries were received and accepted. As required by the Regulations to the Mines Regulation Act, applicants that apply for a Restricted Certificate are also orally examined and interviewed by Board members.

Those successful in the examinations after interview were:—

Smith, N. L.
Larkin, G. J.
Sadowski, T.
Gildare, W. P.
Bertola, B. T.
Cornish, V. S.

A Restricted Quarry Manager's Certificate was issued to N.L. Smith. Other applicants will be issued with Certificates when certain requirements are met.

QUARRY MANAGER'S AND RESTRICTED QUARRY MANAGER'S CERTIFICATES OF SERVICE

During 1977, 37 applicants were issued with Quarry Manager's Certificates of Service and 33 applicants were issued with Restricted Quarry Manager's Certificates of Service.

The names of the successful applicants were:—

Quarry Manager's Certificate of Service

Wilkinson, G. W.
Hall, A.
Vlaming, G.
Shepherd, B. H.
McDermott, J. C.
Bettridge, R. T.
Mainwaring, D. D.
Baars, T. J.
Westall, G.
Bragg, R.
Sinclair, G. G.
Brown, I. R.
Glucina, J. D.
French, G. H.
Sweet, J. R.
Marshall, W.
Johnston, F. A.
Knight, J. D.
Ellett, P. G.
O'Brien, M. D.
Lewis, D. J.
Swann, R. C.
Scott, A.
Green, F. M.
Payne, D. C.
Butterfield, T. C.
Davis, J. H.
Geldard, D.
Hicks, M. K.
Forbes, A. I.
Collie, D.
Frazer, D. M.
Gill, A. E.
Howell, J. M.
Mountford, A. H.
Lee, C. B.
Miller, D. J.

Restricted Quarry Manager's Certificates of Service

Day, L. J.
Byrne, B. L.
Petty, J. W.
Waight, E. E.
Storey, A.
Bertola, B.
Taylor, R. K. A.
Callow, R. J.
Baker, J. J. W.
Cheeseman, S. H.
Topliss, S. T.
Reynolds, W. J.
Zeffertt, J.
Rideout, H. C.
Stati, G.
Kissane, R. R.
Barber, R.

Bremmell, M. J.
Berry, D.
Baggs, B. J.
Farley, B. G.
Johnston, P. D.
Rieck, A.
Toomey, P. A.
Kalajzich, A. J.
Gizzarelli, G.
Johnson, B. T.
Wilson, R. W. K.
Stocks, L.
Taylor, G. A.
Newman, P. W.
Pollitt, S. V.
Strudwick, E. G.

GENERAL

Six meetings were held during the year and a total of 78 certificates were granted.

Prior to the first Mining Law and Quarrying examinations being conducted a decision on the content of examination papers had to be made. It was decided that a 50 per cent mark for examinations would have to be achieved by candidates requiring a Restricted Quarry Manager's Certificate of Competency and a 60 per cent mark for the Mining Law examination pertaining to Quarry Manager's Certificates of Competency would be required.

The nominations by the Chamber of Mines of Messrs B. L. Grieve and J. C. Argus to represent them at board meetings was accepted and Ministerial approval was obtained for their appointment to the Board.

Members of the Board of Examiners (for 1977) were:—

Mr. A. Y. Wilson (Chairman)—Department of Mines
Mr. J. M. Faichney—Department of Mines
Mr. H. Duncan—Technical Education Department
Mr. B. L. Grieve—Chamber of Mines of W.A.
Mr. J. C. Argus—Chamber of Mines of W.A.

VENTILATION BOARD ANNUAL REPORT, 1977

J. A. Suda—Secretary

The Ventilation Board met on 10 occasions and many items of business were discussed and dealt with.

Main items of business were:

The formation of a sub-committee to inspect and identify toxic gases around smelters and refineries and report their findings to the Board.

The preparation of a booklet entitled "Guidelines for the Evaluation of Dust Concentrations in the Mining Industry", which superseded a booklet "Requirements for the Evaluation of Dust Concentrations in the Mining Industry". The "Guidelines" contain information relating to, statutory functions and objectives of the Board, the strategy of dust sampling, sampling results and general administration. A review of all positional and personal codings was also made and the new codings were published in the booklet.

The formation of a technical sub-committee for the purpose of implementing an effective computer dust sampling recording system able to average sampling results and store them for future reference.

The response by the majority of mining companies in forwarding their monthly dust sample results has been good and it is anticipated that these results will be data processed early in 1978.

During the year, members visited most mining centres to meet staff and discussed matters associated with dust control and the Ventilation Board's overall policy.

Some problems associated with the computerisation of sampling results were encountered. It is anticipated that in 1978 these problems will have been overcome and the Board will be able to deal more effectively with matters relating to ventilation, environmental atmospheric control and the health of mine workers generally.

DIVISION III

Report of the Superintendent of State Batteries—1977

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, 1977.

Crushing Gold Ores

One 20-head, six 10-head, and seven five-head mills crushed 44 205·95 tonnes of ore made up of 365 separate parcels, an average of 121·1 tonnes per parcel. The bullion recovered amounted to 337·974 kilograms, estimated to contain 286·433 kilograms of fine gold, equal to 6·47 grams per tonne of ore.

The average value after amalgamation but before cyaniding was 2·44 grams per tonne, giving an average value of ore received of 8·91 grams per tonne, compared with 7·52 grams per tonne for 1976.

The cost of crushing 45 239·95 tonnes, which included 1 034 tonnes of Tantalite and Wolframite ores at Boogardie was $28.74 per tonne. In 1976, 40 748·3 tonnes were crushed at the gold plants, for a cost of $28.66 per tonne.

Cyaniding

Six plants treated 11 886 tonnes of tailings from amalgamation for a production of 24·387 kilograms of fine gold. The average content was 3·05 grams per tonne before cyanidation, while the residue after treatment was 0·95 grams per tonne giving a theoretical recovery of 68·55 per cent. The actual extraction was 67·19 per cent. The cost of cyaniding was $17.92 per tonne, higher than the previous year when 17 728 tonnes were treated at a cost of $14.90 per tonne.

Silver recovered by the cyaniding of gold tailings was valued at $326.27.

TREATMENT OF ORE OTHER THAN GOLD

Lead Ores

The Northampton Battery crushed nine tonnes of lead ore for the recovery of 2·667 tonnes of concentrates.

Tungsten Ores

The Northampton Battery crushed 371·5 tonnes of scheelite and Wolframite ores for a recovery of 3 445·6 kilograms of concentrates. The Boogardie Battery crushed 106 tonnes of Wolframite ore for a recovery of 323 kilograms of concentrates.

Tin Ore

There was no Tin ore treated in 1977.

Tantalum Ores

The Boogardie Battery crushed 928 tonnes of Tantalite ores for the recovery of 1·538 tonnes of concentrates.

Garnet Sands

The Northampton Battery treated 849 tonnes of Garnet Sands for the recovery of 487·9 tonnes of Garnet concentrates.

Value of Production

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

GOLD

	1977 $	Since Inception $
Gold	1 336 858	45 435 987

OTHER METALS

Silver	326	5 778
Tin (Concentrate)	....	487 852
Tungsten (Concentrates)	24 980	69 165
Copper (ores for Agricultural use)	....	11 932
Lead and Zinc (Concentrates)	900	1 561 534
Tantalite—Columbite (Concentrates)	22 587	96 046
Garnet—(Concentrates)	21 957	21 957
Total other metals	$70 750	$2 254 264
Grand Total	$1 407 608	$47 690 251

FINANCIAL

	Tonnes	Expenditure $	Receipts $	Loss $
Crushing—Gold mills	45 239.95	1 300 616	132 206	1 168 410
Crushing—Northampton Lead Plant	1 229.58	36 871	4 006	32 865
Cyaniding	11 886.00	213 041	37 250	175 791
	58 355.53	1 550 528	173 462	1 377 066

The loss of 1 377 066 is an increase of 122 606 on the previous year. It does not include depreciation and interest on capital. Capital expenditure, all from Consolidated Revenue Fund was incurred as follows:—

	$
Marvel Loch (construction Managers quarter)	23 162
Meekatharra (bin and conveyors)	9
Ora Banda (conversion to A/C power)	10 046
	$33 217

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
1975	54 383·6	12 555·0	23·09
1976	40 775·5	8 317·21	20·39
1977	46 469·5	7 957·9	17·12

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

Administrative

Expenditure was $230 414, equal to $3.95 per tonne crushed and cyanide, compared with an expenditure of $241 647, $4.13 per tonne for 1976.

	1976 $	1977 $
Salaries	115 407	107 225
Pay Roll Tax	50 500	49 814
Workers' Compensation	65 918	59 668
Travelling and Inspection	6 093	9 294
Sundries	3 729	4 413
	$241 647	$230 414

Staff

Superintendent K. M. Paterson retired during the 1977 year and Mr. H. J. Rich was appointed to his position.

Mr. Paterson gave dedicated and conscientious service for 22 years and his experience will be a loss to the Department.

Mr. Rich resigned after six months service to take up a position in charge of a scheelite production plant in Queensland.

Mr. E. J. Green was appointed Superintendent after the resignation of Mr. Rich.

General

The average price for gold sold during the year was $133 an ounce, a rise of $32 on the previous year average. The tonnage of ore crushed rose because of this price increase, to a moderate level. A further increase in production is estimated for the coming year. In addition to the normal minerals other than gold some garnet concentrates were produced at the Northampton Battery for further processing in Perth.

The main interest in minerals other than gold was in tungsten concentrates and tantalum from the Murchison area.

E. J. GREEN,
Superintendent State Batteries.

Schedule No. 1

NUMBER OF GOLD ORE PARCELS TREATED, TONNES CRUSHED, GOLD YIELD BY AMALGAMATION AND HEAD VALUES FOR THE YEAR ENDING 31st DECEMBER, 1977

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	18	994·2	4·525	3·835	1·300	5·135	5·16
Coolgardie	62	4 612·6	12·956	10·980	8·413	19·393	4·20
Kalgoorlie	95	13 031·0	116·800	98·988	35·978	134·966	9·21
Laverton	6	491·0	1·776	1·505	0·980	2·485	5·06
Leonora	43	5 461·0	38·946	33·007	15·272	48·279	8·84
Marble Bar	11	787·7	6·266	5·310	2·809	8·119	10·30
Marvel Loch	42	3 738·0	30·206	25·599	7·414	33·013	9·63
Meekatharra	19	3 117·0	61·752	52·335	10·505	62·840	20·16
Menzies	26	2 291·6	28·097	23·812	12·355	36·167	15·78
Norseman	7	3 050·8	4·789	4·059	2·374	6·433	2·10
Ora Banda	19	5 123·0	17·694	14·996	7·587	22·583	4·40
Paynes Find	2	67·0	0·180	0·153	0·091	0·244	3·62
Sandstone	3	98·6	1·367	1·158	0·392	1·550	15·72
Yarri	12	1 343·0	12·620	10·695	2·719	13·414	9·97
	365	44 205·9	337·974	286·432	108·189	394·621	8·92

Average Per Parcel .... 121·1 tonnes
Average Yield by Amalgamation (Fine Gold) .... 6·48 grams per tonne
Average Value of Tailings (Fine Gold) .... 2·45 grams per tonne

Schedule No. 2

DETAILS OF EXTRACTION TAILINGS TREATMENT 1977

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	1 780	3·95	7·031	1·7	3·057	3·974	56·5	4·545	64·4
Kalgoorlie	750	3·0	2·250	0·75	0·562	1·688	75·0	1·366	60·7
Leonora	6 000	2·6	14·835	0·65	3·711	11·124	75·0	11·754	79·2
Marvel Loch	756	4·0	3·050	1·67	1·265	1·784	58·5	1·986	65·1
Menzies	2 080	3·1	6·422	0·7	1·547	4·875	75·9	3·296	51·3
Sandstone	520	5·2	2·704	2·42	1·258	1·445	53	1·440	64
	11 886	3·05	36·292	0·96	11·400	28·490	68·6	24·387	67·2

Schedule No. 3

DIRECT PURCHASE OF TAILINGS YEAR ENDED 31st DECEMBER, 1977

Battery	Tonnes of Tailings Purchased	Initial Payment to $28.00 per ·0311 kg
Coolgardie	280·6	1 171·95
Kalgoorlie	1 662·8	2 181·23
Leonora	1 121·4	2 736·68
Marble Bar	244·3	540·15
Marvel Loch	547·9	2 307·25
Meekatharra	594·0	995·62
Menzies	241·5	274·54
Ora Banda	250·2	208·85
Sandstone	36·9	54·90
	4 979·6	10 471·17

Schedule No. 4

STATEMENT OF RECEIPTS AND EXPENDITURE FOR YEAR ENDED 31st DECEMBER, 1977

Milling

Battery	Tonnes	Management and Supervision	Wages	Stores	Expenditure Total Working	Cost Per Tonne	Repairs and Renewals	Sundries	Gross Expenditure	Cost Per Tonne	Receipts	Receipts Per Tonne	Profit	Loss
		$	$	$	$	$	$	$	$	$	$	$	$	$
Boogardie	2 028·2	14 231.95	29 068.62	5 404.50	48 705.07	24.01	10 160.41	12 101.66	70 967.14	34.99	6 057.15	2.98	....	64 909.99
Coolgardie	4 612·0	21 388.21	35 084.36	8 640.00	65 112.57	14.11	10 764.61	24 029.05	99 906.23	21.66	11 931.40	2.58	....	87 974.83
Cue	....	....	....	....	....	....	....	....	....	....	1 480.00	....	1 480.00	....
Kalgoorlie	13 031·0	28 183.48	190 801.48	36 589.11	255 574.07	19.61	24 872.25	74 362.49	354 808.81	27.22	36 351.12	2.78	....	318 457.69
Lake Darlot	....	....	2 811.25	95.76	2 907.01	....	132.74	285.98	3 325.73	....	....	....	....	3 325.73
Laverton	491·0	9 753.90	11 029.18	1 324.38	22 107.46	45.02	912.23	3 590.13	26 609.82	54.19	1 365.50	....	....	25 244.32
Leonora	5 461.0	21 796.93	40 998.26	9 629.93	72 425.12	13.26	15 282.62	27 472.44	115 180.18	21.09	14 348.88	2.62	....	100 831.30
Marble Bar	787·75	23 528.10	16 438.14	5 741.75	45 707.99	58.02	9 067.40	7 622.73	62 398.12	79.21	2 363.09	2.99	....	60 035.03
Marvel Loch	3 738·0	13 596.96	56 745.46	8 578.60	78 921.02	21.11	10 603.32	16 437.96	105 962.30	28.34	10 418.50	2.78	....	95 543.80
Meekatharra	3 117·0	18 963.55	58 329.75	12 988.91	90 282.21	28.96	17 738.68	21 355.16	129 376.05	41.50	8 080.83	2.59	....	121 295.22
Menzies	2 291·6	6 120.73	44 054.10	7 093.66	57 268.49	24.99	5 408.28	11 021.32	73 698.09	32.16	7 201.44	3.14	....	66 496.65
Norseman	3 050·8	12 876.70	38 257.42	7 673.29	58 807.41	19.27	6 258.69	13 542.20	78 608.30	25.76	7 681.20	2.51	....	70 927.10
Nullagine	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Ora Banda	5 123.0	19 534.24	41 714.54	13 994.26	75 243.04	14.68	6 127.79	19 045.30	100 416.13	19.60	11 229.21	2.19	....	89 186.92
Paynes Find	67·0	2 463.84	5 347.30	319.53	8 130.67	121.35	3 317.82	681.84	12 130.33	181.04	193.50	2.88	....	11 936.83
Peak Hill	....	....	....	....	....	....	....	....	....	....	200.00	....	200.00	....
Sandstone	98·6	782.83	2 454.11	266.02	3 502.96	35.52	596.92	1 021.55	5 121.43	51.94	294.77	2.98	....	4 826.66
Yarri	1 343·0	9 598.03	32 522.72	5 577.86	47 698.61	35.51	7 664.19	6 744.58	62 107.38	46.24	4 093.00	3.04	....	58 014.38
Head Office	....	....	....	....	....	....	....	....	....	....	8 916.38	....	8 916.38	....
Sub total	45 239·95	202 819.45	605 656.69	123 917.56	932 393.70	20.60	128 907.95	239 314.39	1 300 616.04	28.74	132 205.97	2.92	10 596.38	1 179 006.45
Marble Bar (Mag. Plant)	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Northampton	1 229·58	10 785.33	12 979.29	3 904.54	27 669.16	22.50	4 381.15	4 820.45	36 870.76	29.98	4 006.30	3.25	....	32 864.46
Total	46 469·53	213 604.78	618 635.98	127 822.10	960 062.86	20.66	133 289.10	244 134.84	1 337 486.80	28.78	136 212.27	2.93	10 596.38	1 211 870.91

Schedule No. 5

STATEMENT OF RECEIPTS AND EXPENDITURE FOR YEAR ENDED 31st DECEMBER, 1977

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
		$	$	$	$	$	$	$	$	$	$	$	$	$
Coolgardie	1 780	....	19 449.41	7 688.34	27 137.75	15.25	734.26	5 692.67	33 564.68	18.85	1 334.35	0.74	....	32 230.33
Kalgoorlie	750	3 489.49	19 847.87	5 908.54	29 245.90	38.99	1 034.98	4 681.56	34 962.44	46.61	1 247.98	1.66	....	33 714.46
Leonora	6 000	....	41 057.07	12 182.25	53 239.32	8.87	400.71	23 853.16	77 493.19	12.91	28 758.74	4.79	....	48 734.45
Marvel Loch	756	....	4 618.21	1 030.62	5 648.83	7.47	206.50	2 966.25	8 821.58	11.66	6 914.63	9.14	....	1 906.95
Menzies	2 080	5 779.26	11 203.80	5 673.50	22 656.56	10.89	374.21	19 389.33	42 420.10	20.39	2 109.34	1.01	....	40 310.76
Sandstone	520	....	4 901.37	1 235.57	6 136.94	11.80	43.93	2 918.03	9 098.90	17.49	1 205.00	2.31	....	7 893.90
Yarri	....	....	6 680.14	....	6 680.14	....	....	....	6 680.14	....	....	....	....	6 680.14
Total	11 886	9 268.75	107 757.87	33 718.82	150 745.44	12.68	2 794.59	59 500.97	213 041.03	17.92	41 570.04	3.49	....	171 470.99
Less Interest Paid to Treasury											4 320.00			4 320.00
									213 041.03		37 250.04		....	175 790.99

STATE BATTERIES
TRADING AND PROFIT LOSS ACCOUNT FOR THE YEAR ENDED 31st, DECEMBER, 1977

1976 $	1976 $		1977 $	1977 $
		Trading Costs—		
867 497		Wages	949 267	
149 918		Stores	161 541	
120 594		Repairs, Renewals and Battery Spares	136 084	
324 438		General Expenses and Administration	307 949	
	1 462 447			1 554 841
		Earnings —		
	207 987	Milling and Cyaniding Charges		177 782
	1 254 460	**Operating Loss for Year**		1 377 059
		Other Charges—		
63 457		Interest on Capital	63 456	
29 020		Depreciation	27 227	
35 987		Superannuation—Employers Share	44 122	
	128 464			134 805
	1 382 924	Total Loss for Year		1 511 864

STATE BATTERIES BALANCE SHEET AS AT 31st DECEMBER, 1977

FUNDS EMPLOYED

		Capital—		
1 506 140		Provided from General Loan Fund	1 505 663	
449 067		Provided from Consolidated Revenue Fund	482 284	
1 955 207				1 987 947
		Reserves—		
57 244		Commonwealth Grant—Assistance to Gold Mining Industry	57 243	
27 572		Commonwealth Grant—Assistance to Metalliferous Mining	27 573	
84 816				84 816
		Liability to Treasurer—		
2 887 898		Interest on Capital		2 951 355
		Other Funds—		
11 527 910		Provided from Consolidated Revenue Fund (Excess of payment over collections)		12 849 668
16 455 831				17 873 786
		Deduct—		
		Profit and Loss:		
14 892 044		Loss at Commencement of Year	16 274 968	
1 382 924		Loss for Year	1 511 864	
16 274 968		Total Loss from Inception		17 786 832
$180 863				$86 954

EMPLOYMENT OF FUNDS

		Fixed Assets—		
1 945 125		Plant, Buildings and Equipment	1 977 865	
1 688 298		Less Depreciation	1 715 622	
256 827				262 243
		Current Assets—		
43 269		Debtors	52 120	
67 848		Stores	43 589	
41 501		Battery Spares	28 262	
		Purchase of Tailings:		
44 817		Treasury Trust Account	43 064	
53 000		Tailings not Treated	53 334	
11 157		Estimated Gold Premium	14 877	
261 592				235 246
518 419		Total Assets		497 489
		Deduct—		
75 917		Current Liabilities: Creditors	102 571	
248 665		Liability to Treasurer (Superannuation—Employers Share)	292 788	
		Purchase of Tailings:		
1 817		Creditors	299	
11 157		Estimated Premium Due	14 877	
337 556				410 535
$180 863				$86 954

DIVISION IV

Annual Report of the Geological Survey Branch of the Mines Department for the Year 1977

CONTENTS

REPORTS

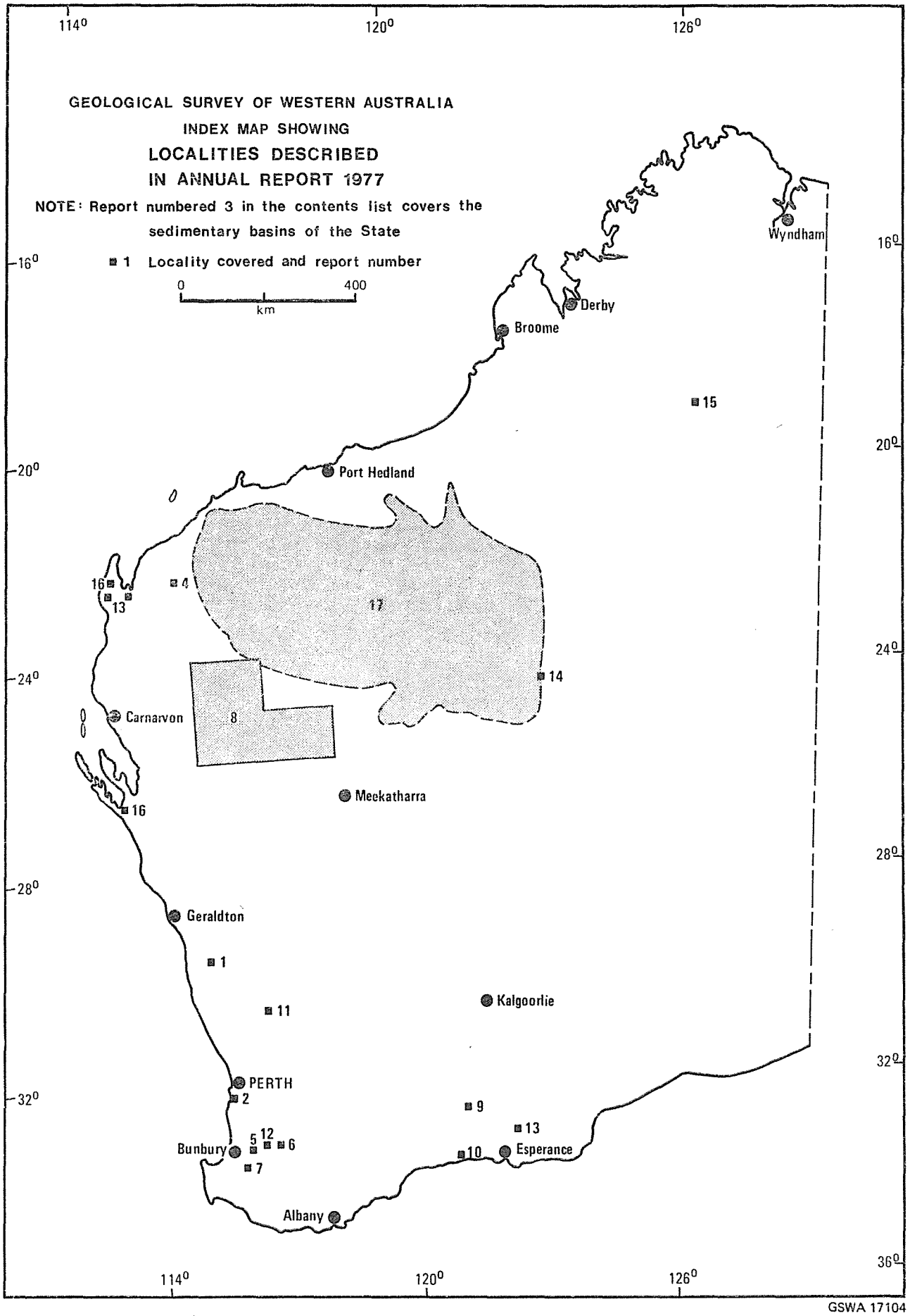

Figure 1 Index map showing areas and localities described in the Annual Report for 1977

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DIVISION IV

Annual Report of the Geological Survey Branch of the Mines Department for the Year 1977

Under Secretary for Mines:

I herewith submit my report for 1977 on the activities of the Geological Survey of Western Australia for the information of the Honourable Minister for Mines, together with selected reports on investigations and studies made for Departmental purposes.

INTRODUCTION

The upward trend of exploration for minerals reported in 1976 levelled off during 1977, probably due to the depressed state of world prices for most metals. The main search was directed towards uranium with less interest than previously being shown in copper, zinc and nickel.

The applications or renewals for Temporary Reserves which may be taken as a guide to exploration activity, remained static.

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

Interest in petroleum exploration showed an increase both on and off-shore when new, such as Exmouth Plateau, and surrendered areas were taken up. A boom in oil exploration is commencing, as programmes costing hundreds of millions of dollars over the next 5 or 6 years have been approved.

There was a marked increase in the amount of drilling during 1977 and the length of marine seismic surveys more than doubled.

Year	Total wells drilled	Total metrage	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

No new oil or gas of commercial interest was found in the drilling done during 1977 but the extension test North Rankin No. 5 was successful.

No new noteworthy mineral prospect was reported during 1977. Exploration continued on most of the previously reported prospects but generally on a reduced scale.

Exploration for iron ore in the Hamersley and Nabberu Basins expanded in the 85 Temporary Reserves for iron granted late in 1976 and the 6 granted in 1977. There are 225 current Temporary Reserves for iron ore, some of which have been adequately tested for their iron ore potential.

The joint venture on a proposed alumina refinery near Wagerup was dissolved. Alcoa will continue with the refinery alone while Alwest is studying Worsley as the site for their own venture.

Uranium prospecting has spread throughout the State with the search being extended to all possible geological environments. Although new occurrences have been reported, none is known to be of possible economic significance.

Because of its importance in the present energy crisis, coal is another mineral which has attracted attention, and many companies have carried out reviews of the possible potential of the sedimentary basins. The area where most interest has been shown is in the Perth Basin in the vicinity of Eneabba. Here a deposit of low-grade coal was located a few years ago and there is the possibility of similar occurrences, but faulting is a major problem in this area.

With the rising price of gold, activity by prospectors and tributors (on the Golden Mile) has increased considerably. The new gold mine at Telfer, 220 km east-southeast of Marble Bar, has commenced production. Notice has been given that the small Blue Spec mine, east of Nullagine, will close early in 1978, having failed to locate more ore or to achieve the estimated extractable grade. If the gold price continues to rise and to stabilise consideration should be given to the feasibility of re-opening the mines on the Golden Mile.

The general level of mineral prospecting has continued without change in the Kimberley this year, but the search for diamond has expanded. As well as recovery of micro-diamonds, it has also been reported that kimberlite plugs have been located.

Due to the drought affecting most of the State, there has been a heavy call on the Hydrogeology Division to provide the public with assistance and to advise on the availability of underground water. This was particularly so in the Metropolitan area where water restrictions, imposed during the winter, have resulted in many home owners considering the establishment of their own water supply from underground. Inquiries for information of this nature have on occasions exceeded 100 per day. At the end of November two Information Pamphlets, No. 12 "Groundwater in Western Australia" and No. 13 "Drilling for Water", were issued. The demand was far in excess of any estimates. On the first day after the media announced their release, over 1 100 people called at this office to obtain a copy of each. Within 3 weeks 4 250 copies of each had been distributed.

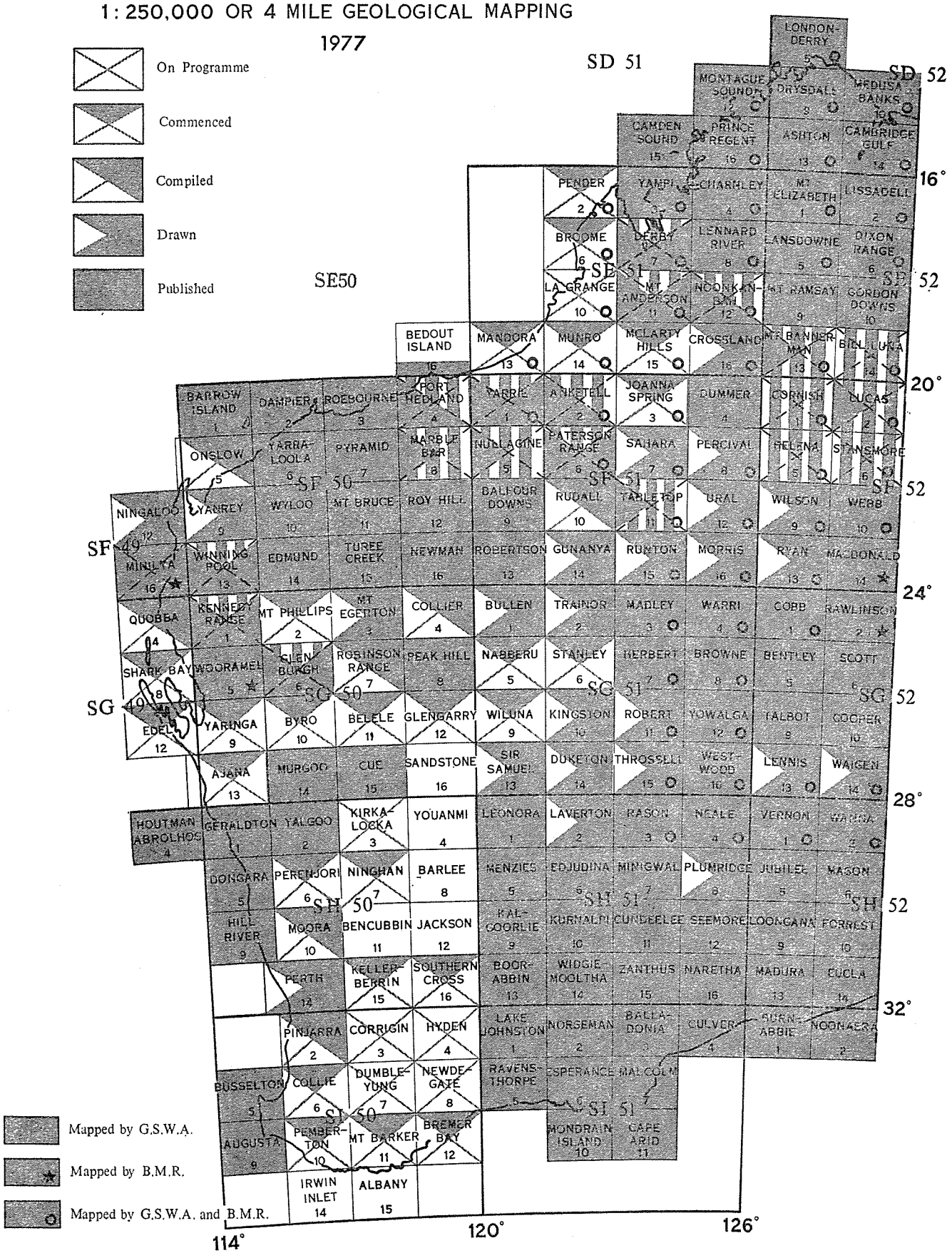

Figure 2 Progress of 1:250 000 or 4-mile geological mapping at the end of 1977

Regional geological mapping of the State continues (Fig. 2) with only 5 sheets not yet on the programme of work. Of the 175 sheets to be completed, only 95 have been printed, the remainder being in progress. There will be a slowing down of final production as the Bureau of Mineral Resources, who were committed to print all maps, has decided no longer to honour that agreement.

Public lectures: On April 15, 1977, a lecture series was inaugurated for those members of the public who are interested in geology. It consisted of nine lectures on aspects of geology emerging from projects on which the speakers were working. The maximum attendance at the morning session was 145 persons from mining and exploration companies, consultants, tertiary and research institutes.

From the results of a questionnaire completed by those who attended, there was an overwhelming opinion that similar lectures should be given each year and plans are being made to repeat the project in 1978.

Field excursion and lecture: A lecture was given at Meekatharra on the results of regional geological mapping on the Robinson Range 1:250 000 sheet, followed by a three day excursion to view the more interesting sites, which illustrate the geological interpretation proposed. Again such a venture proved popular with some 88 geologists attending.

Microfilm library: After many delays a microfilm library was established by the end of the year. It contains two 35 mm reader-printers, one 16 mm reader-printer and one 16 mm reader arranged for use by the public.

Available in the library are 16 mm cassette films of all Survey publications, 35 mm cassette film of reports on surrendered mining and petroleum tenements and microfiche of some reports. Additional film and microfiche will be added to the library as quickly as production permits.

The public may print out individual pages or maps in which they may be interested or purchase the complete roll of film.

Records: Each year since 1962 the Survey has issued Records containing reports requiring quick circulation or which are of insufficient general interest to warrant inclusion in the Annual Report. As Records were assembled internally the distribution was restricted, although a copy was always made available to anyone interested. It has always been debatable whether or not these Records could be regarded as publications as some numbers were classified as "restricted" or "confidential" and distribution was limited.

As from the beginning of 1978 the Record series will be produced on microfiche, will be freely available to those interested, and will not include classified reports. Under these circumstances Records should henceforth be regarded as a published series.

STAFF

There was one resignation and one retirement from the professional staff during 1977 with the number of movements in the general and clerical divisions being more than expected.

Dr Karl Berliat retired on February 25 after 26 years with this Branch. During this service he worked in most parts of the State from the Kimberley to the south coast. In the earlier years he handled all types of geological investigations, but in the later portion of his service he specialized in hydrogeological investigations and in particular property inspections for the general public and town water supply, in which he demonstrated his wide knowledge of the varied geological conditions in this State and their hydrogeological characteristics.

PROFESSIONAL

Appointments

Name	Position	Effective Date
Morrison, R. J., F.R.M.I.T., M.Sc., D.I.C., A.M.Aus.I.M.M.	Geologist L2	27/6/77
Laws, A. T., B.Sc. (Hons), M.Sc., M.Aus.I.M.M.	Geologist L3	4/7/77
Retirement		
Berliat, K.	Geologist L3	25/2/77
Resignations		
Crowe, R. W. A.	Geologist L1	4/11/77

CLERICAL AND GENERAL

Appointments

Willis, R.	Laboratory Assistant	18/2/77
Quinn, P.	Technical Assistant	14/3/77
Rowe, E. H.	Technical Assistant	16/3/77
Geste, P.	Geological Assistant	18/4/77
Wright, R.	Technical Assistant	21/3/77
Elms, B.	Typist	30/3/77
Kelly, D. F.	Technical Assistant	26/10/77
Promotion		
Emery, L.	Laboratory Assistant	22/2/77
Transfer In		
Fahmy, H.	Core Librarian	29/3/77
Transfer Out		
Baints, R.	Technical Assistant	25/2/77
Resignations		
Smith, P.	Typist	25/3/77
Rowe, E. H.	Technical Assistant	19/8/77
Pettigrew, D.	Geological Assistant	16/12/77

ACCOMMODATION

Rearrangement of space on the 6th floor, Mineral House, vacated by Hydrogeology Division in 1976 was completed to provide additional accommodation for the evaluation sections of the Mineral Resources and Sedimentary Geology Divisions. Space vacated on the 4th Floor by the Engineering Geology Division was used to relocate the Environmental Geology Section, two geologists of the Palaeontology Section, and provide space for relocation of plans from the 5th floor library area. A rearrangement of the library to provide needed additional stack space and to establish a public micro-form reading room was completed in readiness to open the reading room at the beginning of 1978.

Although there has been little increase in staff in recent years, the rapid influx of technical data has resulted in overcrowding in some areas, a situation that will require attention in the near future if efficiency is to be maintained.

OPERATIONS

HYDROGEOLOGY DIVISION

T. T. Bestow (Supervising Geologist), A. D. Allen, A. T. Laws (Senior Geologists), J. C. Barnett, W. A. Davidson, A. S. Harley, K-J. Hirschberg, E. H. Briese, D. P. Commander, L. J. Furness, R. E. J. Leech, J. S. Moncrieff, P. A. Wharton.

The aggregate depth of just under 4 000 metres which was drilled by the Department of Mines for groundwater resource evaluation in 1977 represents a reduction on that drilled during the preceding year. This was partly due to the effects of inflationary pressures and costs but also the diversion of effort into hydraulic testing for water resource assessments.

A further eleven bores have been drilled on five sites along the Moora line in the Perth Basin. One previously drilled borehole at Yoganup has been comprehensively test pumped. In the Perth region 23 deep bores have been drilled by the Metropolitan Water Board on 15 sites to depths of up to 838 metres. These provide important new stratigraphic and hydrologic data aiding the assessment of the deeper groundwater resources. The Board also drilled 16 shallow bores at Lake Thompson and Mirrabooka as aids to developmental planning and 31 bores at Lake Jandabup as the first stage of a detailed investigation of the hydrology and water balance of coastal plain lakes. Three bores were drilled at Lake Joondalup by the Survey to complete this shallow aquifer investigation.

One further bore was drilled in the West Canning Basin to a depth of 223 metres to complete the present programme of work in this area. Eighteen bores were comprehensively test pumped to provide hydraulic data for throughflow and storage assessments.

West of Millstream, in the Robe River catchment, seven bores were drilled in continuation of a long term programme of investigation of the complex aquifers of the West Pilbara. Two seismic traverses were completed to aid structural interpretation.

Further progress has been made with interdepartmental studies of the effects of the woodchip and bauxite mining industries on stream and groundwater hydrology. A novel test-pumping technique employed on bores in a pair of catchments at Yaraminup facilitated an assessment of water and salt balances based on groundwater flow and salinity data.

The demand for advisory facilities has been exceptionally high. Bore site inspections were carried out on 153 private properties and a further 23 were for various government

departments. The imposition of water restrictions in the metropolitan area, because of drought conditions, was responsible for much enhanced interest by landholders in drilling for domestic irrigation supplies. In consequence of this telephone and other enquiries increased dramatically. To further assist landholders two information pamphlets were issued: No. 12 "Groundwater in W.A." and No. 13 "Drilling for Water".

ENGINEERING GEOLOGY DIVISION

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

The work of this Division was again confined mainly to investigations for other Government Departments and instrumentalities including:

Department of Public Works:

(a) Further investigations made where necessary and reports completed on the following Pilbara dam sites. Harding River (formerly Cooya Pooya), Robe River "D", Sherlock River and Fortescue 123.

(b) Geological reconnaissance made of Nunyerry proposed dam site.

(c) Report completed on Port Denison proposed quarry sites.

(d) Minor investigations carried out including foundation studies for a tank site at Derby and for basin extension to the inner harbour at Bunbury.

Metropolitan Water Board:

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

(b) Further studies on the South Canning and North Dandalup proposed dam sites.

(c) Studies made for the Beenyup and Burns Beach sewer tunnels and the Wungong proposed water tunnel.

Westrail:

Geological advice given on selection and development of quarry sites.

SEDIMENTARY DIVISION

P. E. Playford (Supervising Geologist), K. A. Crank, W. J. E. van de Graaff (Senior Geologists), M. N. Megallaa (Senior Geophysicist), P. D. Denman, R. M. Hocking, B. P. Butcher.

The processing of data submitted by petroleum companies continued. There was an encouraging small increase in petroleum exploration during the year and many new exploration permits were issued, many of which were taken up by new companies entering the State for the first time. As a result of this, activity is expected to increase considerably in the near future.

Mapping continued in the Carnarvon Basin with the completion of compilation of the Phanerozoic portions of the Mount Phillips and Glenburgh 1:250 000 sheets. Field work has been completed on the Edel, Shark Bay, Yaringa and Ajana sheets, and a start has been made on the Wooramel sheet.

The study of the southern and central Carnarvon Basin has been completed and a study of the northern offshore part of this basin, between latitudes 19° and 23° has been commenced.

The Canning Basin mapping project, in conjunction with the Bureau of Mineral Resources, was completed during the year. The compilation of this Survey's contributions has been completed.

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, I. W. Walker.

Regional mapping for publication at a scale of 1:250 000 (Fig. 2) continued on the Precambrian portion of the State. Field mapping on Glenburgh, Mount Phillips and Glengarry was completed. Mapping on Belele, Bremer Bay and Newdegate commenced.

Work continued on the Bangemall Basin bulletin, which should be completed shortly.

Regional reappraisal of the Peak Hill-Nabberu-Stanley area was undertaken in preparation for a bulletin on the Nabberu Basin.

Compilation for a new, State geological map was completed.

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, K. H. Green.

Mapping of the Precambrian portion of the Perenjori and Ajana 1:250 000 sheets was completed. Mapping continued on Pemberton and commenced on Ninghan. The map compilation and explanatory notes were completed for Moora and Port Hedland and continued on Collie.

The mineral resources bulletin on Copper was completed and one commenced on Nickel. A bulletin on the Pilbara Block is in preparation.

Sundry field work included a study of the Marra Mamba Iron Formation, inspections of Mount Mulgine molybdenum and wolfram, Golden Grove copper-zinc and Mooloyella tin prospects. An inspection and estimation was made of the lime resources of the Boranup sand patch.

Microfilming of statutory mineral exploration reports on relinquished tenements commenced in 1977. 386 exploration projects were filmed ready to be placed on open file at the beginning of 1978.

During the year the Division answered about 260 verbal inquiries from the public and other Government agencies and dealt with some 200 requests for access to company reports on surrendered tenements. About 660 new accessions were added to the Survey's collection of mineral exploration reports, an increase of 160 on 1976.

COMMON SERVICES DIVISION

Petrology

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

A total of 81 petrological reports were completed during the year on a total of 1 964 rock samples. Further thin sections were studied for incorporation into the computer based petrological data system.

For most of the year J. D. Lewis was concerned with the production of the Meckering Earthquake bulletin which has been completed.

Two projects in the GSWA/WAIT co-operative geochronology programme were published during the year (Hardey Sandstone and East Pilbara), three have been prepared for publication early in 1978 (Greenbushes pegmatite, north margin Yilgarn Block, and Fitzgerald Peaks) and several other studies are nearing completion.

The laboratory prepared 2 700 thin sections of which 2 144 were petrological and 556 sedimentological. Thin sections stained for carbonate numbered 56. Polished mounts for petrological work totalled 49 and 336 rock slabs were polished. There were 32 heavy mineral separations and 11 sieve analyses. Samples crushed for chemical or geochronolgical analysis numbered 756 and 35 biotite separations for geochronological work were made.

The Government Chemical Laboratories identified mineral samples and provided access to the X-ray diffractometer and computer.

Palaeontology

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

There was a slight increase in demand for palaeontological information during the year and 80 reports were written. The work of the section included studies on Devonian faunas from the Canning Basin, Cretaceous palynology of the Perth Basin, Precambrian fossils from the Bangemall Basin and various fossils from the Carnarvon Basin. Two manuscripts, one on Devonian atrypid brachiopods and one on Early Cretaceous palynomorphs, were completed.

Geophysics

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

Seismic refraction surveys dominated geophysical activities in 1977 and encompassed various hydrogeology and engineering projects. The latter included a dam site on the Fortescue River, additional work at the Churchman Brook dam and an investigation of the inlet and outlet portals of the proposed Wungong Tunnel. Seismic sections were obtained across the Robe River in the Pilbara, in the Grasmere Valley for the Albany Town Water Supply and for the CSIRO at the Yallanbee Research Station. The Robe River work also involved resistivity profiling and magnetic measurements.

Magnetic surveys were used to delineate the margin of the Bunbury Basalt at Yoganup and to map a dolerite dyke at the Victoria dam.

Water-bore logging operations were carried out in 204 bores with an aggregate total depth of 43 710 m, matching the level of activity for 1976 when 191 bores were logged. The marked increase in aggregate depth is due to systematic temperature and differential temperature logging in some of the deeper cased bores such as the Eneabba line, and the demand for casing-collar locator and caliper completion logs.

Field salinity measurements exceeded 1 200 and the calibration of resistivity and temperature loggers used in various groundwater monitoring studies occupied considerable time. Transceiver and electronic servicing facilities were provided for Survey equipment as usual.

Environmental Geology

E. R. Biggs and R. H. Archer.

Work on the 1:50 000 Urban Geology map series was continued with the completion of 5 sheets (Pinjarra, Nickol Bay/Legendre, Karratha, Point Samson/Delambre and Dampier). Compilation is in progress on a further 4 sheets in the Roebourne and Dampier areas and fieldwork has been completed for two sheets around Port Hedland.

Geological information has been supplied for Karratha townsite development, Maida Vale Town Planning scheme, Joondalup sub-regional centre study, System 6 study, Rural Policy study and many other smaller projects. Committee and liaison meetings continue to occupy a large segment of the section's activities, both on major projects and on individual problems such as the supply of minerals in a specific area.

Appraisal continues on applications for mineral tenements in the Southwest Mineral Field with a view of lesssening adverse impacts of mining on the environment. Temporary excavations in the Perth area are examined to increase geological knowledge in the urban area.

Geochemistry

R. Davy.

Studies of low-grade zinc mineralization in the Bangemall Basin have continued. All investigative work has been carried out and reports are in preparation.

An investigation of the usefulness of B-Ga-Rb diagrams for determining the depositional conditions under which certain Proterozoic sedimentary rocks were formed has been concluded.

Reports on the silicate geochemistry of, and on orientation studies on sediments over, the Saddleback Greenstone Belt are in preparation for release as Records. Fieldwork for rock chip and stream sediment/soil geochemical surveys has been completed but analytical results are not yet available.

A geochemical study of the Mount McRae Shale has been initiated.

Samples of sulphides from various W.A. base metal mines and prospects have been submitted for analysis for mercury.

Technical Information

W. B. Hill, M. E. Wenham, J. F. Cameron, S. M. Fawcett.

The number of publications edited by this section continues to increase. One bulletin and one report were sent to press, and proof reading of these is in progress. At the end of the year editing was being carried out on one bulletin, three mineral resources bulletins and four reports. Twenty-two records have been edited and 17 maps with explanatory notes were published. Two new information pamphlets were prepared and issued.

The library storage facilities were expanded considerably by the addition of seven new compactus units. A room has been set aside for machines for viewing and reproducing microfilm material. This will be available for public use early in 1978.

Requisitions raised on the Surveys and Mapping Branch for drafting services and photography for the Survey totalled 1 157. Photocopying for the public of out-of-print publications numbered 762 requisitions; many of these contained several items.

During the year this section dealt with 702 requests for information including rock identification, and 1 696 members of the public visited the library for research purposes. Book loans to the staff totalled 4 933, and loans to other libraries 187.

ACTIVITIES OF THE COMMONWEALTH BUREAU OF MINERAL RESOURCES

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

(i) Completion of a bulletin on the Officer Basin as a joint project with this Survey.

(ii) Completion of field mapping in the Canning Basin as a joint project with this Survey.

(iii) Analysis of rocks from the Pilbara Block in continuation of a joint geochemical project with this Survey.

(iv) Airborne magnetic and radiometric survey of Bremer Bay, Mount Barker, and part of Pemberton sheets.

(v) Completion of seismic and gravity observations for a crustal structure study between Mount Goldsworthy and Meekatharra.

PROGRAMME FOR 1978

HYDROGEOLOGY DIVISION

1. Continuation of the hydrogeological survey of the Perth Basin including deep drilling, test pumping and report on the Moora and Picton lines and at Irwin View.
2. Hydrogeological investigations and/or exploratory drilling for groundwater in the following areas:
   (a) West Canning Basin—completion of report.
   (b) Fortescue River area—further drilling and testing to assess the calcrete and other aquifers.
   (c) East Pilbara—further bore census, reconnaissance and report writing.
   (d) Reassessment, as required, of groundwater along the Yule, de Grey and Gascoyne rivers, Eneabba and Pinjarra.
3. Town water supply investigations and/or drilling for the following: Bunbury, Albany, Lancelin-Salvado, Australind, Dandaragan and others as required.
4. Hydrogeological investigations for the Metropolitan Water Supply Board:
   (a) Deep drilling at Mirrabooka East, Gnangara and Hamilton Hill.
   (b) Shallow drilling at Lake Jandabup, Lake Mariginiup and Lake Jandakot.
   (c) Continuation of pollution studies at Hertha Road/Jones Street; Gnangara liquid waste disposal and Alcoa red mud lake areas.
   (d) 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, supervising of consultant work and State groundwater monitoring network.
7. Miscellaneous investigations and inspections as required by Government departments and the public.

ENGINEERING GEOLOGY DIVISION

1. Pilbara area—completion of reports on Fortescue and Sherlock Rivers and Nunyerry dam sites.
2. Darling Range area—continuing investigations on Wungong, South Canning, Victoria, North Dandalup, Marrinup Brook and Brunswick River dam sites, commencing reconnaissance investigations Brookman River, Wooroloo and Jane Brooks and safety reviews on existing dams.
3. Investigation of tunnel lines at Wungong, Burns Beach and Bibra Lake.
4. Miscellaneous investigations as required by Government departments including quarry sites for Westrail.

SEDIMENTARY GEOLOGY DIVISION

1. Maintain an active interest in the progress and assessment of oil exploration and potential in Western Australia including the checking and assessing of all company reports on exploration.
2. Continuation of the surface mapping and subsurface study of the Carnarvon Basin including the Minilya and Winning Pool 1:250 000 sheets.
3. Continuation of the compilation of a bulletin on stratigraphic studies of Devonian reef complexes in the Canning Basin.

4. Continuation of the investigation of coal resources of the Perth and Collie basins
5. Minor geological investigations as required.

REGIONAL GEOLOGY DIVISION

1. Continuation of the mapping of the Gascoyne Province, on the Byro, Kennedy Range and Winning Pool 1:250 000 sheets.
2. Completion of the mapping of the Belele 1:250 000 sheet.
3. Continuation of the mapping of the Bremer Bay, Mount Barker, Newdegate, Dumbleyung, Hyden and Corrigin 1:250 000 sheets.
4. Continuation and completion of the bulletin on the Nabberu Basin.

MINERAL RESOURCES DIVISION

1. Maintain records and assess mineral potential in Western Australia.
2. Completion of a bulletin on the regional and economic geology of the Pilbara Block.
3. Regional study of the nickel occurrences in Western Australia and commencement of a bulletin.
4. Complete the mapping of the Darling Range area and commence a bulletin on the geology and bauxite occurrence of this area.
5. Completion of the mapping of the Ninghan sheet to be followed by Kirkalocka sheet 1:250 000.
6. Continuation of assembling the ore reserves of known mineral deposits.
7. Undertake a surface assessment of iron ore reserves on Ministerial Reserves in the Hamersley Iron Province.
8. Miscellaneous minor mineral investigations as required.

COMMON SERVICES DIVISION

Petrology

1. Carry out petrological investigations as required by other Divisions.
2. Further petrological study of the transition from the Yilgarn to the Gascoyne Block.
3. A study of the amphiboles from the Wongan Hills area and of the garnet-cordierite P-T conditions in the Southern Cross area.
4. Miscellaneous minor petrological studies.

Palaeontology

1. Carry out palaeontological investigations as required by other divisions.
2. Continuing a study of the Devonian stromatoporoids Lennard Shelf, Canning Basin.
3. Continuing a detailed palynological study on the Warnbro Group of the Perth Basin.
4. Completion of a study of stromatolites from the Nabberu Basin.
5. Determination of macrofossils from the Carnarvon Basin as required by the basin study group.

Geophysics

1. Well logging on groundwater drilling projects as required.
2. Seismic surveys for:
   (a) Dam sites in the Pilbara and Darling Range as required.
   (b) Tunnels for water supply and sewerage.
   (c) Groundwater supplies at Albany, Nullagine, Toolibin Lake, Norseman and East Fortescue.
3. Trial magnetic surveys over the southern portion of the Darling Fault.
4. Miscellaneous office studies as required.

Geochemistry

1. A study of the use of B-Ga-Rb diagrams as indicators of deposition in WA Phanerozoic rocks.
2. Statistical studies on gossans/ironstones with reference to the Yarri sheet.
3. A study of the Corunna Downs and Mount Edgar batholiths to identify further potential tin/tantalum-bearing rocks.
4. A comparative study of the Saddleback, Jimperding and Wongan Hills greenstone belts.
5. A preliminary study of favourable conditions for formation of chromite ore bodies.

Environmental Geology

1. Complete compilation of urban geology maps in the Roebourne and Port Hedland areas.
2. Complete study of Perth metropolitan sand resources.
3. Commence field work and compilation of urban geology maps in the Bunbury and Leeman areas.
4. Attend to miscellaneous environmental geological problems as required.

PUBLICATIONS AND RECORDS

Issued during 1977

Annual Report, 1976.

Mineral Resources Bulletin 10: Heavy mineral sands of Western Australia.

Report 6: Geology and hydrology of Rottnest Island.

Information pamphlet 12: Groundwater in Western Australia.

Information pamphlet 13: Drilling for water.

Geological map of Billiluna 1:250 000 sheet (SE/52-14 International Grid) with explanatory notes (Second edition).

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

Geological map of Dummer 1:250 000 sheet (SF/51-4 International Grid) with explanatory notes.

Geological map of Edjudina 1:250 000 sheets (SH/51-6 International Grid) with explanatory notes.

Geological map of Helena 1:250 000 sheet (SF/52-5 International Grid) with explanatory notes.

Geological map of Lake Johnston 1:250 000 sheet (SI/51-1 International Grid) with explanatory notes.

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

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

Geological map of Rason 1:250 000 sheet (SH/51-3 International Grid) with explanatory notes.

Geological map of Ravensthorpe 1:250 000 sheet (SI/51-5 International Grid) with explanatory notes.

Geological map of Stansmore 1:250 000 sheet (SF/52-6 International Grid) with explanatory notes.

Geological map of Vernon 1:250 000 sheet (SH/52-1 International Grid) with explanatory notes.

Geological map of Wanna 1:250 000 sheet (SH/52-2 International Grid) with explanatory notes.

Geological map of Webb 1:250 000 sheet (SF/52-10 International Grid) with explanatory notes.

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

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1st February, 1978.

J. H. LORD,
Director.

HYDROGEOLOGY OF THE ENEABBA BOREHOLE LINE

by D. P. Commander

ABSTRACT

The Eneabba Line consists of twenty-eight boreholes drilled to a maximum depth of 800 m in an east-west line across the Perth Basin. These have been left cased for observation. The drilling encountered sediments ranging in age from Triassic to Lower Cretaceous and forming a synclinal structure with a faulted west limb and a very shallow dipping east limb.

Limited testing indicates very large groundwater resources in the upper Yarragadee Formation (Lower Cretaceous) about 350 m thick and in the lower Yarragadee Formation (Upper Jurassic) about 2 500 m thick. Groundwater salinity is in the 200-1 200 mg/l range and low salinity water extends below the depths drilled. The Otorowiri Siltstone acts as an aquiclude between the two groups of aquifers and maintains a head difference of 140 m.

In the west of the area the Cockleshell Gully Formation and the Lesueur Sandstone both contain large reserves of fresh to brackish water.

Groundwater movement in all aquifers is northerly; Triassic sediments near the coast are a barrier to westward movement and are not themselves groundwater sources. The Tamala Limestone in the area contains only limited quantities of brackish water.

Temperature logging shows a high geothermal gradient in the west of up to 5.5°C per 100 m but lower gradients in the east.

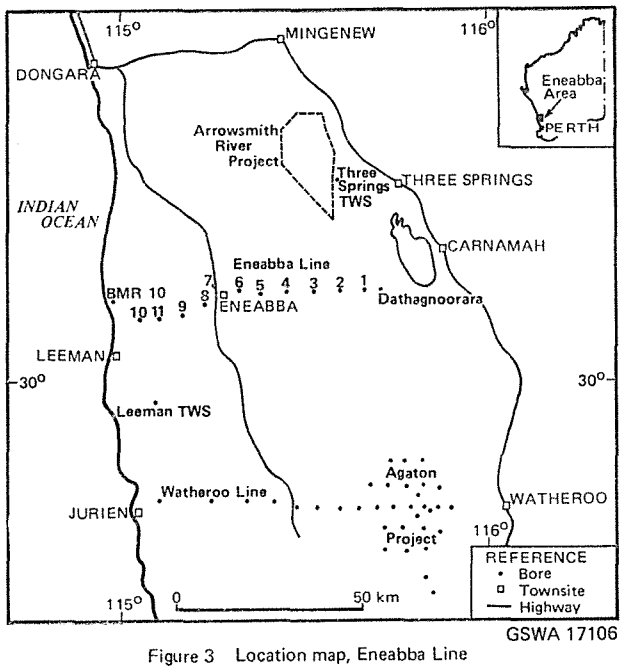


Figure 3 Location map, Eneabba Line

INTRODUCTION

The Eneabba Line of bores was drilled as part of a continuing programme of deep exploratory drilling to assess the hydrogeology of the Perth Basin by providing a stratigraphic and hydrogeological cross section to depths of about 800 m.

Ground water is used extensively in the mineral sands industry at Eneabba, and is also important for town and farm water supplies. The area lies within the North Coastal proclaimed groundwater area.

Exploratory drilling had been carried out in neighbouring areas (Fig. 3) at Arrowsmith River (Barnett, 1969), and at Agaton (Balleau and Passmore, 1972) and Watheroo (Harley, 1975). Drilling on the Eneabba Line commenced in 1972 and was completed at the end of 1976. The line consists of twenty-eight boreholes on eleven sites; all bores but two were drilled by the Mines Department Drilling Section. The bores range in depth from 66 to 797 m and the aggregate depth is 12 745 m. All the bores are cased for observation of water levels.

The Dathagnoorara bore, drilled for Carnamah town water supply, and the Bureau of Mineral Resources stratigraphic bore (BMR 10A), lie on each end of the drilling line, and information from these bores is included.

A more detailed account of the geology and hydrogeology including water level trends is issued as a G.S.W.A. Record (Commander, 1978).

DRILLING AND TESTING PROCEDURES

Strata samples were collected at 3 m intervals from the deep bore on each site and conventional cores were cut in three bores. On completion of drilling, gamma ray and normals resistivity logs were run and sidewall cores were cut. Temperature logs were run in the cased bores in 1977.

At eight sites (1 to 7 and 11) a deep 152 mm diameter bore was drilled to about 760 m and cased with 76 mm casing; subsequently two shallower bores were drilled at each site to test different intervals. Screens or perforations were used and development was by airlifting.

The procedure used on bores 8A and 9A was somewhat different: these bores were drilled by a contractor and cased with 169 and 143 mm casing respectively. The casing was perforated at several intervals and each one tested by an inner casing string of 76 mm pipe with movable rubber packers, which was subsequently left in the bore.

Eneabba Line (EL) bore 10A was not drilled to the planned depth because the Kockatea Shale was encountered; this bore was finished with slotted casing.

The main drilling problems were the presence of squeezing clays in the Otorowiri Siltstone and loss of circulation in parts of the Yarragadee Formation and the Tamala Limestone.

Water samples were chemically analyzed by the Government Chemical Laboratories and the bores were levelled in to Australian Height Datum by the Surveys and Mapping Branch of the Mines Department.

Table 1 summarizes the bore construction; further details are available in the form of composite logs which are available on application to the Geological Survey.

TABLE 1. SUMMARY OF BORE DATA

Bore name	Latitude S	Longitude E	Date drilled	Total depth m bns	Depth cased m bns	Observation Interval m bns	Observation Method *	Elevation Nat. Surf. m above AHD	Elevation Top casing m above AHD
Dathagnoorara	29°48'07"	115°42'15"	Mar 71	305	178	155–178	S	....	276·04
EL1A	29°48'00"	115°39'40"	Feb 74	751	687	675–681	S	256·6	256·900
EL1B	....	....	Apr 74	444	443	422–428	P	....	256·710
EL1C	....	....	May 74	250	242	230–236	P	....	256·685
EL2A	29°48'00"	115°35'30"	Oct 73	762	671	646–658	S	264·3	264·628
EL2B	....	....	Jan 74	250	242	224–236	S	....	264·826
EL2C	....	....	Feb 74	70	68	43–61	S	....	265·334
EL3A	29°48'00"	115°31'30"	July 73	762	687	662–674	S	295·0	295·374
EL3B	....	....	Sept 73	491	484	472–478	S	....	295·396
EL3C	....	....	Oct 73	110	90	71–77	S	....	295·266
EL4	29°48'10"	115°27'10"	May 73	762	627	607–613	S	254·2	254·508
EL4A	....	....	May 73	66	53	35–41	S	....	254·493
EL4B	....	....	June 73	487	477	459–465	S	....	254·526
EL5	29°48'17"	115°23'09"	Mar 73	718	562	543–549	S	201·3	201·675
EL5A	....	....	Mar 73	216	183	171–177	S	....	200·987
EL5B	....	....	Apr 73	402	399	387–393	S	....	201·389
EL6	29°47'45"	115°19'30"	Feb 73	763	635	616–622	S	138·4	138·766
EL6A	....	....	Feb 73	270	269	250–256	S	....	138·446
EL6B	....	....	Mar 73	167	164	145–151	S	....	138·563
EL7	29°45'08"	115°15'45"	Oct 72	765	756	737–743	S	95·5	95·809
EL7A	....	....	Nov 72	598	526	408–414	P	....	95·859
EL7B	....	....	Nov 72	159	157	144–150	S	....	96·074
EL8A	29°50'10"	115°13'40"	July 74	758	730	673–684	P	68·9	69·291
EL8A annulus	....	....	....	....	....	508–518 / 321–327	B / P	....	69·021
EL8B	....	....	Oct 74	177	174	157–162	P	....	68·795
EL9A	29°51'10"	115°10'30"	Oct 74	797	797	785–794	P	50·8	52·472
EL9A annulus	....	....	....	....	....	60–66 / 276–282 / 558–567	P / P / P	....	....
EL10A	29°52'	115°03'	May 74	159	42	24–36	SL	11·3	11·937
EL11A	29°52'	115°06'	June 74	102	97	84–90	P	....	66·813
EL11C	....	....	July 74	762	752	672–678	P	66·8	67·361
EL11D	....	....	Sept 74	458	452	438–444	P	....	68·238

* S Screen SL Slots P Perforation B Break in casing

PHYSIOGRAPHY

The Dandaragan Plateau and the Arrowsmith Region are the most extensive physiographic units in the area (Fig. 4). Both of these are remnants of a laterite-capped plateau with an elevation of about 300 m. The Arrowsmith Region is now subject to dissection by ephemeral streams having their headwaters in the outcrop of the Otorowiri Siltstone, which has given rise to the Dandaragan Scarp. On the Dandaragan Plateau itself drainages are now inactive and the valleys are infilled with sand.

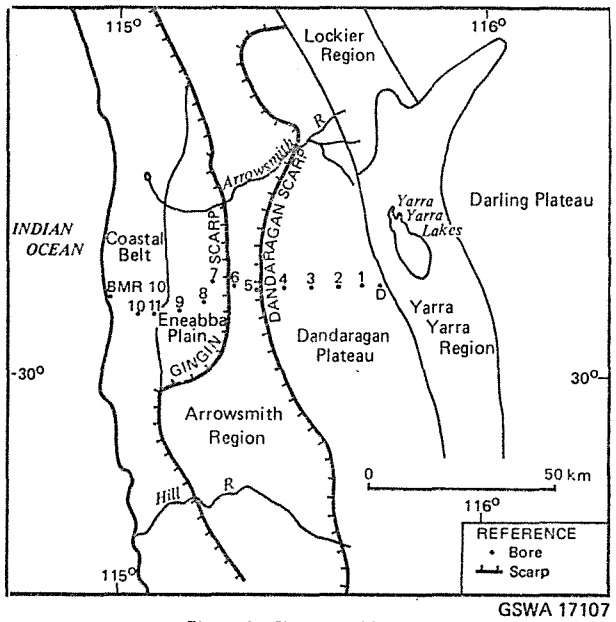


Figure 4 Physiographic regions

The Yarra Yarra Region lies to the east of the Dandaragan Plateau and is an area of low relief, being occupied by the Yarra Yarra Lakes and the upper part of the Moore River system. The region has been formed by erosion along the Darling Fault.

The Gingin Scarp, formed by Tertiary marine erosion, forms the western boundary of the Arrowsmith Region. The alluvial fans, colluvium and former strandlines at the base of the scarp form the Eneabba Plain. To the west of this a series of calcarenite dunes and beach ridges, termed the Coastal Belt, run parallel to the coast. These have the effect of ponding back streams on their east side and drainage then takes place through cave systems. The Coastal Belt includes shallow salt pans a few kilometres from the coast.

CLIMATE

The climate of the area is mediterranean, with hot, dry summers and mild, wet winters. Average annual rainfall decreases inland from 590 mm at Eneabba to 400 mm at Carnamah, and falls mainly between April and October. Mean daily temperatures exceed 30°C from December to March and potential evaporation is three times as great as the annual rainfall. Rainfall only exceeds evaporation in June, July and August.

GEOLOGY

The general geology of the area has been described by Playford and others (1976) and the detailed geology of the sediments encountered by the drilling is described by Commander (1978).

The area lies within the Perth Basin and has been subdivided into three structural units (Fig. 5): the Irwin sub-Basin, the Dandaragan Trough and the Beagle Ridge.

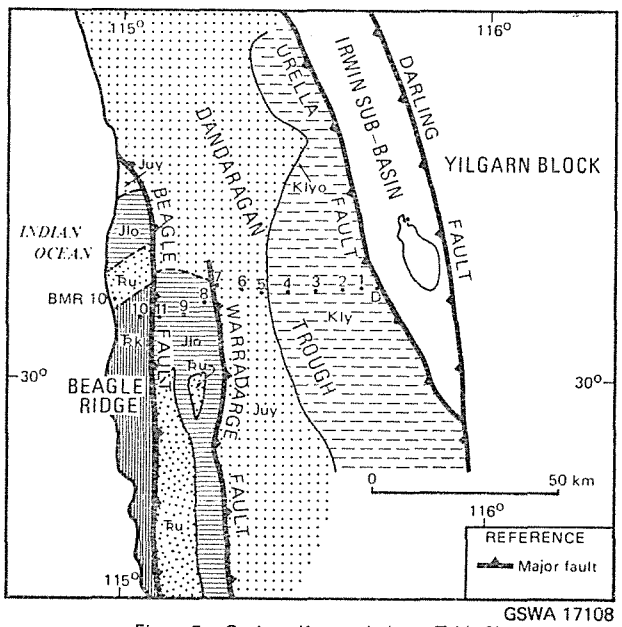


Figure 5 Geology (for symbols see Table 2)

The Irwin sub-Basin is an area of shallow Proterozoic rocks contained between the Darling and Urella Faults on the eastern margin of the basin. The Proterozoic rocks are covered in places by Permian and Quaternary sediments.

The centre of the onshore part of the basin is the Dandaragan Trough. This is occupied by a shallow synclinal structure, with shallow dips on the east and a faulted western limb. The sediments in the trough range in age from Permian to Cretaceous, and the thickness exceeds 8 km.

The Beagle Ridge lies to the west of the Dandaragan Trough and is separated from it by the Beagle Fault. Here the Precambrian basement is shallower, and covered by Permian and Triassic sediments.

Table 2 summarizes the Mesozoic and Cainozoic stratigraphy. The Permian and Lower to Middle Triassic formations are predominantly shaley. The Upper Triassic to Lower Cretaceous sequence is mainly sandy with some shaley sections, and it is in these formations that the major aquifers occur.

TABLE 2. SUMMARY STRATIGRAPHY IN THE ENEABBA AREA

Age	Formation	Symbol	Thickness (approx.) (m)
Quaternary	Safety Bay Sand, Tamala Limestone	Q	80
	unconformity		
Tertiary	Unnamed Channel Sand	Cz	153
	unconformity		
Lower Cretaceous	Yarragadee Formation (upper)	Kly	437
	Otorowiri Siltstone Member	Klyo	99
Upper Jurassic	Yarragadee Formation (lower)	Juy	2 500
Middle Jurassic	Cadda Formation	....	80
	Cockleshell Gully Formation	Jlo	....
Lower Jurassic	Cattamarra Coal Measures Member	Jloc	500
	Eneabba Member	Jloe	700
Upper Triassic	Lesueur Sandstone	Ru	600
Middle Triassic	Woodada Formation	Rk	1 100
Lower Triassic	Kockatea Shale		

Cainozoic sediments are thickest near the coast, west of the Gingin Scarp. In one bore, EL6, a channel sand was encountered extending to 15 m below sea level. The channel is probably associated with the palaeo-drainage system on the Dandaragan Plateau and the sand itself may be of marine origin, similar to other deposits in the Perth Basin (Allen, 1977).

A cross section showing the geology of the bore-hole line is shown in Figure 6.

HYDROGEOLOGY

The Dandaragan Trough contains all the major aquifers, and all the bores except EL10A were drilled into it. The trough is bounded both on the east and the west by impermeable barriers, the Urella and Beagle Faults, which impose a regional south-north groundwater flow on the contained aquifers. Head information from surrounding bores indicates that the flow direction is south to north.

The hydrogeology of the Irwin sub-Basin and the Beagle Ridge are briefly dealt with, and the occurrence of groundwater in the aquifers in the Dandaragan Trough is described in the order of declining potentiometric heads. Generally this is downwards, and the relationship is shown in Figure 6b.

IRWIN SUB-BASIN

Quaternary aquifer

Quaternary sands which overlie Proterozoic rocks and Phanerozoic sediments on both sides of the Urella Fault adjacent to the Eneabba Line, have a shallow water table developed only on the east side of the fault. The water table is several metres below surface and is about 270 m above sea level. Groundwater is recharged directly from rainfall and flows eastwards to be discharged at the surface near the Yarra Yarra Lakes (Fig. 7). Groundwater salinity in the western part of the aquifer is low, only several hundred milligrams per litre.

Proterozoic aquifer

Groundwater occurs in fractured Proterozoic crystalline and sedimentary rocks and in the clayey weathering products. The salinity ranges from 1 500 mg/l to just over 4 000 mg/l. The potentiometric surface is below that of the overlying Quaternary aquifer, but to the north where the Quaternary aquifer is absent it is 290 m above sea level. The amount of water in storage is probably very small, and the rates of groundwater movement very slow. There is a potential for leakage westwards across the Urella Fault, but the quantity is probably not significant.

DANDARAGAN TROUGH

Upper Yarragadee Formation aquifer

This aquifer occurs between the Dandaragan Scarp and the Urella Fault, and includes all the Yarragadee Formation stratigraphically higher than the Otorowiri Siltstone. Harley (1975) uses the term "Agaton groundwater system" to include both the upper Yarragadee Formation and the overlying Warnbro and Coolyena Groups which are absent in the Eneabba area.

The aquifer has a maximum saturated thickness of 300 m, and a salinity range of 160 mg/l to just over 2 000 mg/l, although it is generally less than 1 000 mg/l. The areas of fresher water (less than 500 mg/l) seem to coincide with the lower parts of the palaeodrainage systems where absence of laterite may facilitate recharge.

The water table occurs at a maximum depth of 90 m below surface (about 220 m AHD) and has a very small apparent east to west gradient. The westerly movement gives rise to spring flow along the Dandaragan Scarp. The drilling line lies near the groundwater divide between water flowing north towards the Arrowsmith River discharge area (Barnett, 1969) and southerly flowing groundwater at Agaton (Balleau and Passmore, 1972).

The potentiometric head in the Dathagnoorara bore is 183 m AHD which is significantly lower than heads elsewhere in the aquifer. It is possibly situated in a fault block with a different potentiometric head, and may indicate downward leakage into the lower Yarragadee Formation aquifer.

The base of the aquifer is the Otorowiri Siltstone, which is effectively impermeable and maintains a head difference of 140 m between the upper Yarragadee Formation and the lower Yarragadee Formation aquifers.

Lower Yarragadee Formation aquifer

The lower Yarragadee Formation aquifer is about 2 500 m thick and includes all the Yarragadee Formation below the Otorowiri Siltstone. It extends beneath the upper Yarragadee Formation aquifer as far east as the Urella Fault, and as far west as the Warradarge Fault. It is the most widespread and important aquifer in the Perth Basin; Harley (1975) uses the term "Badgingarra aquifer system" for the lower Yarragadee Formation along the Watheroo borehole line.

To the depths drilled, the salinity is generally less than 1 000 mg/l, and in Eneabba No. 1 oil exploration well (Pudovskis, 1962) the formation water in the whole of the Yarragadee Formation was reported as fresh. Only in EL4 and 4A, where the salinity was just over 1 000 mg/l and in EL3A, at 2 900 mg/l, were the salinities higher.

The lowest salinity water occurs just west of the Dandaragan Scarp, and in the south of the outcrop area. The salinity increases in a northwesterly direction.

East of the Dandaragan Scarp the aquifer is confined by the Otorowiri Siltstone. The apparent hydraulic gradient along the Eneabba Line is very small, but with no information to the north or south the direction of groundwater flow can only be assumed to be south to north as this is the direction in the upper aquifer.

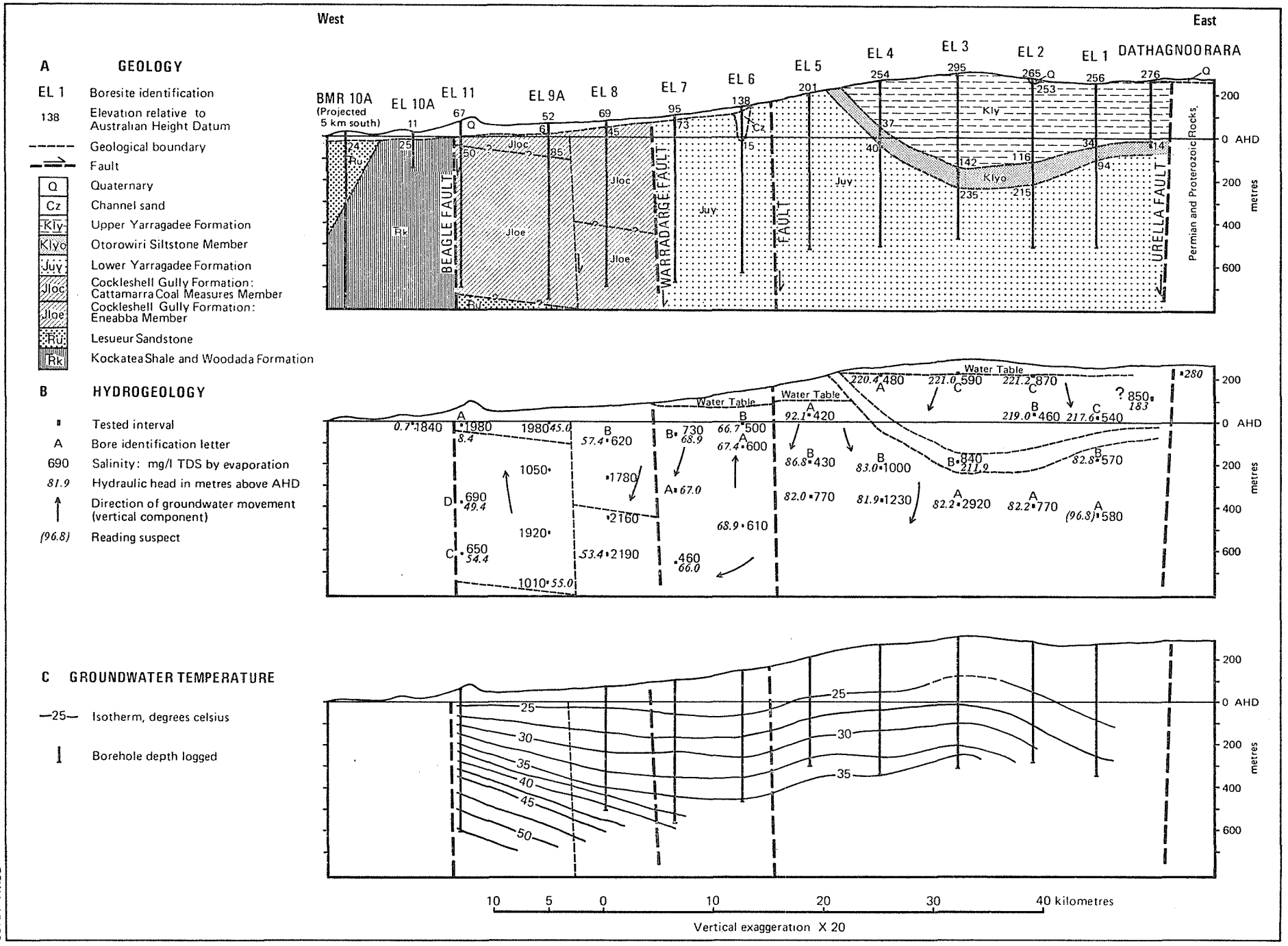
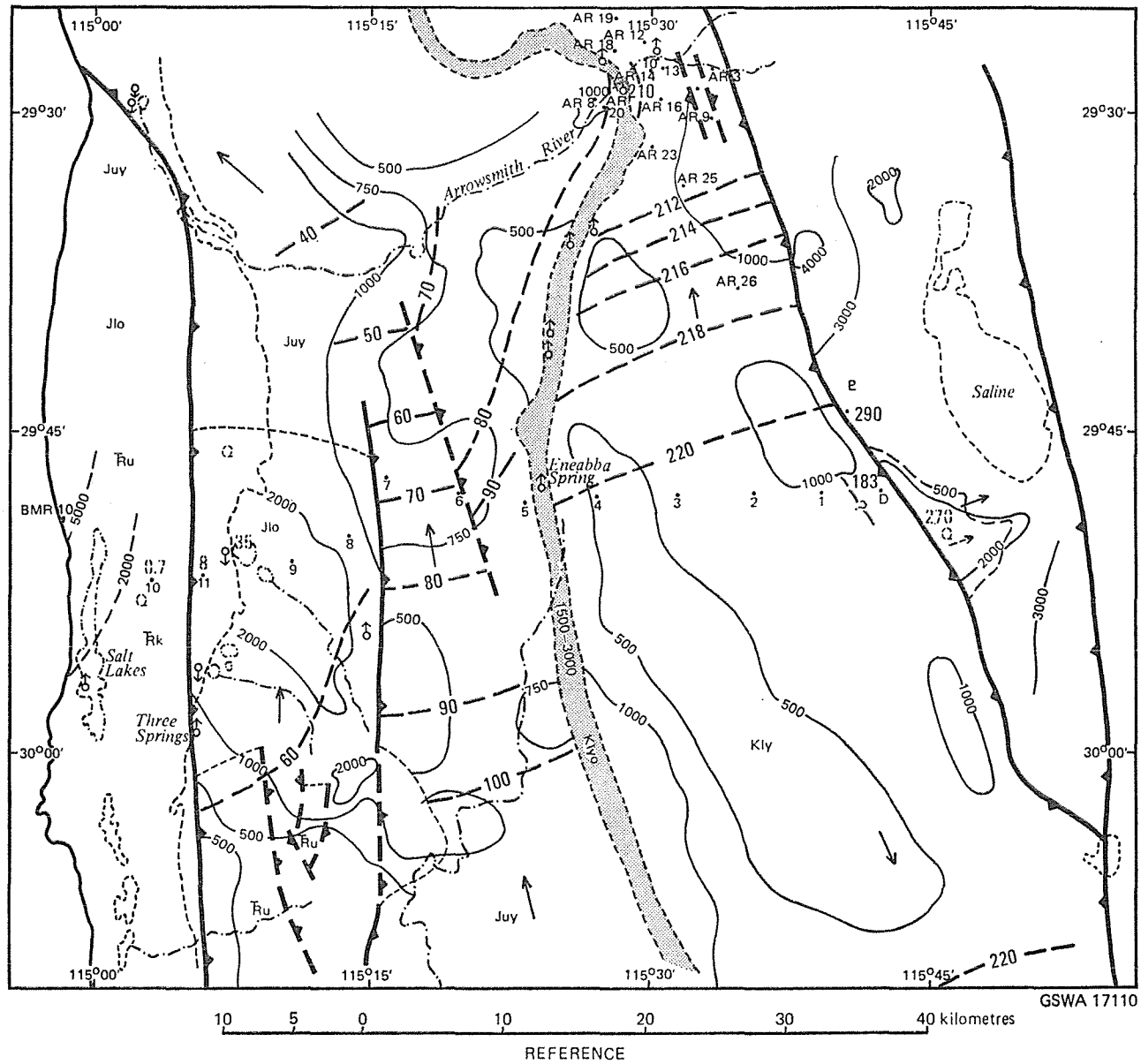


Figure 6 Geology, hydrogeology and groundwater temperature



REFERENCE

----	Formation Boundary	•6	Borehole Eneabba Line	Ω	Quaternary formations
▲▲▲	Fault major	•AR 1	Borehole Arrowsmith River Project	Kly	Upper Yarragadee Formation
▲ —	Fault minor	•D	Borehole Dathagnoorara	Klyo	Otorowiri Siltstone Member
-·-·-	Ephemeral Creek	—750—	Salinity mg/l	Juy	Lower Yarragadee Formation
	Ephemeral Lake	--500--	Salinity mg/l (Quaternary)	Jlo	Cockleshell Gully Formation
	Spring	—210—	Potentiometric head (m)	Ru	Lesueur Sandstone
	Sinkhole	200	Potentiometric head (Quaternary)	Rk	Kockatea Shale and Woodada Formation
•	Borehole	⟶	Direction of groundwater flow	P	Proterozoic rocks

Figure 7 Regional hydrogeology

West of the Dandaragan Scarp there is a regional north to northwesterly flow, the potentiometric heads declining from over 100 m in the south to less than 40 m near the Arrowsmith River (Fig. 7). Groundwater flow seems to be compartmentalized by north-south trending faults, acting as partial hydraulic barriers.

Recharge takes place from rainfall, and also possibly by concentration of surface run off. There may be some inflow from the upper Yarragadee Formation aquifer. Discharge is to the northwest and possibly some leakage may occur across the Warradarge Fault into the Cockleshell Gully Formation. The channel sand encountered at EL6 may act as a drain, as the potentiometric surface at EL6 is locally depressed (Fig. 6b).

Cockleshell Gully Formation aquifer

The Cockleshell Gully Formation was encountered in bores 8, 9 and 11 between the Warradarge and the Beagle Faults. It crops out south of the cross-section line and south of the Gingin Scarp, but along the cross-section line it is covered by Quaternary sands. The formation is about 1 200 m thick.

The salinity in the three bores ranged from 620 mg/l to 2 190 mg/l. The thicker sands in the lower Eneabba Member appear to contain the fresher water, whereas the salinity in the Cattamarra Coal Measures is usually brackish.

Recharge to the formation takes place in its outcrop area and regional groundwater flow is northwards. The potentiometric heads are in the 50-60 m range just west of Eneabba, and bores in the low-lying areas flow. The thick shales provide good confining beds. There may be some leakage into the formation from the lower Yarragadee Formation aquifer and localized recharge at EL8 from the superficial sands.

The basal sands of the Eneabba Member are in hydraulic continuity with the Lesueur Sandstone and there is probably some upward leakage.

Spring discharge, apparently from the Cockleshell Gully Formation aquifer occurs along the Beagle Fault at Three Springs 25 km southwest of Eneabba. There may be other places where there is upward leakage along the fault zone, discharging into the overlying Tamala Limestone.

Lesueur Sandstone aquifer

The Lesueur Sandstone crops out 30 km southwest of Eneabba and extends northwards beneath the Cockleshell Gully Formation. It occurs just below the section drilled in EL9 and EL11, and is hydraulically connected to the overlying Eneabba Member. The formation is about 600 m thick.

The aquifer is recharged by rainfall and concentration of surface run-off on its outcrop area. Groundwater flow is northwards. The salinity is low in its outcrop area (300-800 mg/l) and is probably less than 1 000 mg/l below the cross-section line.

BEAGLE RIDGE

Tamala Limestone

The Tamala Limestone straddles the Beagle Fault and overlies the Cockleshell Gully Formation on the east and the Kockatea Shale on the west. It is in hydraulic connection with the Safety Bay Sand, and in EL10A there is a basal sand unit 20 m thick.

The eastern part of the limestone is a karst aquifer, and surface water from Lake Logue and Stockyard Gully flows directly into caves. In places where the base of the lime stone is above sea level there is no continuous water table. Between EL10A and BMR10 a water table is developed and the saturated thickness is 26 m.

The salinity of the surface water intakes is highly variable and in 1974 was in the 200 to 1 500 mg/l range. The salinity of groundwater in EL11, EL10A and a spring into salt lakes is in the range 1 200 to 2 000 mg/l, but the salinity increases to 5 000 mg/l at BMR10.

Kockatea Shale and Woodada Formation

The Triassic sediments encountered in EL10A were shales, and did not contain any usable water. These beds act as a barrier to westerly groundwater flow.

The top part of the Woodada Formation is known to contain water-bearing sands (Harley, 1975) so that north of the cross-section line there will be groundwater in the Upper and Middle Triassic sediments, but the salinity is unknown (as also in BMR10).

HYDROCHEMISTRY

All groundwater in the area is classified as sodium chloride type. There are no significant differences in chemical composition between water from the different aquifers. The most important influence on the chemical composition is probably the type and mode of recharge.

Laboratory measurements of pH range from 6.8 to 8.3, and it is known that low pH waters in the lower Yarragadee Formation aquifer are very corrosive.

Iron contents vary considerably and in places are as high as 5.7 mg/l; accurate sampling was not possible as samples were aerated during airlifting.

GROUNDWATER TEMPERATURE

The Eneabba Line was the first line of bores across the Perth Basin to have downhole temperature logs run (Fig. 6c).

The results show a high temperature gradient in the west and a low gradient in the east. This is possibly due to three factors: firstly, the Precambrian basement is shallower in the west; secondly, the more shaley Cockleshell Gully Formation in the west is probably a better thermal insulator than the sandier Yarragadee Formation; and thirdly, the direction of groundwater flow is downward in the east and upward in the west.

Actual gradients range from 1.7 to 2.7°C per 100 m in the sandier parts of the Yarragadee Formation to 5.5°C per 100 m in the Cockleshell Gully Formation. The highest temperature is 52.5°C at a depth of 600 m in EL11, and the water-table temperature is 23-24°C.

DEVELOPMENT

The lower Yarragadee Formation aquifer is the most important and extensive aquifer, and contains a large quantity of fresh water. About 50 000 m^3day^{-1} is abstracted from the aquifer by the mineral sand industry at Eneabba. Smaller amounts are used for town water supply at Eneabba and farm water supplies.

The upper Yarragadee Formation is also fairly extensive in the east of the Perth Basin. Its position adjacent to the Darling Fault means that it is the most convenient aquifer to supply water to towns on the Yilgarn Block. Morowa, Three Springs and Carnamah town water supplies are all drawn from the aquifer.

The Cockleshell Gully Formation and the Lesueur Sandstone aquifers are only exploited for the Leeman-Greenhead town water supply. There are also a few farm bores which draw water for domestic and stock consumption. There is considerable potential for further development for domestic and industrial water supplies.

The Tamala Limestone elsewhere is an important source of fresh water near the coast; in this area, however, the marginal quality of the water precludes development for domestic use.

CONCLUSIONS

There are four major aquifers in the area; these are, in order of importance, the lower Yarragadee Formation, the upper Yarragadee Formation, the Cockleshell Gully Formation and the Lesueur Sandstone. Fresh water is present in all the formations and, except in the upper Yarragadee Formation which was completely penetrated by the drilling, extends to below the depths drilled.

Recharge to these aquifers is by rainfall on their outcrop areas, and regional groundwater flow is northwards. Impermeable Triassic rocks on the Beagle Ridge are a barrier to westward groundwater movement. The Otorowiri Siltstone is a major aquiclude which separates the upper and the lower Yarragadee Formation aquifers, and maintains a 140 m head difference across it.

The geothermal gradient is highest in the west and may be due to the shallowness of crystalline basement, the presence of more thermally insulating beds and an upward direction of groundwater flow.

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GEOLOGY AND HYDROGEOLOGY OF THE BECHER POINT LINE AND GEOLOGICAL REINTERPRETATION OF ADJACENT BOREHOLE LINES

by A. D. Allen

ABSTRACT

The Becher Point Line consists of nine bores at five sites ranging in depth from 71 to 810 m and with an aggregate depth of 4 591 m. The bores were drilled to explore the hydrogeology and to provide a section across the Perth Basin about 45 km south of Perth. Results from drilling have shown that the Cockleshell Gully Formation (Early Jurassic) and Yarragadee Formation (Late Jurassic—Early Cretaceous) have been faulted into juxtaposition in large fault blocks and can be considered to form a basement to subsequent formations. This basement is overlain by the South Perth Shale (Early Cretaceous) except in the east where it pinches out, and by the Leederville Formation (Early Cretaceous) which extends over the whole area. Subsequently there have been several periods of erosion, followed by deposition in the Quaternary of the Rockingham Sand and the 'superficial formations'. Structurally the South Perth Shale and Leederville Formation form the eastern limb of a very gentle syncline, incised by deep channels infilled with Rockingham Sand, and covered by a veneer of 'superficial formations'.

Groundwater occurs in two major flow systems above and below the South Perth Shale but the two are interconnected near the Darling Scarp where the South Perth Shale is absent. In the upper system recharge is from rainfall and stream losses which sustain a body of unconfined groundwater in the 'superficial formations'. This body of groundwater is in hydraulic connection and provides recharge to the Leederville Formation and the Rockingham Sand. The latter also receives some recharge by upward and lateral discharge from the Leederville Formation. In the lower system recharge into the interconnected Cockleshell Gully and Yarragadee Formations takes place via the Leederville Formation adjacent to the Darling Scarp where the South Perth Shale is absent. Groundwater in both systems flows towards the west where it is presumably discharged into the sea in favourable stratigraphic and structural situations.

Moderate resources of low salinity (250-1 500 mg/l T.D.S.) groundwater are in the Leederville Formation across the width of the coastal plain, and in the Cockleshell Gully Formation at its intake near the Darling Scarp. More limited resources of good quality water are available in the 'superficial formations' and in favourable situations within the Rockingham Sand. Very large supplies of brackish water (1 500-3 000 mg/l T.D.S.) are available from the Rockingham Sand, Yarragadee and Cockleshell Gully Formations.

INTRODUCTION

LOCATION AND TOPOGRAPHY

The Becher Point Line of boreholes is situated about 45 km south of Perth (Fig. 8). The bores are sited about 6 km apart across the width of the coastal plain from Becher Point (Long Point) to near Serpentine, a distance of about 25 km. All the sites are accessible from existing roads, except for Becher Point No. 1 site which is reached by a track from Warnbro.

The coastal plain extends from the coast to the Darling escarpment. At its western edge it is composed of a series of parallel beach ridges rising to about 5 m above sea level. These extend about 6 km inland to abut against a steep scarp marking a former, small coastal cliff cut into a series of calcretized dunes. The dunes rise to about 30 m and on their eastern side are bounded by another less prominent erosional scarp, east of which is a flat plain with a few sandy hills. The plain gradually rises in elevation from less than 10 m to about 80 m at the foot of the Darling escarpment (Fig. 9b).

PURPOSE AND SCOPE

The Metropolitan Water Supply, Sewerage and Drainage Board (M.W.B.) is presently exploring the groundwater resources of the region. As part of the investigation the Becher Point Line and several other lines of deep exploratory bores have been drilled across the coastal plain. These lines of bores are intended to extend and supplement limited geological and hydrological information which has already been obtained from drilling programmes carried out by the Mines Department. The latest bores are also intended for permanent monitoring of water levels and salinity.

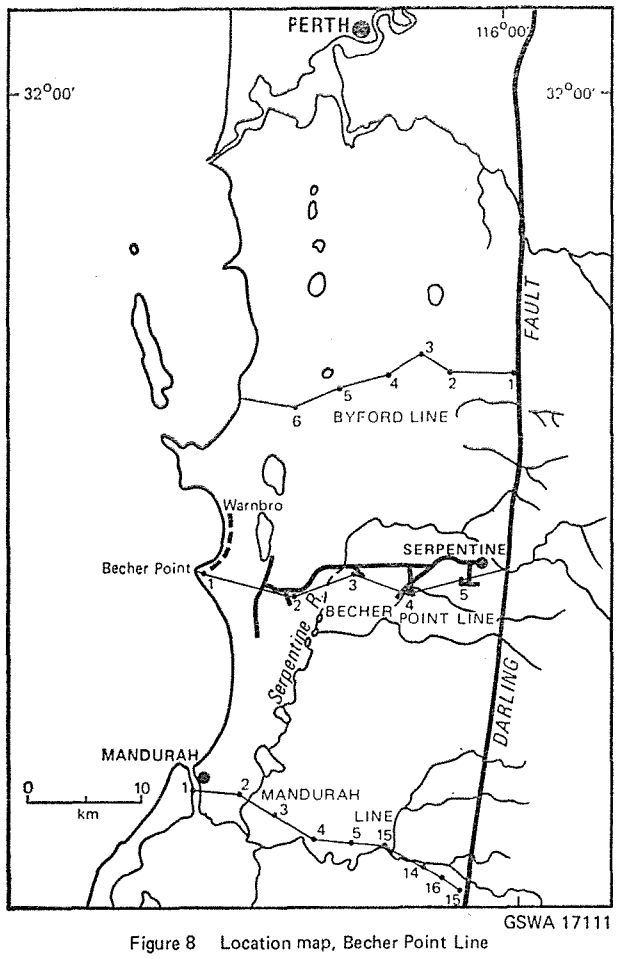


Figure 8 Location map, Becher Point Line

DRILLING AND TESTING

Nine bores at five sites, ranging from 71 to 810 m deep, and with an aggregate depth of 4 591 m were drilled (Table 3). The bores were sunk by a contractor using a mud-flush rotary drilling rig with a depth capability of about 1 000 m.

At each site the deep bore was given the number of the site and shallower bores were designated A and B in order of decreasing depth.

Sludge samples were taken at 3 m intervals. On reaching total depth, gamma ray, long and short normals resistivity, and caliper, wire-line logs were run. From these up to 30 sidewall core targets were selected and shot for palaeontological examination. This was conducted in each of the deep bores and also in No. 5A where additional samples were required.

The usual procedure for bore construction was to first drill a 255 mm hole to about 50 m and then cement 205 mm pipe in place to act as a surface conductor. A 180 mm hole was then drilled to total depth. After logging and coring a casing string was inserted. This consisted of an 18 m sump of 76 mm pipe; 5 m of 0.5 mm wire-wound stainless steel screen; 12 m or 18 m of 76 mm pipe connector; a cement basket; and 76 mm pipe with centralisers back to the surface. The casing string was pressure cemented to the surface and set in a cement block. The top of the casing was fitted with either a hinged cap, or a valve with a tapping for a pressure gauge if artesian

TABLE 3. SUMMARY OF BORE DATA

Name	Latitude	Longitude	Drilling		Elevation (m) A.H.D.		Depth (m)	Completed Depth (m)	Screened Interval (m)	Head (m) A.H.D.[4]	Salinity T.D.S. by Evap. (mg/l)	Status
			Commenced	Completed	Surface	Casing						
Becher Point No. 1	32°22′04″S	115°43′03″	23/11/76	6/12/76	2·258	2·706[1]	804[2]	506	483–488	12·456[5]	2 890	Observation bore Yarragadee Formation
Becher Point No. 2	32°23′06″S	115°46′09″	24/3/77	2/4/77	9·151	9·497[1]	742	405	379–384	13·307[5]	1 710	Observation bore Yarragadee Formation
Becher Point No. 3	32°22′07″S	115°51′05″	1/3/77	9/3/77	8·08	9·08	795	398	375–380	13·047[5]	1 630	Observation bore Yarragadee Formation
Becher Point No. 3A	32°22′07″S	115°51′05″	17/3/77	18/3/77	8·02	8·25	130	130	107–112	4·267	360	Observation bore Leederville Formation
Becher Point No. 4	32°22′15″S	115°54′03″	19/2/76	1/1/77	16·33	17·01	810	578	(554–559[3]) 492–498	13·362	2 230	Deep observation bore Yarragadee Formation
Becher Point No. 4A	32°22′15″S	115°54′03″	15/1/77	21/1/77	16·60	17·12	303	303	280–285	13·348	....	Observation bore Yarragadee Formation
Becher Point No. 4B	32°22′15″S	115°54′03″	24/1/77	24/1/77	16·58	16·96	74	71	54–59	14·680	780	Observation bore Leederville Formation
Becher Point No. 5	32°22′10″S	115°57′04″	26/1/77	19/2/77	37·02	37·40	803	635	603–608	24·306	1 050	Deep observation bore Cockleshell Gully Formation
Becher Point No. 5A	32°22′10″S	115°57′04″	14/4/77	15/4/77	36·54	36·83	130	129	112–117	28·571	....	Observation bore Cockleshell Gully Formation
							4 591					

[1] Elevation to top of valve.
[2] Depth reached by gamma ray logging probe.
[3] Accidentally cemented off, perforated 492–498.
[4] Readings in May, 1977.
[5] Artesian flow.

water had been encountered. In No. 5 bore the cement basket is believed to have collapsed and the screen was filled with cement. This was subsequently rectified by perforating another interval with shaped explosive charges.

For monitoring it was intended to set screens over two intervals, one about 100 m below the bottom of the South Perth Shale as this is the usual production interval from the underlying formations; and the other in the middle of the Leederville Formation so that an 'average' pressure would be obtained. During the work the plan was modified because of the desire to obtain more information about the Cockleshell Gully and Yarragadee Formations, and because of difficulties with correlation. Bores No. 4 and 5 were left to monitor pressures about 300 m and 500 m respectively below the bottom of the South Perth Shale to give information about head variation with depth. In the latter case the screen was actually set in the upper part of the Cockleshell Gully Formation because of mistaken correlation. Financial constraints prevented construction of monitoring bores in the Leederville Formation at sites No. 1, 2 and 5.

The bores were either developed by airlifting, or in the case of artesian bores, were allowed to flow. Subsequently the non-artesian bores were pumped for up to 3 hours at rates of up to 1 l/sec and samples were taken at the end for standard analysis.

The bores were levelled to Australian Height Datum (Mean Sea Level) and left for monitoring pressure in the various formations. Subsequently, pressures have been measured each month and the data stored in the M.W.B. groundwater levels information system.

Sludge and core samples are stored at the Geological Survey of Western Australia (G.S.W.A.) core library. Other data are available on file at the M.W.B. or G.S.W.A.

PREVIOUS WORK

The G.S.W.A. has previously drilled lines of bores across the coastal plain between Byford and Medina, and from Mandurah to Pinjarra, the results of which have been published.

Berliat (1963, 1964) described the results of drilling 6 bores on the Byford Line.

Passmore (1962) and Emmenegger (1963) reported results from Mandurah No. 1 and No. 2 bores respectively. Later, Emmenegger (1964) gave a more comprehensive report on results from Mandurah No. 1 to No. 5 bores.

Commander (1974, 1975) described the hydrogeology of the Mandurah-Pinjarra area based on the results of 18 bores drilled by the G.S.W.A. for the Mandurah Line and from about 20 bores drilled by Alcoa of Australia (W.A.) Ltd. to exploit and monitor groundwater resources used at its refinery site.

The M.W.B. has also drilled a line of bores between Woodmans Point and Forrestdale, but these results have not yet been published.

GEOLOGY

STRATIGRAPHY

The coastal plain is developed on the eastern onshore edge of the Perth Basin, a long narrow trough of sedimentary rocks extending from about the Murchison River to Augusta. It is bounded in the east by the Darling Fault and extends about 120 km offshore (Playford and others, 1975, 1976).

The Becher Point Line was drilled in the southern part of the Dandaragan Trough, a major structural subdivision of the Perth Basin (Jones and Pearson, 1972), which contains about 6 000 m of Phanerozoic, (predominantly Mesozoic) rocks resting on a Precambrian basement. Surficial formations of Quaternary age conceal all the underlying formations.

The near surface formations considered in this report are given in Table 4, and described more fully below.

TABLE 4. STRATIGRAPHIC SEQUENCE, PERTH TO MANDURAH

Formal Age	Group	Formation	Maximum Thickness (m)	Summary Lithology	Remarks
CAINOZOIC— Quaternary	....	'Superficial formations'*	90	Sand, limestone, silt, clay	Major aquifer
		UNCONFORMITY			
	....	Rockingham Sand	110	Sand	Minor aquifer
		UNCONFORMITY			
Early Tertiary	....	Kings Park Formation	240	Siltstone, shale, minor sand	Aquiclude
		UNCONFORMITY			
MESOZOIC— Early Cretaceous	Coolyena	Osborne Formation	120	Siltstone, shale, minor sand	Aquiclude
	Warnbro	Leederville Formation	220	Sandstone, siltstone, shale	Major aquifer
		South Perth Shale	110	Shale, siltstone	Aquiclude
		Gage Sandstone Member	70	Sandstone, siltstone, shale	Aquifer
		UNCONFORMITY			
Early Cretaceous-Late Jurassic	....	Yarragadee Formation	1 200	Siltstone, sandstone, shale	Major aquifer
Middle Jurassic	....	Cadda Formation	?350	Shale, siltstone	Not definitely known
Early Jurassic	....	Cockleshell Gully Formation .... Cattamarra Coal Measures Member Eneabba Member	3 000	Siltstone, sandstone, shale, coal measures	Aquifer

* Informal name for various recognized Quaternary formations

Jurassic

Cockleshell Gully Formation: The Cockleshell Gully Formation (Willmott, 1964) was encountered at Becher Point No. 2 and No. 5 sites. It consists of beds of sandstone, 10 to 30 m thick, composed of fine to coarse-grained, subangular sand with accessory garnet and heavy minerals. These are interbedded with beds of black, dark-grey, or grey-brown, hard to sticky, micaceous, carbonaceous and occasionally pyritic siltstone and shale of similar thickness.

The Cockleshell Gully Formation occurs in fault blocks in juxtaposition with fault blocks of Yarragadee Formation. It is unconformably overlain by the South Perth Shale and the Leederville Formation, and to the north may be conformably overlain by the Cadda Formation (Smith, 1967). The thickest section encountered was 706 m in No. 5 bore.

Sidewall cores from No. 2 bore (Backhouse, 1977e) indicated a Toarcian to Aalenian age, whereas in No. 5 bore (Backhouse, 1977f) they indicate a somewhat younger Aalenian to Bajocian age. The age and lithology suggest that the part of the formation encountered may be correlated with the Cattamarra Coal Measures, the uppermost member of the Cockleshell Gully Formation. The palynology also indicates the formation was deposited under nonmarine conditions.

Jurassic-Cretaceous

Yarragadee Formation: The Yarragadee Formation (McWhae and others, 1958) was intersected at Nos. 1, 3 and 4 sites. It is composed predominantly of thick-bedded sandstone with subordinate beds of siltstone and shale. The sandstone is light grey to light pink (garnetiferous), slightly clayey, fine to coarse-grained and composed of angular to subangular quartz grains. Garnet and heavy minerals are abundant in some beds and show peaks on the gamma ray logs which can be mistaken for shales. The siltstone and shale varies from black to light brown, frequently with micaceous laminae and occasionally with carbonaceous or pyrite laminae. Minor lenses of coal were found in No. 1 and No. 3 bores.

The formation occurs in fault blocks, faulted into juxtaposition with the Cockleshell Gully Formation. It may conformably overlie the Cadda Formation (Smith, 1967), and is unconformably overlain by the South Perth Shale and possibly by the Leederville Formation. The thickest section intersected was 625 m in No. 4 bore.

Many of the sidewall cores taken from the Yarragadee Formation were too sandy to contain palynomorphs, or yielded only sparse assemblages. In No. 1 bore the age of the formation was Kimmeridgian to Tithonian (Backhouse, 1977a), whereas in No. 4 bore the palynology indicated a Callovian or slightly older age (Backhouse, 1977b). Samples from No. 3 bore (Backhouse, 1977d) were non-diagnostic.

Cretaceous

South Perth Shale: The South Perth Shale (Fairbridge, 1953) was intersected at all sites with the exception of No. 5 where it has evidently not been deposited. It consists of a basal section of alternating sandstone and siltstone referred to as the Gage Sandstone Member, which can usually only be distinguished palaeontologically from the underlying Cockleshell Gully and Yarragadee Formations. This is overlain by black or brown-black, slightly silty shale, which grades upwards into a dark grey, slightly sandy, slightly micaceous siltstone, with rare glauconite (No. 1 bore). This upper, argillaceous section of the South Perth Shale can be fairly readily recognized on the gamma and resistivity logs.

The formation unconformably overlies the Cockleshell Gully or Yarragadee Formations without evidence of weathering and is conformably overlain by the Leederville Formation. The South Perth Shale is 138 m thick in No. 1 bore and appears to pinch out between No. 4 and No. 5 bores (Fig. 9b), whereas the Gage Sandstone Member has a uniform thickness of about 27 m.

Palynological analysis of sidewall cores taken from the formation (Backhouse, 1977a,b,d,e) indicate that in Nos. 1, 2 and 3 bores the formation is of Barremian age, whereas in No. 4 bore it is entirely of Aptian age. This confirms the inference from the section (Fig. 9b) that the formation was deposited as the sea trangressed to the east and presumably is youngest near where it pinches out. The formation was deposited in a marine to paralic environment and the Gage Sandstone Member appears to be a basal unit deposited during a slow eastward transgression of the sea.

Leederville Formation: The Leederville Formation (Cockbain and Playford, 1973) was encountered at all the sites. It consists of thin to medium-bedded, fine to medium-grained, slightly silty sandstone, composed of angular to subangular quartz grains, interbedded with grey micaceous siltstone and minor shale. At sites Nos. 1-3 the sandstones are glauconitic, and contain hard bands of calcareous and silicified sandstone. Fragments of molluscs are also present. Passmore (1962) and Emmenegger (1963, 1964) also noted the presence of glauconitic and fossiliferous sandstones. They proposed subdivisions of the unit which appear to be relevant only on a local scale and are not used in this account.

The formation either conformably overlies the South Perth Shale or unconformably overlies the Cockleshell Gully Formation (Site No. 5). Elsewhere it may also unconformably overlie the Yarragadee Formation. The maximum thickness of the Leederville Formation is about 190 m in No. 3 bore where it is estimated about 40 m of the formation may have been removed by erosion. It is conformably overlain by the Osborne Formation on the Byford Line and unconformably overlain by the Rockingham Sand or 'superficial formations'.

Palynological analysis of sidewall cores taken from the formation (Backhouse, 1977a,b,c,d,e,f) indicate that in the west (Sites Nos. 2 and 3 and presumably No. 1) the formation ranges from Barremian to Aptian age; however, in the east it is entirely Aptian. This is consistent with a gradual west to east transgression as previously noted. The palynology also indicates that the formation was deposited under marine conditions with some minor periods of nonmarine or paralic deposition.

The gamma ray and electric log characteristics of the formation intercepted by Becher Point Line bores differ considerably from those of bores nearer the type section in Perth. This reflects a southwestward change from nonmarine to marine facies within the formation.

Osborne Formation: The Osborne Formation (McWhae and others, 1958) was not found on the Becher Point Line where it has been removed by erosion, but was intersected by the Byford Line bores. It consists of black, frequently sandy, shale; green-black sandy shale with a high proportion of amorphous glauconite; and local beds of clayey, coarse-grained sand or well-sorted, fine-grained glauconitic sand.

On palaeontological evidence the formation is believed to disconformably overlie the Leederville Formation (Playford and others, 1975). However, to the south of Perth it overlies glauconitic Leederville Formation and appears to form a continuous, conformable marine sequence. It is unconformably overlain by the Rockingham Sand and by the 'superficial formations'.

The formation has a rich assemblage of microflora and microplankton of Albian-Cenomanian age (Cookson and Eisenack, 1958), which also indicates that it was deposited in a marine environment.

Quaternary

Rockingham Sand: The Rockingham Sand (Passmore, 1970) was encountered at No. 1 and No. 2 sites. It consists of brown to light grey, slightly silty, slightly feldspathic, medium to coarse-grained subangular sand. Within the formation are also occasional layers of oxidized pyrite, rare pebbles, and grains tentatively identified as oxidized glauconite.

The formation unconformably overlies the Leederville Formation and has apparently been deposited in channels. The maximum thickness of 106 m was encountered in No. 1 bore.

No sidewall cores were obtained from the formation. However, according to Passmore (1970) the formation is probably of Quaternary age judged by microfossils which were obtained in the type section in Rockingham No. 1 bore.

'Superficial formations': The term 'superficial formations' is used in this account as a collective term to describe the superficial sediments, which comprise a complex sequence of limestone, sand and clay in which various formations are recognized (Playford and others, 1976). They range in age from possible Late Pliocene to Holocene.

The 'superficial formations' unconformably overlie the Leederville Formation and Rockingham Sand. In broad terms their lithology may be related to the present physiography. The coastal strip extending for about 11 km inland is composed primarily of calcretized beach ridges, dune sand and shallow water calcarenite, which abuts against a belt of aeolian and littoral sand extending a further 15 km inland to the Darling Scarp. This general pattern is modified in the vicinity of the major rivers where there has been deposition of clayey alluvial and estuarine deposits.

STRUCTURE

Folding and faulting

The geological structure is illustrated in the sections given in Figure 9. The Cockleshell Gully and Yarragadee Formations can be considered to form a basement to the succeeding formations. They have a gentle regional dip to the east (Playford and others, 1975) but have been dislocated by large-scale faulting into a series of fault blocks bringing the two formations into juxtaposition.

The overlying Warnbro and Coolyena Groups appear to occupy a syncline which may result from folding or be a growth fold.

The Rockingham Sand is situated in former channels incised into the underlying formations. It is flat lying as are the 'superficial formations', and neither unit is known to be affected by folding or faulting.

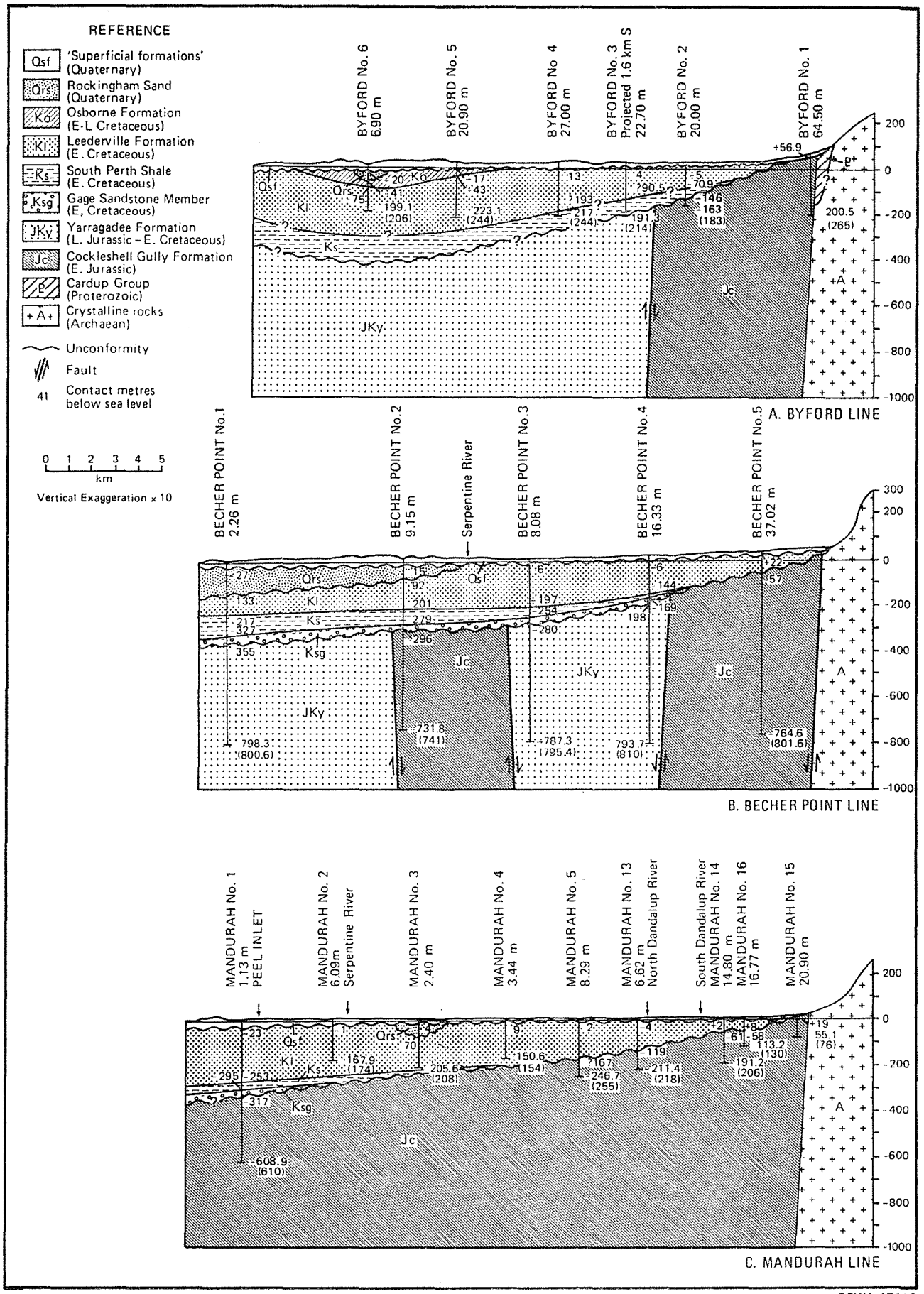


Figure 9 Geological sections

Reinterpretation of the Byford and Mandurah Lines

Results from the Byford Line were described by Berliat (1963, 1964). The deepest bore was only 244 m and identification of the various formations was based on lithology and palaeontology. Since then there has been further subdivision of the stratigraphic sequence and gamma ray logs have been obtained from Byford No. 2 and 5 bores.

A reinterpretation of the Byford Line is given in Fig. 9a. It differs from the section given by Berliat inasmuch as the section is now interpreted as a syncline; the Leederville Formation onlaps almost to Byford No. 1 bore; and the Kings Park Formation (not discussed here) does not extend inland from the coast.

Commander (1974, 1975) gave a composite cross section for the Mandurah area. He considered that the Gage Sandstone Member was well developed and distinctive; and that the upper part of the South Perth Shale had changed in facies to an interbedded sequence of glauconitic and calcareous sand and siltstone which he termed the South Perth Shale equivalent. The top of the South Perth Shale equivalent was defined by the 'green clay marker horizon' previously noted by Emmenegger (1963, 1964).

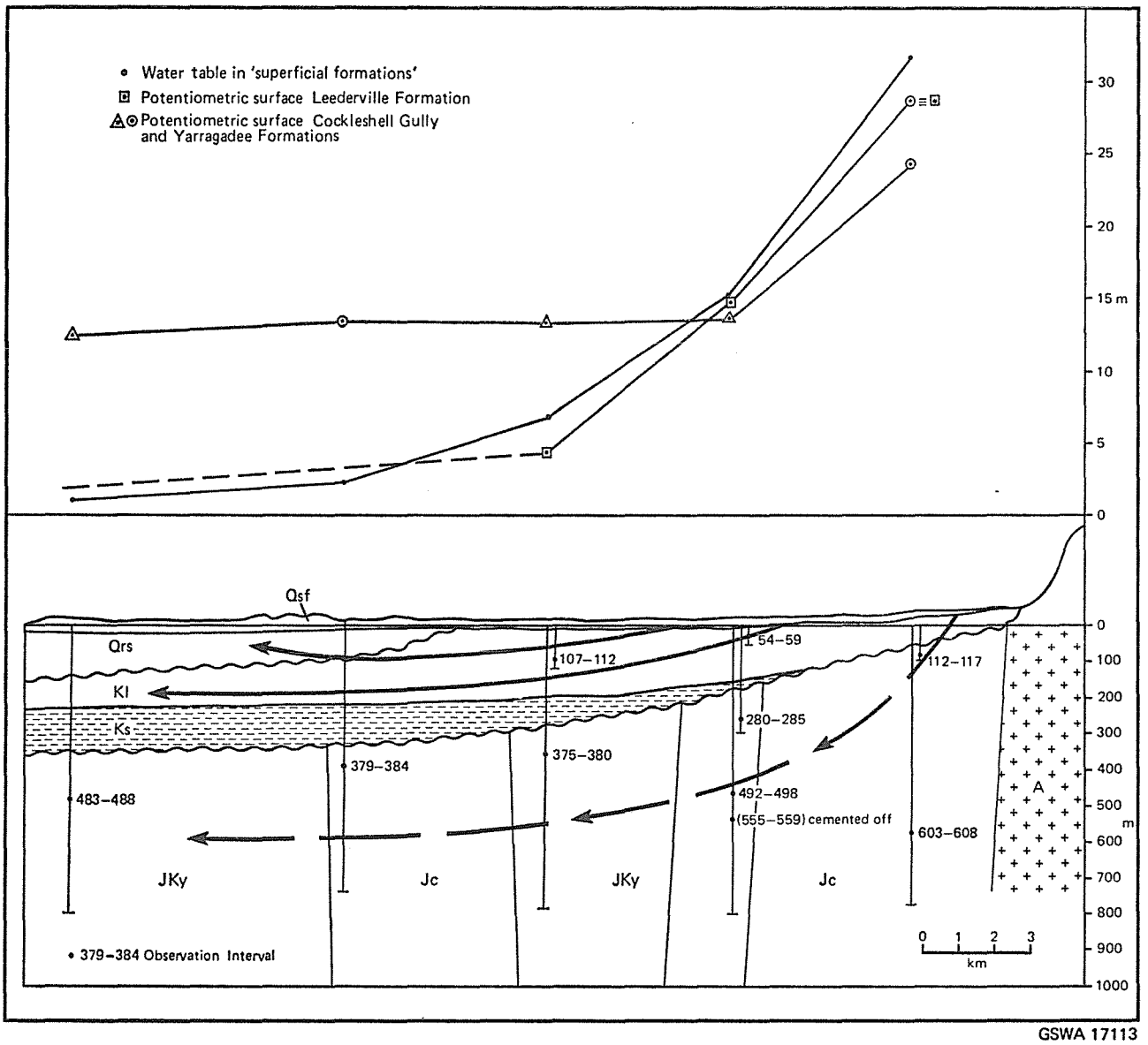
A reinterpretation of the section across the Perth Basin at Mandurah is given in Fig. 9c. The basic differences from Commander's interpretation are that the South Perth Shale can be recognized as a separate rock unit approximately equivalent to his Gage Sandstone (Commander, 1974, Fig. 13), and that the South Perth Shale equivalent is correlated with the Leederville Formation.

GEOLOGICAL HISTORY

During the Jurassic and Early Cretaceous the Cockleshell Gully and Yarragadee Formations were deposited in a continental fluviatile environment. In the mid-Neocomian these units were intensively faulted and subjected to sub-aerial erosion.

Sedimentation recommenced in the late Neocomian. As the sea transgressed eastward the basal Gage Sandstone Member was deposited. This was succeeded by the South Perth Shale which pinched out near the Darling Scarp and was overstepped by the Leederville Formation which locally transgressed across the Darling Fault. The marine transgression extended northeastward and the Osborne Formation, possibly together with some younger Cretaceous formations, were deposited.

In the Early Tertiary erosion took place in the Perth area (Playford and others, 1975) and probably elsewhere. Subsequently the Kings Park Formation was deposited. There is no evidence of succeeding events until the Late Pliocene or Pleistocene. At this time the Rockingham Sand was deposited probably in submarine channels, and the 'superficial formations' were deposited during the various Quaternary changes in sea level.



GSWA 17113

Figure 10 Relationship of aquifers

TABLE 5. WATER ANALYSES

Name	Date Sampled	G.C.L. No.	pH	Appearance	Turbidity (APHA Units)	Colour (APHA Units)	Odour	Specific Conductivity (uS/cm @ 25°C)	Saturation Index Longelier @ 20°C	mg/l									
										T.D.S. (Evap.)	T.D.S. Cond.	Free CO_2	Total Hardness (as $CaCO_3$)	Total Alkalinity (as $CaCO_3$)	Ca	Mg	Na	K	CO_3	HCO_3
Becher Point No. 1	29/12/76	30598/76	8·7	Cl.sl.gry.dep.	9	10	Nil	4 600	+0·7	2 430	2 940	1	120	195	20	17	895	28	21	195
Becher Point No. 1	4/5/77	82292/77	7·8	Cl.sl.dep.	8	10	Nil	4 520	—0·3	2 510	2 890	6	112	186	17	17	886	27	Nil	226
Becher Point No. 2	13/9/77	84857/77	9·1	Cl.	1	8	Nil	....	....	1 710	....	....	....	....	....	....	....	....	....	....
Becher Point No. 3	13/9/77	84858/77	9·9	Cl.	10	6	Nil	....	....	1 630	....	....	....	....	....	....	....	....	....	....
Becher Point No. 3A	22/9/77	85226/77	9·3	....	2	3	Nil	....	....	360	....	....	....	....	....	....	....	....	....	....
Becher Point No. 4	22/9/77	85227/77	8·2	....	1	5	Nil	392	0·2	2 230	2 510	4	84	300	14	12	807	25	Nil	366
Becher Point No. 4A	15/2/78	80666/78	7·0	Cl.br.dep.	....	<5	Nil	148	....	750	950	....	175	117	11	36	210	6	Nil	143
Becher Point No. 4B	22/9/77	84859/77	6·6	Cl.s.br.dep.	380	9	Nil	....	....	780	....	....	....	....	....	....	....	....	....	....
Becher Point No. 5	12/12/77	86866/77	11·9	Cl.sl.br.dep.	9	5	Nil	....	....	1 050	....	....	....	....	....	....	....	....	....	....
Becher Point No. 5A	15/2/78	80667/78	11·2		....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....

Name	mg/l														Remarks
	Cl	SO_4	NO_3	SiO_2	B	F	Fe	Mn	Cu	Pb	As	N (as ammonia)	N (as nitrate)	P (Total in solution)	
Becher Point No. 1	1 240	150	1	16	0·43	0·5	0·05	0·05	0·02	0·02	0·02	0·74	0·02	0·02	Deposit and turbidity could be due to precipitation of $CaCO_3$ after aeration
Becher Point No. 1	1 240	130	1	15	0·63	0·5	0·05	0·05	0·02	0·01	0·01	0·74	0·02	0·02	
Becher Point No. 2	825	....	....	....	....	....	....	....	....	....	....	....	....	....	Sample affected by cement contamination
Becher Point No. 3	861	....	....	....	....	....	....	....	....	....	....	....	....	....	Sample affected by cement contamination
Becher Point No. 3A	106	....	....	....	....	....	0·16	....	....	....	....	....	....	....	
Becher Point No. 4	1 030	115	1	13	1·51	1·8	0·18	0·04	0·02	0·01	0·01	0·81	0·02	0·02	
Becher Point No. 4A	352	25	<1	13	0·15	<0·1	....	....	....	....	....	....	....	....	
Becher Point No. 4B	352	....	....	....	....	....	....	....	....	....	....	....	....	....	Not air free
Becher Point No. 5	189	....	....	....	....	....	....	....	....	....	....	....	....	....	pH suggests sample contaminated with cement
Becher Point No. 5A	....	....	....	....	....	....	....	....	....	....	....	....	....	....	Cement contaminated

HYDROGEOLOGY

INTER-RELATIONSHIP OF AQUIFERS

Within the 'superficial formations' there is a body of unconfined groundwater which extends throughout the coastal plain (Allen, 1976a, 1976b). This is directly recharged from rainfall or by run-off from rivers and streams rising on the Darling Scarp. This groundwater provides recharge to the underlying Rockingham Sand or Leederville Formation by downward leakage. In turn the Leederville Formation provides recharge by leakage into the underlying Cockleshell Gully and Yarragadee Formations, over a limited area near the Darling Scarp where the South Perth Shale is absent.

The groundwater flow system is effectively divided into two parts by the South Perth Shale. A lower part comprising the Cockleshell Gully and Yarragadee Formations in apparent hydraulic continuity, and an upper part formed by the 'superficial formations', the Rockingham Sand and the Leederville Formation. The relationship of the various aquifers and the inferred flow system indicated by arrows is shown in Figure 10.

DETERMINATION OF SALINITY

In the drilling programme it was only possible to get a water sample from the intervals which were selected for observation (Table 5). The salinity of many other beds of sand encountered was estimated from the long-normal resistivity logs. For the calculations it was assumed that the geothermal gradient was 1.9°C per 100 m depth, the Cockleshell Gully and Yarragadee Formations had a formation factor of 7.5, and that the Leederville Formation had a formation factor of 6.

The results should be within ± 20% of real values. Actual samples and estimated values are given in Figure 11 and compare reasonably well, with the exception of No. 1. The estimates for the aquifers not sampled are therefore expected to closely approximate the actual salinities.

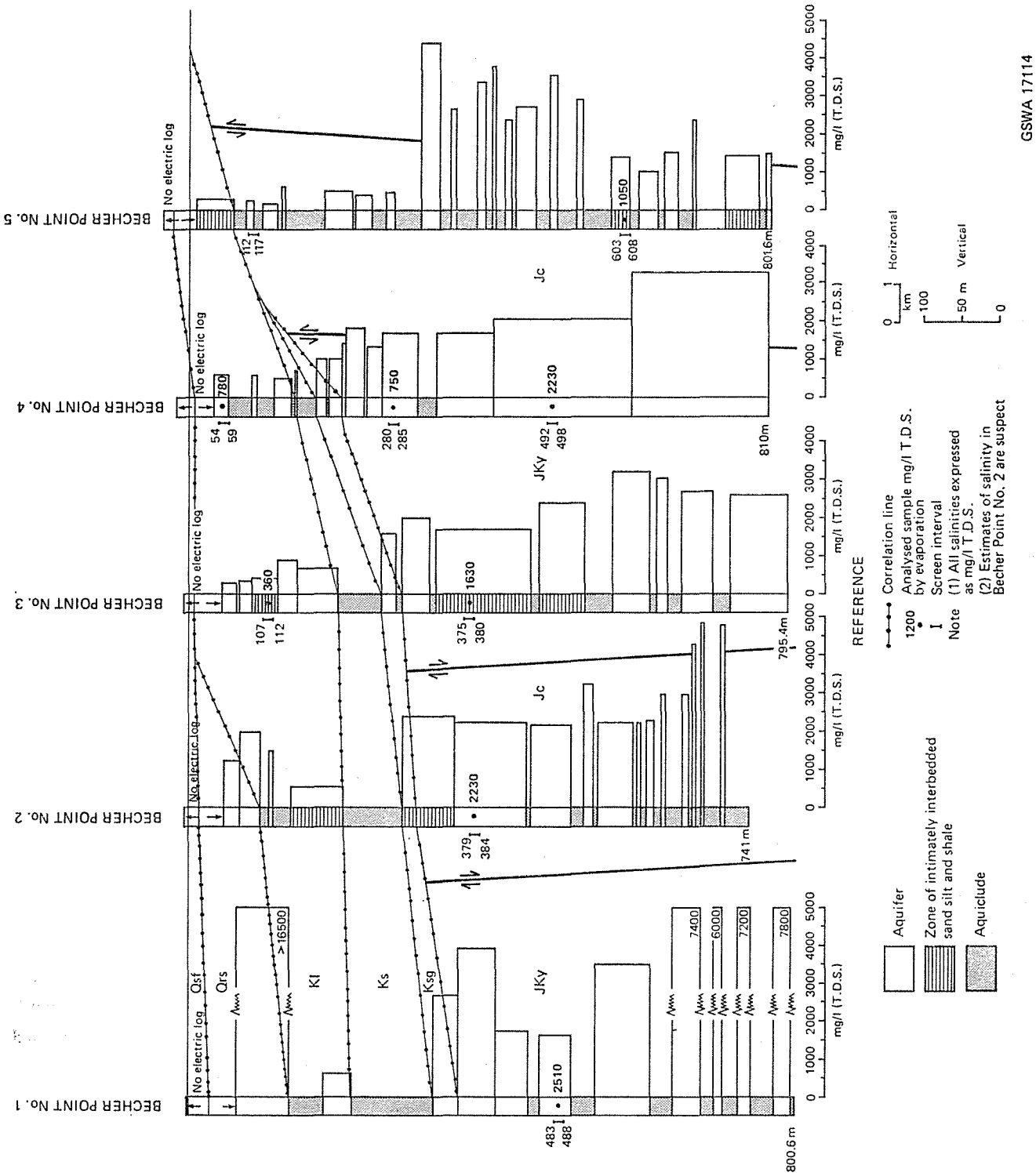


Figure 11 Groundwater salinity estimated from log-normal resistivity logs

AQUIFERS

'Superficial formations'

The 'superficial formations' consist of a complex sequence of sand, limestone and clay. They contain unconfined groundwater throughout the coastal plain.

Groundwater within these formations originates from direct infiltration of rainfall and from stream flow off the Darling Scarp. The saturated thickness of the aquifers is less than 20 m, and the volume in storage is relatively small. Groundwater movement under gravity is towards the west where discharge takes place into the Serpentine River and the sea. Along the coast a seawater interface is developed within the aquifers. In addition, a proportion of the groundwater in storage infiltrates into the underlying formations.

The groundwater salinity is variable but usually less than 1 000 mg/1 T.D.S. except along the coast.

Rockingham Sand

The Rockingham Sand is a thick, relatively clean and uniform sand which contains a body of unconfined groundwater. Recharge to the formation takes place from the overlying 'superficial formations', and in the east presumably by lateral and upward leakage from the Leederville Formation (Fig. 9b).

As the formation has a substantial thickness, a very large volume of water is in storage. In No. 1 bore near the coast salt water occurs from 70 m to the base of the formation. This is overlain by low salinity groundwater which was tapped by shallow bores sunk to supply water for the drilling operation. It is inferred that the salt water is seawater beneath an interface which extends inland to between No. 1 and No. 2 bores (Fig. 11). From this evidence the groundwater flow is inferred to be toward the west with discharge taking place upward through the 'superficial formations', into the sea.

The largest volume of usable water occurs in the eastern part of the formation where it is estimated to be about 1 300 - 2 000 mg/1 T.D.S. increasing in salinity with depth. Elsewhere the formation contains brackish water overlain by a thin layer of low salinity water. Because of its lithology the formation has considerable potential for yielding large supplies of groundwater from suitably constructed bores. Unfortunately, however, most of this water is brackish.

Leederville Formation

The Leederville Formation is an interbedded sequence of sand, siltstone and shale in which the proportion of sand is 40-60 per cent. It contains unconfined groundwater where recharge occurs but where shales occur the groundwater may be confined.

Recharge to the formation is via the overlying 'superficial formations' where the Osborne Formation is absent (Fig. 9b). The Leederville Formation reaches about 200 m in thickness in No. 3 bore but to the east it thins out and to the west it is partially removed by erosion and replaced by the Rockingham Sand. Nevertheless, consideration of Figure 11 indicates that because of the thickness and extent of the formation there must be a large volume of groundwater in storage.

The apparent hydraulic gradient shown in Figure 10 indicates that groundwater movement is from east to west. The reason for the marked change in gradient in the vicinity of No. 3 site presumably results from lateral and upward groundwater discharge into the contiguous more permeable Rockingham Sand.

With the exception of a thin bed of sand in No. 2 bore (Fig. 11) all the groundwater in the formation has a salinity of less than 1 000 mg/1 T.D.S. There is no apparent pattern to the variation of salinity within the formation. This may result from the variability in salinity of the recharge from the 'superficial formations'.

Supplies of low salinity water appear to be available from this formation across the width of the coastal plain. The most prospective site appears to be immediately to the east of the subcrop of the Rockingham Sand.

Gage Sandstone Member

The Gage Sandstone Member is an interbedded sequence of sand and siltstone at the base of the South Perth Shale. It is about 27 m thick and difficult to differentiate from the underlying Cockleshell Gully and Yarragadee Formations. The member is confined beneath shale and siltstone and is in apparent hydraulic continuity with the underlying formations, with which it is grouped for the purpose of describing the aquifer systems. Nevertheless, estimated groundwater salinity in the member is usually somewhat less than the underlying formations.

Yarragadee Formation

On the Becher Point Line the Cockleshell Gully and Yarragadee Formations are faulted into juxtaposition. In the western fault block of Cockleshell Gully Formation (Fig. 9b) the salinity (Fig. 11) and hydraulic gradient (Fig. 10) appear to indicate hydraulic connection with the Yarragadee Formation. However, between the eastern fault block of Cockleshell Gully Formation and the adjoining Yarragadee Formation (Fig. 11) wide differences in salinity are evident, even though the potentiometric head appears to be consistent. Both formations could probably be considered together as a single aquifer but because the Cockleshell Gully Formation is an extensive aquifer further to the south it is discussed separately.

The Yarragadee Formation encountered on the Becher Point Line is composed predominantly of sand with minor beds of siltstone and shale.

Recharge to the formation is inferred to take place from the Leederville Formation and via the Cockleshell Gully Formation along the foot of the Darling Scarp. This is suggested in Figure 10 which shows that adjacent to the Darling Scarp where the South Perth Shale is absent there is a downward head potential from the Leederville Formation to the Cockleshell Gully Formation which is presumed to be in hydraulic connection across fault boundaries with the Yarragadee Formation. Figure 10 also shows that about 7 km west of the scarp the heads in the Yarragadee and Leederville Formations are about the same; whereas further west the head in the Yarragadee Formation is about 10 m higher. This suggests that recharge takes place along the foot of the Darling Range and to the west the South Perth Shale is an effective confining bed.

The substantial thickness of sand in the Yarragadee Formation (Fig. 11) indicates that there is a very large volume of water in storage. The maximum thickness encountered was 572 m in No. 4 bore. The apparent direction of groundwater flow (Fig. 10) is from east to west and the low hydraulic gradient indicates that the aquifer has a high transmissivity. Discharge from the formation probably takes place offshore where the South Perth Shale has been breached by erosion or by faulting.

The estimated groundwater salinity varies from about 1 500-8 000 mg/1 T.D.S. Apart from small local variations (Fig. 11) the salinity in the aquifer shows a general increase with depth and towards the west, consistent with what would be expected for a westward-flowing groundwater system.

Very large supplies of groundwater ranging from 1 500 - 3 000 mg/1 T.D.S. are indicated in the Yarragadee Formation. These may have potential for industrial supplies or for desalination.

Cockleshell Gully Formation

The Cockleshell Gully Formation consists of alternating beds of sand and siltstone or shale but contains considerably less sand than the Yarragadee Formation (Fig. 11).

Recharge to the formation appears to take place adjacent to the Darling Scarp as described for the Yarragadee Formation.

In No. 5 bore the salinity in the top 300 m of the formation is estimated to range between 270 and 700 mg/1 T.D.S., after which it increases but then decreases somewhat toward the bottom of the bore (Fig. 11). The salinity in the adjacent No. 4 bore (Yarragadee Formation) shows a marked dissimilarity in the salinity pattern, the reason for which is not evident. The salinity in No. 2 bore appears slightly higher than would be expected but the estimates from this bore are not particularly good because extraneous earth currents affected the resistivity logs.

The eastern fault block of Cockleshell Gully Formation appears to contain large volumes of low salinity water in storage. This fault block does not appear to be the same as the one adjacent to the Darling Scarp near Pinjarra, noted by Commander (1974). This is composed predominantly of siltstone and contains saline groundwater.

CONCLUSIONS

The Becher Point Line of bores has provided valuable new geological and hydrogeological data in an area between two previously explored section lines to the south of Perth. Comparison with these earlier results has facilitated a stratigraphic reinterpretation.

The Warnbro Group has been shown to form the eastern limb of a very gentle syncline resting on fault blocks of the Cockleshell Gully and Yarragadee Formations. The South Perth Shale at the base of the Warnbro Group has been proven to extend southwards to Mandurah but to pinch out toward the Darling Scarp, and the overlying Leederville Formation which extends over the area appears to have been deposited under predominantly marine conditions. The Quaternary Rockingham Sand has been deposited in channels eroded to greater than 100 m below present sea level.

Groundwater occurs below the regional water table in a flow system separated into two parts, except near the Darling Range where the South Perth Shale is absent. A large volume of low salinity groundwater is available from the Cockleshell Gully Formation in a fault block of unknown size adjacent to the Darling Scarp, and from the Leederville Formation. Very large volumes of brackish water are present in the Cockleshell Gully and Yarragadee Formations beneath the plain and also from the Rockingham Sand.

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PETROLEUM EXPLORATION IN WESTERN AUSTRALIA IN 1977

by K. Crank

ABSTRACT

Oil exploration in Western Australia continued at about the same level as in 1976.

Eight wells were completed, compared with six in 1976; three were drilling ahead at the end of the year for a total penetration of 35 339 m, 13 168 m more than in 1976. Drilling was mainly offshore, in the Perth, Carnarvon, Browse, and Bonaparte Gulf Basins; only two onshore wells were completed, both in the Perth Basin. No major discoveries were made during the year although significant gas shows were encountered in West Australian Petroleum Pty Ltd's Warro No. 1, and in Woodside Petroleum Development Pty Ltd's Haycock No. 1. Woodside drilled a successful extension well within the North Rankin Field.

Geological activity, consisting mainly of marine seismic surveys, decreased by 30% compared with 1976. There were no land surveys. An encouraging feature was a marked increase in permits granted; 22 new permits were granted in 1977 compared with 9 in 1976, to give a total of 67 current permits, compared with 49 current at the end of 1976.

INTRODUCTION

Exploratory drilling for petroleum in Western Australia over the past two years is shown in the following table:

	Wells completed		Wells drilling on 31st December	
	1976	1977	1976	1977
New Field Wildcats	5	7	1	3
Extension Wells	0	1	1	0
Stratigraphic Tests	1	0	0	0
Total	6	8	2	3

Total effective drilling: 1976—22 171 m
1977—35 339 m*

* The aborted Scott Reef No. 1, which drilled to 310 m, and the side-tracked hole at Warro No. 1, are not included in these tabulations.

Only one successful well, North Rankin No. 5, an extension well within North Rankin Field, was drilled in 1977.

Geophysical survey activity for 1977 is shown below (with 1976 figures in brackets). No geological surveys were reported.

Type of Survey	Line km	Party months or geological months
Land seismic	Nil (443)	....
Marine seismic	5 994* (8 599)	....
Magnetic	579 (490)	....
Gravity marine	147 (108)	....
Geological	....	Nil (3·0)

* This does not include 2 384 km of marine seismic conducted outside permit areas by Geophysical Services International which was classed as a "Scientific Investigation".

PETROLEUM TENEMENTS

A summary of the status of petroleum tenements is given in the following table:

	1976 Offshore	1976 Onshore	1977 Offshore	1977 Onshore
Permits current at 31 Dec.	20	29	34	33
Production licenses	....	2	....	2
Permits surrendered or cancelled	....	2	3	5
Permits partially relinquished	....	8	....	1
Permits—surrender pending	1	2	1	6
New permits granted	2	7	15	7
Permit applications under consideration at 31 Dec.	15	3	7	5
Production licenses under application	1	....	6	....

Petroleum tenements current on December 31st, 1977 are shown in Figure 12 and the following tabulation lists details of the various holdings:

PETROLEUM TENEMENTS UNDER THE PETROLEUM (SUBMERGED LANDS) ACT 1967

Exploration Permits

Number	No. of graticular sections	Expiry date of current term	Registered holder or applicant
WA-1-P R1	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 R1 Part 1	110	29/8/79	West Australian Petroleum Pty. Ltd.
R1 Part 2	84 } 194		
WA-14-P R1 Part 1	77	29/8/79	
R1 Part 2	121 } 198		
WA-16-P R1	40	16/4/80	Arco Aust. Ltd.
WA-18-P R1	105	16/4/80	Arco Aust. Ltd., Australian Aquitaine Petroleum Pty. Ltd.
WA-19-P* R1	49	20/3/80	Alliance Oil Development Aust. N.L.
WA-23-P R1	199	3/10/79	West Australian Petroleum Pty. Ltd.
WA-24-P R1	104	17/10/79	West Australian Petroleum Pty. Ltd.
WA-25-P R1	128	16/10/79	West Australian Petroleum Pty. Ltd
WA-28-P R1 Part 1	52	24/3/80	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.
R1 Part 2	126 } 178		
WA-29-P R1 Part 1	36	18/5/80	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.
R1 Part 2	84 } 120		
WA-32-P R1	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 R1	194	18/5/80	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-34-P R1	149	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-35-P	123	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-36-P R1	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 R1	59	2/6/80	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-58-P	222	11/7/82	Western Energy Pty. Ltd.
WA-59-P	190	18/6/82	Esso Exploration and Production Aust. Inc., Western Mining Corp. Ltd.
WA-62-P	226	7/3/83	Oxoco-International Inc., Mid-American Oil Co., Peyto Oils Ltd., Voyager Petroleums Ltd., Australian Oil & Gas Corp. Ltd., Bridge Oil Ltd., Endeavour Oil Co. N.L., 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., Mid-American Oil Co., Peyto Oils Ltd., Voyager Petroleums Ltd., Bridge Oil Ltd.
WA-70-P	251	12/4/83	Getty Oil Development Co. Ltd., Union Texas Aust. Inc.
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-83-P	233	Appn.	Oxoco-International Inc.

* Surrender pending.

PETROLEUM TENEMENTS UNDER THE PETROLEUM (SUBMERGED LANDS) ACT 1967—*continued*

Exploration Permits—continued

Number	No. of graticular sections	Expiry date of current term	Registered holder or applicant
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	Esso Exploration and Production Aust. Inc., Hematite Petroleum Pty. Ltd.
WA-102-P	234	Appn.	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	Appn.	Oberon Oil Pty. Ltd.
WA-105-P	44	Appn.	Agha-Jahri Exploration Co., North West Mining N.L., North West Mining (Petroleum) Pty. Ltd.
WA-106-P	14	Appn.	Agha-Jahri Exploration Co., North West Mining N.L., North West Mining (Petroleum) Pty. Ltd.
WA-107-P	15	Appn.	Agha-Jahri Exploration Co., North West Mining N.L., North West Mining (Petroleum) Pty. Ltd.
WA-108-P	242	Appn.	Metro Industries Ltd., Pluranpe Pty. Ltd., Westwools Holdings Ltd., Westwools Exploration Ltd., Lennard Oil N.L., Malita Exploration Pty. Ltd.

Production Licences

WA-1-L	5	Appn.	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	Appn.	
WA-3-L	5	Appn.	
WA-4-L	4	Appn.	
WA-5-L	5	Appn.	
WA-6-L	4	Appn.	

* Surrender pending.

PETROLEUM TENEMENTS UNDER THE PETROLEUM ACT 1936

Petroleum Leases

Number	Area (km²)	Expiry date of current term	Holders
1H	259	9/2/88	West Australian Petroleum Pty. Ltd.
2H	259	9/2/88	West Australian Petroleum Pty. Ltd.

PETROLEUM TENEMENTS UNDER THE PETROLEUM ACT 1967

Exploration Permits

Number	No. of graticular sections	Expiry date of current term	Registered holder or applicant
EP 7* R1	24	27/8/80	West Australian Petroleum Pty. Ltd.
EP 13* R1	23	27/8/80	West Australian Petroleum Pty. Ltd.
EP 19* R1	18	27/8/80	West Australian Petroleum Pty. Ltd.
EP 21 R1	32	26/7/80	West Australian Petroleum Pty. Ltd.
EP 23 R1	33	6/8/80	West Australian Petroleum Pty. Ltd.
EP 24 R1 Part 1	39	6/8/80	West Australian Petroleum Pty. Ltd.
R1 Part 2	24	85	
R1 Part 3	22		
EP 25 R1	36	6/8/80	West Australian Petroleum Pty. Ltd.
EP 35 R1	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	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 40* R1	19	26/7/81	West Australian Petroleum Pty. Ltd.
EP 41 R1 Part 1	102	18/7/81	West Australian Petroleum Pty. Ltd.
R1 Part 2	1	106	
R1 Part 3	3		
EP 42* R1	19	1/9/80	West Australian Petroleum Pty. Ltd.
EP 50* R1	18	1/9/80	West Australian Petroleum Pty. Ltd.
EP 54 R1	47	22/9/80	Alliance Oil Development Aust. N.L., Canadian Superior Oil (Aust.) Pty. Ltd., Australian Superior Oil Co. Ltd.
EP 58 R1	150	20/7/81	A.A.R. Ltd., Australian Aquitaine Petroleum Pty. Ltd., Abrolhos Oil and Investments Ltd., Flinders Petroleum N.L., Longreach Oil Ltd., Pursuit Oil N.L.
EP 59 R1	139	18/7/81	A.A.R. Ltd., Australian Aquitaine Petroleum Pty. Ltd., Abrolhos Oil and Investments Ltd., Flinders Petroleum N.L., Longreach Oil Ltd., Pursuit Oil N.L.
EP 60	2	Appn.	West Australian Petroleum Pty. Ltd.
EP 61 .... R1	4	19/9/81	West Australian Petroleum Pty. Ltd.
EP 62 R1	8	19/9/81	West Australian Petroleum Pty. Ltd.
EP 63 R1	4	19/9/81	West Australian Petroleum Pty. Ltd.
EP 64	1	Appn.	West Australian Petroleum Pty. Ltd.
EP 65 R1	2	19/9/81	West Australian Petroleum Pty. Ltd.
EP 66 R1	1	19/9/81	West Australian Petroleum Pty. Ltd.
EP 88	1	18/6/81	Esso Exploration & Production Aust. Inc., Western Mining Corp. Ltd.
EP 89	2	18/6/81	Esso Exploration & Production Aust. Inc., Western Mining Corp. Ltd.
EP 90	4	18/6/81	Esso Exploration & Production Aust. Inc., Western Mining Corp. Ltd.
EP 91	7	18/6/81	Esso Exploration & Production Aust. Inc., Western Mining Corp. Ltd.
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.
EP 100	163	3/10/82	Agha-Jahri Exploration Co., North West Mining N.L., Landshire Investments Pty. Ltd., J. M. Goldberg, Wise Nominees Pty. Ltd., R.W.W. Pty. Ltd., Cladium Mining Pty. Ltd., A. R. Burns, V. W. Burns, D. R. Gascoine, J. Gascoine, B. C. Forster, Exploration Geophysics Pty. Ltd.
EP 101	172	24/6/82	Whitestone Petroleum Aust. Ltd., Amax Iron Ore Corp., Pennzoil Producing Aust. Ltd., Australian Consolidated Minerals Ltd.

* Surrender pending.

PETROLEUM TENEMENTS UNDER THE PETROLEUM ACT 1967—*continued*

Exploration Permits—continued

Number	No. of graticular sections	Expiry date of current term	Registered holder or applicant
EP 102	200	24/6/82	Whitestone Petroleum Aust. Ltd., Amax Iron Ore Corp., Pennzoil Producing Aust. Ltd., Australian Consolidated Minerals Ltd.
EP 103	184	22/8/82	Whitestone Petroleum Aust. Ltd.
EP 104	199	31/8/82	Esso Exploration & Production Aust. Inc.
EP 105	4	29/11/82	Colgas Inc.
EP 106	1	Appn.	Oberon Oil Pty. Ltd.
EP 107	146	Appn.	Era South Pacific Pty. Ltd., Era West. Aust. Inc., E.S.P. Explorations Pty. Ltd., Cambridge Royalty Co., Cambridge Petroleum Royalty Ltd. *et al*
EP 108	193	29/12/82	Houston Oil & Minerals Aust. Inc.
EP 109	1	Appn.	Metro Industries Ltd., Pluranpe Pty. Ltd., Westwools Holdings Ltd., Westwools Exploration Ltd., Lennard Oil N.L., Malita Exploration Pty. Ltd.

Production Licences

PL 1	5	24/10/92	West Australian Petroleum Pty. Ltd.
PL 2	4	24/10/92	West Australian Petroleum Pty. Ltd.

PETROLEUM TENEMENTS UNDER THE PETROLEUM PIPELINES ACT 1969

Pipeline Licences

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	

DRILLING

The positions of wells drilled for petroleum exploration during 1977 are shown in Figure 13. Details relating to wells drilled during the year are given in Table 6. All petroleum exploration wells drilled in Western Australia up to the end of 1977 are listed in the Geological Survey Record 1978/1 (Crank, 1978). A summary of the principal results of drilling in each basin during the year is as follows:

PERTH BASIN

One offshore and two onshore wells were completed during the year, and one was drilling ahead (Warro No. 2) on December 31st. Peel No. 1 was located on a culmination on the Peel Arch 30 km southwest of Fremantle, and was drilled by Phillips Australian Oil Company under a farmout agreement with WAPET. No shows of oil or gas were encountered, and the well was abandoned as a dry hole at a total depth of 3 714 m.

WAPET completed Denison No. 1 which was commenced in 1976. This well, located in a fault block to the west of Dongara Gas Field, was drilled to a total depth of 2 300 m. No shows were encountered, and it was plugged and abandoned as a dry hole.

WAPET's Warro No. 1 was drilled on the Warro Anticline on the east flank of the northern part of the Dandaragan Trough. The original hole had to be abandoned at a total depth of 4 435 m because of mechanical difficulties after several gas shows. A sidetrack hole was drilled from 3 356 m to a total depth of 4 385 m, but this had to be plugged and abandoned after encountering high pressure shales. Four separate zones were tested in this well, but the results were inconclusive because of apparent formation damage and communication across perforations. A second well is to be drilled in 1978.

CARNARVON BASIN

One exploration well, Haycock No. 1, and one extension well, North Rankin No. 5, were completed by Woodside in the Carnarvon Basin in 1977 (Fig. 14). Haycock No. 1 was drilled on a north-trending fault block on the northwest margin of the Kendrew Depression adjacent to the Rankin Platform. The well was drilled to a total depth of 3 668 m and, although, some gas pay was encountered between 3 232 and 3 359 m, the well was abandoned as non-commercial.

North Rankin No. 5 was successfully completed as an extension gas well within the North Rankin Gas Field.

WAPET completed one well, Hermite No. 1, and was drilling another, Bundegi No. 1, at the end of 1977. Hermite No. 1, 100 km west of Dampier, was drilled on an anticlinal closure, on the downthrown side of the Flinders Fault System in the Barrow Sub-basin. Only minor gas and oil shows were encountered, and the well was abandoned as a dry hole at a total depth of 3 300 m.

Bundegi No. 1, a new field wildcat in the Exmouth Gulf, was drilling ahead at the end of the year.

BROWSE BASIN

One well Scott Reef No. 2A was completed by Woodside in the Browse Basin; it was drilled downdip on the same closure as No. 1, the gas-condensate discovery well which was completed in 1971. Some gas was encountered, but the well was abandoned as a dry hole. Scott Reef No. 2 was abandoned at 310 m because of mechanical problems.

At the end of 1977, Woodside was also drilling Caswell No. 1, 70 km southeast of Scott Reef.

BONAPARTE GULF BASIN

Arco Australia Ltd completed one well in the offshore Bonaparte Gulf Basin in 1977. Plover No. 3, 30 km southwest of Plover No. 1, was a stratigraphic trap play in the Jurassic. No shows were encountered and the well was plugged and abandoned at a total depth of 1 219 m in the Lower Triassic.

GEOPHYSICAL SURVEYS

SEISMIC

During 1977 seismic surveys were conducted in the offshore Perth, Carnarvon, Canning and Browse Basins. There were no land surveys. Details are as follows:

SEISMIC SURVEYS

Basin	Tenement	Company	Line km
Perth	WA-13-P	West Australian Petroleum Pty. Ltd.	400
	WA-14-P	West Australian Petroleum Pty. Ltd.	85
Carnarvon/ Perth	WA-59-P	Esso Exploration and Production Inc.	465
Carnarvon	WA-1-P	Woodside Petroleum Development Pty. Ltd.	86
	WA-28-P	Woodside Petroleum Development Pty. Ltd.	1 704
	WA-24-P	West Australian Petroleum Pty. Ltd.	17
	WA-25-P	West Australian Petroleum Pty. Ltd.	639
	WA-24-P	Wapet (Continental Oil Co. of Aust. Ltd.—farminee)	571
	WA-58-P	Western Energy Pty. Ltd.	180
Canning	WA-29-P	Woodside (Amax Petroleum (Aust.) Inc.—farminee)	428
Browse	WA-34-P	Woodside Petroleum Development Pty. Ltd.	94
	WA-35-P	Woodside Petroleum Development Pty. Ltd.	715
	WA-37-P	Woodside Petroleum Development Pty. Ltd.	177
Outside Permit areas	....	Woodside Petroleum Development Pty. Ltd.	411
	....	West Australian Petroleum Pty. Ltd.	22
		Total	5 994

GRAVITY

A gravity survey carried out in conjunction with an offshore seismic survey in the Browse Basin was as follows:

GRAVITY SURVEYS

Basin	Tenement	Company	Line km
Browse	WA-35-P	Woodside Petroleum Development Pty. Ltd.	147

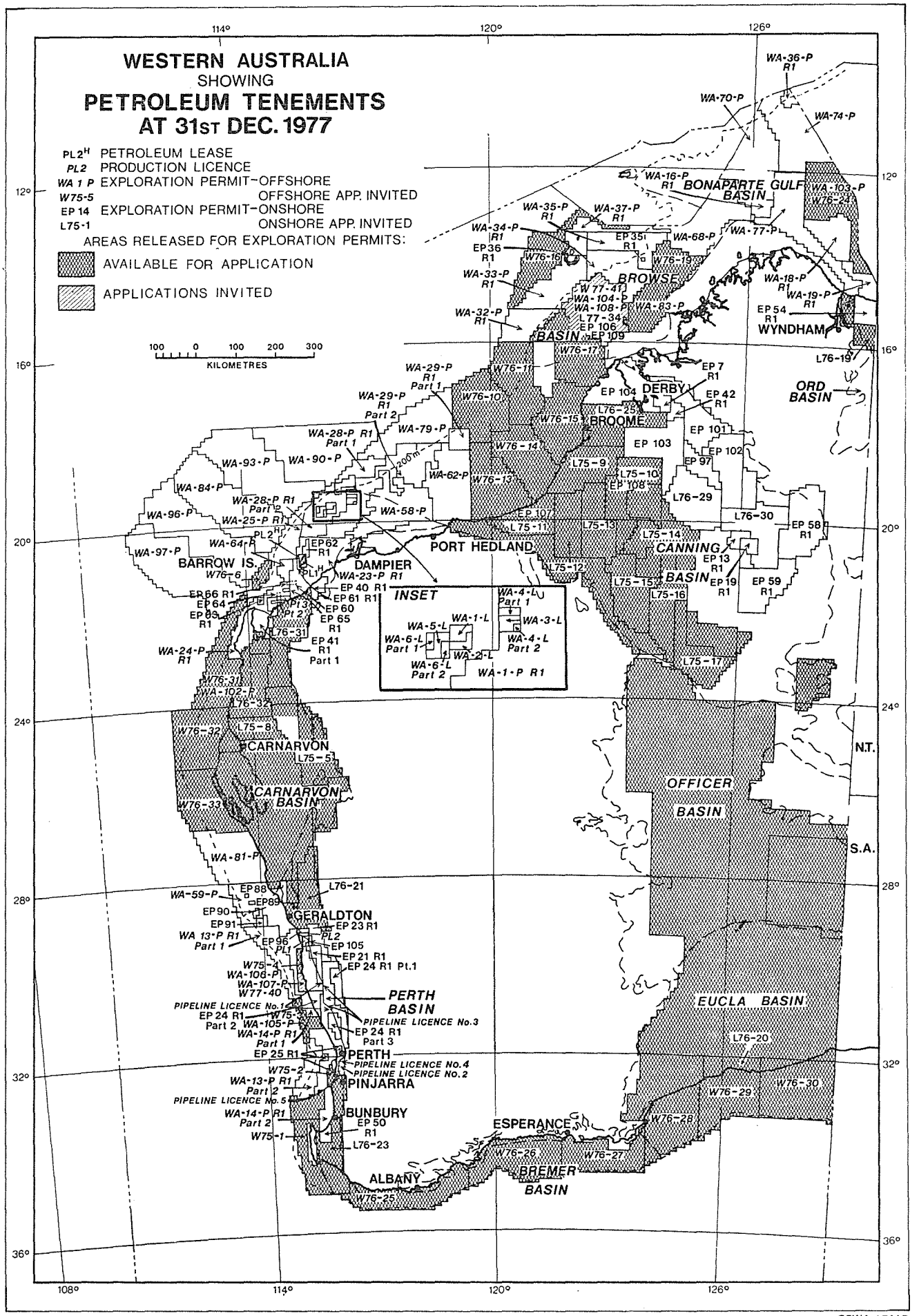

Figure 12 Petroleum tenements at 31st December 1977

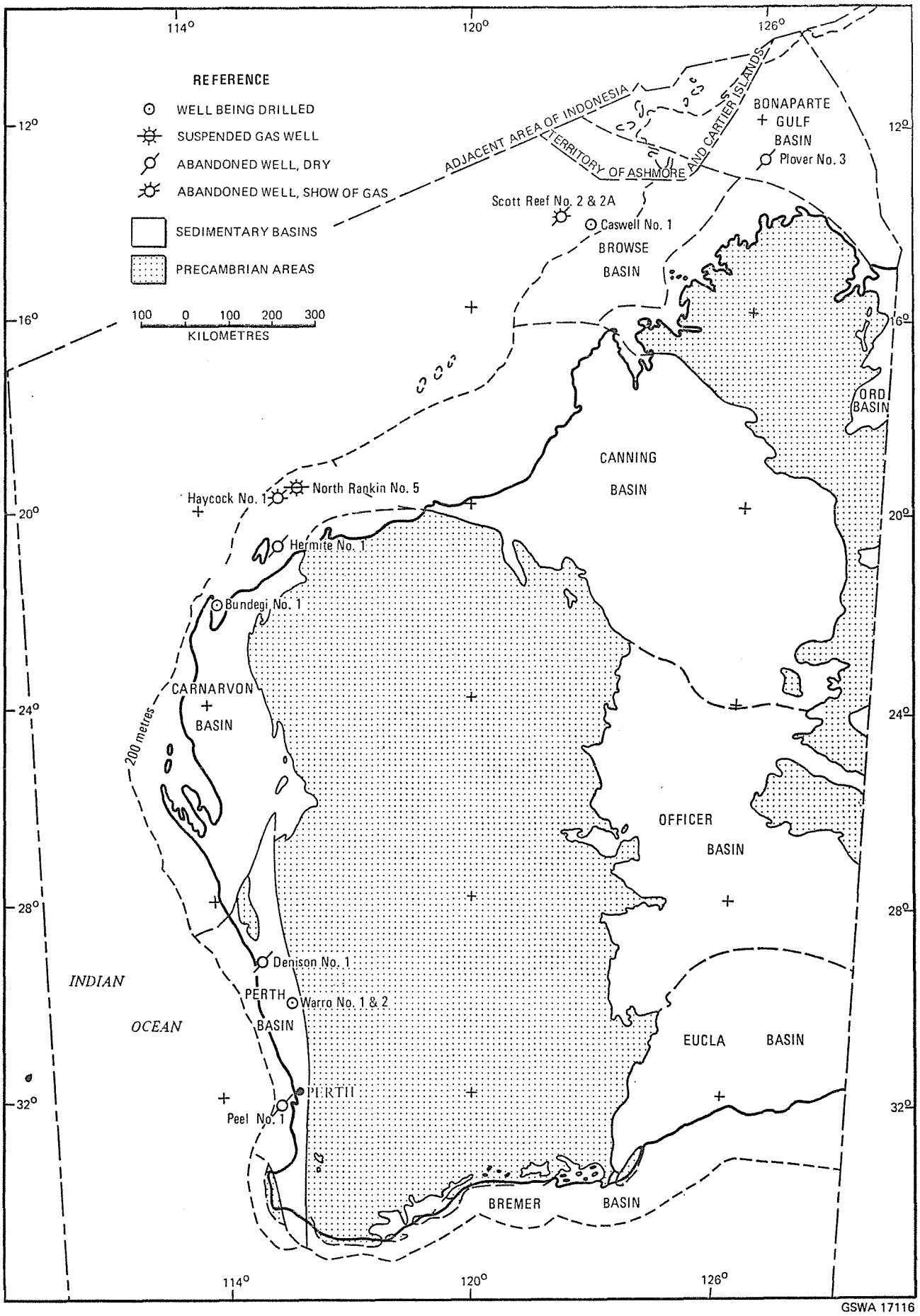

Figure 13 Wells drilled for petroleum in WA during 1977

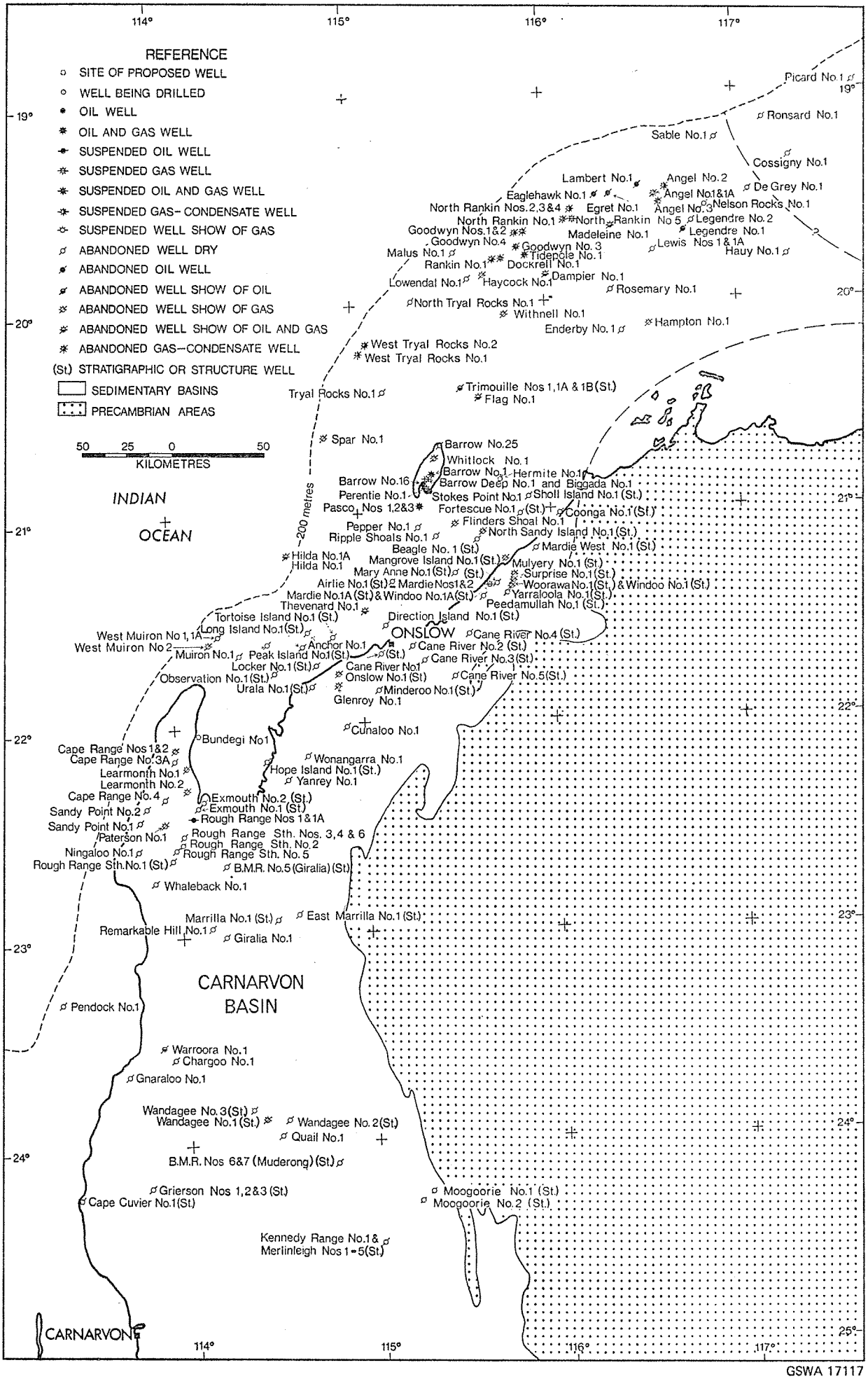

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Figure 14 Northern Carnarvon and southwestern Canning Basin showing wells drilled for petroleum to 31st December 1977

TABLE 6. WELLS DRILLED FOR PETROLEUM EXPLORATION IN WESTERN AUSTRALIA DURING 1977

Basin	Well	Concession	Operating company	Type	Position		Elevation and water depth (metres)			Dates			Total depth (or depth reached) m	Bottomed in	Status on 31/12/77
					Latitude south ° ′ ″	Longitude east ° ′ ″	G.L.	R.T.	W.D.	Commenced	Reached T.D.	Rig released			
Carnarvon	North Rankin No. 5	WA–28–P	Woodside	EXT	19 34 19	116 09 30	....	30	123	8/10/76	9/2/77	23/4/77	3 500	U. Triassic	Gas cond. well, p & a
	Haycock No. 1	WA–28–P	Woodside	NFW	19 50 58	115 43 17	....	8	85	1/2/77	7/4/77	15/4/77	3 668	U. Triassic	Gas shows, p & a
	Hermite No. 1	WA–23–P	WAPET	NFW	20 49 58	115 42 08	....	27	16	15/9/77	24/11/77	29/11/77	3 300	U. Triassic	Dry, p & a
	Bundegi No. 1	EP 41	WAPET	NFW	22 01 06	114 09 33	....	32	16	4/12/77	....	....	2 217	....	Drilling
Perth	Denison No. 1	PL 2	WAPET	NFW	29 13 32	114 57 17	<7	35	....	23/12/76	18/1/77	21/1/77	2 300	?Silurian	Dry, p & a
	Warro No. 1	EP 24	WAPET	NFW	30 10 06	115 44 11	291	299	....	27/2/77	3/7/77	11/9/77	4 435	M. Jurassic	Gas shows, p & a
	Peel No. 1	WA–14–P	Phillips	NFW	32 15 48	115 26 43	....	30	42	7/10/77	2/12/77	10/12/77	3 714	U. Jurassic	Dry, p & a
	Warro No. 2	EP 24	WAPET	NFW	30 10 05	115 44 03	291	299	....	12/11/77	....	....	3 907	....	Drilling
Browse	Scott Reef No. 2	WA–33–P	Woodside	NFW	14 06 04	121 51 27	....	8	55	18/4/77	25/4/77	27/4/77	310	....	Mechanical problems p & a
	Scott Reef No. 2A	WA–33–P	Woodside	NFW	14 06 06	121 51 28	....	8	55	27/4/77	1/8/77	9/8/77	4 820	L. Jurassic	Gas shows, p & a
	Caswell No. 1	WA–34–P	Woodside	NFW	14 14 29	122 28 04	....	8	345	16/8/77	....	....	4 042	....	Drilling
Bonaparte	Plover No. 3	WA–16–P	ARCO	NFW	12 49 05	126 06 57	....	21	75	13/12/77	25/12/77	....	1 219	L. Triassic	Dry, p & a

Woodside = Woodside Petroleum Development Pty. Ltd.
WAPET = West Australian Petroleum Pty. Ltd.
Phillips = Phillips Australian Oil Co.
Arco = Arco Australia Ltd.
EXT = Extension test well
NFW = New field wildcat well
p & a = plugged and abandoned

MAGNETOMETER

Magnetometer surveys conducted in conjunction with offshore seismic surveys were as follows:

MAGNETOMETER SURVEYS

Basin	Tenement	Company	Line km
Carnarvon	WA-1-P	Woodside Petroleum Development Pty. Ltd.	85
	WA-28-P	Woodside Petroleum Development Pty. Ltd.	347
Browse	WA-35-P	Woodside Petroleum Development Pty. Ltd.	147
		Total	579

GEOLOGICAL SURVEYS

No geological surveys were carried out by exploration companies in 1977.

REFERENCES

Crank, K. A., 1978, Wells drilled for petroleum exploration in W.A. to the end of 1977: West. Australia Geol. Survey Rec. 1978/1.

CRETACEOUS STRATIGRAPHY AND SEDIMENTOLOGY, NORTHEASTERN MARGIN OF THE CARNARVON BASIN, WESTERN AUSTRALIA

by R. M. Hocking and W. J. E. van de Graaff

ABSTRACT

Sediments deposited by a major Early Cretaceous transgression are divisible into three facies groups along the northeastern margin of the Carnarvon Basin. In the present-day Kennedy Range area, low sediment-supply rates combined with high erosion produced a transgressive shallow-marine sequence (Winning Group) in which all basal lagoonal deposits were reworked. In the present-day Robe River area, sediment supply relative to coastal erosion was high enough to form a prograding delta (Nanutarra Formation and Yarraloola Conglomerate). In the present-day Ashburton River area, sediment-supply rates were only moderate, but lagoonal and fluviatile deposits were protected by a long, discontinuous offshore barrier of Precambrian rock. This, combined with irregular basement relief behind the barrier, produced a local sequence (Nanutarra Formation) with complexly varying, shallow-marine to fluviatile facies. Correlatives of the open-basin Winning Group can be traced through the Nanutarra Formation, in a less-mature form.

INTRODUCTION

In the Carnarvon Basin, the Early Cretaceous transgression produced a shallow-marine, laterally persistent, simple layered sequence called the Winning Group. In the central and northern parts of the basin, this consists of, in ascending order, the Birdrong Sandstone, Muderong Shale, Windalia Radiolarite and Gearle Siltstone. However, near the basin margin in the Yanrey and Yarraloola Sheet areas (Fig. 15, inset), this sequence grades laterally into a much coarser grained and less-mature, siliciclastic sequence mapped as Yarraloola Conglomerate and Nanutarra Formation. The lithology of these units is described by Playford and others (1975) and van de Graaff and others (1977). Depositional environments in the marginal sequence range from open marine to fluviatile, and the sequence is characterized by rapid lateral and vertical facies changes. The facies distribution presents several stratigraphic and sedimentological problems which are of practical significance, as the principal study area (Fig. 15) has been a major target for uranium exploration. The understanding of depositional environments in these sediments is therefore economically important, as facies changes could be expected to influence any possible uranium mineralization.

The Cretaceous sequences in the Kennedy Range, Ashburton River and Robe River areas (Fig. 15, inset) are compared, using facies interpretations and the relationships of the various stratigraphic units. These sequences are compared to the models of sedimentation along a drowning coast described by Fischer (1961) and Swift (1975) and shown in Figure 16. Figure 16a shows the theoretical arrangement of facies across a drowning coast. Depending on the balance between erosion and sedimentation, very different facies sequences are formed as sea level rises. If deposition predominates (Fig. 16b) a *depositional regressive* sequence forms under transgressive conditions. In this situation, the dune and beach barrier sands function both as protection for landward fluviatile, lagoonal, and swamp deposits (hereafter called 'coastal deposits'), and as a sediment dump. They migrate seawards and coastal deposits are preserved behind and beneath them. Under conditions of net coastal erosion, the sea advances and a *depositional transgressive* sequence forms, with partial or total destruction of coastal deposits (Fig. 16c and 16d). In the first case a *coarsening upwards* sequence (Oomkens, 1967) is preserved, whereas in the second, a *fining upwards* sequence (Allen, 1965) is preserved.

In this paper we demonstrate that, north of the Yannarie River, coastal erosion during deposition of the Nanutarra Formation was insufficient to destroy coastal deposits, and significant progradation of the coast occurred during the later stages of the transgression. In areas where the Winning Group is typically developed, erosion destroyed all coastal deposits. Correlatives of the Birdrong Sandstone, Muderong Shale and Windalia Radiolarite can be traced within most sections of the Nanutarra Formation, but they reflect shallower conditions nearer to the shore than the sequence in the Kennedy Range area.

SECTION ANALYSIS AND CORRELATION

Two groups of sections, in sequences ranging from open marine to fluviatile, have been used to test the validity of the models proposed for the Lower Cretaceous by Fischer (1961) and Swift (1975). The first group (Fig. 17) forms a roughly east-west line through the various facies-realms in the Ashburton area of the Yanrey Sheet (Fig. 15), and illustrates the transition from the simply layered Winning Group sedimentation to the complexly varying Nanutarra Formation. In this area, sediments are preserved in isolated mesas but because they are flat-lying, altimetric data from the Division of National Mapping 1:100 000 compilations can be used where needed to support correlations between sections up to 8 km apart. The second group of sections (Fig. 18) forms a roughly north-south line. It includes, for comparison with Nanutarra Formation sections, the Birdrong Sandstone type section in the Kennedy Range, and a section near the Yarraloola Conglomerate type section in the Robe River area.

EAST-WEST PROFILE

Sections 1 and 2 are essentially open-basin transgressive sequences, except that in Section 1 the Birdrong Sandstone is replaced by the less mature Nanutarra Formation. This fines upwards, with waning terrigenous supply, into Muderong Shale, which is in turn overlain by Windalia Radiolarite. Section 2 illustrates the pronounced relief on the Cretaceous unconformity, in that only the Windalia Radiolarite and the upper facies of the Muderong Shale are present, resting directly on Precambrian bedrock.

Section 3, on the western edge of a large area of granitic bedrock, also demonstrates basement relief. Clean, well-sorted, medium-grained to pebbly Birdrong

Sandstone abuts granite tors and is interpreted as a probable littoral bar, whereas 200 m west at the same level, white siltstone of the Windalia Radiolarite crops out. No Muderong Shale is exposed, and the siltstone coarsens upwards into immature silty to pebbly sandstone identical with the upper Nanutarra Formation further east. This sandstone is replaced in Section 4 by the Peepingee Greensand Member of the Nanutarra Formation, which overlies Windalia Radiolarite and pebbly, immature, Nanutarra Formation, possibly of fluviatile origin, with a minor disconformity. Hoelscher and McKellar (McWhae and others, 1958) originally defined the 'Peepingee Greensand', and tentatively correlated it with the Alinga Formation and Gearle Siltstone. We correlate the unit with the upper part of the Nanutarra Formation (Fig. 17) and reduce it to member status. The unconformity at the base of the unit is a locally significant channel-base scour which is relatively common within the Cretaceous sequence in the Ashburton area. The coarse-grained basal layer of the Peepingee Greensand Member correlates with part of Section 5, 3.5 km to the east at the same elevation. This interval of Section 5 is a cyclic conglomeratic sequence

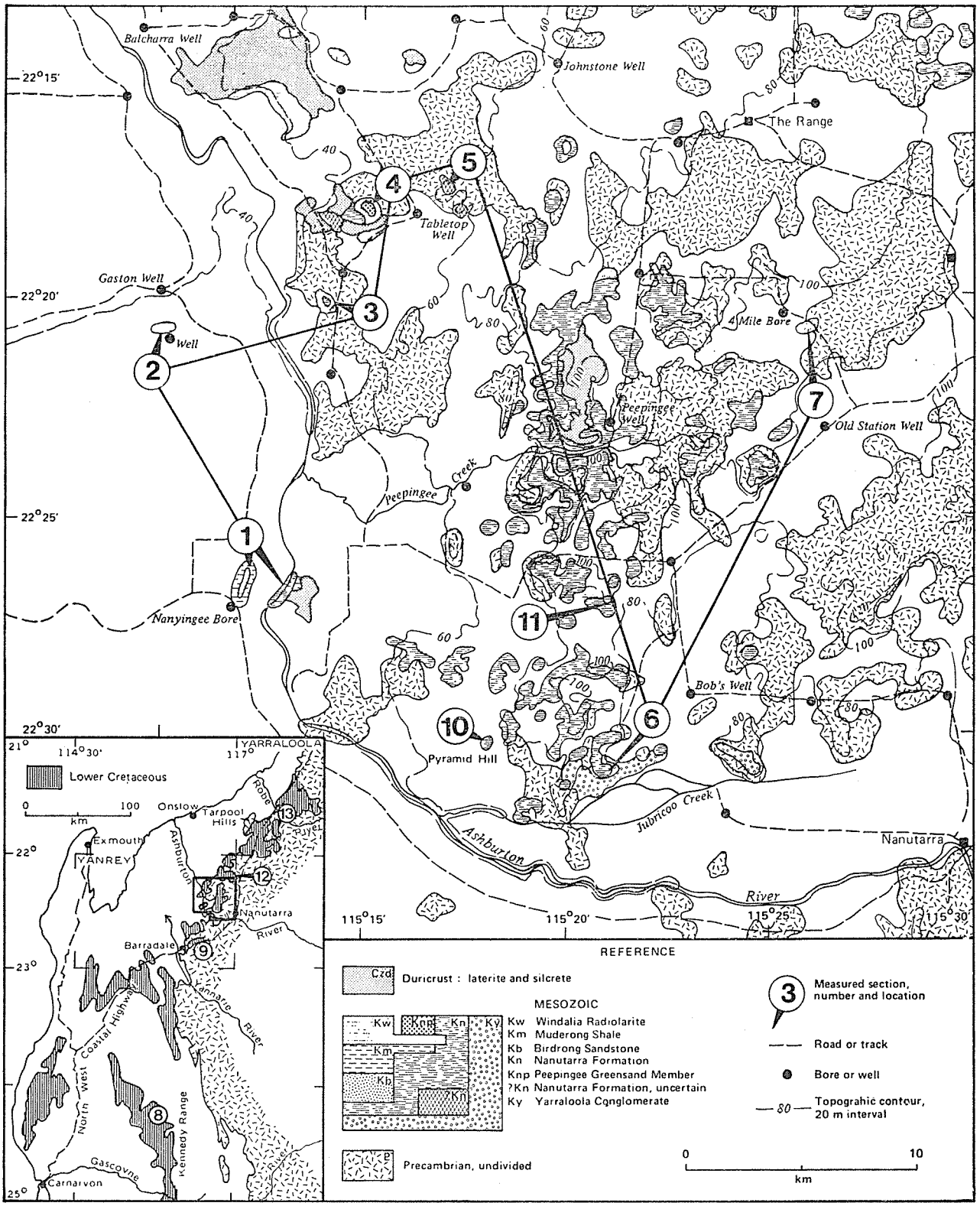

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Figure 15 Distribution of Lower Cretaceous and Proterozoic units, Ashburton River area
Inset: Lower Cretaceous sediments in north-east Carnarvon Basin

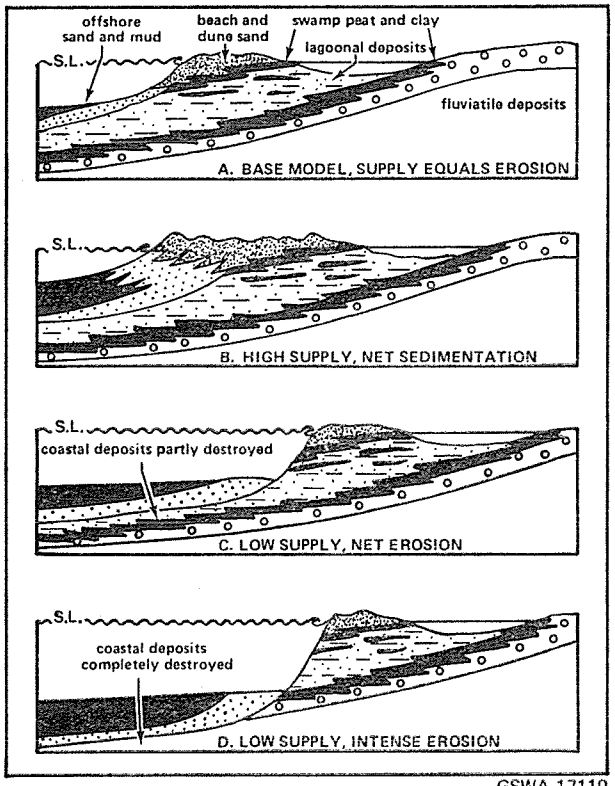

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Figure 16

Coastal stratigraphic sequence developed by marine transgression, under different ratios of erosion to sediment supply. *A* and *D* modified from Fisher (1961), *B* and *C* from Swift (1975).

containing several beds, each with an erosional base, and coarse sand to granule-size matrix. The framework of each bed coarsens upwards from granule to pebble size, although the section as a whole is a fining-upwards sequence. We favour an origin by submarine shoaling, rather than fluviatile deposition.

Section 6 is the most complete section of Nanutarra Formation and Yarraloola Conglomerate. The latter is a fluviatile, valley-fill boulder conglomerate which fines upwards into cross-bedded pebbly sandstone of the Nanutarra Formation. In this area the Nanutarra Formation is divided into four units. The basal unit consists of cross-bedded, poorly sorted sandstone, with minor conglomerate and intensely burrowed siltstone. This is overlain with a sharp erosive contact by a fining-upwards sequence, consisting of large-scale, cross-bedded, moderately sorted sandstone (the second unit), grading up into finer grained, horizontally bedded siltstone, sandstone and claystone (the third unit). This grades into the fourth unit, which consists of locally burrowed coarse-grained to locally pebbly sandstone, and contains an intensely ferruginized (?originally calcareous) bed with *Panopea glaessneri*, a burrowing bivalve, in life position.

As a whole, the Nanutarra Formation in Section 6 is a lagoonal to shallow-subtidal, transgressive sequence, although the fining-upwards character is indistinct. Its four part nature and sequence of depositional environments suggests that the cross-bedded second unit correlates with the Birdrong Sandstone, and the overlying fine-grained unit with the Muderong Shale and/or Windalia Radiolarite. From this, we correlate the upper unit with the Nanutarra Formation in Section 3 and the Peepingee Greensand Member in Section 4, as it represents a change from low to medium energy conditions, and hints at depositional regression.

Five kilometres east of Section 6, conglomerate and sandstone mapped as Yarraloola Conglomerate rests on basement hills at the same elevation as the fine-grained, third unit of the Nanutarra Formation. This sequence is probably of fluviatile origin, similar to the conglomeratic fining-upwards sequences of Section 7, and illustrates both the lateral equivalence of the Nanutarra Formation and Yarraloola Conglomerate, and the proximity of much of the Nanutarra Formation to the Cretaceous shoreline.

NORTH-SOUTH PROFILE

Section 8, the Birdrong Sandstone type section, (Fig. 18) is a fining-upwards shallow-marine sequence, intensely bioturbated in the upper half, but with no body fossils preserved. No lagoonal, swamp, or fluviatile facies are present at the base of the section, indicating low sediment-supply rates and complete removal and reworking of coastal deposits by the transgression. The intensity of internal erosion and recycling is indicated by a scour 3 m deep about one third the way up the type section. In contrast, sections in the Ashburton area commonly contain coastal sediments, with local soil deposits.

In Section 9, Nanutarra Formation is exposed both at the base and the top of the section, with subtidal Birdrong Sandstone and Muderong Shale between. The basal part is of lagoonal and fluviatile origin, whereas the uppermost part is a subtidal pebbly sandstone. Similarly, in Sections 6, 10 and 11, basal fluviatile deposits are overlain firstly by lagoonal, moderately sorted, partly fine-grained deposits, then by subtidal deposits (Birdrong Sandstone and Muderong Shale/Windalia Radiolarite correlatives), and finally by coarser-grained subtidal to tidal deposits; except in Section 10 where the lagoonal facies is replaced by a thicker Birdrong Sandstone correlative.

Only the low-energy, subtidal, Muderong Shale/Windalia Radiolarite correlative, and the upper coarse-grained facies are exposed in Section 12, the Nanutarra Formation type section. The upper facies of the Nanutarra Formation results from an increase in sediment supply relative to the underlying silty facies, and probably reflects a prograding delta to the east. It is uncertain, though, whether the upper facies was deposited in the distal parts of the delta or by longshore drift from the delta.

Section 13 is located approximately 2 km east of the Yarraloola Conglomerate type section, and has at its base very fine to medium-grained silty sandstone, interpreted as Nanutarra Formation. The Yarraloola Conglomerate which overlies this consists of fining-upwards cycles from conglomerate to pebbly sandstone. The cyclic nature of this sequence, the scoured contacts, and the immaturity of the sediments suggest an origin as a delta fan with meandering channels, prograding over shallow marine Nanutarra Formation. This environment was first inferred by Williams (1968) for this area.

SYNTHESIS

Three distinct types of marginal-marine sedimentation are present in the Lower Cretaceous sequence between the Kennedy Range and the Robe River. The first of these is represented by the Winning Group at the Birdrong Sandstone type area, in the Kennedy Range. This sequence fits a model of transgressive sedimentation along a coast where erosion greatly exceeds supply (Fig. 16d, 18, inset). To the east, the Cretaceous is faulted out, and we do not know if barrier and lagoonal sediments were originally preserved.

The second type of marginal-marine sedimentation is seen in the Ashburton area, where coastal deposits are present in the Nanutarra Formation implying a high-supply model like Figure 16b, except there are no barrier-sand deposits. The absence of the barrier sands suggests lower supply rates than are implied by the extensively preserved coastal deposits. However, we consider that relief on the basal Cretaceous unconformity was of major importance in preserving these coastal deposits. On a medium to small scale, the extent of this relief is well illustrated in the Section 9 area, where the Early Cretaceous landscape is presently largely exhumed. Long, narrow Precambrian strike-ridges are still mostly higher than mesas of Cretaceous rocks and would have formed an Early Cretaceous ria coast between Nanutarra and Barradale. North of Section 11, Nanutarra Formation is present at the base of Peepingee Well, which is 20 m deep, yet less than 2 km east the Precambrian crops out more than 10 m above the top of the well. Such irregular relief would have interfered with local marine reworking processes.

On a regional scale, the western limit of the Nanutarra Formation coincides with a belt of Precambrian rocks extending discontinuously from Barradale to the Tanpool Hills. In the Cretaceous this would have been a long, offshore barrier behind which coastal sediments were protected from reworking. Because of this barrier, only a moderate sediment supply is needed to explain observed facies distributions, as distinct from the high level of sediment input required for the model of an unprotected coast. Moderate sediment supply is also suggested by the condensed nature of the Nanutarra Formation, indicated by soil development at depositional hiatuses, and the

correlation of the Nanutarra Formation with the Birdrong Sandstone, Muderong Shale, and Windalia Radiolarite, which are much thicker to the west.

This correlation raises a problem of apparent age discrepancies between the upper part of the Nanutarra Formation and the Windalia Radiolarite. Brunnschweiler (1959) dated the Windalia Radiolarite as Aptian to Albian, whereas Cox (1961) and Skwarko (1967) dated the Nanutarra Formation as Neocomian to Aptian. Considering that the two units were dated by different fossil groups and in widely separated areas, we disregard this discrepancy in favour of the local field evidence.

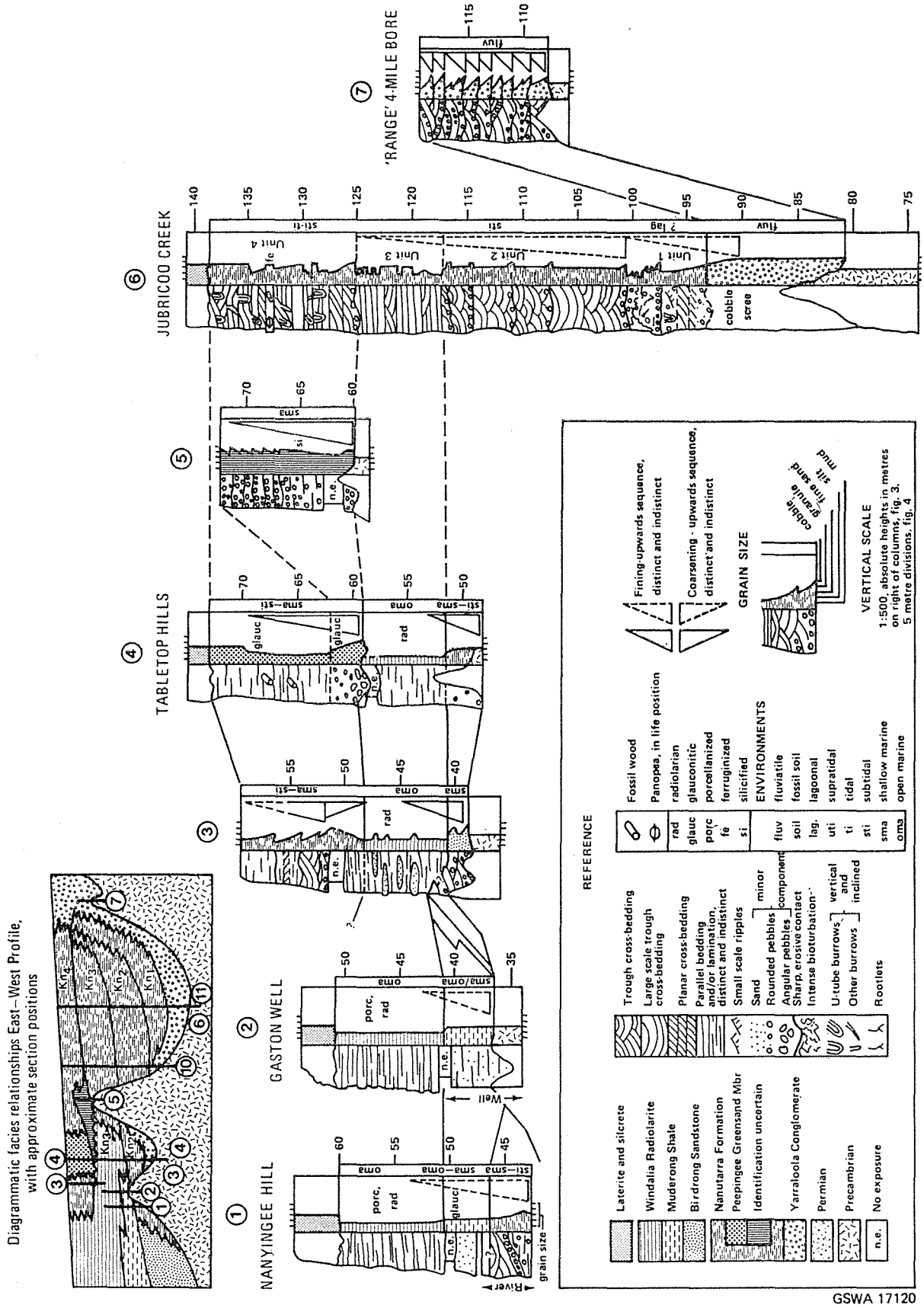

Figure 17 East-west profile and facies relationships, Ashburton River area

The third type of marginal-marine sedimentation is in the Robe River area, where the Yarraloola Conglomerate extends over the Nanutarra Formation. This is a more complete development of the trend seen in the uppermost facies of the Nanutarra Formation. Terrigenous supply increased during deposition of this sequence. In the Robe River area it greatly exceeded marine reworking and erosion of the coastal sediments, resulting in an extensive, prograding delta fan.

CONCLUSIONS

Of the three types of Lower Cretaceous marginal-marine sedimentation in the northern-central Carnarvon Basin, only the Winning Group in the Kennedy Range area fits a simple

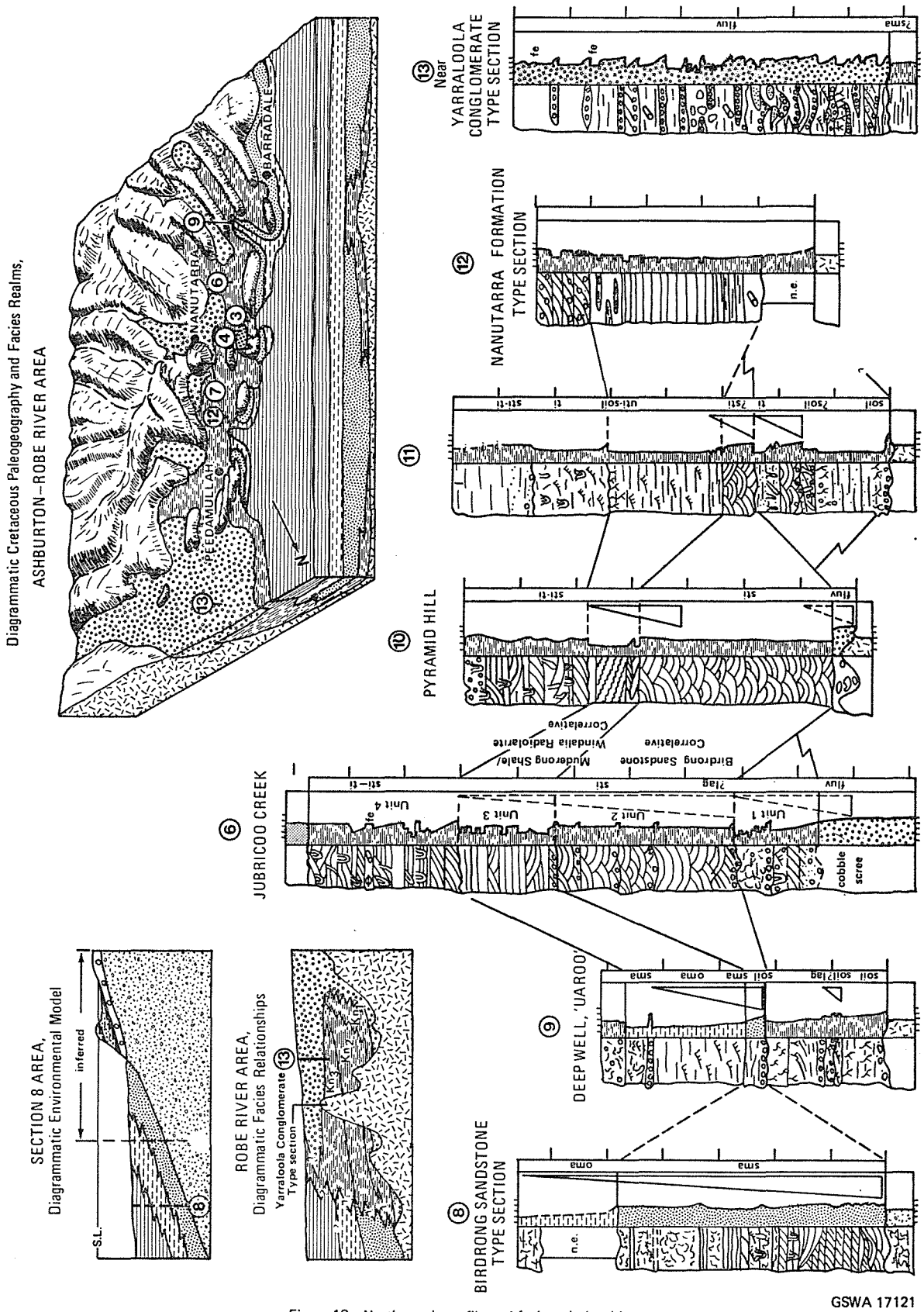

Figure 18 North-south profile and facies relationships,
Kennedy Range to Robe River, and diagrammatic Cretaceous palaeogeography, Ashburton-Robe River area.

model of a drowning, low-sedimentation/high-erosion, coastline. Coastal deposits, characterized by rapid lateral and vertical facies changes in the Nanutarra Formation, are preserved mainly because of the protection given by pronounced and irregular relief on the basal Cretaceous unconformity, rather than high rates of sediment supply. In the Robe River area, supply exceeded erosion and a delta of Yarraloola Conglomerate prograded over the Nanutarra Formation.

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PALAEOCURRENT DIRECTIONS IN THE PERMIAN COLLIE COAL MEASURES, COLLIE, WESTERN AUSTRALIA

by S. A. Wilde and I. W. Walker

ABSTRACT

Foreset bedding directions in cross-bedded sandstones of the Collie Coal Measures indicate palaeo-currents from the south. This direction is consistent across the area and throughout the sequence, and suggests that the present Collie Basin is a remnant of a much larger area of sedimentation.

INTRODUCTION

Coal-bearing Permian strata lie in a northwest-trending basin at Collie (the Collie Basin), 160 km south-southeast of Perth, Western Australia (Fig. 19). The basin is 26 km long and 15 km wide and contains over 1 300 m of weakly lithified sediments. A smaller basin of similar trend occurs 36 km south of Collie at Wilga. It contains up to 365 m of Permian strata, including several coal seams; the rocks are not exposed and no mining has taken place. The only operating coal mines in Western Australia are located in the Collie Basin.

The first detailed survey of the Collie Basin was undertaken by Lord (1952). He summarized the history and development of the coalfield to 1950. Further information from a deep drilling programme, instigated by the Geological Survey of Western Australia in 1950, is contained in Low (1958).

The Permian strata of the Collie Basin consist of the Stockton Formation and the overlying Collie Coal Measures. The Stockton Formation is up to 260 m thick and rests on a glacially striated pavement of Archaean rocks. It comprises a basal tillite overlain by a sequence of mudstone, siltstone and fine-grained sandstone. The Collie Coal Measures appear to conformably overlie the Stockton Formation and are a succession of conglomerate, grit, sandstone, siltstone and shale, with intercalated seams of sub-bituminous coal. They attain a maximum thickness of at least 1 050 m. Three main periods of coal formation are recognized and each of these 'members' contains several coal seams.

The Collie Basin is divided into three units: the Cardiff, Shotts and Muja sub-Basins (Fig. 19). These are separated by basement highs covered by a thin veneer of Permian strata, except in the southeast where the basement reaches the surface between the Cardiff and Muja sub-Basins as the Stockton Ridge. Each sub-basin is asymmetric in profile, with the southwestern margin being much steeper than the northeastern one, and the greatest thickness of strata occurring close to the southwestern boundary. A correlation of the various coal-bearing 'members' between the sub-basins is presented in Table 7 (based on Playford and others, 1975).

TABLE 7. CORRELATION OF COAL-BEARING MEMBERS OF THE COLLIE COAL MEASURES.

		CARDIFF SUB-BASIN	SHOTTS SUB-BASIN	MUJA SUB-BASIN
PERMIAN Upper	Collie Coal Measures	Cardiff Member	Not Present	Muja Member
		Collieburn Member	Premier Member	Premier Member
Lower		Ewington Member	Ewington Member	Ewington Member

PALAEOCURRENT OBSERVATIONS

GENERAL

During the 1:250 000 scale mapping of the Collie sheet (SI/50-6, International Series), foreset dip directions were measured in cross-bedded sandstone units of the Collie Coal Measures to determine the direction of sediment transport.

The Collie Coal Measures are everywhere obscured by later superficial deposits, and all underground workings have been restricted to the coal seams themselves. Observations are, therefore, limited to accessible parts of open-cut mine sites and to a collapsed area above the old Cardiff Colliery. All available sites were studied and these are shown in Figure 19.

Observations were taken on tabular cross-bedded units that make up approximately fifty per cent of the exposed sandstone sequences. These sandstones are poorly lithified, are medium to coarse-grained, and have a high clay content. The quartz grains are angular and much of the clay appears to be derived from decomposed feldspar. Some grit and pebble horizons occur and a few large pebbles of well-rounded quartz are scattered throughout the sandstones. A few clay galls are also present.

The cross-bedded units average about 30 cm in thickness and generally show some compositional variation between adjacent foreset laminae. Following the terminology of Allen (1963), the units are either solitary or grouped in cosets, and are of large scale. The bottom surfaces are mostly planar and either erosional or non-erosional. Alpha, beta and pi-cross stratification have been observed and, although these cannot be used to precisely define the environment of deposition, the variation in style indicates

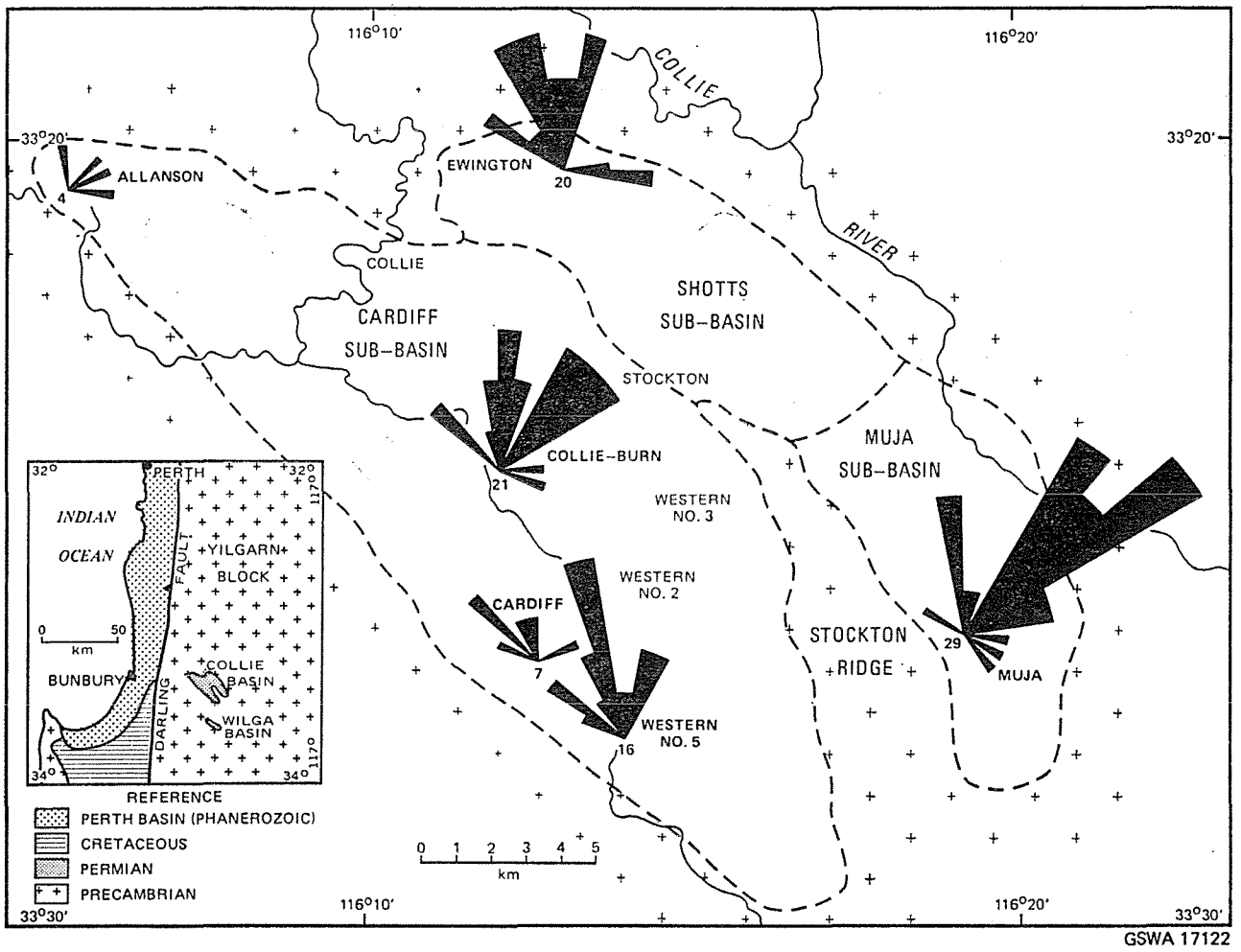

Figure 19 Locality diagram and paleocurrent data for the Collie Basin - readings grouped in 10° intervals, length of segment in rosette proportional to number of readings.

that conditions of sedimentation were changing rapidly. Lowry (1976) has postulated that the sandstones were fluviatile, with deposition as transverse or longitudinal bars in a braided river system.

METHOD

Measurements were made on cross-bedded sandstone units that were continuous for at least 10 m in length; obvious lensoid or trough units were avoided. The friable nature of the sandstones and the irregular pit faces enabled readings to be made directly on bedding surfaces. Measurements were made on separate units where possible, and not closer than 5 m apart when taken on the same horizon. The strike and dip of coal seams closest to the cross-beds were also recorded and used to apply a stereographic correction for tilt, assuming that the coal was horizontal at the time of deposition.

The Lower Permian succession was investigated above the Moira Seam of the lowermost Ewington Member (Table 7) at the Ewington and Allanson (Black Diamond) open cuts. Strata above the Wyvern Seam of the Upper Permian Collieburn Member were measured at the Collie-Burn open cut. Sandstones within the topmost Cardiff Member were measured at Cardiff Colliery and Western Collieries No. 5 (above the Cardiff Seam), and the equivalent Muja Member in the Muja sub-Basin was studied above the Hebe, Galatea, Eos, Ceres and Bellona Seams at the Muja open cut.

The foreset dip measurements thus cover all the main coal-bearing sequences of the Collie Coal Measures and have a span in geological time from Early to Late Permian (Table 7). The sample sites give a reasonable spread across the basin, although more would be desirable.

RESULTS

Foreset dip azimuths from the six available sites are plotted in Figure 19 as rosettes, using a 10° grouping. The number of observations at each site is also recorded.

The prevailing current direction at the Ewington and Western Collieries No. 5 sites was from the south-southeast, whereas at Collieburn and Muja it was from the southwest. Only a small number of readings were obtained at Allanson (4) and Cardiff (7), but these are in harmony with the results from the other four sites, indicating a general current flow from the south (the paucity of data was due to the lack of suitable strata). All 97 readings from across the basin are plotted stereographically in Figure 20. This plot illustrates the strong northerly transport of sediment, with a mean current direction of 015° (based on the arithmetic mean of the foreset dip azimuths). The only observed exceptions to this overall trend were trough units of limited extent, indicating some lateral transport. These may perhaps be equated with larger scale tabular units, represented by a small cluster of points in Figure 20, that indicate currents from the west. There are also a few extremely crudely defined cross-beds above the Flora Seam at the Muja open cut, which seem to indicate transport from the north.

SIGNIFICANCE OF OBSERVATIONS

Since the early days of investigation, two main theories have been advanced to account for the somewhat anomalous position of the Collie Basin; that it originated as a topographic depression in the Precambrian Yilgarn Block (Maitland, 1899) or that it was the result of later downfaulting (Jack, 1905). Lord (1952) has detailed the early history of this debate and favours the topographic depression model, with possible accentuation of the basin by Early Permian glacial scouring. More recently, Lowry (1976) has supported the downfaulting hypothesis. Although the palaeocurrent data cannot be used to prove or disprove either theory of origin, they do impose certain constraints on future interpretations.

In discussing the topographic depression hypothesis, it has generally been assumed that the present asymmetric profile of the basin existed during deposition of the Collie

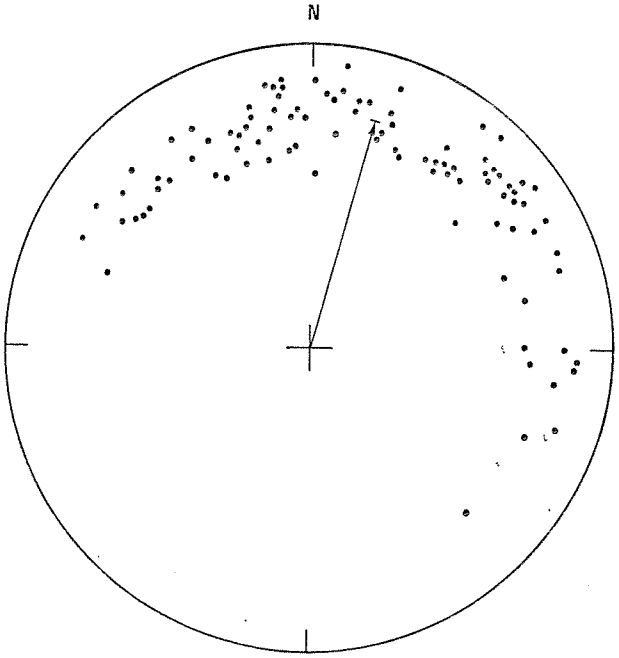

Figure 20 GSWA 17123

Stereographic projection of 97 dip azimuths from the Collie Coal Measures. The arrow represents the arithmetic mean azimuth (015°) and amount of dip (22N°).

Coal Measures and that their low dip to the south was in part primary, with the implication of sediment transport from the north (see Balme, *in* Lord, 1952). This was supported by the original gravity survey of the area (Chamberlain, 1947), which showed that the Permian/Archaean contact has a marked southerly dip over most of the basin. However, the palaeocurrent observations, bearing in mind the limitations imposed by the small number of sample sites, indicate derivation mainly from the south. Of particular importance are the observations at Ewington and Allanson. These sites are close to the northern margin of the basin, but still indicate currents from the south. There was thus a 'flow through' of material and the present Collie Basin could not have been an enclosed depression, at least during the Early Permian when the Ewington Member was deposited (Lowry, 1976). A fluviatile origin for the cross-bedded sandstones (Lowry, 1976) would support this conclusion, although swamp to lacustrine conditions must have existed over extensive areas and for long periods of time to account for the coal seams.

One argument used against the downfaulting hypothesis was the lack of evidence for northwesterly faults affecting the Archaean basement in this area (Lord, 1952). However, recent mapping by this survey has proved the existence of such faults at Quindanning, north of Collie, and bounding the volcanogenic Saddleback Group at Boddington (Wilde, 1976), though the age of faulting is unknown and may well be pre-Permian. But, although the possibility of such faults at Collie cannot be lightly dismissed, there are no photolineaments suggestive of faulting, either along the southwestern boundary or marginal to the Stockton Ridge. It is clear from the palaeocurrent data (Fig. 19) that northwesterly faults did not control the direction of Permian sedimentation at Collie. They do not support Lowry's (1976) hypothesis that graben faults were active during the deposition of the Upper Permian succession for, although measurements within the Cardiff Member at Western Collieries No. 5 do indicate flow subparallel to the present basin axis, those within the Collieburn Member at Collieburn open cut and in the uppermost Muja Member at the Muja open cut are almost perpendicular to the basin trend.

Post-depositional compaction has been invoked for the simple asymmetric synclinal arrangement of the coal measures, with axes aligned along and parallel to the deepest parts of the sub-basins and longest limbs dipping gently to the south. There would certainly have been some differential compaction of the mudstone sequence at the top of the Stockton Formation, coupled with a marked reduction in volume during transformation of peat horizons to coal. Furthermore, the available information on the glacigene Stockton Formation suggests that it varies greatly in thickness over short distances, implying gross irregularities in the basement surface. Therefore, the floor on which the Collie Coal Measures were laid down need not have had the same configuration as the glacially modified basement surface (Brown and others, 1968, indicate ice movement from the southeast). However, these factors are insufficient to account for the predominant southerly dip of the Collie Coal Measures (and the Permian/Archaean contact) over most of the Collie Basin, that is, contrary to the current directions. Some post-depositional tilting must have occurred. The amount and nature of the tilt is uncertain, owing to the general lack of information on the floor and margins of the Collie Basin.

CONCLUSIONS

Sediment transport in the Collie Coal Measures was almost exclusively from the south. This direction, so far as can be ascertained, is consistent throughout the Collie Basin and suggests that the present area does not represent an enclosed palaeo-topographic depression. If a topographic basin existed in Permian times, then its centre lay to the north and has subsequently been removed by erosion. The palaeocurrent trends are also subparallel to the inferred direction of Permian ice movement in the area.

Since the direction of sediment transport in the coal measures is opposite to the present overall southerly dip of the strata and the Permian/Archaean contact, some post-depositional tilting has occurred.

It is suggested that both glacial erosion and tectonics played a part in the formation of the Collie Basin. Glacial topography probably controlled the distribution of the Stockton Formation, whereas the present disposition of the Collie Coal Measures was aided by compactional deformation and post-depositional tectonics.

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HORNBLENDE-BEARING GRANITOIDS OF QUARTZ-MONZONITE AFFINITY FROM THE SOUTHWEST OF THE YILGARN BLOCK

by I. W. Walker

ABSTRACT

Two distinct types of quartz-deficient, hornblende-bearing, xenolithic granitoids of quartz monzonite affinity crop out in the southwest of the Archaean Yilgarn Block. Textural and chemical characters distinguish the two types: the Gilbralter Quartz Monzonite is a metamorphic tectonite and has a dynamic metamorphic history similar, in part, to the lithologies adjoining it; in the Darkan Quartz Monzonite igneous mineralogy and textures predominate. The Gilbralter Quartz Monzonite contains more K_2O, Sr and Ba, and less MgO, CaO, H_2O^+, Li and Ni than the Darkan type.

The Boyup Brook Lineament separates rocks with prominent tectonite fabrics, including the Gilbralter Quartz Monzonite, from extensive areas of adamellite and the Darkan Quartz Monzonite. A second lineament, the Hester Lineament, occurs west of the Boyup Brook feature. It extends over 70 km in length and separates the Gilbralter Quartz Monzonite to the east from a suite of metamorphic rocks, including gneiss, sediments and ultramafic rocks.

The favoured hypothesis for the origin of these rocks is that they are products of discrete magma types. Unlike syenitic and monzonitic bodies elsewhere in the Yilgarn Block, which intrude regional granitoid batholiths, the two quartz monzonite bodies described were emplaced prior to the main period of regional granitoid intrusion.

INTRODUCTION

Rocks of quartz monzonite affinity crop out over part of the Collie and Pemberton 1:250 000 Sheets (SI 50-6 and SI 50-10, International Series, respectively) (Fig. 21). These rocks contain between 3 per cent and 12 per cent hornblende, have low contents of quartz, and consequently are unlike the common granitoid types that crop out extensively in the southwest of the Archaean Yilgarn Block.

Textural characters can be used to identify two contrasting types: the Gilbralter and Darkan quartz monzonites. The Gilbralter Quartz Monzonite is a medium-grained, inequigranular xenolithic rock. Recrystallization during regional metamorphism has destroyed the igneous textures and imparted a tectonic foliation. The type locality for the Gilbralter Quartz Monzonite is at Gilbralter Rock, 8.5 km east-northeast of Mumballup. The Darkan Quartz Monzonite is a xenolithic rock with an igneous porphyritic fabric. The type locality for this quartz monzonite is at Dunleath, 5 km east-southeast of Darkan.

Elsewhere in the Yilgarn Block there are small, scattered areas of quartz-deficient granitoids. Wilde and Low (1973) described quartz diorite, monzonite and syenite on the Perth 1:250 000 Sheet which are associated with mobilized amphibolitic gneiss of the Archaean Jimperding Metamorphic Belt. Rocks with syenite-monzonite affinity intruded into rocks of adamellite composition have been documented by Gower and Bunting (1972) from the Lake Johnston Sheet, and by Bunting and Williams (1976) from the Sir Samuel Sheet. In contrast to the Lake Johnston and Sir Samuel occurrences of quartz-deficient granitoids, the Darkan and Gilbralter quartz monzonites relate more closely to the gneiss terrains than to the voluminous, post-tectonic granitoids. Although no isotopic dating is available, the field relationships suggest that the quartz monzonites predate the regional granitoid intrusions.

This paper summarizes the petrography, chemistry and regional relationships of the Gilbralter and Darkan quartz monzonites, and discusses the possible origin of the rocks.

MINERALOGY AND TEXTURES

Thin sections were stained for potash feldspar and plagioclase according to the method of Laniz and others (1964), and assemblages were point counted. Counts in most cases were made of two separate slides from each of three planes; one parallel, the others at right angles, to the foliation. Included with the modal compositions, shown in Table 8, is a specimen of adamellite (47113) adjoining the Darkan Quartz Monzonite.

Both the Gilbralter and Darkan quartz monzonites are hornblende-bearing, but the variable amounts of quartz, microcline and plagioclase prevent a rigid mineralogical classification. The majority fall within the quartz monzonite field of Streckeisen (1967), others correspond with adamellite, granodiorite, or syenite (Fig. 22).

GILBRALTER QUARTZ MONZONITE

Modal compositions are shown in Table 8. Porphyroblasts of microcline, enveloped by a fine to medium-grained xenoblastic groundmass, are commonly perthitic, and contain inclusions of plagioclase. Hornblende is abundant as pale-coloured, aligned grains with poikiloblastic cores that contain inclusions of quartz and plagioclase. Hornblende also forms grains which are pleochroic from pale green-brown (X) to pale green (Y) to deep blue-green (Z). South of Mumballup, clinopyroxene rimmed by hornblende is the chief mafic mineral. Deformation accompanying regional metamorphism generated the tectonite fabrics in this quartz monzonite.

Small (generally less than 25 cm) mesocratic to melanocratic attenuated xenoliths within the Gilbralter Quartz Monzonite are composed of xenoblastic hornblende and plagioclase. A gneissic fabric is evident within some of these amphibolite xenoliths. In individual exposures the surface area covered by the xenoliths is generally less than 5 per cent of the outcrop area.

DARKAN QUARTZ MONZONITE

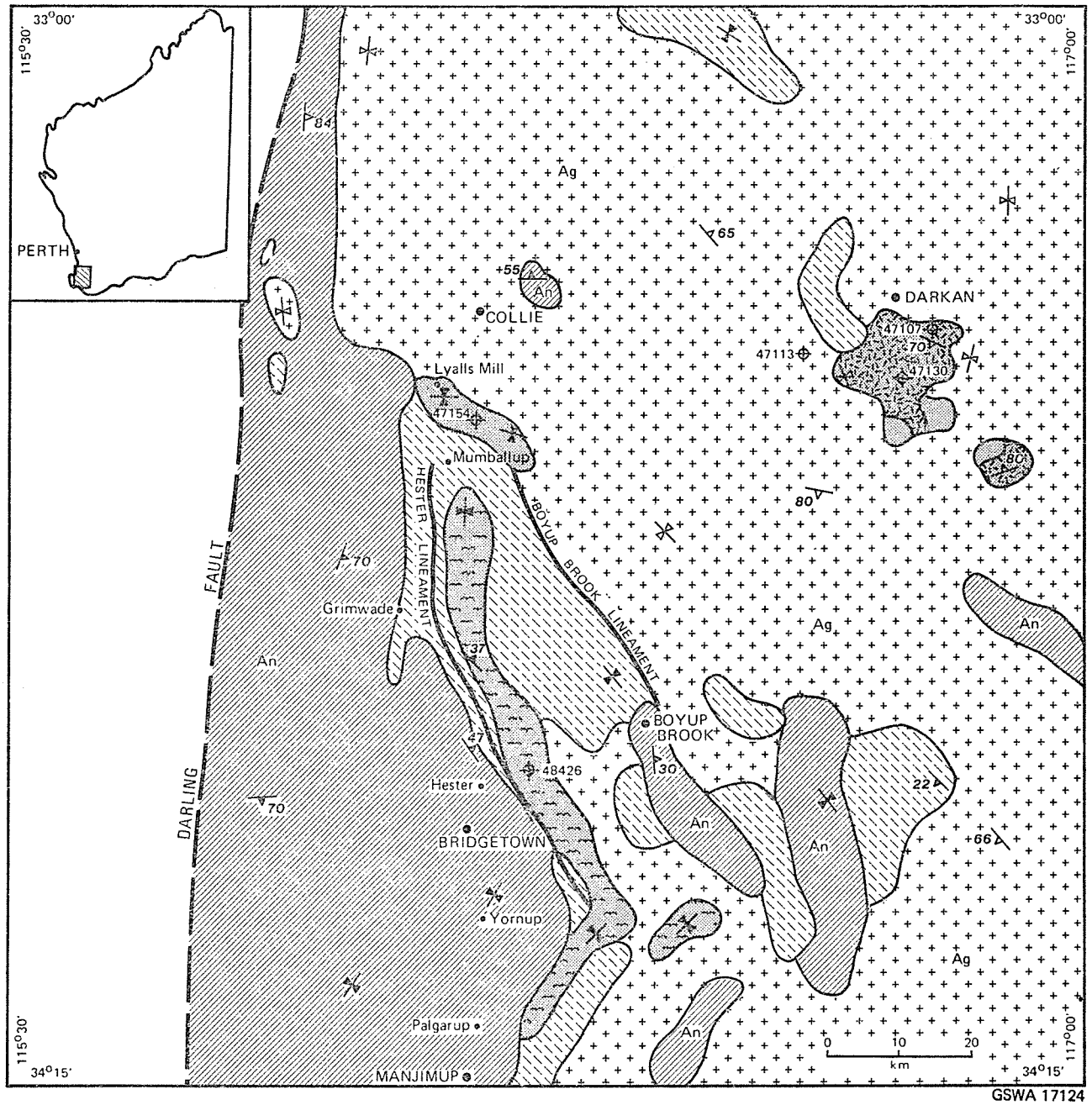
Megacrysts of microcline occur within a hypidiomorphic to allotriomorphic granular mosaic of saussuritized plagioclase, microcline, hornblende, and strained quartz. Some of the microcline is microperthitic, and is replaced by myrmekite along some grain boundaries. Plagioclase is zoned, and occurs as subhedral to anhedral inclusions in

TABLE 8. MODAL COMPOSITIONS OF HORNBLENDE-BEARING GRANITOID ROCKS

Specimen Number	Gilbralter Quartz Monzonite				Darkan Quartz Monzonite					Adamellite
	47154	48426	48444	50977	47107	47130	47136	47159	48475	47113
Plagioclase	37·8	30·3	41·3	41·4	45·9	49·4	43·0	41·5	52·6	33·2
Microcline	46·6	56·6	34·9	35·9	24·4	29·0	24·0	37·9	18·0	24·5
Quartz	11·0	2·0	15·8	13·2	13·0	15·0	17·3	10·6	20·4	31·0
Hornblende	3·0	3·6	5·9	5·5	8·9	1·4	11·6	7·1	3·2	....
Chlorite	....	....	....	....	4·8	1·8	....	....	1·0	....
Biotite	....	....	....	....	....	....	....	....	....	9·3
Accessories (Epidote + sphene)	1·6	7·6	2·0	4·0	3·0	3·5	4·0	2·9	4·9	2·0
Total	100·0	99·9	99·9	100·0	100·0	100·0	99·9	100·0	100·1	100·0
Number of points counted—from three planes at right angles to each other	8 000	10 000	5 600	6 900	10 260	12 500	6 000	10 700	12 400	1 860
Area counted (mm^2 approx.)	2 000	2 500	1 250	1 750	2 500	3 100	1 500	2 500	3 100	500

microcline and hornblende. The microcline and quartz of the groundmass are interstitial to plagioclase. Hornblende predominantly occurs as subhedral grains, pleochroic from pale green-brown (X) to fawn-brown (Y) to olive-green (Z). Less commonly, hornblende pseudomorphs a fibrous mineral, with pale green augite occurring as cores in some of these fibrous grains. In places, chlorite pseudomorphs biotite. Accessory minerals include epidote, apatite, and sphene. An igneous fabric in the Darkan Quartz Monzonite is formed by the planar orientation of tabular megacrysts.

The texture of the xenoliths varies from a xenoblastic aggregate of hornblende and plagioclase, with no evidence of a pre-existing fabric, to those with a gneissic or schistose foliation. In the cores of xenoliths hornblende is homogeneous and twinned, but replaces a fibrous mineral towards the rims of the xenoliths.



REFERENCE

- Phanerozoic sediments
- Adamellite
- Darkan Quartz Monzonite (porphyritic variant)
- (lineated and banded variant)
- Gilbralter Quartz Monzonite
- Migmatite – banded and strongly contorted
- Gneissic rocks (both ortho–and paragneiss), metamorphosed sediments, and intrusive ultramafic rocks
- Metamorphic foliation – inclined
- – dip indeterminate
- Mineral foliation in plutonic rocks – inclined
- – dip indeterminate
- Chemical sample site and specimen number

Figure 21 Regional setting of the hornblende-bearing granitoids.

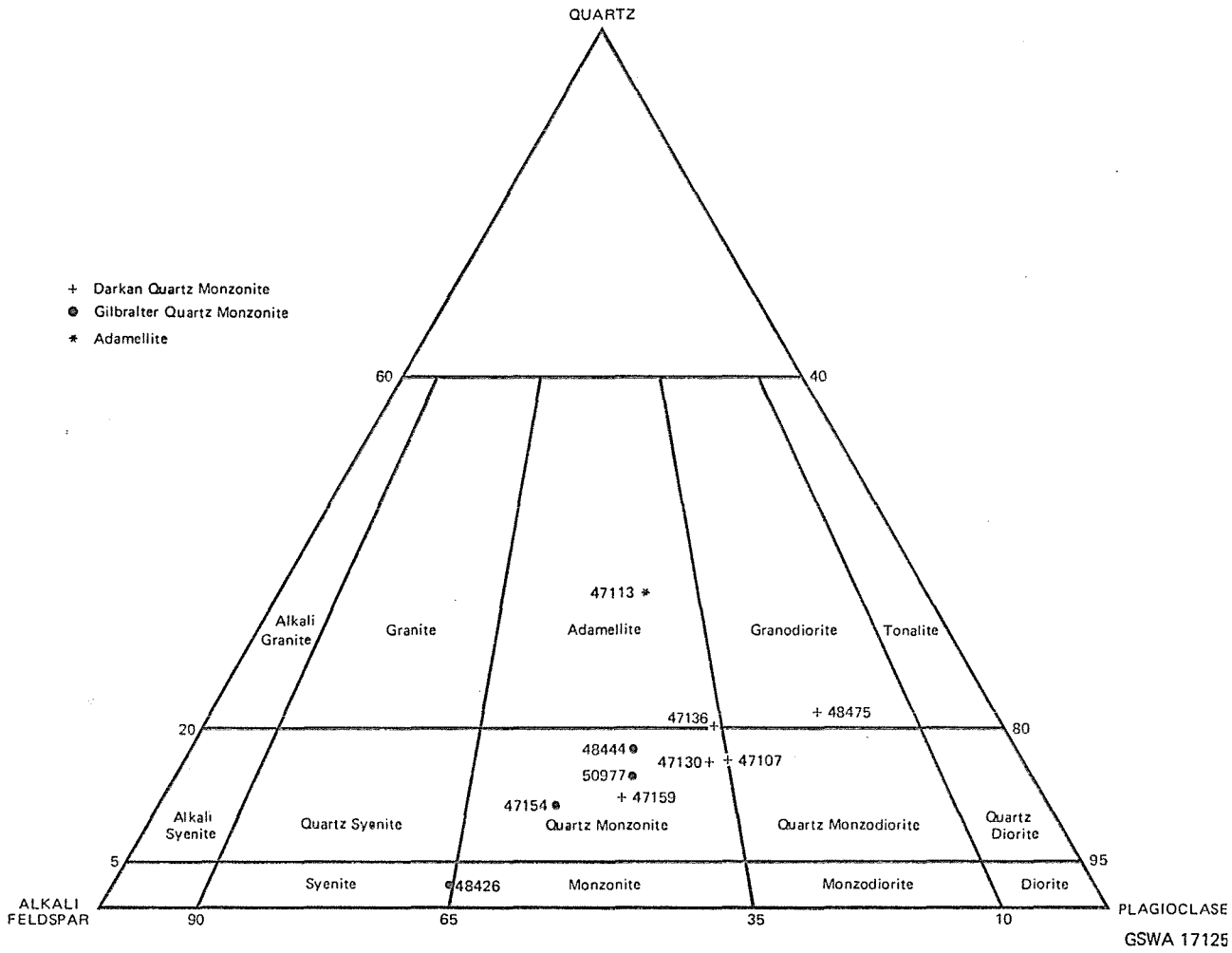


Figure 22 Mineralogical classification of the hornblende-bearing granitoids on the quartz-potash feldspar-plagioclase triangle according to their actual mineral composition (after Streckeisen, 1967).

GEOCHEMISTRY

Whole rock and trace element analyses of two specimens of each quartz monzonite are presented in Table 9. Analyses of granitoids adjoining the two quartz monzonite types are not available. The only analysis available of a granitoid from the area discussed in this paper is of adamellite from Bannister on the Pinjarra Sheet, and this is included for comparison. Also included is an analysis of syenite from Fitzgerald Peaks (Lewis and Gower, 1976).

Discernible differences in both major and trace elements exist between the Gilbralter and Darkan quartz monzonites. The Gilbralter Quartz Monzonite has more K_2O than the Darkan Quartz Monzonite, but is lower in MgO, CaO and H_2O^+. The Sr and Ba values are greater in the Gilbralter Quartz Monzonite, but Li and Ni are more abundant in the Darkan Quartz Monzonite.

The Darkan Quartz Monzonite when compared with the Bannister adamellite is higher in Fe_2O_3, MgO, CaO and H_2O^+, Al_2O_3, Na_2O and P_2O_5, but lower in SiO_2, K_2O and FeO contents.

Figure 23 is a normative Q-Or-Ab plot calculated from analyses presented, and illustrates the contrast between the Gilbralter and Darkan types. The liquidus curves for the system at water vapour pressures of 50 and 500 MPa have been added to the diagram (after Mehnert, 1968). At low pressure the field of the Bannister adamellite plots close to the cotectic trough (m). The spread in the projection of the norms of both types of quartz monzonite at positions away from the cotectic trough (m) for the adamellite indicate that it is unlikely that either the Gilbralter or Darkan quartz monzonites are fractionation products of a melt crystallizing the adamellite.

REGIONAL RELATIONSHIPS

The two types of hornblende-bearing, quartz-poor granitoids help to emphasize major partitions between regions of different rock types and tectonic styles in the southwest of the Yilgarn Block.

GILBRALTER QUARTZ MONZONITE

The Gilbralter Quartz Monzonite extends discontinuously over a strike-length of 90 km, mainly in contact with gneiss and migmatized gneiss. An isolated occurrence 30 km east of Yornup is totally enveloped by massive adamellite. The irregular nature of the contact and the absence of a tectonic fabric in the adamellite are taken to indicate that the adamellite intrudes the quartz monzonite. East of Bridgetown, the contact of the migmatite with the Gilbralter Quartz Monzonite corresponds with a curvilinear aeromagnetic low (from unpublished data). This feature is named the Hester Lineament by Blockley (in press). Another linear aeromagnetic anomaly, here termed the Boyup Brook Lineament, extends parallel to the Hester Lineament, about 20 km to the east of it. This separates migmatized gneiss terrain from the extensive adamellite to the east. It also serves as the locus of emplacement of at least one and possibly two of the outlying bodies of Gilbralter Quartz Monzonite.

The Gilbralter Quartz Monzonite and the adjoining gneiss both participated in a structural event that generated the tectonite fabrics. A later event of regional, open-style refolding is evident southeast of Bridgetown where the trend of the gneissic foliation swings from northeast to northwest. Superimposed folds and transposition structures are found in the banded iron-formation and gneissic rocks of the succession west of the Hester Lineament but not in the Gilbralter Quartz Monzonite. This suggests that the quartz monzonite has not undergone all episodes of deformation experienced by the rocks of the Bridgetown succession, and further suggests that the quartz monzonite was emplaced late in the evolution of the gneiss terrain.

DARKAN QUARTZ MONZONITE

The Darkan Quartz Monzonite crops out in an extensive area of granitoids which lack tectonite fabrics. These granitoids are regionally homogeneous, except for a belt of

TABLE 9. COMPLETE CHEMICAL ANALYSES OF HORNBLENDE-BEARING GRANITOIDS

Specimen number	Gilbralter Quartz Monzonite		Darkan Quartz Monzonite		Adamellite (Bannister)	Syenite (Fitzgerald Peaks area)
	47154	48426	47107	47130		29821
SiO_2	66·1	63·3	62·7	65·3	72·0	61·7
Al_2O_3	16·5	17·3	17·4	17·6	12·5	16·2
Fe_2O_3	1·4	1·8	1·7	1·5	0·6	1·1
FeO	1·1	0·9	2·3	1·0	3·1	1·9
MgO	0·3	0·5	1·8	0·9	0·3	0·6
CaO	2·1	2·2	4·3	3·8	1·4	2·6
Na_2O	4·0	4·2	4·2	4·4	3·5	5·7
K_2O	6·6	8·4	3·6	3·6	5·9	5·6
H_2O^+	0·5	0·5	1·3	1·1	0·3	0·6
H_2O^-	0·1	0·1	0·2	0·1	0·2	0·1
CO_2	0·1	....	....	0·1	0·0	....
TiO_2	0·3	0·5	0·4	0·3	0·4	0·6
P_2O_5	0·2	0·2	0·3	0·2	0·0	0·3
MnO	0·1	0·1	0·1	0·1	0·0	0·1
Total	99·4	100·0	100·3	100·0	100·2	97·1
Trace Elements (ppm)						
Li	5	1	15	25	....	....
Rb	110	140	130	135	....	....
Sr	1 300	1 060	600	690	....	....
Ba	3 550	5 100	1 600	2 200	....	....
Zr	350	25	240	180	....	....
Sn	<20	<20	<20	<20	....	....
Ni	10	10	130	60	....	....
Cu	10	40	40	30	....	....
Zn	50	80	100	60	....	....
U	< 1	2	4	2	....	....
C.I.P.W. Norms						
Q	13·9	5·4	13·5	20·3	25·1	2·5
C	....	....	....	1·2	....	....
Or	39·0	49·6	21·3	21·3	34·7	32·9
Ab	32·8	31·9	34·2	32·8	29·4	48·6
An	8·2	5·4	18·8	16·8	1·0	2·1
Di	0·6	2·5	0·5	....	....	6·3
Wo	0·3	1·3	0·2	....	2·4	3·2
En	0·2	1·2	0·2	....	0·3	1·4
Fs	0·1	....	0·1	....	2·3	1·7
Hy	1·0	....	6·5	2·4	....	....
En	0·6	....	4·3	2·1	0·3	....
Fs	0·4	....	2·2	0·3	2·3	....
Mt	2·0	1·9	2·5	2·2	0·9	1·7
Il	0·6	0·9	0·8	0·6	0·7	1·1
Ap	0·4	0·5	0·8	0·8	0·1	0·7
Cc	0·2	0·1	....	0·2	....	....

discontinuous rafts of migmatite and gneiss trending northwest through Darkan. The two bodies of Darkan Quartz Monzonite are closely associated with this discontinuous belt of migmatized gneiss.

The larger body of Darkan Quartz Monzonite is bounded to the northwest by migmatite, but all other contacts are with adamellite. The adamellite is transgressive, and is inferred to intrude the quartz monzonite.

In places, between the Darkan Quartz Monzonite and surrounding adamellite, are two unusual rock types. One is a fine to medium-grained, mesocratic lineated monzodiorite. The second is a conspicuously banded, medium-grained rock consisting of alternating quartzofeldspathic and hornblende-rich bands. As with the porphyritic Darkan Quartz Monzonite, xenoliths of amphibolite and gneiss are scattered throughout these two variants.

DISCUSSION

Field observations, and some petrographic and chemical data, allow tentative but perhaps important comments to be made on the origin and significance of these quartz monzonites.

The Darkan Quartz Monzonite is the oldest granitoid recognized east of the Boyup Brook Lineament. Two alternative hypotheses for its origin are considered. Firstly, the presence of amphibolite xenoliths suggests the rock may result from assimilation of amphibolitic gneiss by adamellite. However, the assimilated material would require an unusual chemistry to explain the high Al_2O_3 content of the Darkan Quartz Monzonite. A second hypothesis is that the Darkan Quartz Monzonite is the product of a discrete magma type. De Laeter and Lewis (1978) proposed a magmatic origin for the rocks of syenitic affinity from Fitzgerald Peaks on the Lake Johnston Sheet. The Darkan Quartz Monzonite could be derived from a melt of quartz monzonite affinity, modified in part by assimilation, which invaded a migmatite and gneiss terrain. Significantly, the difference between this melt crystallizing the Darkan Quartz Monzonite and those crystallizing the various quartz-poor granitoids elsewhere in the Yilgarn Block, is that this melt was emplaced prior to the invasion of the main adamellite mass and not following it.

The Gilbralter Quartz Monzonite is chemically distinct from the Darkan Quartz Monzonite, and is not simply the deformed equivalent of the Darkan Quartz Monzonite. The Gilbralter Quartz Monzonite was emplaced into a metamorphic succession as narrow, discontinuous bodies. Metamorphism and deformation continued to affect the region after emplacement. Assimilation to produce a melt corresponding to the composition of the Gilbralter Quartz Monzonite, as with the Darkan type, is doubtful. To obtain the high Al_2O_3 and K_2O contents of the Gilbralter Quartz Monzonite would require the host rock, now represented by the gneissic and amphibolite xenoliths, to have unusually high Al_2O_3 and K_2O contents, and remnants of such rocks have not been identified. A more favoured origin is that the Gilbralter Quartz Monzonite is the product of a melt of quartz monzonite affinity, somewhat potassium and aluminium rich, and perhaps modified to some extent by assimilation.

Whatever their origin, both the Gilbralter and the Darkan quartz monzonites are probably the earliest record in the southwest, and possibly the whole Archaean Yilgarn Block, of a melt crystallizing rocks of quartz monzonite to syenite affinity.

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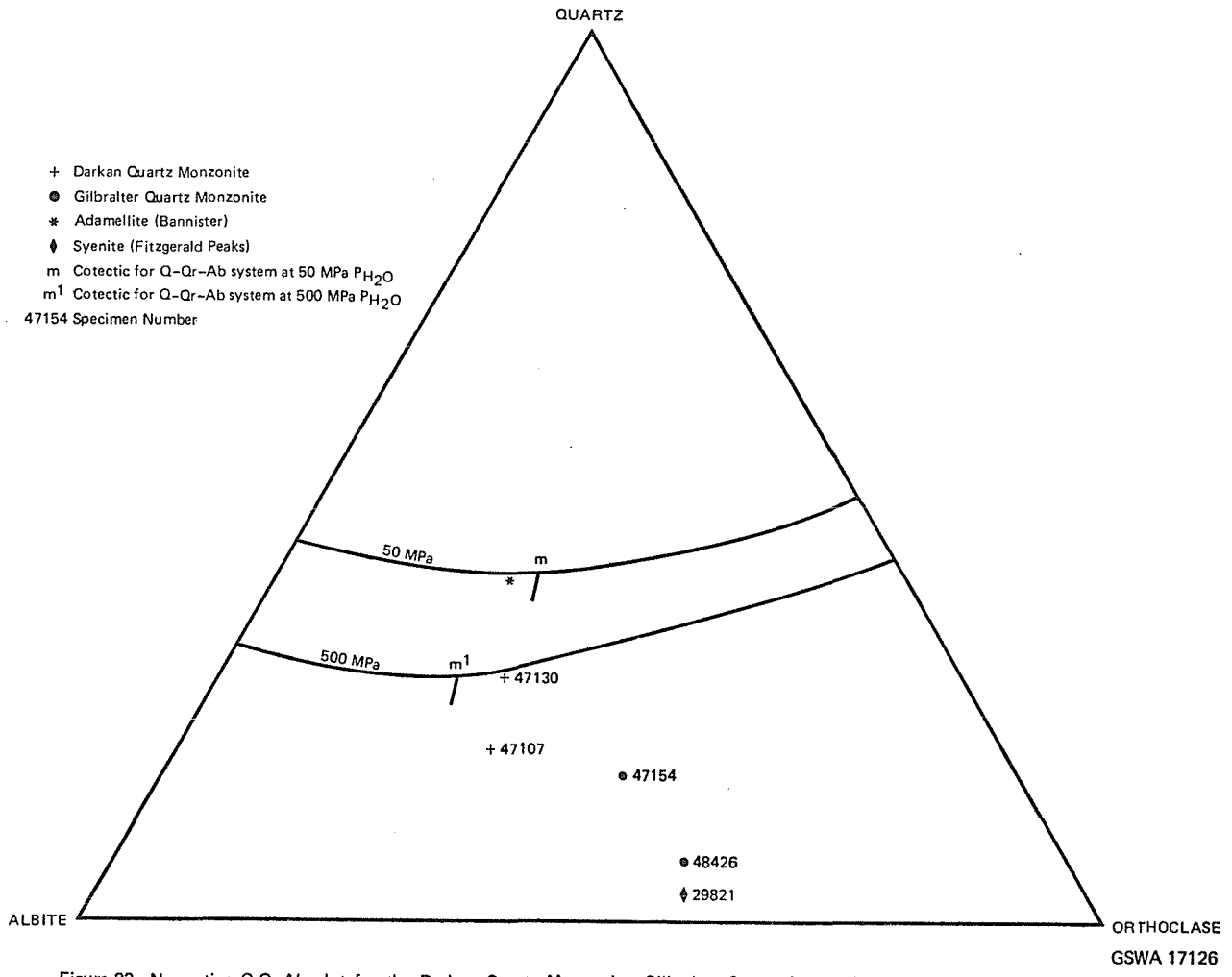

Figure 23 Normative Q-Or-Ab plot for the Darkan Quartz Monzonite, Gilbralter Quartz Monzonite, adamellite (Bannister) and syenite (Fitzgerald Peaks). Full lines are liquidus curves for the ternary system at 50 and 500 MPa (0.5 and 5.0 Kb) water vapour pressure (after Mehnert, 1968)

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AGE OF A TIN-BEARING PEGMATITE AT GREENBUSHES

by J. R. de Laeter * and J. G. Blockley

ABSTRACT

Microcline and muscovite in a cassiterite-bearing pegmatite from the South Cornwall tin mine at Greenbushes give model Rb-Sr ages of about 2 650 m.y. This is considered to be the age of intrusion and agrees well with an earlier date on the closest large body of granitic rocks.

INTRODUCTION

Mineralized pegmatites occurring in a belt 6 km long and up to 600 m wide have been the ultimate source of 18 250 tonnes of cassiterite and 1 360 tonnes of tantocolumbite mined from the Greenbushes Mineral Field in the southwestern Yilgarn Block.

The geology of the Greenbushes Mineral Field is dealt with by Hobson and Matheson (1949). A feature of the deposits is that no granites crop out in their immediate vicinity. The nearest granitic rocks are exposed about 8 km east of Greenbushes, where they are apparently in faulted contact with the metamorphic rocks of the Balingup Metamorphic Belt (Blockley, in press). A sample of this granite, collected from Hester, 12 km southeast of Greenbushes, was dated by Wilson and others (1960) at about 2 700 m.y. using a decay constant for ^{87}Rb of $1.386 \times 10^{-11} yr^{-1}$.

The Greenbushes pegmatites cut mainly metasedimentary rocks of the Balingup Metamorphic Belt on which the only previously available geochronology (all on pegmatites) indicates Proterozoic ages. Wilson and others (1960) found muscovite in a pegmatite at Mullalyup, 14 km northwest of Greenbushes, to be 1 100 m.y. old. The pegmatite was stated to be "clearly related to the granitization of the pelitic sediments" of the area. Riley (1961), using a decay constant of $1.386 \times 10^{-11} yr^{-1}$, obtained concordant muscovite and biotite ages of about 675 m.y. from a 4-cm wide pegmatite vein cutting coarse granitic gneiss

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at Wellington Dam, 55 km northwest of Greenbushes. He considered the age to be that of intrusion of the pegmatite. Compston and Arriens (1968), referring to the work done by Riley but not presented by him, cite an age of about 675 m.y. for feldspar, muscovite and pegmatized gneiss near Donnybrook, 35 km northwest of Greenbushes. Biotite from this material had an age of 500 m.y. Riley (1961) considered that "young" pegmatite ages found near the Darling Scarp represented a period of metamorphism occurring some 2 000 m.y. after the host rocks had formed.

Recalculated using the presently accepted decay constant of $1.42 \times 10^{-11} yr^{-1}$, the previously published ages become 2 650 m.y. for the Hester granite, 1 070 m.y. for the Mullalyup pegmatite, and about 660 m.y. for the Wellington Dam and Donnybrook pegmatites.

From the point of view of future prospecting for tin in the southwestern part of the State, it is important to know whether the mineralized pegmatites are related to the main period of granite emplacement (2 550 to 2 700 m.y.) in the Yilgarn Block, or to possible younger granite intruded during a later metamorphic event affecting the margins of the block.

MATERIAL USED

The mineralized pegmatites at Greenbushes consist mainly of quartz, albite, muscovite, tourmaline, rarer microcline and various rare-metal minerals, some of which are of economic importance. The greater part of the dykes are kaolinized to depths of 30 to 50 m and, despite the large open cuts, fresh material is only available as bore cores and specimens from earlier deep mining operations. Metamorphism sometime after emplacement produced a strong cataclastic foliation and a mineral banding in the pegmatite, although some parts of the dykes escaped these effects. Material suitable for obtaining an estimate of intrusive age is therefore restricted to a few samples of unmetamorphosed pegmatite obtained from the deeper openings in the field. The sample chosen, 40292 (4660 on the old G.S.W.A. numbering system), is of massive cassiterite-bearing pegmatite obtained from the South Cornwall mine in about 1903. It consists of quartz, greenish muscovite, albite, spessartine, abundant cassiterite and two large crystals of microcline which poikilitically enclose grains of quartz and cassiterite.

Samples of microcline and muscovite concentrates were prepared by knapping or scraping appropriate parts of the specimen and hand picking the required mineral grains. The microcline concentrate contained a little quartz and cassiterite, and the muscovite sample contained small quantities of cassiterite, quartz and fluorite.

EXPERIMENTAL PROCEDURE

The experimental procedure for Rb-Sr analyses used in this laboratory is essentially the same as that described by Lewis and others (1975). The value of $^{87}Sr/^{86}Sr$ for the NBS 987 standard measured during this project is 0.7102 ± 0.0001, normalized to a $^{88}Sr/^{86}Sr$ value of 8.3752. The value of $1.42 \times 10^{-11} yr^{-1}$ was used for the decay constant of ^{87}Rb (Steiger and Jäger, 1977). It should be noted that this is the first time this value for the decay constant has been used by this laboratory, as in earlier publications a value of $1.39 \times 10^{-11} yr^{-1}$ has been adopted.

The measured Rb/Sr and $^{87}Sr/^{86}Sr$ ratios, as well as the calculated $^{87}Rb/^{86}Sr$ ratios are given in Table 8. 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 to the ratios which would be derived from the separate Rb and Sr values listed.

TABLE 8. ANALYTICAL DATA FROM GREENBUSHES PEGMATITE

Sample	Rb (ppm)	Sr (ppm)	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
40292 .... (Microcline)	4 500	62	71·9 ± 1	952 ± 15	37·343 ± 0·037
40292 .... (Muscovite)	2 700	34	79·4 ± 1	1630 ± 25	63·144 ± 0·059

RESULTS

Model ages for the feldspar and mica samples can be determined by assuming an appropriate initial ratio. Since the measured $^{87}Sr/^{86}Sr$ ratios for both samples are large, the actual assumed initial ratio is of little consequence. Model ages of 2 659 m.y. and 2 647 m.y. are obtained from the feldspar and mica respectively (using an R_i = 0.700). If the data are treated as a two-point isochron, the resulting mineral age is 2 630 m.y. but the initial ratio of 1.116 is improbably high.

Considering the experimental error involved and the lack of a reliable isochron, the age of the Greenbushes pegmatites is best stated as "about 2 650 m.y.".

DISCUSSION

The results indicate that the metasedimentary rocks of the Balingup Metamorphic Belt are of Archaean age, a conclusion generally accepted (for example, State Geological Map, 1973) but not proven by previous geochronology. They also give the youngest possible age for the Greenbushes pegmatites, representing either the date of intrusion, or the time of a later metamorphism. The close correspondence between the microcline and muscovite ages suggests that the date found is probably that of intrusion rather than metamorphism.

The date of 2 650 m.y. agrees well, when adjustment for the new decay constant is made, with that of the granite from Hester dated by Wilson and others (1960). Blockley (1973) found that the petrography and chemistry of the granitic rocks contiguous with the Hester outcrops showed no characteristics typical of tin granites, and concluded that they were not related to the Greenbushes tin deposits. However, the new information presented here strongly suggests that such a relationship exists. The most plausible explanation is that Greenbushes is situated over a stock or cusp of 2 650 m.y. granite intruded at a much higher structural level than any of the material accessible for sampling to the east of the Balingup Metamorphic Belt.

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GEOCHRONOLOGY AND EVOLUTION OF THE EASTERN GASCOYNE PROVINCE AND THE ADJACENT YILGARN BLOCK

by S. J. Williams, M. Elias and J. R. de Laeter*

ABSTRACT

Rubidium strontium age determinations are presented for whole rocks, biotite, and muscovite, from the eastern part of the Gascoyne Province and the adjacent parts of the Yilgarn Block. Archaean ages are confirmed for granitoids that intrude gneissic terrain south of the Murchison Tectonic Lineament and Bullbadger Shear Zone. The Rocky Bore granite (2 608 m.y.), the Dog Rocks granodiorite (2 573 m.y.), and the Roadside Bore granite (2 461 m.y.) form part of the northern Yilgarn Block, which was stable during Proterozoic orogenesis. A period of dynamic metamorphism and deformation within the Gascoyne Province is indicated by a model muscovite age of 1 700 m.y. for quartz-muscovite schist near Mica Bore. This was followed by a period of granitoid intrusion as indicated by the Red Rock adamellite (1 604 m.y.) and the Forty Mile Well adamellite (1 557 m.y.). Whole rock ages of around 750 m.y. are indicated from reworked Archaean migmatite (suggested initial age of around 2 800 m.y.) from within the Errabiddy Shear Zone. The Red Rock and Forty Mile Well adamellites also have biotite ages of 750-800 m.y. This was probably an age of uplift, although a short thermal event throughout the Gascoyne Province is also possible.

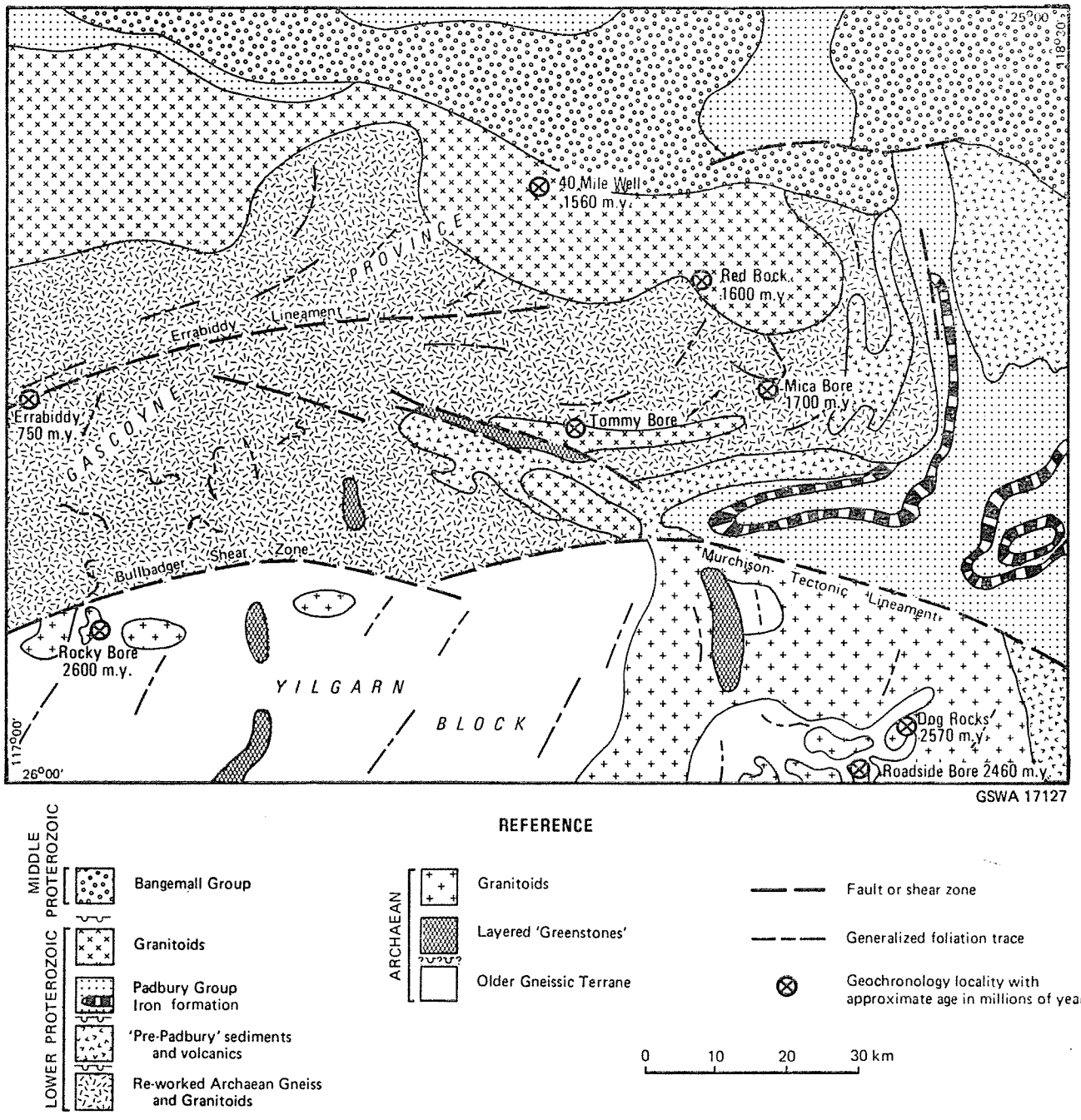

Figure 24 Generalized geology and sample sites, including approximate ages in millions of years.

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INTRODUCTION

The Archaean Yilgarn Block of Western Australia is bounded to the north by the Gascoyne Province, a region of Proterozoic sedimentation, granite intrusion, and polyphase metamorphism. Daniels (1975) gave the first comprehensive account of the province, based on reconnaissance traverses and some regional mapping. Subsequently, regional mapping of the Robinson Range sheet in 1974 and 1975, and more recently of the Mount Phillips and Glenburgh sheets (Fig. 1) has led to an increased understanding of the nature of this complex province. Early in the mapping program however, it became evident that a number of fundamental problems required solution before a unified tectonic framework of the northern marginal area of the Yilgarn Block could be erected. The problems were essentially geochronological, and in 1975, a Rb/Sr geochronological investigation was implemented. This paper reports on the results of the first stage of this program, which was carried out on the Robinson Range sheet. The main objectives were to define the ages of metamorphic and intrusive events across the Yilgarn Block-Gascoyne Province transition, and thereby define the limits of the two provinces in the area studied.

Previous geochronological work in the Gascoyne Province is limited, and its effectiveness is hampered by inadequate knowledge of regional geology. The most recent investigation is by de Laeter (1976), who also reviews earlier isotopic work. No previous work has been carried out on the Yilgarn Block-Gascoyne Province transition. An account of the regional geology of the Robinson Range sheet, on which the following discussion is largely based, is given by Elias and Williams (1977).

REGIONAL TECTONIC SETTING

YILGARN BLOCK

The northern margin of the Yilgarn Block extends across the southern part of the Robinson Range Sheet (Fig. 24). In this part of the block Elias and Williams (1977) identified three distinct rock associations.

The first is gneissic, and consists predominantly of quartz-feldspathic orthogneiss containing elongate enclaves of metamorphosed igneous and sedimentary rocks, which have a complex structural and metamorphic history. The enclaves consist of calc-silicate paragneiss, amphibolite and pyroxene rocks of both sedimentary and igneous origin, banded quartz-magnetite rock, commonly containing iron-rich silicates, quartzite, and ultramafic schist. Regional metamorphic grade ranges from middle amphibolite to granulite facies. The lithological characteristics of the gneiss association suggest an origin as a supracrustal sequence, probably fragmented by granitoid intrusion prior to or during metamorphism.

A second association is of mafic and ultramafic volcanics and intrusives (greenstones) that occur in narrow, linear belts. These rocks are isoclinally folded and metamorphosed in the greenschist to lower amphibolite facies, and they are similar to greenstone belts elsewhere in the Yilgarn Block.

Granitoids form the third association, and intrude the other two. The granitoids are predominantly even-grained biotite adamellite and granite, with seriate and porphyritic phases. Minor granodiorite and alkali granites also occur.

GASCOYNE PROVINCE

The Gascoyne Province is a region of Lower Proterozoic tectonism and metamorphism. The effects range from folding and shearing in the southern part of the province to high-grade metamorphism and migmatization to the north. In the south adjacent to the Yilgarn Block, the rocks affected are Archaean gneiss, granite, and minor greenstone; progressively more Lower Proterozoic supracrustals become involved to the north and east. The Proterozoic supracrustals include possible equivalents of the Wyloo Group (Daniels, 1975). Granitoids were intruded, both during and after the Lower Proterozoic tectonism.

On the Robinson Range sheet, most of the Gascoyne Province rocks are tectonically reworked Archaean basement. Lower Proterozoic structural and metamorphic effects appear north of the Bullbadger Shear Zone and the Murchison Tectonic Lineament (Fig. 24), starting with folding of Archaean foliations, and accompanied by gradually increasing grade of metamorphism towards the north. North of Errabiddy, grade may have reached the point where anatexis and migmatization could occur. Large granitoid bodies intrude the reworked Archaean gneiss, post-dating the main reworking event. These granitoids are lithologically similar to those introding gneiss and greenstone in the northern Yilgarn Block, but age determinations have established a clear difference.

In the eastern part of the Robinson Range sheet, a sequence now consisting of quartz-mica schist, micaceous quartzite, and minor volcanogenic sediments represents Lower Proterozoic supracrustal sediments weakly metamorphosed and folded into the Archaean basement during the main Lower Proterozoic orogenic events. The stratigraphic constitution of this sequence has not yet been formalised and they have been referred to by Elias and Williams (1977) as the 'pre-Padbury Group' supracrustals. A younger sequence of quartzitic sediments and banded iron-formation, the Padbury Group (Barnett, 1975), rests unconformably on reworked Archaean basement and deformed Lower Proterozoic supracrustals. The Padbury Group is also tightly folded, but in a separate event to the main Proterozoic deformation. Its deformation is probably related to the upwelling of the large mass of Proterozoic granitoids to the west and northwest.

EXPERIMENTAL PROCEDURE

The experimental procedure for Rb/Sr analyses used in this laboratory is 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 0.7102 ± 0.0001, normalised to a $^{88}Sr/^{86}Sr$ value of 8.3752. The value of 1.42×10^{-11} yr^{-1} was used for the decay constant of ^{87}Rb (Steiger and Jäger, 1977). It should be noted that this is the first time this value for the decay constant has been used by this laboratory, as in earlier publications a value of 1.39×10^{-11} yr^{-1} had been adopted. In view of this fact, and for the purposes of comparison, previously published ages quoted in this paper have been adjusted to conform to the newer value for the decay constant.

The measured Rb/Sr and $^{87}Sr/^{86}Sr$ ratios, as well as the calculated $^{87}Rb/^{86}Sr$ ratios are given in Table 9. 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.

RESULTS

The data listed in Table 9 have been regressed using the least squares program of McIntyre and others (1966). The age data are listed in Table 10. If the mean square of the weighted deviates (MSWD) is less than or equal to 1.0, the regression fits within the assigned limits for experimental error and the program does not proceed beyond Model 1. Greater scatter indicates departure from the geological assumptions of homogeneous initial $^{87}Sr/^{86}Sr$ and subsequent chemical closure of the samples to Rb and Sr. The program then proceeds to Models 2 and 3 which test alternative methods of distributing the excess residual variance.

Model 2 tests the assumption that the geological variance of $^{87}Sr/^{86}Sr$ (in excess of the assigned experimental limits), is proportional to $^{87}Rb/^{86}Sr$ for each sample, and therefore gives stronger weighting to samples of low $^{87}Rb/^{86}Sr$. This model could be appropriate for samples which have a real spread in ages but the same initial ratio. Model 3 tests the assumption that the excess geological variance of $^{87}Sr/^{86}Sr$ is independent of $^{87}Rb/^{86}Sr$, and therefore adds the same variance to each sample. Model 3 is therefore more appropriate for rocks which have the same age but different initial ratios.

The program examines the trend of the absolute differences between the observed and estimated $^{87}Sr/^{86}Sr$ divided by the respective standard errors as a function of $^{87}Rb/^{86}Sr$. From the gradient of this trend the program may recommend either Model 2 or Model 3 as the best fitted line. In some regressions neither Model 2 nor Model 3 is preferred, and the analysis may stop or continue to Model 4 in which the weighting of the excess geological variance contains elements of Models 2 and 3.

Table 10 lists one, three or four fitted isochrons as appropriate. Where the program has given a preferred model, this is indicated in the table. Uncertainties in age and initial ratio are at the 95% confidence limits. For the cases where the MSWD exceeds unity, the error limits given for Model 1 indicates what the uncertainties would have been if all the samples had fitted within experimental error. One of the Errabiddy 'isochrons' consists only of

TABLE 9. ANALYTICAL DATA FOR 48 WHOLE ROCK SAMPLES, 1 SEPARATED MUSCOVITE AND 5 SEPARATED BIOTITES FROM LOCALITIES MENTIONED IN THE TEXT

Sample	Rb (ppm)	Sr (ppm)	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
Rocky Bore					
47045	150	225	0·66 ± 0·01	1·92 ± 0·02	0·781 96 ± 0·000 31
*47042	163	140	1·16 ± 0·01	3·40 ± 0·03	0·854 51 ± 0·000 33
47043	195	160	1·21 ± 0·01	3·54 ± 0·04	0·841 22 ± 0·000 41
47040	190	145	1·30 ± 0·01	3·81 ± 0·04	0·852 30 ± 0·000 38
47044	225	165	1·37 ± 0·02	4·01 ± 0·04	0·860 11 ± 0·000 51
47041	210	150	1·40 ± 0·02	4·11 ± 0·04	0·866 88 ± 0·000 47
Errabiddy					
47046	185	125	1·51 ± 0·02	4·40 ± 0·05	0·832 17 ± 0·000 53
47047	125	135	0·93 ± 0·01	2·71 ± 0·03	0·814 27 ± 0·000 39
47048	110	140	0·79 ± 0·01	2·31 ± 0·02	0·809 94 ± 0·000 37
47049	61	140	0·44 ± 0·01	1·28 ± 0·02	0·808 36 ± 0·000 51
47050	75	110	0·68 ± 0·01	1·98 ± 0·02	0·817 04 ± 0·000 48
47051	130	100	1·28 ± 0·01	3·76 ± 0·04	0·838 64 ± 0·000 48
47052	290	58	4·87 ± 0·05	14·4 ± 0·1	0·942 90 ± 0·000 58
47053	130	100	1·27 ± 0·01	3·75 ± 0·04	0·872 51 ± 0·000 51
47054	155	82	1·91 ± 0·02	5·61 ± 0·06	0·893 31 ± 0·000 50
Forty Mile Well					
47057	170	260	0·65 ± 0·01	1·89 ± 0·02	0·753 13 ± 0·000 31
47057 (bt)	800	8	100·5 ± 2	426 ± 8	5·492 1 ± 0·005 1
47055	160	235	0·68 ± 0·01	1·97 ± 0·02	0·754 29 ± 0·000 35
47055 (bt)	750	6·5	114·6 ± 2	534 ± 10	6·967 3 ± 0·006 9
47056	210	260	0·80 ± 0·01	2·30 ± 0·02	0·760 55 ± 0·000 29
47056 (bt)	930	18	51·8 ± 1·0	182 ± 4	2·883 5 ± 0·003 3
47058	165	130	1·29 ± 0·01	3·76 ± 0·04	0·793 75 ± 0·000 32
47059	165	120	1·38 ± 0·02	4·03 ± 0·04	0·801 05 ± 0·000 34
Red Rock					
47060	330	280	1·18 ± 0·01	3·42 ± 0·04	0·785 68 ± 0·000 41
47060 (bt)	1 250	37	34·1 ± 0·07	112 ± 2	2·055 9 ± 0·002 1
47063	275	145	1·90 ± 0·02	5·55 ± 0·06	0·833 22 ± 0·000 44
47061	275	140	1·96 ± 0·02	5·73 ± 0·06	0·835 61 ± 0·000 38
47061 (bt)	1 200	27	44·9 ± 0·9	152 ± 3	2·502 5 ± 0·002 6
47064	285	135	2·11 ± 0·02	6·17 ± 0·07	0·848 21 ± 0·000 35
47064 (bt)	1 100	17	65·4 ± 1·0	240 ± 5	3·466 7 ± 0·003 5
47062	190	85	2·24 ± 0·02	6·56 ± 0·07	0·860 71 ± 0·000 40
Roadside Bore					
47080	125	260	0·47 ± 0·01	1·37 ± 0·02	0·754 63 ± 0·000 31
47081	165	340	0·49 ± 0·01	1·42 ± 0·02	0·755 83 ± 0·000 35
47079	135	265	0·51 ± 0·01	1·48 ± 0·02	0·758 50 ± 0·000 46
47076	115	235	0·51 ± 0·01	1·48 ± 0·02	0·758 86 ± 0·000 29
47077	120	235	0·51 ± 0·01	1·48 ± 0·02	0·758 61 ± 0·000 31
47075	110	150	0·74 ± 0·01	2·15 ± 0·02	0·782 08 ± 0·000 39
47074	115	145	0·80 ± 0·01	2·32 ± 0·03	0·788 50 ± 0·000 36
Dog Rocks					
47089	45	470	0·099 ± 0·002	0·286 ± 0·004	0·712 48 ± 0·000 21
47084	50	485	0·101 ± 0·002	0·292 ± 0·004	0·713 13 ± 0·000 25
47088	50	470	0·105 ± 0·002	0·303 ± 0·004	0·713 98 ± 0·000 24
47082	50	440	0·112 ± 0·002	0·324 ± 0·005	0·714 40 ± 0·000 32
47083	55	500	0·112 ± 0·002	0·324 ± 0·005	0·714 39 ± 0·000 30
47086	80	285	0·279 ± 0·004	0·81 ± 0·01	0·732 65 ± 0·000 29
47085	100	265	0·37 ± 0·01	1·07 ± 0·01	0·742 27 ± 0·000 41
47087	110	205	0·54 ± 0·01	1·56 ± 0·02	0·760 14 ± 0·000 38
Tommy Bore					
47066	71	560	0·127 ± 0·002	0·367 ± 0·005	0·717 36 ± 0·000 33
47070	86	630	0·137 ± 0·002	0·396 ± 0·005	0·716 31 ± 0·000 34
47067	70	500	0·140 ± 0·002	0·41 ± 0·01	0·718 58 ± 0·000 28
47069	90	630	0·143 ± 0·002	0·41 ± 0·01	0·715 91 ± 0·000 26
47072	88	585	0·151 ± 0·002	0·44 ± 0·01	0·719 11 ± 0·000 37
47071	90	590	0·153 ± 0·002	0·44 ± 0·01	0·717 20 ± 0·000 29
47068	87	480	0·181 ± 0·003	0·52 ± 0·01	0·720 44 ± 0·000 37
47073	95	425	0·224 ± 0·003	0·65 ± 0·01	0·727 87 ± 0·000 41
Mica Bore					
47065 (musc)	240	35	6·82 ± 0·07	20·7 ± 0·2	1·236 50 ± 0·000 55

* This sample has been omitted from the regression analysis—see text.
(musc)—separated muscovite.
(bt)—separated biotite.

two sample points. In this case the age listed has not been computed by the program and no error limits have been given. No regression analysis data is given for the Tommy Bore samples since the data do not define an isochron. Biotite ages have been calculated for samples from Red Rock and Forty Mile Well, and these are given in Table 13.

DISCUSSION OF RESULTS

ROADSIDE BORE

In the general vicinity of Roadside Bore, amoeboid shaped bodies of granitoid intrude banded gneiss. In places, a protoclastic foliation and banding are developed in the granitoid at the contact with the gneiss. This margin effect diminishes in intensity and becomes very weak about two hundred metres from the contact. The sample site (lat. 25°58′30″, long. 118°11′50″) 3 km northeast of Roadside Bore, is in the granitoid within three hundred metres of such a contact.

Seven samples were collected from within a radius of 150 m. They include 47074, 47076, 47077, 47081 which are coarse-grained to medium-grained, seriate in part, pink, chloritic (after biotite) granite; 47074 and 47076 are weakly banded. Other phases include pegmatite (47075); leucogranite (47080); and a more biotite-rich phase containing biotite schlieren (47079). In thin section, the dominant granite type has microperthitic microcline, quartz, plagioclase, and minor biotite or chlorite after biotite.

This granite gives an isochron of 2 461 ± 92 m.y. The only alteration is dusting of plagioclase and breakdown of biotite into chlorite. The weak foliation is probably syntectonic to the granite intrusion. Therefore the recorded age is likely to be a magmatic event.

The initial $^{87}Sr/^{86}Sr$ ratio of 0.7058 ± 0.0021 is relatively high for a granite with an age of 2 460 m.y. (Faure and Powell, 1972, p. 45). This could be due to one of three factors: metamorphic equilibration on a whole-rock scale; contamination of a granite magma by crustal material rich in ^{87}Sr; or a derivation from reconstituted older crustal rocks. There is no evidence of substantial recrystallization so that metamorphic equilibration is not likely. Neither is there evidence for contamination of the magma by extraneous crustal material. We therefore suggest that the granite is derived from partial melting of the older banded gneiss sequence.

TABLE 10. REGRESSION DATA FOR THE WHOLE ROCK SAMPLES IN TABLE 9
(DATA FROM TOMMY BORE HAVE NOT BEEN TREATED)

Regression	Number of samples	(a) MSWD	Age (m.y.)	R_i	Model
Rocky Bore	5	5·0	2 608 ± 771	0·709 3 ± 0·003 3	1
			2 603 ± 149	0·709 5 ± 0·006 5	(b) 2
			2 619 ± 213	0·708 7 ± 0·010 7	3
Errabiddy	2		783	0·830 6	....
	3	0·03	744 ± 214	0·785 4 ± 0·009 5	1
	4	50·3	725 ± 20	0·796 7 ± 0·001 2	1
			764 ± 207	0·794 9 ± 0·006 2	2
			712 ± 77	0·797 4 ± 0·008 1	3
Forty Mile Well	5	4·2	1 557 ± 53	0·710 2 ± 0·002 0	1
			1 550 ± 122	0·710 4 ± 0·004 3	2
			1 561 ± 100	0·710 0 ± 0·004 1	3
			1 561 ± 100	0·710 0 ± 0·004 1	(b) 4
Red Rock	5	10·8	1 604 ± 56	0·706 3 ± 0·004 0	1
			1 596 ± 165	0·706 9 ± 0·011 8	(b) 2
			1 619 ± 227	0·705 1 ± 0·017 9	3
Forty Mile Well and Red Rock (combined)	10	6·8	1 560 ± 17	0·709 9 ± 0·000 9	1
			1 554 ± 44	0·710 2 ± 0·002 0	(b) 2
			1 602 ± 54	0·709 5 ± 0·003 3	3
Roadside Bore	7	0·57	2 461 ± 92	0·705 8 ± 0·002 1	1
Dog Rock	8	0·74	2 573 ± 52	0·702 3 ± 0·000 5	1

(a) mean square of weighted deviates.
(b) preferred model.

DOG ROCKS

This site (lat. 25°55'45", long. 118°15'30") is 2.5 km south of Dog Rocks within a body of granodiorite and adamellite, and is 2 km south of an intrusive contact with banded gneiss. Near the contact, the granitoid is strongly foliated and has pink and grey banding. These banded phases occur sporadically throughout the granitoid body, and a penetrative foliation is locally developed. Eight samples were collected within a radius of about 50 metres. The dominant rock (samples 47089, 47088) is a grey, medium-grained to coarse-grained biotite granodiorite containing oligoclase and minor microcline. Sample 47082 is similar, but has pink microcline phenocrysts. The remainder of the suite is made up of: foliated, pink and grey banded granitoid (47084, 47083), a cross-cutting pegmatite (47086), a leucogranite dyke (47085), and a medium-grained, pink, biotite granite similar to granite near Roadside Bore (47087).

These granitoids provide an age of 2 573 ± 52 m.y. and this is considered to be a magmatic age. Little alteration is present, but some phases have a strongly developed foliation and/or weak banding. The foliation is strongest near contacts with the older gneiss and decreases in intensity away from the contact. The foliation and banding have a swirling flow-like appearance in some places.

The fabric is considered to be related to the intrusion of the granitoid, and was caused by the magma, in a crystal-mush state, pushing against the older gneiss. No later stage deformation or metamorphism is needed to explain the foliation development, and the age recorded is probably a magmatic event. The initial ratio of 0.7023 ± 0.0005 is consistent with either a direct mantle derivation or partial melting of the base of the crust.

ROCKY BORE

In the vicinity of Rocky Bore, a number of bodies of granitoid of various textural types, ranging from even-grained to seriate, to porphyritic, intrude a north northeast-trending complex of banded gneiss and migmatite. The Rocky Bore body is seriate to porphyritic containing scattered prolate megacrysts of microcline aligned in a northerly direction. Petrographically, it is a biotite-microcline-quartz granite containing subordinate plagioclase. Grain size is 2-4 mm, and quartz has crystallized as sub-grains 0.5-1.0 mm across. Biotite has been recrystallized as have the margins of most other grains. Some biotite has been chloritized. The body was sampled on the eastern margin (lat. 25°46'50", long 117°08'00").

Five points from Rocky Bore give an isochron of around 2 600 m.y. (Table 10). This probably records the intrusion of the granite, and therefore gives a younger limit on the age of the migmatite. The date also falls within the range of major batholithic granitic activity elsewhere in the Yilgarn Block. The quality of the isochron, moreover, precludes the possibility of major Proterozoic events having affected the rock, as happened at Errabiddy. One point (47042) lies well above the isochron and has not been used in the regression analysis. This rock, which is a leucocratic clot of quartz, microcline and plagioclase bounded by a recrystallized sheared margin, presumably acted as a sink of radiogenic strontium liberated from the surrounding, biotite-bearing rock during a later, minor thermal event.

The initial strontium ratio of 0.7093 is too high for a directly mantle-derived granite of that age; therefore, it probably represents anatexis of crustal material. This is supported by the nature of the contact between the granite and the surrounding migmatite. The contact is gradational from massive granite, which develops a migmatitic-style foliation and banding and passes into migmatite with a complex foliation over a distance of several hundred metres. The style of the contact is suggestive of an autochthonous anatectic origin.

ERRABIDDY

A migmatite complex similar to that at Rocky Bore was sampled 10 km west-southwest of Errabiddy homestead, (lat. 25°29'50", long. 117°03'00") with a view to determining directly the age of the metamorphism which produced the migmatite. The rock is a well-layered migmatite with abundant small-scale isoclinal folds, ptygmatic veining and other flow-style structures. The overall trend of metamorphic layering is north-northeast. The metamorphic component of the migmatite is granodiorite (marginal to adamellite) biotite gneiss, with abundant evidence throughout of post-crystallization events indicated by strained polygonized quartz, bent biotite, altered plagioclase, and exsolution of albite from anorthoclase to give perthite. The granitoid component is coarse-grained and leucocratic, and could involve two types—one seen as distinct bands and a possibly later variety occurring as amoeboid-shaped masses. The latter contains clots of biotite. Samples were taken at 3 points within a 200 m radius.

The nine samples analyzed do not form a single isochron (Fig. 25) and the data indicate a complex history.

The only meaningful way to view the results is in three groups, each corresponding to a sampling cluster. Thus 47046, 47 and 48 were collected from one point, the group consisting of 47049, 50, 51 and 52 from another and 47053 and 54 from the third. This grouping produces isochrons of 744 m.y., 725 m.y. and 783 m.y. respectively, and unrealistically high initial ratios. These ages are clearly related to a thermal agent later than the initial crystallization of the rock. The good alignment of the analyses at most of the other sampling localities suggests that restricted whole rock equilibration of this kind only occurred at Errabiddy. Such an event could reflect a period of rapid temperature decrease as a result of uplift, and hence closure of mineral lattices with respect to Rb and Sr. A short heating event at this time could have also occurred. The data is insufficient to distinguish between these two possibilities.

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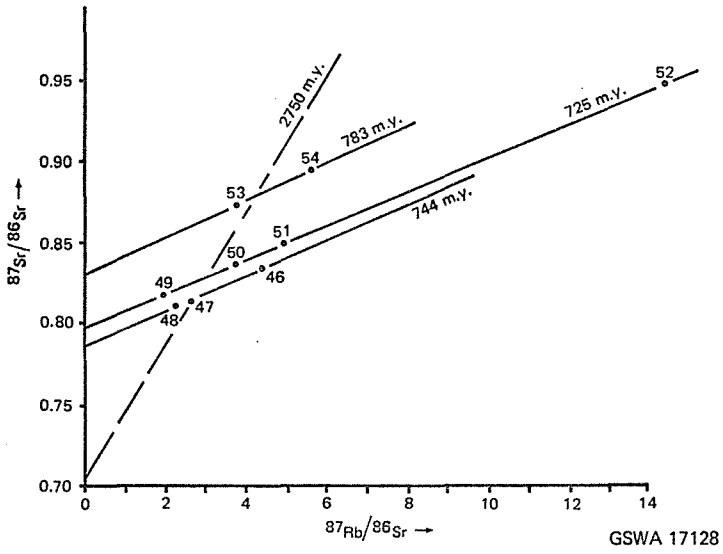

Figure 25 Isochron plot for whole-rock samples from Errabiddy. First three digits of sample numbers omitted. Reference isochron of 2 750 m.y. (R_i = 0.7075) shown by dashed line.

Geological evidence also suggests a complex history. The migmatite at Errabiddy probably was initially part of the same regional tectonic unit as seen at Rocky Bore (the "Archaean gneissic terrane" of Elias and Williams, 1977), but has been affected by Proterozoic tectonic and metamorphic events that formed the Gascoyne Province. Evidence from de Laeter (1976) and this paper indicates that the main metamorphic and intrusive events related to the Gascoyne Province occurred between 2 150 m.y and 1 550 m.y. ago, with a peak at 1 700-1 550 m.y. in the southern part of the province. The age of about 750 m.y. from Errabiddy however, is similar to the widespread mineral ages reported by de Laeter (1976) from the Gascoyne Province. No evidence of an older date, either Lower Proterozoic or Archaean, can be derived from the Errabiddy data. As geological evidence demands that the rocks are older than 750 m.y., then the 750 m.y. thermal event has caused the development of new 'isochrons' of smaller gradient across a much older isochron which would give the original age of the migmatite. Thus points lying above this reference isochron (shown as a dashed line in Fig. 25) would represent whole rock samples of lower than average mica content for their immediate location which soaked up, during the thermal event, radiogenic strontium from neighbouring rock volumes with higher mica contents. Therefore, the three new 'isochrons', although derived from whole rocks, can be considered as effective mineral isochrons of a rock which is mineralogically, and therefore isotopically, homogeneous over a larger volume. Had larger volumes of rock been isotopically analyzed, then the points on each of the new 'isochrons' could possibly be averaged to a single point, and the three resultant "average" points may define an older date representing the time at which strontium was homogeneous over the range in which all the samples were collected. Thus, the data available for Errabiddy do not give direct information on the original age of the migmatite.

The high initial strontium ratios given by the three 'isochrons' however could be a clue to the original age of the migmatite. If it is assumed that no rubidium or strontium metasomatism has occurred, i.e. that the rocks have behaved as a closed system since the migmatite was first formed, then knowing the approximate average Rb/Sr ratio of the migmatite, the rate of development of the $^{87}Sr/^{86}Sr$ ratio can be approximated. Assuming a reasonable value of 0.705-0.710 for the $^{87}Sr/^{86}Sr$ initial ratio for the migmatite at the time of formation, and averaging the strontium ratios prevailing 750 m.y. ago (given by the intercepts of the 750 m.y 'isochrons') to about 0.805 (Fig. 25), the time for the strontium ratios to rise from 0.705 or 0.710 to 0.805 can be calculated, and an estimate of the prehistory of the rock before 750 m.y. ago can be made. Whether any other metamorphic events have affected the rock during this prehistory is immaterial so long as the first assumption remains valid. Using the relationship defining the development of the $^{87}Sr/^{86}Sr$ ratio: (Faure and Powell, 1972, p. 12),

$$^{87}Sr/^{86}Sr = (^{87}Sr/^{86}Sr)_o + {}^{87}Rb/^{86}Sr\ (e^{\lambda t}-1)$$

where:—

$^{87}Sr/^{86}Sr$ = the ratio of strontium isotopes at t = 750 m.y.;

$(^{87}Sr/^{86}Sr)_o$ = the same at the time of initial crystallization of the migmatite;

$^{87}Rb/^{86}Sr$ = the ratio of these isotopes, approximated to a constant value over time, since the rate of decay of ^{87}Rb is very small;

t = the time between the initial crystallization of the migmatite and the last homogenization event (750 m.y. ago);

λ = the decay constant of ^{87}Rb ($1{\cdot}42 \times 10^{-11}$ yr $^{-1}$)

The results for various values of $^{87}Rb/^{86}Sr$ and $(^{87}Sr/^{86}Sr)_o$ which are given in Table 11, show a possible prehistory of the order of 2 000 m.y. before the 750 m.y. thermal event, consistent with the Archaean age assigned to the migmatite by Elias and Williams (1977).

TABLE 11

TIME, IN MILLIONS OF YEARS, FOR DEVELOPMENT OF Sr RATIOS FROM ASSUMED INTIAL RATIOS (R_i), TO 0.805 AT 750 M.Y. AGO, FOR VARIOUS AVERAGE $^{87}Rb/^{86}Sr$ VALUES

$^{87}Rb/^{86}Sr$	Time required (m.y.)	
	R_i = 0·710	R_i = 0·705
3·5	1 885	1 983
3·0	2 195	2 309

RED ROCK

At Red Rock (lat. 25°20'35", long. 1117°59'10"), porphyritic adamellite with some even-grained phases forms part of a large body which intrudes reworked basement.

At Red Rock itself one sample (47060) of medium-grained biotite adamellite was taken. Most of the suite is taken from within a 50 m radius of a point 1 km southwest of Red Rock. Sample 47061 is porphyritic adamellite, and the remaining samples 47062 (aplite), 47063 (fine-grained leucocratic adamellite) and 47064 (fine-grained biotite adamellite) are from small dykes which intrude the porphyritic adamellite. The nearest outcrop of reworked Archaean gneiss to this locality is 3.5 km to the southwest.

An age of 1 600 m.y is recorded, and there is no evidence that this is other than a magmatic event. The samples do show thorough recrystallization but there is little metamorphic alteration other than saussuritization of plagioclase. The initial $^{87}Sr/^{86}Sr$ ratio of 0.7065 is, for a granitoid of this age, indicative of the incorporation of large amounts of older crustal material (Faure and Powell, 1972, p. 45). Anatexis of Archaean gneissic crust is regarded as the most likely origin of this granitoid.

FORTY MILE WELL

Another large body of relatively late-stage granitoid occurs near Forty Mile Well, 24.5 km northwest of Red Rock. In the sampling area, which is within a 200-metre radius of a point (lat. 25°14'30", long. 117°46'10") 2.2 km west of Forty Mile Well there is a complex admixture of coarse-grained, seriate adamellite, porphyritic adamellite, and fine-grained to medium-grained adamellite. Interrelationships suggest that these phases are co-magmatic. There are also some minor raft-like bodies of partly injected, banded gneiss and nebulitic migmatite which probably constitute older material. Samples 47055, 47056 and 47059 are foliated, medium-grained, seriate or porphyritic, biotite-oligoclase-microcline adamellite with muscovite; 47057 is fine-grained adamellite; and 47058 is a cross-cutting dyke rock.

These mixed adamellitic granitoids provide an isochron age of 1 557 m.y. which is considered to be the magmatic age. A probably anatectic origin, related to the partial melting at depth of older, gneissic crustal material is indicated by the high $^{87}Sr/^{86}Sr$ ratio (0.7102) for a granitoid of this age.

Both the Red Rock and the Forty Mile Well sample sites are part of a major granitoid batholith which was intruded along the northern margin of the Yarlarweelor Gneiss Belt (Elias and Williams, 1977). The difference in ages between granitoids from the two areas may be real, reflecting successive phases of intrusion and crystallization in a single magmatic event. Alternatively, the age difference may be regarded as within the limits of experimental error. Table 10 shows that by considering the preferred model age for the two localities, the age ranges indicated overlap completely. Even with the reduced error limits of the model 1 ages, there is still considerable overlap. The age can be better defined by combining the data from the two localities into a single isochron. Table 10 shows the results of this combination, an age of 1 554 ± 44 m.y. The preference for a model 2 isochron suggests that there is an age difference between the two localities, but the doubling of the number of points defining the isochron has resulted in considerably reduced error in both slope and initial Sr ratio. The age of 1 554 m.y. is therefore regarded as a more accure indication of the age of intrusion of this regional granitoid.

TOMMY BORE

In the Tommy Bore area, an elongate pluton of granodiorite is intruded along a shear zone between the layered sequence of the Trillbar Belt (Elias and Williams, 1977) and the reworked gneiss of the Yarlaweelor Gneiss Belt. The contact zones of this granodiorite are strongly foliated, and a penetrative foliation persists into the pluton for about 1 km. The sample site (lat. 25°32′10″, long. 117°47′30″) is 1 km south of a contact between granitoid and banded gneiss. Samples 47070, 47069, 47072 and 47071 are of medium-grained, biotite granodiorite containing abundant microcline. Samples 47067 and 47073 are from rafts of banded leucocratic gneiss; 47068 is a late stage pegmatite; and 47066 is from a dyke of fine-grained adamellite.

Because of the narrow range of $^{87}Rb/^{86}Sr$ (Table 9) no reliable isochron can be obtained from the Tommy Bore data, although four of the eight points form an approximate isochron at 1 420 m.y. with an initial $^{87}Sr/^{86}Sr$ ratio of about 0.71. This date is considered to be too unreliable to postulate a magmatic event of such a young age, and if it has any real meaning it may record a phase of activity along the shear zone which the granodiorite intrudes. There is ample evidence of post-intrusive activity within the granodiorite. It has a well-defined fabric defined by flattened quartz grains and aligned recrystallized biotite flakes. Quartz is completely recrystallized, plagioclase is saussuritized (often heavily), and in some samples there has been complete recrystallization of plagioclase grain boundaries. Continued or sporadic activity along the shear zone may well account for the fact that the strontium isotopes have been irregularly redistributed.

MICA BORE

Interfolding of reworked Archaean gneiss and Proterozoic supracrustal sediments occurs in the Mica Bore area. At the sample locality (lat. 25°28′50″, long. 118°05′30″), 3 km northeast of Mica Bore, quartz-mica schist, considered to be originally part of the Archaean basement, has been remetamorphosed and tightly folded, and a new axial planar fabric is developed. The new fabric is expressed by elongate, recrystallized quartz grains and aligned muscovite flakes. Muscovite therefore appears to have been completely recrystallized, and its model age would date this Proterozoic metamorphic event. Sample 47065 (musc) consists of muscovite separated from the whole rock.

For calculating the model age, some idea of the initial ratio can be obtained by considering Red Rock and Forty Mile Well granitoids which are thought to be derived from the older material in the Yarlarweelor Gneiss Belt. The R_i of these are 0.705 and 0.710, but at Mica Bore, the schists are unusually rich in muscovite, and were therefore probably originally richer in ^{87}Rb. This would cause a comparatively large increase in the ^{87}Sr content of the schist, and hence increase the $^{87}Sr/^{86}Sr$ of the muscovite at the time of recrystallization.

A reasonable range of R_i for muscovite is 0.70 to 0.74, and variations in model age within this range are shown in Table 12. This clearly establishes realistic limits for the age of metamorphism and basement reworking, and the preferred figure is 1 702 m.y.

TABLE 12. VARIATION OF MUSCOVITE MODEL AGE WITH INITIAL $^{87}Sr/^{86}Sr$ RATIOS, MICA BORE (SAMPLE 47065 (Musc.))

Initial Ratio	Model Age (m.y.)
0·70	1 802
0·71	1 769
0·72	1 763
0·73	1 702
0·74	1 672

GEOCHRONOLOGY IN RELATION TO PRECAMBRIAN TECTONISM

South of the Bullbadger Shear Zone and south of the Murchison Tectonic Lineament (Fig. 24), Archaean ages are recorded by granitoids which intrude gneissic terrain and greenstone belts, and there is no evidence of any Proterozoic activity. In this area, structural trends are generally oriented north to northeast, except where locally disturbed by intrusion of granitoids.

North of the Bullbadger Shear Zone and north of the Murchison Tectonic Lineament, Archaean structural trends are disrupted, and are generally easterly, but quite variable. Within this disturbed zone, which contains reworked Archaean gneiss and granitoid together with some metamorphosed supracrustal rocks, a dynamothermal event at about 1 700 m.y., and a thermal event at about 750 m.y. are recorded. The geochronological data presented here support the postulation (Elias and Williams, 1977) that the Bullbadger Shear Zone and the Murchison Tectonic Lineament provide an approximate boundary between the Yilgarn Block to the south and the Gascoyne Province to the north.

Within the Yilgarn Block on the Robinson Range Sheet, lithological, structural, and metamorphic contrasts suggest that the gneisses are older than the greenstone sequences. Both groups are intruded by granitoid bodies, such as the Rocky Bore and Roadside Bore granites, the R_i of which suggest derivation from older crustal rocks. It is proposed that partial melting of older gneissic rocks took place between 2 700 m.y. and 2 500 m.y. and the anatectic granitoids so produced were emplaced in rocks of lower metamorphic grade at higher levels in the crust.

Strontium isotope data for the Dog Rocks granodiorite (R_i = 0.702) is consistent with a direct mantle derivation for granitoid of this age (2 570 m.y.). It would, however, fit the partial melting hypothesis to suggest that the Dog Rocks granodiorite was derived from partial melting of upper mantle or lower crustal material during the same period of heating which was responsible for anatexis at higher crustal levels.

The emplacement of the Roadside Bore granite (2 460 m.y.) is the last recorded Archaean event in the area studied.

A period of Proterozoic orogenesis involving regional metamorphism, deformation and granitoid diapirism is thought to have taken place in the approximate interval of 1 800 to 1 650 m.y. This activity affected 'pre-Padbury Group' supracrustals and involved the tectonic and metamorphic reworking of the Archaean gneissic sequence. Geochronological evidence presented here suggests an Archaean age for the migmatite near Errabiddy. The preferred model age for the regeneration of muscovite at Mica Bore is 1 700 m.y., and this is probably related to the waning of the first Proterozoic metamorphic and tectonic event that affected this mobile region. Gneissic and granitic rocks from the central part of the Gascoyne Province record similar ages of 1 738 m.y. and 1 637 m.y. (de Laeter, 1976). Metamorphic rocks from the northwestern Gascoyne Province have a similar age of 1 693 ± 235 m.y. (Compston and Arriens, 1968).

The regional metamorphism of the Gascoyne Province is broadly contemporaneous with granitoid activity in the central part, but is significantly older than the granitoids in the eastern part, such as at Red Rock and Forty Mile Well (1 550 m.y.). The initial $^{87}Sr/^{86}Sr$ ratio data for these granitoids is consistent with an origin by partial melting of older crustal material. This process of magma generation seems to be the expression at a deeper crustal level of the first Proterozoic regional metamorphism, and the actual emplacement of these granitoids at a higher level in the crust did not occur until sometime after their formation. A subtle alternative is that these granitoids

formed after the first regional Proterozoic metamorphism in an event which left little or no mark at higher crustal levels.

The intrusion of these later granitoid batholiths as diapirs is considered to be responsible for a second period of deformation during which the Padbury Group, along with the pre-Padbury metasediments and reworked Archaean gneissic terrain was folded in mantled gneiss domes (Elias and Williams, 1977). The Padbury Group was not affected by the first Proterozoic regional metamorphism and deformation, but the 'pre-Padbury Group' metasedimentary sequence was so affected.

It is concluded that the Padbury Group was not deposited at the time of the Proterozoic regional metamorphic event, so an older limit on the age of the Padbury Group is approximately 1 700 m.y. The Padbury Group was, however, deformed as a result of the nearby emplacement of the late granitoids, and the best estimate of the age of these (the combined Red Rock-Forty Mile Well isochron) is 1 554 m.y. The Padbury Group is therefore confirmed as a Lower Proterozoic supracrustal sedimentary sequence, as was first suggested by Barnett (1975), with an age of deposition sometime between 1 700 and 1 550 m.y.

A short heating event, widespread throughout the Gascoyne Province at about 800 m.y., may be responsible for the biotite mineral ages recorded from the Red Rock adamellite and Forty Mile Well adamellite (Table 13).

TABLE 13. MINERAL AGES CALCULATED FROM WHOLE ROCK SAMPLES AND THEIR RESPECTIVE SEPARATED BIOTITES (DATA FROM TABLE 9), FROM FORTY MILE WELL AND RED ROCK

	Sample	Age (m.y.)
Forty Mile Well	47055	818
	47056	826
	47057	783
Red Rock	47060	816
	47061	799
	47064	764

At Errabiddy whole rock isochrons also give a date of around 750 m.y. (Table 10). However, there is no petrographic evidence, in terms of alteration or recrystallization, for such a late stage metamorphism. Similar mineral ages (average 765 m.y.) have been reported by de Laeter (1976) from further west in the Gascoyne Province. If such a metamorphic event was so widespread throughout the Gascoyne Province at this time, its effects would be expected to be observed in Gascoyne Province rocks as well as in basal units of overlying Bangemall Group sediments. No such effects have been documented. It seems more likely that this 750-800 m.y. age reflects a period of rapid temperature decrease and hence closure of mineral lattices with respect to rubidium and strontium movement as a result of uplift. Present data suggest an overall decrease in mineral ages from east to west in the Gascoyne Province, but more data would be needed to confirm this.

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THE AGE OF THE SYENITIC ROCKS OF THE FITZGERALD PEAKS, NEAR NORSEMAN

by J. R. de Laeter* and J. D. Lewis

ABSTRACT

The Fitzgerald Peaks Syenite is one of a number of small alkaline intrusives occurring near the axis of the major greenstone belt of the Eastern Goldfields Province of the Yilgarn Block. Using a decay constant of 1.42 x 10^{-11} yr^{-1} a Rb/Sr age of 2 360 ± 96 m.y. (R_i = 0.7044 ± 0.002) is reported which excludes the possibility that this intrusion is related to the nearby Proterozoic Albany-Fraser Province. Because of petrographic and chemical similarities it is suggested that all the syenitic intrusions in the province have a similar age.

INTRODUCTION

Systematic regional mapping of the Eastern Goldfields Province of the Yilgarn Block has located a number of small syenitic and alkali-granite bodies. Most of the intrusions are found in a north-south zone about 70 km wide by 500 km long situated close to the axis of the major greenstone belt of the region (Libby, in press). With the possible exception of the Widgiemooltha dyke swarm the alkaline rocks appear to be the youngest magmatic phase in the province.

The Fitzgerald Peaks Syenite occurs at the southern end of the zone of alkaline intrusions and, with an area of 120 km^2, is the largest single body known. Prior to this study no direct evidence of the age of the Fitzgerald Peaks Syenite was available but its closeness to the Albany-Fraser Province, and the presence in this metamorphic belt of two small alkaline bodies, suggested the possibility of a Proterozoic age. The present paper reports an Archaean whole rock age for the Fitzgerald Peaks Syenite and discusses the implications of this for the regional geology of the Eastern Goldfields Province.

PREVIOUS GEOCHRONOLOGICAL WORK

A review of Archaean geochronology in Western Australia has been made by Arriens (1971) who has shown that the majority of granite ages in the Yilgarn Block fall within the range 2 700-2 500 m.y. These granites occupy at least 50% of the area of the block and form the framework within which the greenstone belts occur. Older ages of up to 3 100 m.y. were obtained from the gneissic belt which forms the western margin of the Yilgarn Block,

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and Proterozoic ages of about 2 200 m.y. for a series of minor acid intrusions and small granite bosses in the South-western Province.

In the Eastern Goldfields Province Turek (1966) obtained ages of about 2 700-2 600 m.y. for a variety of granites and shales in the vicinity of Kalgoorlie, but of particular interest are ages obtained from the Widgiemooltha dyke suite and a whole rock/mineral isochron for a single sample from the Fitzgerald Peaks. The Widgiemooltha dykes, an east-west trending swarm of very large dykes widely scattered throughout the Eastern Goldfields, were generally recognized at the time as being the youngest intrusions in the region and gave an age of 2 420 ± 30 m.y. This event, with the gold mineralization at 2 400 ± 30 m.y., marks the close of the Archaean in Western Australia. A single sample collected from the Fitzgerald Peaks, however, gave an apparent age of 1 670 m.y. on a whole rock/microcline isochron. However, as the associated initial $^{87}Sr/^{86}Sr$ ratio was 0.7473, and the rock was asumed to be Archaean, it was suggested that the age was spurious and that there had been a loss of radiogenic ^{87}Sr from the microcline.

To the east and northeast of the Fitzgerald Peaks a wide variety of Proterozoic ages have been found in the Albany-Fraser Province. Wilson and others (1960) dated muscovite from a pegmatite in the Fraser Range at 1 210 m.y. (K/Ar) and 1 280 m.y. (Rb/Sr) while Bunting and others (1976) found ages ranging from 1 725 m.y. to 1 289 m.y.

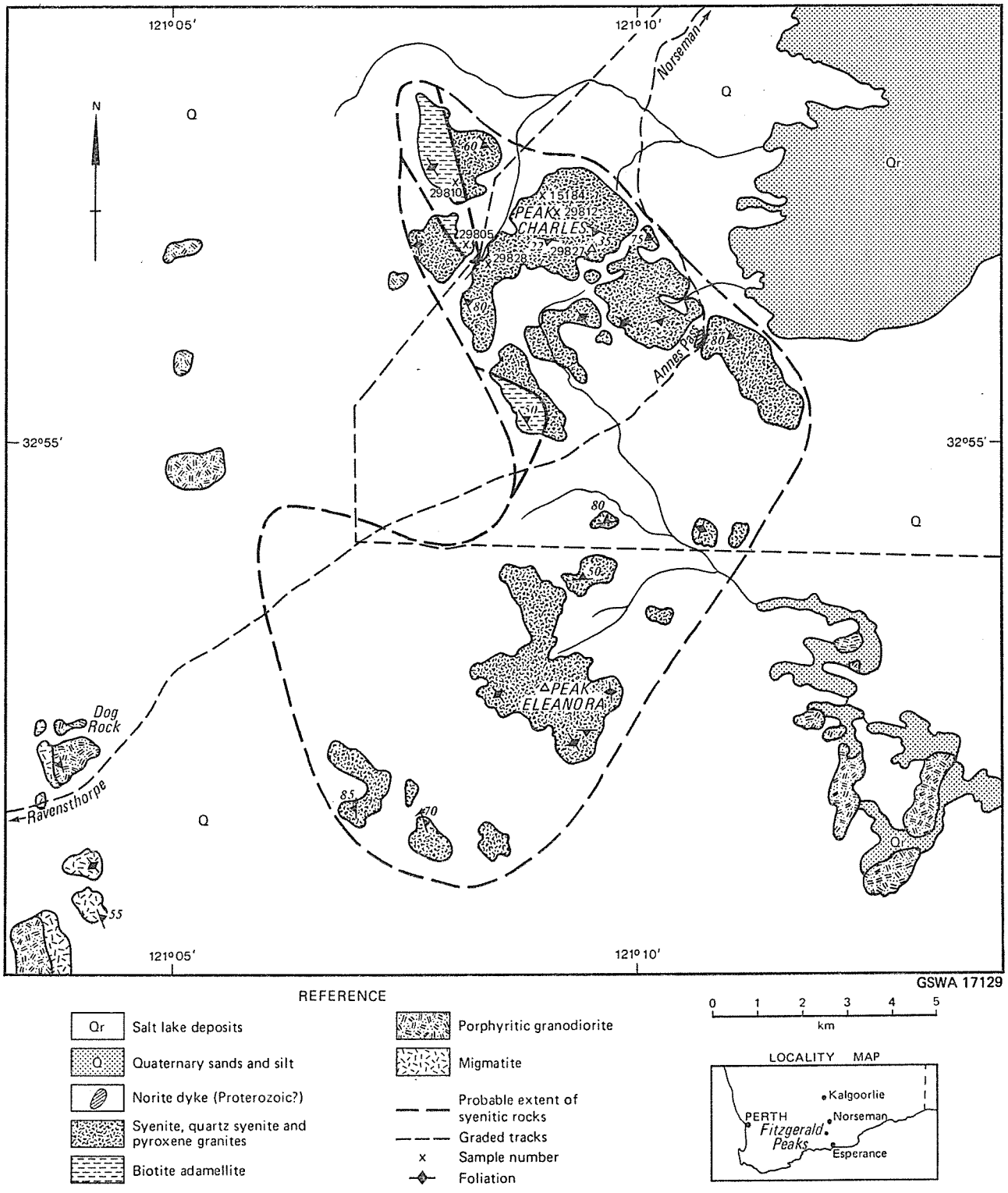

Figure 26 Geological sketch map of the Fitzgerald Peaks.

at the northern end of the belt. It was suggested by Bunting and others (1976) that the marginal rocks of the Yilgarn Block had been reworked and incorporated within the mobile zone along with the intrusion of younger granites. The presence of a riebeckite rhyolite at Bobbies Point with a model age of 1 190 m.y., close to an adamellite dated at 1 725 m.y., indicates the possibility that an alkaline magmatic phase associated with the formation of the mobile zone could also have been responsible for the intrusion of the Fizgerald Peaks Syenite.

GEOLOGY OF THE FITZGERALD PEAKS

The regional geology of the Lake Johnston area, which includes the Fitzgerald Peaks, has been described by Gower and Bunting (1972), while a more detailed account of the geology and petrology of the syenitic rocks has been given by Lewis and Gower (in press). Briefly, the Fitzgerald Peaks Syenite is located 96 km south-southwest of Norseman, near the southwest margin of a large Archaean batholith which occupies the eastern third of the Lake Johnston 1 : 250 000 sheet and covers an area in excess of 5 000 km^2. The principal rock type within the batholith is a porphyritic biotite-adamellite which grades into porphyritic biotite-granodiorite. Foliation is usually north-northwest, parallel to the trend of the Archaean greenstone belts, but 16 km south of the Fitzgerald Peaks the batholith is truncated by the Albany-Fraser Province and foliation in the granite is northeast, possibly reflecting a Proterozoic influence.

The Fitzgerald Peaks are a prominent group of hills rising over 300 m above the plain of the surrounding Archaean granite. Peak Charles, the highest of the group, is a conical hill of bare rock 658 m high. Geophysical evidence outlines a roughly crescent-shaped mass (Fig. 26) and although its margins are nowhere exposed it is presumed to be intruded into the surrounding granite. The rock is pink, medium-grained, and is distinctive in that it contains rare xenoliths of mafic rock in various stages of assimilation and the mafic mineral is a dark-green clinopyroxene. Commonly the rock type is a quartz syenite containing mesoperthite, 5-10% quartz and aegirine-augite. The proportion of quartz is variable, however, from almost nil to 20% thus giving a range from syenite to pyroxene-granite. In places biotite replaces aegirine-augite as the mafic mineral and the perthite has unmixed to give discrete oligoclase crystals, giving rise to biotite adamellite (Fig. 26). Chemically the two varieties are similar except for a slightly lower alkali content in the biotite adamellite (Lewis and Gower, in press). However, Libby (in press) suggests that the biotite adamellite is chemically intermediate between the syenitic rocks and the surrounding granitoids and possibly represents a mixture of the two.

MATERIALS USED

The samples analyzed in this study were all collected during the regional mapping of the Lake Johnston area and their locations are marked on Figure 26. The choice of sample was based on a preliminary determination of Rb and Sr to obtain as wide a range as possible. Six samples were finally analyzed, all from the Peak Charles area, and included two biotite adamellites, two leucocratic alkali granites and two samples which showed intermediate petrographic characteristics.

Specimen 29805 is typical of the biotite adamellite, being medium-grained with a normal granitic texture and mineralogy. Anhedral crystals of microcline, oligoclase (An_{12-15}) and quartz are the principal minerals with small flakes of interstitial olive-brown biotite distributed throughout the rock.

Accessory minerals include apatite, zircon, and magnetite with a little chlorite and fluorite and plentiful sphene. The sphene occurs as lozenges and amoeboid grains and is characteristic of all rock types in the Fitzgerald Peaks. The mineral is orange-brown in colour, often zoned, has relatively low birefringence and is sometimes metamict. Specimen 29828, from the main mass of Peak Charles, is essentially similar to 29805 except that green hornblende replaces biotite and there are a few relict grains of aegirine-augite altering to blue-grey arfvedsonite. The second biotite adamellite specimen, 29810, is a leucocratic variety in which much of the biotite has altered to chlorite and in which a little pumpellyite is present. The feldspar in this rock consists of albite/oligoclase (An_{8-14}) and perthite.

Specimens 15184 and 29812 are both coarse-grained leucocratic alkali granites containing about 80% mesoperthite and 20% quartz with accessory magnetite and sphene. In both specimens the sphene is metamict and partly converted to rutile. Specimen 15184 also contains a little accessory fluorite. Mesoperthite forms large anhedral grains with complex lobate margins. The proportion of exsolved albite (An_{5-10}) varies from about 30% to 90% and occurs as untwinned oriented spindles or broad bands and patches which show poorly developed polysynthetic twinning. The overall texture suggests hypersolvus crystallization.

Specimen 29827 is a medium-grained quartz-poor alkali granite which contains relicts of aegirine-augite altering to arfvedsonite with a few flakes of red-brown biotite. The feldspar is predominantly a mesoperthite with broad bands of exsolved albite, but in part this has broken down to discrete grains of microcline and albite. Orange-coloured sphene, apatite and zircon are common and there is a little secondary carbonate.

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 0.7102 $\pm$ 0.0001, normalized to a $^{88}Sr/^{86}Sr$ value of 8.3752. The value of $1.42 \times 10^{-11}yr^{-1}$ was used for the decay constant of ^{87}Rb (Steiger and Jäger, 1977). It should be noted that this is the first time this value for the decay constant has been used by the laboratory, as in earlier publications a value of $1.39 \times 10^{-11}yr^{-1}$ has been adopted.

RESULTS

The measured Rb/Sr and $^{87}Sr/^{86}Sr$ ratios, as well as the calculated $^{87}Rb/^{86}Sr$ ratios are given in Table 14. 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 14 have been regressed using the least squares programme of McIntyre and others (1966). The age and initial ratio of the Fitzgerald Peaks Syenite, assuming experimental variation only, is 2 356 $\pm$ 25 m.y. and 0.70446 $\pm$ 0.00073 respectively. However, the mean square of weighted deviates (MSWD) is greater than expected from experimental variations alone. A more realistic estimate of the age and initial ratio would be 2 360 $\pm$ 96 m.y. and 0.70436 $\pm$ 0.00225, which is the model 4 age based on the assumption that there is some variation in age and initial ratio in the data itself, in addition to experimental variation. This assumption is supported by the inclusion in the isochron of the adamellite samples which may be mixtures of the alkali magma and older granitic material.

Table 15 also lists the regression data based on a decay constant for ^{87}Rb of $1.39 \times 10^{-11}yr^{-1}$. This allows for a better comparison between the new and old data and gives a preferred age of 2 411 $\pm$ 98 m.y. for the Fitzgerald Peaks Syenite. This age will be used in the following discussion.

DISCUSSION

The confirmation of an Archaean age for the Fitzgerald Peaks Syenite places the intrusive event with several other late Archaean events in the Eastern Goldfields Province. If an affinity with other alkali intrusives throughout the province is accepted then it is possible that the age of the Fitzgerald Peaks rocks dates a period of minor but widespread alkaline activity in the Eastern Goldfields Province. The Archaean age also eliminates the possibility that the Fitzgerald Peaks Syenite is directly associated with igneous activity during the formation of the Proterozoic Albany-Fraser mobile zone. However, as Bunting and others (1976) have suggested, part of the mobile zone may be reworked Archaean material and it is possible that the small alkaline bodies within the zone and to the south of Fitzgerald Peaks may be remnants of Archaean intrusions.

TABLE 14. ANALYTICAL DATA FOR THE FITZGERALD PEAKS SYENITE

Sample	Rb (ppm)	Sr (ppm)	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
29828	45	385	0·116 ± 0·001	0·337 ± 0·003	0·715 31 ± 0·000 51
29805	140	415	0·336 ± 0·003	0·973 ± 0·01	0·738 63 ± 0·000 47
29827	170	330	0·516 ± 0·006	1·50 ± 0·02	0·754 86 ± 0·000 42
29810	147	125	1·18 ± 0·01	3·46 ± 0·03	0·824 60 ± 0·000 53
29812	125	65	1·91 ± 0·02	5·60 ± 0·06	0·889 98 ± 0·000 59
15184	200	85	2·33 ± 0·03	6·90 ± 0·07	0·940 97 ± 0·000 71

TABLE 15. REGRESSION DATA FOR THE FITZGERALD PEAKS SYENITE

	Age (m.y. $\lambda = 1{\cdot}42 \times 10^{-11}yr^{-1}$)	Age (m.y. $\lambda = 1{\cdot}39 \times 10^{-11}yr^{-1}$)	Intercept
Model 1 MSWD = 13·59	2 356 ± 26	2 407 ± 26	0·704 46 ± 0·000 73
2	2 376 ± 103	2 427 ± 105	0·703 96 ± 0·001 39
3	2 347 ± 97	2 398 ± 99	0·704 70 ± 0·005 25
4*	2 360 ± 96	2 411 ± 98	0·704 36 ± 0·002 25

* preferred age.

The possibility of a Proterozoic age for the intrusion of the Fitzgerald Peaks Syenite rested on a correlation between a single point whole rock model age of 1 190 m.y. for the Bobbies Point riebeckite rhyolite (Bunting and others, 1976) and the whole rock/mineral age of 1 670 m.y. obtained by Turek (1966) for a single sample from Peak Charles. The field relations and petrology of this specimen are not known, however, and it cannot be determined with certainty whether the specimen was truly part of the alkaline suite. Turek himself suggested that the age he had obtained was spurious and thought that there had been a loss of radiogenic ^{87}Sr from the microcline. This remains one of a number of possible explanations for the obvious failure of Turek's analysis (GA 1461, Fig. 27) to conform with the simple and coherent pattern of our results.

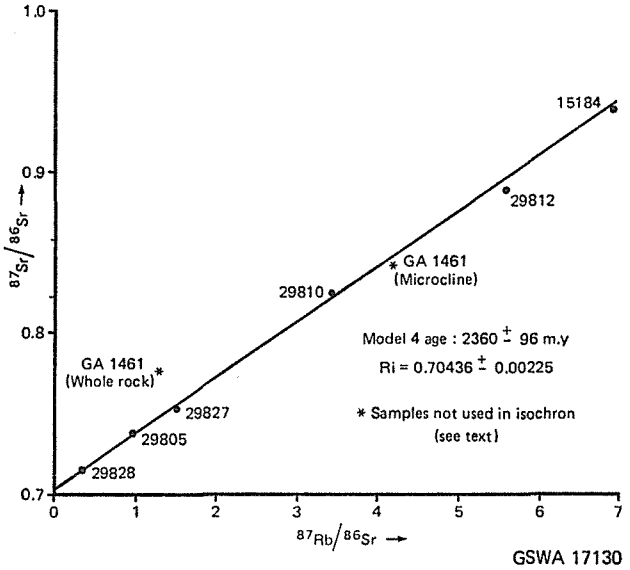

Figure 27 Isochron plot of six whole rock analyses from the Fitzgerald Peaks Syenite.

In the southern part of the Eastern Goldfields Province the age of 2 411 ± 98 m.y. for the Fitzgerald Peaks Syenite places it with the Widgiemooltha dyke suite (2 420 ± 30 m.y.) and gold mineralization (2 400 ± 30 m.y.) (Turek 1966).

The small norite body in Anne's Pass, then, appears to be a member of the major dyke suite intruded shortly after the syenite.

Libby (in press) has shown that petrographically and chemically the Fitzgerald Peaks intrusion is similar to a number of other quartz-poor alkaline intrusives distributed over a distance of more than 500 km along the axis of the major greenstone belt of the region. In particular the rocks contain a distinctive mesoperthite, aegirine-augite or arfvedsonite, and an orange-coloured sphene. It seems possible, therefore, that the formation of this rock-type occurred at a similar time throughout the province, that is at 2 411 ± 98 m.y. The only comparable age determination in the northern part of the area is 2 480 ± 30 m.y. for the Mount Boreas Granite, 300 km north of Kalgoorlie (Bunting and Williams, 1976). This type of granite—potash-rich and fluorite-bearing—is both chemically and mineralogically distinct from the syenites but it does contain a similar orange-coloured sphene, unlike the older granites and gneisses. Mount Boreas-type granite intrusions are widely distributed throughout the same area as the smaller syenitic bodies, and, although in some localities it probably intrudes the syenite, both types are thought to be the youngest intrusive rocks of the area. The Fitzgerald Peaks age determination thus confirms the close association in time of the two rock types.

In conclusion, the final phase of Archaean magmatic activity in the Eastern Goldfields Province of the Yilgarn Block, during the period 2 480-2 400 m.y., appears to have begun with the intrusion of small bodies of quartz-poor alkaline rocks and larger bodies of quartz and potash-rich granites. This was followed by major fracturing of the crust and the intrusion of the east-west Widgiemooltha dyke suite and, finally, by widespread gold mineralization.

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A MONZONITIC PLUTON NEAR LAKE SHASTER

by W. G. Libby and S. L. Lipple

ABSTRACT

A mildly alkaline hornblende-biotite-andesine-microcline monzonite is exposed at Lake Shaster, Western Australia, about 70 km east-southeast of Ravensthorpe, in the Proterozoic Albany-Fraser Province. Small amounts of nepheline and/or olivine appear in the C.I.P.W. norm of several samples but not in the mode. One sample has 0.04 per cent normative quartz. Quartz appears in the mode of several samples.

Chemical trends fail to establish that the monzonite is a product of simple differentiation either from a parent magma of nearby calc-alkaline acid volcanics or from a parent magma of Archaean quartz-poor felsic alkaline plutonic rocks of the Eastern Goldfields Province.

INTRODUCTION

A small syenite body was described in the explanatory notes for the Ravensthorpe 1:250 000 geological sheet (Thom and others, 1977). Chemical and additional petrographic data suggest that the term *monzonite* is more appropriate than *syenite*. Further description of the pluton seems appropriate in the light of increasing interest in silica-saturated and slightly over-saturated granitic rocks in the area (Lewis and Gower, 1978; Libby, 1978; and Lewis and de Laeter, 1978).

The monzonite is exposed at the northern margin of Lake Shaster (Lat. 33° 52' S, Long. 120° 44' E), about 70 km east-southeast from Ravensthorpe. Lake Shaster is a large (about 3 km by 6 km) ephemeral salt lake

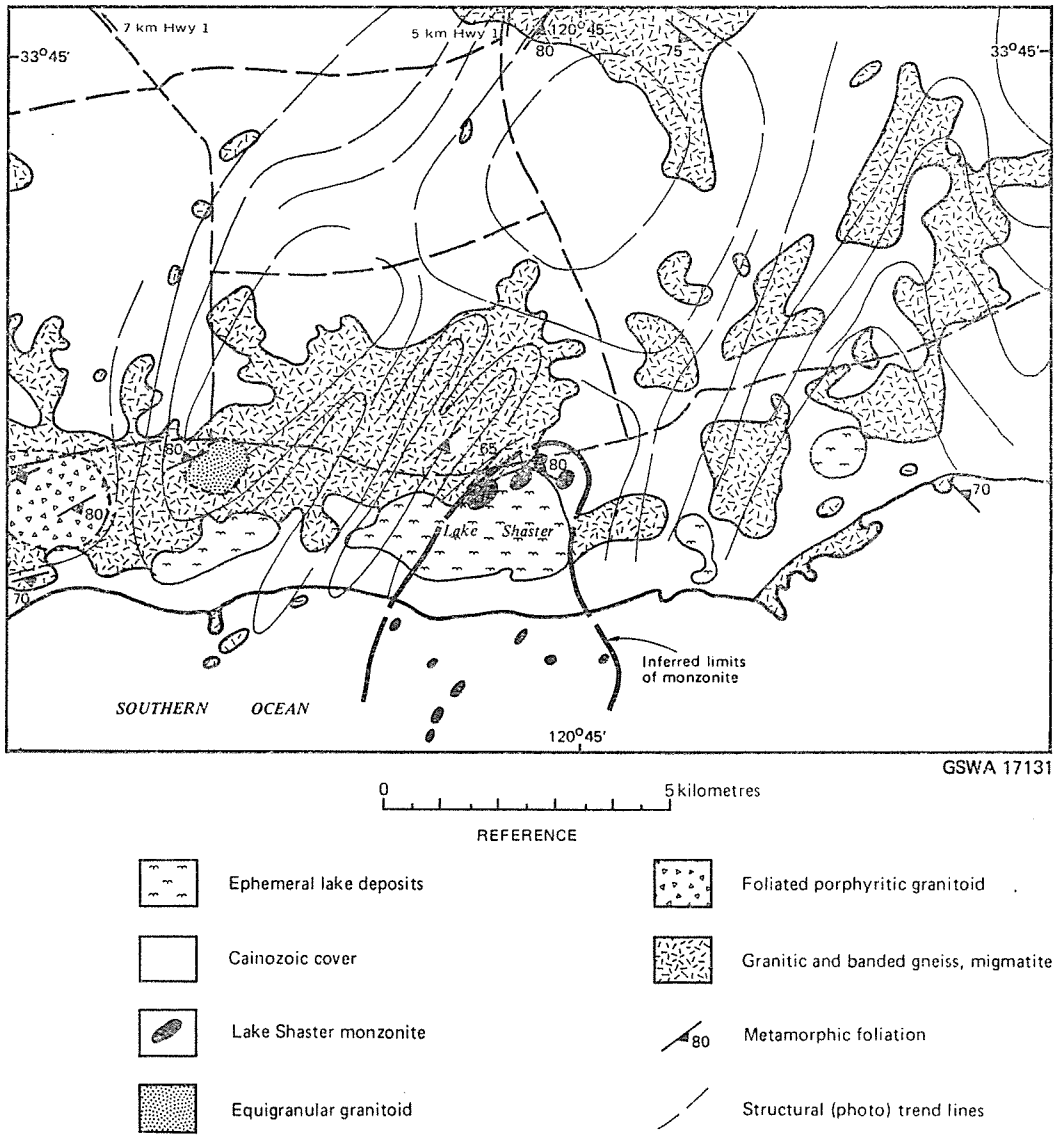

Figure 28 Geological sketch map, Lake Shaster area.

surrounded by low, gently undulating, heath-covered sand-plain, and separated from the Southern Ocean by about 0.5 km of coastal dune and beach sand. Several islets in the ocean to the south of Lake Shaster may also be part of the monzonite stock. Access to Lake Shaster is by good gravel roads southward from Highway 1.

REGIONAL GEOLOGY

The regional geology has been described by Thom and others (1977) and is illustrated in the accompanying geological sketch map (Fig. 28). The monzonite is a rounded mass, 5 to 6 km in diameter, situated in a large box-shaped fold formed by enclosing gneiss. The gneiss is well foliated and banded, and ranges from adamellitic to granodioritic, with rare amphibolitic layers. Banding is fine, 1 to 3 cm in width. The metamorphic gneiss and migmatitic country rock are part of the middle Proterozoic mobile belt defined as the Albany-Fraser Province by Daniels and Horwitz (1969). Thom and others (1977) consider that metamorphic rocks of the Albany-Fraser Province were generated by the reworking of Archaean rocks of the formerly more extensive Yilgarn Block. The monzonite pluton is on strike with abundant metamorphosed amphibolite, ultramafic rock and sedimentary rock, probably remnants of an Archaean greenstone terrain (Fig. 28).

West of Lake Shaster several northeast-trending, east-dipping isoclinal folds separate the monzonite body from an oval mass of poorly-foliated biotite adamellite and nebulitic migmatite. The adamellite is fine to medium-grained, dominantly even grained with rare biotite wisps and a few small feldspar phenocrysts but otherwise homophanous. Mineral foliation is defined by alignment of biotite, quartz and feldspar, and varies from weak to prominent. The mass is considered to form a dome with poorly foliated homogeneous adamellite or nebulitic migmatite in the core becoming increasingly foliated toward the margin, passing gradually into gneiss.

A third discrete pluton is exposed over an area of about 1 km by 3 km, about 9 km west of Lake Shaster (Fig. 28). It consists of a strongly and coarsely porphyritic cream-coloured, strongly foliated granite which appears to intrude the surrounding migmatites.

The relation of the two nearby homogeneous granitoids to the monzonite at Lake Shaster is unknown, but they illustrate that homophanous granitoids punctuating the regional gneisses are common in this part of the province.

FIELD CHARACTERISTICS

The monzonite at Lake Shaster forms relatively prominent, smoothly rounded, well-jointed outcrops adjacent to the northern shore of Lake Shaster. The rock is a fresh, massive, homophanous, coarse-grained biotite-hornblende monzonite. Feldspar grains have a uniform pink colour. Phenocrysts are numerous and laths are commonly 2.5 to 3 cm long. Foliation formed by alignment of feldspar, hornblende, biotite and phenocrysts is mainly weak to indetectable, but locally is moderately developed parallel to the regional foliation. Close examination of outcrops identified only sparse amounts of quartz, which is fine grained and bluish. No xenoliths or schlieren were observed. Several thin (less than 10 cm) pegmatite veins strike 100° to 115° and dip 75° north.

Numerous granitoid rocks which are exposed up to 3.5 km offshore in the Southern Ocean, south from Lake Shaster, although not visited, are probably also monzonite. The outcrops exhibit a similar, non-directional, smooth photo-pattern to that of the rocks identified as monzonite. This photo-pattern is in marked contrast to the prominently banded pattern of the adjacent gneiss and migmatite.

Contacts between the monzonite and enclosing gneiss are obscured by superficial sand deposits. However, the contrast in composition and degree of foliation between gneiss and monzonite, and homogeneity of the monzonite suggest the monzonite is younger than the gneiss.

The monzonite also contrasts with the porphyritic, probably Proterozoic, adamellite which is located west from Lake Shaster and is described above. The adamellite has a distinctive colour, texture and composition, includes abundant quartz and mafic schlieren, and is strongly foliated.

PETROGRAPHY

Thin sections were cut from seven samples: 28345 B, C, and D; 29577 B; and 29606 A, B, and C. Brown biotite is the dominant mafic material in all samples but dark green hornblende is also abundant. Microcline is the dominant felsic mineral, constituting about two thirds of the feldspars, the remainder being sodic andesine. A few sections have obvious but minor intergranular quartz (less than 1 per cent), whereas others have little, if any, visible quartz apart from that in the ubiquitous myrmekite. Black opaque grains, probably magnetite, are common in all samples, as is sphene. Accessory zircon and apatite are several times more abundant than average for granitoids of the Yilgarn Block or the Albany-Fraser Province. Allanite is a prominent accessory in all but two of the samples, approaching one per cent in the thin section of sample 29577 B. The allanite, confirmed by x-ray diffraction, is largely metamict but a few grain cores show some optical crystallographic character. Plagioclase extinction angles on (010) in sections cut normal to crystallographic a-axis indicated compositions between An_{30} and An_{35} in all samples.

All samples are allotriomorphic granular; however (001) faces are developed on biotite, and crystal faces are partially developed on zircon, apatite and allanite. All samples are inequigranular and some have coarse insets of microcline. Microcline, especially where coarse-grained is finely perthitic.

CHEMISTRY

Four samples from two localities were analyzed for major elements by chemical methods. The results, together with C.I.P.W. norms, are listed in Table 16. Analyses were performed by the Western Australian Government Chemical Laboratories. Both sample localities are near the presumed northern margin of the monzonite body; one locality (samples 28345 B, C and D) is at the northern margin of Lake Shaster, the other is about 1 km to the northeast.

TABLE 16. MAJOR ELEMENT ANALYSIS

Oxide (%)	28345 B	28345 C	28345 D	29577 B
SiO_2	59·0	59·9	59·4	59·9
Al_2O_3	19·5	18·6	19·0	18·9
Fe_2O_3	1·9	1·7	1·6	2·0
FeO	2·11	2·17	2·28	1·93
MgO	1·1	1·2	1·2	1·1
CaO	2·54	2·06	2·08	2·17
Na_2O	3·10	3·22	3·15	3·36
K_2O	9·1	9·7	9·8	9·0
H_2O^+	0·50	0·40	0·43	0·51
H_2O^-	0·11	0·12	0·12	0·16
CO_2	0·08	0·08	0·07	0·13
TiO_2	0·43	0·47	0·46	0·59
P_2O_5	0·20	0·26	0·26	0·19
MnO	0·06	0·06	0·06	0·07
Total	99·7	99·9	99·9	99·9
C.I.P.W. Norms				
Q	0·00	0·00	0·00	0·04
C	0·65	0·00	0·17	0·43
Or	53·48	57·03	58·15	53·25
Ab	26·23	26·12	23·35	28·43
An	10·79	7·80	8·18	8·70
Ne	0·00	0·61	1·79	0·00
Di	0·00	0·18	0·00	0·00
Wo	....	0·09	....	....
En	....	0·05	....	....
Fs	....	0·03	....	....
Hy	1·69	0·00	0·00	3·72
En	1·05	....	....	2·64
Fs	0·64	....	....	1·08
Ol	2·02	3·46	3·80	0·00
Fo	1·20	2·02	2·08	....
Fa	0·81	1·44	1·73	....
Mt	2·78	2·49	2·29	2·85
Il	0·82	0·89	0·87	1·12
Ap	0·47	0·62	0·62	0·45
Cc	0·18	0·18	0·16	0·30

The composition of analyzed samples is remarkably uniform, in keeping with the uniform petrographic and field characteristics of the rock.

The silica percentage (averaging about 59.5) is abnormally low for a granitoid rock, and potash percentage (about 9.5) is above average. This combination results in C.I.P.W. norms showing a rock very close to silica saturation, again consistent with petrographic observation. Normative quartz (0.04 per cent) is present in a single sample (29577 B), normative olivine appears in three samples (28345 B, C and D) and normative nepheline is present in two samples (28345 C and D). Neither olivine nor nepheline was observed petrographically. Normative ablite:anorthite ratios suggest anorthite contents in the range An_{23} to An_{29}. These are consistent with a-normal extinction angle determinations of An_{30} to An_{35} if some albite is occult in potash feldspar, both in solid solution and, as observed, in perthitic exsolution.

The appearance of nepheline in the norm of some samples qualifies the monzonite as a marginally alkaline rock in the classification of Curry (1976, p.1) even though the silica deficiency seems to be taken up in the mafics.

The monzonite shows little chemical affinity either with analyzed quartz-rich granitoids elsewhere in the region (Thom and others, 1977) or with silica-saturated to weakly oversaturated alkaline granitoids which constitute a part of the granitic suite of the nearby Archaean Yilgarn Block (Gower, 1974; Bunting and Williams, 1976; Lewis and de Laeter, 1978; Lewis and Gower, 1978; and Walker, 1978).

In a plot (Fig. 29) of weight per cent total alkalies against weight per cent SiO_2 the monzonite lies on a trend established by the Yilgarn Block alkaline suite (after Libby, 1978), clearly distinct from a typical calcalkaline trend (Southern California Batholith, Larsen, 1948). Analyses of granitoid rocks from the Ravensthorpe sheet (Thom and others, 1977), though more limited in compositional range than the Californian data, tend to follow the calcalkaline trend of the Californian rocks, distinctly divergent to the alkaline trend of the rocks from the Eastern Goldfields Province and the monzonite at Lake Shaster (Fig. 29). However, in a plot of agpaitic index against solidification index (Fig. 30) with data after Libby (1978) the monzonite plots well clear of the trend of alkaline rocks of the Eastern Goldfields Province. Thus there is no reason, on the basis of these indices, to believe that the monzonite is part of a simple differentiation series related to the Proterozoic granitoids of the area, to the Archaean granitoids of the area, or to the nearby Archaean alkaline rocks. The monzonite may, of course, have been derived from one or another of these suites by secondary differentiation, contamination, or by metasomatic modification of its original composition.

The monzonite is rich in potash. Not only is the absolute K_2O per cent high, but Figure 31 shows that the K_2O:Na_2O ratio in the monzonite is substantially greater than in the agpaitic Archaean alkaline rocks of the area.

PETROGRAPHIC SYSTEMATICS

In the course of study of samples for the Ravensthorpe mapping project, Libby originally identified the monzonite as syenite (Thom and others, 1977). Closer petrographic work on additional samples and chemical analyses completed after the earlier publication suggests that a more appropriate name for the rock is monzonite, though the composition is near the boundary between the monzonite and syenite fields. Available thin sections probably are inadequate to establish the plagioclase:microcline ratio in the body; indeed, the volume per cent of plagioclase derived by point count of three samples, 29577 B, 28345 B and C (34.8, 45.0 and 22.3 per cent respectively) is quite variable, suggesting that the composition of bulk rock is not accurately portrayed by the sections. However, on average the point count supports a monzonitic plagioclase:microcline ratio. The density-adjusted volume per cent of An + Ab in total normative feldspar gives a more stable result, with suggested plagioclase percentages of 40, 36, 34 and 40 per cent, respectively, for samples 28345 B, C, and D and 29557, thus placing the rock, by analysis of norms, firmly in the monzonite field. However, as in the calculation of plagioclase composition from norms, an unknown proportion of the normative albite is in fact resident in alkali feldspar.

In summary, the rock is an andesine (about An_{33}) monzonite with 34 to 38 volume per cent plagioclase and 62 to 66 volume per cent microcline.

CONCLUSIONS

The monzonite at Lake Shaster has a composition not previously reported from other granitic bodies in the area. Chemical trends give no reason to believe that the monzonite is a product of the direct line of magmatic development which has formed associated Proterozoic granitoids, nearby Archaean granitoids, or the Archaean alkaline suite of the

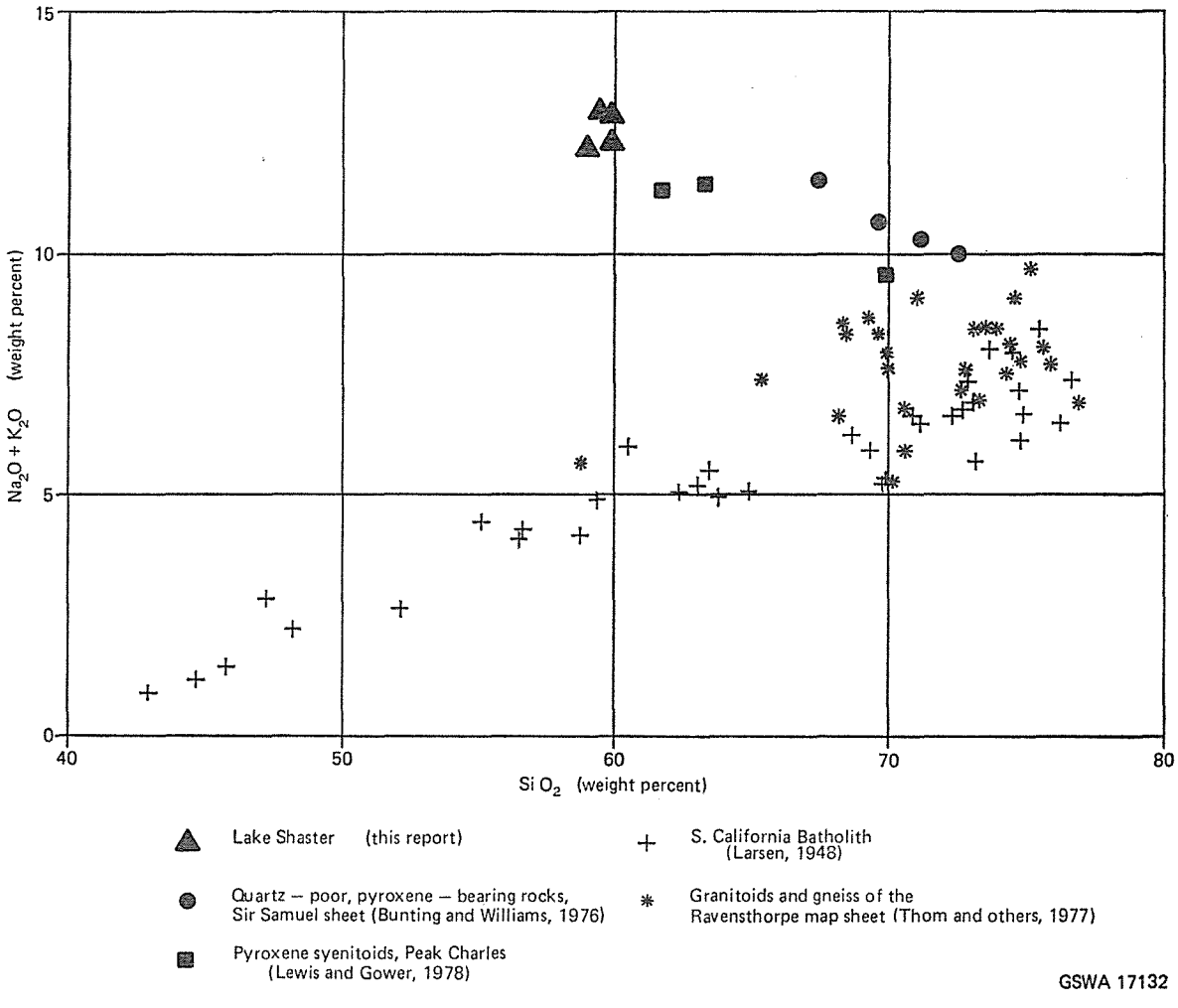

Figure 29 Plot of silica versus alkalis.

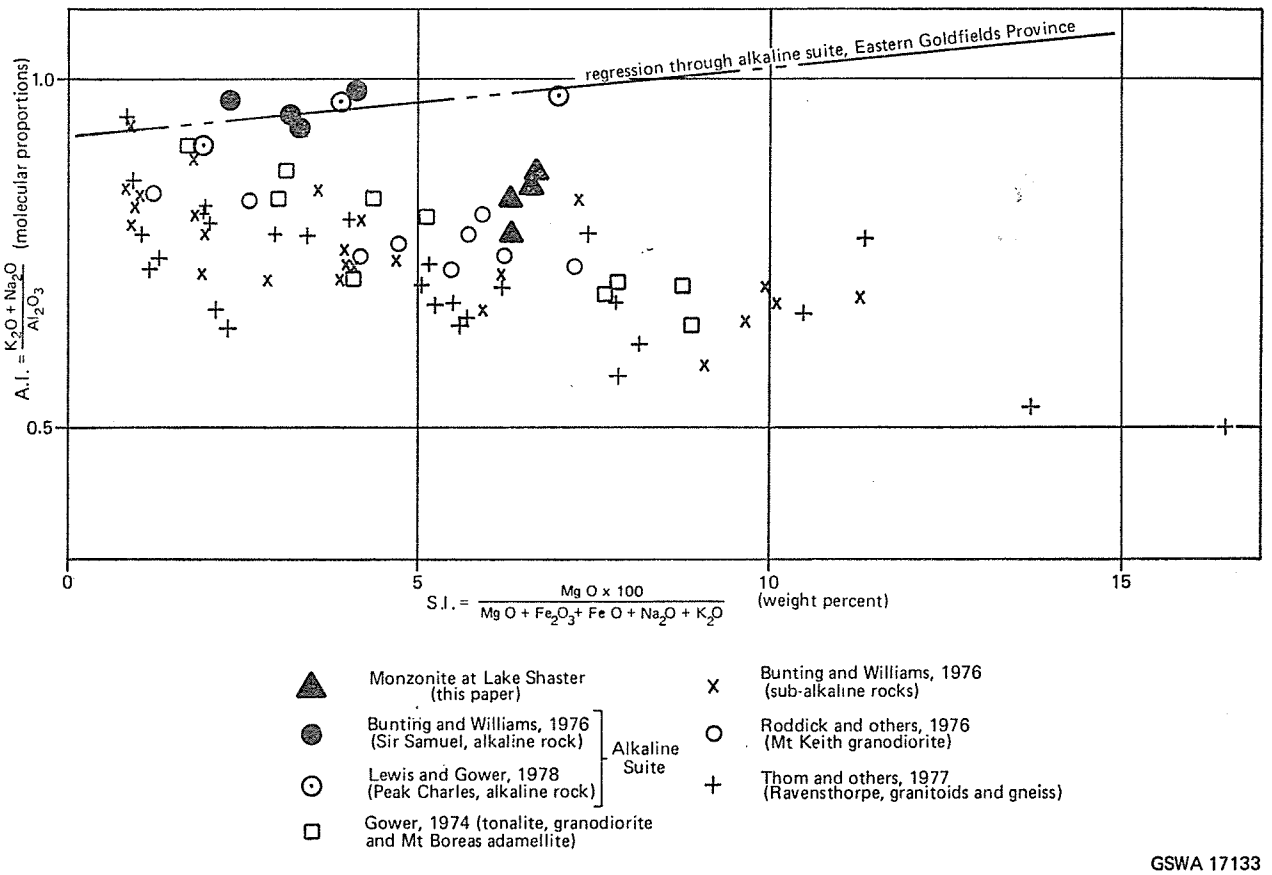

Figure 30 Agpaitic index (A.I.) versus solidification index (S.I.) for Lake Shaster monzonite,two suits of alkaline rock and various granitic rocks from the Eastern Goldfields Province.

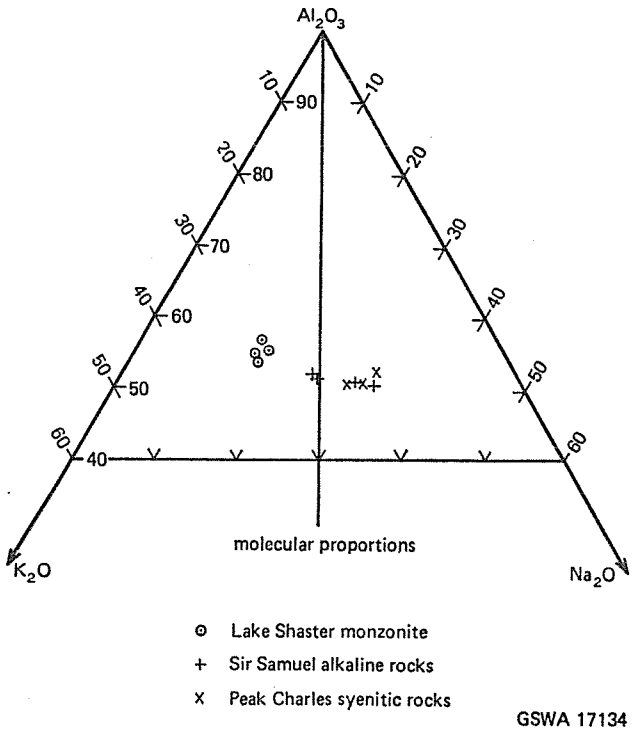

Figure 31 Molecular proportions of Al_2O_3, K_2O and Na_2O in various alkaline granitoids of Western Australia.

Eastern Goldfields Province. However, development from these units by secondary differentiation, contamination, or metasomatic processes is not eliminated.

Miaskitic alkaline affinities are suggested by the alkali and alumina-rich, silica-poor character of the rock, together with abundant zircon and apatite. Despite the apparent homogeneity of the samples examined, syenites undersaturated in silica may be associated with the pluton at a different structural level or at surface level beneath superficial deposits which mostly conceal the pluton.

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PETROLOGICAL EVIDENCE FOR AN UNUSUALLY HIGH ARCHAEAN GEOTHERMAL GRADIENT IN THE WONGAN HILLS AREA, WESTERN AUSTRALIA

by D. F. Blight

ABSTRACT

The mineral assemblage, microcline + andalusite + fibrolite + muscovite + biotite + quartz ± garnet, present in Archaean metapelitic rocks of the Wongan Hills, Western Australia, suggests that physical conditions operating during metamorphism were about 200 MPa pressure at a temperature of about 660°C. This implies an unusually high geothermal gradient of 70°C/km. This high geothermal gradient may well have been caused by the temperature effect of a nearby adamellite body.

INTRODUCTION

During the course of petrological investigations of rocks collected during the regional mapping of the 1 : 250 000 Moora sheet, a mineral assemblage was encountered from which the pressure and temperature of metamorphism could be estimated. This assemblage occurs in diamond drill core donated by Otter Exploration N.L. from their DDH 3 in the southern part of the Wongan Hills (lat. 30° 35′ 19″ S, long. 116° 38′ 25″ E). The Wongan Hills are located approximately 150 km northeast of Perth anl cover an area approximately 20 km long and 6 km wide.

REGIONAL GEOLOGY

The rocks of the Wongan Hills, which have been described by Carter, Low and Lipple (in prep.), constitute part of a belt of Archaean supracrustal rocks. They are composed of metamorphosed and deformed mafic and felsic volcanics intercalated with sediments ranging from banded iron-formations to highly aluminous types. Porphyritic and even-grained Archaean granitoids intrude this sequence. The structure of the area is complex; at least two tectonic events are evident. Presumed Proterozoic dolerite dykes intrude faults and northeast trending fractures. Carter and others (in prep.) suggest a tentative correlation of these Wongan Hills rocks with the "greenstone belts" of the Murchison and Eastern Goldfields Provinces rather than with the Jimperding Metamorphic Belt, some 40 km to the south, previously described by Wilde (1974).

MINERALOGY

The rocks examined from DDH 3 are predominantly metasediments with minor interlayered meta-ultramafics. The metasedimentary assemblages observed are:

(i) microcline (perthitic) + fibrolite + andalusite + muscovite + biotite + quartz ± almandine, with minor tourmaline and sulphide;

(ii) cordierite (altered) + garnet + quartz + biotite + sulphides; and

(iii) quartz + grunerite + sulphides.

The meta-ultramafic assemblage observed is:

(iv) garnet + grunerite + opaques (with minor muscovite and quartz).

Assemblage (i) contains "reaction" textures, which enable a rough estimate to be made of pressure-temperature conditions operating during metamorphism. Rocks of assemblage (i) are composed of large (up to 3.0 mm in size) poikiloblastic crystals of microcline with weakly embayed grain boundaries. The small (0.15 mm) inclusions within the microcline are predominantly quartz, although there is some biotite and muscovite. Between non-abutting microcline grains are ragged (0.4 mm) muscovite flakes and/or laths of biotite or equigranular polygonal mosaics of small (0.2 mm) quartz grains. Scattered throughout the rock are clumps (up to 10 mm) of fibrolite. Fibrolite also occurs as long needles within the microcline and around and within muscovite. In thin section 49162 (Fig. 32a) muscovite can be seen altering to fibrolite via the reaction: muscovite + quartz $\rightleftharpoons$ fibrolite + K-feldspar + H_2O. Garnet, when it forms, occurs as porphyroblasts up to 5 mm in size. Fine-grained tourmaline and opaques are scattered throughout the rock. All specimens examined contained retrograde chlorite. In one thin section (49167-3) retrograde muscovite developing from andalusite can be observed (Fig. 32b).

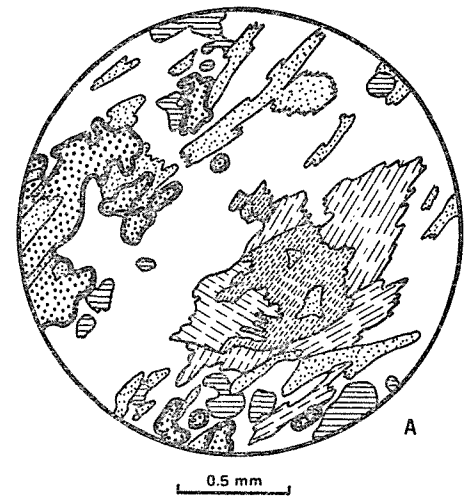

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Figure 32 Line drawings from photomicrographs.
The minerals are andalusite (heavy stipple) biotite (light stipple), muscovite (hatched), fibrolite (dense hatching), quartz (horizontal lines) and microcline (clear). a. 49162 b. 49167-3.

The rock has a strong fabric defined by biotite, and more rarely fibrolite, and the orientation of inclusion trails within the microcline. In parts, this strong fabric is very weakly folded indicating at least two phases of deformation. More commonly, the fibrolite, especially when associated with muscovite, has random orientation suggesting a post-tectonic development. A weak compositional layering, possibly relict sedimentary bedding, is also present.

APPLICATION OF EXPERIMENTAL DATA TO WONGAN HILLS ROCKS

From the assemblage (i) it is possible to place constraints on the pressure-temperature conditions of metamorphism provided that P_{H_2O} (water pressure) = P_{Tot} (total pressure). The rocks at Wongan Hills are thought to satisfy this requirement for the following reasons:

(i) the abundance of hydrous phases;

(ii) the breakdown of muscovite to fibrolite liberates water which should fill available pore space, and unless mass removal of this water from the system takes place the water pressure should be close to, if not the same as, the load pressure; and

(iii) there are no carbonates in the area which could give rise to CO_2, which in turn would reduce the partial pressure of the water in the fluid phase.

Touret (1971), through examination of fluid inclusions within rocks belonging to the sillimanite-muscovite-biotite subfacies of the amphibolite facies from Norway, came to a similar conclusion.

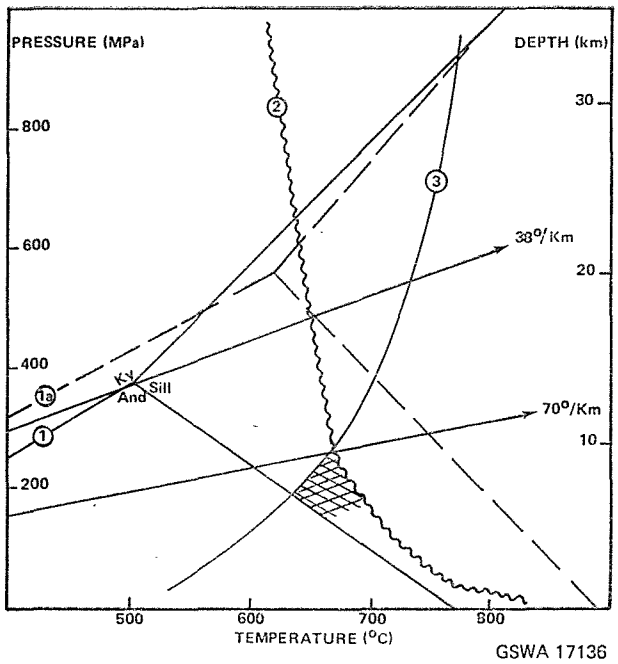

Figure 33 P-T diagram of relevant phases

Curve 1. Andalusite-kyanite-sillimanite (Holdaway, 1971).

Curve 1a. Andalusite-kyanite-sillimanite (Richardson and others, 1969). (note that this andalusite-sillimanite boundary is in the region of a 200°C overstep from that proposed by Holdaway, 1971).

Curve 2. Quartz + albite + orthoclase + $H_2O \rightleftharpoons$ liquid (Winkler, 1967).

Curve 3. Muscovite + quartz $\rightleftharpoons$ K-feldspar + Al_2SiO_5 + H_2O (Winkler, 1967). Note: 100 MPa = 1 kb.

With reference to Figure 33, in which all curves are drawn for the condition of $P_{H2O} = P_{Tot}$, thin section 49162 has co-existing andalusite and sillimanite (fibrolite) and also shows the reaction muscovite + quartz $\rightleftharpoons$ fibrolite + K-feldspar + H_2O. Thus, using the alumino-silicate phase diagram of Holdaway (1971), as suggested by Anderson and others (1977), it could be argued that provided $P_{H2O} = P_{Tot}$, this assemblage formed under conditions corresponding to the intersection of curves 1 and 3, namely 630°C and 200 MPa.

The metastable/stable co-existence of two or more alumino-silicate phases has long been recognised. Fleming (1973, in prep.) has suggested, on textural criteria, that fibrolite may develop from andalusite within the andalusite stability field. In a study of rocks from South Australia, he develops a series of exchange reactions involving biotite for micro-subsystems closed to aluminium to explain the appearance of fibrolite and andalusite and their associated textures. On the other hand, Holdaway (1971) suggests that to form fibrolite from andalusite requires 200°C or more of overstepping, while to form fibrolite from muscovite would require an overstepping of the order of only 10°C. Thus, in such cases rock containing andalusite and fibrolite would be in the sillimanite field: the andalusite is metastable.

Holdaway's (1971) hypothesis is preferred for rocks from the Wongan Hills. Examination of textures shows that the fibrolite develops from muscovite (Fig. 32a) *without* the involvement of biotite. Furthermore, if the fibrolite present in these rocks had formed in the andalusite stability field, the resulting geothermal gradient would be even higher than that suggested by this study (Fig. 33).

Assemblage (i) is most likely a disequilibrium assemblage in which the fibrolite developed from muscovite on the high temperature side of curve 3 in the sillimanite stability field (Fig. 33).

Further constraints may be placed upon the pressure-temperature conditions of metamorphism by curve 2 (Fig. 33), which indicates the beginning of melting of a hydrous granite. No evidence for melting was observed in metamorphic rocks of granitoid composition from the Wongan Hills, either in field observations (e.g. no migmatites, Lipple, pers. comm.) or by microscope examination (compare with Mehnert, Busch and Schneider, 1973). Thus these rocks have formed on the low-temperature side of curve 2.

The presence of andalusite requires a geothermal gradient of 38°C/km or more (Fig. 33), and consequently these rocks must have formed on the low-pressure side of such a geothermal gradient.

From the above-mentioned observations, the estimated pressure-temperature conditions of metamorphism of rocks from the Wongan Hills are 140-240 MPa and 640-680°C (shaded area in Fig. 33).

This implies that the rocks from the Wongan Hills were metamorphosed under an unusually high geothermal gradient of 70°C per kilometre. This high gradient may, in part, be due to an Archaean geothermal gradient, which may have been as high as 40-50°C/km (Stewart, 1977), but is more likely to be due to the presence of an external heat source nearby, such as an igneous body. Such a body, in the form of an equigranular, medium to coarse-grained biotite adamellite, crops out approximately 1 km south of DDH 3 (Carter, Low and Lipple, in prep.). This body may well have locally provided the heat to impart the apparently anomalous geothermal gradient, and presumably was responsible for the breakdown of the muscovite to fibrolite.

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HIGH-GRADE RETROGRESSIVE METAMORPHISM AND MINERAL CORONA DEVELOPMENT IN BASIC ROCKS OF THE COLLIE AREA, WESTERN AUSTRALIA

by D. F. Blight

ABSTRACT

Gneisses in parts of the Collie 1:250 000 Sheet were sporadically metamorphosed to the granulite facies by heating and dehydration associated with the intrusion of dolerite dykes. The dykes were emplaced near the end of a period of major tectonic activity while the regional temperature was still high. As the contact-heated gneisses and associated dolerites cooled to a regional temperature corresponding to the amphibolite facies, hornblende, garnet and epidote coronas were locally generated, especially where preferred solution paths facilitated chemical transfer.

INTRODUCTION

During the course of regional mapping and the geological investigations of proposed dam sites on the Collie 1:250 000 Sheet, a few isolated rocks with mineral assemblages indicating granulite facies metamorphism were collected. A more comprehensive sampling and petrological programme was initiated to examine the extent of these granulite facies rocks and to attempt to determine the cause of their occurrence. Because of the extensive development of a laterite profile on the Darling Plateau, fresh rock is generally only exposed along stream-incised valleys. Thus, the two areas around which this investigation was centred are:

(1) along the banks of the Brunswick River south of the Mornington Fire Tower (lat. 33°12'S, long. 115°57'E), and

(2) along the banks of the Collie River near Mount Lennard (lat. 33°20'S, long. 115°53'E).

The area studied is part of a north-trending, probable Archaean, polytectonic gneiss belt (possibly a mobile zone), which grades eastward into a relatively undeformed porphyritic adamellite. Numerous coarse-grained dolerites intrude this sequence. A description of these rocks from Collie Sheet is detailed below.

GNEISSES

The gneisses, which commonly show indications of two deformative events, and which are commonly layered, have a granoblastic, equigranular, polygonal to interlobate texture. As in other high-grade metamorphic terrains, acidic rocks dominate the more basic ones. The majority of the rocks collected showed mineralogical assemblages indicative of the amphibolite facies. In basic rocks the assemblages noted were plagioclase + hornblende + opaques ± quartz ± sphene ± clinopyroxene; and in acid rocks the assemblages were quartz + plagioclase + microcline + biotite ± hornblende ± apatite ± opaques. No evidence was found which might suggest that the amphibolite-facies rocks are downgraded granulites.

Some of the rocks examined contained hypersthene, whose appearance in basic rocks marks the incoming of the granulite facies (Binns, 1969). The majority of granulites from the area are leucocratic. These range in composition from granodiorite to quartz diorite and have the mineral assemblage quartz + plagioclase + biotite + hypersthene + opaques and minor apatite. A few basic granulites were noted (e.g. 48465); these have a disequilibrium assemblage of plagioclase + hypersthene + clinopyroxene + hornblende + garnet + opaques, some of these minerals forming as coronas.

From field and petrological examination, the granulite facies assemblages were found to be very localised, occurring within a regional amphibolite facies terrain. Furthermore, when the locations of the granulite-facies rocks were examined closely it was found that they occurred adjacent to, or nearby (less than 100 m), the coarse-grained dolerites which intrude the region.

DOLERITES

These basic intrusive igneous rocks have a relict subophitic texture overprinted by a static metamorphism. The apparent, primary igneous mineralogy, still partly discernible in thin sections, was labradorite + clinopyroxene + orthopyroxene + opaques and sparse apatite. The subsequent, static, retrograde metamorphism produced diverse minerals, which are commonly manifest as reaction coronas.

CORONITES

Rocks containing minerals with coronas, referred to as coronites, develop from static metamorphism of the basic assemblage (both dolerites and granulites). Hornblende associated with varying amounts of opaques and vermicular quartz, is produced from both types of pyroxenes (Fig. 34); the alteration progressed from the rims of the pyroxene grains inward. This alteration of pyroxene can be seen in all stages: in some cases, hornblende occurs as corona shells about the pyroxene. These hornblende coronas have partly replaced adjacent plagioclase grains; the replacement is apparently greater where the coronas have formed about orthopyroxene. The iron liberated by this reaction commonly forms opaques, frequently as oriented reticulated masses (Fig. 34a) in the cores of hornblende masses, especially when the whole pyroxene grain has altered to hornblende. It may be that these opaques formed from the alteration of hypersthene, a more iron-rich pyroxene, but in any case, the shape of these reticulated opaques is presumably the result of the crystallographic control that the host pyroxene exerts on the exsolution of the opaques. In some thin sections, the presence of microscopic blebs and rods of exsolved opaques imparts a dusty appearance to the pyroxenes. Rarely, some recrystallization has taken place within the pyroxene core so that the hornblende seems to have formed from a secondary pyroxene.

Thin coronas of garnet and varying amounts of vermicular quartz commonly occur around the hornblende masses and shells (Fig. 34b). The coronas abut plagioclase grains, which are zoned progressively from labradorite in the core to andesine adjacent to the garnet. A similar zoning of plagioclase has been noted in coronites studied by Griffin and Heier (1973) and by Starmer (1969). Plagioclase laths are commonly cloudy in the cores, but clear in the less calcic rims.

The garnet corona development within a rock tends to occur in patches or in elongate trails (Fig. 34c). Whether these elongate trails are a linear or planar feature is not known. Rarely, the garnet is present as coronas directly around pyroxene grains.

In two samples (52401 and 52402) the corona structures are augmented by discontinuous patches of epidote-quartz symplectite between the garnet and plagioclase.

GENESIS OF CORONITES

Coronites have been studied since the early work of Sederholm (1916), and the general consensus has been that they are formed by subsolidus metamorphic reactions rather than by magmatic reactions. It is now generally accepted that they result from deuteric alteration during the cooling of an igneous rock or a high temperature metamorphic rock. Griffin and Heier (1973), who have given a most comprehensive account of coronites, emphasise that such cooling must take place " . . . at *moderate to high pressures* in order that the rock should pass through the P-T curve(s) of the appropriate reaction(s) at temperatures high enough to allow reasonable reaction rates" (Author's italics).

Coronas similar to those described above have been observed in basic rocks from Uganda (Hepworth, 1964; de Waard, 1967), Scandinavia (Starmer, 1969; Griffin and Heier, 1973), Spain (Hubregtse, 1973) and New Zealand (Blattner, 1976).

De Waard (1967) suggests that the development of the hornblende and garnet coronas about orthopyroxene occurs in response to the reaction:

$$\text{Opx} + \text{Alb} + \text{An} + \text{H}_2\text{O} \rightleftharpoons \text{Hbd} + \text{Gnt} + \text{Qtz}$$

Hepworth (1964), on the other hand, suggests that in many cases the orthopyroxene alters to hornblende and garnet via a phase of secondary clinopyroxene. The coronites

from Collie and New Zealand show that the hornblende appears to develop directly from both orthopyroxene and clinopyroxene, and Hepworth admits that the generation of a secondary clinopyroxene is not always evident in the Ugandan rocks.

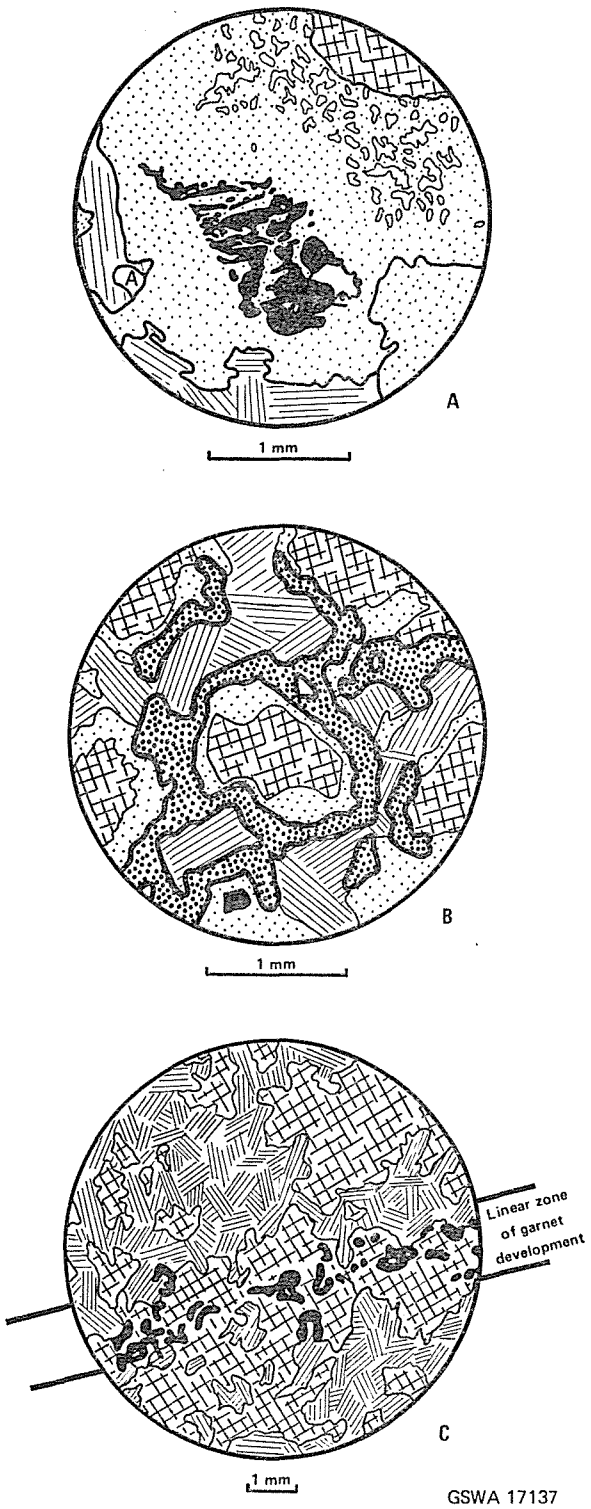

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Figure 34 a Hornblende-quartz rim about clinopyroxene core with "crystallographic" controlled exsolved opaques. (50367C)
(Key : cross hatching - clinopyroxene, light stipple - hornblende, dense stipple garnet, hatching - plagioclase, solid - opaques, clear - quartz, A - apatite).
Figure 34 b Garnet corona about hornblende with clinopyroxene core; garnet abuts plagioclase (50370A)
(Key : same as Fig. a).
Figure 34 c Linear zone of garnet corona developed (50370A)
(Key : cross hatching - pyroxene and hornblende, solid - garnet, hatching - plagioclase).

The coronites from Collie provide a range of textures which suggest that the formation of garnet coronas passes through an intermediate stage. Hornblende is produced first, from which the garnet forms, rather than the hornblende and garnet forming at the same time. Thus, two reactions are postulated for the ultimate formation of the hornblende-garnet coronas:

(1) Cpx/Opx + Plag $\rightleftharpoons$ Hbl + Qtz + Fe oxides

(2) Hbl + Plag $\rightleftharpoons$ Gnt + Qtz + Fe oxides

These two reactions can be combined to give the overall reaction:

(3) Cpx/Opx + Plag $\rightleftharpoons$ Hbl + Gnt + Qtz

The variation in textures seen in the rocks from Collie show the first of these two reactions frozen in various stages of completion (e.g. Fig. 34d shows reaction (1) and Fig. 34b shows reactions (1), (2) and (3)). Where pyroxene is mantled directly by garnet with no intervening hornblende it is assumed that hornblende generated by reaction (1) is all used up in the production of garnet by reaction (2). Blattner (1976) also came to a similar conclusion and postulated similar reactions to (1) and (2) above to produce hornblende and garnet mantles about pyroxene.

The production of the epidote-quartz symplectites is a result of the reaction:

(4) Plag + Gnt + Fe oxides + H_2O $\rightleftharpoons$ Epid + Qtz

which is nearly independent of temperature above about 200 MPa water pressure (Winkler, 1967, p. 113).

Without the aid of chemical analyses it is impossible to write balanced equations for reactions (1) and (2). Furthermore it is possible that during the corona development the system was chemically open. Evidence for an open system is two-fold. Firstly, within the same thin section, the amount of quartz produced by the alteration of pyroxene to hornblende, and hornblende to garnet, is variable. This can be accounted for if SiO_2 were allowed to migrate out of the system. Secondly, the patchy development of the garnet coronas is very similar to that described by Blattner (1976). He attributes this fact to the formation of garnet along a system of joint planes within the host rock (metadiorite) by means of cation migration along channels thus created by the joints. Elements were lost to these channels, " . . . Na (and K) preferentially, and Al least so". Thus, it is possible that the production of hornblende and garnet coronas in coronites of the Collie area involved fluid phases which facilitated the movement of ions and enabled Ca, Na, Al, and Si to be removed from the system.

Figure 35 is an idealized sketch showing a possible cooling path for the dolerites and basic granulites. Corona development takes place as this cooling curve intersects each

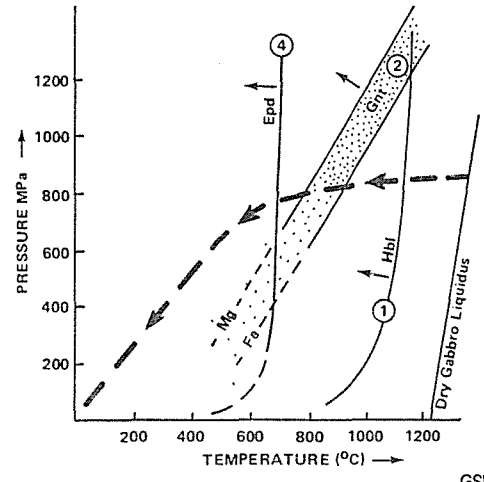

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Figure 35
Idealized sketch of probable cooling path for the dolerites and basic granulites
(1) First appearance of hornblende for $P_{H_2O} = P_{Tot}$ (Touret, 1971)
(2) First appearance of garnet (Green and Ringwood, 1967)
(3) First appearance of epidote for $P_{H_2O} = P_{Tot}$ (approximate position from Winkler, 1967)
Passing through these curves gives rise to successive coronas of hornblende, garnet and epidote.

particular upper-stability-limit curve of the appropriate mineral. While these particular stability curves may not be strictly appropriate for this particular system (e.g. P_{H2O} of the system may not be the same as P_{Tot}) the gross features will be comparable.

The similarity of the basic granulites to the metamorphosed dolerites, both in the development of the coronites and in their close spatial relationship, suggests that the localised occurrence of the granulite-facies assemblage of the Collie area is a result of rocks under amphibolite facies conditions being locally heated by adjacent dolerite dykes into P-T conditions suitable for the development of granulite facies mineralogy.

CONCLUSIONS

Granulite facies rocks were sporadically developed in parts of the Collie 1:250 000 Sheet (between Collie and Bunbury, and between Collie and Harvey), in response to the deep seated (pressure between 500 and 1 000 MPa) intrusion of dolerite dykes towards the end of a major tectonic event. The heat of the dykes dehydrated rocks which were under amphibolite facies conditions, and these elevated temperatures locally produced "contact" granulite facies assemblages.

As the rocks slowly cooled to amphibolite-facies conditions in order to equilibrate with the surrounding material, hornblende, garnet and epidote coronas developed. With this temperature fall, hydrous fluid phases capable of carrying cations moved along preferred solution paths facilitating the garnet development and giving rise to the sporadic, patchy, and linear occurrence of the garnet.

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DISCOCYCLINID FORAMINIFERS FROM WESTERN AUSTRALIA

by A. E. Cockbain

ABSTRACT

Nearly a dozen discocyclinid species have been previously recorded from the Giralia Calcarenite (Carnarvon Basin). Re-examination of the original material does not confirm this taxonomic diversity. Two species, both previously recognized, are described and illustrated from the Giralia Calcarenite on the basis of matrix-free specimens; they are *Discocyclina* cf. *discus* and *Asterocyclina* cf. *stella*. *A.* cf. *hornibrooki* and *D.* sp. are described and illustrated from the Werillup Formation (Bremer Basin).

INTRODUCTION

Discocyclinid foraminifers have long been known to occur in Eocene rocks in Western Australia, and nearly a dozen species have been recorded in the literature. The purpose of this note is to review the previous identifications and to illustrate, for the first time, oriented thin sections cut from matrix-free specimens. Localities mentioned in the text are shown in Figure 36.

PREVIOUS RECORDS

Chapman and Crespin (1935) recorded and illustrated the first discocyclinids (and first positively identified Eocene rocks) from Western Australia. Their samples came from two localities in the Giralia Calcarenite, one on the east flank and one on the west flank of the Giralia anticline. The species identified were:

Asterocyclina cf. *stellata* (d'Archiac)
Actinocyclina cf. *aster* Woodring *(sic)*
Discocyclina dispansa var. *minor* Rutten
D. douvillei (Schlumberger)
D. pratti (Michelin)

Further records of discocyclinids from the Giralia Calcarenite in the Giralia anticline were given by Condon and others (1956), based on identifications by Edgell (1952). The following species were identified but not figured:

Asterocyclina stella Gümbel
A. stellaris (Brunner)
Discocyclina cf. *chudeaui* (Schlumberger)
D. discus (Rutimeyer)
D. fritschi (Douville)
D. cf. *turnerensis* Vaughan

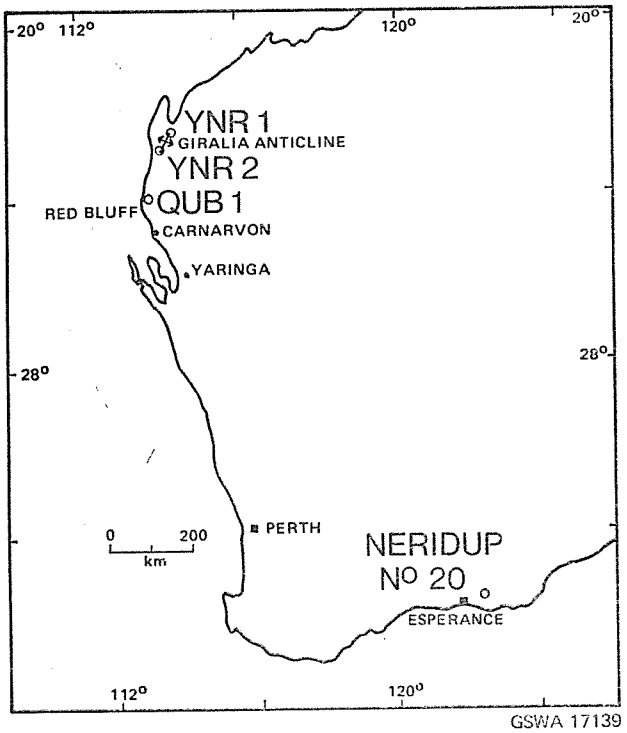
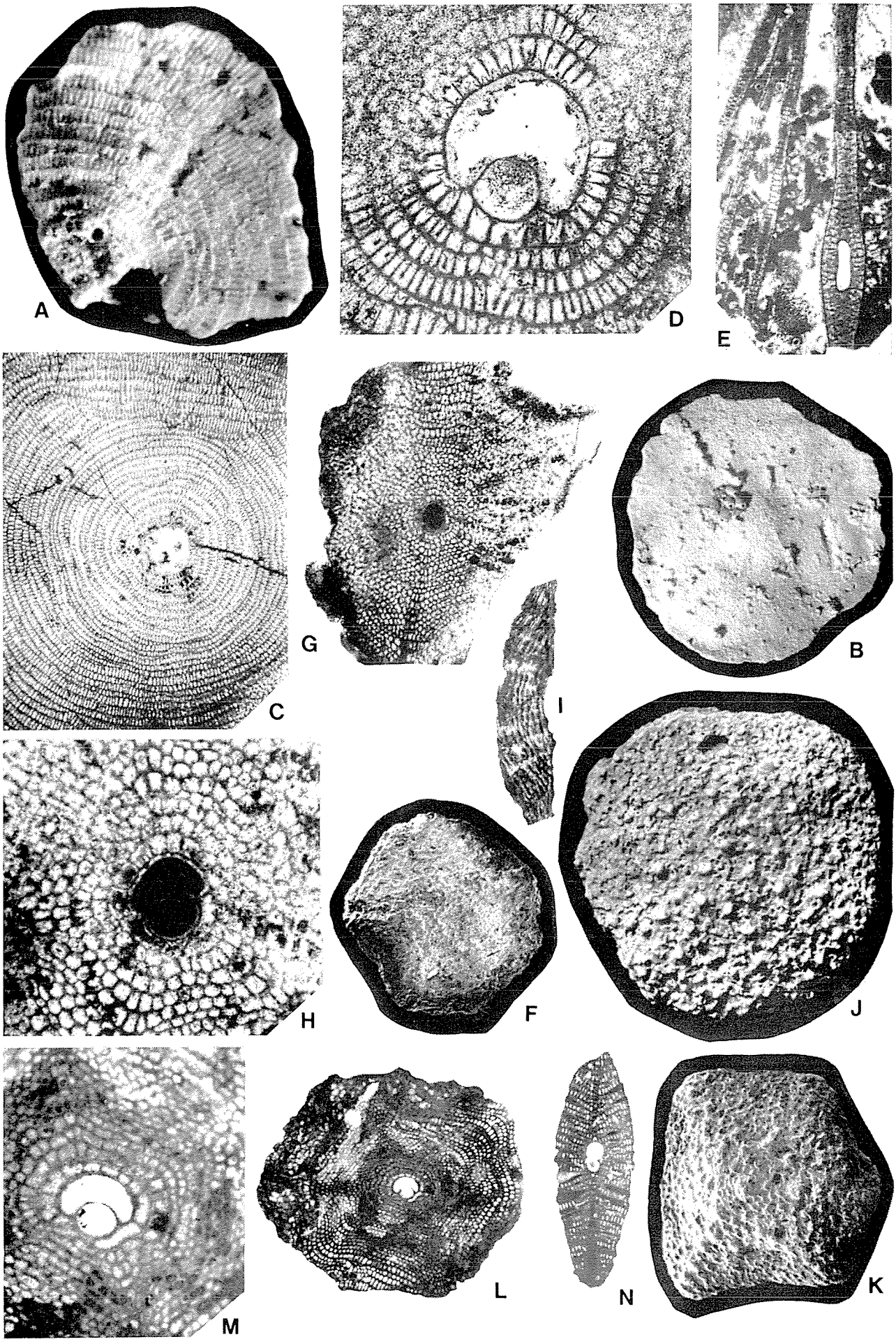


Figure 36 Locality map



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Konecki and others (1958) recorded *Asterocyclina* cf. *aster* and *Discocyclina* sp. (identified by Crespin) from the Giralia Calcarenite near Yaringa North (now called Yaringa) homestead. Both *Discocyclina* and *Asterocyclina* have been identified from Red Bluff (Crespin, 1955) from the same formation.

The only other discocyclinid record from Western Australia known to me is that of *Asterocyclina* from the Plantagenet Group in the Bremer Basin near Esperance (Cockbain, 1967).

RE-EXAMINATION OF GIRALIA ANTICLINE SPECIMENS

The original thin sections which Chapman and Crespin used to illustrate their paper are in the Commonwealth Palaeontological Collection housed in the Bureau of Mineral Resources in Canberra. Through the courtesy of the Bureau, I have been able to examine these slides. There are three slides with discocyclinids, and as can be seen from Chapman and Crespin's (1935, pl. 3, 4) illustrations, most of the specimens are axial sections with rare but poor equatorial sections (e.g. their pl. 4, fig. 8). All that can be confidently said from these thin sections is that discocyclinids including *Asterocyclina* are present.

Edgell's slides, on which Condon and others' (1956) faunal list is based, are also in the Bureau of Mineral Resources collection. However, a letter (July 1977) from the Bureau states that ". . . we cannot now identify the particular sections from which Dr Edgell identified the species . . .". I have examined some 30 thin sections from the Giralia Calcarenite in the Bureau collection which were used by Edgell. Most are randomly cut thin sections which show axial and equatorial sections of discocyclinids, a few of which can be recognized as *Asterocyclina*. Four slides are oriented sections of matrix-free *Asterocyclina*, one axial and three equatorial; three of them are labelled *'Asterocyclina aster'*, a name which does not occur in the published faunal list. *A. aster* is a North American species and similar forms from the Giralia Calcarenite are identified below as *A.* cf. *stella*.

MATRIX-FREE SPECIMENS

The difficulties of identifying larger foraminifers in random thin sections are well known. Indeed, Adams and Belford's (1974, p. 499) remarks on *Eulepidina* apply equally well to the discocyclinids. "The specific characters on which the numerous nominal species have been based need to be evaluated statistically on the basis of matrix-free material. Until this has been done it will not be possible to name specimens occurring in hard limestones satisfactorily". Matrix-free specimens of discocyclinids have been obtained from a number of samples and are described below. The localities from which the samples came are listed in Table 17.

SYSTEMATIC PALAEONTOLOGY

The systematics of discocyclinid foraminifers is in need of revision, and until this is done it is difficult to know how variable the various species are. Because of this, the species discussed below are placed in open nomenclature.

Discocyclina sp. cf. **D. discus** (Rutimeyer)
Figure 37, B, C, D, E

cf. 1850 *Orbitolites discus* Rutimeyer; p. 115, pl. 5 (not seen)

cf. 1958 *Discocyclina discus* (Rutimeyer): Neumann; p. 90, pl. 14, fig. 1-8; pl. 15, fig. 1, 2; pl. 27, fig. 3, 4; text-fig. 25.

Material: F9776 (6 sectioned specimens) from YNR1; F9774 (15 specimens, 5 sectioned) from YNR2; F9775 (8 sectioned specimens) from QUB1; all from Giralia Calcarenite, Middle and Upper Eocene.

Description: A flat thin discocyclinid ranging in diameter from 6 to 16 mm; maximum thickness 1.8 mm. The surface is smooth or finely pustulose. There is a low swelling at the centre of the disc in some specimens, and a slight pimple at the centre in others. The nucleoconch is eulepidine with the following dimensions:

Specimen No.	Protoconch		Deuteroconch		Nucleoconch overall length
	length	width	length	width	
F9774/2	180	155	230	425	415
F9774/3	....	....	....	450	450
F9774/4	....	....	....	475	490
F9774/5	....	....	....	750	575
F9775/4	155	200	300	455	455
F9775/5	175	180	250	415	430
F9775/6	....	....	....	....	500
F9776/3	....	....	....	....	615
F9776/4	190	275	315	575	540

All measurements in μm

TABLE 17. LOCALITY DATA

Fossil Locality No.	Latitude south	Longitude east	Locality	Formation	Collector and GSWA Fossil No.
			Yanrey 1:250 000 map sheet		
YNR 1	22° 37′	114° 17′	Giralia anticline, east flank; north end	Giralia Calcarenite (base)	W. J. E. van de Graaff, 1975 F9394, F9776
YNR 2	22° 55′ 30″	114° 02′	Giralia anticline, west flank; near Cardabia No. 10 bore	Giralia Calcarenite (middle); type section	J. Backhouse, D. J. Belford, 1969; F9774
			Quobba 1:250 000 map sheet		
QUB 1	24° 02′	113° 25′ 30″	Red Bluff	Giralia Calcarenite (near top)	P. D. Denman, A. E. Cockbain, 1977; F9775, F9778
			Esperance 1:250 000 map sheet		
....	33° 40′	122° 17′	Neridup No. 20 borehole; 72 km east of Esperance	Werillup Formation	F6425 (30·5 m), F6427 (35 m), F9777 (35 m)

Figure 37 A - *Discocyclina* sp., Werillup Formation, Neridup No. 20 bore, 35 m, exterior (worn), F9777; x40.
B, C, D, E - *Discocyclina* cf. *discus*, Giralia Calcarenite from localities YNR2 and QUB1. B - exterior, F9774/6 (YNR2); x4.
C - equatorial section, F9774/3 (YNR2); x20.
D - equatorial section, F9775/5 (QUB1); x60.
E - axial section, F9775/3 (QUB1); x20.
F, G, H, I - *Asterocyclina* cf. *stella* Giralia Calcarenite from locality YNR1.
F - exterior, F9394/23; x20. G, H - equatorial section, F9394/1; G, x20; H, x60. I - axial section, F9394/4b; x30.
J, K, L, M, N - *Asterocyclina* cf. *hornibrooki* Werillup Formation, Neridup No. 20, 30.5 and 35 m. J - exterior, F 6425/2 (30.5m); x20.
K - exterior, F 6427/14 (35m); x20. L, M - equatorial section, F6427/1 (35 m); L, x20; M, x60. N - axial section, F6427/4 (35 m); x20.

Periembryonic chambers are slightly larger than the other equatorial chambers. The primary auxiliary chambers (i.e. those adjacent to the wall separating the protoconch from the deuteroconch) are similar in size to the other periembryonic chambers. There are 3-4 periembryonic chambers in contact with the protoconch.

Lateral chambers are difficult to make out; there seem to be no more than 10 layers on either side of the equatorial layer in the centre.

Remarks: The overall test shape and appearance of the nucleoconch recall *D. discus;* however in that species the nucleoconch is very much larger. Discocyclinids with a nucleoconch of comparable size with the Giralia form (e.g. *D. sella*) do not have the same arrangement of periembryonic chambers. Those with similar periembryonic chambers (e.g. *D. dispansa*) have a fat test.

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Discocyclina sp.

Figure 37A.

Material: F9777, Werillup Formation, Plantagenet Group; Upper Eocene; Neridup No. 20 borehole, 35 m.

Remarks: One worn fragment of a large lenticular foraminifer, which when complete would have had a diameter of around 10 mm, has the typical discocyclinid pattern of equatorial chambers. The genus has not been recorded previously from the Plantagenet Group.

Asterocyclina sp. cf. **A. stella** (Gümbel)

Figure 37 F, G, H, I.

cf. 1861 *Hymenocyclus stella* Gümbel; p. 543 (not seen)

cf. 1958 *Asterodiscus stella* (Gümbel): Neumann; p. 112, pl. 28, fig. 1-6, text-fig. 36.

Material: F9394 (22 sectioned specimens) from YNR1; F9778 (one microspheric form, questionably assigned to this taxon) from QUB1; Giralia Calcarenite, Middle and Upper Eocene. Specimens are frequently ferruginized and it is difficult to make adequate sections showing internal features.

Description: Lenticular forms from 1.3 to 3.8 mm in diameter and between 0.5 and 0.75 mm in thickness. They may be circular or polygonal in outline and the surface is pustulose. The nucleoconch is bilocular to slightly nephrolepidine with the following dimensions:

Specimen No.	Protoconch		Deuteroconch		Nucleoconch overall length
	length	width	length	width	
F9394/1	140	150	105	225	250
F9394/4a	150	155	95	200	265
F9394/5	....	140	....	210	240
F9394/8	....	180	....	215	245
F9394/9	....	100	....	140	195
F9394/10	180	190	150	275	315

All measurements in μm

The periembryonic chambers are difficult to make out. They seem to completely encircle the nucleoconch, with the primary auxiliary chambers being more tangentially elongated than the other chambers. Lateral chambers are distinct and up to 10 layers occur on either side of the nucleoconch.

Remarks: The preservation of the nucleoconch and surrounding chambers makes identification difficult. The specimens most closely resemble *A. stella* with which they are compared.

Asterocyclina sp. cf. **A. hornibrooki** Cole

Figure 37 J, K, L, M, N.

1967 *Asterocyclina* sp. Cockbain; p. 68

cf. 1967 *Asterocyclina hornibrooki* Cole; p. 6, pl. 1, fig. 1-12; pl. 2, fig. 1, 5, 6, 8, 10.

Material: F6425 (about 50 specimens), F6427 (about 50 specimens, 12 sections); Werillup Formation, Plantagenet Group, Neridup No. 20 borehole, 30.5 m and 35 m respectively.

Description: The specimens are all small (from 1.1 to 3.2 mm in diameter), lenticular (up to 1.4 mm thick), with no clear differentiation into umbo and flange. Some are circular in outline, others somewhat polygonal. The surface is pustulose. The nucleoconch is nephrolepidine with the following dimensions:

Specimen No.	Protoconch		Deuteroconch		Nucleoconch overall length
	length	width	length	width	
F6427/1	100	125	80	230	195
F6427/2	165	195	115	275	275
F6427/13	140	190	115	290	260

All measurements in μm

The periembryonic chambers completely encircle the nucleoconch in one specimen; in another they seem to be interrupted at the base of the protoconch where the second ring of equatorial chambers is in contact with the nucleoconch wall. Lateral chambers are distinct and there are up to 10 layers on either side of the nucleoconch.

Remarks: The specimens most closely resemble the New Zealand species *A. speighti* and *A. hornibrooki* (Cole, 1962, 1967). In *A. hornibrooki,* the periembryonic chambers completely encircle the nucleoconch, while in *A. speighti* they are interrupted and the first complete ring of equatorial chambers is the third according to Cole (1962, p. 347), although his illustrations are not clear and this feature may be variable. The lateral layers of chambers of the Neridup specimens are more in accord with those of *A. hornibrooki* (which has 8-15 layers) rather than *speighti* (with 16-17) and are less regularly arranged than in *A. speighti.* How variable these characters are is uncertain. For the present these specimens are compared with *A. hornibrooki.*

DISCUSSION

The large number of discocyclinid species previously recorded from the Giralia Calcarenite is not confirmed by this study, although admittedly only a small amount of material has been examined. Only two species can be identified from matrix-free material and both have been recorded previously. The species *D.* cf. *discus* and *A.* cf. *stella* are compared with forms which are predominantly European in their distribution and occur in Middle and Upper Eocene rocks (Neumann, 1958).

The Werillup Formation is of Late Eocene age and *A. hornibrooki* is known from rocks of this age in New Zealand (Cole, 1967). The presence of a New Zealand species of *Asterocyclina* in the Esperance area is in agreement with the evidence of the other benthonic foraminifers, which Backhouse (1970) points out are similar to those recorded by Dorreen (1948) from the west coast of the South Island. The occurrence of *Discocyclina* in the Esperance area is the most southerly record of the genus known to me.

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ACACIELLA cf. *AUSTRALICA* FROM THE SKATES HILLS FORMATION, EASTERN BANGEMALL BASIN, WESTERN AUSTRALIA

by Kathleen Grey

ABSTRACT

The stromatolite group *Acaciella* Walter, previously known only from the Late Proterozoic and Cambrian in Australia, occurs in the late Middle Proterozoic Skates Hills Formation in the eastern part of the Bangemall Basin. The Western Australian form closely resembles *Acaciella australica* (Howchin) from the Late Proterozoic Bitter Springs Formation of the Amadeus Basin in central Australia.

INTRODUCTION

Stromatolitic carbonates are an important feature of the western and northern facies of the Bangemall Basin. Although stromatolites are abundant, taxonomic diversity is low, the main forms present being *Baicalia capricornia* and *Conophyton garganicum australe,* both recorded by Walter (1972). Carbonates are less common in the eastern facies, but a stromatolitic dolomite, containing a form not known from the western and northern facies, occurs near the top of the Skates Hills Formation, a basal unit in the Madley and Trainor 1 : 250 000 Sheet areas (Williams and others, 1976).

The Skates Hills Formation consists of a succession of conglomerate, interbedded sandstone, shale, and siltstone capped by a dolomitic unit containing several stromatolitic biostromes. Samples of cumulate and columnar stromatolites were collected from three localities during regional mapping by A. T. Brakel and R. E. J. Leech (Fig. 38). Samples (F9828 and F9829) from locality TRN1 consist of cumulate forms only, but extremely well-preserved columnar specimens were collected from localities TRN2 (F9830 and F9831) and TRN3 (F9832).

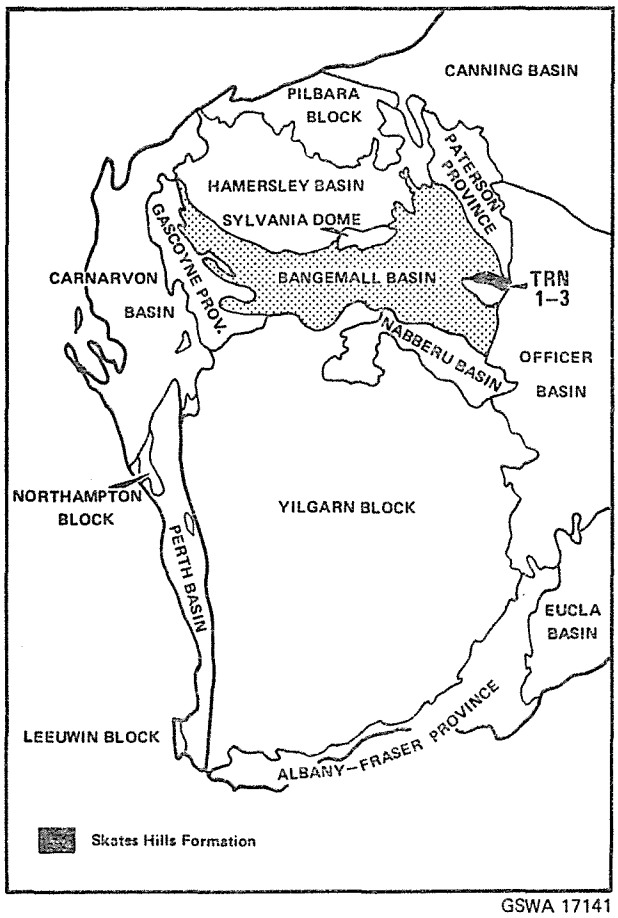

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Figure 38 Regional setting of the Bangemall Basin showing stromatolite localities in Skates Hills Formation

Because only relatively small samples were collected it is difficult to determine the diversity shown by the columns. However, the material which is available shows the characteristics of the group *Acaciella* Walter. Columns are nearly straight, parallel and subcylindrical, with numerous low bumps, some cornices and peaks, and small areas of wall occurring infrequently. The Skates Hills specimens are similar to the type-form *Acaciella australica* (Howchin), described from the Amadeus Basin by Walter (1972), but show more frequent bridging, and, from the specimens available, show less diversity of column shape than *Acaciella australica.*

AGE

The age-range of *Acaciella* is from less than 1 000 m.y (Late Riphean) to Early Cambrian (Preiss *in* Walter, 1976, p. 369). The precise age of the Skates Hills Formation is uncertain. Geochronological ages for the Bangemall Group have been obtained from only three sources. A poor Rb/Sr isochron of about 1 080 m.y. was obtained from the Mount Palgrave felsic rocks by Compston and Arriens (1968). These authors also obtained a Rb/Sr age of 1 080 ± 80 m.y. from shale in the Curran Formation. The stratigraphic relationship of the Skates Hills Formation to these occurrences is not clear.

More recently, Gee and others (1976) reported a Rb/Sr age of 1 098 ± 42 m.y. from an altered rhyolite from the lower part of the Bangemall Group near Tangadee. The rhyolite occurs in the Coobarra Formation (Brakel and Muhling, 1976), which underlies the Backdoor Formation. The Backdoor Formation is considered by Williams and others (1976) to be a possible facies equivalent of the Skates Hills Formation. The maximum age of the Skates Hills Formation is therefore less than about 1 100 m.y. No minimum age has been determined, but it is probably in the region of 1 000 m.y.

Acaciella australica occurs in the Loves Creek Member of the Bitter Springs Formation. Radiometric dating of basement rocks indicates a maximum age of 1 076 ± 50 m.y. (Majoribanks and Black, 1974) for the onset of sedimentation in the Amadeus Basin, and the actual age

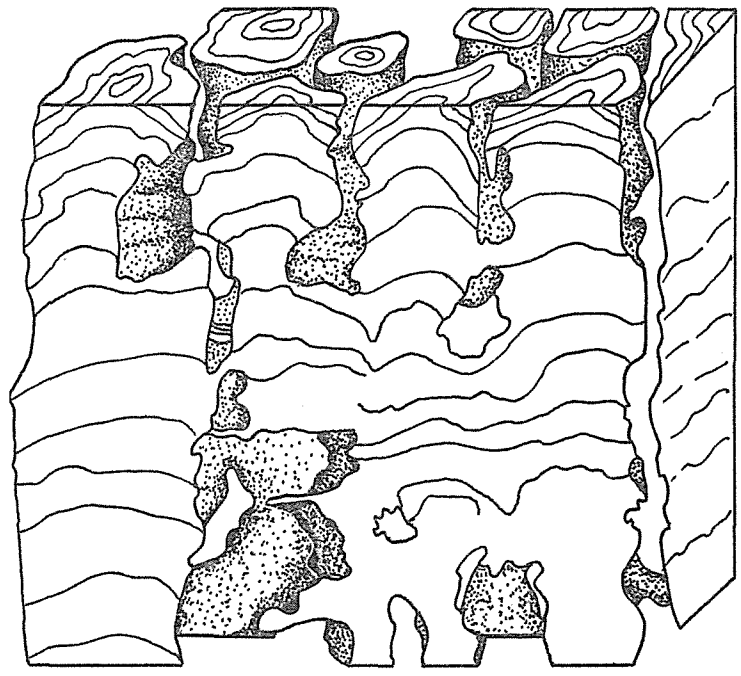

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Figure 39 Three-dimensional reconstruction of part of specimen F9830 *Acaciella* cf. *australica.*

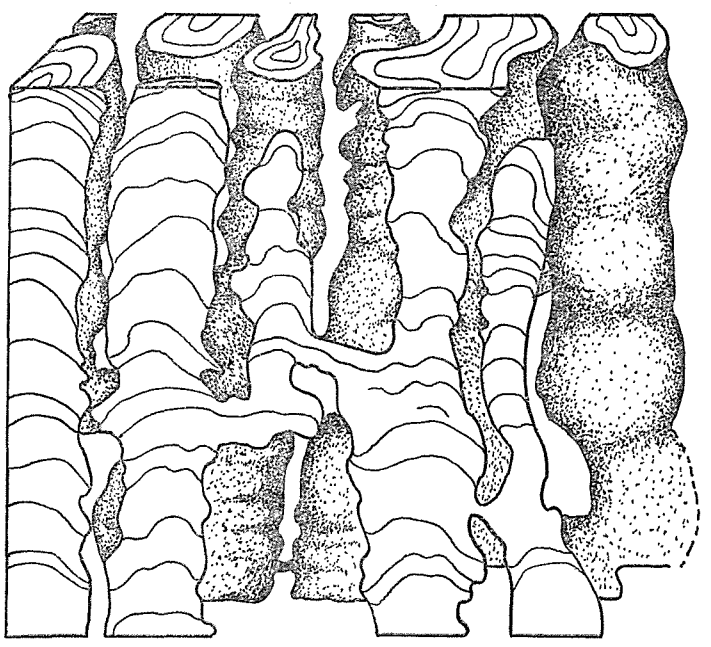

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Figure 40 Three-dimensional reconstruction of part of specimen F9830 *Acaciella* cf. *australica*

is probably much less than this (for discussion see Walter, 1972). Thus *Acaciella* cf. *australica* probably occurs in slightly older rocks in the Bangemall Basin than does *Acaciella australica* in the Amadeus Basin.

SYSTEMATIC DESCRIPTION

Group *ACACIELLA* Walter 1972

Acaciella sp. cf. *A. australica* (Howchin)
Figs 39-41

Material: Five specimens from three localities in the Trainor 1 : 250 000 Sheet area.

Mode of occurrence: At locality TRN1 interbedded dolomite and calcareous siltstone overlie shale. Three thin units of well-bedded dolomite contain cumulate stromatolites. The sequence is capped by a ripple-marked sandstone. Two specimens of cumulate stromatolites were collected from this locality.

Two specimens of well-preserved, columnar stromatolites were collected from locality TRN2. The stromatolite horizon apparently forms an extensive biostrome (Fig. 41a) approximately 6 m in thickness, and occurs near the top of a finely crystalline and laminated dolomite, which overlies a fine-grained sandstone and is capped by a siltstone. The dolomite contains irregular chert nodules up to approximately 15 cm in length.

Stratiform stromatolites occur below the columnar forms, with banding up to approximately 2 cm thick, but usually less than 1 mm. The column development and lateral variation were not recorded. The biostrome is probably stratiform, although some lensing may occur, and extends laterally for several hundred metres (Fig. 41a).

At locality TRN3 approximately 10 m of grey-pink dolomite with beds of columnar stromatolites is overlain by interbedded siltstone and dolomite, with sandstone at the top of the sequence. The small sample collected from this locality shows elongation of the tops of columns into ridges resembling ripple marks. A similar sequence occurs at a nearby locality, where the stromatolite bed is thinner. No samples were obtained from this locality.

Column shape and arrangement: The origin of the columns could not be determined in hand specimen. Both flat-laminated and cumulate stromatolites occur and columns probably arise from the cumulate forms. Columns tend to be perpendicular, relatively straight, and closely and regularly spaced. Width varies from 10 to 25 mm and in transverse section columns are usually rounded-polygonal to occasionally lobate, although in F9832 the tops of the columns form elongate ridges.

Most of the columns are discrete, but massive bridging and rare coalescence occurs. Small-scale bridging is common, and peaks, cornices, and irregular bumps of variable size are present. The smaller columns may terminate as steeply convex domes. The termination of larger columns is not known because the top of the biostrome is eroded.

Branching: Branching is almost exclusively α parallel, and occasionally β parallel. The origin of the branches cannot be determined from the hand specimen, but branches may increase slightly in width from the point of divergence.

Margin structure: Columns lack walls except for occasional development, usually in the area of bumps. Laminae generally terminate abruptly at column margins.

Lamina shape: Laminae are smooth, gently convex to rarely steeply convex, occasionally rectangular to rhombic, and rarely wavy.

Microstructure and texture: Microlaminae are variable in regularity and thickness, but tend to be continuous across the columns. In addition to light and dark microlaminae, white, vermiform patches are present. Macrolaminae are present but are not readily distinguished.

Dark microlaminae consist of fine-grained (less than 5 μm), equigranular, polygonal to interlobate, xenotopic dolomite. Microlaminae are from 50 to 500 μm in thickness and have smooth, parallel boundaries. They tend to thin towards column margins. Pigmentation is in the form of small specks of probable organic material, and the presence of oxides of iron which give a patchily pink colour to some laminae.

Light microlaminae are similar to the dark microlaminae, although grains are larger (10 to 30 μm) and xenotopic to hypidiotopic. Microlaminae range from 60 to 500 μm in thickness.

White, vermiform patches are more irregular, and sometimes thicker than the light and dark microlaminae. The patches anastomose frequently and the upper margin is markedly irregular. Grain size is extremely small, and determination of the mineralogy was not possible, although clay minerals are most probably present.

Interspace fillings: Interspaces are from 5 to 15 mm wide and are filled with fine-grained altered micrite containing large intraclasts of dolomite. Pink staining with iron oxide is common, but banding of the material in the interspaces is poorly developed. Layers of very fine-grained, altered micrite indicate periods of relative quiescence between periods of intraclast deposition. Intraclasts lie at a high angle to the bedding and are from 1 to 10 mm long and up to 4 mm thick. They are probably eroded fragments of algal mat. Relief of the columns was seldom greater than 5 mm and the frequent bridging suggests that for much of the time it was probably less than this.

Secondary alteration: Walter (1972, p.117) considered *Acaciella australica* from Katapata Gap to be primarily dolomitic, and this also seems to be the case with the Skates Hills specimens. Small veins of secondary calcite cross-cut the dolomitic laminae and occasional concordant stylolites are present. Some column margins are also stylolitic.

COMPARISONS

In gross morphology (mode of occurrence, column shape, branching and margin structure) there is a close resemblance to specimens of *Acaciella australica* (Howchin). Bridging may occur more frequently in the specimens from Skates Hills, columns appear more regular and there are minor differences in microstructure. Since *Acaciella australica* is a somewhat variable form, these differences may well be encompassed within the range of known variation. However, the samples collected from Skates Hills represent only a small portion of what is probably a fairly extensive biostrome. Until more material is available for the variation to be studied, the Skates Hills specimens are referred to as *Acaciella* cf. *australica*.

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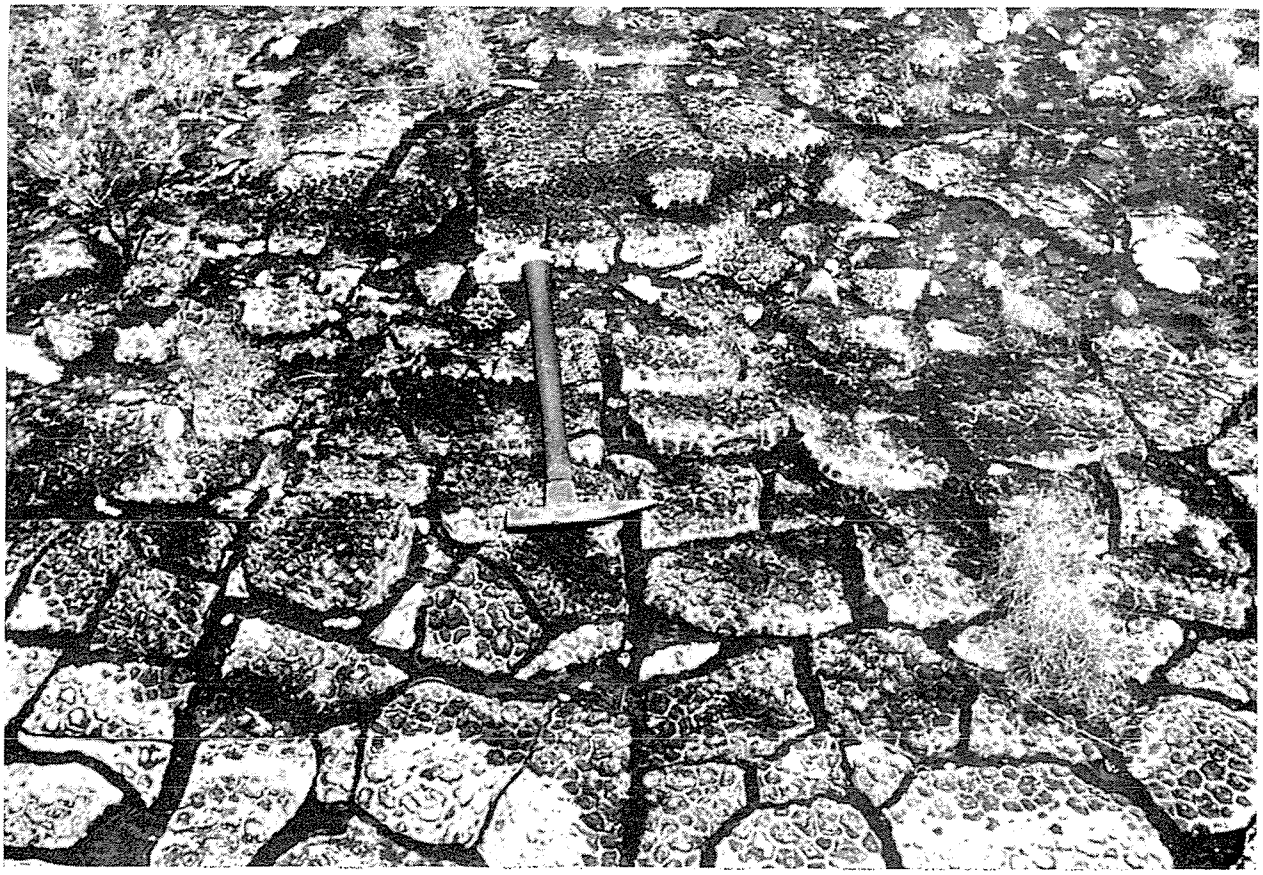
Figure 41a View of stromatolitic bioherm at locality TRN 2 showing tops of columns.

41b Polished section of part of specimen F9830. *Acaciella* cf. *australica*, showing columns.



A

2 CM

B

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LIVING STROMATOLITES IN THE NORTHERN GREAT SANDY DESERT, WESTERN AUSTRALIA: A MODERN ANALOGUE FOR PROBABLE TERTIARY DEPOSITS IN THE AREA

by R. W. A. Crowe, A. N. Yeates* and Kathleen Grey

ABSTRACT

Living freshwater stromatolites occur in the Canning Basin at McDonaldson Spring on the Mount Bannerman Sheet area. They are growing in water moderately rich in bicarbonate. Three growth forms are recognized: encrusting laminar, domal, and club-shaped columnar. The structures are calcareous, and the carbonate is believed to have been precipitated around algal filaments, in addition to being trapped and bound by the algae. Fossil stromatolites are also present in the adjoining probable Tertiary Lawford Beds, and similarities between the modern and fossil forms suggest similar depositional processes and environments. This means that rocks in the area, formerly regarded as calcrete of unspecified origin, are now thought to have been deposited biogenically.

INTRODUCTION

During regional mapping of the Canning Basin in 1973 living stromatolites were discovered in the headwaters of a spring-fed creek on the edge of the Great Sandy Desert in the northwestern part of the Mount Bannerman 1:250 000 sheet area in northern Western Australia (Yeates and others, 1975).

Stromatolites, formed by blue-green algae, are present in most of the springs and extend for a short distance downstream. The structures occur in pools and in places form barriers which produce small waterfalls. Such stromatolitic structures, though fairly common, have not been widely reported in Australia although they have been described elsewhere (see Golubic, 1973, for discussion).

The probable Tertiary rocks which form the reservoir for the springs in the area consist largely of limestone. Following the terminology of Goudie (1972) such terrigenous limestones of unknown and/or variable origins are normally referred to as calcrete, but in this area parts of the limestone contain structures suggesting a biogenic, algal origin. This paper describes the living stromatolites that occur in one of the springs—McDonaldson Spring—and suggests that they may represent an analogue for the origin of parts of the probable Tertiary deposits in the area.

SETTING

The northwestern part of the Mount Bannerman 1:250 000 Sheet and adjacent areas are underlain by gently dipping calcareous shale, mudstone and fine-grained quartz wacke of the Permian Liveringa Group and Noonkanbah Formation (Veevers and Wells, 1961; Yeates and others, 1975).

The Permian deposits are overlain by beds of probable Tertiary age, the Lawford Beds (defined by Casey and Wells, 1964). The Lawford Beds consist mainly of limestone with associated chalcedonic limestone, poorly consolidated conglomerate, and ferruginous sandstone. The unit attains a maximum thickness of 25 m and crops out

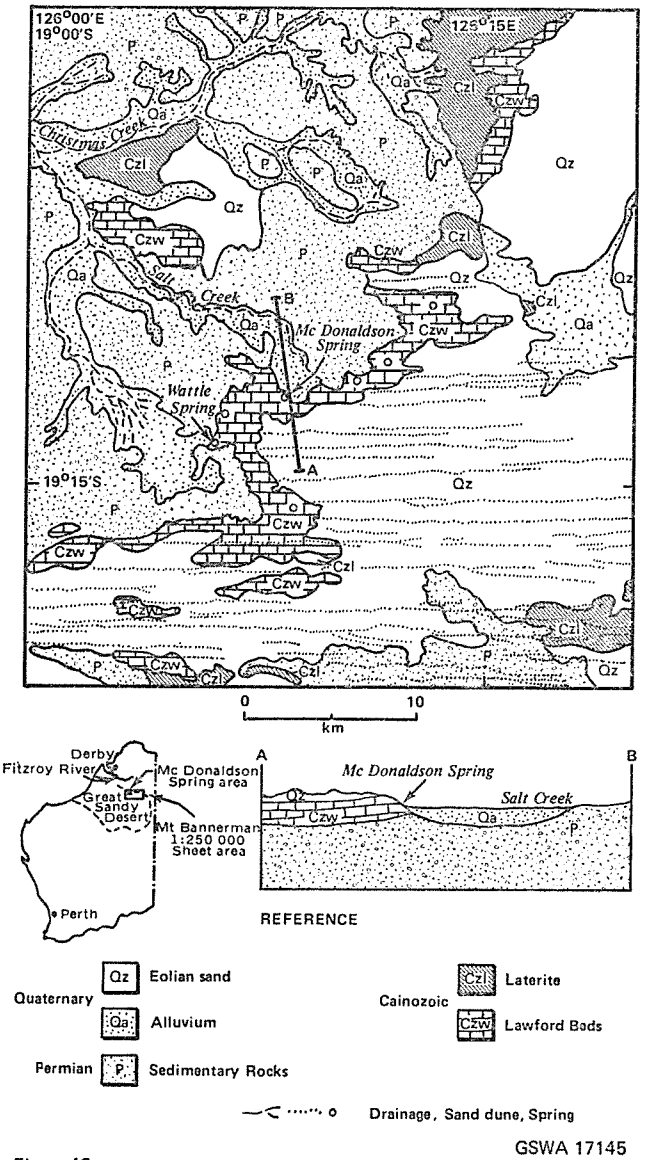


Figure 42
Simplified geological map, diagrammatic cross-section and drainage profile of the McDonaldson Spring area, and its location in Western Australia.

* Bureau of Mineral Resources, Canberra; published with the permission of the Director.

along the banks of Christmas Creek (a major tributary of the Fitzroy River) and is believed to have been deposited by the ancestral Christmas Creek (Casey and Wells, 1964).

There is no direct evidence for the age of the Lawford Beds, but as the unit is lateritized and contains detrital laterite pisoliths within it, it is thought to be mainly Tertiary in age. This is when the main periods of lateritization are thought to have occurred in the northern and eastern parts of Western Australia (van de Graaff and others, 1977).

The Lawford Beds are overlain by laterite and by Quaternary deposits, which are mainly eolian sand (Fig. 42).

Due to the low porosity of the underlying argillaceous Permian rocks, the Lawford Beds act as a reservoir for a series of springs producing potable water. These occur where the headwaters of Salt Creek (so called because salt occurs in the banks of the lower reaches) have dissected the contact between the two units (Fig. 42). Stromatolites are present in the springs and extend for approximately 500 m downstream.

The best examples of the stromatolites occur at McDonaldson Spring (lat. 19°12'18"S, long. 126°08'24"E) in a narrow creek up to 2 000 m downstream from the spring. The spring waters flow for about 1 km before soaking into alluvial deposits of the main creek.

McDonaldson Spring lies in a semi-arid area which experiences erratic rainfall (annual average 375 mm), most of which falls in summer. Evaporation rates are high and the area has an average yearly temperature of 28°C, with average maxima of about 39°C in January and about 27°C in July. The average minima are about 24°C in January and about 9°C in July (Atlas of Australian Resources, 1973).

The spring usually flows all year but during the summer wet season a catchment area above the spring contributes floodwater to the creek. At such times the creek then discharges into Salt Creek and from there into Christmas Creek (Fig. 42). When sampled, the water at McDonaldson Spring was moderately rich in bicarbonate and mildly alkaline. It was not saturated in any dissolved salts (Table 18).

TABLE 18. ANALYSIS OF WATER SAMPLE FROM McDONALDSON SPRING

(Sample collected in September, 1973)

Specific conductivity (micromhos 20°C)	2 090
pH	8·0
Appearance	clear
Colour	colourless
Odour	nil

Mineral Matter	mg/litre	me*/litre
Total dissolved solids—		
By evaporation	1 450	
By conductivity x 0·7	1 470	
Sodium chloride (calculated from chloride)	630	
Total hardness (calculated as $CaCO_3$)	481	
Total alkalinity (calculated as $CaCO_3$)	438	
Calcium	51	2·54
Magnesium	86	7·07
Sodium	304	13·2
Potassium	61	1·56
Iron (Fe in solution)	<0·05	
Boron	0·8	
Fluoride	2·3	
Bicarbonate	534	8·75
Carbonate	nil	nil
Sulphate	213	4·81
Chloride	382	10·8
Nitrate	27	0·44
Silica	50	0·44

* Milli-equivalents

DESCRIPTION OF STROMATOLITES

MORPHOLOGY

Three main varieties of stromatolite morphology are represented at McDonaldson Spring. These are: encrusting laminar, domal, and club-shaped columnar. Domal forms frequently develop from encrusting laminar forms, usually forming above small irregularities in the laminae, or above fenestrae. Club-shaped columnar forms (Fig. 43a) arise from domal forms and these may branch and form further club-shaped forms. Encrusting laminar types are common in pools or areas of slow-moving water. In faster-moving water domal and club-shaped columnar types are more common, and are abundant in waterfalls and old waterfall barriers.

Domal forms are between 5 and 10 cm in diameter and are approximately 10 cm in height. The club-shaped columns develop from the domal forms on short 'stalks' which swell upwards and outwards to give the club-shaped appearance (Fig. 43b). Columns vary in diameter from a few millimetres up to 30 mm, although the majority are approximately 10 mm. Branches arise from the larger columns and are also approximately 10 mm in diameter. The flattened tops of some columns appear to be erosional features. The columns resemble abiogenically formed cave popcorn (Thrailkill *in* Walter, 1976), but in the case of the McDonaldson Spring structures blue-green algae are directly involved in their formation. The most abundant micro-organism in the McDonaldson Spring mats is *Phormidium* sp., a cyanophyte characterized by single narrow trichomes within a thin sheath (M.R. Walter, pers. comm.).

All three forms of McDonaldson Spring stromatolites range from finely laminated to unlaminated (massive). Finely laminated forms are common; massive fabric is only rarely developed. The mat which forms the stromatolites is soft and is underlain by a thin gelatinous layer. Lithification occurs only a few millimetres below the surface.

FABRIC AND MICROSTRUCTURE

Fenestrae are abundant and in some instances are quite large, often reaching up to 5 mm in length and occasionally as large as 25 mm. Although many of the fenestrae seem to have developed as a result of the decomposition of enclosed algal material, and the bridging of undulations on the stromatolitic surfaces by algal mat, the presence of truncated laminae in some of the cavities suggests that weathering and/or solution, may be a factor. Many of the cavities are lined with a thin layer of micrite.

Three types of fabric are common in the McDonaldson Spring stromatolites. Striped laminated fabrics, according to Monty (Walter, 1976), constitute a large part of many of the stromatolites and are particularly common in the finely laminated and columnar forms. These laminae contain interlocking, elongate crystals formed around radial filaments of *Phormidium*. Frequently the boundaries of the laminae are defined by a layer of horizontal filaments, or by a thin layer of micrite, indicating a phase of chemical precipitation which may mark a temporary cessation of algal growth.

The second type of fabric tends to occur in domal stromatolites and gives rise to coarse laminae. The fabric consists of a coarse reticulum of calcified algal filaments. Laminations result from the alternation of horizontally growing filaments with layers of erect bundles.

The third type consists of patches of massive fabric, which are probably the result of the deposition of calcium carbonate as a replacement of mucilaginous film associated with diatoms. Diatom frustules occur in the massive fabric patches and also in some of the fenestrae. They are similar to the massive cryptalgal diatomaceous mats associated with massive fabric which have been described from the Bahamas by Monty (Walter, 1976).

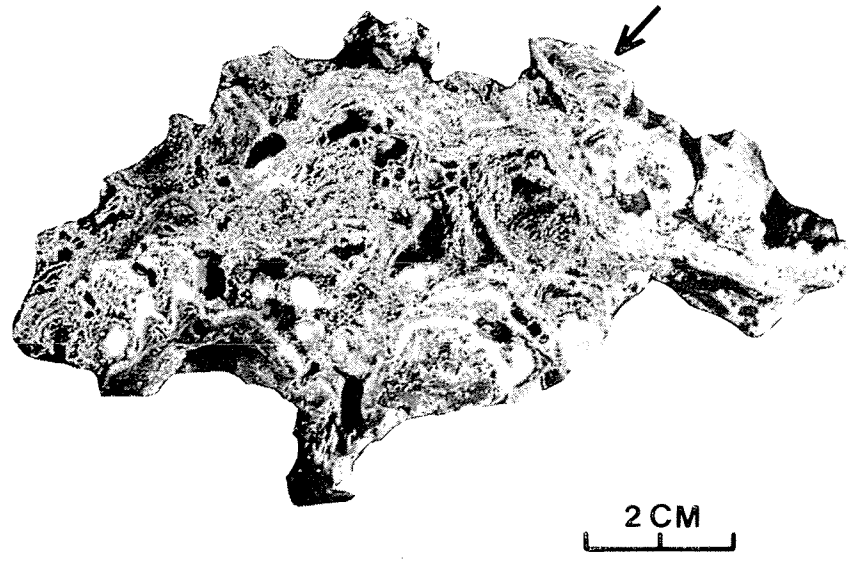
Precipitation of calcium carbonate around algal filaments and the replacement of mucilaginous film by carbonates are regarded as being more important than the trapping and binding of detrital grains in the formation of the stromatolites.

Fragments of plants and small organisms, encrusted with carbonate, are incorporated in the stromatolites. Some of the latter may have grown in association with the algal mat; others may have been washed in after death. Small patches of detrital quartz occupy cavities between the stromatolitic laminae, and small lateritic pebbles occur infrequently.

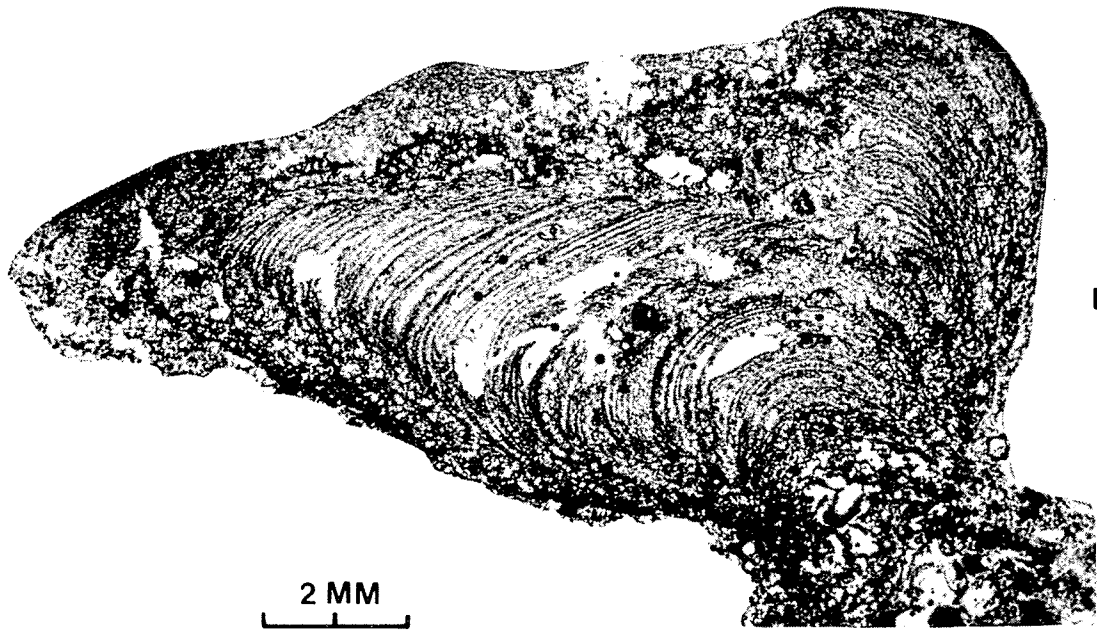
LITHIFICATION

The stromatolites at McDonaldson Spring are cemented by calcium carbonate. Carbonate lithification of algal structures can be either inorganic or biogenic, or a combination of both, and it is often difficult to distinguish which of these processes is taking place.

Precipitation of $CaCO_3$ from emerging groundwater is a common phenomenon with complex chemical controls. Precipitation often occurs within or around algal structures which have a large surface area in contact with $CaCO_3$-rich water. Precipitation is particularly common where the water is well aerated, such as in waterfalls (Golubic, 1973).



A



B

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Figure 43a F.9835 cross-section of stromatolite showing domal and club-shaped columnar forms (specimen is 10.2 cm long). Specimen was collected from a waterfall face, McDonaldson Spring, Great Sandy Desert.

43b Photomicrograph of detail of club-shaped stromalolite. (Part of specimen F.9835 indicated by arrow).

Biogenic precipitation of $CaCO_3$, on the other hand, can be caused by changes in the pH due to the respiratory processes of the organisms involved. In algae, the process of photosynthesis (which utilizes C and O) can cause the changes necessary to bring about precipitation of carbonate.

Golubic (1973) believes that precipitation of carbonate in the upper part of a river flow is predominantly inorganic and that only lower downstream, where the water gains equilibrium with the atmosphere, does biogenic precipitation become more important. Because the stromatolites at McDonaldson Spring occur near the source of the spring it is suggested that the precipitation of calcium carbonate is dominantly inorganic although some biogenic precipitation may also occur. The dominant role of inorganic precipitation is supported by the occurrence of leaves and twigs in the stream which appear to have been recently fossilized, probably since the preceding flood.

FOSSIL ALGAL STRUCTURES IN THE LAWFORD BEDS

Fossil algal structures also occur in the Lawford Beds, which are probably of Tertiary age. They occur at a locality several hundred metres upstream from the spring in compact and well-lithified rock. The structures, consisting of undulating cryptalgal laminae, are very similar to the living encrusting laminar types described above, suggesting that deposition of this part of the Lawford Beds occurred in a similar environment.

CONCLUSIONS

The occurrence of stromatolites in McDonaldson Spring constitutes one of the few records of freshwater stromatolites in Australia. It is probable that the micro-environment largely controls the distribution of the various growth forms. Encrusting laminar types occur in slow-moving water and in pools, whereas the club-shaped, columnar, and domal types occur in waterfalls and appear to be restricted to faster-moving, well-aerated water. Old waterfall barriers are mainly composed of the latter types.

Most of the structures are composed of calcium carbonate, which is thought to have been precipitated around algal filaments from the spring water. Trapping of sediment also occurs but is of less significance.

The occurrence of cryptalgal structures in the probable Tertiary Lawford Beds and the similarities of these structures to the modern encrusting laminar forms, suggest that at least part of the Lawford Beds, formerly regarded as calcrete of unspecified origin, were laid down in quiet water fed from springs, and are of stromatolitic origin.

ACKNOWLEDGEMENTS

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PSEUDOVELOCITY APPLICATIONS IN THE CARNARVON BASIN

by I. R. Nowak

ABSTRACT

Pseudovelocity (synthetic sonic) logs may be generated from short-normal resistivity logs using the relation $TT^1 = A + (B)R_a^{-1/c}$ where TT^1 is the pseudotransit time, R_a the apparent resistivity, and A, B and C, empirically established constants. Pseudovelocity data can be a valuable aid to seismic interpretation in areas where resistivity logging is abundant and continuous velocity logging scarce. The method has been applied in the Carnarvon Basin in Western Australia where resistivity and sonic information from several bores has provided a formula from which a pseudovelocity model has been obtained for the petroleum exploration well Dirk Hartog 17B. Sources of error, limitations, and possible improvements to the method are discussed.

INTRODUCTION

Interest in pseudovelocities was initiated by M. Megallaa (G.S.W.A.; Sedimentary Division) who has recently been assessing seismic data from the Carnarvon Basin. An area of particular signficance centred around an isolated petroleum exploration well Dirk Hartog 17B, on Dirk Hartog Island, west of Shark Bay (Fig. 44). This well was completed in 1957, and wire-line logging operations did not include the sonic facility.

The interpretation of seismic reflection requires a knowledge of the vertical distribution of velocity to the depth of interest. The most commonly used and accurate way of obtaining this is from sonic logs of bores in the area. The sonic log is a recording of the time required, versus depth, for a compressional sound wave to traverse one foot* of formation. This 'interval transit time' is the reciprocal of the seismic velocity of the relevant formation. Sonic information is also useful for porosity determinations in sandstone and limestone sections, where the total travel time over any section is the sum of the travel time through the fluid-filled pores and that through the solid matrix (Table 19, equation (a)).

The sonic log is often omitted in wildcat or development wells and in wells drilled before about 1960. Therefore, a method for providing data equivalent to that normally obtained from a sonic log would be very useful. Almost invariably the suite of logs from any well includes the short-normal (406.4 mm or 16 inch) resistivity log which can be transformed, within limits, to yield pseudosonic information.

VELOCITY RELATIONSHIPS

There have been various attempts to link the sonic velocity of a formation with depth, age, and electrical resistivity. An early empirical relationship was equation (b) (Table 19), but it was soon realized that the situation was far more complex than this formula suggests. Sonic velocity is basically dependent on the bulk elastic modulus, and therefore on matrix and fluid proportions; this implies that porosity is a key parameter. Relation (c) is well known, but the true formation resistivity is not reliably measured by the short-normal method which records an apparent resistivity (R_a). This apparent resistivity relates to that of the formation invaded by the mud filtrate such that equation (d) holds. Combinations of these relationships were considered by various workers seeking to relate R_a directly to velocity. Equation (e) was widely applied,

* The imperial foot (0.304 8 m) continues to be used internationally in well logging.

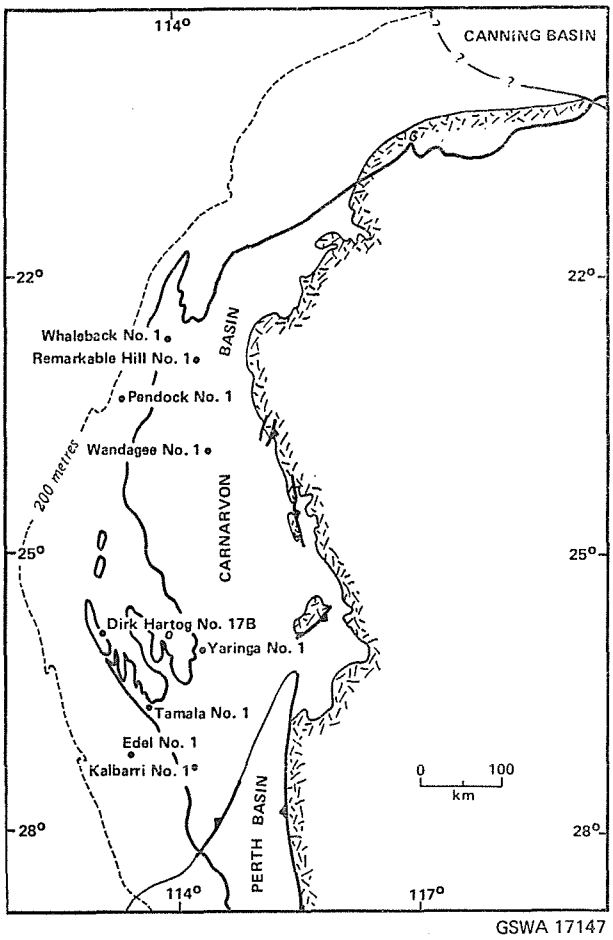

Figure 44 Carnarvon Basin, W.A. and relevant petroleum wells

especially in its inverse form where TT^1 is a pseudo interval-transit-time generated from observed resistivity values.

However, it became increasingly clear that neither depth nor age were major factors in controlling the sonic velocity of a formation, and that variation in lithology had the greatest influence.

DERIVATION OF THE SCALE FUNCTION

A group of researchers in the United States of America recently applied equation (e) to selected wells in the Illinois Basin (Rudman and others, 1975). When their work indicated that a resistivity-velocity transform which did not involve depth, was required, an empirical approach suggested by Kim (1964) appeared a likely avenue of inquiry. Comparisons of the overall form of sonic and short-normal logs for the same well show distinct similarities (Fig. 45) and suggest that there is a mathematical relationship between transit time and resistivity. The development of a practical relationship is amply described by Rudman and others (1975), and only an outline of the procedure is given here.

Relatively uniform (non-oscillating) portions of both logs at the same depth are selected, and their average values plotted on a semilog grid as in Figure 45. These values constitute one point on the plot, and additional values are produced from various sections over the length of the logs where relative stability is maintained. Sufficient points are established to enable a smooth curve to be constructed. This curve is then a predictive function because it specifies a transit time for any resistivity value. Note that, although each plotted point is associated with a particular depth, that depth is not identifiable from the curve.

A mathematical representation of this curve or 'scale function' is required, and theoretical considerations lead to the general equation: $TT^1 = A + (B)R_a^{-1/c}$ (Table 19, equation (f)). This form was derived by Kim who combined the sonic equation (a) and the resistivity formula (d) using porosity as the link. The constants A, B, and C are determined empirically and are not held to be physically significant parameters.

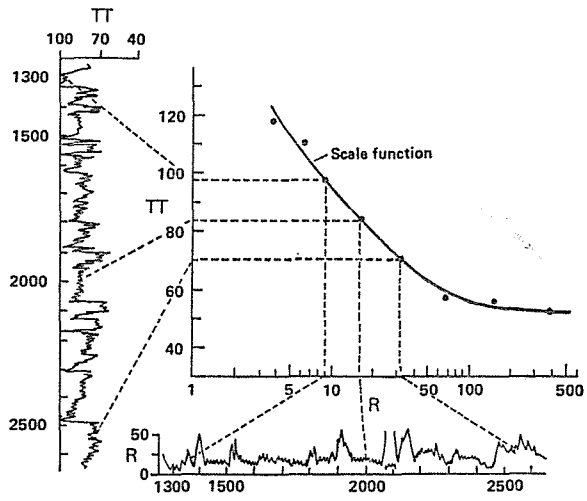

Figure 45
Sketch illustrating generation of scale-function curve. R (resistivity) in ohm-metres, and TT (transit time) in micro seconds per foot from specific depth interval form pair of values for each data point (after Kim, 1964)

TABLE 19. RESISTIVITY AND VELOCITY EQUATIONS

(a) $TT^1 = \phi TT_f + (1-\phi)\, TT_m$
(b) $V = K(ZS)^{1/6}$
(c) $R_t/R_f = \phi^{-c}$
(d) $R_a/R_{mf} = \phi^{-c}$
(e) $V = K(ZR_a)^{1/6}$ or $1/V = TT^1 = 1/K(ZR_a)^{-1/6}$
(f) $TT^1 = A + (B)R_a^{-1/c}$ .... scale function

where:

TT	= Transit time in porous medium
TT_f	= Transit time in fluid
TT_m	= Transit time in matrix
ϕ	= Porosity
V	= Velocity
Z	= Depth
S	= Age
R_t	= True resistivity
R_a	= Apparent resistivity
R	= Resistivity of formation fluid
R_{mf}	= Resistivity of mud filtrate
TT^1	= Pseudotransit time

A, B, K, and C are constants

USE OF THE SCALE FUNCTION

Considering any particular well, e.g. Edel No. 1, an apparent resistivity (R_a) versus pseudotransit time (TT^1) curve may be established from field resistivity and sonic logs run in that well. In Figure 46, the curve has been carefully fitted by eye through a wide range of points. Values for the constants A, B, and C are determined (Rudman and others, 1975), and the predictive qualities of the scale function may then be applied to determine its validity. By means of the functions, a pseudosonic model is constructed from the known resistivity log, and this model is compared with the sonic log recorded in the field. Where a curve has been defined by a sufficient number of points, correlation is excellent: the differences between genuine (TT) and pseudo (TT^1) transit times are normally less than five per cent.

Having established accuracy of this order for any one well for which good data are available, Rudman and others (1975) then selected several wells from the Illinois Basin and produced R_a *versus* TT^1 plots for each. Then they simply calculated the arithmetic mean to arrive at their average scale function (ASF) to characterize the area concerned. When this ASF was re-applied to various wells, the TT^1/TT error was normally less than ten per cent. Obviously the ASF is not as applicable as the specific scale function of any well to that particular well. However, its use is realistic in the context of generating a pseudovelocity model for any given well in that area for which no sonic data are available.

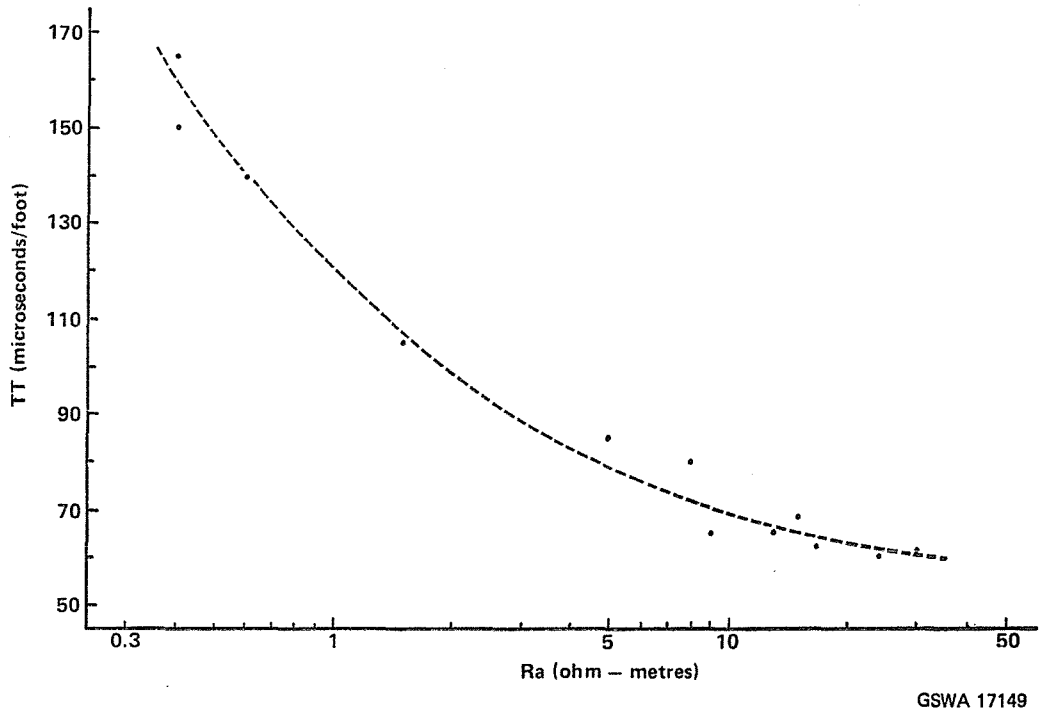

Figure 46 Example of a scale-function plot for a single well (Edel No. 1)

APPLICATION TO CARNARVON BASIN

The above concept, that an ASF may be established which characterizes the pseudosonic regime in a particular region, has been tentatively applied to the Carnarvon Basin (Fig. 44). Seven wells contributed and numerous R_a *versus* *TT* points were plotted on a single diagram. Readings were taken at relatively quiet intervals, to minimize errors, on both sonic and short-normal logs for each well. As this exercise involves generalizing at the scale of a basin, the plotting of points from several pairs of logs on the one diagram is essentially equivalent to plotting points for individual wells and then averaging the resulting curves. Moreover, the procedure used here is probably more accurate when information from some wells is scarce.

Again, a curve was constructed by eye (Fig. 47). Note that the data from Tamala No. 1 (circled) are judiciously ignored in the placement of the curve. This omission is justified because the Tamala values are clearly anomalous;

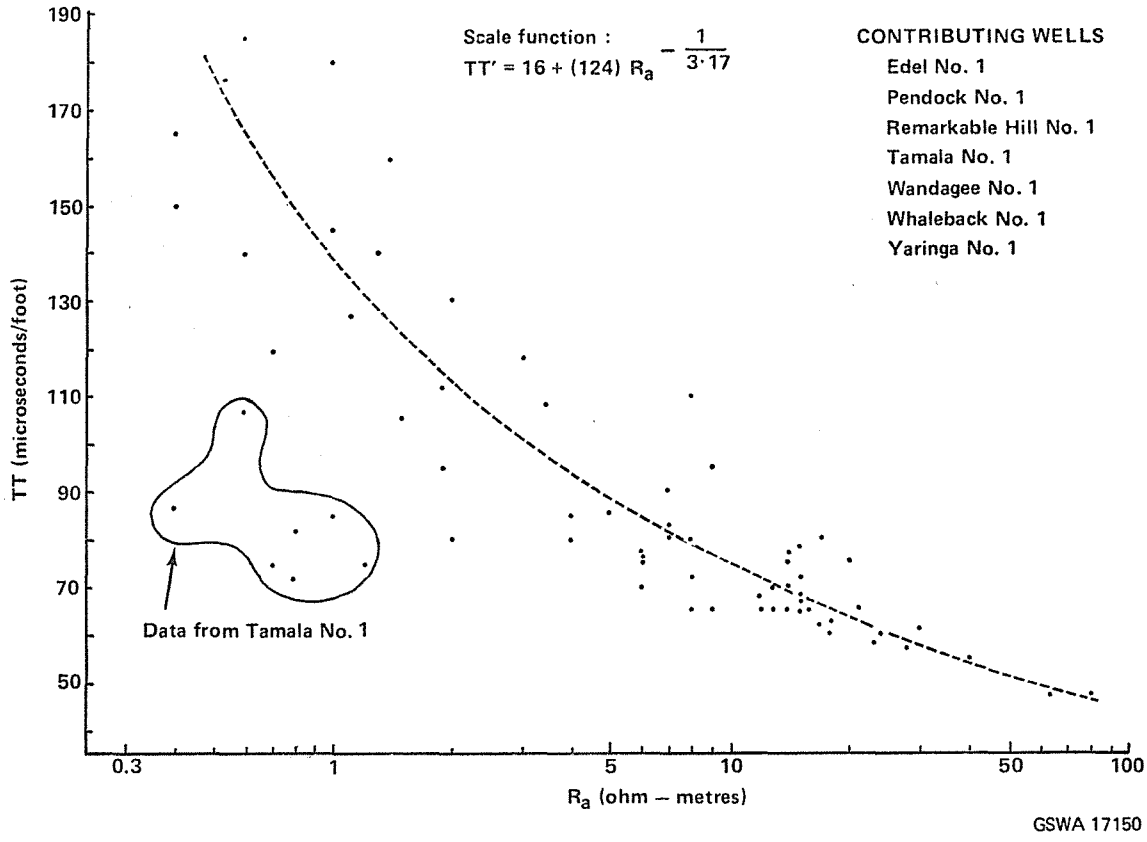

Figure 47 Scale function derived from R_a v *TT* points for seven wells in the Carnarvon Basin.

their inclusion would result in undue bias to the ASF. The constants of the scale function defining the curve were then calculated, and the following equation obtained:

$$TT^1 = 16 + (124)R_a^{-1/3.17}$$

This equation is considered to define the resistivity-velocity relationship for the entire Carnarvon Basin. As a check, the equation was used to generate pseudovelocity logs for those wells where sonic logs were recorded and TT^1 compared with TT. Continuous pseudosonic logs have not yet been generated by computer; however, for four wells, Edel No. 1, Remarkable Hill No. 1, Kalbarri No. 1, and Pendock No. 1, the entire resistivity log was divided into sections, each characterised by a reasonably stable R_a. Pseudotravel times were calculated by the scale function for each of these sections and added to give a total pseudotravel time from a selected upper datum to total depth of the well. Comparison with true total travel times from the sonic log for each well showed an average error of around eight per cent. Whilst of a slightly greater magnitude than had been hoped, it is reasuring that the error occurs in the one sense for two of the wells and in the opposite sense for the other two. Moreover, the likelihood of bias in the R_a to TT^1 transformation is further lessened as each pair of wells includes one from the northern and one from the southern group.

PENDOCK No. 1

Pendock No. 1 well is taken as an example of the above procedure. Plots have been made of travel time against depth, and also of interval velocity against depth—both standard presentations used in seismic interpretation. Although the diagram for Pendock No. 1 (Fig. 48) is somewhat simplified in that minor changes over thin sections of the sequence have been ignored, certain comparisons are significant. Firstly, the plots of pseudo data (the unbroken lines) derived from the resitivity information show the following features. Interval velocities are generally in the 2 130 to 2 740 m/s range from the upper hole to around 1 040 m below which depth a sharp increase occurs. This pattern is reflected in the pseudotravel time curve where the gradient is low for the upper 1 040 m, and then increases to total depth. Minor changes in gradient correspond to variations in interval velocity.

The dotted lines of Figure 48 summarise data obtained directly from the field-recorded continuous velocity (sonic) log. The genuine and pseudo plots of both interval velocity and travel time show excellent agreement and thus indicate a successful transformation. Note that the 400 to 800 m section accounts for most of the final percentage error. The travel-time curves diverge between 400 and 800 m and then are virtually parallel to total depth. Obviously, over this section, the scale function indicates a lower

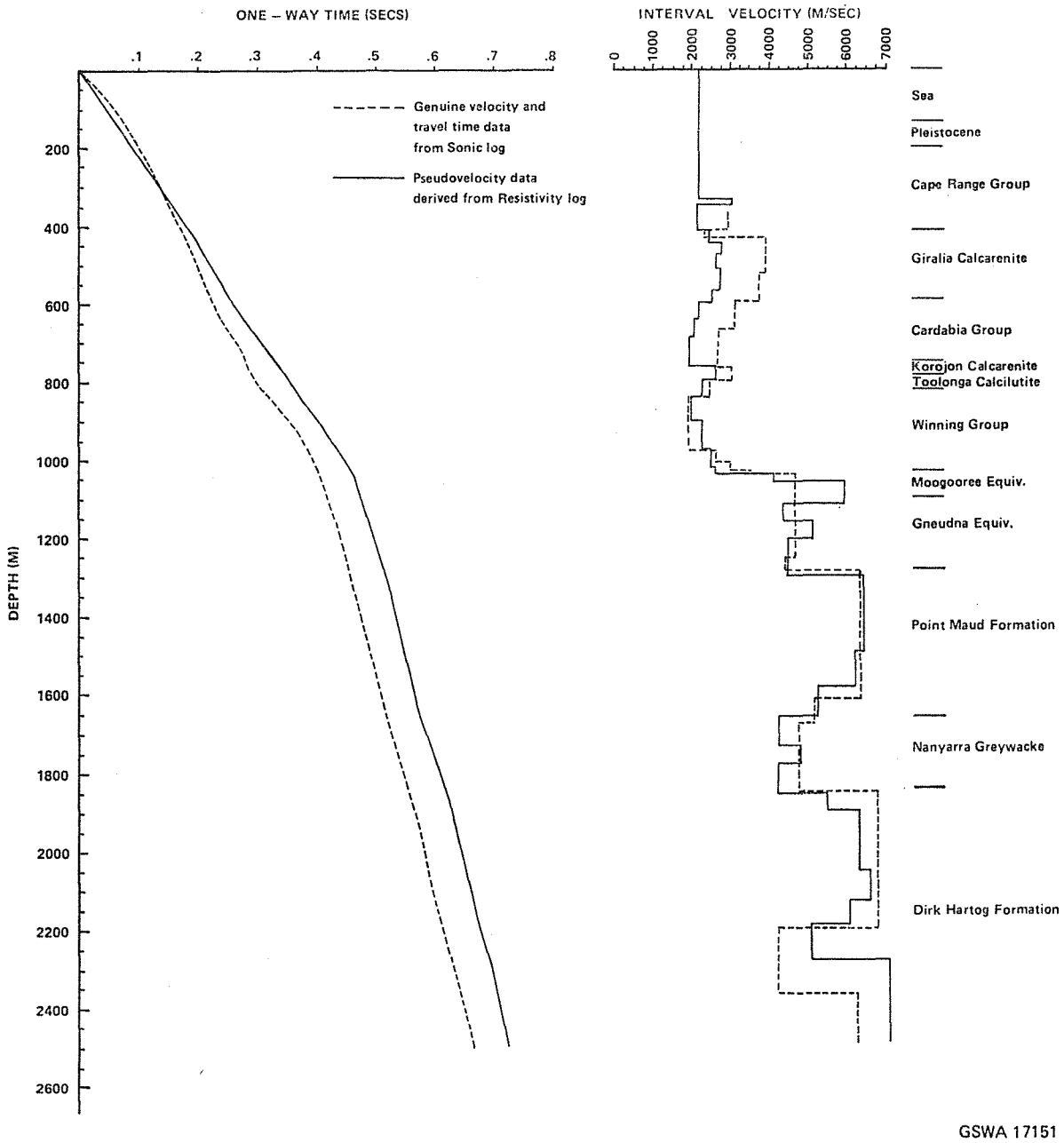

Figure 48 Comparison of sonic and pseudovelocity data for Pendock No. 1.

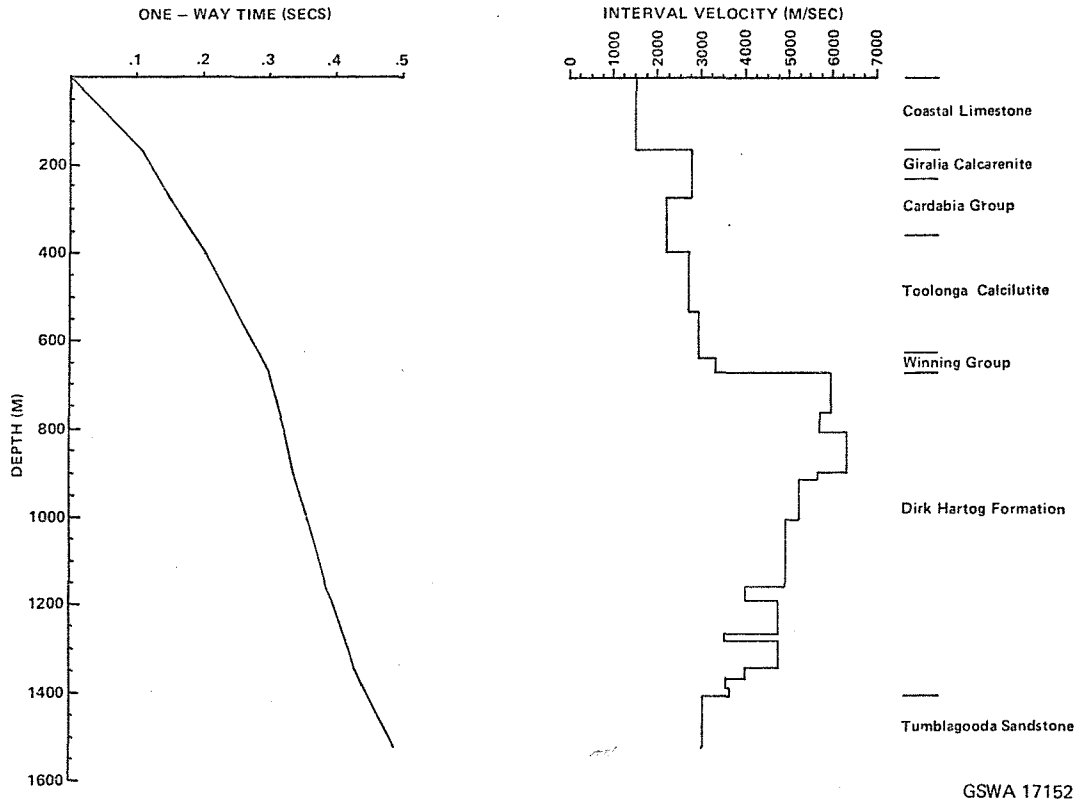

Figure 49 Pseudovelocity model proposed for Dirk Hartog No. 17B.

velocity from the resistivity data than is actually the case. Although the reason for this anomaly is not evident, it is noted that this section includes the Giralia Calcarenite and the Cardabia Group. These units should be carefully studied in other logs where pseudo and true travel times may be compared. A corrrection factor for this section may need to be empirically established.

From about 800 m down, the two interval-velocity curves vary with depth in relative harmony until the Dirk Hartog Formation is encountered; there the range of velocity variation in the genuine curve is somewhat greater than in the pseudo curve. Overall, however, it is considered that the disparity between the two sets of data in the example of Pendock No. 1 (and three other wells) is not excessive and that extension of the method is warranted.

DIRK HARTOG No. 17B

At this point, the purpose of this exercise can be fulfilled: that is, to generate a pseudovelocity model for a well which has never been sonically logged. The Dirk Hartog No. 17B petroleum exploration well was selected for initial attention because it was drilled in a locality where reliable velocity information is scarce. Using the basin scale function, the short-normal resistivity log was transformed to pseudovelocities as outlined above, and the resulting data presented, as for Pendock No. 1, in the form of travel-time and interval-velocity curves (Fig. 49).

Obviously no direct check can be made on the validity of these curves, but the pseudovelocity characteristics of certain formations can be compared with equivalents in other wells. For example, the velocities derived from the resistivity log for the Giralia and Cardabia sections are similar to those obtained in the relevant sections for Pendock No. 1. A further comparison between the Dirk Hartog and Pendock wells in the upper section of the Dirk Hartog Formation reveals a velocity of around 6 000 m/s in each case. Basically, then, there is a consistency of R_a values for the same stratigraphic unit in the logs from both Pendock and Dirk Hartog wells. Moreover, such equality needs to be sustained throughout the region in which a specific scale function is asumed to be valid.

CONCLUSION

An outline has been given of a recently proposed method for transforming short-normal borehole resistivity data into pseudovelocity information. A transforming scale function of the form $TT^1 = A + (B)R_a^{-1/c}$ can be used to generate a continuous pseudosonic log or, more simply, to approximate equivalent material from stable 'blocks' of the resistivity log. A specific scale function: $TT^1 = 16 + (124)R_a^{-1/3.17}$ has been formulated for part of the Carnarvon Basin. The validity of the function has been verified by counter checks against other wells in the basin, and then it was used to generate a pseudovelocity system for Dirk Hartog No. 17B; a well which has never been sonically logged. It is suggested that errors in total travel time over the length of a well should not exceed ten per cent. The pseudosonic information can be used as a guide to seismic interpretation in the vicinity of the wells and, as some insight is gained into the velocity characterisation of particular formations, as a guide to stratigraphy. Determination of porosity in limestone and sandstone sections should also be possible.

There are several restrictions to general application of the method, and these, and some suggested improvements, are discussed below.

(a) The use of logs from wells where the drilling mud resistivity was unusually high or low may be invalid. R_m for Tamala No. 1 was low at around 0.2 ohm-metres, whereas it was around 0.8 to 1.5 ohm-metres for the other bores.

(b) Pseudovelocities should not be generated for depths less than 150 m where resistivities are often anomalously high because of the presence of fresh water or only partial saturation.

(c) It may be necessary to apply a correction factor to certain stratigraphic units where resistivities are consistently anomalous (Rudman and others, 1976). The Giralia-Cardabia sequence may exhibit exceptionally high resistivities which would transform to erroneously low velocities.

(d) Rudman and others, (1976) note that the accuracy of the transformation may be improved if the final R_a *versus* TT^1 curve is defined by three distinct equations for three different sections of the curve rather than by the one scale function used here. Such a modification may have an effect on the Giralia-Cardabia anomaly.

(e) Investigation into changes to the mathematical form of the scale function and improved methods of curve-fitting are warranted.

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THE VALUE OF B-GA-RB DIAGRAMS IN DETERMINING DEPOSITIONAL CONDITIONS IN PROTEROZOIC ROCKS IN THE NORTHWEST OF WESTERN AUSTRALIA

by R. Davy, A. T. Brakel, and P. C. Muhling

ABSTRACT

Boron, gallium and rubidium data are summarized for 94 samples of sedimentary rock from the Hamersley and Bangemall Groups, and rocks underlying the Bangemall Group, of northwest Western Australia.

Interpretation of triangular diagrams for these elements supports near-shore deposition postulated for the Bangemall Group by regional sedimentary interpretation, though there is no complete agreement on the salinity of the depositional conditions. Interpretation of the diagrams for the older Proterozoic rocks is more tenuous though the conclusions deduced are compatible with available sedimentological evidence.

B-Ga-Rb diagrams can be of value in assessing the broad depositional condition of Proterozoic sedimentary rocks, supplementing sedimentological interpretation. The use of these elements is apparently not affected by weathering, diagenesis and low temperature recrystallization of phyllosilicates.

INTRODUCTION

Boron-gallium-rubidium (B-Ga-Rb) triangular diagrams have been tested for their value in supplementing sedimentological investigations of the depositional conditions of Proterozoic rocks of the northwest of Western Australia. The main rocks of interest were those of the Bangemall Group which contain stratabound low grade Pb-Zn mineralization, but other available data from Proterozoic rocks, namely rocks underlying the Bangemall Group, and rocks from the Hamersley Group, have been included.

Previous usage of these diagrams, originally proposed by Degens and others in 1958, has, with one exception, been restricted to Phanerozoic rocks where palaeontological evidence has assisted interpretation. The exception is a paper by Hickman and de Laeter (1977) on shale from Meentheena in the Pilbara of Western Australia.

The diagrams are based on the differential partitioning of B, Ga and Rb between clay minerals at the time of formation of the original sediment. The main clay minerals of interest are illite, supposedly more common in marine sediments, and kaolinite, more common in freshwater sediments. According to Degens and others (1957) marine sediments commonly contain larger absolute concentrations of B and Rb, and B/Ga ratios than do freshwater sediments, apparently reflecting a higher original illite/kaolinite ratio. B and Rb are collected preferentially in illite, where they replace Al and K respectively. Ga substitutes for Al in most minerals and is more concentrated in kaolinite than illite by virtue of the higher Al content of the former mineral; it is therefore normally more concentrated in freshwater sediments. The triangular diagrams allow for representation of relative abundances, obviating the need for the separation of pure clay minerals from the sediment which normally includes a varying proportion of quartz.

Tourmaline can also contribute B to sediments. In the present case modal estimation suggests that the contribution of B from this source is limited to less than 5 ppm except at one locality (Mount Palgrave) where for some samples the contribution may be 15 ppm.

A difference between the Proterozoic rocks and those studied by Degens and others (1957, 1958) is the degree of recrystallization of the Proterozoic rocks by post-depositional, mainly diagenetic, changes. The phyllosilicates* now present are muscovite and chlorite, and in rocks of the Hamersley Group, stilpnomelane. Kaolinite is only present as an alteration product in weathered samples.

STRATIGRAPHIC SETTING

Three main stratigraphic groups have been investigated:—

(i) Bangemall Group—approximate age 1 100 m.y.

(ii) pre-Bangemall Group rocks that occur as basement to the Bangemall Group—age uncertain, probably 1 600-2 000 m.y.

(iii) Hamersley Group—approximate age 2 200-2 400 m.y.

The stratigraphic succession of the Bangemall Group has been discussed by Brakel and Muhling (1976). Rock types sampled include black shale, siltstone, carbonated siltstone, silicified siltstone and chert. Mineralization occurs in the Kiangi Creek Formation (Glen Ross Shale Member) and in the Jillawarra Formation. Most samples were selected from these formations, with other samples from overlying formations.

The pre-Bangemall Group rocks, sampled from drill core only, include black, carbonated shales and siltstones, and quartz-magnetite-chlorite rocks with minor sulphide. The latter appear to have been ferruginous siltstones and shales metamorphosed to the greenschist facies level.

Hamersley Group samples were collected from the Dales Gorge Member (Trendall and Pepper, 1977), and include both shales and iron formation. One sample of iron formation from the younger Joffre Member was also collected.

CHEMISTRY

Analysis was carried out by the Western Australian Government Chemical Laboratories.

Values obtained are summarized as follows:

	No. of samples	B ppm	Ga ppm	Rb ppm	K_2O %
Bangemall Group rocks (oldest first)—					
Kiangi Creek Formation	25	10–215	<1–17	5–230	0·2–4·5
Jillawarra Formation, shales	22	30–155	3–32	60–375	1·1–7·4*
Jillawarra Formation, cherts	2	5–25	<2–4	6–65	N.D.†
Discovery Chert	11	2–20	<1–5	5–95	0·1–1·4▲
Ullawarra Formation	1	20	12	8	N.D.†
Curran Formation	3	70–120	16	160–180	3·0–3·6
Fords Creek Shale	1	350	18	170	3·8
Kurabuka Formation	1	30	8	57	N.D.†
Backdoor Formation[1]	11	10–210	<2–20	7–225	0·5–2·6°
Pre-Bangemall Group rocks—					
Unmetamorphosed	3	15–85	2–20	20–200	0·4–3·0
Metamorphosed	4	5–120	4–17	10–175	0·2–2·6
Hamersley Group rocks—					
Joffre Member iron formation	1	15	1	50	1·26
Dales Gorge Member, shale	6	30–100	2–6·5	45–135	1·47–4·21
Dales Gorge Member, iron formation	5	10– 30	≤0·5	5–30	0·13–0·37

* 17 samples only.
° 5 samples only.
† N.D. = not determined.
[1] Equivalent to Ullawarra Formation – Fords Creek Shale.
▲ 8 samples only.

* Determination, by X-ray diffraction analysis, by the Western Australian Government Chemical Laboratories.

In general the shales and siltstones have the highest values in all the above constituents. In most shales/siltstones B exceeds 40 ppm, Ga 12 ppm, Rb 60 ppm and K_2O 1.5%. Boron and Rb were always detected in the cherts and iron formation, commonly in the 10-30 ppm range for B, 5-70 ppm for Rb. Gallium, however, is commonly below detection in these rocks.

Relative behaviour of the trace elements is shown in the triangular plots—Figures 50-53 (Ga is multiplied by a factor of 10 following Degens and others, 1958, to enhance differences in distribution). A separate plot has been generated for chert samples, for most of which Ga is below detection (Fig. 54). The Ga figures for this plot have been assumed to be half the minimum detectable value.

Correlation coefficients, which indicate how the concentrations of elements vary with one another, show a high degree of significance between the constituents. In all formations with enough determinations Rb, Ga and K_2O correlate at the 99% probability levels. Boron also correlates with these constituents at the 99% level except at Mount Palgrave (Jillawarra Formation, seven samples in sub-group 676-689) where there has been lower greenschist facies metamorphism with the formation of authigenic tourmaline. The correlation here is significant at the 90% probability level. The high degree of correlation confirms the association of the trace elements with K_2O in the phyllosilicates, for there are no other K-bearing minerals.

DISCUSSION

The absolute proportions of the constituents depend to some degree on the provenance of the detritus and the waters which have contributed to the formation of the rocks. It was originally felt that a study of the relative proportions of the constituents was likely to provide more reliable information than the sole consideration of absolute values. In the event, the absolute values of B, Ga and Rb obtained from the shales and siltstones are in accord with values from previous literature summarized in Hickman and de Laeter (1977), encouraging belief that the study was viable.

EFFECTS OF WEATHERING AND METAMORPHISM

Data from a number of visibly weathered samples are included in the analyses, particularly from the Jillawarra and Kiangi Creek Formations. Their absolute values and plotted positions on the triangular diagrams are consistent with those for the fresh rocks. These observations support Degens and others (1957) who, after carrying out accelerated weathering tests, found these elements suitable for use in weathered as well as unweathered rocks.

All the rocks sampled here have been diagenetically altered and some have been metamorphosed. Diagenesis, involving low temperature recrystallization of phyllosilicates appears to have had no effect on the absolute values of the three elements considered even when authigenic tourmaline has been formed. At higher temperatures there is the suggestion of mobilization and loss of boron.

INTERPRETATION OF THE RESULTS

(a) Shales/siltstones

The triangular diagrams for shales/siltstones suggest deposition in environments which are variously marine, brackish or freshwater.

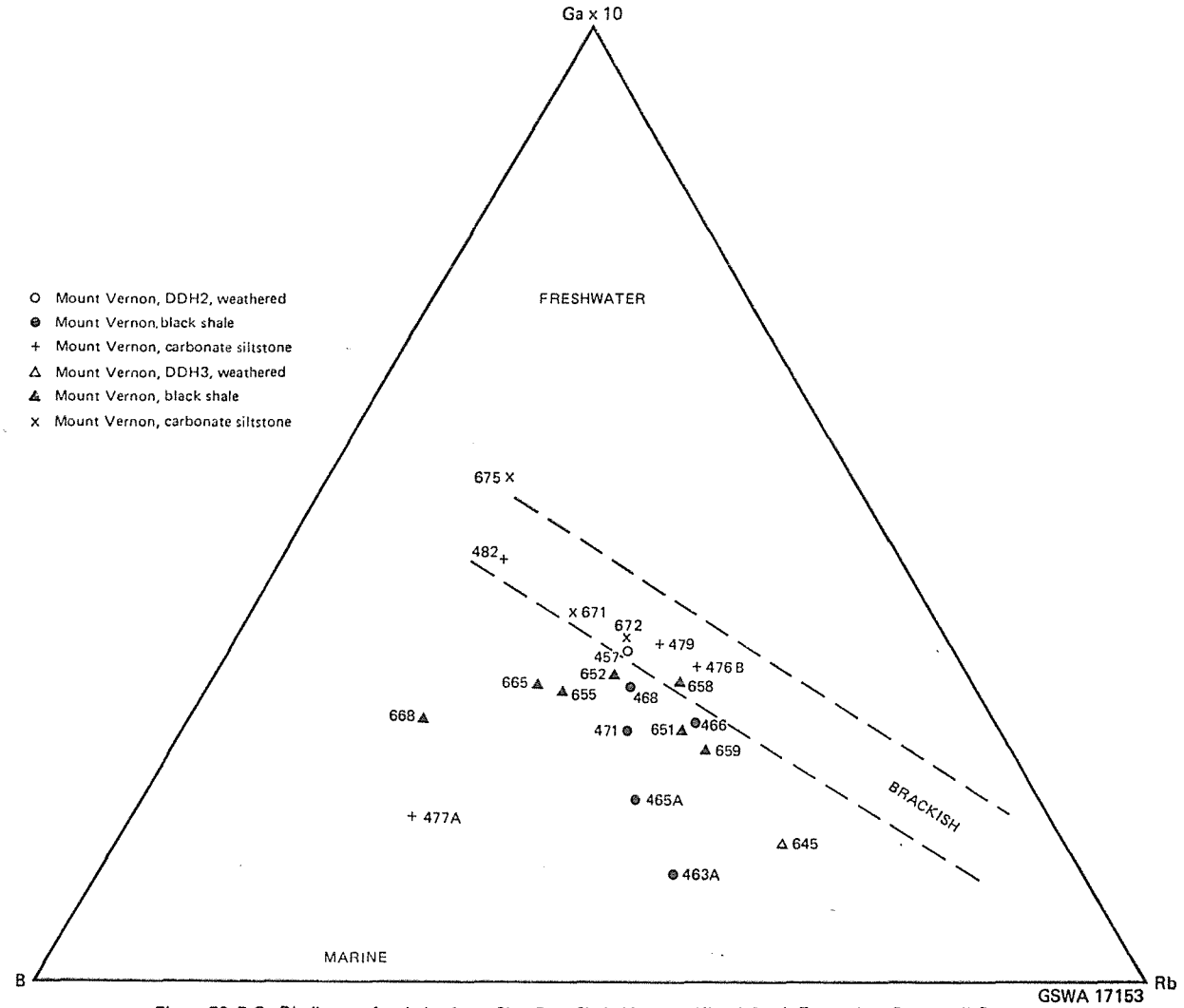

Figure 50 B-Ga-Rb diagram for shales from Glen Ross Shale Member, Kiangi Creek Formation, Bangemall Group

(i) Bangemall Group

Interpretation is expressed below in tabular form:

Formation	Environment Based on Chemistry	Environment Based on Regional Mapping
Kurabuka Formation	freshwater	coastal lagoons
Fords Creek Shale	marine	marine shelf, usually below wave base
Curran Formation	brackish water	marine shelf, pro-delta
Ullawarra Formation	freshwater	marine platform (rare evaporites), very shallow in places
Discovery Chert	marine-brackish-freshwater	restricted basin, usually below wave base, probable sabkhas around edge
Jillawarra Formation	marine-brackish-freshwater	marine shelf below wave base except for rare shoals
Kiangi Creek Formation	marine-brackish	barrier bar and beach
Backdoor Formation	marine-brackish-freshwater	marine shelf usually below wave base

The geochemistry suggests that conditions ranging from fresh to brackish-deltaic to marine were present within many formations. For example, at Mount Palgrave the Jillawarra Formation (Fig. 51) is inferred to have had a brackish water to marine origin; in the Mount Vernon Syncline its origin appears to have been freshwater; whilst at Maroonah there is an apparent cycle from fresh-brackish water to marine and back to freshwater (samples 711 to 717) from the bottom to the top of the sequence.

Though there are differences of interpretation between the conclusions drawn from geochemistry and those from sedimentological considerations, the clustering of the chemical data in the vicinity of the brackish water zone suggests that sedimentation took place in shallow water as opposed to deep sea deposition. Differences in interpretation are mainly whether the waters were fresh or saline. Apparent freshwater deposition in sediments considered to be of marine origin can be explained by periodic freshwater flushing of the Bangemall embayment. Both sedimentological and chemical findings indicate that the Bangemall Basin was a zone of subsidence with sedimentation almost balancing downwarp, maintaining the whole area in the vicinity of sea level.

(ii) The pre-Bangemall Group rocks

The chemistry of the unmetamorphosed rocks suggests a brackish water origin (Fig. 53). Microscopic scour and fill structures suggest deposition in shallow water. The stratigraphic and sedimentological significance of these rocks has not yet been established, but future workers should consider this chemical evidence as part of their overall interpretation.

Superficially, the metamorphosed equivalents are of brackish to clearly freshwater origin. However, the B values of 517 and 520 (Fig. 53) are so low that mobilization and loss of B is suspected.

(iii) Hamersley Group

A marine origin for the Dales Gorge Member shale is suggested by the geochemistry, but these rocks are characterized by low absolute Ga values (Fig. 53). The

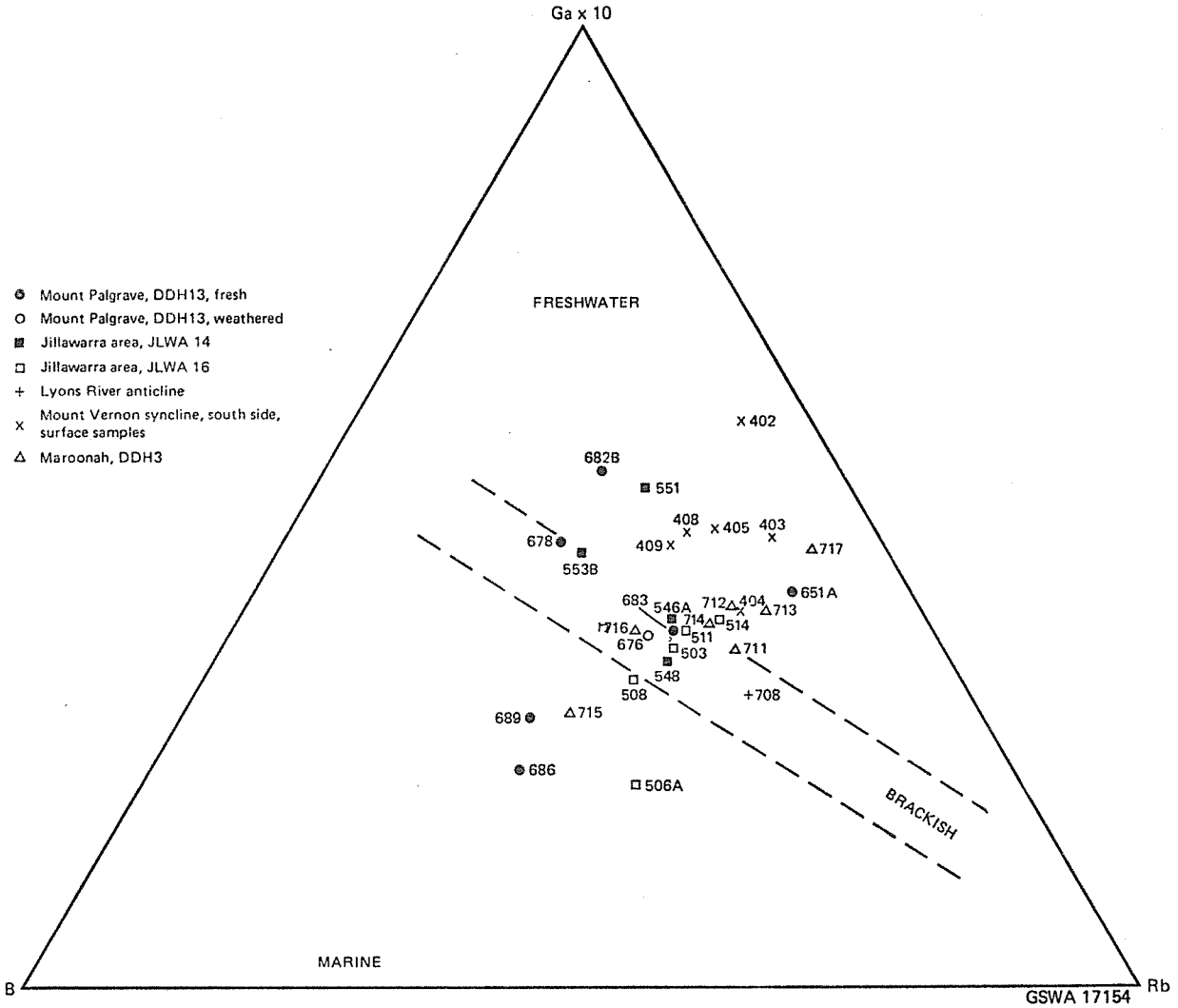

Figure 51 B-Ga-Rb diagram for rocks from the Jillawarra Formation (shales and siltstones), Bangemall Group

origins of the associated iron-formation rocks are still in debate, with opinions divided amongst marine (Trendall and Blockley, 1970; Garrels and others, 1973) and lacustrine (Eugster and Chou, 1973; van der Wood, 1977).

(b) Cherts and iron formation

The value of the triangular diagram for the cherts and iron formation is inherently low, with low absolute values of all trace elements. Where Ga is below detection the plotted point is a stylized estimate of the true position. Notwithstanding this potential for error, the Dales Gorge and Joffre iron formations plot as marine (like the Dales Gorge shales), and the cherts from the Bangemall Group show a scatter about brackish water deposition analogous to their more shaly equivalents.

IMPLICATIONS OF INTERPRETATION

The use of B-Ga-Rb diagrams, prior to the work of Hickman and de Laeter (1977), has been restricted to rocks no more than 450-500 m.y. old. Use of these diagrams for indicating depositional conditions in the Proterozoic carries with it the implication that the oceanic composition and the conditions of transport and deposition of the various constituents have not changed appreciably from the Proterozoic to the present day. Interpretation on this basis is reasonable for the Bangemall Group since there is substantial agreement that the oceanic composition has been close to that of the present for 1 000-1 500 m.y. (MacKenzie, 1975; Holland, 1976; Maynard, 1976).

Interpretation for the older rocks is more subject to doubt. Data for rocks underlying the Bangemall Group are limited, with no adequate external evidence for the conditions of deposition, and the Dales Gorge Shale, whilst indicating marine deposition, is anomalous in its Ga content. The freshwater deposition of the Hardey Sandstone shale deduced by Hickman and de Laeter (1977) does not assist in an assessment of the oceanic conditions extant at that time.

CONCLUSIONS

It is concluded that B-Ga-Rb diagrams can be of value in assessing the depositional conditions of Proterozoic sedimentary rocks, supplementing rather than displacing lithological and sedimentological indicators of deposition. The use of these elements is apparently not impeded by weathering, diagenesis, and low temperature recrystallization of phyllosilicates. However, increased temperatures of metamorphism may be reflected in a loss of boron.

These diagrams for the Bangemall Group are consistent with near-shore deposition postulated previously from the sedimentological and palaeontological studies made in the course of regional mapping, though there is no complete agreement on the salinity of the depositional conditions.

The value of these diagrams for older Proterozoic rocks is more tenuous, but the conclusions deduced are compatible with such sedimentological evidence as is known.

ACKNOWLEDGEMENTS

This study could not have been carried out without the chemical and mineral analyses performed by members of the Western Australian Government Chemical Laboratories.

Samples from Mounts Palgrave and Vernon were provided by Westfield Minerals (W.A.) N.L. and from the Jillawarra Bore area by Amoco Minerals Australia Company. The cooperation of these companies and their personnel is gratefully acknowledged.

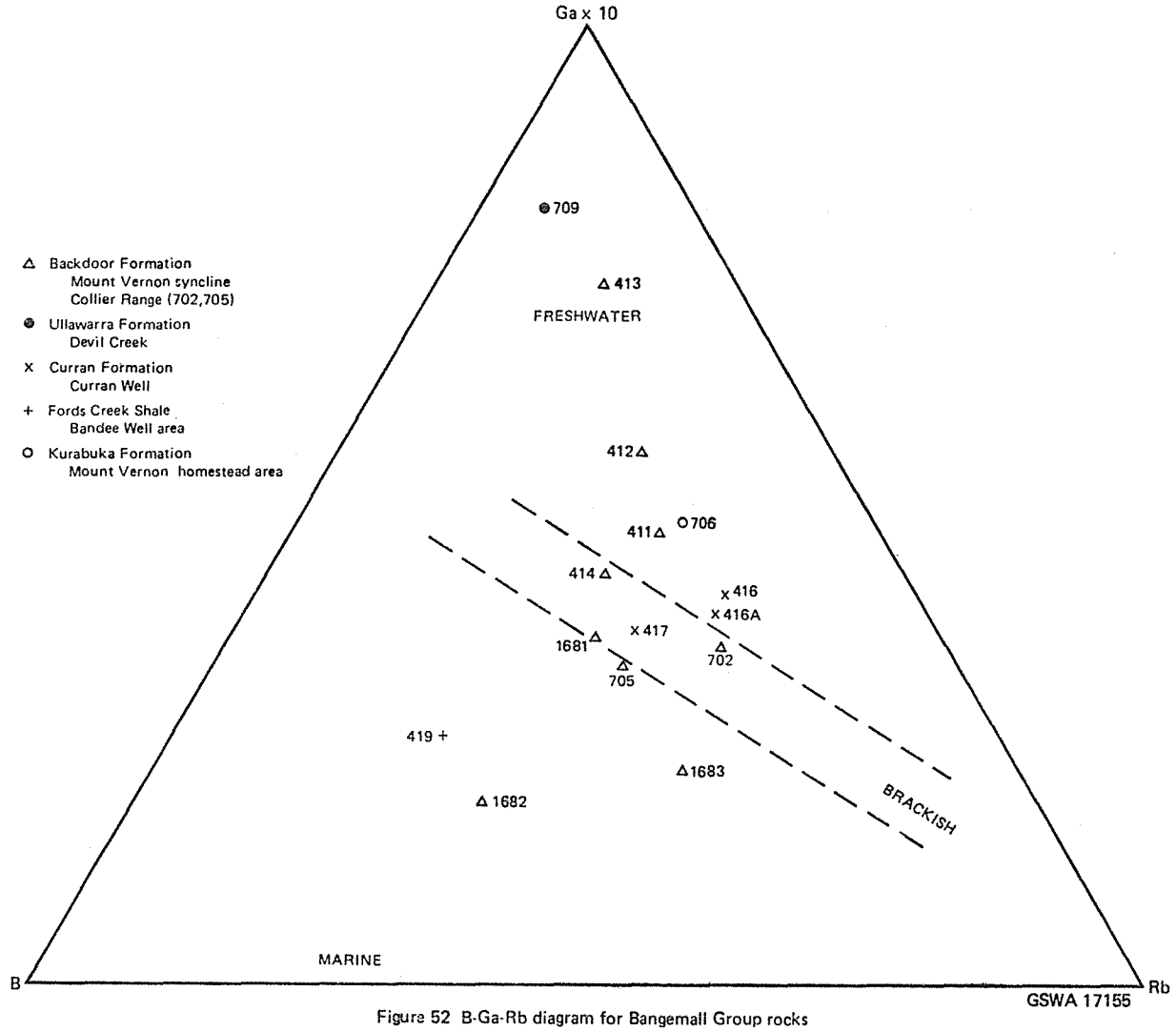

Figure 52 B-Ga-Rb diagram for Bangemall Group rocks

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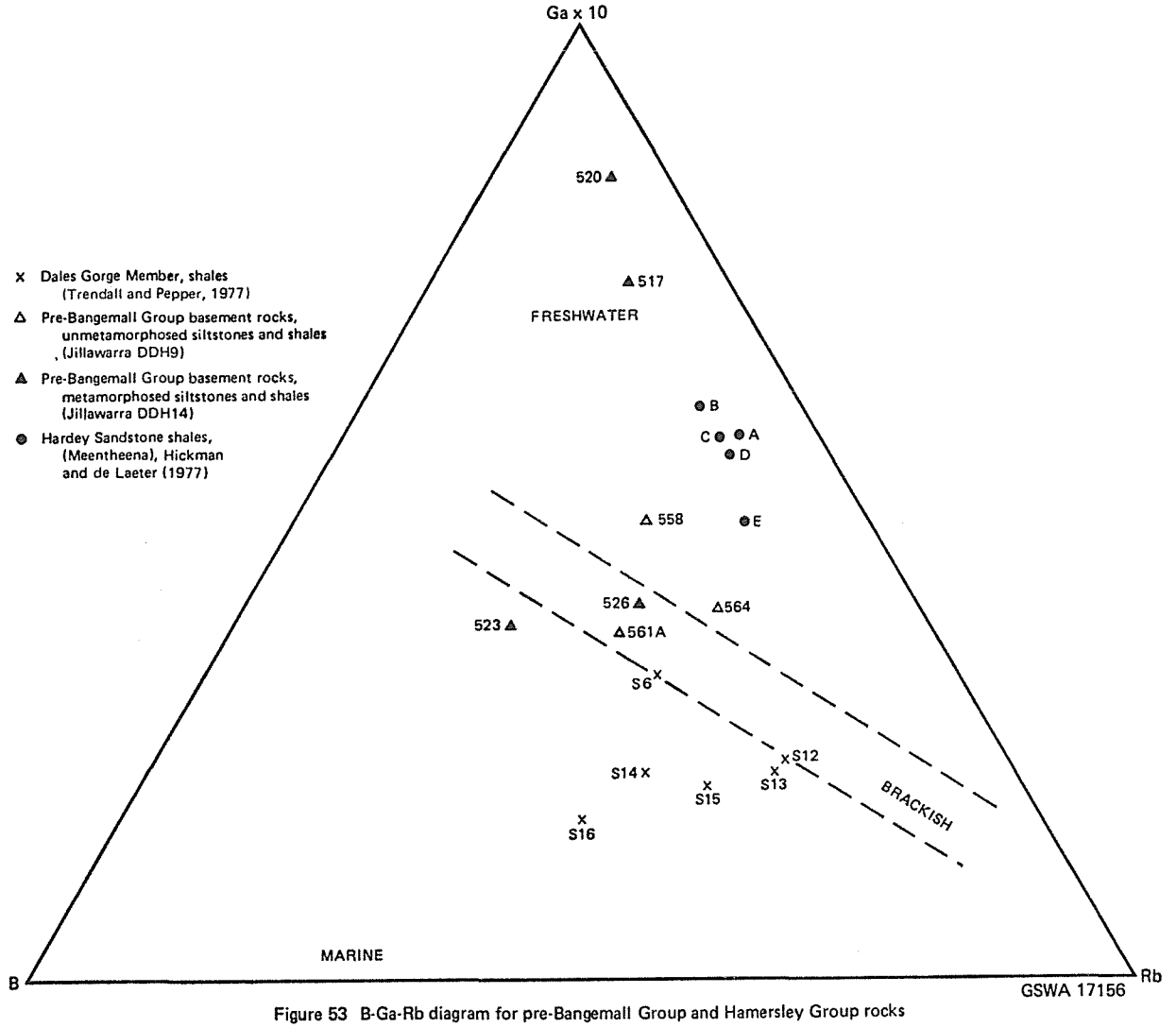

Figure 53 B-Ga-Rb diagram for pre-Bangemall Group and Hamersley Group rocks

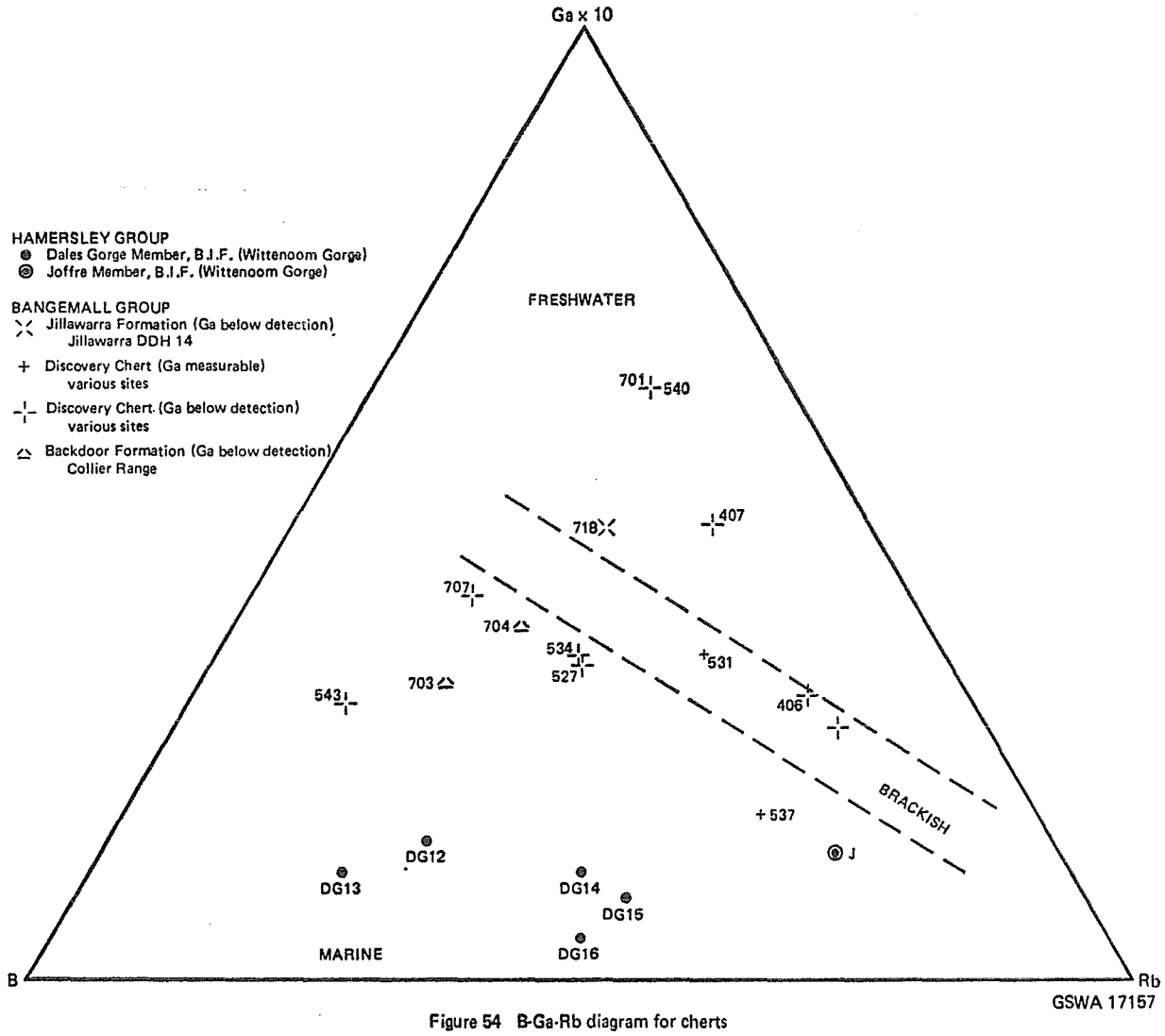

Figure 54 B-Ga-Rb diagram for cherts

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DIVISION V

Report of the Director of The Petroleum Branch for the Year 1977

Under Secretary for Mines

I hereby submit my Annual Report for the Petroleum Branch for 1977.

PETROLEUM RESERVES

The total recoverable petroleum reserves of the State are estimated to stand at 19·72 x 10^6 m^3 crude oil, 61·01 x 10^6 m^3 condensate and 439·84 x 10^9 m^3 natural gas. Details of the reserves as at 31st December 1977 are set out in Table I.

PETROLEUM EXPLORATION OPERATIONS

Petroleum exploration drilling operations increased significantly during 1977. A total of 35 339 metres were drilled compared to 22 171 metres in 1976. The 1977 figure was achieved by four offshore rigs and one onshore rig. The distribution of the rigs and the metres drilled by each at the various locations is illustrated in Figure 1. Of the four offshore rigs engaged in Western Australian waters during the year only the shipshape Regional Endeavour was fully occupied. The Ocean Digger completed North Rankin No. 5 in April and then remained idle off Fremantle until the last quarter of the year when Peel No. 1 was drilled in the Perth Basin. The new jack up rig, Maersk Endurer, arrived in the Carnarvon Basin in mid-September and has since been fully occupied for WAPET. The semi submersible Southern Cross drilled one well in the Bonaparte Gulf Basin in December. The National 110 DE land rig completed Denison No. 1 in the Dongara area in January and was then almost continuously occupied at Warro No. 1 and No. 2 wells to the end of the year. Three rigs were operating at the end of the year. They were the Maersk Endurer at Bundegi No. 1 (2 143 m and drilling), the National 110 at Warro No. 2 (3 900 m and drilling) and the Regional Endeavour at Caswell No. 1 (3 997 m and drilling).

Figure No. 2 is a summary comparison of the petroleum exploration operations for the 10 year period 1967 to 1977. Drilling activity (Figure 2A, 2B, and 2C) has continued to increase slowly from 1975 onwards. Total rig months for 1977 were 29·6 of which 20·6 were offshore and 9·0 onshore. This represents a 57 per cent overall increase in rig months compared to 1976. Peak activity for the 10 year period in terms of metres drilled; wells completed and rig months, clearly, occurred in 1972 following the first major gas discoveries at Scott Reef and North Rankin.

Marine seismic surveys conducted during the year totalled 8 378 line kilometres. There was no land seismic carried out in 1977. Figure 2D summarises seismic activity since 1971.

Four tropical cyclones were active in the areas of petroleum operations namely cyclones Irene, Jack, Karen and Leo, of which two (Karen and Leo) affected offshore drilling operations. There was no loss of life or injury as a result of these weather disturbances, however a combined total of 15 drilling rig days were lost and there was an estimated deferment of Barrow Island production amounting to 86 700 barrels.

TABLE I

IDENTIFIED PETROLEUM RESERVES (RECOVERABLE) 31st DECEMBER 1977

Field	OIL (m^3 x 10^6)			GAS $C_1 + C_2$ (m^3 x 10^9)			LPG $C_3 + C_4$ (m^3 x 10^6)			CONDENSATE C_5 + in gas fields (m^3 x 10^6)		
	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
PRODUCING FIELDS—												
Carnarvon—												
Barrow Island	8·69	18·07	....	....	....	....	0·22	0·22	....	0·09	0·46	....
Perth—												
Dongara	0·30	0·30	....	6·68	6·68	....	....	....	....	0·03	0·03	....
Mondarra	....	....	....	0·22	1·20	....	....	....	....	neg	0·01	....
Totals		18·37			7·88			0·22			0·50	
UNDEVELOPED FIELDS—												
Carnarvon—												
Angel	....	....	....	10·56	40·35	....	....	....	....	2·48	9·47	....
Goodwyn	0·17	0·17	....	25·77	72·78	....	....	....	....	5·29	14·94	....
North Rankin	....	....	....	134·50	242·67	....	....	....	....	16·16	29·17	....
Tidepole	0·97	1·18	....	13·03	17·21	....	....	....	....	2·26	2·99	....
West Tryal Rocks	....	....	....	8·25*	58·91*	....	....	....	....	0·55	3·94	....
Perth—												
Yardarino	neg	neg	....	0·04	0·04	....	....	....	....	neg	neg	....
Totals		1·35			431·96			....			60·51	
Grand Totals		19·72			439·84			0·22			61·01	

P1 equivalent 95% probability;
P2 equivalent 60% probability;
P3 equivalent 5% probability;
* Excludes 27% inerts.

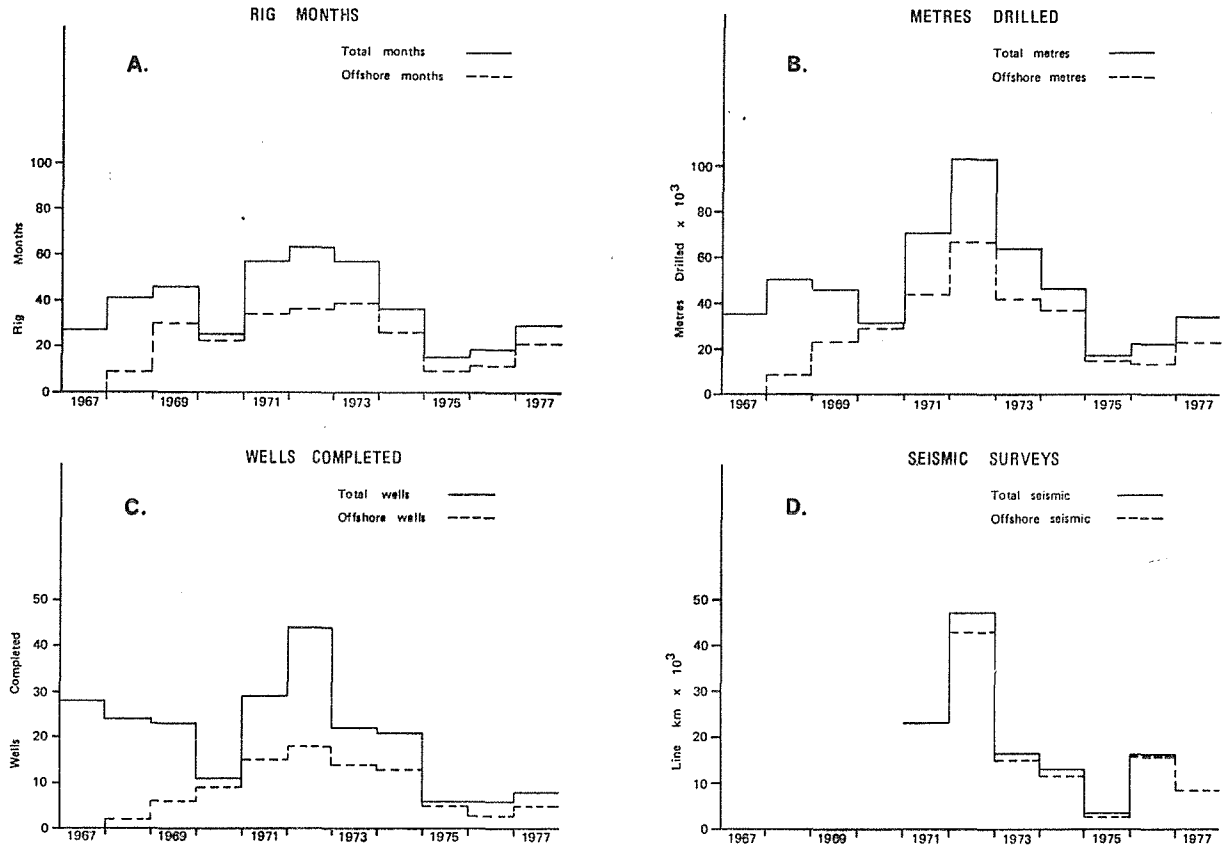
1977 OFFSHORE DRILLING OPERATIONS

OPERATOR	CONTRACTOR	RIG	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
WOODSIDE	ODECO	OCEAN DIGGER (Semisubmersible)	NORTH RANKIN No.5 3500 m PLUGGED and ABANDONED											
WOODSIDE	ATWOOD OCEANICS	REGIONAL ENDEAVOUR (Shipshape)		HAYCOCK No.1 3668 m PLUGGED and ABANDONED		SCOTT REEF No.2 310 m P&A	SCOTT REEF No.2A 4820 m PLUGGED and ABANDONED				CASWELL No.1 DRILLING			
PHILLIPS	ODECO	OCEAN DIGGER (Semisubmersible)										PEEL No.1 3714 m PLUGGED and ABANDONED		
WAPET	MAERSK DRILLING	MAERSK ENDURER (Jack-up)									HERMITE No.1 3300 m PLUGGED and ABANDONED			BUNDEGI No.1
ARCO	SOUTH SEAS DRILLING Co.	SOUTHERN CROSS (Semisubmersible)												PLOVER No.3 1219 m P&A

1977 ONSHORE DRILLING OPERATIONS

OPERATOR	CONTRACTOR	RIG	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
WAPET	SHELF DRILLING	NAT 110 DE	DENISON No.1 2300 m P&A		WARRO No.1 4385 m PLUGGED and ABANDONED								WARRO No.2	

0 5 10 15 20 25 30 days



APPRAISAL AND DEVELOPMENT

Barrow Island Field

(Operator—West Australian Petroleum Pty Limited)

There were no exploration or development wells drilled on Barrow Island during 1977. Routine well servicing and remedial work continued throughout the year using both the Ideco H–35 and the Cooper rigs. Remedial work carried out included the cementing of four inch casing in six Windalia wells which had experienced corrosion damage to the original 5½ inch casing.

The status of the 511 wells within the Barrow Island Field as at the end of 1977 is shown in Table II. At the end of the year 490 of the wells were operating with respect to the "Windalia Sand Member" which is the principal reservoir in the field.

As part of a continuing programme to change the original inverted nine-spot water flood pattern to a North—South line drive configuration, a further eight Windalia production wells with high water cuts were converted to injection. The status of all wells on Barrow Island is shown on Figure 3. Those not specifically annotated refer to "Windalia" operations.

TABLE II

BARROW ISLAND FIELD WELL STATUS BY RESERVOIRS AT 31st DECEMBER, 1977

Number of wells

Reservoir	Flowing	Pumping	Gas lift	Closed in	Water injection	Water source	Water disposal	Total
Lower Gearle	....	1	....	....	....	....	....	1
Windalia	1	177	85	19	192	9	7	490
Muderong	....	3	2	3	....	....	....	8
Jurassic 5 500′	....	....	....	1	....	....	....	1
Jurassic 6 200′	....	....	....	1	....	....	....	1
Jurassic 6 600′	....	1	....	1	....	....	....	2
Jurassic 6 700′	1	2	....	2	....	....	....	5
Jurassic 3 550 m	....	....	....	1	....	....	....	1
Jurassic 11 250′	....	....	....	2	....	....	....	2
Total number of wells	2	184	87	30	192	9	7	511

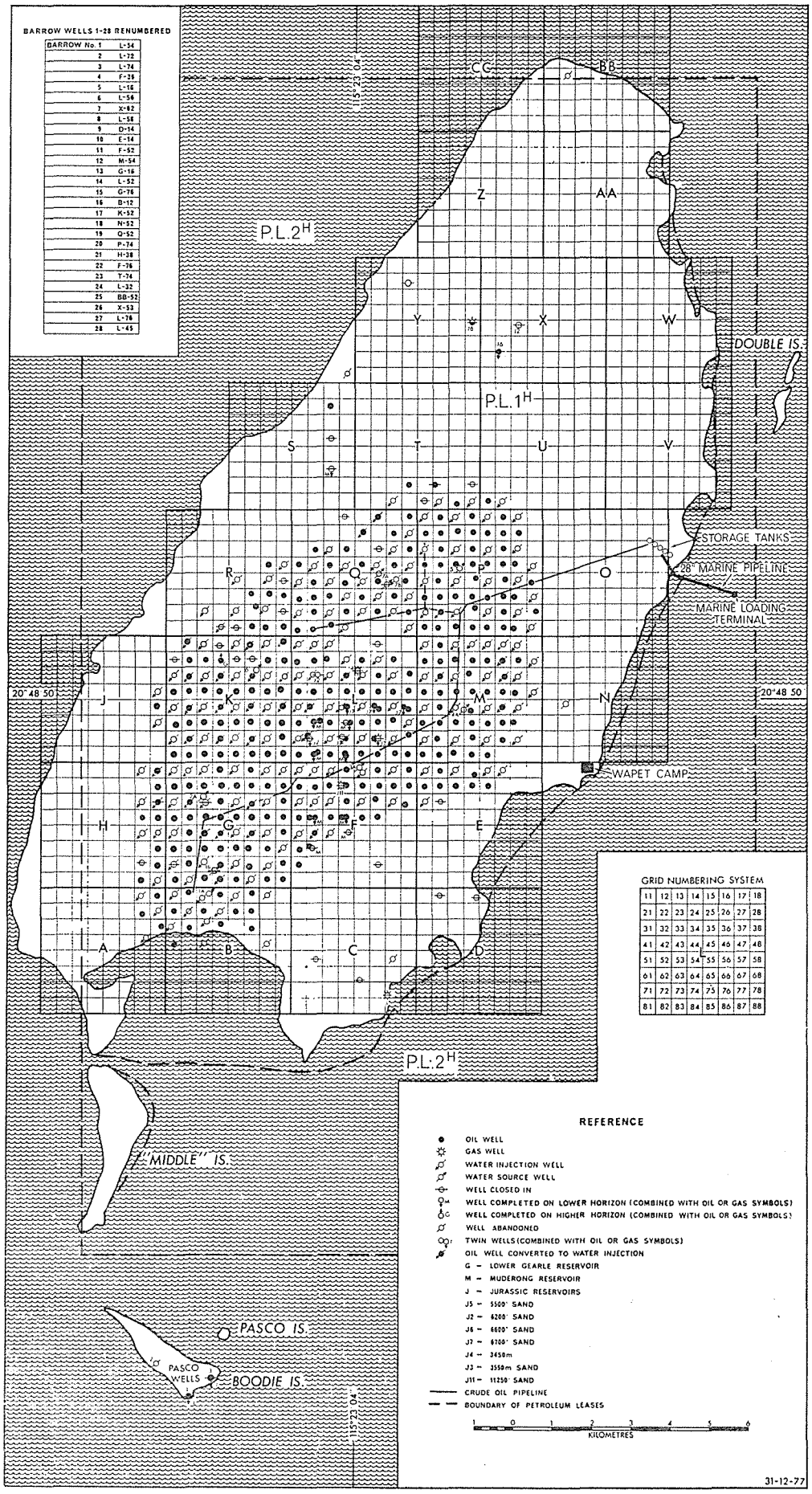


Figure 3. Barrow Island Field, northern Carnarvon Basin. Status of all wells on Barrow Island on 31st December, 1977.

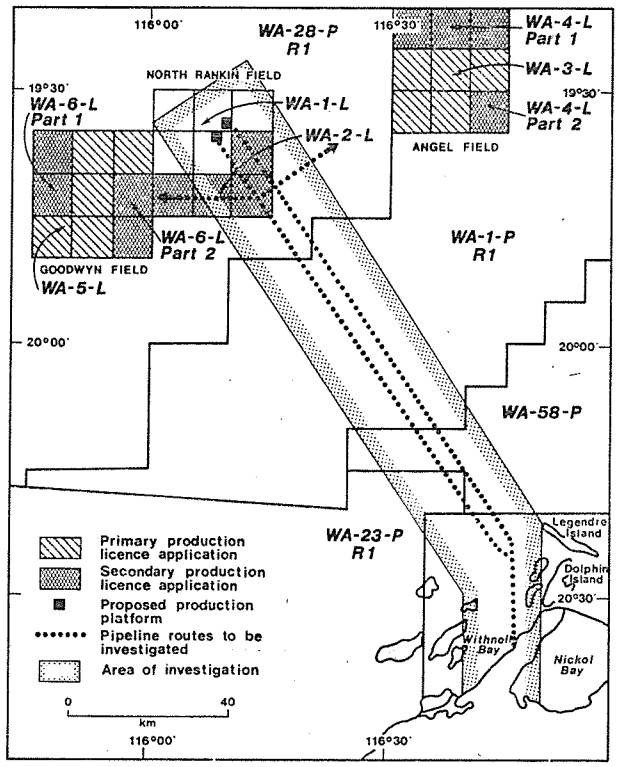


Figure 4. Angel, North Rankin and Goodwyn locations showing the proposed pipeline route to Wwithnell Bay.

North Rankin Field

(Operator—Woodside Petroleum Development Pty Ltd)

Operations to provide data for field development continued. The entire gas bearing reservoir section of the North Rankin No. 5 well was cored and the well extensively production tested. Testing operations on North Rankin No. 5 were completed during the first quarter and were followed by an appraisal marine seismic survey over the North Rankin field. Toward the year end preparations were being made for oceanographic and hydrographic surveys to investigate the possible pipeline route from the North Rankin field to Withnell Bay and the approach channels for a marine terminal. A secondary production licence with respect to the North Rankin Location 2SL was applied for by Woodside Petroleum Development during the year together with applications for primary and secondary production licences with respect to both the Angel (1SL) and Goodwyn (3SL) locations. (Figure 4.)

Dongara and Mondarra Fields

(Operator—West Australian Petroleum Pty Limited)

Prolonged testing of the Dongara oil wells to establish individual well and overall reservoir performance characteristics was continued throughout 1977. The status of the wells in these fields is shown in Figure 6. The No. 17 well, which had exhibited a tendency toward high gas/oil ratio production, was shut in during January and the No. 8 well was placed on production. So far, the No. 8 well has shown no trend towards gas coning and produces at near solution gas/oil ratio. The average daily production of oil from Dongara during 1977 was 30·61 m^3.

PETROLEUM PRODUCTION

Barrow Island Field

The total production and disposal of liquids and gas, produced from the various reservoirs during 1977 is shown in Table III.

Of the associated gas produced with the crude oil some 13·2 per cent was used as field fuel and the remainder flared after extraction of the plant products such as liquid petroleum gas (L.P.G.) and natural gasoline. The natural gasoline is mixed with the crude oil for sale while the L.P.G. is either sold to markets in the north-west of the State, or if these are not available, blended with the crude oil. A break down by reservoirs of the annual and cumulative production for the Barrow Island field is given in Table V and the daily average production of crude oil for each month from the start of production until the end of 1977 is shown in Figure 5. The total royalty paid on Barrow Island sales during 1977 was $2 037 843, an increase of $759 993 over 1976.

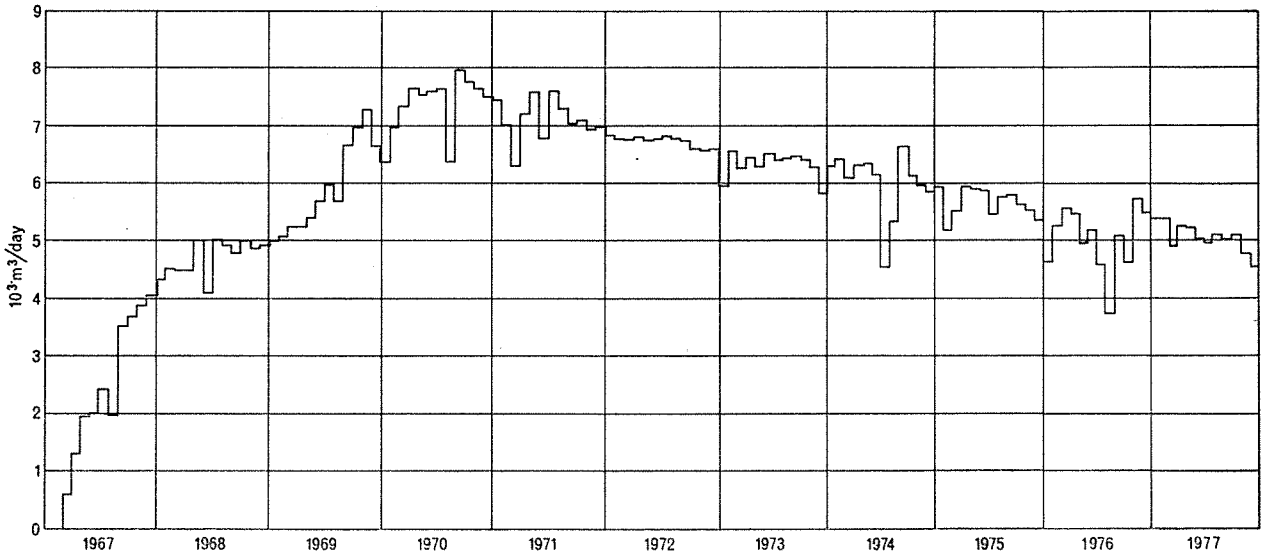


Figure 5. Barrow Island Field (Petroleum Lease 1H), northern Carnarvon Basin. Average daily production of crude oil month by month between March 1967 and 31st December, 1977.

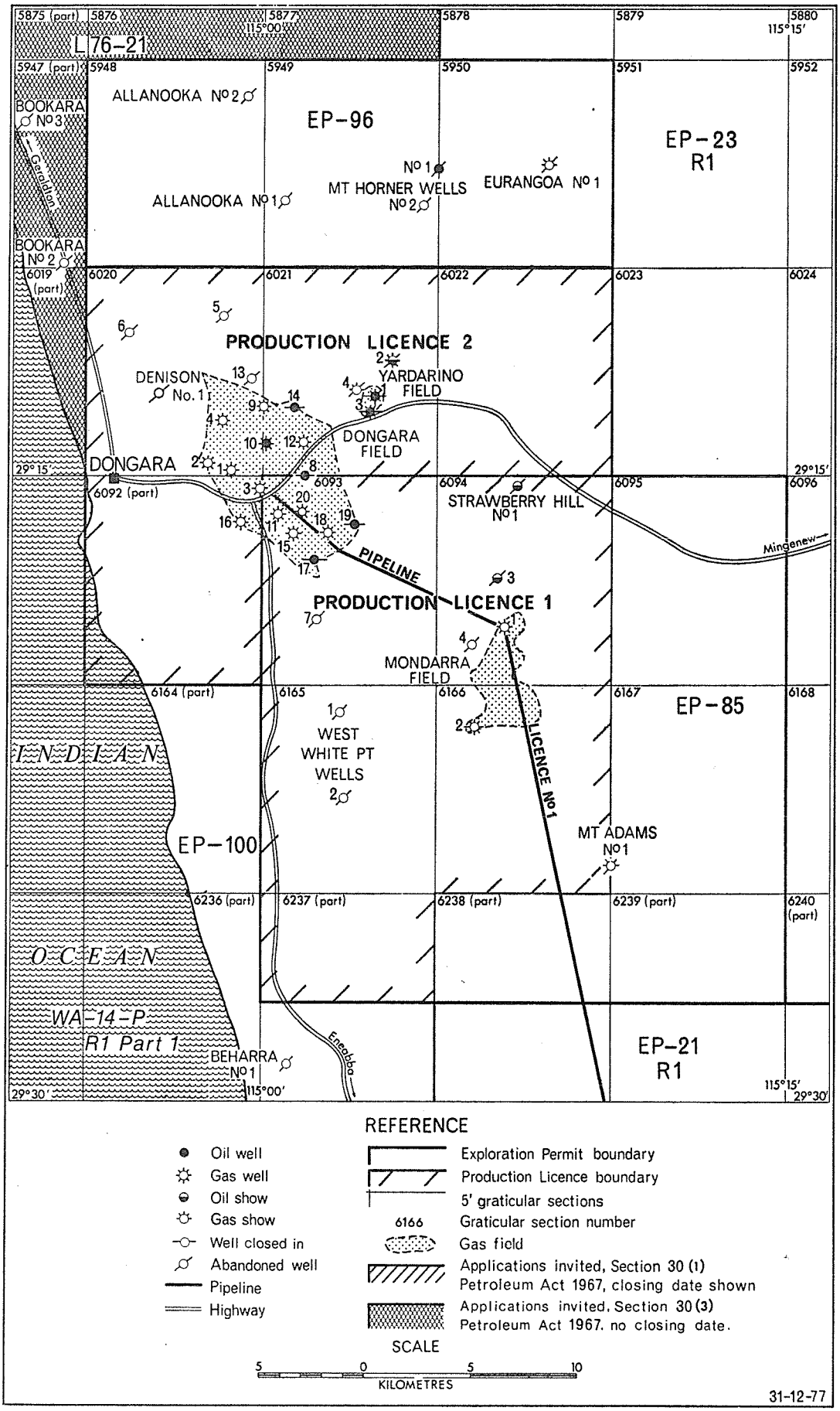


Figure 6. Dongara area, northern Perth Basin. Status of petroleum tenements and wells at 31st December, 1977.

TABLE III

BARROW ISLAND FIELD OIL AND GAS DISPOSAL DURING 1977

	Oil m^3 (bbls)	Natural gasoline m^3 (bbls)	Liquefied petroleum gas m^3 (bbls)	Gas 10^3m^3
Total Production	1 835 015 (11 541 877)	4 078 (25 653)	4 938 (31 060)	120 093
Field Fuel	....	....	326 (2 050)	15 809
Sales	1 860 694 (11 703 393)	....	3 163 (19 894)	....

Royalty paid on petroleum sales during 1977 = $A 2 037 843

Dongara and Mondarra Fields

Table IV shows the quantities of the various types of petroleum produced from the northern Perth Basin during 1977 together with the cumulative production since 1971.

Gas production from the two fields averaged 2·2 x 10^3 m^3/day. The monthly gas production from the northern Perth Basin between 25th October, 1971 and 31st December, 1977 is shown graphically on Figure 7. It is now estimated that approximately 33 per cent of the original in-place gas at Dongara and Mondarra has been produced.

The total royalty paid on petroleum production from the north Perth Basin fields increased by $244 483 to $749 458.18.

TABLE IV

DONGARA, MONDARRA AND GINGIN FIELDS: PETROLEUM PRODUCTION DURING 1977

Field	Number of producing wells at 31/12/1977	Production for year 1977				Cumulative production			
		Gas 10^3m^3	Condensate m^3 (bbls)	Oil m^3 (bbls)	Water m^3 (bbls)	Gas 10^3m^3	Condensate m^3 (bbls)	Oil m^3 (bbls)	Water m^3 (bbls)
Dongara	13	752 175	3 031 (19 064)	11 168 (70 244)	6 787 (42 689)	4 395 780	21 578 (135 721)	27 902 (175 498)	22 238 (139 873)
Mondarra	1	70 037	586 (3 686)	....	724 (4 554)	349 898	5 422 (34 103)	....	2 246 (14 127)
Gingin	....	....	....	....	....	48 561	3 164 (19 901)	....	3 488 (21 939)
Total	14	822 212	3 617 (22 750)	11 168 (70 244)	7 511 (47 243)	4 794 239	30 164 (189 725)	27 902 (175 498)	27 972 (175 939)

Total royalties paid on petroleum sales during 1977 = $A749 458.18.
Total gas sold in 1977 = 813 786·93 10^3m^3.
Total Condensate sold in 1977 = 3 621·71 m^3.
Total oil sold in 1977 = 11 065·40 m^3.

NOTES:

1. Metric standard conditions for both gas and oil are 15°C and 101·325 kPa.
2. Where oil is expressed in barrels, imperial standard conditions are used, i.e. 60°F and 14·73 psia.

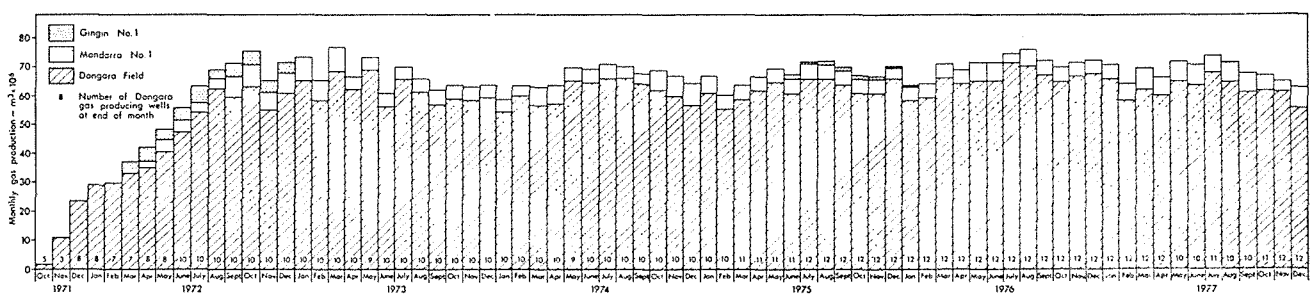


Figure 7. Dongara, Mondarra and Gingin Fields, northern Perth Basin. Monthly gas production between 25th October, 1971 and 31st December, 1976.

TABLE V

BARROW ISLAND FIELD: PETROLEUM PRODUCTION DURING 1977

Reservoir	Production for year 1977					Cumulative Production				
	Oil m^3 (bbls)	N.G. m^3 (bbls)	L.P.G. m^3 (bbls)	Gas 10^3m^3	Water m^3 (bbls)	Oil m^3 (bbls)	N.G. m^3 (bbls)	L.P.G. m^3 (bbls)	Gas 10^3m^3	Water m^3 (bbls)
Lower Gearle	7 193			1 229	239	36 240			4 909	415
	(45 240)	....	....		(1 502)	(229 940)	....	....		(2 610)
Windalia	1 799 535	4 079	4 938	98 390	816 225	21 943 507	21 029	21 773	1 960 063	5 918 639
	(11 318 717)	(25 653)	(25 653)		(5 133 892)	(138 000 269)	(132 262)	(136 947)		(37 227 056)
Muderong	9 912	....	....	2 184	5 169	223 504	....	....	34 974	74 633
	(63 344)				(32 511)	(1 405 795)				(469 428)
Jurassic 6 600′	6 784	....	....	581	19 105	75 229	....	....	23 713	148 055
	(42 668)				(120 164)	(473 178)				(931 238)
Jurassic 6 700′	11 321	....	....	8 927	13 180	220 562	....	....	125 071	92 755
	(71 229)				(82 897)	(1 387 290)				(583 412)
Jurassic 3 550 m	....	....	....	....	....	*100	....	....	4 229	41
						(629)				(255)
Jurassic 11 250′	270	....	....	8 792	97	*731	....	....	26 662	282
	(1 699)				(613)	(4 596)				(1 773)
Total	1 835 015	4 079	4 938	120 093	854 014	22 499 872	21 029	21 773	2 179 622	6 234 820
	(11 541 877)	(25 653)	(31 060)		(5 371 579)	(141 519 697)	(132 262)	(136 947)		(39 215 772)
Cumulative totals for reservoirs which did not produce in 1977						12 009	....	....	98 442	36 002
						(75 534)				(226 447)
Cumulative grand totals						22 511 881	21 029	21 773	2 278 064	6 270 822
						(141 595 231)	(132 262)	(136 947)		(39 442 219)

Water injected during 1977 = 5 540 685 m^3 (34 849 800 bbls). Cumulative water injected = 48 204 183 m^3 (303 194 670 bbls).

NOTES:

1. *Denotes condensate which is blended with crude for sale.
2. Metric standard conditions for both gas and oil are 15°C and 101·325 kPa.
3. Where oil is expressed in barrels, imperial standard conditions are used, i.e. 60°F and 14·73 psia.
4. Natural gasoline and liquified petroleum gas are obtained by treatment of solution gas in the low temperature separation plant.

TABLE VI

ACCIDENT STATISTICS RELATING TO THE PETROLEUM EXPLORATION, PRODUCTION AND PIPELINE INDUSTRY DURING 1977

PETROLEUM INDUSTRY CATEGORIES

	Drilling Activities		Barrow Island Oil-field	Dongara Gas-field	Natural Gas Trans-mission Pipeline	Seismic Activities		Totals
	Onshore	Offshore				Onshore	Offshore	
NATURE OF INJURY			**NUMBER OF INJURIES**					
Head	2	5	3	....	....	....	1	11
Eye	1	6	10	....	....	....	....	17
Trunk	7	17	20	1	....	....	2	47
Arm	1	7	7	....	....	....	1	16
Hand	3	19	29	2	....	....	....	53
Leg	2	7	11	1	....	....	1	22
Foot	1	5	7	1	....	....	....	14
Occupational diseases	....	....	....	....	....	....	....	....
Other injuries and shock	....	7	1	....	....	....	....	8
AGENCY OF INJURY			**NUMBER OF INJURIES**					
Machinery in operation	2	5	5	....	....	....	....	12
Vehicles	1	....	1	....	....	....	....	2
Tools—hand	4	15	12	....	....	....	....	31
Tools—power	....	....	....	....	....	....	....	....
Manual handling	4	5	21	3	....	....	1	34
Harmful contacts	1	6	13	....	....	....	1	21
Persons falling or striking	2	22	16	1	....	....	1	42
Objects flying or falling	1	14	16	1	....	....	....	32
Other	1	6	2	....	....	....	....	9
MAGNITUDE OF INJURY			**NUMBER OF ACCIDENTS**					
Minor	4	46	63	5	....	....	....	118
Serious	12	27	24	....	....	....	3	66
Fatal	....	....	....	....	....	....	....	....
TIME FACTOR			**EXPOSURE TIME AND TIME LOST**					
Days lost	111	310	262	....	....	....	17	700
Manhours exposure	83 221	438 734	291 225	12 048	17 347		23 288	865 863

SAFETY

A summary of all accidents reported by the petroleum exploration, production and pipeline industry during 1977 is presented in Table VI. No fatalities occurred. The frequency rate and severity rate variations by quarters for 1977 are graphed in Figure 8 as a continuing comparison from 1976 onwards.

PETROLEUM PIPELINES

Dongara to Pinjarra Natural Gas Pipeline

(Operator—West Australian Natural Gas Pty Ltd)

A total of 305 transmittals each covering multiple work proposals were received from the various Public Utilities and processed with reference to petroleum pipelines during 1977. Of these, 25 proposals involved construction works across or within a few feet of WANG's high pressure natural gas pipeline. Nineteen of the proposals were in the metropolitan area. A 610 metre section of the 101·6 mm (four inch) lateral in the Spearwood area was re-located.

As a result of a new rail crossing in the Canning Vale industrial area, a section of the main 356 mm line (14 inch) which underlies the crossing was sleeved to comply with (SAA) Code requirements for pipeline protection.

TITLES

Offshore (see Table VII, IX and Figure 9)

During the year, seven areas totalling 182 610 square kilometres were advertised inviting applications for permits and 23 areas totalling 414 080 square kilometres were made available without a closing date. At the end of the year 34 offshore permits totalling 527 879 square kilometres were held by petroleum exploration companies. A total of 47 applications for permits were received during 1977 in respect of 25 areas. Sixteen applications totalling 345 830 square kilometres were granted and seven applications in respect of six areas were pending at the end of the year. Eighteen applications were refused and six were withdrawn. Applications were received for two Primary and three Secondary Production Licences.

A summary comparison of dealings in relation to exploration permits for 1976 and 1977 is shown in Table IX.

TABLE VII

DEALINGS UNDER THE PETROLEUM (SUBMERGED LANDS) ACT, 1967 DURING 1977
(Abbreviations are listed after Table VIII)

(a) ADVERTISEMENTS (SECTION 20)

Area Number	Basin	Date Gazetted	Closing Date	No. of Blocks	Area (km²)
"Closing Date" Section 20(1)					
W77–35	Exmouth Plateau	14/1/77	15/7/77	400	32 670
W77–36	Exmouth Plateau	14/1/77	15/7/77	400	32 470
W77–37	Exmouth Plateau	14/1/77	15/7/77	400	32 330
W77–38	Exmouth Plateau	14/1/77	15/7/77	400	32 180
W77–39	Exmouth Plateau	14/1/77	15/7/77	400	32 080
W77–40	Perth	15/7/77	11/11/77	15	1 110
W77–41	Browse	15/7/77	11/11/77	242	19 970
	Sub-total			2 257	182 610
"No Closing Date" Section 20(3)					
W76–6	Carnarvon	7/1/77		25	2 000
W76–8	Carnarvon	7/1/77		16	1 300
W76–9	Canning	6/5/77		235	19 155
W76–10	Canning	15/7/77		239	19 510
W76–11	Canning	7/1/77		227	18 500
W76–13	Canning	15/7/77		250	20 205
W76–14	Canning	7/1/77		247	20 050
W76–15	Canning	7/1/77		248	20 200
W76–16	Browse	7/1/77		202	16 760
W76–17	Browse	7/1/77		248	20 370
W76–19	Browse	7/1/77		233	19 280
W76–23	Bonaparte	7/1/77		254	21 170
W76–24	Bonaparte	15/7/77		247	20 610
W76–25	Bremer	7/1/77		274	19 210
W76–26	Bremer	7/1/77		324	22 920
W76–27	Bremer	7/1/77		236	16 690
W76–28	Bremer	7/1/77		280	20 030
W76–29	Bremer	7/1/77		279	20 080
W76–30	Bremer	7/1/77		388	20 070
W76–31	Carnarvon	7/1/77		234	18 410
W76–32	Carnarvon	7/1/77		250	19 450
W76–33	Carnarvon	7/1/77		248	19 100
W76–34	Carnarvon	7/1/77		249	19 010
	Sub-total			5 433	414 080
	Grand total			7 690	596 690

(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–62–P	W76–12	Oxoco *et al* 1	21/7/76	Canning	226	18 265	Granted	8/3/77
WA–63–P	W76–13	Oxoco *et al* 1	21/7/76	Canning	250	20 205	Withdrawn	21/2/77
WA–64–P	W76–7	Offshore *et al*	21/7/76	Carnarvon	22	1 760	Granted	1/3/77
WA–65–P	W76–9	Getty *et al* 1	22/7/76	Canning	235	19 155	Withdrawn	3/4/77
WA–66–P	W76–10	Meekatharra	23/7/76	Canning	239	19 510	Refused	4/2/77
WA–67–P	W76–12	Meekatharra	23/7/76	Canning	226	18 265	Refused	25/1/77
WA–68–P	W76–20	Oxoco *et al* 2	5/10/76	Browse/Bonaparte	249	20 730	Granted	8/3/77
WA–69–P	W76–21	Oxoco *et al* 2	5/10/76	Bonaparte	251	21 060	Refused	29/3/77
WA–70–P	W76–21	Getty *et al* 2	7/10/76	Bonaparte	251	21 060	Granted	13/4/77
WA–71–P	W76–21	Crusader	8/10/76	Bonaparte	251	21 060	Refused	29/3/77
WA–72–P	W76–18	Oberon	8/10/76	Browse	242	19 970	Granted	29/1/77
WA–73–P	W76–21	Magnet *et al* 2	8/10/76	Bonaparte	251	21 060	Refused	29/3/77
WA–74–P	W76–22	Pelsart	8/10/76	Bonaparte	258	21 270	Granted	25/6/77
WA–75–P	W76–24	Pelsart	8/10/76	Bonaparte	247	20 610	Withdrawn	24/5/77
WA–76–P	W76–21	Pelsart	8/10/76	Bonaparte	251	21 060	Withdrawn	24/5/77
WA–77–P	W76–23	Magnet *et al* 1	8/3/77	Bonaparte	254	21 170	Granted	2/8/77
WA–78–P	W76–34	Magnet *et al* 3	8/3/77	Carnarvon	249	19 010	Refused	12/10/77
WA–79–P	W76–9	Getty *et al* 3	12/5/77	Canning	235	19 155	Granted	2/8/77
WA–80–P	W76–8	Otter *et al*	13/5/77	Carnarvon	16	1 300	Granted	7/10/77
WA–81–P	W76–34	Continental *et al*	23/5/77	Carnarvon	249	19 010	Granted	14/10/77
WA–82–P	W76–34	Pursuit	18/5/77	Carnarvon	249	19 010	Refused	12/10/77
WA–83–P	W76–19	Oxoco *et al* 3	28/6/77	Browse	233	19 280	Pending	....
WA–84–P	W77–37	Phillips *et al*	15/7/77	Exmouth Plateau	400	32 330	Granted	19/11/77
WA–85–P	W77–38	Mobil *et al*	15/7/77	Exmouth Plateau	400	32 180	Refused	8/11/77
WA–86–P	W77–38	Offshore *et al*	14/7/77	Exmouth Plateau	400	32 180	Refused	8/11/77
WA–87–P	W77–37	Shell *et al* 1	15/7/77	Exmouth Plateau	400	32 330	Refused	15/11/77
WA–88–P	W77–38	Shell *et al* 1	15/7/77	Exmouth Plateau	400	32 180	Refused	8/11/77
WA–89–P	W77–39	Shell *et al* 2	15/7/77	Exmouth Plateau	400	32 080	Refused	8/11/77
WA–90–P	W77–35	Woodside *et al* 1	15/7/77	Exmouth Plateau	400	32 470	Granted	19/11/77
WA–91–P	W77–36	Woodside *et al* 1	15/7/77	Exmouth Plateau	400	32 470	Refused	17/11/77
WA–92–P	W77–35	Hudbay *et al*	15/7/77	Exmouth Plateau	400	32 470	Refused	7/11/77
WA–93–P	W77–36	Hudbay *et al*	15/7/77	Exmouth Plateau	400	32 470	Granted	19/11/77
WA–94–P	W77–37	Esso *et al*	15/7/77	Exmouth Plateau	400	32 330	Refused	15/11/77
WA–95–P	W77–38	Esso *et al*	15/7/77	Exmouth Plateau	400	32 180	Refused	8/11/77
WA–96–P	W77–38	Esso *et al*	15/7/77	Exmouth Plateau	400	32 180	Granted	19/11/77
WA–97–P	W77–39	Esso *et al*	15/7/77	Exmouth Plateau	400	32 080	Granted	19/11/77
WA–98–P	W77–38	Esso *et al*	15/7/77	Exmouth Plateau	400	32 180	Refused	8/11/77
WA–99–P	W77–37	Esso *et al*	15/7/77	Exmouth Plateau	400	32 330	Refused	15/11/77
WA–100–P	W75–1	Phoenix	4/8/77	Perth	231	16 440	Withdrawn	8/11/77
WA–101–P	W75–2	Phoenix	4/8/77	Perth	16	1 160	Withdrawn	8/11/77
WA–102–P	W76–31	Canada *et al*	29/9/77	Carnarvon	234	18 410	Pending	....
WA–103–P	W76–24	Natomas *et al*	7/10/77	Bonparate	247	20 610	Granted	30/12/77
WA–104–P	W77–41	Oberon	31/10/77	Browse	242	19 970	Pending	....
WA–105–P	W75–3	Agha-Jari *et al* 1	11/11/77	Perth	44	3 240	Pending	....
WA–106–P	W75–4	Ahga-Jari *et al* 1	11/11/77	Perth	14	1 040	Pending	....
WA–107–P	W77–40	Agha-Jari *et al* 1	11/11/77	Perth	15	1 110	Pending	....
WA–108–P	W77–41	Metro *et al*	11/11/77	Browse	242	19 970	Pending	....

(c) SPECIAL AUTHORITIES AND CONSENTS (SECTIONS 112 AND 123)
(AA = Access Authority—Section 112)
(SI = Scientific Investigation—Section 123)

Number	Applicant	Basin or Area of Survey	Permit or Area requiring Access Authority
AA41SL	Woodside *et al* 2	Carnarvon, Canning and Browse	Vacant
AA42SL	Woodside *et al* 2	Canning	Vacant
AA43SL	Woodside *et al* 2	Carnarvon	Vacant
AA44SL	Western Energy	Carnarvon	WA–1–P
AA45SL	Getty *et al* 2	Bonaparte	WA–16–P, WA–68–P, WA–74–P, WA–77–P
AA46SL	WAPET	Carnarvon	Vacant
AA47SL	Continental *et al*	Carnarvon	Vacant
SI11SL	G.S.I.	Exmouth Plateau	Vacant

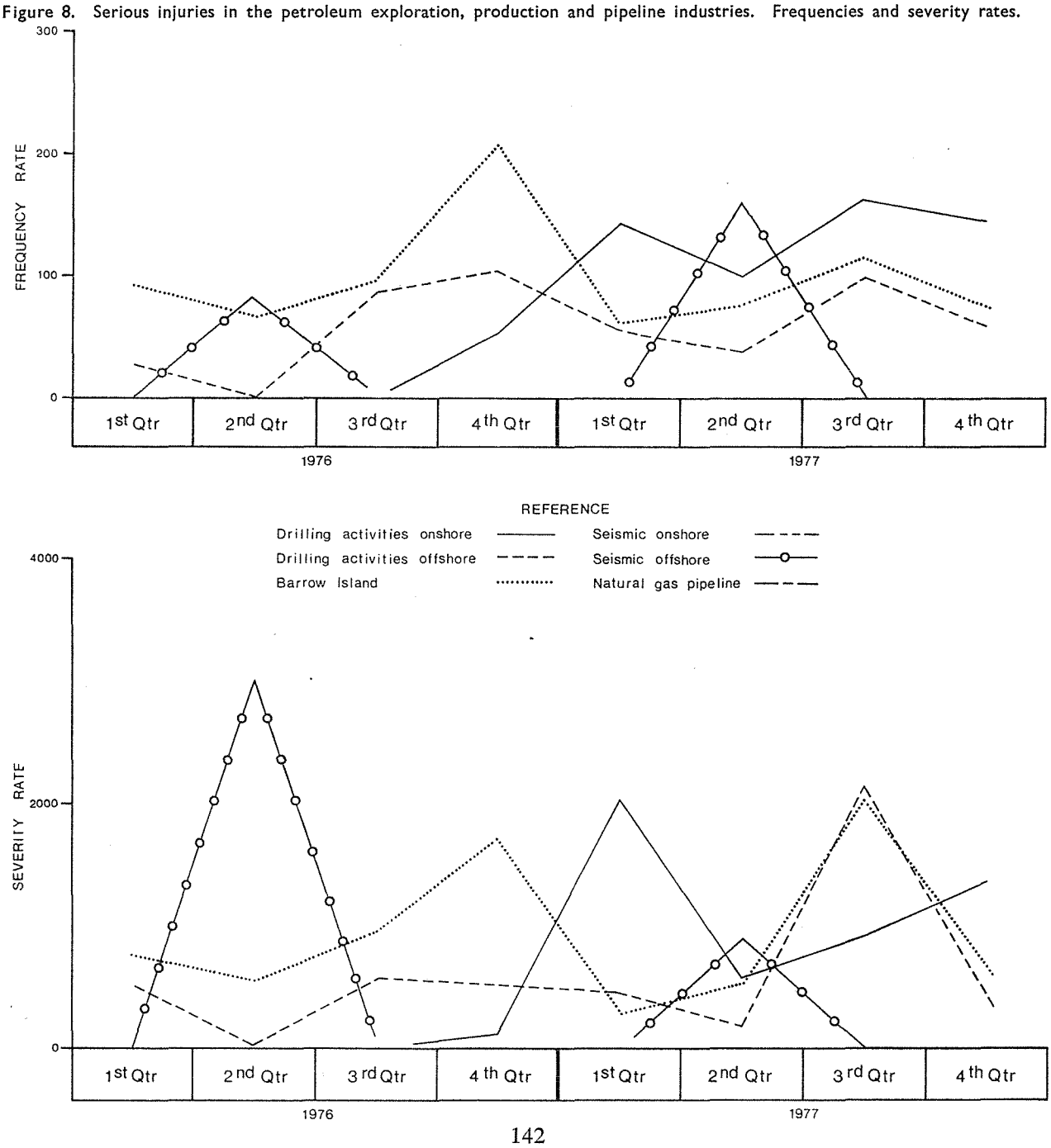
(d) EXPLORATION PERMIT SURRENDERS (SECTION 104)

Permit Number	Basin	Permittee	Date Surrender	No. of Blocks and Area (km²)	
				Original	Surrendered
WA–19–P R1	Bonaparte	Alliance	Pending	49 (4 058)	0
WA–20–P R1	Perth	WAPET	4/3/77	15 (1 112)	15
WA–31–P R1	Browse	Woodside *et al* 2	19/8/77	80 (6 548)	80
WA–72–P	Browse	Oberon	7/4/77	242 (19 970)	242

(e) PRODUCTION LICENCE APPLICATIONS

Application	Location	Applicant	Date Received	Basin	No. of Blocks	Status
WA–1–L (Primary)	North Rankin 2SL	Woodside *et al* 2	31/12/75	Carnarvon	5	Pending
WA–2–L (Secondary	North Rankin 2SL	Woodside *et al* 2	7/12/77	Carnarvon	4	Pending
WA–3–L (Primary)	Angel 1SL	Woodside *et al* 2	7/12/77	Carnarvon	5	Pending
WA–4–L (Secondary)	Angel 1SL	Woodside *et al* 2	7/12/77	Carnarvon	4	Pending
WA–5–L (Primary)	Goodwyn 3SL	Woodside *et al* 2	7/12/77	Carnarvon	5	Pending
WA–6–L (Secondary	Goodwyn 3SL	Woodside *et al* 2	7/12/77	Carnarvon	4	Pending

Figure 8. Serious injuries in the petroleum exploration, production and pipeline industries. Frequencies and severity rates.



Onshore (see Table VIII, IX and Figure 9)

At the end of the year current onshore exploration permits were 34. These cover an area totalling 156 218 square kilometres. Twelve applications for vacant areas were received during the year but only six of these were for the areas advertised in 1977. The other six applications were for areas advertised in 1976. Eight permits totalling 89 450 square kilometres were granted during the year and three were pending as of 31st December. A summary comparison of exploration permit dealings for 1976 and 1977 is shown in Table IX.

STAFF

It is with deep regret that the death of Dr. R. N. Cope on 28th May 1977 is recorded. Dr. Cope joined the Geological Survey Branch of the Mines Department in January 1969 and transferred to the Petroleum Branch in 1974.

The staff of the Petroleum Branch during 1977 were as follows:—

A. J. Sharp—Director Petroleum Branch (Level 6)
A. H. Pippet—Senior Petroleum Engineer (Level 5)
P. H. Hammett—Operations Engineer (Level 4)
D. N. Smith—Production Geologist (Level 4)
Vacant—Reservoir Engineer (Level 4)

TABLE VIII

DEALINGS UNDER THE PETROLEUM ACT, 1967, DURING 1977
(Abbreviations are listed after this table)

(a) ADVERTISEMENTS (SECTION 30)

Area Number	Basin	Date Gazetted	Closing Date	No. of Blocks	Area (km²)
"Closing date" (Section 30 (1))					
L77–33	Perth	6/5/77	9/9/77	4	300
L77–34	Browse	15/7/77	11/11/77	1	80
			Sub-total	5	380
"No closing date" (Section 30 (3))					
L76–19	Bonaparte	7/1/77		76	6 260
L76–20	Eucla	7/1/77		81	5 880
L76–21	Perth	6/5/77		170	12 800
L76–23	Perth	15/7/77		135	9 600
L76–24	Canning	6/5/77		199	16 280
L76–25	Canning	6/5/77		196	15 970
L76–29	Canning	6/5/77		200	16 140
L76–30	Canning	6/5/77		200	16 060
L76–31	Carnarvon	6/5/77		200	15 830
L76–32	Carnarvon	6/5/77		200	15 700
			Sub-total	1 657	130 520
			Grand total	1 662	130 900

(b) EXPLORATION PERMIT APPLICATIONS AND GRANTS (SECTIONS 31 AND 32)

Application or Permit Number	Area Number	Applicant	Date Application	Basin	No. of Blocks	Area (km²)	Status	Operative Date
EP– 98	Part L76–18	Oberon	8/10/76	Browse	1	80	Granted	29/1/77
EP– 99	Part L76–23	Union	28/1/77	Perth	22	1 560	Withdrawn	20/5/77
EP–100	L76–22	Agha Jari *et al* 2	28/1/77	Perth	163	12 000	Granted	4/10/77
EP–101	L76–26	Whitestone *et al*	9/3/77	Canning	172	14 040	Granted	25/6/77
EP–102	L76–28	Whitestone *et al*	9/3/77	Canning	200	16 180	Granted	25/6/77
EP–103	L76–27	Whitestone	10/3/77	Canning	184	14 950	Granted	23/8/77
EP–104	L76–24	Esso	14/7/77	Canning	199	16 280	Granted	1/9/77
EP–105	L77–33	Colgas Inc.	5/9/77	Perth	4	300	Granted	30/11/77
EP–106	L77–34	Oberon	31/10/77	Browse	1	80	Pending	....
EP–107	L75–11	Era *et al*	4/11/77	Canning	146	11 740	Pending	....
EP–108	Part L75–10 and other	Houston	7/11/77	Canning	193	15 620	Granted	30/12/77
EP–109	L77–34	Metro *et al*	11/11/77	Browse	1	80	Pending	....

(c) EXPLORATION PERMIT EXPIRIES AND RENEWALS

Permit Number	Basin	Permittee	No. of Blocks	Area (km²)	First Term Expiry Date	Status	No. of Blocks Renewed	Area (km²)
EP–58 R1	Canning	A.A.R. *et al*	200	16 000	20/7/76	Renewed	150	12 067
EP–59 R1	Canning	A.A.R. *et al*	186	14 880	18/7/76	Renewed	139	11 075
EP–70	Canning	A.A.R. *et al*	71	5 420	25/9/77	Expired	....	5 420

(d) EXPLORATION PERMIT SURRENDERS (SECTION 98)

Permit Number	Basin	Permittee	Date Surrender	No. of Blocks		Area (km²)
				Original	Surrendered	
EP– 7 R1	Canning	WAPET	Pending	24	....	1 961
EP–13 R1	Canning	WAPET	Pending	23	....	1 847
EP–19 R1	Canning	WAPET	Pending	18	....	1 443
EP–40 R1	Carnarvon	WAPET	Pending	19	....	1 516
EP–42 R1	Canning	WAPET	Pending	19		1 551
EP–50 R1	Perth	WAPET	Pending	18	....	1 285
EP–85	Perth	Endeavour *et al*	18/3/77	4	4	300
EP–98	Browse	Oberon	7/4/77	1	1	80

(e) PERMIT CANCELLATIONS (SECTION 99)

Permit Number	Permittee	Basin	Cancellation Date	No. of Blocks	Area (km²)
EP–68	W. I. Robinson	Bremer	10/6/77	175	12 300
EP–86	X.L.X. N.L.	Carnarvon	12/8/77	118	9 200

TABLE IX
SUMMARY COMPARISON OF EXPLORATION PERMIT DEALINGS
(1976–1977)

	1976		1977	
	No.	Area (km²)	No.	Area (km²)
Areas Advertised—				
Onshore	28	365 470	12	130 900
Offshore....	33	546 405	30	596 690
Totals	61	911 875	42	727 590
Permits Granted—				
Onshore	6	6 467	8	89 450
Offshore....	2	32 208	16	345 830
Totals	8	38 675	24	435 280
Permit Applications (pending at year end)—				
Onshore	5	23 461	3	11 820
Offshore....	10	182 535	7	63 050
Totals	15	205 996	10	74 870
Permits Held (at end year)				
Onshore	29	84 490	34	156 218
Offshore....	21	209 679	34	527 879
Totals	50	294 169	68	684 097
Permits Surrendered—				
Onshore	2	18 180	2	380
Offshore....	0	0	3	27 630
Totals	2	18 180	5	28 010

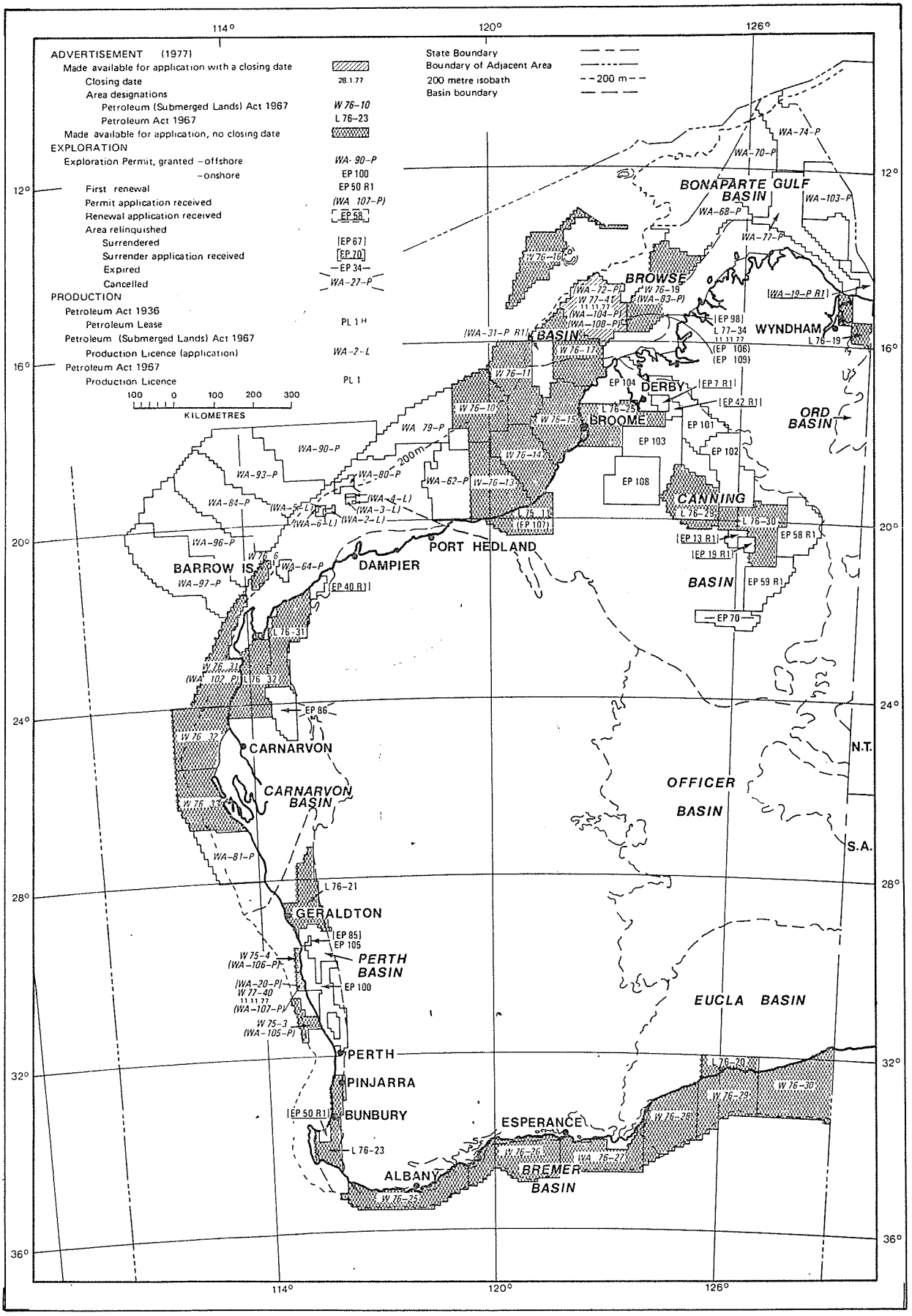


Figure 9. Petroleum tenement dealings during 1977.

77239—10

Abbreviations:

A.A.R. *et al*	A.A.R. Ltd. Abrolhos Oil and Investments Ltd. Australian Aquitaine Petroleum Pty. Ltd. Flinders Petroleum No Liability Longreach Oil Limited Pursuit Oil No Liability
Agha-Jari *et al* 1	Agha-Jari Exploration Co. (Iran) North West Mining No Liability North West Mining (Petroleum) Pty. Ltd.
Agha-Jari *et al* 2	Agha-Jari Exploration Company North West Mining No Liability Landshare Investments Pty. Ltd. J. M. Goldberg Wise Nominees Pty. Ltd. R. W. W. Pty. Ltd. Cladium Mining Pty. Ltd. A. R. Burns V. W. Burns D. R. Gascoine J. Gascoine B. C. Forster Exploration Geophysics Pty. Ltd.
Alliance	Alliance Oil Development Aust. No Liability
Canada *et al*	Canada North West Land Ltd. Star Oil and Gas Ltd. Cultus Pacific N.L. Oakwood Petroleums Ltd.
Continental *et al*	Continental Oil Coy of Australia Ltd. General Crude Oil Company International Ltd.
Crusader	Crusader (Surat) Pty. Ltd.
Endeavour *et al*	Endeavour Oil Co. No Liability Target Minerals No Liability I.O.L. Petroleum Ltd. A.A.R. Limited Alliance Minerals (Australia) No Liability
Era *et al*	Era South Pacific Pty. Ltd. Era Western Australia Inc. E.S.P. Explorations Pty. Ltd. Cambridge Royalty Company Cambridge Petroleum Royalties Ltd. North West Mining N.L.
Esso	Esso Exploration and Production Australia Inc.
Esso *et al*	Esso Exploration and Production Australia Inc. Hematite Petroleum Pty. Ltd.
Getty *et al* 1	Getty Mining Pty. Ltd. Hematite Petroleum Pty. Ltd. The Shell Co. of Aust. Ltd. Phillips Australian Oil Company
Getty *et al* 2	Getty Oil Development Co. Ltd. Union Texas Aust. Inc.
Getty *et al* 3	Getty Oil Development Co. Ltd. Continental Oil Company of Australia Ltd. The Shell Company of Australia Ltd. Hematite Petroleum Pty. Ltd.
G.S.I.	Geophysical Service International
Houston	Houston Oil and Minerals Australia Inc.
Hudbay *et al*	Hudbay Oil (Australia) Ltd. Canadian Superior Oil International Ltd. Pan Canadian Petroleum Ltd. Australian Oil and Gas Corporation Ltd.
Magnet *et al* 1	Magnet Metals Ltd. Jeerinah Mining Pty. Ltd. Sundance Resources (Cayman) Ltd. Crux (International) Ltd. Scorpio Petroleum Ltd. Pluto Petroleum Ltd.
Magnet *et al* 2	Magnet Metals Ltd. Malita Exploration Pty. Ltd.
Magnet *et al* 3	Magnet Metals Ltd. Bronzite Mining Pty. Ltd. Sundance Resources (Cayman) Ltd. Crux (International) Ltd. Cirius Ltd. Pisces Energy Ltd.
Meekatharra	Meekatharra Minerals (Australia) Pty. Ltd.
Metro *et al*	Metro Industries Ltd. Pluranpe Pty. Ltd. Westwools Holdings Ltd. Westwools Exploration Ltd. Lennard Oil N.L. Malita Exploration Pty. Ltd.

Mobil *et al*	Mobil Oil Australia Ltd. Phillips Australian Oil Coy. Australian Gulf Oil Coy M.I.M. Investments Pty. Ltd.
Natomas *et al*	Natomas of Western Australia Inc. Wainoco International Inc. Bonaparte Petroleum Ltd. Petro Energy Ltd. Lennard Oil N.L. White Pine Mining Pty. Ltd.
Oberon	Oberon Oil Pty. Ltd.
Offshore *et al*	Offshore Oil N.L. Southern Cross Exploration N.L. Hallmark Minerals N.L. Cocks Eldorado N.L.
Otter *et al*	Otter Exploration N.L. Target Petroleum N.L. Endeavour Oil Coy N.L. Timor Oil Ltd. Spargo's Exploration N.L. Alkane Exploration (Terrigal) N.L.
Oxoco	Oxoco-International Inc.
Oxoco *et al* 1	Oxoco-International Inc. Mid-American Oil Co. Peyto Oils Ltd. Voyager Petroleums Ltd. Australian Oil and Gas Corp. Ltd. Bridge Oil Ltd. Endeavour Oil Co. N.L. A.A.R. Ltd. Offshore Oil N.L.
Oxoco *et al* 2	Oxoco-International Inc. Mid-American Oil Co. Peyto Oils Ltd. Voyager Petroleums Ltd. Bridge Oil Ltd.
Oxoco *et al* 3	Oxoco-International Inc. A.A.R. Ltd. Bridge Oil Limited
Pelsart	Pelsart Oil N.L.
Phillips *et al*	Phillips Australian Oil Company Mobil Oil Australia Ltd. Australia Gulf Oil Company M.I.M. Investments Pty. Ltd. B.P. Petroleum Development Australia Pty. Ltd.
Phoenix	Phoenix Canada Oil Company Limited
Pursuit	Pursuit Exploration Pty. Ltd.
Shell *et al* 1	The Shell Company of Australia Ltd. California Asiatic Oil Company Texaco Overseas Petroleum Company Ampol Exploration Ltd. Getty Oil Development Company Ltd. Continental Oil Company of Australia Ltd. Union Oil Development Corporation
Shell *et al* 2	The Shell Company of Australia Ltd. California Asiatic Oil Company Ampol Exploration Ltd. Continental Oil Company of Australia Ltd. Union Oil Development Corporation Texaco Overseas Petroleum Company
Union	Union Oil Development Corporation
Wapet	West Australian Petroleum Pty. Ltd.
Western Energy	Western Energy Pty. Ltd.
Whitestone	Whitestone Petroleum Australia Ltd.
Whitestone *et al*	Whitestone Petroleum Australia Ltd. Amax Iron Ore Corporation Pennzoil Producing Australia Ltd. Australian Consolidated Minerals Ltd.
Woodside *et al* 1	Woodside Petroleum Development Pty. Ltd. Woodside Oil Ltd. Mid-Eastern Oil Ltd. B.P. Petroleum Development Australia Pty. Ltd. California Asiatic Oil Company The Shell Company of Australia Ltd. Hematite Petroleum Pty. Ltd.
Woodside *et al* 2	Woodside Petroleum Development Pty. Ltd. Woodside Oil Ltd. Mid-Eastern Oil Ltd. North West Shelf Development Pty. Ltd. B.P. Petroleum Development Australia Pty. Ltd. California Asiatic Oil Company
X.L.X. N.L.	X.L.X. N.L.

DIVISION VI

Report of the Superintendent Surveys and Mapping for the Year 1977

The Under Secretary for Mines

For the information of the Hon. Minister, I submit my report of the activities of the Survey and Mapping Division for the year ended 31st December, 1977.

STAFF

The membership of the staff now totals 115 comprising the following categories:—

Professional	68
General	28
Clerical	11
Technical	5
Trainee	7
Total	119
Surveyors (outside the Public Service)	24

During the year the Superintendent, Mr. A. A. Hall retired under the provisions of the Public Service Act. Major new appointments as a consequence have been:—

Mr. S. M. Hocking promoted to Superintendent.
Mr. W. R. Moore promoted to Assistant Superintendent.
Mr. D. J. Pollard promoted to Draftsman-in-Charge (Surveys) and
Mr. D. L. J. Walsh promoted to Draftsman-in-Charge (Applications and Public Plans).

It is hoped to finalise the remaining consequential positions shortly in order to maintain the full establishment required to cope with the increasing demands on the services of this Division.

The Mapping Branch again found that there was a heavy demand on all resources and an accumulated work load developed from the programme of the Geological Survey Branch. The new series of Urban Geology maps gained impetus and this together with the supervisory type activity required after the drawing process, such as checking and organising process and printing work, has placed a heavy burden on the relatively few senior staff. It is considered that staff structural changes will be necessary in the near future.

As at this time the outcome is awaited of Public Service Board reviews of both the Clerical and the General Divisions.

Accommodation

Accommodation is becoming a pressing problem particularly in such service areas as the photographic and plan printing areas. Some other areas of drafting activity are also being hampered by inadequate space. In spite of this a large output of work has emanated from this Division and these activities are itemised under the three main sub-branches of the Division.

SURVEY BRANCH

Field Surveys

Surveys of mining leases, claims, and other tenements were carried out during 1977 by 24 Licensed Surveyors attached to 19 individual survey practices.

Survey work done is summarised in the following table:—

Number of Surveyors	24
Number of tenements surveyed	1 455
Number of field books lodged	219
Number of connection points established (horizontal)	40
	3 631 km
Total boundary line run	203 km
Total area delineated by survey	148 761 ha
Total distance travelled in positioning	38 270 km
Total value of cadastral survey	$564 794
Total value of connection survey	$35 981

The work performed by individual Practitioners is itemised in the following table:—

Company	Surveyor(s)	No. of Surveys	Area Surveyed Hectares
Ranieri Bateman & Associates	J. S. Ranieri G. G. Bateman	171	19 238
D. F. V. Wilson	D. F. V. Wilson	179	19 766
M. M. Fisher & Associates	M. M. Fisher E. J. Still	142	15 132
F. R. Rodda	F. R. Rodda L. Silby	178	18 782
Bernard McCarthy & Partners	J. Zuideveld	144	11 302
Benetti, Croghan & Associates	R. J. Benetti	161	18 155
McKimmie, Jamieson & Partners	G. S. Chignell I. F. Moss	66	5 850
K. F. Patterson & Associates	R. G. Agnew	33	3 672
Byrne & Associates	M. J. Byrne T. G. Moran	8	764
K. R. Maguire	K. R. Maguire	83	9 332
Associated Surveys	D. J. McGay M. L. Hawker	74	5 508
A. K. King & Company	K. R. Maguire K. M. Edwards	79	9 289
P. D. Heyhoe	P. D. Heyhoe	39	4 649
Hille & Thompson	A. G. Thompson	32	2 984
D. J. McGay	D. J. McGay	34	1 974
A. R. Williams	A. R. Williams R. G. Beardman	19	1 896
H. W. Denton	H. W. Denton	6	416
I. M. Gordon	I. M. Gordon	7	52
W. A. Berryman	...	...	...
Totals 19	24	1 455	148 761

The 1 455 tenements surveyed during the year is consistent with that for last year although both the total boundary line run and the total area of tenements show an increase which indicates a trend to larger tenements. In all cases surveys are carried out only after a careful vetting of the potential of the tenancy being on a long term basis and to provide an economical and efficient service to the Industry.

Field Inspection

Kalgoorlie region: Officers from this Branch inspected various tenements and proposed connections for surveys, at Kalgoorlie, Kookynie, Laverton, Leonora, Teutonic Bore and Weebo.

Boddington: A field evaluation was made by officers of this Branch of the proposed survey of part of the common boundary between Mineral Lease 1SA (Alcoa) and Temporary Reserve 6304H (Alwest) in order to gain first hand information on field conditions likely to be encountered.

Field Heighting—GSWA

Elevations on bore sites for the Hydrological Branch were obtained for projects at Dandaragan (five days) and Eneabba (four days).

Connection Projects

New points of connection were established as part of the continuing programme to co-ordinate tenement surveys to facilitate integration and provision of AMG co-ordinates for the CADMAPS system.

Meekatharra—12 new stations were established.

Wiluna—12 new stations were established.

Cue-Nannine—reconnaissance completed.

Laverton—two new stations were established and five stations updated.

Ravensthorpe—(extension of)—Three new stations were established.

Kalgoorlie Project—The relocation and remarking of all lease corners by EDM has been completed and co-ordinates of the established positions are being transferred to permanent CADMAPS records. A detailed report on this activity is being prepared for separate publication.

Co-ordinate Traversing

The results of this office activity are shown in the table:—

Project	Area Covered North/South (km)	Area Covered East/West (km)	Total length of traverse (km)	Total points co-ordinated
Meekatharra	85	35	(not yet commenced)	
Wiluna	105	60	(not yet commenced)	
Cue-Nannine	70	90	(not yet commenced)	
Ravensthorpe	20	33	147	203
Kalgoorlie	8	2	133	517
Kanowna	80	45	1 296	1 438
			1 576	2 158

Office Activity

The activities associated with survey instruction, survey examinations, geodetic calculation, calculation of AMG co-ordinates and general drafting is steadily contributing to the very effective cadastral control and mining map system of the State. The location of a section of the Survey Branch on the first floor whilst the main Branch is located and controlled from the seventh floor is still a difficult situation requiring solution.

Standard Plans

The system to provide a standard plan position for all new surveys has been maintained.

The activity relating to co-ordinate traversing has resulted in the following new computer plots.

Project	Number at 1:50 000	Number at 1:10 000
Sir Samuel	15	....
Agnew-Leinster	....	9
Gullewa	4	....
Youanmi	4	4
Forrestania	7	....

Computer Section

As well as the normal duties relating to Geodetic calculations and surveying this Section provides computer service to the Department generally. Programmes are being established for Dust Sampling under the State Mining Engineer and bore-hole records for the Director of Geological Survey with further projects in the planning stage.

Petroleum

During the year publicity was given through overseas journals, press releases and the *Government Gazette* relating to areas open for application.

These activities caused a general upsurge in interest and activity in the Section.

The State Petroleum Map (1:4 000 000) and the Graticular Section (1:1 000 000) series were continuously up-dated and always available.

Wardens Court

Disputed surveys involving Quarrying Areas at Kununurra, disputed marking off of claims at Yandicoogina and marking off of Gold Mining Leases and Prospecting Areas at Wiluna were dealt with.

In each case the evidence submitted by the Mines Department Authorised Surveyor was upheld.

South Pacific Aid Programme

At the request of the Australian Development Assistance Bureau through the Australian Survey Office, Mr. Etueni Topou, a surveyor from Tonga, was attached for training to the Surveys Branch.

Instruction on the "Offshore" and "Onshore" Acts (including the Commonwealth Act) in relation to departmental procedures, e.g. advertising, form of applications, registration, mapping relinquishments, types of tenements under the Acts, (including the Pipe-lines Act) was given.

MAPPING BRANCH

Cadastral Mapping Section

Compilation: Seventy-two sheets at scale 1:50 000 and comprising the Laverton, Menzies and Kurnalpi sheet areas were commenced. Drafting was commenced on the 24 sheets of the Menzies area. All new compilations are being made on the Australian Map Grid.

Revision: The revision programme continued and a total of 117 sheets were revised covering the areas of Lake Johnston, Yalgoo, Sir Samuel, Yarrie, Nullagine, Balfour Downs and Robertson.

Geological Mapping—1:250 000 *Series*

This programme continued at a much heavier rate than previous years and some delays did occur. With colour guides of each map having to be prepared, this represented a substantial increase in work for the section.

In progress: Fourteen sheets were in progress throughout the year, more than twice the normal.

First editions in progress were Perth, Nullagine, Marble Bar, Mt. Egerton, Sir Samuel, Duketon, Bullen and Pinjarra.

Preliminary editions were continued of Trainor, Port Hedland, Robinson Range and Ningaloo-Yanrey whilst Collier and Gunanya were commenced.

Published

Five maps were published in 1977; they being, Edjudina, Lake Johnston, Ravensthorpe, Yalgoo, Leonora. This leaves Laverton at the BMR, unpublished.

Geological Publications Section

Although the number of black and white drawings prepared for the various publications was less than last year, the work coming into the section was maintained at a very high rate.

The Perth Basin Bulletin was brought to conclusion and published at the Government Printing Office. The Tin Bulletin was concluded and proofed and the Copper Bulletin was commenced and was well advanced by the end of the year. The Meckering Bulletin was revived and drawing work began again.

Some preliminary work commenced on the Pilbara Bulletin and the Bangemall Basin. Many base sheets containing grids and shot point data were drawn for the Carnarvon Basin project.

Other projects such as the Rottnest Report and Bugle Gap were completed during the year.

The Urban Geology series at 1:50 000 scale continued with the coloured editions of Moore River and Gingin being completed and printed. Other sheets in progress were Mandurah, Pinjarra, and the preliminary sheets of Nickol Bay, Legendre, Pt. Samson-Delambre Island, Karratha, Dampier were all commenced.

As is usual, the section prepared many drawings for coloured slides, figures for Government Chemical Laboratories and other miscellaneous drawings. Attention has been drawn to the oversize of this section and it is hoped that some relief may be given during the coming year.

Microfilm

At the beginning of the year it was programmed to film and duplicate 50 rolls of "M" series files. This was achieved despite some minor problems. A great deal of time was saved through the Microfilm Bureau's 35 mm Microfilm Camera being installed in Mineral House. In all, this programme is moving quite steadily now and the rate should be maintained. Sales of Microfilm rolls continued despite the need to increase prices.

Photographic Section

During the year it was necessary to transfer a clerical officer into the photographic section to help. This has worked very well and relieved the senior officers from some of the more tedious work.

The number of work items for each photographic unit was at a very high rate and if it were not for the efforts of our Photo technicians to work longer hours and overtime, backlogs of work would have occurred.

The actual figure for each unit was:—

Printing frames	2 320
Camera	1 773
Black and White printing	5 281
Colour printing	1 689
Total	11 063

(average approximately 300 per week).

Emphasis is now placed on colour photography, particularly for display purposes and additional equipment is being investigated.

The work of the plan printing area was:—

Plans printed (approximate)	32 000
Photocopying (approximate)	2 000
Plans mounted (approximate)	800

PUBLIC PLANS

Applications: New applications for tenements were received and processed:—

Mineral Claims	3 986
Mineral Leases	39
Gold Mining Leases	312
Licenses to Treat Tailings	67
Prospecting Areas	229
Coal Mining Leases	1 677
Other Tenements	132
Total	6 442

Temporary Reserves

Iron	67
Gold	....
Coal	6
Other Minerals (including Uranium)	83
Other Minerals	15
Total	171

Plans

A full set of public plans at Perth and an appropriate set in each of the District Offices were maintained and these carried all title dealings during the year.

Plan sales totalled $9 912, made up of:—

Dyelines	8 127
Micro, Photocopies	4 231
Transparencies	235
Gold Bearing Area Maps	48
State Maps	297
Gazetteer	202
Mineral Occurrence Maps	100
Temporary Reserve Lists	
Iron	49
Other Minerals	66

Plan and Document Record

The numbers of public plans and other associated survey documents registered and in use within the Department are listed in the following table.

	Current	Obsolete
Public Plans—		
1:1 000 000 Index Sheets	14	71
1:1 000 000 Temporary Reserve	14	32
1:1 000 000 Petroleum	33	29
1:250 000 Public Plans	113	287
1:100 000 Public Plans	52	20
1:50 000 Public Plans	1 140	1 733
1:10 000 Public Plans	4	9
Lands Old Series (Imperial)	201	750
Mines Old Series (Miscellaneous)	33	450
Lands Old Series (TM)	14	176
Old Index Sheets	....	137
Petroleum Map (M175)	1	57
	1 619	3 661
Standard Plans—		
Old Projection (20 Chains)	677	137
Transverse Mercator	208	5
Australian Map Grid—		
1:50 000	147	2
1:25 000	29	....
1:10 000	12	....
Provisional	344	....
	1 417	144
Field Books—		
Cadastral surveys	5 305	....
Survey Plans (Op's)—		
Imperial	286	
Metric	263	
	549	
Survey Diagrams—		
Imperial	49 000	
Metric	5 400	
	54 400	

S. M. HOCKING,
Superintendent, Surveys and Mapping.

DIVISION VII

Government Chemical Laboratories Annual Report—1977

UNDER SECRETARY FOR MINES

I submit the Annual Report for the year ending December 1977 on the operation and functions of the Government Chemical Laboratories.

ADMINISTRATION

The laboratories consist of 6 Divisions on the Plain Street site plus the Engineering Chemistry Division at Bentley and the Kalgoorlie Metallurgical Laboratory at Kalgoorlie These 8 Divisions are under the control of the Director (Government Analyst, Chemist and Mineralogist) as follows:

Director—R. C. Gorman, B.Sc., M.A.I.A.S., F.R.A.C.I.

Deputy Director—H. C. Hughes, B.Sc., M.A.I.A.S., A.R.A.C.I.

Agricultural Chemistry Division—J. Jago, B.Sc., A.R.A.C.I. Chief of Division.

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.

Food and Industrial Hygiene Division—F. E. Uren, 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.

Kalgoorlie Metallurgical Laboratory—G. H. Muskett, A.W.A.S.M., M. Aust., I.M.M., Officer in Charge.

Mineral Division—D. Burns, B.A., B.Sc., A.R.A.C.I., Chief of Division.

Toxicology and Drug Division—V. J. McLinden, A.P.T.C. Chem., A.R.A.C.I., Chief of Division.

Water Division—N. Platell, B.Sc., A.R.A.C.I., Chief of Division.

Office—A. D. W. Kinghorn, B.A., Senior Clerk.

Librarian—J. Bryant, B.Sc., Dip.Ed., Dip.Lib.

The breadth of the functions of the Laboratories in providing scientific service, research and advice is illustrated in part by the following statutory, official or *ad hoc* interdepartmental committees on which various staff members served during the year.

Australian Coal Industry Research Laboratories Ltd., Board of Management.

Ecology of the Ord Dam Sub-Committee and Pesticides Sampling Study Group.

Fluoridation of Public Water Supplies Advisory Committee.

Food and Drug Advisory Committee.

Government Paint Committee.

Laboratory Safety Committee of the Industrial Foundation for Accident Prevention.

Laporte Effluent Disposal Committee and Environmental and Hydrogeological *ad hoc* Sub-Committees.

Laporte Industrial Factory Agreement Review Committee.

Lupin Technology Committee.

National Association of Testing Authorities—W.A. State Committee.

Oils Committee of the Government Tender Board.

Paints Advisory Committee of the Government Tender Board.

Pesticide Registration Committee.

Pesticides Residues Advisory Committee.

Poisons Advisory Committee.

Rights in Water and Irrigation Act—Licensing Panel.

Scientific Advisory Committee under the Clean Air Act and the Fluoride Sub-Committee.

Standard Association of Australia—Iron Ore Analysis Committee.

Swan River Management Authority—Industrial and Biological Committees.

Veterinary Preparations and Animal Feeding Stuffs Advisory Committee.

W.A.I.T. Advisory Committee of Applied Chemistry.

Waste Disposal Technical Committee.

Water Purity Advisory Committee.

STAFF

The establishment of the Laboratories now consists of the following.

Professional Division officers	80
General Division officers	44
Clerical Division officers	12
Wages staff	2
TOTAL	138

There has been general stability of staff during the year with no major changes in professional staff. Staff growth restrictions impose a serious problem because of the continually increasing work load without any corresponding staff increase. Approval has been received for two new General Division officers in 1978 and for 3 new staff for the large increase in volume of work expected for the Australian Water Resources Council Network Survey.

Staff development and training continues through attendance at scientific conferences and seminars and in management development courses at the R. H. Doig Centre. It is pleasing to see the way staff are acting in exective capacity on a number of relevant scientific societies. During the years staff of the Laboratories served on the committees of the W.A. Branches and/or national bodies of the following professional scientific societies.

Analytical Group, Royal Australian Chemical Institute.

Australian Forensic Science Society.

Australian Soil Science Society.

Australian Water and Waste Water Association.

Australasian Corrosion Association.

Institute of Chemical Engineers.

Institute of Engineers Australia Chemical Engineering Branch.

Institute of Fuel.

Occupational Health Society of Australia.

Oil and Colour Chemists Association.

Royal Australian Chemical Institute.

ACCOMMODATION

Approval has now been received for the extension of the Water Division for the Australian Water Resources Council Network Survey. Work will start on these extensions in January, 1978. These extensions will virtually complete all the possible extensions on the Plain Street site except for the Hay Street frontage. The space on the Hay Street frontage is reserved for future multi-storey extensions which are likely to be required in the next few years.

Pilot plant extensions at the Engineering Chemistry Division at Bentley have been on the waiting list for four years. This delay has unfortunately seriously restricted the type of work the Division can undertake and affects their forward planning.

With the decision during the year to retain the School of Mines in Kalgoorlie, the site of the present Kalgoorlie Metallurgical Laboratory building on their campus will be required by the School of Mines. A decision whether to rebuild the Kalgoorlie Metallurgical Laboratory either within the School of Mines extensions or on a seperate site will have to be made in the coming year. Repairs and renovations of some of the older parts of the Laboratories were scheduled for 1977 after postponement over the past two years. Unfortunately these did not eventuate and it is hoped that early in 1978 a start will be made on these necessary renovations and on additional minor alterations.

The Public Service Board and Public Works Department during the year assessed the need for and approval of air conditioning for the Laboratories. Two chilling units of sufficient capacity taken out of another building are available but funds for their installation and necessary auxiliary fittings have not yet been approved. The need for air-conditioning in a laboratory, where there is additional heat input from furnaces, ovens and electrical instrumentation, is far greater than the need in office buildings. Some urgent attention to our needs in this respect is required in 1978.

LIBRARY

The continued growth of the Library is putting a severe strain on available library space. Additional culling of older material for separate storage and more shelving has temporarily relieved the congestion.

An additional 2 768 items were added during the year, consisting of 287 monographs, 2 020 journal issues and 461 official publications. A further 4 new journals were added and one discontinued.

EQUIPMENT

The introduction of funding and approval for all equipment over $5 000 by the Equipment Purchase and Replacement Committee of Treasury appears to be a successful innovation. This is especially so with respect to very long delays that can occur in the delivery of such equipment. Funding through the Committee removes the need for equipment to be delivered, approved and paid for within the financial year of first approval.

Interfacing of the various instruments to the PDP 11/40 computer was completed during the year after an appreciable delay. Additional equipment ordered for the Water Resources Network Survey will also be interfaced with the computer when the building extensions are completed. The total investment in computer facilities is now over $130 000 about $100 000 coming out of our funds, the remainder from other branches of the Mines Department. Since maintenance costs on such facilities are of the order of 10 per cent a year, this alone accounts for a fair proportion of our equipment maintenance and repair allocation.

Approval was received for purchase of a G.C.-mass spectrograph primarily for drug work and an automated gas chromatograph for pesticide residues. These, it is hoped, will be delivered early in 1978. Additional equipment purchased during the year includes a high speed centrifuge, an automatic sample changer for the X-ray fluorescent spectrometer, radiation detectors, a pH selective ion meter, a drum magnetic separator, an automatic sample feeder and spectrophotometer, automatic titration equipment, a gas chromatograph for forensic work as well as a number of lesser items such as rotary evaporators, automatic flow through cells, deionisers and deep freezers.

GENERAL

Samples received for 1977 increased by nearly 20 per cent over 1976, that is nearly 6 000 more than have ever been received before. While automation and further instrumentation have been introduced, we have reached the limit of what can be efficiently handled without increases in staff and buildings. Once again the Department of Agriculture was our major client, 46 per cent of all samples received were from that Department. Figure 1 shows the increase in sample receivals over the years 1970 to 1977 and the corresponding receivals from the Department of Agriculture and our own Department of Mines.

For the years 1970-1977 the source of our service work on an average for the eight years was

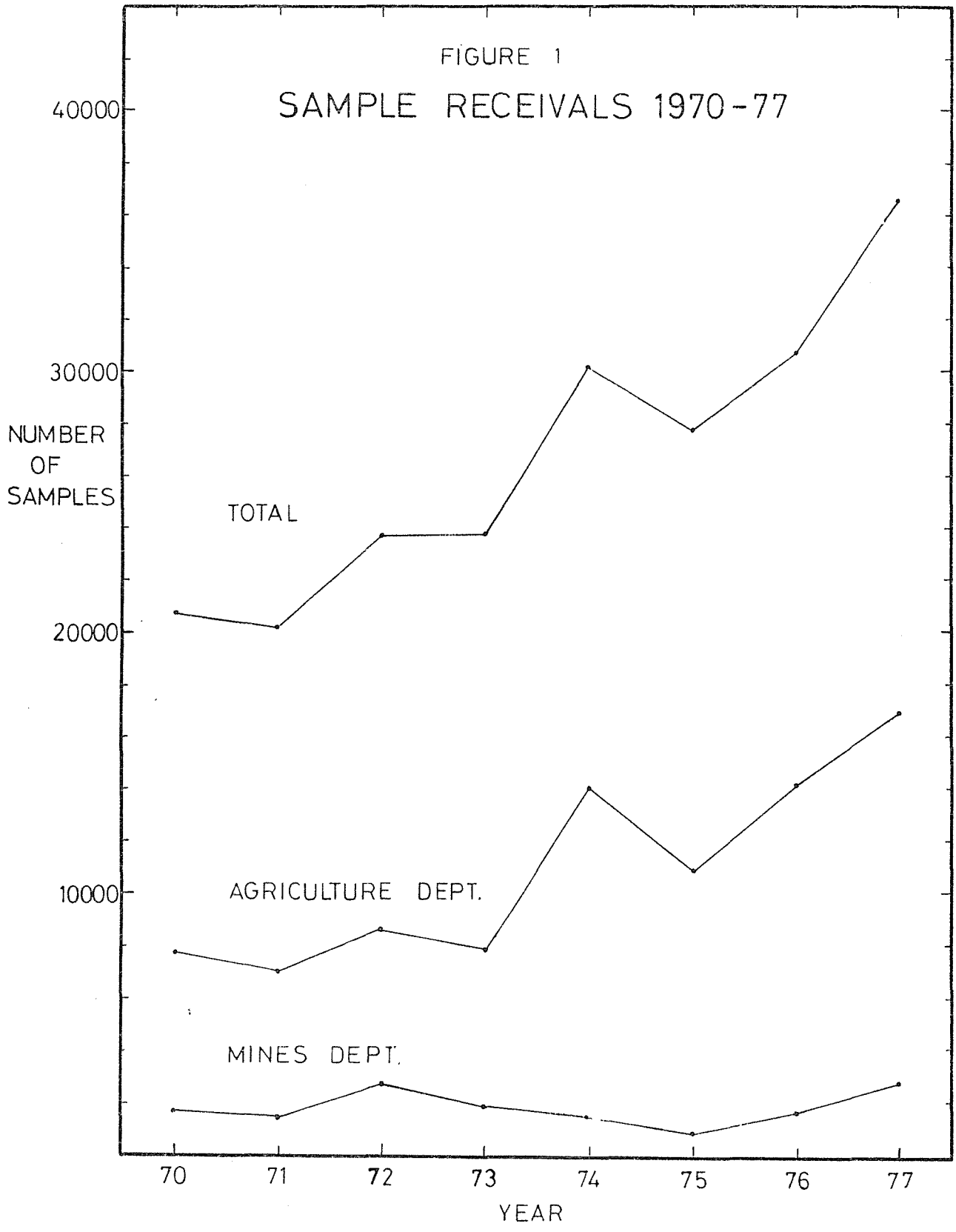
Source	1970-1977 Per cent of total samples
Department of Agriculture	40
Police and Road Traffic Authority	10
Public Health Department	9
Metropolitan Water Board	9
Public Works Department	9
Mines Department	7
All other sources	16

These figures emphasise the fact, that though we are administratively part of the Mines Department, only a small part of our work is functionally associated with our parent Department. In most of our work we are acting as an extension of other Departments.

The numbers and source of work or samples received and their allocation to Divisions is given in Table 1.

The summarised reports of the eight Divisions which follow show the variety and complexity of work undertaken in 1977.

R. C. GORMAN,
Director.



AGRICULTURAL CHEMISTRY DIVISION

GENERAL

Re-organisation of the Division was completed during the year by creation of a plant chemistry section and a trace and environmental chemistry section in addition to a soil chemistry section established in 1976. This allows work to be dealt with in specialist areas. The purpose is to increase the scope and quality of research activity and to improve the efficiency of analytical procedures required to cope with increasing quantity and variety of service work.

The increase in the amount of work submitted was not anticipated and emphasised the difficulties of forward planning for requirements of staff, equipment and development of techniques without knowledge of the policies of client departments.

TABLE 1.
SOURCE AND ALLOCATION OF WORK 1977

Source	Agricultural Chemistry Division	Engineering Chemistry Division	Food and Industrial Hygiene Division	Industrial Chemistry Division	Mineral Division	Toxicology and Drug Division	Water Division	Total
STATE—								
Aboriginal Lands Trust	....	....	....	....	34	....	....	34
Agriculture Department	15 884	3	797	3	26	35	52	16 800
Agriculture Protection Board	....	....	112	....	....	1	....	113
Albany Port Authority	....	....	....	....	....	....	81	81
Conservation & Environment Department	....	....	4	....	2	....	146	152
Consumer Affairs Bureau	....	....	2	12	11	....	1	26
Education Department	40	....	....	....	....	....	....	40
Fisheries and Wildlife Department	38	....	277	40	6	....	75	436
Geological Survey	20	2	....	....	1 295	....	558	1 875
Government Chemical Laboratories	4	92	34	2	198	196	13	539
Government Stores Department	....	....	47	172	....	....	....	219
Labour and Industry Department	....	....	154	....	....	....	....	154
Leschenault Inlet Management Authority	....	....	2	....	....	....	49	51
Main Roads Department	....	....	2	1	7	....	51	61
Metropolitan Water Board	....	....	156	....	5	....	2 225	2 386
Mines Department	....	....	90	9	800	....	....	899
Museum	....	....	....	....	2	....	21	23
Peel Inlet Management Authority	....	....	....	....	....	....	88	88
Police Department	....	....	....	....	36	1 794	....	1 830
Public Health Department	30	1	1 676	25	1 096	16	172	3 015
Public Works Department	2	....	230	34	20	....	2 713	2 999
Road Traffic Authority	....	....	....	....	27	1 300	....	1 327
State Energy Commission	....	....	10	2	8	....	....	20
State Housing Commission	....	....	....	7	....	....	8	15
Swan River Management Authority	....	....	1	....	....	....	270	271
Various Authorities (9)	....	7	2	13	5	....	5	33
COMMONWEALTH—								
Various departments	....	....	33	....	....	20	....	53
PUBLIC—								
Free	....	....	....	....	16	....	1	17
Pay	747	248	255	35	476	604	655	3 020
TOTAL	16 765	353	3 884	355	4 070	3 966	7 184	36 577

The re-organisation is expected to assist with the problem by improving liaison between chemist and agricultural scientist. Joint appraisal of research progress should allow more frequent review of priorities and modification of requests for chemical work and indicate changes in emphasis for future work.

A re-organisation of procedures for dealing with receival of samples and the accompanying paper work was very successful. The large increase in the number of samples handled would not have been possible without the new system and the collaboration of the preparation section staff in the introductory stages.

Regular meetings of staff were held to encourage participation in decision making affecting Divisional policy. Attendance at talks, seminars, field days and in-service training courses maintained staff participation in professional activities appropriate to our work.

CONFERENCES, PAPERS AND PUBLICATIONS

B. J. Codling and P. E. Wilson presented papers on "Computerisation of an Automatic Amino Acid Analyser" and "A Venturi Sampler for Atomic Absorption Spectroscopy and its Application to the Determination of Cadmium, Cobalt, Copper, Nickel and Lead in Bovine Liver Samples" respectively to the 4th Australian Symposium on Analytical Chemistry in Brisbane.

P. E. Wilson and L. A. Plues-Foster presented a paper, "Monitoring of Fluoride Emissions with Limed Filter Papers", to a symposium in Perth on "Air, its Impurities their Measurement and Control".

L. A. Plues-Foster was co-author of a paper entitled "Improved method of Analysing Difficult Soil Extracts by Flame AAS-Application to measurement of copper in ammonium oxalate extracts" published in Australian Journal of Soil Research, Vol 15, 171 (1977).

NATURE OF SAMPLES

Table 2 shows the nature and sources of samples. For many years the Department of Agriculture has been responsible for practically all the samples received.

The increase in the amount of work following a previous marked increase in 1974 is shown in Table 3.

Despite the improved output in terms of sample numbers the work outstanding included some samples received ten months earlier, an unsatisfactory situation for the client and ourselves.

TABLE 2
AGRICULTURAL CHEMISTRY DIVISION

	Agriculture Department	Public Pay	Other	Total
ANIMAL—				
Liver	33	....	....	33
Tissue	334	....	....	334
Various	8	....	2	10
CEREAL—				
Barley	121	3	....	124
Maize	45	....	....	45
Oats	105	9	....	114
Rice	288	....	....	288
Sorghum	32	....	....	32
Wheat	3 306	....	....	3 306
FERTILISER—				
Fertiliser Act	159	....	....	159
Various	55	12	....	67
HORTICULTURE—				
Cabbage	91	....	....	91
Apple Leaves	658	....	....	658
Citrus Leaves	205	....	....	205
Grapevine Leaves	401	....	....	401
Peach Leaves	137	....	....	137
Plum Leaves	61	....	....	61
Tomato Leaves	45	....	....	45
Various	44	....	....	44
MISCELLANEOUS—				
Filter Papers	....	....	28	28
Rapeseed	58	4	....	62
Various	42	34	57	133
PASTURE AND STOCK FOODS—				
Clover	470	....	....	470
Feeding Stuffs	137	43	....	180
Feeding Stuffs Act	46	....	....	46
Legumes	36	....	....	36
Hay	30	10	....	40
Native Pasture	224	....	....	224
Pasture	611	1	....	612
Lupins	1 162	1	....	1 163
Plant Material	112	....	....	112
Silage	37	....	....	37
Various	29	2	1	32
SOIL	6 762	622	52	7 436
Total	15 884	741	140	16 765

TABLE 3
SAMPLES RECEIVED 1973–1977

Year	1973	1974	1975	1976	1977
Receivals	7 350	13 863	11 210	13 803	16 765
In hand at 31 Dec.	2 864	7 286	6 313	7 281	8 158
Output	7 291	9 441	13 183	11 835	15 888

The increase in receivals was due almost entirely to 3 000 more samples of soil than last year. A series of new long term fertiliser trials to study the residual values of various forms of phosphate fertiliser accounted for 1 100 of these. There were decreases in numbers of lupin, pasture and hay and increases in wheat, clover and horticultural material.

The work of the three sections included the samples outstanding from 1976 as well as those given priority in 1977. Research and investigation undertaken within the sections together with summaries of the service work dealt with is discussed below.

PLANT SECTION

The section is responsible for work on pasture plants, cereals, horticultural crops, oilseeds, mixed feeds and fertilisers. Samples are mainly from field trials of the Department of Agriculture and there is some diagnostic work for agricultural advisers. Assistance to farmers is given through analysis of feeds and fertilisers.

Research

Research and investigation was centred on improvement of procedures to deal with service work and on lupinseed projects. Multiple digestion of samples, new equipment for the automatic analyser and programming of the computer for receiving output from instruments were investigated. The programme to link the computer with the amino acid analyser was completed. Calculation of amino acid composition from data of one chromatogram using an internal standard procedure takes four minutes per sample. Manual calculation took 40 minutes.

Aminoacids

The current procedure for preparation of samples for amino acid analysis includes a performic acid oxidation step, excess performic acid being removed by heating before acid hydrolysis and chromatography. Tyrosine, phenylalanine and histidine are destroyed, so that if these amino acids are required in the analysis a separate hydrolysis without the oxidation step must be used. A preliminary investigation of the use of sodium metabisulphite to remove excess performic acid resulted in complete recovery of phenylalanine and histidine. Thus, in the six types of sample examined, a single preparation step may be suitable for all amino acids except tyrosine.

Methods of determination of available lysine in meatmeal are being compared and evaluated in a collaborative study arranged by our Victorian counterparts. Results for total and available lysine in a standard meatmeal were forwarded for inclusion in the study. In W.A. it has been the practice to report total lysine and assume that 80 to 90 per cent is in available form. Because of the renewed interest of animal nutritionists in available lysine, rations from feeding trials are being re-analysed.

Lupins

Amino acid composition of bitter and sweet lupin seeds and pods was determined at several stages of development and related to the manganese and nitrogen contents in an attempt to gain insight into the mechanism by which split-seededness in sweet lupin varieties is overcome by the application of manganese. The application of 48 kg/ha of manganese sulphate reduced the incidence of split seeds in Uniharvest lupins from 72 per cent to 4 per cent, but no obvious changes in total amino acid composition resulted. Analysis of the non-protein fraction showed that manganese application produced no changes in the relative amounts of the two major transport amino acids, aspartic acid and glutamic acid.

Alkaloid content of sweet lupinseed is extremely low. Investigations to find a reliable method for quantitative estimation of the total and individual alkaloids were therefore carried out using cv Fest which contains about 1.5 per cent of total alkaloids of the type found in commercial sweet varieties. This allowed smaller quantities of material to be used for the investigations. Solvent extraction and thin layer chromotography was used to show that multiple extraction with chloroform from an alkaline aqueous phase (1M NaOH) was necessary to extract a reasonable proportion of the free alkaloids present. The most difficult to extract was hydroxylupanine and the efficiency of extraction was dependent on pH. The use of solvents more polar than chloroform did not improve the extraction. It was also shown that the aqueous ethanol soluble N-oxide alkaloid fraction which had been ignored in qualitative studies elsewhere may be important.

Sampling

The importance of proper sample preparation and subsampling for analysis was demonstrated by an examination of the reproducibility of results for N, P, K, Ca and Mg in wheat tops. Fractions of different particle size were separated by sieving. Analysis showed that concentrations of N, Ca and Mg varied markedly between fractions, but that by careful subsampling, acid digestion of a 200 mg subsample gave reproducible results. With some types of sample, such as lupinseed, this is difficult to achieve unless the sample is finely milled.

Service Work

Service work was handled satisfactorily by automatic colorimetric analysis for N, P, K and Na and atomic absorption spectroscopy for Ca, Mg, Cu, Fe, Mn and Zn.

Five thousand samples were received this year for an average of four of the above analyses per sample. The increasing number of samples requiring these analyses makes it imperative to have computer programming for the four channel auto analysis output as soon as possible to relieve staff of the task of reading peaks on chart recorders. Work completed fell into the following categories of sample type.

1. *Cereal*

Plant tops and grain from field experiments were analysed to measure effects of fertiliser treatments or management practices on uptake of nutrients.

Wheat

Most of the samples came from the second year of trials of the project to find a soil test for estimating soil nitrogen status prior to sowing a first wheat crop after legume pasture. Analysis for nitrogen was carried out on 978 wheat tops and 1 293 samples of grain from 46 trials. Nitrogen levels in grain (1 202 samples) from the first year of the programme were reported early in the year.

Two hundred and thirty-four samples of straw and grain were analysed for N and P to measure the effects of rates of phosphate fertiliser on wheat, lupin and clover. Other samples came from trials in which a cropping phase was used to measure in economic terms differences in soil fertility induced by different species of legume supporting grazing regimes.

Oats

Chemical composition of State Average Oats for 1976-77 season is shown in Table 4.

TABLE 4
COMPOSITION OF STATE AVERAGE OATS 1976–77

	as received per cent
Moisture	9·5
Ash	2·5
Crude protein (N x 6·25)	7·9
Crude fat	6·4
Crude fibre	11·5
Nitrogen free extractives	62·2
Calcium, Ca	0·07
Phosphorus, P	0·25
Kernel content	70·8
	megajoules per kilogram
Gross energy value	17·8

Barley

Crude protein and moisture was determined in nine samples representing shipments to Europe. Low levels of selenium were found in grain from the Manjimup district an area where deficiency of this element in stock is common.

Rice

Grain and straw samples from Kununurra Research Station trials with anhydrous ammonia and phosphate fertilisers were analysed for nitrogen and phosphorus to complement yield data.

2. *Pasture, Hay and Fodder Crops*

A large proportion of the work in this category arose from monitoring of methods of pasture utilisation and hay making. Samples were from various centres in the south west and results were required to evaluate effects of treatments such as continuous or strip grazing, cutting and leaving material before baling, methods of silage making

and comparisons of different cultivars. Close monitoring of chemical composition at the production stages and also of the quality of the product as fed to animals involved analyses of pasture cuts and cores taken from hay bales at weekly intervals for major and minor elements.

Haymaking

Hay can be prepared at a higher moisture content by preserving it with anhydrous ammonia. Material from trials by the Department of Agriculture showed that hay treated with anhydrous ammonia had markedly higher levels of total nitrogen and ammonium nitrogen due to absorption of the gas.

Lupin

Lupin plants, seeds, pods and stems from a number of trials were analysed for potassium, calcium, magnesium and nitrogen mainly from studies of potassium fertiliser requirements. Eighty eight samples comprising stems, pods and seeds were analysed to evaluate feed value of varieties thought to have most potential for breeding cultivars for commercial production of protein for animal and human consumption.

Native Pasture

Samples for proximate analysis came mainly from Fitzroy Pastoral Research Station where feed quality of several plant species was measured each month. Samples represented simulated grazing cuts taken from nine species of pasture plants growing on black soil plains and other pasture lands in the district. Crude protein was generally less than 10 percent in the 190 samples analysed.

3. *Oilseeds*

Rapeseed from varieties produced by Department of Agriculture plant breeders for low erucic acid content and resistance to black leg disease were evaluated for fatty acid composition. Half of the varieties had less than 0.5 percent of erucic acid and ten crossbreds had less than 0.1 percent.

The Grain Pool of W.A. submitted samples for determination of moisture and oil content and rancidity to assist with price negotiations.

Eighteen samples of sunflower seed were analysed for oil content. Results did not confirm an expected drop in oil content due to a late harvest in October.

4. *Horticulture*

Nutrient levels in leaves from orange and mandarin variety/rootstock combinations growing at Wiluna showed higher levels of nitrogen and boron when compared with standards in Australia and California. Boron at toxic concentrations was derived from irrigation water. Most other elements were at satisfactory concentrations but low levels of manganese and zinc were evident.

One hundred and sixty orange leaves from a fertiliser trial at Stoneville were analysed for eight elements to measure effects of four types of nitrogenous fertiliser.

A range of fruit tree leaves was analysed to assist with recommendations to growers and included apple, apricot, cherry, nectarine, pear, peach and plum.

Increasing interest in avocado as a commercial crop required information of the chemical composition of leaves to establish standard nutrient levels for W.A. Comparison with data from California showed that leaves from growers' properties in the Hills area had higher levels of nitrogen and chloride and lower boron. In some cases copper, manganese and zinc were low.

Grapevine leaves were analysed for major and trace elements in connection with fertiliser trials in the newer wine grape areas of the South West and problems of declining vigour and a suspected copper deficiency in vineyards north of Perth.

Cabbage leaves from a trial using heavy dressings of poultry manure contained up to 6 percent of total nitrogen including levels of nitrate as high as 0.8 percent. Different irrigation rates had no effect on the levels of nutrients in the leaves.

5. *Stockfood*

Samples of feed components or formulated rations were submitted for feed quality evaluation either for information required to calculate correct nutritional levels for animal feeding experiments or for farmers checking product quality or mixing their own rations.

Dehydrated paunch material from abattoirs analysed for the W.A. Meat Commission contained about 17 per cent of crude protein and 14 per cent crude fat, indicating that use as a protein source for stock may be a useful method of utilising the waste.

The ban on the use of raw swill as a pig feed led private firms to investigate means of producing a dehydrated and sterilised product. Several samples were analysed for crude protein content, amino acids and heavy metals for comparison with meatmeal as a protein source for pigs in feed trials.

Sorghum samples from Kununurra were analysed for tannin content in connection with exports to Singapore. The protein content of sorghum grain from a nitrogen fertiliser trial showed little effect of treatments on the nitrogen content.

An ester of caretonoic acid used as a yolk pigmenter in feed for laying hens was shown to be absent in rations where poor yolk colour was evident. A simple test was devised for use by poultry advisers to check for the presence of the additive in rations and premixes.

6. *Fertiliser and Manures*

Commercial and experimental fertilisers and manures including triple superphosphate, superphosphate, rock phosphate from Christmas Island or Queensland, fly ash from Bunbury power house, estuarine weed from Peel Inlet and fowl manure were examined.

Two samples of triple superphosphate contained less than 0.1 per cent N. The results did not confirm X-ray diffraction analysis which indicated the presence of ammonium dihydrogen phosphate.

Farmers submitted samples of limestone and lime sand for determination of neutralising value and checks were made on copper content of trace element mixtures.

Estuarine weed raked from Peel Inlet to remove a pollution problem at Coodanup had slight value as a fertiliser but could be useful in improving soil organic matter content. The difficulty of separating the weed from sand during the collection process was shown by the analysis of one sample which contained 70 per cent of sand and shell fragments.

Fowl manure used on a cabbage trial had high levels of molybdenum (12 and 20 ppm) the source of which could not be ascertained. Cabbage leaves contained up to 120 ppm of molybdenum and could indicate indiscriminate use of this element in basal fertiliser dressings.

SOIL SECTION

All work on soil samples is carried out in this section including some trace element analysis. The rapid increase in demand for chemical analysis as an aid to better evaluation of soil fertility and more economical use of fertilisers necessitated building alterations to accommodate a revision of work procedures and proposed new instrumentation. This hampered operations for several weeks but despite this the back log of soil samples was reduced. At the end of the year the main outstanding samples required analyses for copper or nitrogen.

A dramatic jump occurred in the numbers of samples submitted for extractable phosphorus and potassium for assisting agricultural advisers with fertiliser recommendations for cereal crops and pastures. The number of samples of this nature was 620, a ten fold increase compared to last year. A further 3 000 samples were from long term field trials of the Department of Agriculture. Despite this the section was able to maintain a satisfactory return of results during the early part of the year when requests for these services were concentrated.

Research

Methodology

The determination of potassium by atomic absorption spectroscopy in the 0.5M sodium bicarbonate solution used to extract phosphate was desirable because only one extraction was needed, but problems with precision caused by the bicarbonate solution forced a change to a separate extraction for potassium using O.1M HCl at a soil:extractant ratio of 1:5. The automated procedure for phosphate was improved by using a more reliable sampler unit.

Precision of the method for measuring available soil nitrogen by determination of ammonium produced during anaerobic incubation was shown to vary between soil types. Improved precision for difficult soils was obtained by better mixing at the commencement of incubation. The procedure

for total nitrogen by Kjeldahl digestion was modified by replacing the selenium catalyst with copper sulphate/titanium dioxide.

Cation exchange capacity procedure was modified to follow the procedures of Tucker (C.S.I.R.O. Div. of Soils Tech. Paper No. 23) for the pre-wash step and leaching in columns. Ammonium chloride exchange solution at pH 8.5 instead of pH 7 was more suitable for alkaline sodic soils of the Pilbara. Comparison of the modified procedure with the current method of samples from long term field trials is required before adopting it for all soils.

Soil Test

Copper extracted by 0.2M ammonium oxalate pH 3 is used as a guide to determine whether soils in copper deficient areas have received past dressings of copper fertiliser. The test is not suitable for calcareous soils. An alternative extractant, diethylenetriaminepentacetic acid (DTPA), which is used in Queensland was tried for a number of acid and alkaline soils. DTPA extracted less copper than ammonium oxalate but the method may have application in W.A.

A proposal to investigate an extraction procedure for cobalt in W.A. soils was suspended after it was found that four of the five samples involved contained 1 ppm or less of total cobalt.

Dam sites

Advisory work on the suitability of soils for use as earth fill for dam sites at Wungong and the Pilbara was undertaken. Advice was based on results of tests for pH, cation exchange capacity, total soluble salts, dispersion index, sodiom absorption ratio (SAR) and calcium carbonate content. An apparent disparity between values for exchangeable sodium percentage calculated from exchange data either chemically derived or extrapolated from determination of SAR of saturation extracts, was due to poor reproducibility of SAR. Technique was modified to simplify this determination.

Peat

Demand for gardening peat by nurseries and home gardeners led to a number of samples being submitted for determination of organic matter content, pH and total soluble salts. Several of the samples were typical of peat soils found in W.A. Unusual samples from Balcatta were acid, pH 3.5 and had 3 percent total soluble salts. This was shown to be due to sulphides which oxidised after excavation of the peat deposit to give sulphates of calcium and magnesium.

Service Work

Analytical work was mainly related to regular samplings of field trials of the Department of Agriculture studying leaching of potassium fertilisers, effects of tillage practices, feasibility of a soil test for nitrogen, and measurement of residual phosphate. The work is summarised below.

Potassium

Leaching of potassium chloride on deep white sands with less than 10 ppm potassium at Badgingarra was followed at weekly intervals through the growing season by extraction of 970 topsoils and depth samples with 0.1M HCl. A proportion of the potassium leached to 100 cm and probably deeper. At the end of the season a reasonable proportion of the potassium remained in the top 0-20 cm. Sampling problems in the laboratory were encountered due to insufficient cores per sample and incomplete mixing of cores before subsampling to ensure that residual fertiliser was uniformly distributed.

Soil test for nitrogen

Work on samples from trials in 1976 to look for a soil test for predicting nitrogen requirements for wheat crops continued. Analysis of 340 samples of topsoils and profiles from 49 experimental sites from the second year of the programme was completed. The relationship between total nitrogen and alkaline distillable nitrogen gave a regression for topsoils $Y = 0.00196X - 0.00246$, $r = 0.970$ where Y = total (Kjeldahl) nitrogen percent and X = alkaline distillable nitrogen ppm. The regression differed significantly from that of the 1975 data. Random repeat checks of analyses of samples from both years of the programme showed that analytical techniques were satisfactory and could not account for the variation. Chemical work for the third year of trials will be completed before it is decided whether the rapid distillable fraction mentioned in our Report for 1976 can be used to predict total soil nitrogen.

Minimum tillage trials

Over 1 000 topsoil samples were examined for ammonium and nitrate nitrogen during the first season of a four year programme to study short and long term effects of minimum and conventional tillage methods. In general, zero tillage plots had higher ammonium and lower nitrate levels than conventional tillage but there were exceptions. There were no clear effects of the use of herbicides to replace tillage for weed control and no change in C/N ratios during the season.

Effect of Legumes

The search continued for an explanation, in terms of soil fertility, of the greater yields of cereals grown after a lupin crop than after other legumes. A large number of analyses for total ammonium and nitrate nitrogen and organic carbon have consistently shown no reason for the effects. Future work on incubatable forms of nutrients may be justified but it would seem that other parameters apart from nitrogen need consideration.

Phosphorus

Extractable phosphorus and potassium were determined in 115 topsoils from Denmark Research Station. Twenty cores from different soil types on the station were analysed separately and results were used by advisers to demonstrate to field staff the variability encountered in sampling soils. The phosphate and potassium needs of soils from Wokalup Research Station were also measured.

Analyses for extractable phosphorus and buffering capacity were made in connection with fertiliser rate trials in high and low rainfall areas on new and old land, phosphate maintenance trials, and for relating yield response to split dressings of fertiliser to soil test values.

One hundred and eighty six samples for extractable phosphorus were from a glass house trial. Residual values of superphosphate, rock phosphate and calcined ore were evaluated after incubation of the fertilisers with a sandy and a gravelly soil.

Rangelands

Further work failed to demonstrate any real differences between chemical properties of topsoils from good, medium and poor rangeland conditions caused by grazing of pastoral land in the Leonora district. Advice was given on the degree of variation in analytical results to be expected relative to errors due to site variation and sampling.

Effects of fertilisers

Analysis for 10 parameters on 108 samples from three long term trials on wheatbelt soils showed the continuation of effects of three types of nitrogenous fertiliser used for continuous cropping of wheat reported in the Annual Report of 1973. Sulphate of ammonia, for example, decreased pH and increased extractable aluminium at each site.

Sandy soils at Medina Vegetable Research Station were analysed for total nitrogen and extractable phosphorus and potassium to follow effects of fertiliser and irrigation practices on cabbage production. Surface and depth samples showed uniformity of nutrients prior to application of heavy dressings of inorganic and organic fertilisers. Resampling after the harvesting of the crop gave results which did not fit the fertiliser treatments and indicated the difficulty of obtaining representative samples.

Soil erosion

Two hundred and twenty seven samples were analysed in connection with studies of plant nutrient losses resulting from wind erosion of wheat belt soils. Data indicate that potential losses are of the order of 40 to 80 g phosphorus, 40 to 400 g potassium and 1 to 3 kg nitrogen per tonne of eroded topsoil. Organic matter losses could amount to 15-45 kg per tonne of soil. Based on estimates of soil loss resulting from wind erosion of up to 15 tonnes per hectare of topsoil, nutrient losses may amount to 600 to 1 200 g phosphorus, 600 to 6 000 g potassium, 15 to 45 kg nitrogen and 225 to 675 kg of organic matter per hectare.

Miscellaneous

Irrigation of citrus at Wiluna did not show any build up of soil salinity from use of irrigation water, but boron levels were higher than desirable. Alkalinity of the water

may have been responsible for low leaf levels of manganese and zinc. Analysis of extractable manganese, potassium and zinc were uniform over the orchard.

Soils from the Kimberleys were received in relation to growing of peanuts, sugar, sunflower, sorghum and rice at Kununurra. Analyses were mainly for nitrogen and phosphorus, potassium generally being adequate in these soils.

Mine wastes from Collie were shown to require heavy dressings of lime to correct acidity and to lower availability of heavy metals before plant establishment would be possible.

Other work included analysis for a number of elements on different soils to determine the suitability of experimental sites, the effect on fertility of clover burr harvesting, the final stages of the long term trial at Wongan Hills W56H and diagnostic tests for copper, manganese and zinc.

TRACE AND ENVIRONMENT SECTION

The section undertakes work on a wide variety of samples relating to trace elements and development of techniques applicable to determining submicrogram quantities of elements in samples from studies of human and animal health and plant nutrition and effects of environmental pollution.

Research

Fluoride emissions

Research involved estimation of fluoride concentration in grapevine leaves and lime impregnated filter papers from the second season of a survey of gaseous emissions from brickworks and their effects on grapevines. The survey was carried out in collaboration with the Departments of Public Health and Agriculture. Results showed an apparent decrease in average concentration of gaseous fluoride near the vineyard over the season as measured by fluoride absorbed by papers and leaves. A report on the interpretation of the results and the conclusions to be drawn in terms of overseas reports of fluoride monitoring with limed papers was prepared for the Sub Committee on Fluoride Emission, Air Pollution Control Council.

The method for analysis of leaves in the above project used ashing and fusion to extract fluoride. A more rapid procedure was investigated in which the plant material is extracted with cold acid solution. Preliminary results were promising.

Emission of smuts from a brickworks at Albany prompted the submission of samples of clay by Department of Public Health. Analysis of fired and unfired bricks showed that fluoride, chloride and sulphur compounds were lost from the clay during firing and could have contributed to the acidic nature of the smuts.

Methodology

A micro technique was devised for use with flame atomic absorption spectroscopy. Very small quantities of sample may be analysed by a venturi micro sampling device which is fitted to the AAS nebuliser. Aliquots of 200 microlitre are used for a single determination. There was no loss of sensitivity, absorbances being equivalent to those achieved using continuous aspiration. The device was used to estimate the levels of 10 elements in small specimens of human tissue in a study which contributes to the knowledge of concentrations of these elements in tissues of infants.

Fluoride content of rations, bones and tissues was estimated in studies of effects of feeding a supplement of rock phosphate to pigs. Work is continuing on the project which is a joint exercise with officers of the Department of Agriculture. As part of the study, the effects of various methods of drying tissues before analysis were examined. Initial results did not substantiate claims reported in the literature of losses of some elements during freeze drying.

Cobalt determination in C grade rock phosphate ore required investigation because of the high concentrations of calcium, iron and phosphorus present in the samples which made our usual procedure unsuitable.

Investigation of the trans-esterification step in the determination of fatty acids in oils was commenced in an attempt to develop a batch process instead of the current procedure which treats each sample individually. Precision of the batch process was unsatisfactory but the method showed promise.

Service Work

Service work included analyses for copper, cobalt, manganese, molybdenum and selenium in samples of lucerne, pasture, mixed feeds, liver and kidney for diagnostic purposes, and for ensuring that animals in experimental work were not subjected to trace element deficiencies in feeds. Examination of human tissue from a hip joint was made for evaluation of the cause of failure of a metal implant.

Animal and plant tissue

Manganese was determined in samples of liver from cattle suffering from cerebrocortical necrosis, as this element is associated with nerve structure and levels were slightly below normal.

Cobalt in ovine and bovine liver samples was generally at satisfactory levels with the exception of that from animals from cobalt deficiency trials and one case of suspected toxicity. Thirty six pasture samples from a trial at Denmark representing six plant species growing on five soil types ranged in cobalt content from 0.02 to 0.10 ppm. Pasture from another trial on the station in which cattle responded to drenching with cobalt sulphate contained 0.02 to 0.04 ppm cobalt.

Eighty eight samples of porcine bone were analysed for ash, calcium and phosphorus. Increasing the phosphorus content of rations from 0.29 percent to 0.44 or 0.54 percent has no effect on either the ash content or the Ca/P ratio of the bones.

Molybdenum determinations in sub clover and strawberry clover from Harvey district showed that levels in sub clover were generally low and approaching deficiency level.

MISCELLANEOUS

Feeding Stuffs Act

This Act has now been replaced by the Veterinary Preparations and Feeding Stuffs Act. The Division made recommendations on the draft document and its supporting regulations. Forty six samples were received under the old Act. Certificates of Analysis were issued for these and 43 samples taken in 1976.

Of these 89 samples, 83 failed to comply with the manufacturers' guaranteed composition. There were 106 individual deficiencies, mainly in crude protein (36) and sodium chloride (29). Individual excesses totalled 66 and were due to crude fat, crude fibre, calcium, phosphorus and sodium chloride.

Fertilisers Act

The Division contributed comment on the new Fertilisers Act 1977, assented to in September.

Certificates of Analysis were issued for 84 samples. Deficiencies were found in 37 (44 percent) and were due mainly to insufficient quantities of potassium and nitrogen in mixed fertilisers. Ninety nine samples awaited analysis at the end of the year.

Chitin from Rock Lobster Shells

Further work showed that the preparation of chitin from rock lobster waste does not appear economically feasible in W.A. because of low yield of chitin obtained in laboratory tests and the costs of transporting waste shell between sources along the coast and any central processing plant.

J. JAGO,
Chief Agricultural Chemistry Division.

ENGINEERING CHEMISTRY DIVISION

The Engineering Chemistry Division undertakes work for industrial firms, consultants and individuals on a contract basis. Its services are available to other Government Departments and the Division also initiates its own research and development projects on topics assessed to be of future significance to the State.

Work may take the form of simple tests or investigations of short or long term nature. The investigations may consist of laboratory scale studies, pilot plant work and where necessary technical appraisals and surveys.

Contract or sponsored work maintained its premier position of occupying most of the Division's man-hours in 1977. The requirement was for a variety of small and large scale operations for both companies and Government

Departments. One company was responsible for a prominent and perhaps permanent alteration to the Division's skyline caused by the erection of three leaching towers as described later in this Report.

Senior Officers were again involved in considerable Government Committee and representational activities and in the review of some aspects of agreements and submissions from companies wishing to exploit indigenous resources.

Where possible, some effort was maintained in projects originated by the Division and aimed at assisting utilisation of the State's potential mineral reserves.

The activities for the year are reviewed under the broad headings of contract work, Government work and internally initiated programmes.

CONTRACT INVESTIGATIONS

The diverse enquiries received reflect the expectation of industry that Government laboratories have a role to play in the development of the State's minerals. The experimental facilities and consultative expertise of the Division are made available on request and the practical work is charged at a rate which depends on the scope of the work.

Again in 1977, the major sponsored projects were representative of the main areas of operation—extractive metallurgy (hydrometallurgy and pyrometallurgy), mineral processing and fuel utilisation.

Hydrometallurgy—Copper Leaching

In common with some other metals there is a recession in the world market for copper which is reflected in the 1977 year end price of $1 145 per tonne for wirebar grade. Nevertheless a company requested a programme of experimental leaching of low grade oxidised copper ores. The testwork was carried out at both laboratory and pilot plant scales and was complementary to some previous exploratory testing done by the Kalgoorlie Metallurgical Laboratory.

Leaching of copper ore in heaps, vats or in situ is an established industrial practice and successful operation depends on the outcome of the interaction between economic and technical factors. The rate of leaching, reagent consumption, method of liquor distribution and level of recovery of copper are key parameters which influence any such operation.

The test programme requested by the company was aimed to simulate commercial vat leaching and involved two levels of testing. Sixty kilogram batches of two different ores were leached in 1.3 metre x 0.24 metre diameter columns and 6 tonne batches were leached in the large 7.3 metre x 0.88 metre diameter columns. These latter columns were erected on site by the company and are shown in the accompanying photograph taken during loading. The project is continuing into 1978.

Pyrometallurgy—Vanadium Processing

A local company with a long standing interest in definition of a process for treatment of a vanadium bearing deposit requested large scale testwork complementary to that carried out some years earlier for the same company.

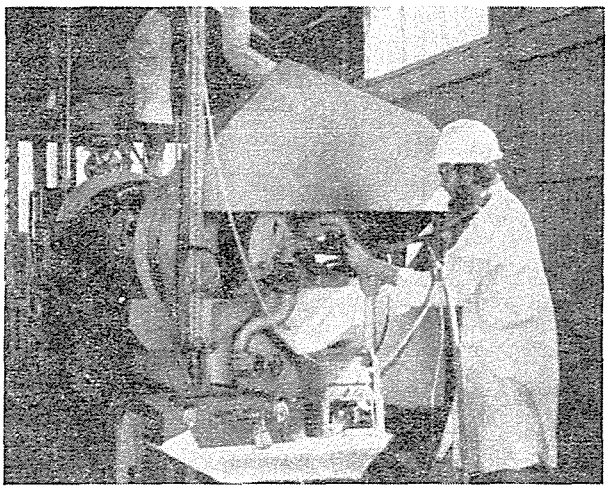
The present programme called for the controlled mixing of flux with ore followed by separate roasting of powdered and pelletised feed. In this phase the vanadium in the ore is converted to a water soluble form and the tests were aimed at defining conditions to yield maximum solubilisation and recovery of the vanadium and the most efficient method of processing.

The roasting has been carried out in the Division's rotary kiln illustrated in the accompanying photograph. Batches of approximately 5 tonnes can be processed by operating continuously over 5 days on a 3 shift per day basis. Kiln operating conditions such as roasting temperature profile (to a maximum of 1 300°C), time of retention, kiln atmosphere (oxidising or reducing) can be varied as required.

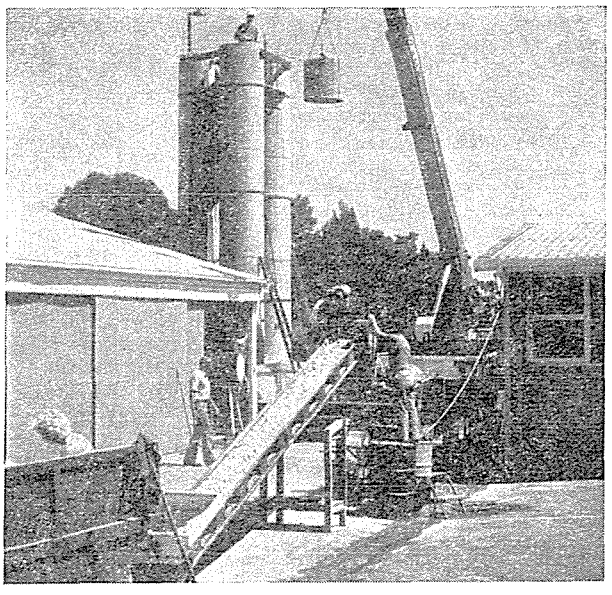
The project will continue into 1978 and will extend to work on the hydrometallurgical aspects of extraction of vanadium from the roasted ore.

Mineral Processing—Zircon Beneficiation

The presence of surface coatings on the zircon grains that are recovered from coastal heavy mineral sand deposits can influence the separation characteristics during processing and also impart a detrimental colour to the final zircon concentrate. The nature of the coating varies with the genesis of the zircon deposit and subsequent weathering conditions. Hence the stain removal process needs to be defined for a particular zircon.



Pilot Scale Rotary Kiln



Loading Leaching Columns

Testwork along this theme was undertaken for three producing companies during the year.

The major effort was a continuation of the development of a novel process for surface treatment of zircon concentrate which had been initiated in the previous year. The fully integrated process is now in full commercial operation and a patent claim has been lodged in the joint names of the Government and the sponsoring company. Laboratory and pilot scale trials were also carried out on an alternative type of leaching process for a currently operating mineral sand company. In addition to the influence of colour, the marketing of zircon can be influenced by other physical properties and another company requested testwork aimed at size classification. In recognition of the industry's evident concern with zircon quality and marketing potential, it was deemed appropriate to initiate a Divisonal investigation. This work is referred to in a later section of this Report.

Fuel Utilisation—Metallurgical Carbon

In metallurgical practice, carbon frequently serves the dual functions of providing heat energy and also acting as a reducing agent. An example is the use of coke in an iron producing blast furnace. The characteristics of the form of carbon can be critical and there are frequently economic constraints which influence the selection of a carbon source.

A local company made several requests for comparative physical testing of different forms of carbon and for investigation of several aspects of briquetting carbon for metallurgical use. Similar investigations, largely for the one company, have been an on-going part of the Division's activities for about three years. This situation reflects the paucity of indigenous metallurgical carbon in Western Australia for many requirements ranging from the blacksmith's forge through to the blast furnace. The technically successful process for briquetting Collie coal char, developed in these Laboratories in the 1950's, has never surmounted the economic barriers to commercial implementation. This sponsored work and a further departmental test programme which is referred to below are complementary to the earlier process.

Miscellaneous

Several limited investigations were carried out on a variety of minerals and product materials. Among these were:

(1) The upgrading of micaceous hematite to test its suitability for incorporation in a corrosion-resistant paint; such material is currently being imported from Austria and is subject to stringent specifications.

(2) The pelletising of a very fine iron oxide residual from an industrial process; the investigation confirmed the difficulties of pelletising very fine powders but offered some promise for use of this currently waste material.

(3) Laboratory scale roasting trials of a carnoite type uranium ore were carried out to allow the controlling company to refine their design data for a section of the proposed process. This work complements the larger scale rotary kiln trials carried out on the same ore in 1974. Although no significant level of radiation was detectable, safety precautions to protect personnel were observed.

(4) A sample of vermiculite was upgraded before its exfoliation characteristics were determined. The company concerned was sufficiently encouraged to persist with their examination of the deposit.

(5) Chromite sands were subjected to comprehensive particle size analysis and selected sizes were upgraded on a Wilfley table. The samples were submitted by a consultant engineer acting for a major company investigating the deposit.

(6) In continuation of previous similar work for an exploration company, 84 drill core samples from the Banded Iron Formation in the Hamersley Range were examined. Upgrading was accomplished by fine grinding to a liberation size and magnetic separation to yield a concentrate for analysis.

(7) A minor investigation begun in 1976 was concluded early in 1977. The requirement was to determine the temperature necessary to prepare cement clinker of a specified composition. The Division's oil fired Etchell's furnace was able to achieve the high temperatures (above 1 500°C) required.

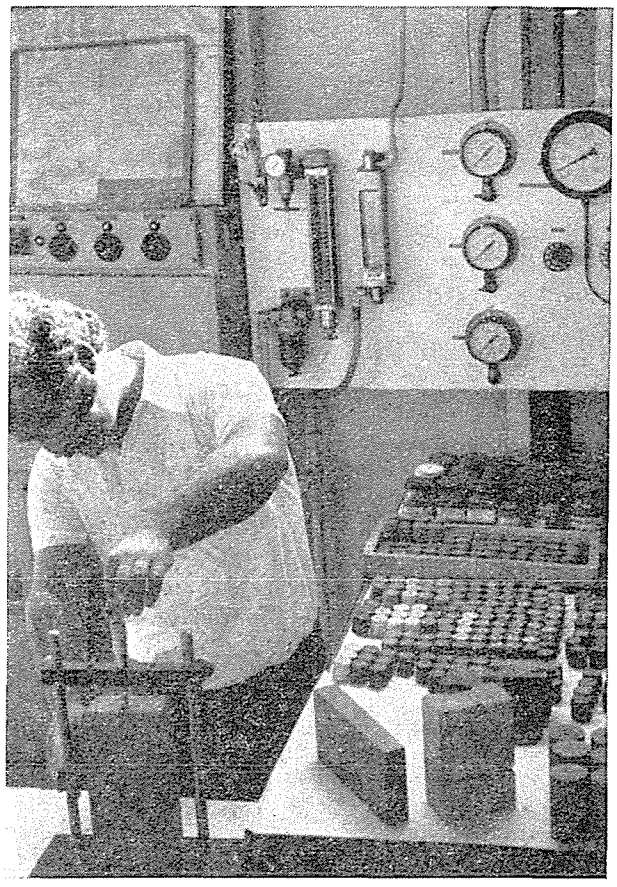
(8) A company requested a brief assessment of residues from alunite processing for use as filter aids. Alunite from Lake Chandler was processed during the 1940's to provide potash for fertilizer. The residual clays are investigated by entrepreneurs from time to time for potential exploitation.

PROJECTS ARISING FROM OTHER DEPARTMENTS

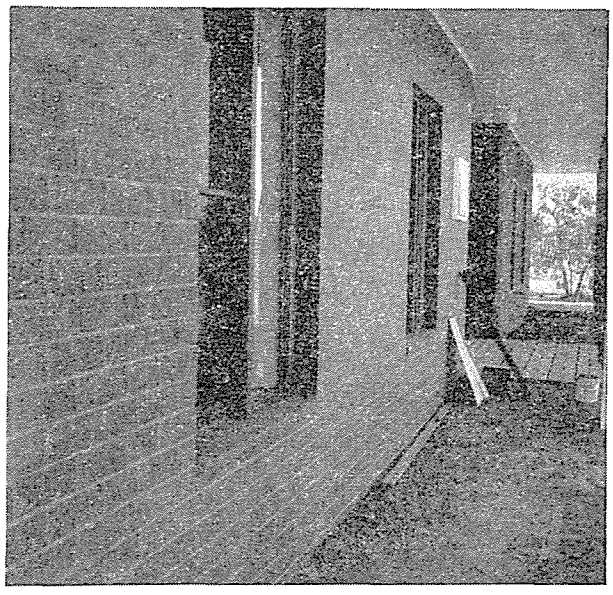
Other Government Departments have a limited requirement for investigations into mineral processing. However, assistance is frequently sought in other areas of the Division's activities and the facilities and expertise are made available as required. Some of the relevant details are indicated below.

Stabilised Pindan Soil Bricks

The Pindan house referred to in last year's Report was completed at Broome and occupied this year. Photographs showing the preliminary laboratory work carried out by this Division and the subsequent construction by the State Housing Commission in Broome are included in this Report. This Division has continued its association with the State Housing Commission and the Office of the North West who are jointly managing the project. Some soils from other areas of the north-west are being tested and the future of the project is currently under review. This Division has established liaisons with the appropriate CSIRO Division and the Commonwealth Experimental Building Station.



Laboratory testing of Pindan Bricks and Briquettes



Pindan house under construction in Broome

Barite Potential

In association with the Geological Survey a deposit of barite at Cooke Bluff Hill in the north-west of the State was reviewed for its commercial significance. The mineral barite is a source of barytes (barium sulphate) which is a high specific gravity (4.2-4.5) material used in drilling.

Brown Coal

A sample of low grade brown coal from the Norseman area was submitted for analysis. The material was found during drilling for water and its discovery initiated some activity aimed at defining the nature and extent of the resource. The exploitation of a remote deposit of such low grade material is subject to severe economic constraints.

Temperature Measurement

The Clean Air Section of the Public Health Department requested assistance with the measurement of temperatures in a heat exchanger at the Midland Abattoir. The unit received the gases vented from cookers at the works and reduced their temperature and moisture content before they passed into an incinerator for odour destruction. The relevant temperatures were recorded on a Leeds and Northrup multi-point instrument and the data reported to the Clean Air Engineer. It was expected that the data would be used in the design of a new system that would eliminate malodorous emissions from this section of the works.

INTRA-DIVISION PROJECTS

The allocation of man-hours to internally innovated projects is affected by their topicality vis-a-vis the quantity and urgency of work arising from the two areas referred to above. The latter sources are accorded a high priority but the Laboratories' policy is to attempt to maintain momentum on Divisional projects as indicated below.

Copper Processing

The investigation into the potential of the Parker-Muir process for the production of high purity copper powder, which began in 1974, has continued throughout the year. While close contact with Professor Parker and Dr. Muir of Murdoch University was maintained, an independent approach was adopted. This has enabled a completely objective economic feasibility study to be performed on the known aspects of the process. A completely definitive assessment cannot be made until several important technical aspects of the process are confirmed by further testwork at pilot plant level.

The study, completed during the year, examined the competitiveness of the process with a conventional smelter at an annual capacity of 100 000 tonnes. Such a scale of operation is well beyond that foreseeable in Western Australia. However, as the process is essentially a copper refining technique, the recovery of copper from scrap is a possible use for the process. The viability of a plant to convert 0.5 tonne per hour scrap copper to pure copper powder was also determined in conjunction with the larger feasibility study. At year's end the feasibility study was being prepared for distribution as a Report of Investigation (No. 17).

Zircon Processing

The industry's difficulties with matching market specifications for premium grade zircon colour and iron content prompted the Division into making its own investigation of zircon from three different W.A. deposits. With the assistance of the Mineral Division an attempt is being made to determine the nature of the stain and the phase changes that occur during stain removal processes.

Diatomite

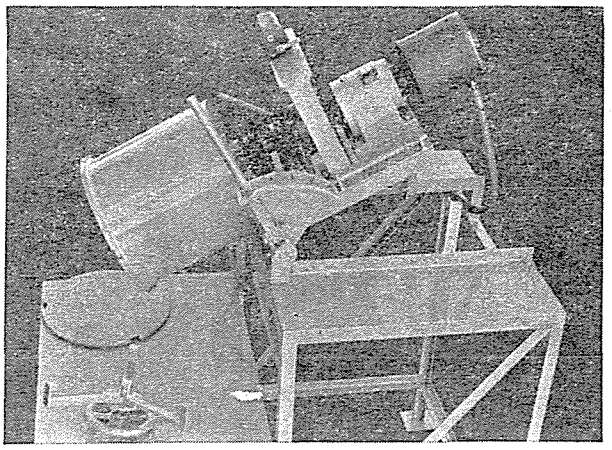
The Division's interest in diatomite as a filter aid as expressed in previous Annual Reports was maintained during 1977. In particular an overseas patent for treating diatomaceous earth with polyelectrolytes was examined for its applicability to indigenous diatomite.

Formcoke

The large scale effort of these Laboratories during the 1950's produced a technically feasible method of producing a substitute coke from Collie coal. The knowledge then gained has subsequently served as the basis for satisfying requests for general assistance from relevant commercial ventures. The various changes in sources (of carbon) and requirements over the last 15 years prompted a review of basic data and an experimental programme was concluded during 1977. The general validity of the earlier data was confirmed and some attention was given to current sources of binder.

Banded Iron Formation

The Division continued its own investigation into drill core samples of the Banded Iron Formation in the Hamersley Range. This ore is similar to the commercially exploited taconite ores of the Mesabi Range and other areas of North America. Methods of upgrading are being examined and in particular the vast amount of literature on the subject is being reviewed to determine a continuing programme of investigation. The work is considered to be of long term significance for the State.



Standard grindability mill

Bond Grindability Mill

A standard Bond mill was fabricated in the Division to allow the determination of the Work Index parameter for ores. Measurement of this Index allows the prediction of power requirements in industrial grinding circuits. The unit has been used on the banded iron ore referred to above and the Work Index measured was 15.9 k Wh per short ton. This compares with the value of 15.4 determined in another unit. This agreement is satisfactory in view of a detailed analysis of the method carried out in this Division. A photograph of the mill accompanies this Report.

B. A. GOODHEART,
Chief, Engineering Chemistry Division.

FOOD AND INDUSTRIAL HYGIENE DIVISION.

GENERAL

There has been an increase of 13 per cent in the number of samples received by the Division. The increase of food samples was only slightly more than the previous year but the increases of 30 per cent in industrial hygiene samples and 21 per cent in miscellaneous samples were most significant.

A Miran Infra Red Gas Analyser and a Hobart food chopper were received this year. A portable mercury meter has been ordered and tenders called for an automated gas chromatograph for handling the increase in pesticide residue analyses.

A workshop on mercury determination in fish was organised in Melbourne jointly by the Australian Fisheries Council and the Australian Environmental Council; Mr. G. A. Taylor was one of a limited number of chemists invited to participate in the workshop.

A meeting of food analysts in Melbourne was convened on the initiative of the Chief of Food and Industrial Hygiene Division, to establish a regular meeting of food analysts to continue the good work of the now disbanded Food Analysis (Reference) Sub Committee of NH&MRC. The meeting resolved to meet annually in the various capitals.

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 is given in Table 5.

FOODS

A request for an industrial hygiene inspection of a confectionery store resulted in an intense food and industrial hygiene investigation case. Fumigation of a basement store of a confectionery merchant had been carried out with a pressurised cylinder of dichlorvos when the hose burst releasing the content of the cylinder into the store. The investigating chemist noted the condition of the confectionery in the store and arranged sampling. A large number

77239—11

TABLE 5

FOOD AND INDUSTRIAL HYGIENE DIVISION

	Agriculture Department	Agriculture Protection Board	Departmental	Fisheries & Wildlife Department	Government Stores	Hospitals	Labour & Industry Department	Metropolitan Water Board	Mines Department	Pay	Public Health Department	Public Works Department	Other	Total
FOODS—														
Apples	97	....	....	....	....	....	....	....	....	....	1	....	....	98
Beer	....	....	....	....	....	....	....	....	....	....	16	....	....	16
Bread	....	....	....	....	....	....	4	....	....	....	10	....	....	14
Cheese	8	....	....	....	....	1	....	....	....	....	8	....	....	17
Coconut	....	....	....	....	....	....	....	....	....	....	48	....	....	48
Confectionery	....	....	....	....	....	....	....	....	....	....	30	....	....	30
Eggs	....	....	....	....	....	....	....	....	....	....	12	....	....	12
Fish	....	....	....	224	....	2	....	....	....	25	451	....	....	702
Fruit	6	....	1	....	....	....	....	....	....	....	4	....	....	11
Fruit and soft drinks	5	....	....	....	....	1	....	....	....	....	32	....	....	38
Grapes	32	....	....	....	....	....	....	....	....	....	....	....	....	32
Human milk	....	....	....	....	....	....	....	....	....	....	12	....	....	12
Liquor	....	....	....	....	....	....	....	....	....	....	25	....	....	25
Loquats	20	....	....	....	....	....	....	....	....	....	....	....	....	20
Meat and meat products	2	....	....	....	....	....	....	....	....	....	45	....	1	48
Milk	87	....	15	....	....	....	....	....	....	....	15	....	....	117
Potatoes	11	....	....	....	....	....	....	....	....	....	5	....	....	16
Prawns	....	....	....	....	....	....	....	....	....	....	22	....	....	22
Preserved fruit	....	....	....	....	....	....	....	....	....	....	20	....	....	20
Rice	17	....	....	....	....	....	....	....	....	....	....	....	....	17
Shark	....	....	1	....	....	....	....	....	....	....	44	....	....	45
Tripe	....	....	....	....	....	....	....	....	....	....	47	....	....	47
Various	1	....	4	....	....	6	....	....	....	9	90	....	2	112
INDUSTRIAL HYGIENE—														
Air	....	....	....	....	....	6	....	....	....	....	196	....	....	202
Anaesthetic gases	....	....	....	....	....	....	....	....	....	....	47	....	....	47
Exhaust gases	....	....	....	....	....	....	....	....	11	....	....	....	....	11
Gloves	....	....	....	....	....	....	....	....	....	....	15	....	....	15
Inspections	2	....	1	....	....	....	....	....	....	1	13	1	1	19
Rubber tyres	....	....	....	....	....	....	....	....	....	....	19	....	....	19
Urines	....	....	....	....	....	....	148	....	74	35	76	....	....	333
Various	....	....	....	....	....	....	....	....	....	....	14	....	....	14
MISCELLANEOUS—														
Animal tissue and fat	62	9	....	....	....	....	....	....	....	....	90	....	....	161
Animal toxicology	61	....	....	....	....	....	....	....	....	9	5	....	....	75
Birdseed	69	....	....	....	....	....	....	....	....	....	....	....	....	69
Detergent	....	....	....	....	24	....	....	....	....	....	1	....	2	27
Eucalyptus leaves	45	....	....	....	....	....	....	....	....	....	....	....	....	45
Fish tissue	....	....	....	53	....	....	....	....	....	....	....	....	....	53
Pesticides	62	2	....	....	....	....	....	....	....	4	32	....	....	100
Senna	52	....	....	....	....	....	....	....	....	....	....	....	....	52
Soils	104	101	....	....	....	....	....	....	....	....	....	....	10	215
Specimen from patient	....	....	....	....	....	84	....	....	....	40	109	....	....	233
Surgical dressings	....	....	....	....	46	....	....	....	....	....	....	....	....	46
Water	1	....	11	....	....	....	....	156	....	8	22	222	2	422
Various	53	....	1	....	1	9	2	....	5	15	97	7	17	207
Total	797	112	34	277	71	109	154	156	90	146	1 673	230	35	3 884

of the confectionery was sampled and examined. It was found that only confectionery packed in sealed tins were free of dichlorvos. Affected confectionery valued at $30 000 had to be subsequently destroyed.

Preserved fruits which were imported from Asia were examined for saccharin; of the 20 samples examined, 10 contained saccharin.

A number of infant formula milk powders were submitted for chemical analysis. There had been complaints about the samples being contaminated with a black material. Examination of the samples showed that in all cases the black material was charred milk powder.

Seven samples of cheese were examined for colouring in the rind. Several of the cheese rinds contained oil soluble dyes which are not permitted by the Food and Drug Regulations. It was noted that one of the samples had a plastic wrap around the cheese which was then coated with a coloured wax. Because the wax was not in contact with the cheese, the oil soluble dye would be permitted in this case.

A sample of Marmite was submitted with a complaint that it contained glass. The "glass" was in fact crystals of salt which had been deposited due to evaporation of the sample. The price tag on the sample was one third of the current price for that size container and gave an indication of the age of the sample.

Of the 47 samples of tripe analysed, 12 had a pH in excess of the limit of 7.5 as required by the Food and Drug Regulations.

The Department of Agriculture conducted a survey of grapes grown commercially in the south west of the State. Thirty-two samples were analysed for the effects of various nutrients on the composition of grape juice.

Following an outbreak of vomiting by school children after eating fish and chips bought at a shop, several samples of materials in the shop were examined for heavy metals, pesticides and the potatoes for solanine, all with negative results.

A sample of chocolate liqueurs was examined for alcohol content. The alcohol content of 4.6 per cent exceeds the one per cent allowed by the Food and Drug Regulations.

Several samples of wholemeal breads were submitted by the Public Health Department. Three of the samples failed to comply with the fibre content required by regulation.

TABLE 6

SPECIMENS FROM PATIENTS—ANALYSES

Analysis	Number
Arsenic	121
Iron	15
Lead	49
Manganese	10
Mercury	81
Thallium	34
Zinc	11
Miscellaneous*	23

* Includes antimony, atrazine, bismuth, cadmium, chromium, copper, D.D.T., dieldrin, fluorine gold, magnesium and selenium.

SPECIMENS FROM PATIENTS

There has been a slight increase in the number of samples received from doctors and hospitals to assist in their patient's diagnosis.

Table 6 lists the analyses which were carried out on the samples.

Also four breast milks were examined in connection with feeding problems in children.

INDUSTRIAL HYGIENE

Of the 333 samples of urine, 241 were for lead determination. These determinations were used to monitor the uptake of lead of exposed workers. Workers with a normal level of 80 μg/1 or less lead content accounted for 57.7 per cent of these samples, an acceptable level of 90 to 150 μg/1 for 27.0 per cent and greater than 150 μg/1, an excessive level, for 15.3 per cent.

As forecast in last year's report the arrival early this year of an infra red gas analyser has increased the number of gas samples analysed. Visits have been made to the operating theatres at Fremantle Hospital, King Edward Memorial Hospital, Princess Margaret Hospital and Repatriation General Hospital to measure the concentration of anaesthetic gases and to check on the effectiveness of scavenging techniques. The equipment has also been used in factories and laboratories to measure various toxic gases.

An officer of the Division visited Kalgoorlie during the year to take measurements of carbon monoxide in the exhaust gases from diesel engines operating underground.

A brief survey was made of service stations and areas where benzene and toluene could be present. No levels in excess of the TLV's were found.

Following a reported incident of fainting by staff in a city bank where the air conditioning may have been implicated, the infra red gas analyser was used to monitor the air in the supposedly affected area of the bank for several days. No abnormal results were found and there have been no subsequent similar incidents in the bank.

Several pairs of gloves were examined to determine penetration by various compounds. It was found that both organochlorine and organophosphorus pesticides will permeate rubber and plastic gloves. Heavy PVC gloves used by workers handling acrylamide were found to be permeable to that substance.

Sand moulds used in a foundry were found when heated within the laboratory to give off formaldehyde and hydrogen cyanide. Measurements were made when these moulds were used in the industrial situation. The levels of formaldehyde and hydrogen cyanide were below the TLV.

A series of air samples were taken from the Mt. Henry Dental Therapy School for mercury to assess the effect of amalgam preparation on the working atmosphere at the school; all had acceptably low levels.

A firm which reuses old rubber tyres by removing and pulverising the rubber to manufacture a surface coating material and a firm recapping used tyres were inspected. Samples were taken of the various brands of used tyres for determination of β-Naphthylamine, a carcinogen which can be present in rubber. β-Naphthylamine was not detected in any of the tyres.

The histopathology laboratory of the Department of Agriculture was visited to determine the toluene and xylene levels. Air velocity measurements were also taken in the fume hood where the tissue processing unit is housed. Osmium tetroxide is also used in this laboratory and recommendations were made for safe handling of these materials.

An oil blending plant was visited to determine the concentration of oil mist in the atmosphere. Oil mist was determined on an N Class diesel locomotive for Westrail. The N Class locomotives have been the subject of complaint by unions and amongst the complaints was one of excessive engine fumes. The amount of oil mist was below the TLV.

A mineral research laboratory was visited to determine the levels of tetra-bromo-ethane (TBE) and acetone. The level of TBE was found to be excessive and recommendations were made to reduce the level. The laboratory is to be revisited when alterations have been made to assess their effectiveness.

During the year a number of biological samples have been examined for elements other than lead. These have included antimony 5, arsenic 13, fluorine 21, mercury 75 and thallium 7. A sample of urine was examined for diquat and paraquat.

At the request of the Mines Ventilation Board Mr. Uren has taken part in a 'Walk through survey' of several mineral processing plants to ascertain what toxic dusts and gases are present as a result of the processing of various ores.

At the new grain terminal at Kwinana a series of measurements were made to determine the concentration of fenitrothion. This pesticide, at the time of use, was unregistered but was allowed for experimental purposes. The spraying area was only a temporary arrangement and was unsatisfactory. We understand that the temporary structures have been removed and the use of fenitrothion has ceased.

Several officers have made inspections on board ships at Fremantle. No serious spillage or hazardous situations were encountered this year.

PESTICIDES

Again this year many of the samples of pesticide emulsions for termite treatment samples on building sites did not comply with Australian Standard CA43-1966 with respect to active ingredient content.

Two samples of phenoxyacetic acid type herbicides were submitted for determination of dioxin. Dioxin was not detected in the samples.

Pesticide Residues

Table 7 gives a summary of the major types of the samples received this year for pesticide residue determination.

TABLE 7
PESTICIDE RESIDUE ANALYSES

Sample	Number
Bird seed	69
Bovine—	
Bloods	20
Fats	23
Breast milk	12
Coconuts	47
Confectionery	22
Dairy products	45
Eucalyptus leaves	45
Fish tissue—Ord area	108
Foods	56
Loquats	20
Pastures and stock foods	19
Potatoes	17
Rice—Ord area	17
Soils	219
Trace back samples	91
Waters	409

The Metropolitan Water Board have this year conducted a pesticide residue trial on an isolated orchard in one of its catchment areas. With the co-operation of the orchardist, a complete list was obtained of which pesticides and herbicides were used. Samples of run-off water from the property were obtained whenever it rained. Some of the pesticides used in the orchard were detected in the run-off water.

An interesting trial has been the injection of various systemic organophosphorus insecticides into eucalyptus trees. These trees have been attacked by insects which were eating the leaves. Monitoring the insecticide in the leaves showed that a maximum level is reached six to eight weeks after injection. A similar trial was carried out on a loquat tree. It would appear that this method of treatment shows some promise and further trials are warranted.

Samples of bovine fat and blood were taken from the individual animals. The samples were analysed for DDT and metabolites to see if a correlation between fat and blood levels existed. The number taken was relatively small, and the apparent correlation found in the initial samples was not confirmed in all of the susbsequent samples.

The Agricultural Department trial plots and several of the wheat belt soil samples were analysed for picloram. Picloram is used for the control of the skeleton weed and there have been areas where it has been used but the cereal crops have been very poor up to two years after its use.

The persistence of organochlorine pesticides was demonstrated by the following case. A poultry run in a suburban home was treated by a pesticide operator with aldrin. Some time after, the house-holder had eggs from the hens checked for aldrin. Dieldrin, the metabolite of aldrin was found in the eggs at a level well above the maximum level allowed by the Food and Drug Regulations. The top soil of the run was removed and the birds were replaced by new birds. Samples of eggs from the new birds were still very high in dieldrin and it was found that the top soil had not been completely removed. The top soil was removed again and the birds replaced. Eggs are still showing high levels of dieldrin. This experience raises the question of how many other fowl yards in suburban residents' yards have been similarly treated and are now producing dieldrin contaminated eggs?

ANIMAL TOXICOLOGY

Several samples of cats' organs and litter have been examined for pentachlorophenol. The wood used in making the litter had been treated with pentachlorophenol. Significant concentrations of pentachlorophenol were found in the organs of affected cats.

In a Department of Agriculture trial to assess the fate of warfarin eaten by pigs, several pigs were fed varying single doses of warfarin and then kept for a month before slaughter. No warfarin was detected in any of the organs or muscle of the pigs.

The cause of the death of several flocks of turkeys was traced to arsenic. An arsenical coccidiostat was incorporated into the turkey pellets and the supplier of the compound had increased the compound's strength by a factor of ten. The formulator had forgotten this fact and made up the pellets using the old formula.

MISCELLANEOUS

Several articles of children's night clothes were examined for the presence of the retardant tris BP which is a suspected carcinogen. One article was found to contain tris BP.

Because of the current concern over the effects of fluorocarbon on ozone in the atmosphere three aerosol products with claims on their labels that they contained no fluorocarbons, were checked and found to be free of fluorocarbons.

Fifty-two samples of senna leaves, pods and stems were examined for sennoside content. The senna plant is being grown experimentally in the Ord area; the levels found to date were not encouraging.

An enamelling kit was investigated. The pigments contain small amounts of arsenic, cadmium and lead. The pigments, when mixed with the epoxy type enamel and used according to instructions, should not present a hazard to users.

A sample of diesel fuel from a tractor which caught fire was examined. The fuel was found to be diluted with about 10 percent of a low boiling range flammable substance.

The Government Stores Department submitted 46 samples of surgical dressings and bandages to assist them in selecting which tenders for these articles to accept.

F. E. UREN,
Chief Food and Industrial
Hygiene Division.

INDUSTRIAL CHEMISTRY DIVISION

The Division continues to be engaged in a variety of activities and some interesting work was done during the year. The flow of enquiries, both by telephone and by visit, continues unabated and as usual a large proportion dealt with plastics.

Dr. Smith delivered a lecture on plastics to Manual Arts students at the Secondary Teachers College and to the Plastics Institute of Australia "Know Your Plastics" series.

MATERIALS TESTING

Paint

Seventeen samples of paint were submitted on behalf of the Tender Board for testing and comparison of laboratory results with a practical evaluation by painters at three Public Works Department depots. Although there was some variation between depots with some of the samples, correlation between practical application trials and laboratory tests was generally quite good. A further 70 samples of paint were tested for the annual Government paint tender and a report made to the Tender Board Paint Advisory Committee. Several paint samples were examined for identification of components and to see that they were of the type claimed.

Samples of paint flakes from the handrail sections of a road bridge were examined for the Main Roads Department. The specification required the use of an etch primer and two top coats of a chlorinated rubber paint. In fact a proprietary phosphoric acid etching solution was used in place of the etch primer. This should have been satisfactory but it had not been used properly, if at all, where the paint was flaking off.

Building Materials

Some work was done on removing tobacco smoke stains from PVC coated metal ceiling panels. A general purpose detergent was reasonably satisfactory and chlorinated trisodium phosphate was a little better. There are several commercial cleaners which were found to remove the stain very well.

Twenty nine samples of carpet were received for examination with respect to several aspects. Most were examined for Public Works Department Architectural Division for assessment by our standard tests. The others related to problems of effectiveness of treatment against staining, residual water repellency of a carpet shampoo, staining, tuft retention and identification by comparison with previously supplied carpet.

Samples of acoustic screen as used in office areas as dividers were fire tested in accordance with AS 1530-1976, Part 3, "Test for Early Fire Hazard Properties of Materials". Both samples had a core of glass fibre faced with hardboard and the whole covered with a woollen fabric. Slightly but significantly different results were obtained from the two differently coloured fabric coverings.

A wool upholstery fabric backed with a thin PVC film was examined. It was claimed that the film would prevent liquid spillages penetrating into the chair padding. A variety of tests was requested including several fire tests, resistance to stains, UV light, water penetration, and washing in a wool detergent, dimensional stability and resistance to spotting solvents. The material generally behaved well, although, being wool, shrinkage occurred on washing and its dimensional stability was not good. The PVC film prevented penetration of liquids through the fabric.

Ten samples of vinyl flooring were examined. They were all of similar type, being a comparatively thin layer of PVC on a fibrous backing. The backing material was either polyester, jute or asbestos. Various tests were carried out such as thickness of layers, resistance to UV light, lime, indentation, impact and abrasion, dimensional stability and the staining effect of iron ore dust. All samples behaved similarly and were generally satisfactory.

A sandwich panel was submitted for testing of dimensional stability. The panel had a core of rigid polyurethane foam and facing sheets of Hardiflex. Two buildings constructed with these panels have shown some movement with cracking of the facing panels near joints. The foam from several parts of the panel was tested for density and dimensional stability. The density was found to be a little low and the samples were dimensionally unstable.

Plastics

Advice was requested on the lining of concrete roof tanks with fibreglass reinforced plastics. The specification that had been provided was grossly in error as to thickness of both laminate and gel coat and appropriate corrections were made. Some comments were also made on a specification provided by a company quoting for the job.

Heavy gauge vinyl wall covering in a new nursing post at Beagle Bay had become detached. It was found that application of adhesive was very uneven, in some areas hardly any being visible. The adhesive itself may also not have been suitable for the hot conditions.

A series of 40 bird tags for pelicans were exposed in the UV weatherometer for 1 500 hours. The tags were made from flexible PVC sheeting in several colours marked with various types of ink. After exposure some of the ink combinations had faded a little, but there were no failures and the PVC seemed virtually unaffected.

Samples of electric cable and rubber grommets were submitted for examination by Telecom. Where the PVC covering of the cable was in contact with the rubber a brown stain had developed and the PVC had shrunk somewhat and hardened. The brown stain was probably caused by migration of a staining-type antioxidant from the rubber to the PVC and the shrinkage and hardening by migration of plasticiser from the PVC to the rubber. The use of PVC grommets instead of rubber would prevent this problem.

A number of plastic intravenous drip sets were examined for the State Health Laboratories. The major components were of PVC, with some items of nylon and stainless steel. Continuous washing with distilled water, which was recycled, eventually produced a very small amount of water soluble material identified as sodium chloride with traces of other unidentified materials. The water soluble material would be most unlikely to be responsible for problems that have occurred with these drip sets.

A sample of cable contaminated with a bright green exudate was submitted. The exudate was shown to be the plasticiser in the PVC insulation, decyl 2-ethylhexyl phthalate, containing dissolved copper. The cable must have been overheated since heating a piece of copper with another phthalate ester produced a green solution.

Ten samples of synthetic resin laminate were submitted for physical and chemical testing. Five samples were of well known brands and the other five were various colours of an imported French product. The French material was somewhat thinner than the others and performed in a similar way in all tests except UV exposure, hot iron and lighted cigarette tests where it was inferior.

A number of miscellaneous samples were submitted for identification of the plastic contained therein.

Miscellaneous

The Chief Inspector of Explosives submitted samples of 5 litre tin cans designed for storage of flammable liquids such as petrol. They were tested for drop impact strength and hydrostatic pressure resistance according to AS 1936-1976, "Plastic Containers for the Transport of Materials". All cans failed the tests.

Two samples of light tent canvas were examined. The material was identified as cotton and it was considered that holes in the side of the tent had been caused by fungal attack after the tent had been packed away with the sides still damp.

A crystalline deposit found near electric cable in a junction box was found to be chlorinated naphthalene wax, a component of some insulating compositions. Overheating can cause the material to sublime.

The Department of Agriculture has been investigating the toxin in annual ryegrass. A series of extractions with a final low temperature concentration have been carried out twice on a pilot plant scale to provide material for further research.

Considerable time was spent in assessing the information received for the detergent tender and for the floor and wall cleaning and maintenance products tender. Reports were made to the Tender Board in each case.

Two samples of fire hose were submitted in which the bond between the rubber liner and the polyester canvas outer had failed. The adhesive appeared to have soaked into the canvas. No contaminants could be detected, but it was considered that solvent attack, such as might be causesd during the cleaning up of a petrol spill, could have caused the failure.

An investigation of True-to-Scale transfer paper was carried out to determine the reason for blotchiness during the coating of the paper. Replacement of an anionic type of wetting agent with a nonionic type cured the problem. Some information on photo-active ferric salts was also supplied and some work was carried out on suitable stabilisers.

A sample of impure triacontanol, a 30 carbon fatty alcohol, was prepared for the Department of Agriculture from beeswax. This chemical was isolated from the surface wax of lucerne (alfalfa) in the U.S.A. after plant growth promoting effects were noticed when lucerne hay was ploughed in prior to the planting of a new crop. The W.A. Department of Agriculture had noted similar effects after ploughing in lupins. A sample of material containing about 30 percent triacontanol plus other long chain fatty alcohols was supplied to the Department for trials. No significant results were obtained at the recommended rate of application, but another trial will be carried out at a higher rate and with greater experimental control.

Samples of two fabrics were tested for flammability. Both were polyester/cotton blends, one being a lightweight fabric suitable for shirts and the other a heavier material suitable for overalls. The tests were carried out in accordance with BS 2963:1958, Vertical Strip Test. Both materials burned freely, but without evidence of molten droplets.

A set of 6 jarrah panels has been tested in the Early Fire Hazard test equipment. A copy of the report together with a similar set of panels was sent to the Experimental Building Station in Sydney for testing on their equipment. In return they have sent us 6 panels of hardboard which they use for regularly calibrating their equipment. When these are tested here a copy of the report will be sent to Experimental Building Station and the results compared.

Six samples of synthetic running surface were examined for the Community Recreation Council and Perth City Council. Various physical determinations were carried out such as density, resiliency, frictional coefficient, abrasion resistance, resistance to UV light and various chemicals. The results obtained assisted the Council in choosing one of the materials for relaying the running track at Perry Lakes Stadium.

ASSISTANCE TO INDUSTRY

An investigation of some properties of a new material being developed locally was carried out. The product consisted of reclaimed rubber crumb prepared from old tyres bonded into slabs with a polyurethane resin binder and also spray applied to asbestos cement with and without a polyurethane surface coating. Tests were carried out for resiliency, Shore hardness, resistance to UV light for 1 000 hours and resistance to water, petrol, lubricating oil and chlorine solutions.

The resiliency results were satisfactory and compared well with other rubber compositions. UV light resistance was excellent. Resistance to water and aqueous solutions was poor under full immersion conditions, the bond between the polyurethane and rubber being weakened. Under intermittent exposure, simulating rain, resistance was satisfactory. Resistance to petrol was poor, but to lubricating oil was good.

Later, two lots of rubber crumb were received from the same company for determination of fibre content. This caused some difficulty but a sufficiently accurate figure was finally obtained. Suggestions were made for improving the separation of fibre from the rubber.

A can manufacturer submitted several sets of samples of 5 litre cans for strength testing. From the results of our tests the manufacturer was able, by making stronger seams and a heavier raised rim to protect the closure, to produce cans that passed the drop impact and hydrostatic pressure tests.

A number of metal jerricans were submitted by a chain store for drop impact and hydrostatic pressure tests. The containers passed the drop impact test but failed the hydrostatic pressure test.

A comparison of corrosion resistance between local and imported electrogalvanised sheet was carried out in the salt spray cabinet. The imported material was more resistant to surface attack but showed slightly more rusting in areas of severe attack than the local product. The thickness of the zinc coating on the imported sheet was 0.003 mm and on the local sheet 0.010 mm.

At the request of a local importer nine garments imported from Indonesia were examined. All were found to be 100 per cent cotton as claimed.

Four sets of painted metal panels were exposed in the salt spray cabinet for an agricultural machinery manufacturer. Each set used a different paint system. The coatings generally behaved well, but the assessment of results was carried out by the company.

An investigation into the preparation of a high protein animal feed from hospital and restaurant food residues was carried out. The experiments were aimed at low energy methods of dewatering the mixture but initial results are not encouraging. Some further work may be done.

INVESTIGATIONAL

The karri painting project has been completed and the final report issued as a Report of Investigation.

The report on the chemical treatment of Laporte effluent was revised by updating cost estimates.

The investigation of clear finishes for timber is continuing with a series of test panels now on outdoor exposure.

CONSULTATIVE

As usual a diverse range of enquiries was received in considerable numbers and a selection is given below.

Use of silicate ester binders in bronze casting.
Removal of epoxy adhesives from concrete floors.
Dyeing of nylon buttons.
Suitability of plastic electrical fittings outdoors in the North West.
Textured finishes for roof tiles.
Repairs to a fibreglass tank.
Use of plastics in mineral treatment plant.
Removal of tannin stains from ceramic floor tiles.
Peeling of paint from plaster ceilings.
Coating system for bricks and plaster walls to resist daily applications of disinfectant and detergent.
Use of plastics for food contact applications.
Use of various plastic components in a new design of swimming pool cleaner.
Fireproofing of timber.
Plastic materials for a dispenser of fertiliser solutions.
Sealing leaks in concrete tanks.
Formulation for a detergent for aircraft cleaning.
Plastic tank lining for hard chrome plating baths.
Production of methanol from wood and other wastes.
Use of plastics in a new wheelbarrow design.
Permeability of plastic films to ethylene oxide.

E. B. J. SMITH,
Chief Industrial Chemistry Division.

KALGOORLIE METALLURGICAL LABORATORY

GENERAL

Three hundred and forty-nine reports on sponsored work were issued during the year including twenty-one reports on research work.

The increased price of gold has encouraged prospectors and companies to again become very active in the field and this trend is expected to continue during 1978. Forty-eight bullion bars were received for assay and 11 research reports dealt with the treatment of gold ores. The technique of trickle leaching with cyanide solution, which would be applicable to an ore from a porous sedimentary type of deposit, was subject to two lengthy investigations.

An investigation was carried out for a company who were experiencing extraction difficulties with a normal amalgamation and cyanidation procedure. The gold was found to coat the outside surface of the sulphide particles, which prevented normal amalgamation in that the mercury could not be separated from the sulphides. These problems were overcome and the plant is now operating satisfactorily.

Six investigations dealt with standard conditions of leaching tailing dumps with cyanide solution and the operators were advised of their respective lime and cyanide consumptions and recovery.

Two investigations dealt with separate dumps showing free gold with the object of using a gravity separation to recover the gold, but neither contained sufficient free gold or at a particle size that would give a satisfactory recovery by gravity methods.

Test work was carried out on gold loaded activated charcoal to determine an accurate method of assay and the method adopted was to grind the sample very fine, dry at 110°C and take 2 grams for a direct fire assay, excellent checks are always attained.

A total of 1 459 gold assays were carried out including 318 with respect to investigational work and 457 concessional assays for prospectors. In 1976 only 48 samples were submitted for concessional gold assays. The increase is an indication of the increased activities of prospectors.

A mine water was received for examination from a company who wished to pump the water ten miles for treating sands. The water was found to contain a large amount of calcium bicarbonate, which must receive treatment before it was pumped as excessive precipitation of the calcium carbonate would soon block the line and the sun's heat would accelerate this condition.

A second mine water used in treating sands was causing a high cyanide consumption. This sample also contained calcium bicarbonate and as the amount was not excessive it could be treated, then allowed to settle out in a dam and the clear overflow could be used. The cyanide would only be added to the treated solution.

Extensive work was carried out for a company on an oxidised copper ore, who were examining the leaching requirements of a dilute solution of sulphuric acid. Effective copper recoveries can be obtained on a porous ore from a sedimentary type deposit.

Company sponsored laboratory test work on a graphite ore had shown that considerable upgrading was possible, and subsequent sponsored work in the pilot plant had produced a high grade graphite concentrate. This should find a market now that the company can offer a sample of the product to prospective buyers.

CONSULTATIVE AND ADVISORY

Companies and prospectors have been busy during the year and further activity can be expected during 1978, particularly if the price of gold continues to increase, as many will require advice on marginal ores.

BUILDINGS

The laboratory has been painted inside and out and the very needed improvement is good for staff morale and client confidence.

G. H. MUSKETT,
Officer in Charge,
Kalgoorlie Metallurgical Laboratory.

MINERAL DIVISION

GENERAL

The total number of samples received rose again this year, from 2 826 to 4 070, the largest increases being in airborne dusts and multi-element geochemical scans.

The percentage of total samples submitted by the public increased slightly to 12 percent. These were largely for mineral identifications and experimental products derived from mineral dressing projects at the Engineering Chemistry Division.

The output of work was again predominantly for the Geological Survey of Western Australia in the form of silicate rock analyses for regional map surveys and other investigations, but large numbers of samples were submitted by the Public Health Department and other branches of the Mines Department.

Co-operation with authorities aligned with improving accuracy and reliability of analyses universally, has been maintained at a high level. The collection and systemisation of data on mineral occurrences continued and the characterisation of new mineral species from Western Australia was undertaken as time permitted.

During the year the Chief of the Division made assessments of 7 laboratories in Melbourne on behalf of the National Association of Testing Authorities.

The Division continued its close association with the Standards Association of Australia Sub-Committee on Chemical Analysis of Iron Ores. Significant contributions were made at Sub-Committee meetings in Melbourne, Perth and Adelaide as well as in method standardisation experiments.

The sources and nature of samples received are shown in Table 8.

GEOCHEMISTRY

Listed under this heading are analyses of elements in the parts per million range mostly associated with full silicate analyses which are used for the differentiation of primary rock masses in regional mapping surveys.

Other groups are part of investigations such as the study of the Bangemall Basin mineralisation and a comparison of the environment of precipitation of sediments there, with those of other areas. Ba:Sr ratios were determined to assist with interpretation of the origin of some cherts relative to replacement of aragonite.

TABLE 8

MINERAL DIVISION

	Aboriginal Lands Trust	Bureau of Consumer Affairs	Geological Survey	Government Chemical Laboratories	Mines Department	Police Department	Public Health Department	Public Works Department	Road Traffic Authority	Other	Public			Total
											Pay	Concession	Free	
Building Materials	....	11	7	1	2	....	5	8	....	9	1	....	....	44
Dusts	....	....	....	8	703	....	1 038	1	....	....	15	....	....	1 765
Forensic Examinations	....	....	....	....	....	36	....	....	....	....	....	....	....	36
Geochemistry	....	....	929	....	....	....	....	....	....	....	4	5	....	938
Metals and Alloys	....	....	....	1	....	....	10	2	....	2	1	....	....	16
Mineral Identifications	34	....	80	86	7	....	14	1	....	4	112	90	3	431
Miscellaneous	....	....	3	12	3	....	28	1	....	3	21	1	....	72
Ores and Minerals—														
Clay	....	....	84	....	....	....	....	7	....	34	6	2	....	133
Copper	....	....	....	7	....	....	....	....	....	....	70	1	....	78
Gold	....	....	1	1	8	....	....	....	....	....	27	36	13	86
Iron	....	....	2	75	....	....	....	....	....	....	2	1	....	80
Limestone	....	....	37	....	....	....	1	....	....	1	....	....	....	39
Tantalum/Tin	....	....	....	....	66	....	....	....	....	....	....	....	....	66
Vanadium	....	....	....	....	....	....	....	....	....	....	42	....	....	42
Other	....	....	....	....	11	....	....	....	....	....	20	8	....	39
Silicate Rocks	....	....	85	....	....	....	....	....	....	....	....	....	....	85
Soils	....	....	67	7	....	....	....	....	....	....	....	....	....	74
Pyrometry	....	....	....	....	....	....	....	....	27	....	19	....	....	46
Total	34	11	1 295	198	800	36	1 096	20	27	53	340	144	16	4 070

Studies of mineralisation have included classification of groups of gossans from Yarrie sheet, Nabberu Basin and other groups from Pemberton, Mt. Phillips and Glenburgh sheets. A large number of samples have been associated with the Saddleback greenstone belt, including comparison with the greenstones of the Eastern Goldfields. Groups have included basalts, dolerites and laterites. An extensive program relating to sediments was preceded by a pilot study of trace metal content in fractions separated by sizing and heavy liquids.

Duricrust samples from the Carnarvon Basin were examined for elements of accessory minerals.

A group of sulphide samples separated into fractions by size, density and magnetic susceptibility were submitted as part of an investigation of a mercury halo prospecting technique.

Overall, the elements determined were antimony, arsenic, barium, bismuth, cadmium, cerium, chromium, cobalt, copper, gallium, germanium, gold, lanthanum, lead, lithium, manganese, mercury, molybdenum, nickel, niobium, phophorus, rubidium, scandium, silver, strontium, tellurium, thorium, tin, titanium, tungsten, uranium, vanadium, yttrium, zinc and zirconium.

SILICATE ROCKS

Most of these samples were derived from Regional Mapping programs and often required calculation of normative minerals and quantitative X-ray diffraction studies of actual mineral species, together with trace metal contents. X-ray diffraction was of special use for fine-grained siliceous rocks suspected of being volcanic and for which normal petrographic techniques were not effective. An X-ray diffraction study was made of relict evaporative minerals. A large number of these samples were from the Bangemall Basin, and groups were also received from the Collie sheet, Pinjarra sheet, Mt. Phillips sheet, Nabberu Basin and Rundall sheet. One group was associated with a comparison of Archean and Proterozoic basalts on the Glengarry sheet.

Granite samples from the Nabberu basin were compared with granites from the Eastern Goldfields.

Analyses were also made for a Basic Irruptive Rocks geochronological project. Calculations of normative minerals from analyses provided by other laboratories were made.

ENVIRONMENT AND INDUSTRIAL HYGIENE

The large majority of examinations concerned with the environment, were again dusts encountered both in the work situation and generally, and other materials of potential hazard or nuisance.

Problems of disposal were responsible for samples of soil, mine mullock, stream sediments, vegetation and water examined for natural arsenic and its mineral occurrence to assess the usefulness of a disused mine for disposal of an industrial arsenical sludge. Other samples of arsenical sludge were examined to assess the potential of the material for recycling into the pesticide industry.

Examination of soils at various depths, associated with the dune pond disposal of Laporte effluent, revealed, in addition to expected species of silicate minerals, gypsum, calcite and iron hydrate, the presence of a minor percentage of siderite. Perusal of data on Eh, pH and ferrous iron concentration shows a restricted area of conditions where siderite is stable. The relative scarcity of siderite in the limesand soils examined indicates that these conditions do not normally occur naturally in the disposal area or that the kinetics of the reaction are not favourable to siderite formation.

Dusts

A 50 percent expansion in the number of dusts examined, occurred this year. As before, the major sources have been the Public Health Department, monitoring industries and the environment, and the Ventilation Inspectorate of the State Mining Engineer's Branch. Other sources have been mining companies and other industries.

Quartz

Approximately a third of all samples were for monitoring the quartz percentage of mine and quarry dusts and also in this connection talc and asbestos were determined on a large proportion of the samples. Rocks related to dust in various areas were examined to seek a correlation between the two as a practical guide. No firm correlation was obtained.

Lead

Approximately 400 samples of lead from air sampled in Perth City were examined as part of a continuous survey. Lead in air was also tested from industries such as battery works, and assay offices associated with gold mining.

Iron and Manganese

Continued monitoring of iron ore shipping areas produced approximately 300 dusts for iron content with manganese also in many cases.

Asbestos

Publicity given to asbestos in dust from deterioration of ceilings in a number of commercial buildings highlighted the survey of possible hazards which had been commenced in earlier years. Samples were also examined relating to workers replacing brake drums.

The largest group of "asbestos" dusts was associated with the mining industry where ore is being mined in a talcose matrix. In some American deposits asbestos fibres are associated with talc and the possibility of this hazard in W.A. is constantly checked. Cosmetic talc from retail sources has been examined for asbestos, with negative results.

An occurrence of asbestos fibres which has caused some interest is in the rain water collected in a tank from off a cement asbestos roof. An investigation is in progress to check the delivery of fibres from cement asbestos roofing sheets under simulated rainfall conditions.

An advance this year has been the acceptance by the National Health and Medical Research Council, of standard procedures for the membrane filter method for estimating airborne asbestos dust, and our acquisition of a high quality optical system for fibre counting. Efforts have been made to achieve a correlation of counting results with other authorities.

A large grouping of samples related to dust associated with particular localities, such as cement, lime and coal from one area, phosphate and sulphur from another and graphite, alumina, lime, calcium carbonate and fly ash from others.

Apart from quartz and asbestos, dusts from mines and treatment plants were examined for such components as carbon from diesel fume, selenium, mica, vanadium, arsenic and antimony. Particular medical problems led to the examination of dusts for suspected causes. These included estimation of scandium, of fluoride associated with monazite and examination of alunite. Numerous dusts were examined to identify the component materials so that they could be related to sources.

Hazards Other Than Dusts

Analogous to the survey of asbestos in airborne dusts, samples have been examined for asbestos in drinking water and in beer which is filtered through a filter bed including asbestos. Filtered beer is recycled through the filters after each bed is prepared and before the beer is allowed to go into production storage. No asbestos fibres were found in this storage.

The handle of a barbecue grilling plate was submitted for assessment of possible food contamination by lead. It was suspected from the lustre of the metal that the lead content was high. It was in fact less than 20 parts per million.

A sample of powder found on cupboard door catches in a hospital was examined for the cause of the occurrence. It was found to consist of hydrous zinc formate probably formed by corrosion of the galvanising on the fittings by formalin solutions used as a sterilizing agent.

Various component sections of a selection of soft drink cans were analysed for cadmium, together with tin and lead used for soldering. A calculation of the total cadmium content of an average can as a concentrate in the 370 ml of contained liquid, assuming total extraction, would be 0.04 μg Cd per ml. As total extraction of the cadmium into the liquid could not occur, this level of cadmium is not of significance.

A cooking dixie, which had been subjected to considerable heat over a camp fire, was examined to determine the nature of the soft metal lining which had melted and flowed. The alloy was essentially lead, tin and antimony.

FORENSIC EXAMINATIONS

Forensic samples with an essentially mineral character were dealt with by this Division, as follows.

Dirt on trousers and shirt from a man charged with rape was compared with that on a pillow case and the victim's bikinis. The major component was found to be iron dust, originating from his place of employment and was identified in the victim's belongings.

In another alleged rape case three sand exhibits were examined and conclusively shown to be dissimilar.

Soils from the scene of a murder at Halls Creek were found by optical methods to be comparable with soil taken from the body of the deceased.

Dirt from a windowsill at a suspected break and entry point in the city was found to be consistent with dirt swabbed from the suspect's body, but had extra paint flakes due to its manner of collection.

Sands from the scene of a bag-snatch robbery at Karrinyup were compared with sands from a site in Huntriss Road, and with material vacuumed from the floors of two cars used by the suspects. Grain size analysis proved to be inconclusive, but mineralogy showed significant correlations of feldspar and organic content, between the Karrinyup sand and the sand from the first car, said to have been used for the getaway.

An exhibit from Busselton consisted of rock fragments from the base of a large vase alleged to have been stolen. A critical point was whether the rocks were local or from Eastern Australia. The rocks were of two kinds; fossiliferous limestone and laterite, both common in the local region but foreign to large areas near the population centres in the Eastern States.

A sample of a broken cement asbestos sheet from a damaged fence and a sample of grey material from a suspect's car were submitted for comparison. The material from the car was shown by optical and XRD examination to be composed of calcite $CaCO_3$ and alite Ca_3SiO_5 (a major ingredient of cement), bonded together with chrysotile and amosite (white asbestos minerals). The asbestos from the fence was composed of the same materials and had a similar appearance, implying a correlation.

MINERAL IDENTIFICATIONS

Where sufficient information could be given, mineral identifications were made for the public on the basis of visual inspection, and only those entailing some doubt were registered for examination in the laboratory. Samples from this source again accounted for approximately half of the determinations made.

Of the samples submitted by the public a high proportion were from prospecting firms interested in both metalliferous and industrial minerals, and from the Aboriginal Lands Trust acting on behalf of various communities.

A large group also arose from regional surveys by the Government Geologist, and consisted of minerals not recognised in normal petrographic work.

These included the colouring in the clay infill of coral from the Quobba sheet and also microfossils from the Bangemall Basin. Both occurrences were carbon. Material from vughs and vein quartz from 1 km north of Bunbury Well, Mooloo Downs contained a copper oxalate hydrate $CuC_2O_4 . x H_2O$ and the copper phosphate libethenite.

The regional survey of the Robinson Range sheet produced a sample containing graphite, rockbridgeite and apatite.

Other mineral occurrences recorded largely from material acquired by the Division by approaches to companies and individuals were:

- A stalactitic gibbsite on goethite and lithiophorite, donated from Wingellina.
- The nickel telluride melonite from Kambalda in larger masses than previously seen.
- Hisingerite donated from bore core at the Perseverance Nickel Mine near Agnew.
- Lavendulan and pharmacosiderite, recovered from the Transvaal gold mine dumps.
- Clinobisvanite (bismuth vanadate) from the Curlew Emerald Mine, Hillside, which is a further occurrence of a mineral recently described from Western Australia.
- Vauquelinite (lead, copper chromate-phosphate) found in baryte at Jimblebar.
- Akrochordite (magnesium, manganese, arsenate hydrate) which was identified by the British Museum of Natural History amongst samples from Milgun forwarded as part of a joint investigation.
- Sampleite (copper phosphate) donated from Brookton is the third world occurrence. A description is in press with the *Mineralogical Magazine.*
- The interesting secondary arsenates, arseniosiderite and conichalcite, found in a new locality at Southern Cross.
- The new mineral $(NH_4)_2Ca(HPO_4)_2\ H_2O$ which occurs with archerite and several other new minerals in small but mineralogically interesting guano deposits in the Nullarbor caves.
- Specimens of nickel minerals from Lionel, loaned from this Department's collection to CSIRO, have been the source of other new minerals.

New Mineral Occurrences

Listed below are localities from which the specific minerals were recorded at the Laboratories for the first time this year.

Greater detail of localities may be available on application depending on the source of the material.

Species identified for the first time in Western Australia are marked with an asterisk *.

The Divisions used are those of Simpson's "Minerals of Western Australia".

Kimberley

Nil

North West

Akrochordite*	Milgun
Apatite	Lionel
Brochantite	Jimblebar
Clinobisvanite	Hillside Station
Fluorite	Hillside Station
Gaspeite	Lionel
Leuchtenbergite*	Karratha
Millerite	Lionel
Pecoraite	Lionel
Prehnite	Paraburdoo
Reevesite	Lionel
Saponite	Lionel
Vauquelinite*	Jimblebar

Murchison

Aluminium strengite	Erong Station
Apatite	Robinson Range
Graphite	Robinson Range
Leucophosphite	Erong Station
Rockbridgeite	Robinson Range

South West

Beryl	Mulgine
Molybdenite	Wandering
Sampleite	Brookton
Spodumene	Greenbushes
Stibian microlite	Greenbushes
Varlamoffite	Greenbushes

Central

Arseniosiderite	Southern Cross
Conichalcite	Southern Cross
Garnierite 10Å	Siberia
Hisingerite	Perseverance Nickel Mine
Lavendulan	Southern Cross
Melonite	Kambalda
Pharmacosiderite	Southern Cross

Eucla

Aphthitalite	Petrogale Cave, Madura
Archerite*	Petrogale Cave, Madura
Archerite	Weebubbie Cave, Eucla
Biphosphammite	Weebubbie Cave, Eucla
Biphosphammite	Petrogale Cave, Madura
Brushite	Dingo Donga Cave, Madura
Brushite	Weebubbie Cave, Eucla
Guanine	Petrogale Cave, Madura
Loveringite*	Jimberlana
Monetite	Weebubbie Cave, Eucla
Newberyite	Petrogale Cave, Madura
Nitre	Weebubbie Cave, Eucla
Oxammite	Petrogale Cave, Madura
Stercorite	Petrogale Cave, Madura
Syngenite	Petrogale Cave, Madura
Syngenite	Dingo Donga Cave, Madura
Syngenite	Weebubbie Cave, Eucla
Weddellite	Petrogale Cave, Madura
Whitlockite	Dingo Donga Cave, Madura
$(NH_4)_2Ca(HPO_4)_2 H_2O$	Petrogale Cave, Madura

South East

Cryptomelane	Waraan area, Warburton
Gibbsite	Wingellina
Lithiophorite	Wingellina
Prehnite	Snake Well area, Warburton

MINERAL COLLECTIONS

The collections maintained by the Division are the Simpson Collection of 4 989 entries and the Mineral Division Collection now numbering 6 066 specimens. In 1977 one hundred and sixty-eight specimens were added representing localities in Western Australia. A further 31 specimens from overseas and 26 from Eastern State localities were added in donated suites. In an effort to improve coverage of Western Australian localities, firms operating in the field have been requested to provide samples of significant occurrences. The response so far has been slow but this source of material is expected to be an important part of future build up.

The role of the collection as a record of W.A. minerals is supported by its function of providing authenticated material for scientific investigation, both within these Laboratories and in outside institutions. For this purpose a number of specimens have been loaned this year.

A preliminary print-out of a computerised index having recall by species, locality and a modified international grid reference area, has been made and verification of the data is in progress. Logging of data from other collections in the State is in hand.

BUILDING MATERIALS

Accent on building materials this year moved away from popping plaster. One such occurrence was recorded from a building which although completed, had not been occupied for a period of 18 months. The walls were apparently satisfactory during this time but when the building was opened for use and air conditioning was operative numerous small popouts appeared on walls painted with non-gloss paint. Examination of the popout cores showed them to have the previously observed components of calcite and portlandite, $Ca(OH)_2$. No unhydrated lime was present, indicating that these particular pops would not grow further.

A more frequent problem this year was the "drumming" of plaster which indicates the non-adhesion, and thus parting of cement render of float coat applied to brickwork.

Examination and sampling of sites was done for the Parliamentary Commissioner for Administrative Investigations, for the Bureau of Consumer Affairs and for the P.W.D. This type of failure of plaster was assessed from the point of view of original materials, proportions of mix and technique of plastering. In most cases failure was attributed to faulty technique although cases were found of extremely weak mix, and of the use of fine aggregate which did not comply with the recommendations of Australian Standard CA 27-1959.

In summary, failure of plaster by drumming can be attributed to one or a combination of the following:

(1) Mixes weaker than those specified by CA 27-1959, i.e. 1 volume of binder to 3-4 volumes of sand, are considered to be a poor basis for a top coat.

(2) The use of "fat" or loamy sands as aggregate does not conform with CA 27-1959. Good practice in the past has been to include lime putty in the mix to achieve workability. This has the additional advantage that shrinkage of the setting cement is controlled. Other techniques of achieving workability include use of various additives, such as air entraining agents, or reliance on the presence of fine material in the sand aggregate. With these techniques workability is obtained without control of shrinkage.

(3) Other elements of technique which can cause failure are:
   (a) Lack of prewetting of brickwork.
   (b) Too fast drying.
   (c) Excessive water in the mix.
   (d) Over trowelling.
   (e) Failure to provide sufficient keying to brickwork.

Other problems with building materials included the investigation of the cause of premature setting of a cement slurry designed to plug a drill hole. The slurry was carted by road to the drill site.

Soils were also examined for potential use in lime stabilised bricks.

ORES AND MINERALS

Clay

Soils associated with work on dam foundations and those involved in Geological Survey mapping projects were again the source of the majority of samples.

The characteristics of interest, relative to dam sites, were the size ranges in relation to bearing strength and the abundance of clay species such as montmorillonoids and vermiculite which are liable to cause failure.

Particle sizing and semi-quantitative clay determinations were carried out on 23 soils from dam sites in the Pilbara region and 22 soils from the Wungong and N. Dandalup sites. Semi-quantitative determinations only were done on five standard clays to be used for engineering testing.

Geological Survey mapping samples included semi-quantitative identification of 11 soils from the Carnarvon basin duricrust study, 4 clay stones from Ajana and 2 soils from Dampier/Roebourne.

Seven samples were submitted by the P.W.D. for identification of clay minerals associated with the Frankland and Salmon Gums tank sites. An expanding soil from the Frankland site was found to contain montmorillonoids.

Two soils from sewer trenches in Redcliffe contained kaolin, illite and montmorillonoids.

Clay suspensions from the Mirrabooka shallow well, and water entering the Wanneroo treatment plant contained halloysite and kaolin respectively.

Six clay suspensions from farm dams were identified as kaolin or montmorillonite type, to assist in turbidity studies aimed at providing visual protection of fish population from birds.

Samples from industrial sources included the identification of clay minerals from a milling company and a montmorillonoid clay that was inhibiting the dispersion of 'slime' at a mineral separation plant.

A trend towards using mineralogical identifications as an adjunct to soil chemistry, resulted in semi-quantitative clay mineral determinations on 26 Agriculture Department soils from Weaber Plains, Kununurra. All soils were composed of montmorillonoids with minor amounts of kaolin and mica.

Gold

The number of submissions for gold assay was reduced again this year. Only five samples umpiring on State Battery assays, were tested.

Almost 90 percent of assays were for the public and included a large proportion with uneconomic values.

The following are the more significant localities with gold in grams per tonne; Black Hills south of Bulong 21.9; Bullabulling 66; Halls Creek 152; Jerramungup 16; 10; Nullagine 8.9; 19.6; Tobias' Find Mt. Gibson area 14.4; 68.9; 9.1.

An interesting feature of gold occurrences this year was the number of nuggets which have been viewed, having been found by use of metal detectors. Nuggets in sizes attractive to specimen collectors attain a value approximately twice that of the contained gold. An estimation of contained gold has been made by calculation from gravity.

Assistance was given to a private experimenter attempting a novel extraction of gold.

Limestones and Lime Sands

Limestone samples from Wanneroo were examined in connection with the processing of a mineral claim application.

A group of lime sands from Boranup was examined for an economic assessment of the deposit.

Other limestones from the Pinjarra and Collie sheets were examined to delineate areas of usable grade including road building and industrial use. These samples were in connection with a study of System 6 resources.

A high quality limestone from a locality on the Halls Creek-Fitzroy Crossing road was examined for local use in lime production or agriculture.

Analyses including trace metals were made of calcretes and associated rocks in connection with the Millstream water storage investigation.

Tantalum-Tin

These samples consisted of a sampling to assess the economic potential of a stream bed system at Pilgangoora, for which an application for mining assistance had been made.

METALS AND ALLOYS

Samples were received from a number of sources, in addition to those queried as a health hazard.

A sample of metallic copper stated to occur in a mass on the sea bed had the characteristics of blister copper and is considered to be of artificial origin probably from a wreck.

Lead telephone cable sheathing was examined to determine the nature and cause of corrosion. The products identified were consistent with attack by water of high alkalinity caused by contact with freshly laid cement.

The thickness of various layers of electroplating on copper tubing for hospital use was compared with Australian Standard recommendations.

A sample of silver brazing alloy was analysed for its alloying metals as part of a co-operative testing programme conducted by the National Association of Testing Authorities.

A series of anodes of aluminium alloy exceeding 70 kg each, were received for examination, for conformation with a specified composition designed to provide cathodic protection of steel pipe in sea water. The anodes analysed conform to specifications except for minor variations in iron and mercury content.

White powder associated with metal wire forming part of the cargo of a State ship was examined to determine whether it was the cause of corrosion of the wire. It was shown to be a corrosion product rather than the agent of corrosion. Sea water as the agent of corrosion was eliminated.

PYROMETRY

Facilities for calibration of mercury in glass thermometers were maintained during the year as a service to Industry.

Calibrations were made for several private firms, but the largest group was for the Road Transport Authority for use with Breathalyzer instruments.

MISCELLANEOUS EXAMINATIONS

A build up of material on the sliding face of a railway coupling which depended on friction for its operation, was shown to be hematite dust compressed to resemble micaceous hematite.

Unusual materials for analysis were experimental products such as sludges, mattes and residues from projects at the Murdoch University Mineral Chemistry Research unit. There was a need to establish the crystal form of the elements present.

A white, apparently crystalline substance found on the walls of a heater compartment of a deaerating plant were shown to be a wax probably derived by sublimation of plasticiser from cables in the compartment.

A large mass of material from a remote locality and closely resembling common opal was found to be artificial plastic material.

A readily conducting deposit which was associated with misfiring of an internal combustion engine was shown to have a high content of lead and iron.

The crystal form of shells both modern and fossil, from an archeological site, was examined to determine whether leaching and recrystallisation had effected the original structure of the fossils.

INVESTIGATIONS

Investigations relative to improving methods of analysis have largely been associated with Standards Association of Australia work on iron ores. The analyses examined have included hygroscopic moisture, metallic iron, total iron by a mercury-free method, sodium and potassium by atomic absorption and arsenic.

Establishment of Standards

Over the last 10 years there has been a considerable firming of international approach to standard analytical methods and to the procedures for establishing standard analysed samples.

This has been necessary for evaluation of a mass of data collected in environmental studies and also in geochemical work. The need for standardisation in commerce has long been evident but methods tended to be accepted methods rather than methods which had been checked internationally for precision and accuracy.

Working groups exist within the International Standards Organisation (I.S.O.) to do this testing, both on wet chemical methods and lately in attempts to establish instrumental techniques such as X-ray fluorescence, as standard. These Laboratories have contributed by test-work to assess many variations of methods, by technical comment and by committee representation with the Standards Association of Australia (SAA) committee dealing with the analysis of iron ores particularly, but also with bauxites. A commitment has been entered into regarding the preparation and certification of proposed Australian Standard analysed iron ores.

Statistical analysis of results from checking precision of X-ray fluorescence measurements has pointed out the need to check the vagaries of individual instruments with regard to response in various sampling positions as well as more obvious sources of variation such as mode of preparation of sample discs.

A contribution to standardisation was also made through a Tasmanian Department of Environment study of methods used for determining heavy metals in estuarine sediments.

Other chemical methods investigated include: An exchange resin estimation of uranium in the sub-parts per million ranges. A uranium method using 4(2-pyridylazo) resorcinol (PAR) instead of bromo-padap, which was found to be unreliable in supply and quality. An hydrolysis method for fluorine determination. A new assembly for determination of carbon dioxide.

Mineralogical Investigations

During 1977 an arrangement was made with the National Parks Authority for minerals research to be carried out in the National Parks of W.A. The general objective was to gain more precise knowledge of the minerals in the Parks than is at present available in publications and also to carry out research in specific areas of mineralogical interest.

In an initial field trip, collections were made from Precambrian gneisses in the vicinty of Cape Leeuwin, Kilcarnup, Ellensbrook and Bunker Bay and several caves were visited in search of paleosols (fossil soil horizons).

Two paleosols in vertical superposition were noted along 300 metres of coastal limestone cliffs about 2.5 km north-north-west of Cape Leeuwin. Heavy mineral concentrations in the limestone in Strong's Cave were collected from a former strand line of the Pleistocene glacial epoch, and the tufa deposit at Meekadarrabee waterfall was examined.

The paleosol occurrence is significant in that these are well developed soil profiles, having limestone caprocks with pinnacles and solution pipes, indicating that at least two substantial time gaps intervened during the deposition of the Coastal Limestone sequence. Previous published accounts of the Coastal Limestone had stated that any time gaps were short and of no significance.

An investigation into iron ore genesis which was commenced earlier, was planned to compare individual microbands in cores from adjacent drill holes, one in high grade iron ore and the other in unmineralised banded iron formation. The available drill core was not sufficiently complete to allow correlation of specific microbands at equivalent stratigraphic levels, and the project was abandoned.

To provide experience which will support future forensic work a series of sands from different positions in a beach profile were examined for size grading and accessory minerals.

COMPUTING ACTIVITIES

The main concentration of effort has been with programs relating to X-ray spectrometry. Systems are operative for dust analysis, silicate analysis, trace element analysis and X-ray fluorescence file management, comprising on-line data logging, calculations and report generation. These have evolved during the year to give greater ease of operation of the system and to provide for computer controlled, fully automatic operation of the spectrometer.

Assistance has been given with computing for other Divisions of the Laboratories and also for the following Branches of the Mines Department, Geological Survey of W.A., Surveys and Mapping and the State Mining Engineer. This work has involved both program development and transfer of programs from external sources onto the Government Chemical Laboratories' system.

Mineral Division staff also shared responsibility for the day to day operation of the computer system. This work included advice and assistance to users of the computer system, weekly copying of programs and data on to 'backup' magnetic storage, and correction to and maintenance of operating systems programs.

A preliminary version of the index of the combined Mineral Division-Simpson Collection was produced at the Western Australian Regional Computing Centre. This work cannot be carried out on the GCL system due to the very large amounts of data involved. A final version of the index will be produced when the preliminary version has been fully validated.

EQUIPMENT

A logic controller has been received for the existing X-ray fluorescence spectrometer, but has yet to be installed. This unit will allow a series of 10 samples to be analysed for more than thirty elements without manual intervention.

The increased capacity of the instrument will make greater demands on staff both in preparation of samples and in conventional analyses of elements beyond the capacity of X-ray fluorescence.

Maintenance service has been controlled by laboratory officers, and down-time of the system during 1977, including X-ray spectrometer and computer, has been very short.

PUBLICATIONS

Papers published during the year are as follows:

"Properties of Western Australian Concrete Aggregates with Particular Reference to Their Potential Alkali Reactivity". G. H. Payne. Report of Investigations No. 13 Government Chemical Laboratories.

"The Dravite Crystal Bonanza of Yinnietharra, Western Australia". P. J. Bridge, J. L. Daniels, M. W. Pryce. Mineralogical Record 8, 109-110.

"Archerite $(K,NH_4)H_2PO_4$, a new mineral from Madura, Western Australia". P. J. Bridge. Mineral Mag. 41, 33-35.

D. BURNS,
Chief Mineral Division.

TOXICOLOGY AND DRUG DIVISION.

Despite intensive efforts to restrict the inflow of samples by screening the necessity for analysis of certain samples, there was an overall increase of 3.3 percent in the number of samples received during 1977. This slight increase in sample numbers, however, does not reflect the large increase in the work handled by the Division. Whilst there was a decrease in the animal toxicology work and in the blood and urine alcohol analyses there has been a 21 percent increase in the physical and chemical examinations carried out in connection with criminal investigation. This work which is non-routine and highly labour-intensive has increased because of greater awareness by the Police Department in our capacity to assist them in their criminal investigations. It is an unfortunate fact in the present climate of staff economies but one which must be accepted that this type of work is not only time consuming in the laboratory but also leads to the spending of many valuable man-hours giving expert evidence in the Courts.

The result of shortage of staff has meant that not only has much research and development work had to be sacrificed thus bringing about a delay in the introduction of new techniques and developments into the daily operations of the Division, but also sufficient time cannot be devoted to each particular case. The ultimate result of this can lead only to a decline in the quality and the quantity of scientific assistance which can be given to the Police and in turn to the consequent lessening of their effectiveness in coping with their criminal investigations.

Of the 3966 samples received in 1977 over 97 percent were of a forensic nature including the samples received in connection with doping control in sport.

The source and type of samples received are shown in Table 9.

HUMAN TOXICOLOGY

Over a thousand exhibits were received from 321 cases of sudden death which were the subject of police investigation. Of the 321 cases, 196 were submitted for examination for drugs and/or poisons.

In 52 cases no drug or poison was detected however two cases in this category are of note. In one case, involving paraquat, the person died several days after ingesting the poison and although no paraquat was detected in post mortem exhibits, the presence of paraquat was detected in a plasma sample taken several days prior to death. At that time the person was undergoing dialysis treatment. In the other case examination of syringes and other paraphenalia accompanying post mortem exhibits assisted the pathologist in discovering a death resulting from an insulin overdose. This was subsequently confirmed by analysis of the tissues at the State Health Laboratories using radioimmunoassay.

TABLE 9
TOXICOLOGY AND DRUG DIVISION

	Agriculture Department	Australian Narcotics Bureau	Departmental	Greyhound Racing Control Board	Public Pay	Public Health Department	Police Department	Road Traffic Authority	Western Australian Trotting Association	Other	Total
AUTO PARTS	....	....	116	....	....	....	....	....	....	....	116
BAITS	2	....	....	....	5	1	6	....	....	....	14
BLOOD AND URINE ALCOHOL—											
Sobriety	....	....	....	....	....	....	....	925	....	....	925
Traffic deaths	....	....	....	....	....	....	14	362	....	....	376
Various	....	....	....	....	....	....	....	9	....	....	9
CRIMINAL INVESTIGATION	....	20	19	....	....	....	244	....	....	....	283
DOPING CONTROL IN SPORT—											
Greyhounds	....	....	....	153	....	....	....	....	....	....	153
Horses	....	....	35	....	....	....	....	....	414	....	449
DRUGS	....	....	14	4	1	1	463	1	....	....	484
MARITIME POLLUTION	....	....	....	....	....	....	23	....	....	....	23
TOXICOLOGY—											
Animal	30	....	....	....	12	....	9	....	....	....	51
Human	....	....	....	....	....	....	1 036	....	....	....	1 036
VARIOUS	3	....	12	....	8	14	....	3	4	3	47
TOTAL	35	20	196	157	26	16	1 795	1 300	418	3	3 966

In the 141 cases in which a drug or poison was detected, alcohol occurred in 14 cases, alcohol plus a drug or poison in 48 cases and a drug or poison alone in a further 79 cases. In 86 cases a single drug or poison was detected and in 41 cases two or more drugs and/or poisons were present.

In addition to the above, blood and/or urine was submitted in 125 cases which required only an alcohol determination. In these cases the cause of death had in general been determined e.g., industrial accident, shooting, hanging, drowning etc. Alcohol was detected in 66 cases and in 47 of those cases the blood alcohol level was in excess of 0.08 percent. In two cases extremely high blood alcohol levels were recorded, these being alcoholics who were found dead, with 0.539 and 0.518 percent, respectively.

The risk which some people will take after they have consumed a considerable amount of alcohol is demonstrated by a 60 year old man who was refused entry to the lounge of a Perth hotel. He tried to enter the premises from the roof of an adjoining building on to a tree in the courtyard. In doing so he fell from a height of 45 feet. His blood alcohol level was 0.297 percent.

In 22 cases where the cause of death was given as drowning 9 had alcohol levels in excess of 0.150 percent. Again it seems necessary to stress the dangers of mixing alcohol consumption with swimming or boating.

Details of drug and poison cases are listed in Table 10.

TABLE 10
DRUG AND POISON CASES

Drug or Poison	Positive Identifications
Carbon Monoxide	36
Propoxyphene	15
Paracetamol	12
Phenytoin	10
Diazepam	9
Phenobarbitone	9
Amylobarbitone	8
Pentobarbitone	8
Methadone	8
Amitriptyline	7
Methaqualone	5
Salicylates	4
Morphine	3
Arsenic	3
Diphenhydramine	3
Doxepin	3
Various*	35

* Acetone, butobarbitone, carbamazepine, chlorbutol, chlorpromazine, cyanide, cyproheptadine, desipramine, dextromoramide, dibenzepin, dieldrin, ephedrine, ethylfenthion, fenfluramine, fluoride, fluphenazine, freon, glutethimide, imipramine, metoclopramide, nitrazepam, normethadone, nortriptyline, orphenadrine, paraquat, phenformin, phenol, phorate, probenecid, quinalbarbitone, quinine, thioridazine, toluene, trichlorethanol, trimipramine.

With reference to Table 10, in a number of cases the presence of one or more drugs was established. In certain cases the concentrations of the drugs present in the organs were such that their toxicological significances were uncertain.

In 1977 there was an increase, when compared to past years, both in drug types detected and in the number of positive identifications. The increase is possibly due in part to an increase in the community's use of drugs and in part to the normal year to year variations in drug associated deaths. However a portion of the increase in detections is undoubtedly due to the greater operating efficiency of the Division. This improvement has been brought about by the increasing experience of the personnel within the Division, by access to a computer managed data handling system based on chromatographic and spectrophotometric parameters devised and instituted within the Division and the continuing improvement and updating of analytical methods and drug screening procedures. During the year improved screening procedures for benzodiazepines, tricyclic antidepressants and phenothiazines were investigated and a number of new methods of analyses were tried and instituted in those cases where improvement was evident.

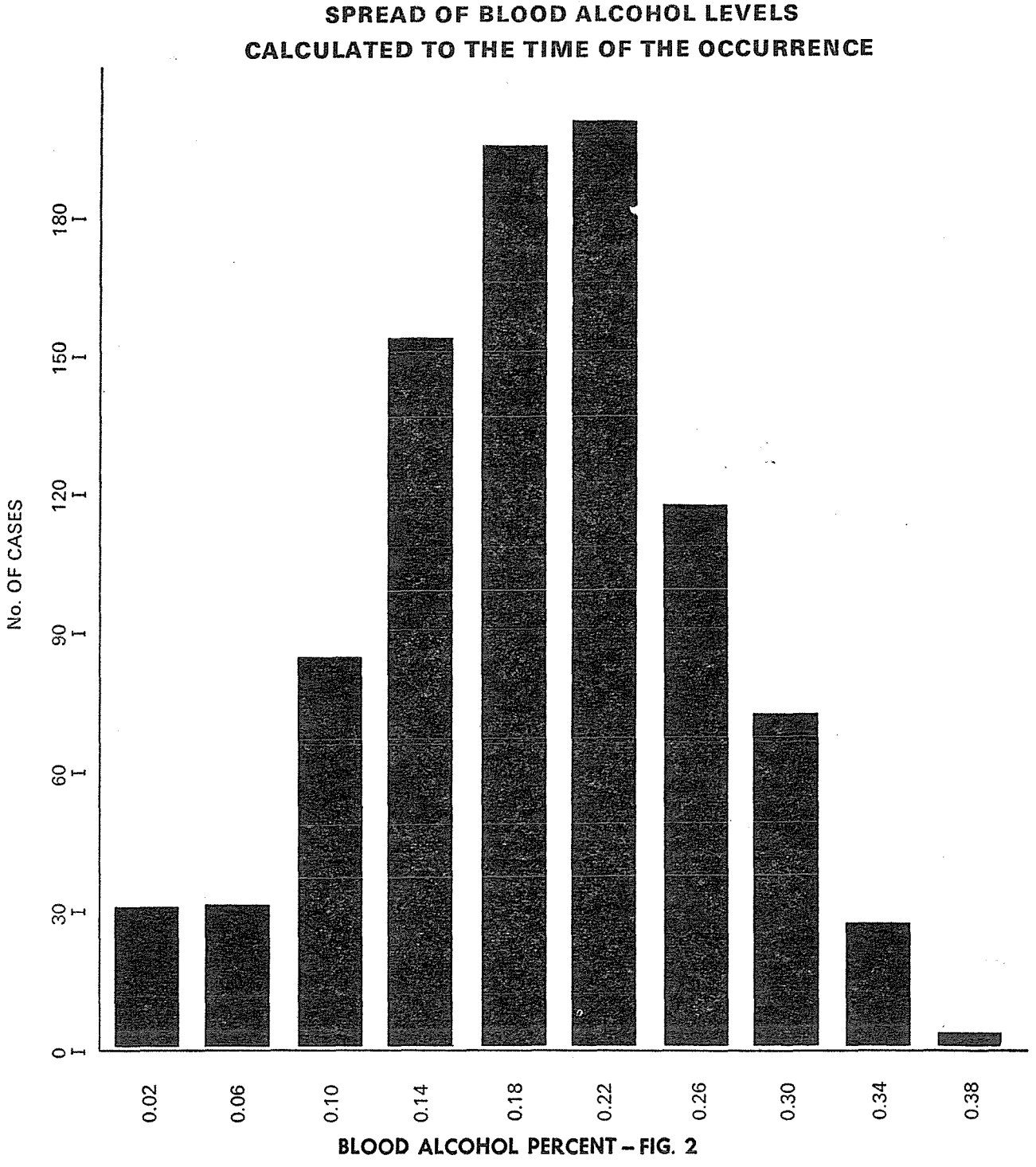
As in past years carbon monoxide and barbiturate cases constituted the largest percentages of positive identifications, 19 and 15 per cent, respectively. Of note is the continuing decline, as a percentage of positive identifications, in the proportion of barbiturate cases, from 29 percent in 1974 to 15 percent in the current year.

Of note and concern has been the continuing high frequency of propoxyphene and paracetomol associated deaths (noted in the 1976 report) and the large increase (240 per cent) in the number of deaths associated with the abuse of narcotic analgesics, principally methadone and heroin. This trend, which has been noted in other States, appears to be closely related to the increase in the availability of methadone and heroin and the resulting increase in abuse of these drugs.

In each case involving methadone and heroin, death was the result of an accidental overdose, and it is this fact which makes for particular concern. That the risks associated with the abuse of these drugs are well publicised is beyond question, however possibly more attention should be given to informing the population at risk, of the high and unpredictable toxicity of these drugs, with particular attention being directed to methadone.

ANIMAL TOXICOLOGY

There was a considerable decrease in the number of samples submitted under this heading in 1977. This was brought about by the reluctance of the Police Department to involve themselves in cases of animal poisoning. Additionally we have been able to convince the Department of Agriculture of the need to exercise more constraint on the submission of their samples, confining themselves to cases where something definite may be achieved by an analysis.



The co-operation of the Department of Agriculture in this regard brought about a drop of 75 percent from the previous year in the number of samples submitted.

Fifty animal post-mortem exhibits were received mainly taken from dogs. Of these there were 14 positive strychnine and three positive methaldehyde cases. All positive cases were in connection with canine poisoning. Of the 17 positive cases 14 were submitted by the Department of Agriculture.

In addition to the above there were three cases of positive strychnine baits out of fourteen samples submitted, and fluoroacetate was detected in a sample of oats submitted for analysis.

BLOOD ALCOHOLS (TRAFFIC ACT)

Blood samples are taken under the Road Traffic Act, 1974, from persons who choose to submit a blood sample in preference to or in addition to a Breathalyser test.

The histogram Fig. 2 shows the frequency of the levels of alcohol in the blood (calculated to the time of the offence) on samples received. The results show that 68 percent had a blood alcohol level greater than 0.15 percent and 92 percent had a level in excess of 0.08 percent. A disturbing factor emerging from the statistics is that there were about 100 persons with blood alcohol levels above 0.26 percent. The number of persons who submitted themselves for Breathalyser samples in 1977 was 5 504. On the basis that there was a similar spread in the blood alcohol levels it means that over 600 persons with blood alcohol levels in excess of 0.26 per cent were apprehended. These persons must belong to the category of "problem drinkers" and it is somewhat alarming to learn that so many of these people remain as a hazard on the roads.

A disturbing feature in connection with the back calculation to the time of the offence, required under the Road Traffic Act, and one which has resulted in a number of

acquittals, is the number of cases where the accused has stated that he has consumed alcohol after the time of the alleged offence. The situation often occurs when an accident has taken place and the accused leaves the scene of the accident. By the time he is apprehended by the Police he is able to state that he has had, for example, a few nips of brandy to steady himself down. Where the blood alcohol level is only slightly greater than 0.08 or 0.15 percent, their cases are being dismissed because those few drinks would have been sufficient to lift the blood alcohol level above the level at which prosecution can take place.

In some other States it is an offence to consume alcohol after an accident and before reporting to the Police, thus eliminating a loophole which is currently being exploited here.

Table 11 shows the frequency of the amounts by which the blood levels calculated to the times of offence varied from the actual blood alcohol level found on analysis.

TABLE 11
LAST DRINK CALCULATION

Calculation (percentage range)	No. of times
—0·040 to —0·031	33
—0·030 to —0·021	178
—0·020 to —0·011	315
—0·010 to —0·001	166
0·000 to 0·009	69
0·010 to 0·019	76
0·020 to 0·029	51
0·030 to 0·039	17
0·040 to 0·049	8
0·050 to 0·059	3
0·060 to 0·069	2

The following points also arise from the calculations:

75 percent of the cases resulted in lower blood alcohol levels.

23 cases (2.5 percent) resulted in blood alcohol levels being lowered from greater than 0.08 percent to less than 0.08 percent.

70 cases (7.6 percent) resulted in blood alcohol levels being lowered from greater than 0.15 percent to less than 0.15 percent.

5 cases (0.5 percent) resulted in blood alcohol levels being raised from less than 0.08 percent to greater than 0.08 percent.

18 cases (2.0 percent) resulted in blood alcohol levels being raised from less than 0.15 percent to greater than 0.15 percent.

An increase in 4.2 to 7.6 percent from 1976 to 1977 in the number of cases where the blood alcohol level fell from greater to less than 0.15 percent is probably due to a greater awareness by the public of the effect of the back calculation.

BLOOD ALCOHOL (TRAFFIC DEATHS)

Blood and urine samples (and sometimes other exhibits) are generally submitted for alcohol determinations in cases of fatal road accidents. In 1977, 376 such exhibits were received mainly from the Road Traffic Authority.

The distribution of alcohol in the blood of drivers, passengers, pedestrians, motor cycle riders and push cycle riders is shown in Table 12. The figures apply to post-mortem samples received at the Laboratories.

Table 12 shows that 33 percent of motor vehicle drivers had blood alcohol levels of 0.15 percent or more and the corresponding figures for passengers, pedestrians and motor-cycle riders were 21, 49 and 29 percent respectively.

Blood alcohol levels of 0.08 percent or more were found in 47 percent of drivers, 36 percent of passengers, 54 percent of pedestrians and 41 percent of motor cycle riders.

TABLE 12
TRAFFIC DEATHS—BLOOD ALCOHOL LEVELS

Alcohol percent.	Motor Vehicle Drivers	Passengers	Pedestrians	Motor Cycle Riders	Push Cycle Riders
negative	38	36	11	8	5
less than 0·050	5	3	4	1	....
0·050–0·079	1	1	1	1	....
0·080–0·099	1	4	1	1	...
0·100–0·149	11	6	1	1	....
0·150–0·199	6	2	2	2	....
0·200–0·249	11	6	8	....	....
0·250–0·299	6	3	3	1	....
more than 0·299	4	2	4	2	....
	83	63	35	17	5

No alcohol was detected in the blood of 46 percent of drivers, 57 per cent of passengers, 31 percent of pedestrians and 47 percent of motor cycle drivers. The bloods of the five push cyclists who were killed in traffic accidents also contained no alcohol.

BREATHALYZER

The Chief of the Division liases with the Breathalyzer Section of Traffic Patrol and assists in the assessment of any new breath instruments which are marketed. He also examines new Breathalyzer operators and re-tests other operators on an annual basis for the Director whose province it is to certify the competency of Breathalyzer operators.

Currently under test is a new breath testing instrument known as the Intoxilyzer which makes use of the principle of measurement of alcohol absorption at a fixed wave-length in the infra-red range of the spectrum. Although at an early stage of assessment the instrument appears to have advantages over the Breathalyzer, some of these being speed (a test takes less than two minutes), the instrument produces a printed record of the test and the machine is tamper-proof. Further assessment of the Intoxilyzer is proceeding.

DRUGS

One hundred and six cases comprising 464 exhibits were received for the identification of drugs or suspected drugs. The exhibits were submitted mainly from the CIB Drug Squad.

Table 13 shows a breakdown of the drugs identified.

TABLE 13
DRUGS—POLICE DRUG SQUAD

Type of Drug	No. of positive identifications
Cannabis	66
Heroin	11
Mandrax	5
Methadone	4
Opium	3
LSD	2
Amphetamine	1
Morphine	1
Non narcotic drugs	8
Total	101

Cannabis, cannabis products and implements associated with the use of the drug were the most frequently encountered type submitted. The 66 identifications which were made, represent a decrease from both 1975 and 1976. The decrease was in part due to the use by the Police of a botanist, whenever possible, to identify the drug and in part to the policy of the police which is to concentrate on eliminating drug traffickers and sources of supply. An indication of this policy is reflected in the size of seizures submitted for identification, twelve cases being in excess of 500 grams, with the largest seizure submitted being 33 kilograms of cannabis in the form of 'Budda' or 'Thai' sticks.

The number of identifications of narcotic drugs remained at the same level as 1976. Of particular interest were a number of cases which occurred early in the year involving opium. In each case the drug was in the form of a concentrated solution of prepared opium in small glass vials.

The opium had been smuggled into Australia impregnated in cotton rugs. Once in the country the opium was extracted from the rugs. The opium concentrate was then sold as an approximately 50 per cent solution in small 4 ml glass vials.

The twenty-two rugs seized were submitted for examination and each was found to contain opium, the quantity in the rugs varying between 115 and 186 grams. The magnitude of the seizure can be grasped from the fact that in the twenty-two rugs there was approximately 3 kg of opium and at 2 grams per vial this totals 1 500 saleable amounts.

The average opium content of the rugs was 17 percent, however in three rugs which had allegedly had the opium extracted the content was 6 percent, a figure which supported the allegation.

Two cases involving suspected hallucinogens were submitted and on each occasion LSD was identified in tablets. In these cases, which were not related, the LSD was in the form of grey-black microdots and in each case the LSD content was relatively high.

The appearance of bromodimethoxyamphetamine which occurred in the latter months of 1976, now seems to have been an isolated occurrence, there having been no seizures of this drug submitted in 1977.

During the year the Division participated in a collaborative study in the quantitation of a number of illicit drugs. The study, which was initiated at the Third Annual Conference of Illicit Drug Analysts held in Sydney in November, 1975, was designed to evaluate the accuracy, precision and reproducibility of methods of analysis for illicit drugs adopted for the conference. The study put particular emphasis on heroin, and the results of the study indicated that all laboratories which participated had a high degree of competence.

There has been an increasing acceptance by the courts and defence counsel of 'Certificates of Analysis' as evidence in drug cases, and this has led to some diminution in the number of court appearances by analysts. It is hoped that this trend continues, thus eliminating many court appearances, which in the past have proved to be little more than a waste of both the court's and the analyst's time.

CRIMINAL INVESTIGATION

Chemical and physical examination of exhibits collected from crime and accident scenes is undertaken in this Division for the Police Department. The number of cases received in 1977 was approximately 20 percent greater than that in the previous year, reflecting an increase in awareness of the value of scientific evidence. Table 14 summarises the cases investigated.

TABLE 14
CRIMINAL CASES

Type of Exhibit	No of Cases
Flammable liquids (including fire debris)	42
Paint and paint flakes	21
Explosive and incendiary residues	5
Clothing	3
Food and drink	3
Gunshot Residues	3
Miscellaneous	20

The categories of offence or event relating to the exhibits received are tabulated below:

TABLE 15
CRIMINAL CASES

Category	No. of Cases
Arson	36
Hit-run traffic	14
Stealing	11
Explosions	7
Sex offences	4
Wilful damage	4
Shootings	3
Murder	2
Unclassified	14

Suspicious fires continue to account for a large proportion of the cases received and the exhibits examined included containers, debris and remains of incendiary devices found at the fire scene. In 37 percent of the cases examined some incendiary or fire accelerant was detected. This does not suggest that none were involved in the remainder since the intense heat and fire-fighting activities may destroy evidence of volatile accelerants.

The activity which has shown the greatest increase has been the examination of paint flakes. The majority of these cases have been related to hit-run traffic offences with a lesser number related to breaking, entering and stealing. In the majority of hit-run cases, this work has involved comparison of paint flakes left at the scene or on a victim's clothing with paint from a suspect vehicle. This work has been greatly assisted by experience gained from the examination of a large number of paint chips from a wide variety of makes and models of vehicles supplied by Traffic Patrol.

The paint specimens examined in breaking and entering cases usually involve comparisons of paint on the suspect's tools with that on the building or goods. A typical example involved the breaking and entering of a restaurant in Kalgoorlie. Subsequent analysis of particles of paint found on a jemmy bar owned by the suspect confirmed that the paint was identical to that from the woodwork at the break in point.

Numerous incidents involving explosions and explosives have been investigated during the year. These related to vandalism, suicide and safe breaking. During the year two very useful training exercises were held with the Police Communications Scientific Branch's bomb squad. The first of these dealt with improvised explosive and incendiary devices which could be assembled by anyone using easily obtainable ingredients. The second exercise involved high explosive and much valuable experience in bomb scene evaluation was gained.

The examination of clothing for gunshot residues is being carried out more frequently. The purpose of such an examination is to attempt to evaluate the range from which the weapon was fired. This enables judgement to be made as to whether the wound may have been self inflicted or not. It is expected that this work may increase as not all such cases have been routinely submitted.

Much of the work relating to criminal investigation involves examination of quite unusual exhibits. These included such items as rubber bands, dyes, inks, metals, crystals, plastics, adhesives, egg powder, electronic calculator parts and broken bottles. Such variety necessitates a wide range of analytical techniques and great care in the evalution of the significance of the results.

The scope for expansion of forensic work is great and projects are planned to provide experience which will increase our services to the Police. For example the examination of glasses, fibres and hairs are potentially of great value but are not yet frequently submitted. It is proposed to build up data on these topics and then to inform Police through detective training schools and the Scientific Branch of the value of such examinations. Increased work performed in these areas will inevitably lead to chemists spending more time in the Courts giving expert evidence and will result in the need for increased manpower and equipment.

MARITIME POLLUTION

Twenty-three samples of oil were received in connection with nine incidents of maritime pollution. These samples include oils both from the pollution incident and from possible offenders and were analysed to identify the sources of the oil spills.

CONFERENCES—PAPERS

Mr. A. Stenhouse, who was awarded a travel grant by the W.A. Branch of the Australian Forensic Science Society to attend the National Symposium on Forensic Sciences held in Melbourne, presented a paper entitled "Computers in a Forensic Laboratory".

V. J. McLINDEN,
Chief, Toxicology and Drug Division.

WATER DIVISION

GENERAL

Despite the excessive demands on the consultatory and analytical services, which were mainly due to three consecutive dry years of 1975, 76 and 77, the Division has been able to cope satisfactorily.

Although there were no staff increases during the year, one of the Administration laboratory technicians spent most of the year in the Division. Sample output was increased by about ten percent of that recorded for 1976 and has followed a consistent trend since 1969 where each successive year's output has exceeded the previous year's by similar margins. Due mainly to increased activity in environmental monitoring as well as samples from the Metropolitan Water Board and the Geological Survey of W.A., an increased number of components were analysed per sample. The increase was estimated as having achieved an increase in overall analytical efficiency, based on components analysed per staff member, of approximately thirty percent and was at least partly due to increased use of automated analytical equipment.

Late in 1977, official commitment was finally given to the Australian Water Resources Council Network Survey sampling and this has involved approval for

(a) new buildings to be commenced early in 1978;
(b) three additional staff to perform the additional analyses;
(c) two major items of equipment, which were a 4 channel autoanalyser and a double beam atomic absorption unit.

These increases in building, staff and equipment are in order to cope with the analysis of an increased number of samples, ranging from 1 000 samples for 12 components in 1978 to 4 000 samples for more than 20 components by 1980. The increased building area will relieve the congestion in the present building.

Two Reports of Investigation, No. 14 "Seasonal Variations in the Water of the Swan River" and No. 16 "Iron Stain Prevention", both by P. N. Jack, were issued during the year.

There was also increased involvement in committee representation for the year, the extra commitment being for the Technical Committee on Waste Disposal, the corrosion panel of the Building, Owners and Managers Association and for the licensing panel covering the Regulations of the Rights of Water and Irrigation Act.

Table 16 indicates the nature and source of samples received during the year and some of the more interesting aspects of the analyses and advice undertaken during the year include—

TABLE 16
WATER DIVISION

	Agriculture Department	Albany Port Authority	Cockburn Sound Study Group Conservation and Environment	Departmental	Fisheries and Wildlife Department	Geological Survey	Leschenault Inlet Management Authority	Main Roads Department	Metropolitan Water Board	Museum	Pay and Public	Peel Inlet Management Authority	Public Health Department	Public Works Department	Swan River Management Authority	Other	Total
Corrosion	....	....	....	1	....	....	....	....	....	....	....	....	....	4	....	....	5
Deposits	2	....	....	....	....	....	....	....	....	....	5	....	....	6	....	1	14
Effluents	....	15	122	2	....	....	....	....	....	....	15	....	2	21	76	....	253
Environmental Monitoring—																	
Albany Harbour	....	66	....	....	....	....	....	....	....	....	....	....	....	....	....	....	66
Leschenault Inlet	....	....	....	....	....	....	49	....	....	....	....	....	....	....	....	....	49
Peel Inlet and Harvey Estuary	....	....	....	....	....	....	....	....	....	....	....	88	....	....	....	....	88
Swan River	....	....	....	....	....	....	....	....	....	....	....	....	....	....	144	....	144
Investigations	....	....	....	....	....	....	....	....	....	....	1	....	1	2	....	....	4
Treatment Chemicals	....	....	....	....	....	....	....	....	14	....	....	....	....	1	....	....	15
Waters—																	
Fluoridated	....	....	....	....	....	....	....	....	736	....	....	....	....	745	....	....	1 481
General	50	....	22	9	75	558	....	51	1 475	21	630	....	167	1 931	50	16	5 055
Various	....	....	2	1	....	....	....	....	....	....	1	....	2	3	....	1	10
Total	52	81	146	13	75	558	49	51	2 225	21	652	88	172	2 713	270	18	7 184

PUBLIC WATER SUPPLIES

Hills Catchment Dams Salinity

Rainfall recorded at the Perth Weather Bureau for 1977 was 608 mm, being 69 percent of the annual average of 881 mm and was the third successive year where rainfall was significantly less than the average. Although other variables such as clearing of catchment area, percentage of rainfall as surface or subsurface runoff and deliberate bleed of dam water or natural overflow all have an effect on salinity of the dam water, a general trend for all Hills Catchment dams is for the salinity to be inversely proportional to the rainfall. A study of Table 17 which lists the average annual surface salinities of the major drinking water supply Hills reservoirs and annual recorded Perth rainfall, shows most of the dams close to or at their highest ever salinity values. These salinity values are tabulated back as far as 1960, beyond which salinity values were not regularly monitored at monthly or more frequent intervals. It will be noted that those reservoirs which are more saline were subject to greater fluctuations in salinity over the seventeen years, and this is not unexpected. Wellington had a 5 fold variation, Mundaring had a 3.5 fold, Canning had a 2 fold and Serpentine had a 1.5 fold. All dams had similar minimum salinities in 1964-65.

Manganese in Hills Catchment Dams

The low levels of water in the Hills Catchment dams has caused some unexpected results in relation to the quality of that water. Some of the older dams, which were considered to be beyond the stage where manganese could pose a problem are now recording significant levels of that element. These levels are adequate to cause slight but noticeable discoloration after the normal chlorination practice, due to the separation of the manganese in a colloidal hydrated oxide form. The colour of the affected dams, namely Canning, Serpentine and Wungong, which now have levels of manganese between 0.05 and 0.10 mg/l throughout the whole dam profile, is increased by 5 to 15 Hazen Units after chlorination. Fortunately this colour increase can be reduced to satisfactory levels to most consumers by judicious blending.

Perth Metropolitan Supply

Due to the poor runoff into the Hills Catchment dams, where levels are at their lowest recorded values, the underground water contribution to the reticulated supply has been maximised. Because of imposed water restrictions which have caused summer consumption to drop to below fifty percent of the normal, the underground supply contribution is major with the nett result that a more saline and harder water is being supplied to the majority of consumers.

TABLE 17
SALINITY OF HILLS CATCHMENT DAMS 1960–1977
Chloride, Cl*
mg/l

Year	Rainfall mm	Canning	Churchmans	Mundaring	North Dandalup	Serpentine	South Dandalup	Victoria	Wellington	Wungong
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

* The total dissolved solids for the above supplies approximates to Cl x 2·0.

The salinity in many cases has increased from 300 to 700 mg/l and the hardness from 30 to 100 mg/l. The effect of this on water treatment, water heating and cooling, and steam raising procedures has been profound and has caused increased involvement at both consultative and analytical level to rectify some of the problems encountered.

Perth Metropolitan Treatment Plants

Because the bores from the shallow aquifers servicing the three major treatment plants at Mirrabooka, Gwelup and Wanneroo are in areas close to metropolitan housing and industry these are being annually monitored for about 20 components and once every three years for about 30 components. The present bores servicing these treatment plants number about eighty and this number is expected to double within the next few years.

Of the upflow clarifier treatment plants, Gwelup is still continuing with its treatment of chlorination and coagulant aid (either sodium alginate or polyelectrolyte). Trials in 1977 showed Mirrabooka to give the improved performance with activated silica coagulant aid predicted by laboratory testing in 1976. Because of the precise controls required for activated silica, the present treatment of alum and sodium alginate will continue until there is a necessity for the plant output to double by the connection of additional bores predicted within the next several years. The Wanneroo clarifier will not be operational till January, 1978, and its chemical treatment will be similar to that of Mirrabooka. At present, selected bores with a total capacity of 30 Ml daily and with low levels of colour and organically bound iron are being treated, the treatment being oxidation with permanganate and chlorine, aeration and sand filtration. The designed capacity for the plant is 70 Ml daily, and this is intended to be at least doubled in the near future.

A recently developed type of treatment, namely CSIRO "Sirofloc" which utilises the magnetic properties of finely ground activated magnetite to effect colour removal appears to perform satisfactorily with coloured waters at Mirrabooka, Wanneroo and Jandakot. Although the quantity of chemicals used is similar to that associated with conventional upflow clarifiers, the main advantage of this method is a reduction in plant costs due to the rapid settling characteristics of the floc. These settling velocities are approximately an order of magnitude greater than with conventional treatment. Had this treatment been discovered earlier it probably would have replaced the existing upflow clarifier treatment at Mirrabooka and Wanneroo.

Fluoridated Water Supplies:

With the exception of Collie and Esperance all other towns with fluoridated water supplies have maintained mean levels during 1977 at the intended value. The levels at Collie and Esperance were 0.03 and 0.05 mg/l respectively below the minimum of the intended range. Means for the submitted samples for 1977 are listed below in Table 18.

Fluoridation of the town supplies at Derby and Broome should commence early in 1978 and Exmouth should follow soon after. Of the unfluoridated country town supplies which are either wholly or partly supplied by local bores, the natural fluoride levels of the blended bore supply is indicated in Table 19 if it exceeds 0.2 mg/l. All town supplies serviced by unfluoridated surface waters have natural fluoride levels of 0.2 mg/l or less. Many town supplies, although they can in emergency situations draw from local unfluoridated water, are connected to the fluoridated water from Mundaring or Wellington.

TABLE 18
FLUORIDATED WATERS

Supply	No. of samples	Fluoride, F mg/l mean	Fluoride, F mg/l intended
Perth Metropolitan	736	0·71	0·8±0·1
Mundaring/Goldfields	157	0·82	0·8±0·1
Wellington/Comprehensive	51	0·75	0·8±0·1
Albany	182	0·83	0·9±0·1
Collie	112	0·67	0·8±0·1
Esperance	98	0·75	0·9±0·1
Geraldton	54	0·76	0·8±0·1
Manjimup	73	0·83	0·9±0·1

Levels of fluoride between 0.3 and 0.5 would be 50 to 90 percent as effective as the optimum dose level which varies between 0.7 and 0.9 mg/l for most W.A. town supplies.

Levels of fluoride above 1.5 mg/l are not recommended for human consumption.

TABLE 19
NATURAL FLUORIDE LEVELS OF BORES SERVING COUNTRY TOWN SUPPLIES*

Fluoride range mg/l			
0·3 to 0·5	Bremer Bay	Jurien Bay	Seaburn
	Busselton	Kununurra	Watheroo
	Carnarvon	Menzies	Wiluna
	Coomberdale	Mt. Magnet	Wittenoom
	Derby	Nullagine	Yalgoo
	Exmouth	Port Hedland	
	Gascoyne Junction	Roebourne	
0·6 to 1·0	Cape Lambert	Meekatharra	Onslow
	Dampier	Mullewa	Port Samson
	Halls Creek	Nabawa	Sandstone
	Karratha	Northampton	Wickham
1·1 to 1·5	Marble Bar	Rottnest†	

* Town supplies with bores containing 0·2 mg/l or less not listed.
† Blended with surface water prior to use.

Nitrate Levels of Town Water Supplies

Levels of nitrate (as NO_3) in the major Hills Catchment dams are always less than 1 mg/l and this is also true for most country town supplies where they come from surface runoff storage. Nitrate at levels greater than 45 mg/l can cause infantile methaemoglobinaemia to infants less than 12 months old. A number of town supplies have levels of nitrate close to or exceeding the 45 mg/l limit. Table 20 lists all those supplies where present nitrate levels of the bore supplies exceed 2 mg/l. Inhabitants of those towns whose water supplies are above 45 mg/l are notified that an alternative supply such as rainwater should be used for infants less than 12 months of age. Some of the bores with unsatisfactory levels are blended with a surface supply to give a satisfactory level.

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TABLE 20
NATURAL NITRATE LEVELS FOR COUNTRY TOWN SUPPLY BORES*

Nitrate, NO_3 (range) mg/l	Town Supply		
2–5	Augusta	Gascoyne Junction	Miling
	Boddington	Greenhead	Mingenew
	Bremer Bay	Halls Creek	Port Hedland
	Carnarvon	Jurien Bay	Roebourne
	Cervantes	Kalbarri	Wittenoom
	Coorow	Ledge Point	Yerecoin
6–10	Balingup	Dandaragan	Lancelin
	Calingiri	Exmouth	Port Samson
	Cape Lambert	Guilderton	Wickham
	Dampier	Karratha	Yuna
11–45	Bolgart	Marble Bar	Mullewa
	Broome	Mt. Magnet	Nabawa
	Esperance		
46–60	Leonora	Meekatharra	Rottnest†
80–100	Cue	Menzies†	Wiluna
	Laverton†	Sandstone	Yalgoo

* Supplies with less than 2 mg/l of Nitrate, NO_3 not recorded in Table.
† These bores blended with surface supplies to give satisfactory level.

Treated Country Town Supplies

There has been the usual number of tests for country town supplies associated with complaints relating to tastes and odours, and performances of treatment plants in relation to removal of iron or manganese or colour or turbidity. Also this year we have been involved in testing the chemical performance of the recently installed reverse osmosis plant at Denham. Pretreatment of the 4 500 mg/l total salts raw supply has included iron removal and acid addition for pH control to prevent calcium carbonate deposition. Based on design criteria no problems were expected with calcium sulphate, calcium fluoride or silica deposition and submitted samples from various stages of the treatment confirm that performance is as intended. Because of the costs involved in producing such a supply, Denham has a dual reticulated supply with restrictions on the use of the 200 mg/l total salts water. Although Rottnest also has a dual reticulation this is a "first" for the Public Works Department Country Water Supply.

ENVIRONMENTAL

Laporte Effluent Disposal

Staff have been involved in three separate areas of activity in relation to disposal of Laporte effluent.

1. Sand Dune Disposal at the Surface into No. 7 Lagoon:—As outlined in the 1976 annual report a grid pattern of shallow and deep bores in the vicinity of and to the north of No. 7 disposal lagoon have been sampled at regular intervals to assess the effects of the spread of the effluent and to predict the extent of chemical reactions involved. This involved analysis and interpretation of 60 samples for 10 components at 2 monthly intervals.

This lagoon which had previously been used for disposal of approximately 18 months effluent production has again been used for a continuous period of 11 months. After 6 months to August, 1977, it was obvious from the results that significant proportions of the iron (greater than 100 mg/1) were gaining access to the ocean. At the end of 10 months it was obvious that a major portion of the iron was gaining access to the ocean (greater than 5 000 mg/1). It was gaining access to the ocean via both the shallow and deep aquifers but the analytical results indicated that the spread of the partly neutralised effluent was greater in the shallow aquifer. The shallow aquifer also allowed access of high iron levels to the ocean before the deep aquifer.

At no point in either aquifer was the iron value greater than 100 mg/1 within 200 metres of the estuary.

Soil samples were taken prior to recommencement of this discharge in February, 1977, but subsequent samples after completion of the disposal intended for January, 1978, have not been taken. A study of the water and soil analyses is intended for 1978 and will enable confirmation or otherwise of the likelihood of an achievable efficiency of iron deposition within the dune or aquifer system of 95 percent, as indicated in the 1976 annual report.

2. Direct Injection of the Effluent into the Deep Limestone Aquifer:—This deep limestone aquifer with its relatively high neutralising capacity generally underlies the entire sand dune disposal area at depths approximately 5 metres below the water table and its thickness is of the order of 5 to 10 metres. It has rarely been utilised in past practice of surface disposal, although some neutralisation of it has occurred in the No. 7 disposal lagoon area. In this trial, which lasted for two separate periods totalling 37 days, the quantity disposed was 10 percent of the total plant output over that period and the injection bore was sited 260 metres from the sea shore.

One of the observation bores, sited 24 metres away, had iron levels in the deep aquifer of 600 mg/1 at the completion of the trial but all other observation bores in either the shallow or deep aquifers had iron level below 100 mg/1, the level generally considered to be fully neutralised. Based on horizontal distances traversed by the 3.7 days of total effluent output it could be calculated that it would take approximately one year before levels of iron in excess of 100 mg/1 gained access to the dune boundary with the ocean.

3. Disposal via Pipeline Directly Into the Ocean:—The involvement in this exercise has been at the committee stage and the examinations, tests and analyses have been mainly undertaken by other Government Departments or private consultants and analysts. This has involved a small scale study of discharging approximately 10 percent of the total factory output into the ocean, via a 50 mm pipeline, at a site approximately 6 km from the shore, for a period commencing in February, 1976, and continuing to the end of 1977. Studies have included predicted boundaries for toxic and avoidance effects for marine life, boundaries for toxic and growth reduction for marine plants, boundaries for permanent iron stain of bottom sands, and boundaries for various suspended iron levels in the ocean.

Waste Disposal

Regular monitoring of bores at the Hertha Road and Jones Street refuse disposal sites continued during 1977 with similar results to those previously reported. The leachate trial at Hertha Road also gave similar results to those given in the 1976 annual report. Three bores used for irrigation at the Graylands Hospital site in the vicinity of the Brockway Refuse Disposal have very high levels of inorganic nitrogen, presumably derived from the refuse disposal. One of the bores, No. 10, was sited within 100 metres of a recently filled area while two others, Nos. 3 and 4, were sited several hundred metres apart but at distances of approximately 500 metres from the nearest refuse disposal activity. The nitrate nitrogen level of bore No. 10 averaged 24 mg/1, while those from the other two bores had average levels below 10 mg/1, the maximum level allowed in water for human consumption. Bores 10, 3 and 4 had average ammonia nitrogen levels of 120, 21 and 22 mg/1 respectively. While desirable for irrigation purposes these levels are well above those desirable for a drinking water and present a potential nitrate nitrogen problem because of possible bacterial oxidation.

Monitoring of bores from 9 sites at the waste liquid disposal site at Gnangara commenced in 1977. Each site has separate bores penetrating to various selected depths. The contaminants were found to be similar to those from refuse disposal sites, and in this particular case were generally lower in concentration. The lower concentration is probably dependant on water movement in the aquifer as well as the load at the site. Inorganic nitrogen as ammonia was the greatest contaminant.

Cockburn Sound Study

The Division has been involved in this study, particularly in relation to assessing the levels of nutrients and heavy metals being discharged into the sound. Sampling procedures, storage methods and analytical methods have been fully investigated. Interlaboratory comparisons involving private Laboratories, the Metropolitan Water Board and the W.A. Institute of Technology have been undertaken to ensure that analytical methods were optimum. Techniques involving anodic stripping voltametry, X-ray fluorescence and acid digestion with solvent extraction were generally in acceptable agreement.

Intensive surveys of each of the industries discharging into the Sound are taken out over 7 days at 3 monthly intervals. Bulk weekly samples are analysed as well as selected bulk daily samples where variation in component level is suspected. These surveys were carried out in March, July and October 1977. Because of staff shortage these Laboratories were able to accept only the nutrient samples for regular intensive surveys, the involvement with the heavy metals being only at the initial stage to optimise sampling, storage and analytical techniques.

Based on an assessed capacity of Cockburn Sound of 10^9 m^3 and a maximum residence time of the water within the Sound of 1 month, the average heavy metal content of the water in the Sound would be approximately one order of magnitude lower than that considered harmful to marine animals. In the case of nutrients the calculated effect is more severe, with average nitrogen and phosphorus levels being of the same order as those generally considered limiting for eutrophic conditions in fresh water. The precipitation or adsorption of heavy metals and phosphates at various sites makes the situation much more complicated than the simplified calculation expressed above and only seawater and seabed survey analyses can confidently predict overall effects.

Princess Royal Harbour, Albany, Monitoring

At the request of the Albany Port Authority, the harbour and surrounds were inspected with a view to carrying out a monitoring survey to assess the main source of pollutants into the harbour and their effects on the water within it. Samples from 22 selected sites within the harbour and from six outfalls of industrial effluent or natural drainage have been collected and analysed at 3 monthly intervals commencing in April 77. Calculated and measured effects of the effluents are being studied and present indications are that the contamination of the harbour is only visual and is limited to within several hundred metres of the shoreline in the vicinity of the outfalls. The contamination by nutrients is considered to be approximately one order of magnitude lower than those levels generally considered limiting for eutrophic conditions in fresh water, which are 0.3 mg/l of inorganic nitrogen and 0.02 mg/l of phosphorus. Apart from the aesthetic effect, the complaint of nuisance odours including hydrogen sulphide on the western shore is considered to be natural and due to decomposing organic matter of predominantly seaweed origin in a section of the harbour where water movement is minimal.

Estuarine and River Monitoring Surveys

Several modifications have been made during the year to the frequency and testing procedures for analyses undertaken for the Swan River, Peel Inlet and Leschenault Inlet Management Authorities. The "albuminoid plus ammonia" determination has been replaced by the "ammonia" determination, so that results can be interpreted more in line with the limiting values for inorganic nitrogen for eutrophic conditions. Physical measurements of colour and turbidity are also now included. For Peel Inlet, Chlorophyll A levels are now also undertaken because the system is reputedly the closest to eutrophic conditions. Leschenault Inlet is now being analysed at the same frequency as the others, whereas it was formerly monitored at only six monthly intervals.

An unexpected source of gross contamination to the Swan River was discovered during the year. The emptying of the ornamental ponds at the South Perth Zoo, which were accommodating far more than the intended bird population, involved the discharge of approximately 2 000 m^3 with a BOD equivalent to that of raw sewage. This practice is now discontinued but may have been responsible for past reports of heavy fish mortality in the vicinity of Perth waters. Of greater concern than the BOD was the high faecal coliform loading.

"Rights in Water and Irrigation Act," Regulations

Applications for disposal licences will involve these Laboratories in analyses of a wide variety of effluents, under new regulations of the Act. The full impact of this may not be felt for several years. These regulations should in due course prevent all undesirable contamination of surface and ground waters which do not come under the jurisdiction of statutory controls. These licences and regulations will make it difficult for irresponsible discharge of undesirable industrial wastes.

There are at least three known areas in the metropolitan area where the underground aquifer has gross contamination, which may be partly natural but which is expected to show some past or present contribution by industry. The boundaries of these contaminated areas have not been clearly defined. Apart from unsuitability of the water for irrigational uses these waters pose a serious corrosion problem to building foundations and other underground structures.

1. An area in Ashfield/Bassendean extending both sides of the railway line has an extremely acidic shallow aquifer water with pH values in the range 2-3. The sulphate ion, which in normal shallow underground water contributes less than 10 per cent of the anions is a major component of the water and in many instances exceeds 1 000 mg/l. Iron, aluminium, copper and zinc are also present at variable levels, the iron and aluminium being sometimes present at values exceeding 100 mg/l while those of copper and zinc are only of the order of 1 mg/l. This may be natural but is suspected of being due to the dumping of raw or burnt pyrites by a nearby fertiliser works during the 1940s when elemental sulphur was in short supply.

2. An area in the vicinity of the Hamilton Interchange, Mitchell Freeway, also has low pH values in the shallow aquifer water in the range 3 to 4, sulphate as the major anion and iron levels in excess of 100 mg/l. The most affected sites were at the Main Roads Department bores at Oxford Street and Aberdeen Street. No present industry is suspected.

3. The water in the shallow aquifer in an area near Division Street and Welshpool Road, Welshpool, is apparently contaminated by effluent discharge from a "hot dip" galvanising industry. The pH values at sites several hundred metres away from the effluent discharge were close to 4, with sulphate, iron, zinc and inorganic nitrogen levels of 1 100 to 1 500, 300 to 500, 50 to 100 and 8 to 12 mg/l respectively.

CORROSION

Concrete Walls of Major Dams

Regular samples of leachate water from the dam walls at Canning and Victoria have been analysed at monthly intervals since construction. Concern was expressed by the Metropolitan Water Board as to whether the sampling technique and analysis were optimum for assessing the condition of the wall. There was also some concern about the apparent attack on the upstream face of the walls. The result of the inspection allayed any fears about the extent of the attack in the walls. Some sections at Victoria were obviously eroded but this was considered to be due to a weak concrete mix that could not withstand the erosive effects of the waves. Potential aggressive components of the stored water, namely free carbon dioxide and sulphate, were at the very low levels of 2 to 4 and 5 to 10 mg/l respectively. The quantity of cement leached from the wall is a function of the calcium content and the rate of flow of the leachate. While concrete is still "green" and comparatively unleached the sodium content of the leachate as the hydroxide is significant. For the leachate from Canning dam the calcium and sodium levels were 110 and 280 mg/l respectively. Corrected for chloride, sulphate and carbonate levels, these levels implied that the ratio of sodium hydroxide to calcium hydroxide was approximately 2 to 1 and indicated a comparatively green unleached state. All future samples from these sources will be analysed for sodium and calcium as well as for the hydroxide, carbonate, chloride and sulphate.

Asbestos Cement Pipes

Failure of asbestos cement pipes at Wittenoom was considered to be mainly due to hydraulic factors, but sections of the pipeline had been attacked by the naturally aggressive raw water supply containing 80 mg/l of free carbon dioxide. The wall thickness of the 100 mm I.D. pipe was 13 mm and the inner surface of this had been partially depleted of calcium to a depth of approximately 5 mm. The pipe was still considered to have some service life remaining.

Hot Water Storage Cylinders

The corrosion problems associated with low pressure hot water storage containers fabricated from copper have apparently been rectified by reducing hot water temperature or installation of sacrificial aluminium anodes. Copper is not suitable for mains pressure operation, for which there is an increasing demand and the two alternatives in W.A., namely stainless steel or glass lined steel with a magnesium sacrificial anode have not been proven. Apart from the necessity for precise fabricating controls, austenitic stainless steel is prone to stress chloride attack at temperatures close to that of boiling water while glass lined vessels, in addition to potential corrosive attack on the glass at temperatures approaching that of boiling water, can only perform satisfactorily while the magnesium sacrificial anode remains in circuit. Investigations in this glass lined area have shown the necessity to have an anode of adequate weight to last the five year period before replacement is normally recommended. All such storage containers should be designed for replacement anodes, the replacement period for which will be a function of the salinity and for waters with total salts

less than 1 000 mg/l should be at 5 year intervals or sooner. The life of the anode will depend on the number of "holidays" in the glass coating. Present tests on one manufacturer's vessels have indicated that in the metropolitan area, calculated anode lives, based on 1.5 kg anode in a 240 litre container with a 180 litre daily usage life would in 95 percent of cases be more than 5 years. Inlet "cold" and outlet "hot" magnesium levels in 30 installations were used to obtain these results.

MISCELLANEOUS

Queen Elizabeth II Medical Centre Cooling Water

A variety of optional treatments to remove iron from an onsite bore water and make the water suitable for an evaporative cooling system were investigated. The iron level of 7 mg/l was marginally high for an aeration/filtration technique which satisfactorily removed the iron. Chlorination gave a slow settling floc which was not adequate for a satisfactory upflow clarifier performance, but either aeration or chlorination supported by sodium alginate coagulant aid addition gave satisfactory settling rates of several metres per hour. After iron removal it was still necessary to dose acid or soften or dealkalise the water to allow an acceptable fivefold concentration of the raw water prior to discharging as a bleed. The quantity of water to be treated was 50 to 100 m^3/hour and although chemical treatment costs would be more than competitive with the costs of the reticulated metropolitan supply, its main purpose was to reduce the load on the already overtaxed metropolitan supply.

Swimming Pools

Because of the restrictions in the Perth reticulated supply, pool owners were not allowed to top up or replace pool water other than by holding a hose. Many owners wanted to use their own bore water for swimming pools. Apart from possible relatively high breakpoint chlorine demands which could be accommodated by normal chlorination and testing procedures, other potential nuisances included the presence of either iron or manganese. Apart from producing staining on the pool wall, iron and manganese can cause very noticeable turbidity and or colour in the pool water after chlorination, the respective levels considered maximum being 0.5 and 0.1 mg/l respectively. Unless the topping up water is added at the pool exit on its way to the filter, at a rate equivalent to one fifth that of the recirculating water, which must in turn contain at least 1 mg/l of free chlorine, the water would be best treated in an external container for iron and manganese removal.

Black Stain in Glass Fibre Reinforced Plastic Pools

A sample of liquid from an "intact" blister between the gel coat and the fibre reinforced backing, from a swimming pool in Darwin was analysed. See Table 21 for analytical results.

TABLE 21
ANALYSIS OF G.R.P. BLISTER CONTENT

pH	3·8	
Conductivity (mS/m at 25°C)	31 600	
	mg/l	me/l
Residue on evaporation (105°C)	140 000	
Organic carbon	55 000	
Acidity to pH 8·2 (as hydrogen phthalate)	68 000	410
Calcium, Ca	10 600	529
Cobalt, Co	520	17·6
Copper, Cu	5	0·2
Iron, Fe	170	6·1
Magnesium, Mg	380	31·3
Manganese, Mn	11	0·4
Potassium, K	90	2·3
Sodium, Na	170	7·4

The analysis is compatible with the breakdown of the polyester resin of the gel coat by hydrolysis to form the acid and glycol. In this instance the phthalate radical was identified and the glycol was presumed to be either propylene, ethylene or neopentyl. The phthalic acid formed would attack the calcium carbonate filler and presumably also the cobalt napthenate promoter.

The strength of the solution in the blister, approximately 0.5 molar would be capable of exerting an osmotic pressure against the fresh water of the pool of approximately 10 atmospheres.

The results of the analysis confirm what has already been postulated in Report of Investigation No. 8 of 1974; namely that osmotic pressure is responsible for blister formation between the gel coat and fibre glass backing and the cobalt content is significantly greater than the several mg/l required to form a black discoloration of hydrated cobaltic oxide when in contact with several mg/l of chlorine.

Black Stains in Concrete Pools

There are an increasing number of complaints of black stains in concrete swimming pools and to date there has not been a detailed examination of all the likely causes. Use of copper as an algaecide frequently causes absorption of copper on the surface of the pool wall, generally displaying a pale green or blue-green discoloration. Subsequent heavy chlorination, particularly if added in the solid form as calcium hypochlorite, appears to be at least partly responsible for the black discoloration in some situations. The mechanism of this reaction on the concrete is not understood but is expected to be similar to that previously reported in the 1976 Annual Report where the chlorine appears to convert the blue-green hydroxide precipitate to the black hydrated cupric oxide. This problem is often associated with the use of silver/copper anodes where the level of copper in the pool water is as high as several mg/l.

Iron Staining Prevention

Previously reported work on the iron silica complex was mainly in association with the ferric complex for water supply treatment, but because of the apparent stability of the ferrous complex in some laboratory tests an investigation of its ability to prevent staining in normal overhead irrigational practices was undertaken. The complexing agent was sodium silicate and provided it was added to the water prior to aeration, at a level in excess of 7 mg/l of silica, SiO_2 to each mg/l of iron, Fe, it was capable of maintaining the iron in apparent solution for periods in excess of one month. A field test carried out for 34 days involving 14 waterings with a water containing 3.5 mg/l of iron was unfortunately dosed at an inadequate level for a significant portion of the time. The resultant staining on asbestos cement sheeting was less than 20 percent of the staining which occurred with no treatment. These and other tests indicated that with correct dosing of the sodium silicate a 95 percent or higher reduction in staining could be achieved.

The ability of this complexing agent to stabilise a variety of iron bearing waters was established in the laboratory. Although it was capable of stabilising iron levels in excess of 15 mg/l at ambient temperature the following considerations have made it inadvisable to use for waters above this level.

1. The dosage of between 110 and 150 mg/l of silica is of the same order as the solubility of silica in water.
2. The increased residual sodium carbonate due to such an addition could be of the order of 1 me/l which could have an adverse effect on the irrigated soil.
3. The costs of dosing 150 mg/l (based on current price of $11 for 23 litres containing 10 kg of silica) is approximately 15 cents per m^3 which is 68 cents per 1 000 gallons.

Proposed methods of injection vary from utilising suction of the pump inlet with an adjustable orifice or selected small diameter tubing, which a handyman could install for approximately $10, to a sophisticated positive injection pressure pump co-ordinated into the existing electrical system by a contractor for which the cost would be between $500 to $1 000.

Sodium Tripolyphosphate as a Sealant for Marron Dams

Advice was sought on the use of this chemical (S.T.P.P.) to seal several dams for which there was an inadequate supply of water to maintain the desired level due to leakage. The leakage was of the order of 100 mm daily. The dosage rate intended was 50 mg/l. Possible adverse effects investigated were potential toxicity to marron, likely changes in pH values, changes in sodium adsorption ratio and effects of the increased nutrient levels. There was little data on toxicity effects and a short term pilot trial with 10 fold the intended dose was suggested. The pH and sodium adsorption ratios were not altered outside the acceptable range of values for marron but as a significant portion of the S.T.P.P. hydrolysed almost immediately the phosphate status of the water would have been increased dramatically from its existing value of 0.02 mg/l or less.

Despite the drawbacks the treatment was used. It successfully reduced leakage to 30 mm daily although some slight detrimental effects on health of marron were obvious to the client but not quantitatively recorded.

N. PLATELL,
Chief, Water Division.

DIVISION VIII

Annual Report of the Chief Inspector of Explosives, for the Year 1977

In accordance with Section 10 of the Explosives and Dangerous Goods Act 1961–1974, 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, 1977.

LEGISLATION

Following a resolution by statutory explosives authorities of all States to effect the United Nations classification for explosives throughout Australia, proposed amendments to the Second Schedule of The Act and concomitant regulations were prepared and discussed with representative bodies throughout the industry. After concurrence by all parties the amendments were approved by the Hon. Minister and forwarded to Parliamentary Draftsmen for early action. To date no amendments to the Act or regulations have been effected.

AUTHORISATION OF EXPLOSIVES

Five additions were made to the List of Authorised Explosives for Western Australia, these were:

Class 3: Nitro Compound: Division 2
"Tovex" (zz)
Class 6: Ammunition: Division 1
"Nonel Tube" (x)
Class 6: Ammunition: Division 2
"Flexicord" (zz)
"IDL Detonating Fuse" (zz)
Class 6: Ammunition: Division 3
"Nonel System" (z)

A further five explosives were approved for use under the newly authorised generic name "Tovex", these were "Tovex" 100, 200, 500, 800 and PX. Restricted approval was given for use of the binary explosive systems "Astrolite", "Triex" and "Quadrex". Approval was given for changes in the authorised composition of the explosives "A3 Monobel" and "Ajax".

MANUFACTURE OF EXPLOSIVES

The manufacture of nitrate based explosives at licensed plants throughout the State continued at an increased level of 14·7 per cent over the previous year and involved a total quantity of 69 630 tonnes. A breakdown of these explosives and comparison with the previous year is as follows:

	1976 (tonnes)	1977 (tonnes)
ANFO	56 099	62 945
Al/ANFO	3 011	5 059
Water Gel	1 605	1 626
Total	60 715	69 630

These explosives are manufactured mainly from a special grade of ammonium nitrate in prilled form, the bulk of which is conveyed approximately 1 000 kilometres, by rail two-thirds of the way and the remainder by road, to minesites in the north west of the State where it is stored in accordance with safety requirements prescribed by the Explosives Branch. The largest bulk store for explosives grade ammonium nitrate is currently at Mt. Newman where 1 100 tonnes can be safely maintained in 11 concrete bins each of 100 tonnes capacity. During the year under review, specifications were approved for the construction at Mt. Tom Price of an ammonium nitrate store of 2 600 tonnes consisting of 13 bins each of 200 tonnes capacity which will provide ample reserves of ammonium nitrate to ensure continuity of the Company's blasting programmes.

Approval was given throughout the year for the manufacture and cartridging of six tonnes of a detonator sensitive nitrate explosive at Woodman Point manufacturing plant. These cartridges were used in experimental blasting at a minesite on the Collie coalfields. Evaluation of this explosive is still under consideration by the manufacturer.

IMPORT AND USAGE OF EXPLOSIVES

Though both nitroglycerine type and water gel type cartridged explosives were imported in greater quantity than in the previous year, the use of water gel explosives increased more rapidly. Water gel explosives have been shown to be safer to handle and give relief from the physiological effects associated with nitroglycerine explosives, they are, however, still in the development stage and problems with loss of sensitivity have yet to be resolved. Notwithstanding those problems there has been an increase of some 83 per cent in the use of cartridged water gel explosives throughout the year, whilst the use of nitroglycerine explosives showed an increase of less than nine per cent.

The quantities of other imported explosives showed an increase similar to that for nitroglycerine explosives. Additionally, however, some 1 150 tonnes of explosives grade ammonium nitrate were imported to maintain the manufacture of blasting agents at north-western minesites. The following summary shows the quantity of explosives, both imported and manufactured locally, which was used throughout Western Australa during the year:

TOTAL CONSUMPTION OF EXPLOSIVES FOR 1977

	Tonnes
Propelling Powders (including gunpowders, fireworks, etc.)	3·2
Bulk Nitrate Explosives	69 630·0
Cartridged Nitrate Explosives	307·1
Nitroglycerine Based Explosives	1 100·5
Primers and Boosters	61·0
Detonating Cords (4·54 x 10^6 metres)	101·3
Primary Initiators (2·72 x 10^6 units)	116·0
Total	71 319·1

The usage of explosives in Western Australia continued to be satisfactorily controlled under the permit system and though this system has caused inconvenience to some Local Authorities throughout the year it is acknowledged by most that competent supervision must be provided for the use of explosives and especially so in those places where the safety of persons other than the shotfirer may be affected.

Similarly, the use of fireworks was strictly controlled by the issue of permits. In all, 38 permits were issued for the public display of fireworks and with the exception of one, where a boy was burned when he pocketed a misfired charge, all were conducted without any untoward incident.

EXPLOSIVE RESERVES

Woodman Point Explosives Reserve

A high standard of security continued at the Woodman Point storage depot with no illegal entry or theft of explosives. Though improvements have been made in the extension of security fences on the northern boundary to the ocean edge, the main contributing factor to security was the presence of an alert and diligent watching staff within the reserve.

The jetty facilities, though used only twice throughout the year for transhipment of explosives to and from vessels, continue to be maintained in safe working order by the Fremantle

Port Authority as an isolated berth for the handling of explosives and dangerous goods. Though shipping movements were minimal, the explosives depot remains essential to the storage and distribution of explosives throughout the Metropolitan and south western parts of the State. Some 4 000 tonnes of explosives and 350 tonnes of prilled ammonium nitrate were dispatched by road from the Woodman Point area. The compulsory check of vehicles leaving the reserve with explosives (more than 3 500 vehicles) no doubt contributed to the safe conveyance of explosives during 1977.

The Study Group formed to investigate and recommend alternative sites for relocation of the Woodman Point Reserve facilities submitted its recommendations to the Hon. Minister for Mines. The Hon. Minister, in company with the Under Secretary for Mines and the Chief Inspector of Explosives, visited the proposed areas and gave his approval for further detailed investigation of the site which appeared most suitable. Should this site finally be approved then it is anticipated that a transfer of the entire Woodman Point storage and manufacturing activities may take place within three years from the date of approval.

Kalgoorlie Explosives Reserve

The manufacturing facilities at the Kalgoorlie Reserve together with the slurry explosives plant at Windarra were examined in detail by one of the Branch's scientific officers. This inspection confirmed the satisfactory reports received from the general inspectorate. The Kalgoorlie Reserve has experienced a high level of activity both in storage and manufacture throughout the year (with the production of nitrate explosives equalling that of the Woodman Point plant) and provides an essential service to the surrounding mining industry.

Further action was taken to ensure that the safety zone around the explosives reserve would not be encroached upon by applying for an injunction to prevent the construction of buildings on adjoining Miner's Homestead Leases and quarrying operations within eight hundred metres of the reserve boundaries. This action will permit the future construction of magazines of capacity up to 50 tonnes thereby ensuring that the reserve may be utilized to its maximum extent. The need for increased explosives storage was evidenced when approval had to be given to permit a 10 per cent overstocking of all magazines of less than 30 tonnes capacity—in all cases, however, the prescribed safety distance to protected works was more than totally maintained.

During 1977, a perimeter road system was constructed within the boundaries of the Kalgoorlie Reserve which now not only facilitates the movement of essential vehicles within the reserve but also, in conjunction with annual maintenance of firebreaks throughout the area, ensures the further safety of the reserve in the event of bushfire.

ANALYSIS AND TESTING

Samples of all explosives tested by the Branch for authorisation during 1977 were submitted to the Department's laboratories for analysis. It was found necessary to request the American manufacturer of the explosive "Tovex" to provide a suitable method for the determination of an organic sensitizer used in their explosive, however, confidential information provided on the manufacture of "Tovex" enabled authorisation to proceed without confirmatory analysis.

Other chemical analyses required throughout the year were for quarterly samples of locally produced ammonium nitrate all of which were found suitable for the manufacture of blasting agents. Additionally, samples of a Western Australian manufactured metal cannister were submitted to the Government Chemical Laboratories for evaluation of drop and pressure properties to see if the cannister could conform to the test methods of Australian Standard 1936:1976, required under the Flammable Liquids Regulations. Only after some modification of the containers and the completion of further tests by the Laboratories were the cannisters finally approved for the storage of flammable liquids.

Tests were conducted by the inspectorate to assess the fire hazard of several imported and locally manufactured fireworks which were intended for use in aerial displays during restricted burning periods of summer. Only those fireworks of a type assessed as being of minimal fire hazard were approved for use and it was found necessary to make alterations in the construction of the locally produced pieces before the required standard of safety was attained.

Specifications were reviewed and the Branch requirements updated in accordance with Australian Standard 1768:1975 for the lightning protection of high explosives magazines. An examination was made of the lightning arresting systems at several south western magazines located in areas of high thunderstorm activity and in all cases conductivity measurements indicated that a lightning strike could be safely dissipated to earth.

Two hundred photo-electric powered circuit testers were tested by the Branch scientific officers and all were approved for electrical firing on minesites. Additionally, four of the larger mining operations were visited within the Kalgoorlie area for the purpose of testing electrical firing equipment—all were found to use equipment which was in compliance with the prescribed safety requirements. New firing equipment specially designed for large scale blasting was examined and provisionally approved for a period of one year in order to allow experimental work in underground operations at Kalgoorlie to proceed. These instruments are currently under investigation by statutory authorities of other States where similar approvals for use have been granted.

Cartridged nitrate explosives manufactured at the Woodman Point plant were tested throughout the year for sensitivity prior to experimental use in coal mining at Collie. The results from these experiments indicate that a gap sensitivity of less than one cartridge diameter may be successfully used for drill hole blasting. As a consequence of these tests and of recommendations from the manufacturer of the cartridged explosives, future sensitivity tests based on the double cartridge method will require only propagation of detonation through two cartridges with no gap separation.

The routine heat 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 area. In all, the Abel Heat Test was conducted on 424 samples of NG explosives and 63 samples of safety fuse were tested for burning rates. One batch of safety fuse was rejected because of non-standard burning times.

EXPLOSIVES LICENCES AND PERMITS

Once again there was an increased number of licences issued for explosives but only of the order of five per cent over the previous year. It would appear that the public have become more aware of their responsibilities with regard to the use of explosives and this opinion is reinforced by the increased interest in training programmes for shotfirers conducted by the Branch.

During 1977, a total of nine training courses for shotfirers were conducted by the explosives inspectorate. Those courses were attended by 194 trainees—65 of whom were from three evening courses and the remainder, government employees, from six in-service training classes. At the end of all courses the trainees were examined and only twelve failed to obtain the Shotfirers Permit. Additionally throughout the year, 89 shotfiring candidates (66 in the Metropolitan Area and 23 in country areas) were examined and 83 were assessed as having the required knowledge to use explosives safely. The number of persons throughout the State holding a current Shotfirer's Permit now totals 963.

A comparison of the number of licences and permits issued for explosives during the past two years is shown below.

	1976	1977
Licence to Import	8	8
Licence to Manufacture Explosives	25	28
Licence to Manufacture a Blasting Agent	278	281
Licence to Store, Mode A	33	35
Licence to Store, Mode B	18	16
Magazine Licence, Type One (1 000 kg)	86	113
Magazine Licence, Type Two (5 000 kg)	44	45
Magazine Licence, Type Three (greater than 5 000 kg)	71	73
Licence to Sell Explosives	43	41
Licence to Convey Explosives	44	45
(5·4% Increase) Total Licences	650	685
Shotfirer's Permit	757	963
Permit to Conduct a Fireworks Display	35	38
Entry Permit for Explosives	34	37
(16·7% Increase) Total Licences and Permits	1 476	1 723

EXPLOSIVES STOLEN, CONFISCATED OR DESTROYED

An outstanding feature of the Explosives Inspectorate's activity throughout the year was their effort to ensure that the security of explosives continued at a high level. More than 400 inspections were made of the various modes of explosives usage and follow up checks were made in 140 instances on advice received of explosives sold from licensed dealers. In addition greater effort was made to visit remote locations where farmers required advice on the safe use and storage of explosives which they needed for such purposes as stump blasting, etc. This facet of the inspectorate's duties, though time consuming, was considered most worthwhile.

One disturbing incident which related to poor explosives security was the finding of several cartridges of gelignite in a metropolitan rubbish tip. The foolishness of such disposal cannot be over-emphasized and it is particularly remiss when it is known that the inspectorate will readily collect unwanted explosives and arrange their safe destruction free of charge. It is to be hoped that the persons likely to dispose of explosives in such an irresponsible manner would only be those who procured the explosives unlawfully.

Despite the provision of substantial security, seven instances of theft occurred from licensed premises throughout the State and a total of 91 kilograms of explosives and 2 600 detonators were stolen. After each incident the premises were again inspected to ensure compliance with the regulations and, where practicable, further measures were taken to improve security. It must be acknowledged, however, that the most stringent security, even to the extent where explosives storage becomes impracticable, will not withstand a determined lawbreaker. Several instances of theft were also reported from small gold mining leases throughout the year, in all involving approximately 12 kilograms of explosives and some 500 detonators. No further action could be taken on these incidents beyond the initial Police investigation.

A total of 1·1 tonnes of explosives and some 2 000 detonators were collected by the inspectorate from various locations throughout the State where the explosives were no longer required or were found to be deteriorated. In some instances these explosives were destroyed in an adjacent safe place but in the majority the explosives were taken to Woodman Point for controlled destruction. However, in one instance, where a part case of explosives found in the bush by Police at Wanneroo was considered too dangerous to attempt to remove (corroded detonators were scattered throughout exuding gelignite), the Explosives Inspector decided it would be safer to detonate the lot *in situ*. Unfortunately the resulting noise was heard over a wide area and caused complaints over radio and television.

Sixty-five obsolete marine distress signals, which were confiscated by officers of the Harbour and Light Department, were also disposed of at the Woodman Point depot.

DANGEROUS GOODS

Although flammable liquids currently remain the only dangerous goods (apart from explosives) to be regulated under the Explosives and Dangerous Goods Act, the need for statutory control over the other dangerous goods was evident throughout the year. The policy of restraint on Government spending inevitably meant the forfeiture of some public services and in this instance prevented the appointment of additional staff to enable the Branch to control other dangerous goods within Western Australia. Serious consideration has been and continues to be given to the practicality of gazetting regulations for the safe handling of dangerous goods without appointing additional inspectorate to enforce these regulations. Unfortunately, the effect of such action would inevitably be the reduction of safety standards which have been established for explosives and flammable liquids mainly through the sustained efforts of an already overworked inspectorate.

The Explosives Inspectorate, both general and professional, together made more than 6 000 inspections during the year to give advice on the safe storage of flammable liquids at licensed and non-licensed premises throughout the State. In all, 5 117 licences were issued for the storage of flammable liquids and 528 vehicles conveying flammable liquids in bulk were inspected and, in those instances of non-compliance, were given instructions to maintain the safety requirements of the regulations.

The standard of tank wagon conveyance for flammable liquids received a much needed fillip last year in the publishing of the Australian Standard code for tank vehicles, AS2016:1977, and in the agreement between statutory authorities for reciprocity of approvals for tanker vehicles constructed to that standard. This, however, demanded yet more time of the Branch scientific inspectorate for the examination of the various tank design specifications and for certification of the constructed product. Nevertheless, because the code AS2016 is acceptable to all States and because its requirements are comprehensive and specific, time will be saved in the long run. A total of 12 tanks constructed in Western Australia were certified throughout the year by the inspectorate as complying with AS2016 requirements for the conveyance of flammable liquids.

Four new approvals for road train conveyance of bulk fuel to remote areas of Western Australia were given last year, thereby permitting the conveyance of bulk flammable liquids on trailers in much greater quantity than is prescribed by the regulations. A pre-requisite for such approval is the vehicle's movement mainly through isolated areas of the State and the provision of additional safety features together with placarding as recommended by the Model Code for the Transport of Dangerous Goods by Road.

After an incident in New South Wales in which successful proceedings were taken against a petroleum company for marketing flammable liquids in unsafe packages, the company requested approval under the Flammable Liquids Regulations for its use of a locally manufactured metal cannister. Close liaison between the Explosives Inspectorate and officers of the Government Chemical Laboratories enabled approval to be given to a modified form of the container for use within Western Australia.

As described previously, dangerous goods other than explosives and flammable liquids continue to play an increasing role in the activities of the Branch. The Explosives Branch does not have sufficient staff to provide satisfactory control over hazardous substances other than those currently gazetted as dangerous goods. However, because of their expertise in this field, officers of the Explosives Inspectorate cognisant with requirements for the control of dangerous goods are frequently called upon to give advice in these matters which may affect public safety.

Good liaison with the Port Hedland Port Authority and a company involved with the road transport of two shipments of imported ammonium nitrate totalling 1 000 tonnes ensured that the transport and temporary storage of the material took place in a safe manner. During the year, advice was requested of the Branch and given for safety requirements in the location of a loading gantry to be used in the transfer of bulk ammonium nitrate from rail to road conveyance at Dalwallinu.

Fortunately, ammonium nitrate can be satisfactorily controlled as the ingredient of a blasting agent, however, the two other most common non-regulated hazardous substances dealt with by the Branch, liquefied petroleum gases and swimming pool chemicals, may be used with impunity in Western Australia. Advice given to Local Authorities and others on the safe handling of these chemicals is frequently found to be ignored. From this particular aspect, especially as queries concerning these dangerous goods occupy as much as 10 per cent of the scientific inspectorate's time, there would be merit in having controlling legislation even without the appointment of additional inspectorate for enforcement.

ACCIDENTS AND OUTRAGES

(a) *Explosives*

One death caused by the deliberate initiation of explosives by a shotfirer while in a depressed state of mind, was recorded during the year. Other accidents involving explosives were as follows:

(i) A student was injured at a shotfirers' training school when struck by flying material from a blast during practical work. Though the student was detained in hospital for two days he was able to attend classes the following week and give a personal warning of the need to take adequate cover during stump blasting.

(ii) A preliminary investigation was made of an accident which occurred when a detonator fired prematurely causing injury to the shotfirer. Fortunately no primer charge was involved and the injury was slight.

(iii) A boy was burned whilst playing with some fireworks residues he retained after a public display. Conditions of the accident were such that no blame was placed on the fireworks operator.

(iv) Considerable time was spent by both the Police and the Explosives Inspectorate in the investigation of two outrages at a country townsite where explosives were stolen and used to demolish the town courthouse and to destroy fuel storages at the local airfield. No person was injured in either of the two explosions.

(v) After an abortive attempt to break into a city bank vault by the use of gunpowder, a schoolboy was apprehended by the Police. Some 30 kilograms of various explosives and accessories, stolen from a licensed retailer of explosives, were ultimately recovered from the boy's possession.

(vi) Vandals were thought to have detonated an explosives charge against the front wall of the Waroona Police Station. No person was injured and the building was only slightly damaged. The matter was further investigated by the Police.

(vii) A complaint lodged by the manager of a mine resulted in proceedings being instituted against the driver and assistant of a licensed explosives vehicle for breaches of the Explosives Regulations while conveying explosives to the minesite magazine.

(b) *Flammable Liquids*

As in previous years, most accidents involved small quantities of flammable liquids and were caused mainly through the lack of thought rather than flagrant disregard for the regulations. One fatality and four persons injured were reported from accidents involving flammable liquids in storage or road transport throughout the year, viz:

(i) The cause of fire within a laboratory in which a man was fatally burned was investigated. A report of the incident was presented at the Coroner's hearing and various recommendations were made (all of which were acted upon by the Company concerned) to prevent further ignitions.

(ii) Three service station licensed premises were destroyed by fire, two of which did not involve any dangerous goods and were believed to have started from an electrical fault. The third involved a tanker vehicle which also was destroyed when ignition occurred during the filling of underground tanks at the service station. The driver was slightly injured in the incident but could not assist in determining the source of ignition.

(iii) Flammable liquids were involved in the burning of four other vehicles; One, a tanker vehicle, rolled over and burned out on the Eyre Highway; another, conveying empty fuel drums caught alight from a burning tyre; and the remaining two, in widely separated incidents, were private vehicles which burned out when ignition of petrol vapours occurred immediately after the vehicles had been refuelled from jerry cans. One person was seriously injured in this latter mishap.

(iv) Two men were seriously injured in two separate accidents caused by welding operations in the vicinity of drums containing small quantities of flammable liquids or vapours.

(v) A fire destroyed a petrol tank storage and damaged surrounding proprety when ignition occurred during filling operations. The refuelling vehicle conveyed only drums and was using non-approved equipment for pumping the Class 1 liquid. However, because the vehicle conveyed only drummed fuel, the regulations which apply only to tanker vehicles could not be invoked. Nevertheless, the driver was warned that his practice was hazardous and must not continue.

(vi) Fires involving distillate fuel storage were reported from two separate locations. One, suspected to have been started by vandals caused no damage to property other than the tank. The other, suspected to have been caused by a lightning strike, partly destroyed a country town's power station.

(vii) A fire in a Metropolitan store, initially reported to contain explosives, was found to have engulfed several hundred litres of kerosine. Some 500 kilograms of bagged ammonium nitrate were the only other hazardous goods in the store but fortunately this did not contribute to nor was it involved in the fire.

(c) *Other Dangerous Goods*

(i) Only two incidents involving the misuse of swimming pool chemicals (calcium hypochlorite) were reported throughout the year. One, in which two youths were charged by the Police, resulted in the explosion of a mixture prepared by the youths within the grounds of a church. The other, when a youth at a north western mining town was charged with "having caused an explosion". In this case the charge was dismissed under a section of the Act dealing with first offenders.

(ii) Swimming pool chemicals featured in another incident in which a truck driver and his assistant were badly burned when their vehicle conveying 2·5 tonnes of calcium hypochlorite caught fire. It is debatable whether legislative control could have prevented this accident.

(iii) Acetylene gas featured in one incident in which a 200 litre drum containing a mixture of the gas with oxygen was exploded outside the police office of a country town. This incident was not investigated further by the Branch.

(iv) A warning had to be given to a Western Australian distributor of agricultural chemicals to remove a 30 tonne storage of calcium cyanide (Class 6: Poison dangerous goods) from within their flammable liquids store. Prior to this warning the Branch had given the company detailed advice for the safe storage of these dangerous goods.

(v) A report was received of a fire in the vaporizer of a liquefied butane gas tank. The faulty vaporizer was later examined by machinery inspectors from the Department of Labour and Industry. No further action was taken by this Branch.

MISCELLANEOUS ACTIVITIES

(i) *Committee Attendance*

The scientific officers of the Branch participated in the activities of several SAA committees throughout the year. These were:

— Melbourne, March 1–2; Committee AU/17, tank vehicles for hazardous substances (liquefied petroleum gases)

— Sydney, May 10–11; Committee AU/17, tank vehicles for hazardous substances (anhydrous ammonia)

— Melbourne, August 16–17; Committee CE/5, handling of explosives

— Sydney, October 25–26; Committee AU/17, tank vehicles for hazardous substances (anhydrous ammonia and LPG)

— Perth, December 5–7; Committee CE/5, handling of explosives.

Additionally, the annual conference of Chief Inspectors of Explosives from all States was attended in Adelaide, October 4–6.

(ii) *Lectures*

— The Chief Inspector delivered a lecture, "Bulk Nitrate Blasting Agents in Western Australia", at the Sprengtechnik 1977—International in Linz, Austria, November 16–18. Advantage was taken of this overseas visit to discuss dangerous goods control with Her Majesty's Chief Inspector of Explosives and other statutory authorities who have responsibility in this field.

— Three lectures, two on the "Explosives and Dangerous Goods Act" and one on "Explosives and Improvised Bombs" were delivered by the Deputy Chief Inspector to officers of the Police Department.

— An informal talk on the subject of explosives was given by the Deputy Chief Inspector to members of the Australian Forensic Science Society.

— A meeting of the Petroleum Engineers Advisory Committee for Australia and two meetings of the Western Australian members of the Australian Institute of Petroleum were addressed by the Chief Inspector on the subject of proposed amendments to the Flammable Liquids Regulations, 1967.

— A revised and metricated edition of the training manual "Notes for the Shotfirer" was printed during the year. It is hoped that this publication will assist those persons in country areas who cannot attend the Department's shotfirers courses.

(iii) *Police Assistance*

Liaison with the Police continued in matters concerning explosives and flammable liquids. Two reports were prepared for the Coroner of accidents which had caused injury through fire or explosion. Evidence was given at an inquest into the fatality recorded with flammable liquids in an earlier part of this report.

CONCLUSION

The staff of the Explosives Branch continues to serve the public in maintaining the provisions of the Explosives and Dangerous Goods Act. Current regulations which are directed towards the protection of life and property have proven adequate for the control of explosives and flammable liquids. The need for further regulations to control other dangerous goods used throughout Western Australia is now apparent.

Excellent co-operation has been received by the Branch from officers of Local Authorities throughout the State, the W.A. Fire Brigades Board, the Police Department and other Government Departments (particularly in matters concerning the training of shotfirers). Special assistance has been rendered by officers of the Department of Mines and their help to me throughout the year is gratefully acknowledged.

H. DOUGLAS,
Chief Inspector of Explosives.

DIVISION IX

Report of Superintendent, Mine Workers' Relief Act, and Chairman, Miners' Phthisis Board 1977

Annual Report 1977—Mine Workers' Relief Act 1932 and Miners Phthisis Act 1922

Under Secretary for Mines:

1. This report is submitted for the information of the Honourable Minister for Mines, on the above Acts for the year ended 31st December, 1977.

2. *General*

The State Public Health Department, under arrangements made with this Department, continued the periodical examination of mine workers throughout the year and the following mining sites were visited by the mobile X-Ray unit:—

Cape Lambert, Carnamah, Carnarvon, Coolegong, Cue, Dampier, Goldsworthy, Finucane, Jigalong, Marble Bar, Meekatharra, Moolyella, Mt. Magnet, Newman, Nelson Point, Nullagine, Northampton, Pannawonica, Paraburdoo, Paynes Find, Port Hedland, Robe River, Shay Gap, Three Springs, Tom Price, Walkaway, Wittenoom, Yalgoo.

3. *Mine Workers' Relief Act*

3.1 TOTAL EXAMINATIONS

The examinations made under the Mine Workers' Relief Act during the year totalled 7 414 and compared with 5 788 for the previous year; an increase of 1 626. The results of examinations are as follows:—

Normal	
Silicosis early, previously normal	7 172
Silicosis early, previously silicosis early	18
Silicosis advanced, previously normal	212
Silicosis advanced, previously silicosis early	....
Silicosis advanced, previously silicosis advanced	1
Silico-tuberculosis, previously normal	7
Silico-tuberculosis, previously silicosis early	
Silico-tuberculosis, previously silicosis advanced	....
Silico-tuberculosis, previously tuberculosis	....
Tuberculosis, previously normal	....
Asbestosis early, previously normal	....
Asbestosis early, previously asbstosis early	....
Asbestosis advanced, previously normal	....
Asbestosis advanced, previously asbestosis early	....
Silico-asbestosis early, previously normal	
Silico-asbestosis early, previously asbestosis early	3
Silico-asbestosis early, previously silicosis early	....
Silico-asbestosis early, previously silico-asbestosis early	....
Silico-asbestosis advanced, previously silicosis early	1
Silico-asbestosis plus tuberculosis, previously normal	....
Silico-asbestosis advanced plus tuberculosis, previously silico-asbestosis early	....
Total	7 414

The 1977 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 ANALYSIS OF EXAMINATIONS

In explanation of the examination figures, I desire to make the following comments:—

3.2.1 NORMAL ETC.

These numbered 7 414 or 96·74 per cent of the men examined and include men having first class lives or suffering from fibrosis only. The figures for the previous year being 5 495 or 94·94 per cent of the men examined.

3 2.2 EARLY SILICOSIS

These numbered 230 of which 18 were new cases and 212 had previously been reported; the figures for 1976 being 270 and 20 respectively. Early silicotics represent 3·10 per cent of the men examined, the percentage for the previous year was 4·67 per cent.

3.2.3 ADVANCED SILICOSIS

There were eight cases reported, one of which advanced from early silicosis. Advanced silicotics represent 0·11 per cent of the men examined, the percentage for the previous year being 0·12 per cent.

3.2.4 SILICOSIS PLUS TUBERCULOSIS

There were no cases reported.

3.2.5 TUBERCULOSIS ONLY

There were no cases reported.

3.2.6 ASBESTOSIS

There were no cases of early asbestosis reported during the year as against two on the previous year.

3.2.7 SILICOSIS-ASBESTOSIS

Three cases of early silicosis-asbestosis were reported during the year, plus one being an advanced case. This category represents 0·05 per cent of the men examined.

4. *Mines Regulation Act*

4.1 TOTAL EXAMINATIONS

Examinations under the Mines Regulation Act totalled 7 414. There was an increase of 1 248 under this Act in 1977, as compared with 1976.

Of the total of 7 414 examined, 4 316 were new applicants and 3 098 were re-examinees.

4.2 ANALYSIS OF EXAMINATIONS

Particulars of examinations are as follows:—

4.2.1 NEW APPLICANTS

Normal	4 312
Silicosis early	....
Silicosis early with tuberculosis	....
Tuberculosis	....
Other conditions	4
Total	4 316

4.2.2 RE-EXAMINEES

Normal	3 098
Silicosis early	....
Silicosis early with tuberculosis	....
Tuberculosis	....
Other conditions	....
Total	3 098

These men had previously been examined and some were in the industry prior to this examination.

4.3 HEALTH CERTIFICATES ISSUED TO NEW APLICANTS AND RE-EXAMINEES

The following health certificates were issued under the Mines Regulation Act:—

Initial Certificates (Form 2)	7 410
Temporary Rejection Certificates (Form 3)	....
Rejection Certificates (Form 4)	4
Re-admission Certificates (Form 5)	....
Special Certificates (Form 9)	....
Total	7 414

5. *Miners' Phthisis Act*

The amount of compensation paid during the year was $4 950.40 compared with $4 964.57 for the previous year.

The number of beneficiaries under the Act as on 31/12/1977 was 22 being two ex-miners and 20 widows.

R. J. THOMPSON,
A/Superintendent
Mine Workers' Relief Act
and
Chairman,
Miners' Phthisis Board.

24th February, 1978.

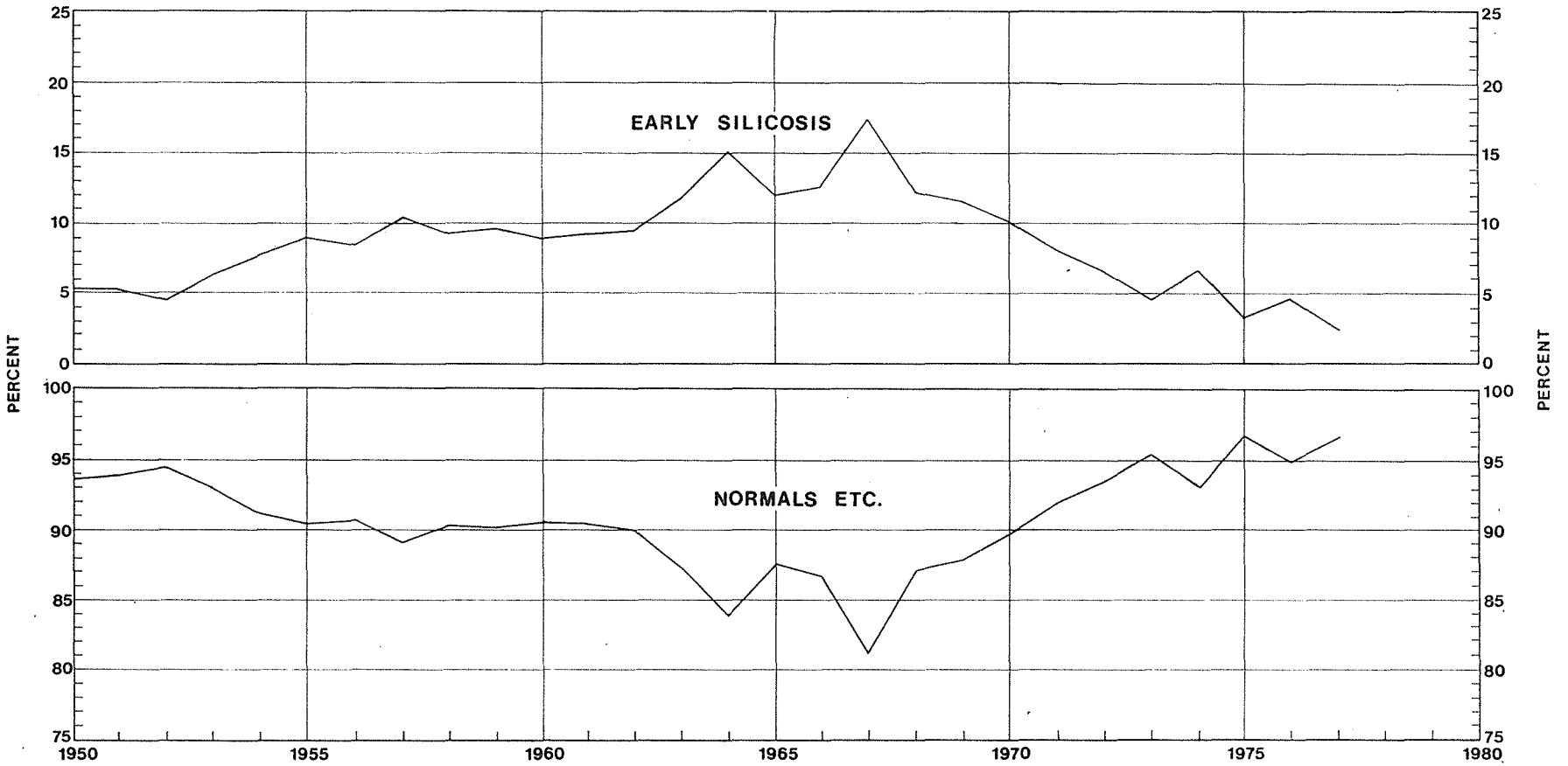
TABLE SHOWING RESULTS OF PERIODICAL EXAMINATION OF MINE WORKERS FROM INCEPTION OF EXAMINATIONS (1925)

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

PERIODICAL EXAMINATION OF MINE WORKERS

GRAPH Nº1

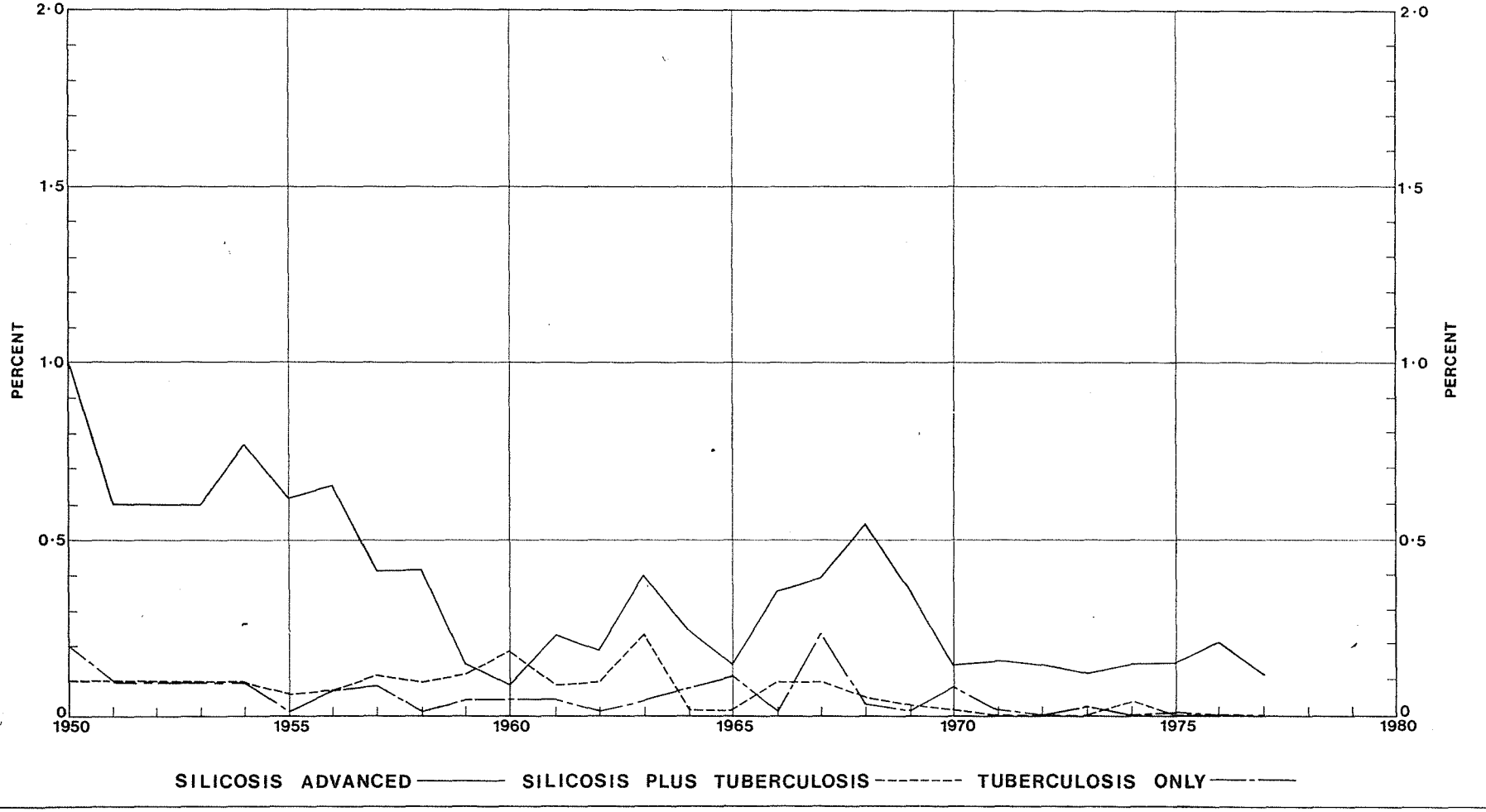
SHOWING PERCENTAGES OF NORMALS AND EARLY SILICOTICS FROM 1950 ONWARDS



PERIODICAL EXAMINATION OF MINE WORKERS

GRAPH Nº 2

SHOWING PERCENTAGES OF SILICOSIS ADVANCED, SILICOSIS PLUS TUBERCULOSIS AND TUBERCULOSIS ONLY, FROM 1950 ONWARDS



MINING STATISTICS

to 31st December, 1977

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TABLE I

PRODUCTION OF GOLD AND SILVER AS REPORTED TO THE MINES DEPARTMENT DURING 1977.

(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

Mining Centre	Number of Lease	Registered Name of Company or Lease	Total for 1977					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
Pilbara Goldfield.												
MARBLE BAR DISTRICT.												
Bamboo Creek	G.M.L. 45/1118	Kitchener	....	....	152·00	1·741	....	....	....	3 446·22	94·807	·110
	1203	Mt. Prophecy	....	....	272·00	1·593	....	....	....	6 060·76	86·167	3·536
Marble Bar	1487	Charger	....	....	181·00	·222	....	·292	....	1 400·00	3·069	....
	1520	Golden Trail	....	....	11·00	·177	....	....	....	11·00	·177	....
	927	Halleys Comet	....	....	....	16·252	1·149	....	....	6 462·06	280·952	31·630
	1209	Ironclad	....	....	142·00	·168	....	....	....	2 109·23	4·067	·006
	1247	Stray Shot	....	....	20·00	·103	....	....	....	20·00	·103	....
Moolyella		Sundry Claims	....	....	9·00	·038	....	....	....	59·00	·108	....
Telfer	1421 etc.	Newmont Proprietary Limited	....	....	293 087·00	4 433·184	76·238	....	....	293 087·00	4 433·184	76·238
NULLAGINE DISTRICT.												
Middle Creek	G.M.L. 46/339 etc.	Mulga Mines Pty. Ltd.	....	....	30 669·00	532·878	....	....	....	45 833·00	679·070	....
		Prior to transfer to present holders	....	....	....	....	....	....	....	64 200·43	1 187·748	·342
East Murchison Goldfield.												
BLACK RANGE DISTRICT.												
Barrambie	G.M.L. 57/1117	Scheelite Leases	....	....	58·00	·877	....	....	....	1 977·77	37·306	·610
Montague	(1261)	Montague Boulder	....	....	34·00	·272	....	....	....	131·00	·976	....
Sandstone		Sundry Claims	....	....	7·00	·011	....	1·464	44·200	16 697·17	216·385	....
		State Battery—Sandstone	....	....	....	*1·440	·010	....	....	295·16	*746·781	1·936
Murchison Goldfield.												
CUE DISTRICT.												
Reedys	G.M.L. 20/2381	Bronzewing	....	....	54·00	·600	....	....	....	64·00	·968	....
MEEKATHARRA DISTRICT.												
Meekatharra	G.M.L. 51/2068	Halcyon	....	·051	900·00	1·579	....	....	·051	3 935·20	7·936	....
	2015	Haveluck	....	....	1 202·00	2·348	....	....	....	16 970·51	32·785	....
	2217	Hawk Hill	....	....	6·00	·785	....	....	....	6·00	·785	....
	2139	Ingliston Gold Mine	....	....	725·00	37·431	....	....	....	1 063·00	39·042	....
	(2185)	Lenanphyl	....	·053	....	....	....	....	·053	....	....	....
	2210	Queen of the Lake	....	....	230·00	·360	....	....	....	230·00	·360	....

Murchison Goldfield—cont.

MOUNT MAGNET DISTRICT.

Lennonville	G.M.L. 58/1793	Ard Patrick	....	....	....	....	....	....	....	....	345·00	·439	....	....	....	345·00	·439	....
Mt. Magnet	1782	Joanne	....	....	....	....	....	....	....	·344	....	....	....	....	·344	230·00	·339	....
	1766	St. George	....	....	....	....	....	....	....	....	250·00	·200	....	....	....	250·00	·200	....
	1752	Windbag	....	....	....	....	....	....	....	....	273·00	·177	....	....	....	273·00	·177	....
		Sundry Claims	....	....	....	....	....	....	....	·050	50·00	·043	....	5·103	83·930	64 731·70	944·510	·918

Yalgoo Goldfield.

Goodingnow	G.M.L. 59/1349	Two By Two	....	....	....	....	....	....	....	....	67·00	·075	....	....	....	67·00	·075	....
		Sundry Claims	....	....	....	....	....	....	....	·653	....	....	....	....	....	11 078·97	162·906	·004
Warda Warra	1267	The Shamrock	....	....	....	....	....	....	....	....	23·00	·368	....	4·757	6·220	119·68	1·651	....

Mt. Margaret Goldfield.

MT. MORGANS DISTRICT.

Redcastle	G.M.L. 39/675	Agau	....	....	....	....	....	....	....	·009	....	....	....	....	·009	135·00	·347	....
	689	Lady Susan	....	....	....	....	....	....	....	....	85·00	·211	....	....	....	85·00	·211	....

MOUNT MALCOLM DISTRICT.

Diorite	G.M.L. 37/1974	Puzzle	....	....	....	....	....	....	....	....	30·00	·194	....	....	....	82·88	·718	....
Leonora	2065	British King	....	....	....	....	....	....	....	....	200·00	4·151	....	....	....	200·00	4·151	....
	2067	Central Primary	....	....	....	....	....	....	....	....	40·00	·041	....	....	....	40·00	·041	....
	2045	Gray Lode	....	....	....	....	....	....	....	....	340·00	·265	....	....	....	430·00	·411	....
	2057	Great Barnera	....	....	....	....	....	....	....	....	400·00	·327	....	....	....	400·00	·327	....
	2015	Island	....	....	....	....	....	....	....	....	436·00	4·847	....	....	....	786·72	10·107	....
	1948	Jessie Alma	....	....	....	....	....	....	....	....	60·00	·096	....	....	....	414·01	·271	....
	(2052)	Lands End	....	....	....	....	....	....	....	....	28·00	·114	....	....	....	28·00	·114	....
	1907	Longs Lucky Lode	....	....	....	....	....	....	....	....	62·00	·212	....	....	....	132·00	·510	....
	1762	Sons of Gwalia	....	....	....	....	....	....	....	....	2 319·00	6·845	....	....	·676	7 049·07	18·374	....
	1860	Tower Hill	....	....	....	....	....	....	....	....	290·00	·647	....	....	....	6 219·61	14·299	....
	1906	Two Glads	....	....	....	....	....	....	....	....	60·00	1·373	....	....	....	8 744·28	56·538	....
		Sundry Claims	....	....	....	....	....	....	....	....	248·00	5·182	....	1·207	12·211	26 197·52	421·031	·833
		State Battery—Leonora	....	....	....	....	....	....	....	....	....	*9·257	·482	....	....	92·46	*97·222	2·301
		L.T.T. 37/31 (2626H) Smith, G. J.			....	....	....	....	....	....	....	·066	....	....	....	....	·066	....

MOUNT MARGARET DISTRICT.

Burtville	G.M.L. 38/2770	Aybe	....	....	....	....	....	....	....	....	131·00	·150	....	....	....	131·00	·150	....
Laverton	2747	Merry Mack	....	....	....	....	....	....	....	....	60·00	·041	....	....	....	60·00	·041	....
	2789	Anthus	....	....	....	....	....	....	....	....	200·00	·605	....	....	....	200·00	·605	....

North Coolgardie Goldfield.

MENZIES DISTRICT.

Goongarrie	M.L. 29/24	Goongarrie	....	....	....	....	....	....	....	....	10·00	·019	....	....	....	10·00	·019	....
		Sundry Claims	....	....	....	....	....	....	....	....	7·00	1·130	....	1·445	66·699	3 360·84	177·986	....
Menzies	G.M.L. 29/5971	Alfia	....	....	....	....	....	....	....	....	32·00	2·316	....	....	....	64·00	3·063	....
	5992	Black Jack	....	....	....	....	....	....	....	....	144·00	·237	....	....	....	144·00	·237	....
	5815	Espacia	....	....	....	....	....	....	....	....	1 349·00	8·754	....	....	....	2 440·60	13·903	....
	5799	First Hit	....	....	....	....	....	....	....	....	152·00	·277	....	....	....	995·32	5·387	....
	5996	Forty Five Show	....	....	....	....	....	....	....	....	41·00	·247	....	....	....	41·00	·247	....
	5804	Gladys Mary	....	....	....	....	....	....	....	....	165·00	·268	....	....	....	774·63	1·099	....
		Sundry Claims	....	....	....	....	....	....	....	....	62·00	·670	....	1·769	19·490	44 042·69	828·939	25·311
		State Battery—Menzies	....	....	....	....	....	....	....	....	....	*2·479	·415	....	·237	20·32	*134·778	35·072

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 1977					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
ULARRING DISTRICT.												
Davyhurst	G.M.L. 30/1333	Makai	....	....	13·00	·068	....	....	....	13·00	·068	....
Morleys	1221	Emerald	....	....	76·00	·646	....	....	....	414·60	3·207	....
Mulline	1107	Ajax West	....	....	20·00	·280	....	....	·043	8 832·58	210·379	....
	1340	Little Willee	....	....	454·00	1·571	....	....	....	454·00	1·571	....
		Sundry Claims	....	·086	69·00	·340	....	·336	9·305	12 586·08	312·622	·035
Mulwarrie	1113	Oakley	....	....	60·00	·196	....	....	....	6 012·05	284·515	10·387
Ularring	1348	Dimers Patch	....	....	16·00	·031	....	....	....	16·00	·031	....
NIAGARA DISTRICT.												
Tampa	G.M.L. 40/974	New Gregory	....	....	21·00	·037	....	....	....	21·00	·037	....
		L.T.T. 40/21 (2629H) Bailey, P. L.	....	....	....	·259	....	....	....	....	·259	....
YERILLA DISTRICT.												
Pinjin	G.M.L. 31/1448	Sundry Claims	....	....	5·00	·052	....	....	4·817	5 738·14	108·160	....
Yarri		Porphyry	....	....	1 338·00	3·732	....	....	....	72 795·91	324·228	8·147
		Prior to transfer to present holder	....	....	....	....	....	....	....	30 831·44	169·477	15·785
Broad Arrow Goldfield.												
Bardoc	G.M.L. 24/2439	Sundry Claims	....	....	46·00	·241	....	1·709	37·887	20 064·17	268·130	....
Black Flag		Watsons Find	....	....	363·00	·520	....	....	....	363·00	·520	....
Ora Banda	2430	Dip	....	....	8·00	·206	....	....	....	12·50	·335	....
	2270	Gimlet South Leases	....	....	3 406·00	6·785	....	....	....	72 195·56	210·055	5·120
	2290		....	....	....	....	....	....	....	....	....	....
	2412	Ora Banda South	....	2·284	....	....	....	....	3·728	....	....	....
		Sundry Claims	....	·166	183·00	·279	....	....	15·034	18 694·93	165·014	....
Paddington	2329	Shirley Lorna	....	....	97·00	·201	....	....	....	97·00	·201	....
Siberia	2405	Pride of Erin	....	....	123·00	·078	....	....	....	147·00	·169	....
		L.T.T. (24/46 (1872H)) Aurex Pty. Ltd.	....	....	....	·211	....	....	·079	....	67·274	8·192
		L.T.T. 24/50 (1872H) Harford, P.	....	21·217	....	....	....	....	21·217	....	....	....
		T.L. 24/2 (245H) Aurex Pty. Ltd.	....	....	....	5·103	·211	....	....	....	5·103	·211
North-East Coolgardie Goldfield.												
KANOWNA DISTRICT.												
Six Mile		Sundry Claims	....	....	93·00	·287	....	....	2·434	1 085·13	9·408	....
KURNALPI DISTRICT.												
Karonie	G.M.L. 28/492	Row's Find	....	....	65·00	·365	....	....	....	65·00	·365	....

East Coolgardie Goldfield.

EAST COOLGARDIE DISTRICT.

Binduli	G.M.L. 26/6881	Golden Aces								1·435	27·00	2·779			1·435	27·00	2·779	
Boorara	6671	Waterfall North								·316	597·00	·827			·361	975·75	8·023	
Boulder	5815	Great Boulder No. 1 South									6·00	·030				6·00	·030	
	5345 etc.	Kalgoorlie Lake View Pty. Ltd.										112·834	21·647			1 108 024·40	6 363·791	2 344·091
		Prior to transfer to present holder													26·70	62162730·32	732 838·733	106 492·417
	6663	Kalgoorlie Lake View Pty. Ltd.									394·00	3·019				394·00	3·019	
	6702	Do.									273·00	·683				273·00	·683	
	6890	Do.									61·00	·028				61·00	·028	
	6897	Do.									4 451·00	12·894				4 451·00	12·894	
	6905	Do.									1 705·00	3·072				1 705·00	3·072	
	6593	Do.									734·00	1·457				734·00	1·457	
	6835	Do.									240·00	·264				240·00	·264	
Boulder	G.M.L. 26/6688	Kalgoorlie Lake View Pty. Ltd.									755·00	2·018				755·00	2·018	
	6810	Do.									80·00	·076				80·00	·076	
	6838																	
	6869	North Kalgurli Mines Ltd.									87·00	·031				87·00	·031	
Feysville	6791	Butterfly									14·00	·067				24·10	·093	
		Sundry Claims									8·00	·045			6·189	1 717·00	22·635	
Hampton Plains	S.L. 24, Loc. 48	Trinidad, B.									347·00	·584				347·00	·584	
Kalgoorlie	G.M.L. 26/6589	Grays Central									53·00	1·495				1 108·11	12·100	·092
	6591	Kalgoorlie Lake View Pty. Ltd.								·008					·008	11 313·89	26·291	
	6563 etc.	Kalgoorlie Lake View Pty. Ltd. (Mt. Charlotte)									549 717·00	2 354·625	483·409			2 847 739·38	11 451·172	1 009·735
		Prior to transfer to present holders													·178	4 947 601·36	21 751·229	5·336
	6485	Maritana Hill									413·00	·946				7 343·95	22·049	
	6991	Taroya									52·00	·072				52·00	·072	
		Sundry Claims									129·00	·172		7·229	35·073	65 249·85	731·068	·006
Wombola	6844	Daisy Leases								1·674	568·00	11·480			1·756	29 791·50	861·375	27·519
	6845																	
	6844	Daisy														6 383·06	156·511	
	6845	Happy-Go-Lucky														2 108·55	52·125	
	6635	Hodad									187·00	1·711				3 968·26	19·756	1·611
	6877	Lurgan								·310	136·00	1·474			·310	537·00	4·380	
	6676	Rosemary									259·00	·629				924·00	11·264	
	(6989)	Roughans Find									630·00	1·293				630·00	1·293	
		Sundry Claims									157·00	·370			22·459	3019·31	488·471	·006
		State Battery—Kalgoorlie										*·129				396·97	*1 318·061	24·938

Coolgardie Goldfield.

COOLGARDIE DISTRICT.

Bonnievale	G.M.L. 15/6151	Melva Maie									19·00	·259			·084	1 182·38	3·752	
	6289	Mystery									10·00	·062				36·10	·166	
	5890	Rayjax								·226	14·00	·680			1·416	2 013·09	59·710	·159
Burbanks	6225	Glenloth									29·00	·187				29·00	·187	
Cave Rocks		Sundry Claims									187·00	·655			1·555	5 210·74	35·659	
Coolgardie	6333	Bicentenary									45·00	·183				45·00	·183	
	6282	Doreen Rose									333·00	·633				505·26	1·465	
	6059	Empress									145·00	·329				350·00	·769	
	6337	Golden Hope									83·00	·140				83·00	·140	
	6314	McPhersons Reward									48·00	·190				170·00	·435	
Coolgardie	G.M.L. 15/6154	Monkani									1 701·00	1·834				13 412·92	19·055	
	6242	Paradise								·134					·134	97·00	4·362	
	6195	Rose Hill									596·00	·479				1 118·04	·807	
	6158	Tindals East									385·00	·590				414·46	·887	
		Sundry Claims								·016	523·00	1·773		7·375	95·560	93 658·12	944·116	·059
Gibraltar	6300	Manfred Curry									8·00	·031				8·00	·031	
Hampton Plains	P.P.L. 486, Loc. 59	Boucher, H.									162·00	·165				650·66	3·639	
	S.L.A. 22, Loc. 53	Clements, S. A.									84·00	·015				84·00	·015	
	S.L.A. 19, Loc. 53	Ross, P. A.									137·00	·523				137·00	·523	
Higginsville	G.M.L. 15/5647	Fair Play Gold Mine									2 860·00	2·867		·137	1·950	39 578·04	114·347	·001
Kambalda	M.C.'s 152 etc.	Western Mining Corporation										105·448	348·119		22·003	32·00	281·741	1 079·703
Widgiemooltha	G.M.L. 6344	Host Group									9·00	·028			·396	1 638·89	17·602	
		Sundry Claims									34·00	·134		1·446	14·620	16 695·21	215·323	·002
		State Battery—Coolgardie										*4·545	·118			783·38	*1 350·114	1·029
		(L.T.T. 15/46 (2573H)) Paul, J.										·065					·065	

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Mining Centre	Number of Lease	Registered Name of Company or Lease	Total for 1977					Total Production				
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			kg	kg	Tonnes	kg	kg	kg	kg	Tonnes	kg	kg
KUNANALLING DISTRICT.												
Breakaway		Sundry Claims	....	....	51·00	·152	....	....	....	51·00	·152	....
Carbine	G.M.L. 16/1082	Hawkins Find	....	·018	912·00	1·893	....	....	·270	2 722·00	6·531	·065
Dunnsville	1128	Min Min Revisited	....	·091	4·00	·234	....	....	·091	4·00	·234	....
Kunanalling	1052	Catherwood	....	....	150·00	·152	....	....	....	2 282·00	2·720	....
		Sundry Claims	....	....	5·00	·060	....	6·735	30·928	18 378·66	322·615	·674
		(L.T.T. 16/35 (2565H)) Smith, F. R.	....	·682	....	2·796	....	....	·682	....	2·796	....
Yilgarn Goldfield.												
Bullfinch	G.M.L. 77/4607	Open Cut	....	·315	99·00	·157	....	....	·315	664·49	2·197	....
		Sundry Claims	....	....	13·00	·076	....	·263	1·741	8 118·48	135·253	·755
Eenuin		Sundry Claims	....	....	48·00	·175	....	·098	2·829	2 488·39	64·636	·167
Kennyville	(4802)	Dorothy Leslie	....	....	308·00	·306	....	....	....	308·00	·306	....
		Sundry Claims	....	....	127·00	·224	....	....	·157	9 081·67	73·782	·017
Marvel Loch	4434	Cornwall	....	....	18·00	·114	....	....	....	18 222·23	77·256	....
	4637	Eclipse	....	....	291·00	·395	....	....	....	440·00	·761	....
Parkers Range	4512	Constance Una	....	....	705·00	7·849	....	....	....	8 892·81	187·177	2·628
	4765	Ripper	....	....	248·00	1·262	....	....	....	321·00	2·077	....
	4626	The Australia	....	·549	....	....	....	....	·660	182·00	·929	....
	4621	The Dollar	....	....	68·00	·279	....	....	....	293·18	1·992	....
		Sundry Claims	....	....	23·00	·196	....	·205	9·453	14 949·83	179·166	·101
Southern Cross	G.M.L. 77/4674	Bounty	....	....	1 293·00	3·027	....	....	....	1 293·00	3·027	....
	4638	Three Boys South	....	....	52·00	·095	....	....	....	52·00	·095	....
		Sundry Claims	....	....	117·00	·806	....	2·983	20·218	9 247·74	87·194	·298
		State Battery—Marvel Loch	....	....	....	*2·747	2·048	....	....	149·36	*186·910	91·825
		L.T.T. 77/122 (2620H) Beavis, Jordan & Gould	....	....	....	35·724	....	....	....	....	35·724	....
		(L.T.T. 77/86 (2521H)) Carnicelli, L.	....	....	....	·506	....	....	....	....	·506	....
		(L.T.T. 77/105 (2594H)) Casas, B.	....	·078	....	....	....	....	·208	....	....	....
		L.T.T. 77/119 (1948H) Casas, B.	....	·126	....	....	....	....	·336	....	·143	....
		L.T.T. 77/126 (2635H) Johnstone, K. R.	....	....	....	·219	....	....	....	....	·219	....
		L.T.T. 77/131 (2656H) Kings, B.	....	....	....	·105	....	....	....	....	·105	....
		(L.T.T. 77/56 (2396H)) Smith, A. E.	....	....	....	3·042	....	....	....	....	3·042	....
		L.T.T. 77/104 (2588H) Wright, L.	....	....	....	·388	....	....	....	....	·708	....
Dundas Goldfield.												
Dundas	G.M.L. 63/2187	Haycraft	....	....	143·00	·166	....	....	....	143·00	·166	....
Norseman	1936 etc.	Central Norseman Gold Corporation N.L.	....	....	155 517·00	2 908·129	891·365	....	....	5 891 589·18	82 174·413	53 987·496
		Prior to transfer to present holders	....	....	....	....	....	....	51·735	70 940·22	1 489·610	513·482
		Sundry Claims	....	....	49·00	·208	....	32·729	112·653	50 888·01	705·106	7·623
Phillips River Goldfield												
Kundip	G.M.L. 74/277	Western Gem	....	....	73·00	2·211	....	....	....	813·33	9·503	·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 1977.

Goldfield	District	District						Goldfield					
		Alluvial	Dollied and Specimens	Ore Treated	Gold Therefrom	Total Gold	Silver	Alluvial	Dollied and Specimens	Ore Treated	Gold Therefrom	Total Gold	Silver
		kg	kg	Tonnes	kg	kg	kg	kg	kg	Tonnes	kg	kg	kg
Kimberley		....	....	....	....	....	....	....	....	....	....	....	....
West Kimberley		....	....	....	....	....	....	....	....	....	....	....	....
Pilbara	Marble Bar	....	....	293 874·00	4 453·478	4 453·478	77·387	....	....	324 543·00	4 986·356	4 986·356	77·387
	Nullagine	....	....	30 669·00	532·878	532·878	....						
West Pilbara		....	....	....	....	....	....	....	....	....	....	....	....
Ashburton		....	....	....	....	....	....	....	....	....	....	....	....
Gascoyne		....	....	....	....	....	....	....	....	....	....	....	....
Peak Hill		....	....	....	....	....	....	....	....	....	....	....	....
East Murchison	Lawlers	....	....	....	....	....	....	....	....	99·00	2·600	2·600	·010
	Wiluna	....	....	....	....	....	....						
	Black Range	....	....	99·00	2·600	2·600	·010						
Murchison	Cue	....	....	54·00	·600	·600	....	....	·498	40 035·00	43·962	44·460	....
	Meekatharra	....	·104	3 063·00	42·503	42·607	....						
	Day Dawn	....	....	....	....	....	....						
	Mt. Magnet	....	·394	918·00	·859	1·253	....						
Yalgoo		....	....	....	....	....	....	....	·653	90·00	·443	1·096	....
Mt. Margaret	Mt. Morgans	....	·009	85·00	·211	·220	....	....	·009	4 989·00	34·624	34·633	·482
	Mt. Malcolm	....	....	4 513·00	33·617	33·617	·482						
	Mt. Margaret	....	....	391·00	·796	·796	....						
North Coolgardie	Menzies	....	....	1 962·00	16·397	16·397	·415						
	Ularring	....	·086	708·00	3·132	3·218	....						
	Niagara	....	....	21·00	·296	·296	....	....	·086	4 034·00	23·609	23·695	·415
	Yerilla	....	....	1 343·00	3·784	3·784	....						
Broad Arrow		....	....	....	....	....	....	....	23·667	4 226·00	13·624	37·291	·211
North East Coolgardie	Kanowna	....	....	93·00	·287	·287	....	....	....	158·00	·652	·652	....
	Kurnalpi	....	....	65·00	·365	·365	....	....	3·743	562 080·00	2 515·104	2 518·847	505·056
East Coolgardie	East Coolgardie	....	3·743	562 080·00	2 515·104	2 518·847	505·056						
	Bulong	....	....	....	....	....	....						
Coolgardie	Coolgardie	....	·376	7 412·00	121·815	122·191	348·237	....	1·167	8 534·00	127·102	128·269	348·237
	Kunanalling	....	·791	1 122·00	5·287	6·078	....						
Yilgarn		....	....	....	....	....	....	....	1·068	3 410·00	57·692	58·760	2·083
Dundas		....	....	....	....	....	....	....	....	157 709·00	2 908·503	2 908·503	891·365
Phillips River		....	....	....	....	....	....	....	....	73·00	2·211	2·211	....
South West Mineral Field		....	....	....	....	....	....	....	....	....	....	....	....
Northampton Mineral Field		....	....	....	....	....	....	....	....	....	....	....	....
State Generally		....	....	....	....	....	....	....	....	....	....	....	....
Outside Proclaimed Goldfield		....	....	....	....	....	....	....	....	....	....	....	....
Total		....	....	....	....	....	....	....	30·891	1 071 980·00	10 716·482	10 747·373	1 825·426

TABLE III

Return showing total production reported to the Mines Department to 31st December, 1977.

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	23 299·89	537·841	914·867	4·005
Pilbara	Marble Bar	487·965	143·119	662 262·97	15 111·807	15 742·891	1 131·058	815·036	233·817	860 817·92	20 006·367	21 055·220	1 164·678
	Nullagine	327·071	90·698	198 548·95	4 894·560	5 312·329	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	172·829	796 897·12	10 042·938	10 321·649	118·009
East Murchison	Lawlers	221·544	73·823	2 055 172·12	25 750·065	26 045·432	848·153	280·939	691·665	12 833 588·81	113 736·285	114 708·889	1 876·336
	Wiluna	7·355	39·007	9 016 065·65	58 236·113	58 282·475	321·060						
	Black Range	52·040	578·835	1 762 351·04	29 750·107	30 380·982	707·123						
Murchison	Cue	160·036	284·366	6 926 226·34	43 660·955	44 105·357	8 548·605	802·353	1 861·757	15 790 738·67	188 902·927	191 567·037	16 343·740
	Meekatharra	457·427	584·045	2 389 373·85	40 891·775	41 933·247	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	639·460	4 404 428·75	61 557·707	62 279·676	2 360·540						
Yalgoo		....	....	....	....	....	....	56·477	102·155	455 347·04	8 284·810	8 443·442	47·372
Mt. Margaret	Mt. Morgans	111·191	292·443	1 239 444·67	22 335·939	22 739·573	181·374	366·763	1 104·393	11 728 681·70	154 724·156	156 195·312	8 176·669
	Mt. Malcolm	126·552	520·996	7 917 488·88	95 866·032	96 513·580	5 936·534						
	Mt. Margaret	129·020	290·954	2 571 748·15	36 522·185	36 942·159	2 058·761						
North Coolgardie	Menzies	52·773	219·239	1 991 445·83	44 661·911	44 933·923	1 221·576	151·123	622·023	3 811 771·17	80 637·445	81 410·591	2 259·122
	Ularring	4·033	227·341	550 420·43	13 945·012	14 176·386	693·202						
	Niagara	53·451	56·717	961 032·06	16 445·431	16 555·599	177·793						
	Yerilla	40·866	118·726	308 872·85	5 585·091	5 744·683	166·551						
Broad Arrow		....	....	....	....	....	....	684·367	907·335	1 480 234·55	23 630·458	25 222·160	185·796
North East Coolgardie	Kanowna	3 314·052	424·792	1 058 292·73	19 655·676	23 394·520	94·903	3 713·342	683·713	1 074 001·10	20 256·006	24 653·061	95·298
	Kurnalpi	399·290	258·921	15 708·37	600·330	1 258·541	·395						
East Coolgardie	East Coolgardie	1 049·527	1 303·515	106 908 041·18	1 233 502·253	1 235 855·295	208 471·479	1 901·934	1 803·347	107 103 570·69	1 237 671·824	1 241 377·105	208 474·582
	Bulong	852·407	499·832	195 529·51	4 169·571	5 521·810	3·103						
Coolgardie	Coolgardie	545·974	720·124	3 118 169·37	48 633·671	49 899·769	2 774·307	593·310	911·018	3 502 623·35	56 570·568	58 074·896	2 798·428
	Kunanalling	47·336	190·894	1 384 453·98	7 936·897	8 175·127	24·121						
Yilgarn		....	....	....	....	....	....	69·348	398·938	8 471 213·37	76 625·771	77 094·057	6 746·993
Dundas		....	....	....	....	....	....	70·176	519·883	7 972 283·26	112 450·639	113 040·698	66 990·746
Phillips River		....	....	....	....	....	....	18·883	25·608	133 596·68	3 918·313	3 962·804	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		....	....	....	....	....	....	10 471·555	10 207·238	176 080 244·23	2 109 448·888	2 130 127·681	321 551·369

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
	361 278·976	1 816 030·717	2 177 309·693	1 258 732 392

	1976 $A	1977 $A
Estimated Mint value of above production	1 131 003 589	1 142 357 726
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	79 976 762	111 195 462
Estimated Total	$A1 216 159 555	$A1 258 732 392
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 245 683 062	$A1 288 255 899

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 1977

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.	1 246 468	....	99 717 440
M.L. 70/1SA	South-West	Alcoa of Australia (W.A.) Ltd.	2 210 519	....	176 841 520
			3 456 987	....	(*l*) 276 558 960
		ANTIMONY		Sb Tonnes	
G.M.L. 45/339 etc.	Pilbara	Mulga Mines Pty. Ltd.	836·04	505·16	99 228
		BARYTES			
M.C. 45/1522	Pilbara	Dresser Minerals International Inc.	7 117	....	87 450
		BENTONITE (See Clays)			
		BUILDING STONE			
		Quartz			
M.C. 70/1921	South-West	Cutts, J. E.	1 277	....	1 277
M.C. 70/2110	South-West	Snowstone Pty. Ltd.	3 111	....	140 137
			4 388	....	(*a*) (*c*) 141 414
		Quartzite			
M.C.'s 70/1158, 1159	South-West	House R. P.	730	....	(*a*) (*c*) 7 670
		Spongolite			
M.C. 70/726	South-West	Universal Milling Co. Pty. Ltd.	17	....	(*a*) (*c*) 253
		CLAYS			
		Bentonite			
M.C.'s 70/1042–5	South-West	Scott, W. E., W. J. & R. J.	147	....	(*a*) 1 470
		Cement Clay			
M.C. 70/788	South-West	Bell Bros. Pty. Ltd.	28 390	....	(*c*) 70 969
		Fireclay			
M.C.'s 70/436, 437	South-West	Midland Brick Co. Pty. Ltd.	207 445	....	39 571
M.C. 70/304 etc.	South-West	Clackline Refractories Ltd.	4 831	....	9 594
M.C.'s 70/522, 523	South-West	Bridge, J. S.	29 607	....	29 544
M.C. 70/1302	South-West	Bridge, J. S.	21 824	....	21 387
			263 707	....	(*a*) (*c*) 100 096
		White Clay-Ball Clay			
M.C.'s 70/109	South-West	H.L. Brisbane and Wunderlich Ltd.	323	....	(*a*) (*c*) 3 230
		Kaolin			
M.C.'s 70/247, 605	South-West	Universal Milling Pty. Ltd.	425	....	2 546
M.C. 70/2110	South-West	Snowstone Pty. Ltd.	57	....	1 254
			482	....	(*a*) (*c*) 3 800
		COAL			
C.M.L. 12/448 etc.	Collie	Griffin Coal Mining Co. Ltd.	1 102 485	....	9 401 944
C.M.L. 12/437 etc.	Collie	Western Collieries Ltd.	1 255 521	....	13 770 149
			2 358 006	....	(*e*) 23 172 093
		COBALT (Metallic By-Product of Nickel Mining)		Cobalt Tonne	
M.L. 15/150 etc.	Coolgardie	Western Mining Corporation	....	200·661	712 884

TABLE V.—*Quantity and Value of Minerals, other than Gold, Reported during the Year* 1977—*continued*

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonne	Metallic Content	Value $A
		COPPER (Metallic By-Product of Nickel Mining)			
				Copper Tonne	
M.L. 15/150 etc.	Coolgardie	Western Mining Corporation	....	1 483·456	1 286 490
M.L. 15/246	Coolgardie	Anaconda Australia Inc.	....	347·440	448 295
			....	1 830·896	1 734 785
		DIATOMACEOUS EARTH			
M.C. 70/10791	South-West	Mallina Mining & Exploration N.L.	20	....	500
		EMERALDS			
				Grams	
M.C. 30/1243, 1245	North Coolgardie	McKay, N. J.	....	739	5 803
				Carats	
M.L. 20/116, 2131	Murchison	Bellairs, R. D.	....	13 830	12 182
		FELSPAR			
M.C. 70/2110	South-West	Snowstone Pty. Ltd.	182	....	9 100
M.L. 59/5801	Yalgoo	Chandilla Exploration & Investments Pty. Ltd.	463	....	6 955
			645	....	(*a*) 16 055
		GLASS SAND			
M.C. 70/417 etc.	South-West	Australian Glass Manufacturers Co.	19 869	....	26 404
M.C. 70/1074	South-West	Ready Mix Group (W.A.)	58 246	....	N.A.
M.C. 70/1191	South-West	Silicon Quarries Pty. Ltd.	58 756	....	46 572
M.C. 70/6056	South-West	Zaninovich, L. V.	310	....	155
			137 181	....	(*c*) 73 131
		GYPSUM			
M.C.'s 77/50 etc.	Yilgarn	H. B. Brady & Co. Pty. Ltd.	20 934	....	51 517
M.C.'s 77/9 etc.	Yilgarn	W.A. Plaster Mills	30 536	....	97 087
M.C.'s 9/43, 49, 50	Gascoyne	Agnew Clough Ltd.	25 381	....	87 437
M.C. 70/612 etc.	South-West	Gypsum Industries of Australia Pty. Ltd.	27 814	....	44 412
M.C. 70/15467	South-West	Nixon, P. F. & R. S.	237	....	1 185
M.C. 70/1115, 1116	South-West	McAndrew, R. W.	200	....	400
			105 102	....	(*a*) 282 038
			Plaster of Paris reported as manufactured during the year 39 366 tonnes from 56 735 tonnes of Gypsum by two companies.		
		GARNET SANDS			
M.C. 70/11563	South-West	Target Minerals N.L.	164	....	(*b*) 12 300
		IRON ORE			
		Pig Iron			
			Ore Treated Tonne	Pig Iron Recovered Tonne	
M.L. 77/2SA	Yilgarn	Wundowie Iron & Steel Industry	71 695	45 090	(*c*)(*d*) 3 903 976
		Ore Railed to Kwinana			
				Av. Assay Fe%	
M.L. 77/2SA	Yilgarn	Dampier Mining Co. Ltd.	*1 418 046	63·00	(*n*) 10 440 807
		Ore Shipped to Eastern States			
M.L. 4/10 etc.	West Kimberley	Dampier Mining Co. Ltd.	35 300	68·23	(*n*) 243 179
M.L. 52/244 SA	Peak Hill	Mt. Newman Mining Co. Ltd.	6 533 984	64·00	(*b*) 55 537 394
		Ore Exported Overseas			
M.L. 4/10 etc.	West Kimberley	Dampier Mining Co. Ltd.	277 698	68·33	(*b*) 2 826 284
M.L. 4/50 etc.	West Kimberley	Dampier Mining Co. Ltd.	2 266 800	67·60	(*b*) 24 468 856
M.L. 52/244SA	Peak Hill	Mt. Newman Mining Co. Ltd.	22 464 142	63·00	(*b*) 260 263 622
M.L. 47/4SA	West Pilbara	Hamersley Iron Pty. Ltd.	29 680 122	62·95	(*b*) 344 545 811
T.R. 2401H	West Pilbara	Cliffs W.A. Mining Co. Pty. Ltd.	8 786 142	57·19	(*b*) 71 148 618
M.L. 45/235SA	Pilbara	Goldsworthy Mining Ltd.	6 396 175	63·16	(*b*) 68 330 960
			77 858 409	....	837 805 531

*Includes 526 101 wet tonnes shipped to Eastern States and 34 166 wet tonnes exported overseas.

TABLE V.—*Quantity and Value of Minerals, other than Gold, Reported during the Year* 1977—*continued*

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonne	Metallic Content	Value $A
		Pellets (Exported Overseas)			
M.L. 47/4SA	West Pilbara	Hamersley Iron Pty. Ltd.	1 958 354	62·95	(*b*) 37 770 653
T.R. 2401H	West Pilbara	Cliffs W.A. Mining Co. Pty. Ltd.	3 700 434	62·54	(*b*) 75 533 803
			5 658 788	....	113 304 456
		***LIMESTONE (For Building Burning Purposes etc.)**			
M.C. 70/692	South-West	Bell Bros. Pty. Ltd.	20 827	....	18 327
M.C. 70/1662	South-West	Bell Bros. Pty. Ltd.	124 197	....	109 292
M.C. 70/1290	South-West	Bellombra, V.	5 529	....	15 776
M.C. 70/1298	South-West	Maffescioni M.C.	1 483	....	1 483
M.C. 70/1093	South-West	Piper Walker Pty. Ltd.	169	....	169
M.C. 70/2735 etc.	South-West	Ready Lime Putty Pty. Ltd.	2 807	....	2 807
M.C. 70/989	South-West	W.A. Limestone Co. Pty. Ltd.	23 997	....	59 992
M.C. 70/1660	South-West	Swan Portland Cement Ltd.	292 799	....	689 808
M.C. 70/709	South-West	Snader R.	25 892	....	12 739
M.L. 47/266/277 etc.	West Pilbara	Hamersley Iron Pty. Ltd.	49 088	....	36 955
M.L. 47/513	West Pilbara	Specified Services Pty. Ltd.	353	....	353
	South-West	†Unspecified Producers	222 727	....	234 350
			769 868	....	(*c*) 1 182 051
	*Incomplete.	†From private property not held under the Mining Act.			
		MAGNESITE			
M.C. 74/76, 77	Phillips River	Norseman Mining N.L.	23 897	....	637 315
M.C. 25/1109	East Coolgardie	Securico Nominees Pty. Ltd.	9	....	134
			23 906	....	(*b*) 637 449
		MANGANESE (Metallurgical Grade)			
				Av. Assay Mn%	
T.L. 52/14	Peak Hill	Universal Milling Co. Pty. Ltd.	2 267	47·5	(*b*) 39 663
		MINERAL BEACH SANDS			
		Ilmenite (*g*)			
				Av. Assay TiO2%	
M.C. 70/619 etc.	South-West	Westrailan Sands Pty. Ltd.	106 079	52·65	....
M.C. 70/746 etc.	South-West	Cable Sands Pty. Ltd.	95 324	54·25	....
Sussex Loc. 7	South-West	Cable Sands Pty. Ltd.	31 777	54·25	....
M.C. 70/389 etc.	South-West	Westralian Mineral Sands Pty. Ltd.	262 629	54·00	....
M.C. 70/7556	South-West	Jennings Mining Ltd.	192 775	59·42	....
M.C. 70/7062	South-West	Allied Eneabba Pty. Ltd.	231 915	61·03	....
M.C. 70/516	South-West	Western Titanium Ltd.	238 365	54·44	....
			1 158 864	56·59	
		Upgraded Ilmenite (*g*)			
M.C. 70/619 etc.	South-West	Westralian Sands Ltd.	15 405	67·78	
M.C. 70/516	South-West	Western Titanium Ltd.	27 409	92·40	(*b*) 22 210 438
		Reduced Ilmenite (*g*)			
M.C. 70/516	South-West	Western Titanium Ltd.	206	68·30	....
		Rutile (*g*) (*h*)			
				TiO2 Tonne	
M.C. 70/516	South-West	Western Titanium Ltd.	11 611	11 181·00	2 814 820
M.C. 70/7556 etc.	South-West	Jennings Mining Ltd.	30 133	28 971·96	5 762 661
M.C. 70/7062	South-West	Allied Eneabba Pty. Ltd.	37 901	36 431·73	8 105 973
M.C. 70/15565-9	South West	W.M.C. Mineral Sands Ltd.	8 522	8 155·68	1 863 066
M.C. 70/516	South-West	Western Titanium Ltd.	1 706	1 637·00	374 368
			89 873	86 377·37	(*b*) 18 920 888
		Leucoxene (*g*) (*h*)			
				TiO2 Tonne	
M.C. 70/619 etc.	South-West	Westralian Sands Ltd.	5 437	4 731	816 293
M.C. 70/516	South-West	Western Titanium Ltd.	1 669	1 484	242 599
			7 106	6 215	(*b*) 1 058 892

TABLE V.—*Quantity and Value of Minerals, other than Gold, Reported during the Year 1977—continued*

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonne	Metallic Content	Value $A
		Monazite (*g*) (*h*)			
				ThO2 Units	
M.C. 70/619 etc.	South-West	Westralian Sands Ltd.	1 999	11 295	318 338
M.C. 70/516	South-West	Western Titanium Ltd.	1 237	8 249	206 224
M.C. 70/7062	South West	Allied Eneabba Pty. Ltd.	1 696	10 158	270 702
M.C. 70/746 etc.	South-West	Cable Sands Pty. Ltd.	163	1 063	25 243
Sussex Loc. 7	South-West	Cable Sands Pty. Ltd.	55	358	8 414
			5 150	31 123	(*b*) 8 28 921
		Zircon (*g*) (*h*)			
				ZrO2 Tonne	
M.C. 70/619	South-West	Westralian Sands Pty. Ltd.	22 616	14 807	2 319 164
M.C. 70/746 etc.	South-West	Cable Sands Pty. Ltd.	3 016	1 990	215 242
Sussex Loc. 7	South-West	Cable Sands Pty. Ltd.	1 008	665	71 748
M.C. 70/7556	South-West	Jennings Mining Ltd.	10 609	6 981	796 389
M.C. 70/7062	South-West	Allied Eneabba Pty. Ltd.	42 404	28 000	3 683 319
M.C. 70/15565-9	South-West	W.M.C. Mineral Sands Ltd.	342	226	44 686
M.C. 70/516	South-West	Western Titanium Ltd.	12 144	8 060	915 001
M.C. 70/7002	South-West	Western Titanium Ltd.	12 141	8 064	1 058 290
			104 280	68 793	(*b*) 9 103 839
		NICKEL CONCENTRATES			
				Av. Assay Ni%	
M.C. 15/150 etc.	Coolgardie	Western Mining Corporation	307 010	11·99	166 513 259
M.L. 15/336	Coolgardie	Selcast Exploration Ltd.	16 754	17·10	11 993 728
M.L. 15/246	Coolgardie	Anaconda Australia Inc.	21 826	14·78	14 404 588
M.L. 24/39	Broad Arrow	Western Mining Corporation—Great Boulder Operations	3 684	13·30	2 353 419
M.C. 29/41	North Coolgardie	Western Mining Corporation—Great Boulder Operations	1 994	9·64	917 366
M.L.'s 38/32, 35	Mt. Margaret	Windarra Nickel Mines Pty. Ltd.	104 320	10·20	45 140 357
			455 588	....	(*o*) 241 322 717
		NICKEL ORE			
				Av. Assay Ni%	
M.C. 15/1288 M.L. 15/248	Coolgardie	Metals Exploration N.L.	71 541	3·29	7 049 104
		PALLADIUM (*h*) (Metallic By-Product Nickel Mining)			
				kg	
M.C. 15/150 etc.	Coolgardie	Western Mining Corporation	....	298·245	499 599
		PLATINUM (*h*) (Metallic By-Product Nickel Mining)			
				kg	
M.C. 15/150 etc.	Coolgardie	Western Mining Corporation	....	114·885	527 666
		RUTHENIUM (*h*) (Metallic By-Product Nickel Mining)			
				kg	
M.C. 15/150 etc.	Coolgardie	Western Mining Corporation	....	7·322	13 073
		OCHRE			
M.C. 20/26, 29	Murchison	Universal Milling Co. Pty. Ltd.	42	....	717
		PETROLEUM			
		Crude Oil			
			Barrels		
1 H	Ashburton	West Australian Petroleum Pty. Ltd.	11 703 393	....	(*m*) 46 337 303
LIC 1	South-West	West Australian Petroleum Pty. Ltd.	69 597	....	(*m*) 263 345
			11 772 990	....	46 600 648
		Natural Gas			
			$m^3 10^3$		
LIC 1	South-West	West Australian Petroleum Pty. Ltd.	813 787	....	(*p*) 14 707 822
		Condensate			
			Tonne		
LIC 1	South-West	West Australian Petroleum Pty. Ltd.	2 816	....	N.A.
		SALT			
		State Total Reported to Mines Dept.	3 705 476	....	(*b*) 26 138 310

TABLE V.—*Quantity and Value of Minerals, other than Gold, Reported during the Year* 1977—*continued*

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonne	Metallic Content	Value $A
		SEMI-PRECIOUS STONES			
		Amethyst	kg		
M.C. 9/444	Gascoyne	Soklich, F.	88	....	370
		Tiger Eye			
M.C. 47/3023	West Pilbara	Sterpini, M.	90	....	200
M.C. 47/3461, 3463	West Pilbara	Patterson, F. R. & Grant, B. J.	2 000	....	1 500
M.C. 45/7013, 7548	Pilbara	Ord Riddley Mining Pty. Ltd.	16 760	....	7 544
		Moss Opal			
M.C. 63/60	Dundas	Soklich, F.	16 748	....	8 687
		Chalcedony			
M.C. 9/498	Gascoyne	Soklich, F.	265	....	307
M.C. 9/1921	Gascoyne	Butler, R. G. & A. W.	5 887	....	3 946
		Serpentinite			
M.C. 45/1094	Pilbara	Stubbs, S. H.	455	....	1 820
			....	....	24 374
		TALC			
M.L. 70/433	South-West	Three Springs Talc Pty. Ltd.	60 734	....	N.A.
M.C. 52/190	Peak Hill	Westside Mines N.L.	29 732	....	N.A.
			90 466	....	....
		SILVER			
			kg		
		By-Product of Gold Mining	1 739·856	....	146 337
		By-Product of Nickel Mining	348·119	....	38 211
			2 087·975	....	184 548
		TANTO-COLUMBITE ORES AND CONCENTRATES (*g*) (*h*)			
				Ta205 Units	
M.L. 1/660 etc.	Greenbushes	Greenbushes Tin N.L.	151·41	6 362	2 063 669
M.C. 59/5052	Yalgoo	Warda Warra Mining Co. Pty. Ltd.	5·33	228	60 969
			156·74	6 590	(*b*) 2 124 638
		TIN CONCENTRATES (*g*) (*h*)			
				Sn Tonnes	
M.L. 1/660 etc.	Greenbushes	Greenbushes Tin N.L.	480·00	348·00	3 138 560
D.C. 45/195 M.C. 45/384	Pilbara	Pilbara Concentrates	140·56	101·20	1 051 600
D.C. 45/672, 700	Pilbara	Hart, D. N. & L. E.	5·03	3·41	25 780
	Pilbara	Crown Lands—District Generally	10·80	7·69	57 892
			636·39	460·30	(*b*) 4 273 832
		VERMICULITE			
M.C. 74/1567	Phillips River	Vermiculite Industries Pty. Ltd.	716	....	7 160

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 published prices.
(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 computed by the Department of Mines based on the Price of Alumina F.O.B. Jamaica.
(m) Value based on the price per barrel as assessed by the Industries Assistance Commission for Barrow Island Crude Oil a Kwinana.
(n) Nominal Value.
(o) Estimated F.O.B. Value based on the current price for Nickel Cathodes.
(p) Nominal Value at Well Head.

TABLE VI

Total Mineral Output of Western Australia

Recorded mineral production of the State to 31st December, 1977, 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)	,,	18 383 046	1 287 154 340
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	,,	29 035	1 558 580
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	,,	39 335	693 011
Quartzite	,,	12 396	70 039
Sandstone	,,	681	4 020
Sandstone (Donnybrook)	,,	84	3 486
Slate	,,	239	2 115
Spongolite	,,	3 968	43 597
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	,,	656 427	1 305 039
Fireclay	,,	2 271 415	1 943 826
Fullers Earth	,,	467	3 821
White Clay—Ball Clay	,,	32 167	228 021
Kaolin	,,	9 297	44 435
Coal	,,	52 707 127	218 560 857
Cobalt (Metallic By-Product Nickel Mining)	,,	1 637	5 429 688
Copper (Metallic By-Product Nickel Mining)	,,	10 041	9 025 647
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	,,	3 096	26 118
Emeralds (Cut and Rough)	carats	33 953	23 474
Emeralds	grams	739	5 803
Emery	tonne	21	750
Felspar	,,	76 143	615 083
Fergusonite	kg	300	783
Gadolinite	tonne	1	224
Garnet Sands	,,	164	12 300
Glass Sand	,,	1 565 343	1 207 000
Glauconite	,,	(*h*) 6 571	300 769
Gold (Mint and Export)	kg	2 177 309	1 258 732 392
Graphite	tonne	156	2 608
Gypsum	,,	2 221 767	5 521 184
Iron Ore—			
Pig Iron Recovered	tonne	1 138 064	64 229 813
Ore Exported	,,	580 669 432	4 481 725 686
Pellets Exported	,,	38 194 316	497 463 839
Locally Used Ore	,,	18 269 384	117 465 567
For Flux	,,	58 996	74 096
Jarosite	,,	10	75
Kyanite	,,	4 283	43 562
Lead Ores and Concentrates	,,	489 720	10 636 394
Limestone	,,	13 150 591	14 547 042
Lithium Ores—			
Petalite	,,	8 042	124 123
Spodumene	,,	108	3 627
Magnesite	,,	60 376	1 075 116
Manganese—			
Metallurgical Grade	,,	1 929 349	41 437 208

TABLE VI.—Total Mineral Output of Western Australia—*continued*

Mineral		Quantity	Value $A
Manganese—*continued*			
Battery Grade	,,	2 254	90 860
Low Grade	,,	5 135	81 538
Mica	,,	1 986	17 005
Mineral Beach Sands—			
Ilmenite Concentrates	,,	9 840 504	128 727 643
Monazite Concentrates	,,	39 947	5 256 037
Rutile	,,	236 408	43 149 101
Leucoxene	,,	109 315	9 482 269
Zircon	,,	824 991	52 594 551
Xenotime	,,	250	245 611
Crude Concentrates (Mixed)	,,	158	1 553
Molybdenite	,,	79	1 730
Nickel Concentrates	,,	2 895 804	1 137 190 978
Nickel Ore	,,	565 702	36 664 263
Ochre—			
Red	,,	13 374	264 900
Yellow	,,	455	5 956
Peat	,,	4 052	62 633
Petroleum (Crude Oil)	bbls.	141 065 778	391 480 426
(Natural Gas)	$m^3 10^3$	4 821 914	41 489 480
(Condensate)	tonne	22 959	N.A.
Palladium (By-Product Nickel Mining)	kg	850	1 548 125
Platinum (By-Product Nickel Mining)	kg	384	1 543 940
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	25 186 290	112 928 849
Semi Precious Stones—			
Amethyst	kg	27 166	23 799
Beryl (Coloured)	,,	91	100
Chalcedony	,,	83 093	35 213
Chrysoprase	,,	122 202	121 142
Dravite	,,	8 640	15 594
Green Beryl	,,	50	629
Magnesite	,,	5 073	2 780
Moss Opal	,,	109 792	46 504
Moss Agate	,,	16 257	4 800
Opal	,,	4	16 994
Opaline	,,	11	8
Opalite	,,	1 020	400
Serpentinite	,,	455	1 820
Prase	,,	3 955	730
Quartz	,,	33 484	13 545
Tiger Eye Opal	,,	20 447	14 412
Topaz (Blue)	,,	3	4
Tourmaline	,,	1 035	2 124
Sillimanite	tonne	2	26
Silver (*c*)	kg	427 280	9 368 932
Soapstone	tonne	574	3 856
Talc	,,	525 204	4 719 452
Tanto/Columbite Ores and Concentrates	,,	2 538	9 516 307
Tin	tonne	34 619	41 013 067
Tungsten Ore and Concentrates—			
Scheelite	,,	172	143 424
Wolfram	,,	310	125 810
Vermiculite	,,	4 237	44 891
Zinc (Metallic By-Product) (*d*)	,,	2 934	(*j*)
Zinc Ore (Fertiliser)	,,	20	200
Total Value to 31st December, 1977	....		$10 123 056 001

(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 Industries Assistance Commission 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 1976 and 1977.†

Company	1976			1977		
	Above	Under	Total	Above	Under	Total
Gold*—						
Central Norseman Gold Corporation N.L.	139	70	209	149	72	221
Kalgoorlie Lake View Pty. Ltd. (Boulder)	336	....	336	....	....	....
Kalgoorlie Lake View Pty. Ltd. (Mt. Charlotte)	11	94	105	19	131	150
Mulga Mines Pty. Ltd.	69	26	95	69	25	94
Newmont Pty. Ltd. (Telfer Project)	....	....	....	90	....	90
All Other Operators	260	148	408	204	112	316
State Average	815	338	1 153	531	340	871
Alumina (from Bauxite)—						
Alcoa of Australia (W.A.) N.L.	2 367	....	2 367	2 594	....	2 594
Coal—						
Griffin Coal Mining Co. Ltd.	275	....	275	272	....	272
Western Colleries Ltd.	257	328	585	267	323	590
Iron Ore—						
Charcoal Iron and Steel	11	....	11	8	....	8
Cliffs Western Australian Mining Co. Pty. Ltd.	287	....	287	366	....	366
Dampier Mining Co. Ltd.	513	....	513	555	....	555
Goldsworthy Mining Ltd.	866	....	866	879	....	879
Hamersley Iron Pty. Ltd.	1 940	....	1 940	2 034	....	2 034
Mt. Newman Mining Co. Pty. Ltd.	1 196	....	1 196	1 367	....	1 367
Mineral Beach Sands—						
Allied Eneabba Pty. Ltd.	213	....	213	203	....	203
Cable Sands Pty. Ltd.	60	....	60	65	....	65
Jennings Mining Limited	192	....	192	175	....	175
Western Mining Corporation	120	....	120	53	....	53
Western Mineral Sands Pty. Ltd.	45	....	45	45	....	45
Western Titanium Ltd.	219	....	219	226	....	226
Westralian Sands Ltd.	95	....	95	105	....	105
Nickel—						
Anaconda Australia Inc.	18	100	118	22	99	121
Western Mining Corporation-Great Boulder Operations	27	55	82	25	62	87
Metals Exploration N.L.	101	144	245	92	131	223
Selcast Exploration Ltd.	31	81	112	35	77	112
Western Mining Corporation	687	842	1 529	624	802	1 426
Windarra Nickel Mines Pty. Ltd.	265	138	403	239	125	364
Petroleum—Crude Oil—						
West Australian Petroleum Pty. Ltd.	104	....	104	101	....	101
Salt—						
Dampier Salt Limited	156	....	156	164	....	164
Lefroy Salt Co.	16	....	16	14	....	14
Leslie Salt Co.	45	....	45	39	....	39
Texada Mines Pty. Limited	176	....	176	166	....	166
All Other Minerals	223	....	223	346	25	371
State Total—Other than Gold	10 505	1 688	12 193	11 081	1 644	12 725

* 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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