DEPARTMENT OF MINES

ANNUAL REPORT 1978

REPORT OF THE
DEPARTMENT *of* MINES
WESTERN AUSTRALIA
FOR THE YEAR 1978

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

WILLIAM C. BROWN, Government Printer, Western Australia

To the Honourable the Minister for Mines.

Sir,

I have the honour to submit the Annual Report of the Department of Mines of the State of Western Australia for the year 1978, *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, 1979.

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Report of the Department of Mines for the Year 1978

DIVISION I

PART 1—GENERAL REMARKS

I have the honour to submit for your information a report on the Mining Industry for 1978.

The estimated value of the mineral output of Western Australia (including gold, coal and petroleum) for the year was $1 721·59 million an increase of $22·5 million or 1·3 per cent over the previous year and an all time record. This increase was due mainly to increased production and much higher prices for gold and petroleum but offset to some extent by lower values for nickel.

ROYALTIES

The royalty revenue for the year amounted to $54·03 million which is $·46 million below the figure for 1977. Iron Ore royalties amounted to 83 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 export and local use fell marginally from 83·6 million tonnes in 1977 to 82·5 million tonnes in 1978. However the value increased slightly from $951·1 to $957 million.

ALUMINA

Production of alumina by Alcoa of Australia (W.A.) Ltd from bauxite mined at Jarrahdale and Del Park was almost static at 3·4 million tonnes worth an estimated $277·6 million.

NICKEL

The total value of nickel in concentrates, briquettes and powder amounted to an estimated $186·1 million, a decrease of $62·2 million which highlights the effect of a world wide nickel price slump and a prolonged producer discounting war. Nickel concentrate and nickel ore produced during the year amounted to 404 528 and 64 413 tonnes respectively.

PETROLEUM

(Crude Oil and Natural Gas)

Sales of crude oil produced from Barrow Island during 1978 totalled 11·4 million barrels valued at $77·5 million compared with 11·7 million barrels valued at $46·6 million in 1977.

This large increase in value is a direct result of the Commonwealth Government policy of progressively moving the price of indigenous crude oil towards full world parity price and on August 15th 1978 it was announced that all indigenous crude production should be priced as such. As from that date the gross price of Barrow Island crude oil was $12·64 per barrel.

The Dongara and Mondarra Gas field supplied a total of 806·9 million cubic metres of natural gas valued at $17·2 million to sales outlets in the Perth-Fremantle-Kwinana and Pinjarra areas.

Interest in both on and off-shore petroleum exploration remained at a high level. As at the 31st December 1978, petroleum tenements covered an area of 173 540 square kilometres on-shore and 614 280 square kilometres off-shore.

GOLD

The estimated value of gold received at the Perth Mint during 1978 was $73 719 472 an increase of $31 146 635 over the 1977 figure. The quantity of gold received was 13 444 kilograms an increase of 3 617 kilograms over the 1977 figure.

The weighted average price obtained for Western Australian gold as recorded by the Department of Mines for 1978 computed to $170.55 per fine ounce (troy) compared to $134.75 for 1977.

The increased values and production quoted above reflects the continuing steady increase of world gold prices and subsequent renewed interest in gold mining in Western Australia.

The Telfer mine operated by Newmont Proprietary Limited was the State's major producer during the year contributing 7 000 kilograms of the above total of 13 444 kilograms.

Details of gold production reported to the Department as distinct from that received at the Perth Mint are set out in Table 1 of Part 2 of this report. The quantity of auriferous ore treated during the year was 1 280 532 tonnes compared to 1 071 980 tonnes in 1977 and the average number of persons engaged in gold mining increased from 871 in 1977 to 960 in 1978.

COAL

Coal production from the Collie Coal Field during the year showed an increase of 45 497 tonnes over that for 1977.

Figures for the last three years were:—

	1976	1977	1978
Tonnes	2 268 727	2 358 006	2 403 503
Total Value	$20 613 647	$23 172 093	$28 642 245
Average value per tonne	$9·090 0	$9·826 9	$11·916 9
Average effective workers	860	862	870
Proportion of deep mined coal	24·34%	22·82%	23·04%

OTHER MINERALS

Other Minerals valued at over a million dollars for the year were: Salt $27·4 million, Ilmenite $23·7 million, Rutile $22·4 million, Zircon $8·6 million, Leucoxene $1·8 million, Monazite $1·8 million, Tin concentrates $5·3 million, Tanto columbite $2·7 million, Limestone $1·3 million, Copper (by-product of Nickel Mining) $1·3 million. Pig Iron valued at $3·7 million was produced by the Wundowie Iron and Steel Industry.

OUTLOOK

The mining industry in Western Australia had its lowest growth rate for several years in 1978 showing an overall increase in value of only 1·3 per cent compared to a 14 per cent increase in the previous year.

Towards the end of the year there were indications that world wide cutbacks in demand for iron ore appeared to be easing particularly with the emergence of China on the world iron ore market.

There was also evidence that nickel producers appeared to be emerging from a depression caused by over-supply and subsequent price discounting and higher prices are expected in 1979.

It is pleasing to note the increasing activity in gold mining throughout the State and the continuation of increasing world gold prices should encourage further interest in that industry.

Overall the prospect of increased demand and rising prices augurs well for the continued development and prosperity of the State's Mining industry.

PART 2—COMPARATIVE STATISTICS

TABLE 1

SUMMARY

Mineral Production: Quantity, Value, Persons Engaged

	1977	1978	Variation
IRON ORE—			
Tonnes	83 562 287	**82 498 589**	— 1 063 698
Value ($A)	$955 013 963	**$956 965 039**	+ $1 951 076
Persons Engaged	5 209	**5 151**	— 58
ALUMINA—			
Tonnes	3 456 987	**3 470 380**	+ 13 393
*Value ($A)	$276 558 960	**$277 630 400**	+ $1 071 440
Persons Engaged	2 594	**2 804**	+ 210
NICKEL—			
Tonnes (Ore and Concentrates)	527 129	**468 941**	— 58 188
Value ($A)	$248 371 821	**$186 088 405**	— $62 283 416
Persons Engaged	2 333	**1 748**	— 585
PETROLEUM—CRUDE OIL—			
Barrels	11 772 990	**11 448 355**	— 324 635
†Value ($A)	$46 600 648	**$77 907 370**	+ $31 306 722
Persons Engaged	101	**102**	+ 1
GOLD—			
Reported to Department (Mine Production)—			
Ore Treated (Tonnes)	1 071 980	**1 280 532**	+ 208 552
Gold (Kilograms)	10 747	**13 332**	+ 2 585
Average Grade (grams per tonne)	10·00	**10·40**	+ ·4
Persons Engaged	871	**960**	+ 89
Mint and Export (Realised Production)—			
Gold (Kilograms)	9 827	**13 444**	+ 3 617
Estimated Value ($A) (including Overseas Gold Sales Premium)	$42 572 837	**$73 719 472**	+ $31 146 635
COAL—			
Tonnes	2 358 006	**2 403 503**	+ 45 497
Value ($A)	$23 172 093	**$28 642 245**	+ $5 470 152
Persons Engaged	862	**870**	+ 8
MINERAL BEACH SANDS—			
Tonnes	1 408 293	**1 329 014**	— 79 279
Value ($A)	$52 122 978	**$58 358 767**	+ $6 235 789
Persons Engaged	872	**736**	— 136
OTHER MINERALS—			
Value ($A)	$54 626 160	**$62 279 559**	+ $7 653 399
Persons Engaged	754	**695**	— 59
TOTAL ALL MINERALS—			
Value ($A)	$1 699 039 460	**$1 721 591 257**	+ $22 551 797
Persons Engaged	13 596	**13 066**	— 530

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

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

TABLE 1 (*a*)

Quantity and Value of Minerals other than Gold and Silver produced during 1977 *and* 1978

Western Australia

Mineral	1977 Quantity	1977 Value	1978 Quantity	1978 Value	Increase or Decrease for Year Compared with 1977 Quantity	Increase or Decrease for Year Compared with 1977 Value
	Tonnes	$	Tonnes	$	Tonnes	$
Alumina (from Bauxite)	3 456 987	276 558 960	3 470 380	277 630 400	+ 13,393	+ 1 071 440
Antimony	836	999 228	....	....	— 836	— 999 228
Barytes	7 117	87 450	....	....	— 7 117	— 87 450
Building Stone (Quartzite)	730	7 670	615	7 466	— 115	— 204
(Quartz)	4 388	141 414	3 516	103 088	— 872	— 38 326
(Spongolite)	17	253	225	3 350	+ 208	+ 3 097
Clays (Bentonite)	147	1 470	....	....	— 147	— 1 470
(Cement Clay)	28 390	70 969	22 927	57 317	— 5 463	— 13 652
(Fire Clay)	263 707	100 096	266 703	135 451	+ 2 996	+ 35 355
(White Clay—Ball Clay)	323	3 230	519	6 228	+ 196	+ 2 998
(Kaolin)	482	3 800	408	3 314	— 74	— 486
Coal	2 358 006	23 172 093	2 403 503	28 642 245	+ 45 497	+ 5 470 152
Cobalt (By-product of Nickel Mining)	201	712 884	172	854 689	— 29	+ 141 805
Copper (By-product of Nickel Mining)	1 831	1 734 785	1 501	1 330 712	— 330	— 404 073
Diatomaceous Earth	20	500	....	....	— 20	— 500
	Carats		Carats		Carats	
Emeralds (cut)	13 830	12 182	7	875	— 13 823	— 11 307
	Grams		Grams		Grams	
Emeralds (rough, uncut)	739	5 803	668	5 346	— 71	— 457
	Tonnes		Tonnes		Tonnes	
Felspar	645	16 055	889	29 278	+ 244	+ 13 223
Garnet Sands	164	12 300	479	33 474	+ 315	+ 21 174
Glass Sand	137 181	73 131	104 697	36 505	— 32 484	— 36 626
Gypsum	105 102	282 038	159 537	588 660	+ 54 435	+ 306 622
Iron Ore (Pig Iron Recovered)	45 090	3 903 976	42 691	3 760 667	— 2 399	— 143 309
(Exported and locally used)	77 858 409	837 805 531	76 119 045	830 516 035	— 1 739 364	— 7 289 496
(Pellets)	5 658 788	113 304 456	6 379 544	126 449 004	+ 720 756	+ 13 144 548
Limestone	769 868	1 182 051	715 490	1 373 387	— 54 378	+ 191 336
Magnesite	23 906	637 449	....	....	— 23 906	— 637 449
Manganese (Metallurgical Grade)	2 267	39 663	922	16 140	— 1 345	— 23 523
Mineral Beach Sands (Ilmenite)	1 201 884	22 210 438	1 039 331	23 687 589	— 162 553	+ 1 477 151
(Monazite)	5 150	828 921	10 457	1 848 767	+ 5 307	+ 1 019 846
(Rutile)	89 873	18 920 888	114 643	22 422 136	+ 24 770	+ 3 501 248
(Leucoxene)	7 106	1 058 892	13 273	1 773 702	+ 6 167	+ 714 810
(Zircon)	104 280	9 103 839	151 297	8 614 435	+ 47 017	— 489 404
(Xenotime)	....	....	13	12 138	+ 13	+ 12 138
Nickel Concentrates	455 588	241 322 717	404 528	179 630 243	— 51 060	— 61 692 474
Nickel Ore	71 541	7 049 104	64 413	6 458 162	— 7 128	— 590 942
Ochre	42	717	281	4 776	+ 239	+ 4 059
	kg		kg		kg	
Palladium (By-product of Nickel Mining)	298	499 599	230	418 136	— 68	— 81 463
Platinum (By-product of Nickel Mining)	115	527 666	92	557 698	— 23	+ 30 032
Ruthenium (By-product of Nickel Mining)	7	13 073	....	....	— 7	— 13 073
	bbls		bbls		bbls	
Petroleum—Crude Oil (barrels)	11 772 990	46 600 648	11 448 355	77 907 370	— 324 635	+ 31 306 722
	$m^3 10^3$		$m^3 10^3$		$m^3 10^3$	
Natural Gas ($m^3 10^3$)	813 787	14 707 822	806 865	17 232 225	— 6 922	+ 2 524 403
	Tonnes		Tonnes		Tonnes	
Condensate	2 186	N.A.	2 368	N.A.	— 448	N.A.
Salt	3 705 476	26 138 310	3 888 065	27 410 412	+ 182 589	+ 1 272 102
	kg		kg		kg	
Semi-precious Stones	42 293	24 374	11 523	10 575	— 30 770	— 13 799
	Tonnes		Tonnes		Tonnes	
Talc	90 466	N.A.	120 352	N.A.	+ 29 886	N.A.
Tanto/Columbite Ores and Concentrates	157	2 124 638	139	2 751 264	— 18	+ 626 626
Tin Concentrates	636	4 273 832	692	5 341 725	+ 56	+ 1 067 893
Tungsten Ores and Concentrates (scheelite)	....	....	140	1 108	+ 140	+ 1 108
Vermiculite	716	7 160	244	2 440	— 472	— 4 720
		1 656 282 075		1 647 668 532		— 8 613 543

TABLE 1 (*b*)

Quantity and Value of Gold and Silver received at the Perth Mint during the years 1977 *and* 1978

Mineral	1977		1978		Increase or Decrease for Year Compared with 1977	
	Quantity	Value	Quantity	Value	Quantity	Value
	kg	$	kg	$	kg	$
Gold	*9 827·184	42 572 837	*13 444·140	73 719 472	+ 3 616·956	+ 31 146 635
Silver	*2 087·975	184 548	*2 178·107	203 253	+ 90·132	+ 18 705
Total		42 757 385		73 922 725		+ 31 165 340
Grand Total		1 699 039 460		1 721 591 257		+ 22 551 797

* 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 1977
	1977	1978	
	$	$	$
Alumina	1 379 403.03	1 720 808.47	+ 341 405.44
Amethyst	1.85	.53	— 1.32
Antimony	191.95	30.24	— 161.71
Barytes	350.39	....	— 350.39
Bentonite	7.23	....	— 7.23
Building Stone	534.22	345.09	— 189.13
Chalcedony	21.18	16.77	— 4.41
Clay	15 791.10	15 897.69	+ 106.59
Coal	58 616.05	64 334.73	+ 5 718.68
Cobalt	3 705.89	6 322.22	+ 2 616.33
Diatomaceous Earth	3.00	....	— 3.00
Emeralds	120.52	....	— 120.52
Felspar	19.35	36.61	+ 17.26
Glass Sand	13 973.28	4 450.31	— 9 522.97
Gold	1.00	9.00	+ 8.00
Gypsum	6 237.57	6 808.37	+ 570.80
Ilmenite	346 333.25	325 529.84	— 20 803.41
Iron Ore	45 887 023.66	45 006 521.75	— 880 501.91
Leucoxene	31 073.39	21 407.44	— 9 665.95
Limestone	25 350.43	23 858.47	— 1 491.96
Magnesite	3 529.28	....	— 3 529.28
Manganese	358.50	138.34	— 220.16
Monazite	17 842.00	29 598.52	+ 11 756.52
Moss Opal	31.40	8.94	— 22.46
Natural Gas	726 742.96	777 685.90	+ 50 942.94
Natural Gas-Condensate	2 916.38	4 571.48	+ 1 655.10
Nickel	3 264 079.02	1 836 545.82	— 1 427 533.20
Ochre	.75	7.32	+ 6.57
Opal	10.59	....	— 10.59
Oil (Crude)	1 847 891.28	3 170 681.67	+ 1 322 790.39
Palladium	1 161.60	2 337.89	+ 1 176.29
Platinum	1 208.42	2 353.10	+ 1 144.68
Ruthenium	30.73	....	— 30.73
Rutile	412 304.50	563 783.36	+ 151 478.86
Salt	220 123.59	212 859.61	— 7 263.98
Scheelite	....	5.00	+ 5.00
Serpentenite	....	9.20	+ 9.20
Talc	7 443.90	11 547.69	+ 4 103.79
Tanto-Columbite	11 310.20	12 566.40	+ 1 256.20
Tiger Eye	8.50	....	— 8.50
Tiger Iron	....	37.72	+ 37.72
Tin	116.35	672.67	+ 556.32
Vermiculite	35.80	12.20	— 23.60
Xenotime	67.46	242.77	+ 175.31
Zircon	210 164.41	210 249.58	+ 85.17
Total	54 496 135.96	54 032 292.71	— 463 843.25

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	
	1977	1978	1977	1978	1977	1978
	kg	kg	Per cent	Per cent	grams	grams
Kimberley	....	....	....	....	....	....
West Kimberley	....	....	....	....	....	....
Pilbara	4 986·356	7 070·873	46·53	53·23	15·4	16·2
West Pilbara	....	....	....	....	....	....
Ashburton	....	....	....	....	....	....
Gascoyne	....	....	....	....	....	....
Peak Hill	....	1·745	....	·01	....	·8
East Murchison	2·600	·363	·02	....	26·3	4·2
Murchison	43·962	43·952	·41	·33	10·9	8·4
Yalgoo	·443	2·194	....	·02	4·9	5·9
Mount Margaret	34·624	41·010	·32	·31	6·9	5·0
North Coolgardie	23·609	18·629	·22	·15	5·8	6·1
Broad Arrow	13·624	12·994	·13	·10	3·2	2·5
North-East Coolgardie	·652	·547	·01	....	4·1	2·9
East Coolgardie	2 515·104	3 243·304	23·47	24·41	4·5	5·0
Coolgardie	127·102	99·737	1·19	·75	14·9	8·0
Yilgarn	57·692	37·478	·54	·28	16·9	12·6
Dundas	2 908·503	2 711·291	27·14	20·41	18·7	18·0
Phillips River	2·211	....	·02	....	30·3	....
South West Mineral Field	....	....	....	....	....	....
State Generally	....	....	....	....	....	....
	10 716·482	13 284·117	100·00	100·00	10·0	10·4

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

TABLE 4

Total Coal Output from Collie River Mineral Field, 1977 *and* 1978, *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
1977	538 028	8 050 325	124	323	....	....	1 666	1 204
1978	553 849	10 025 567	116	319	....	....	1 736	1 273
Open Cut Mining—								
1977	1 819 978	15 121 768	....	....	415	4 385	....	....
1978	1 849 654	18 616 678	....	....	435	4 252	....	....
Totals—								In All Mines
1977	2 358 006	23 172 093	124	323	415	....	....	2 735
1978	2 403 503	28 642 245	116	319	435	....	....	2 763

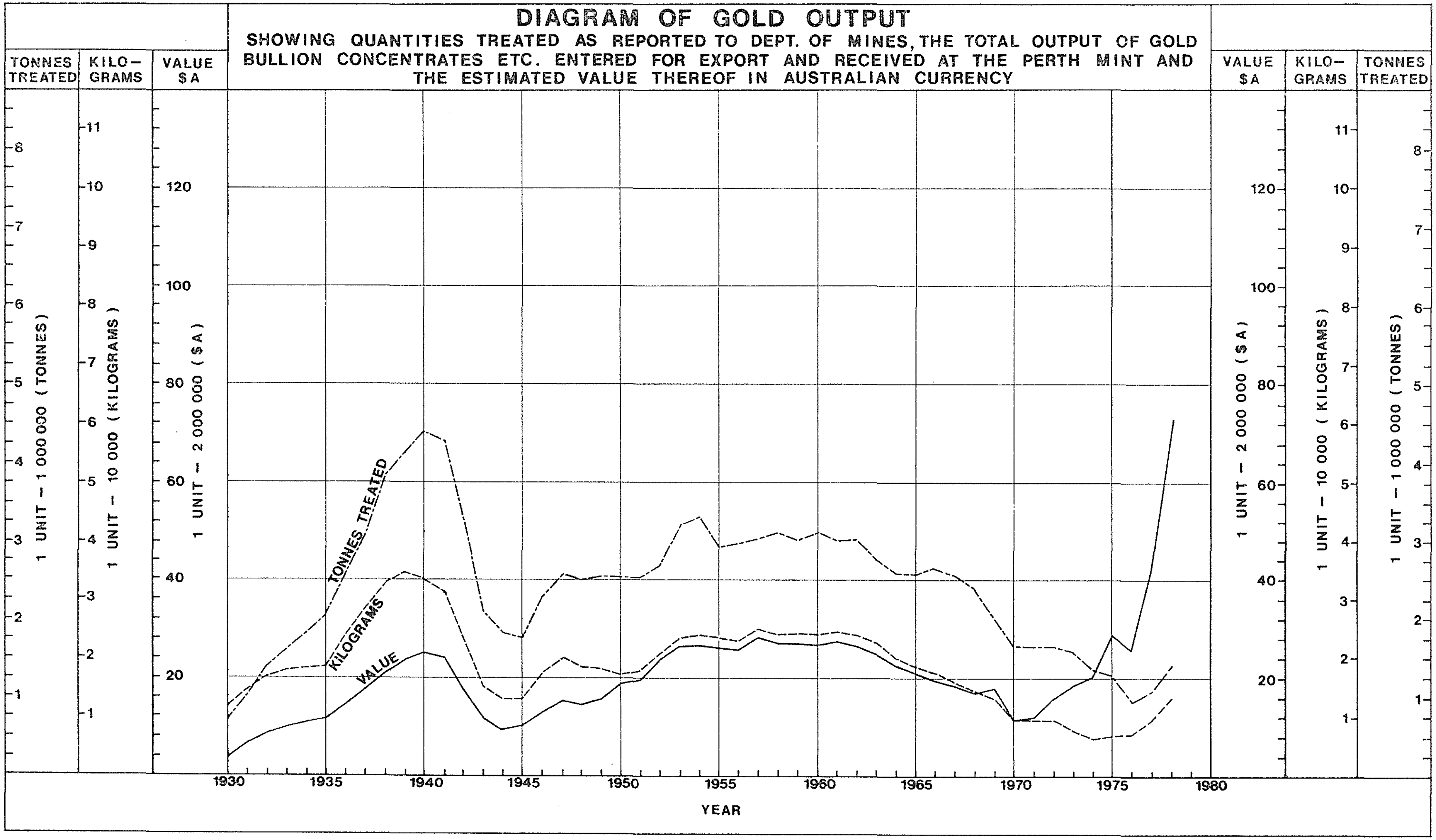
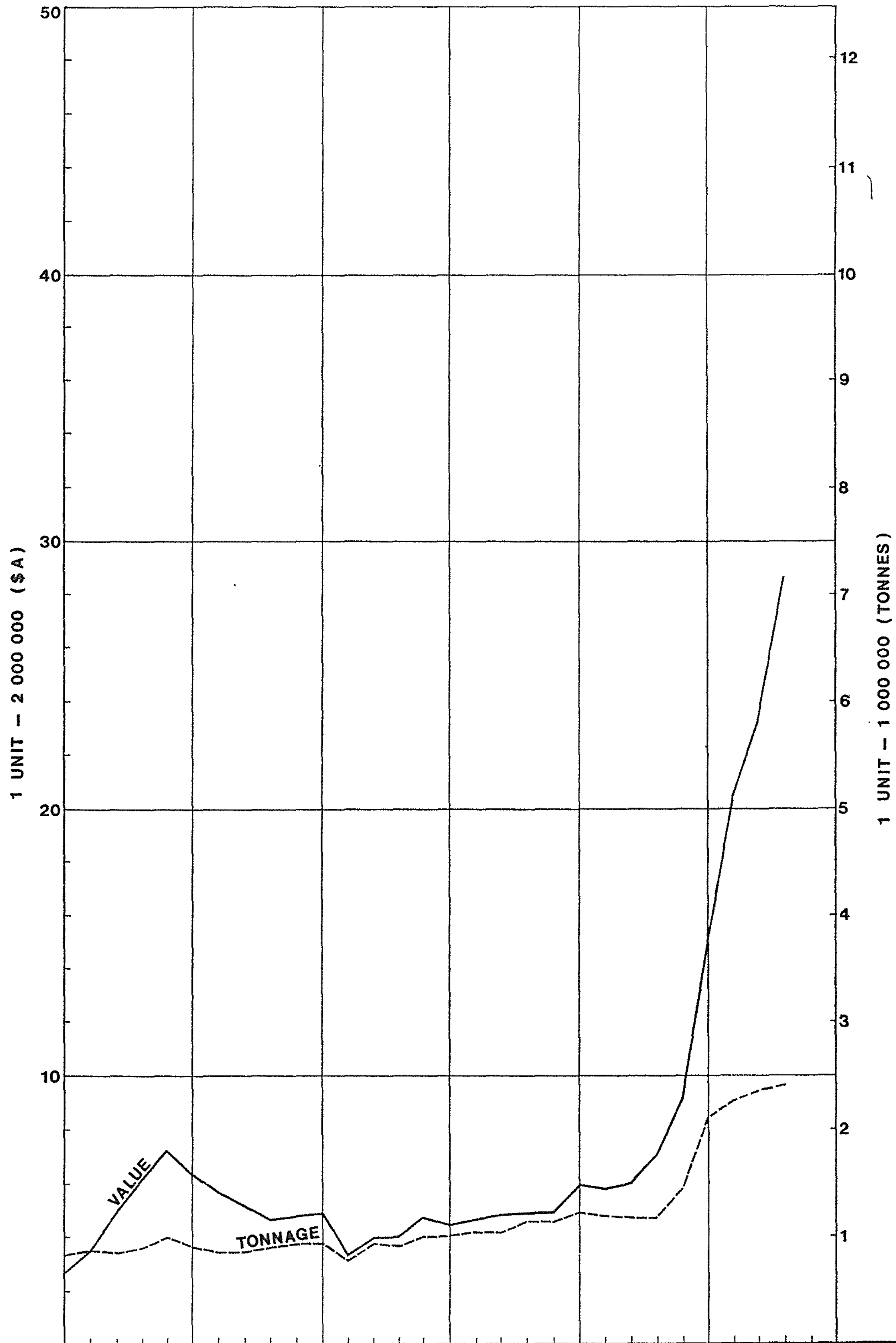


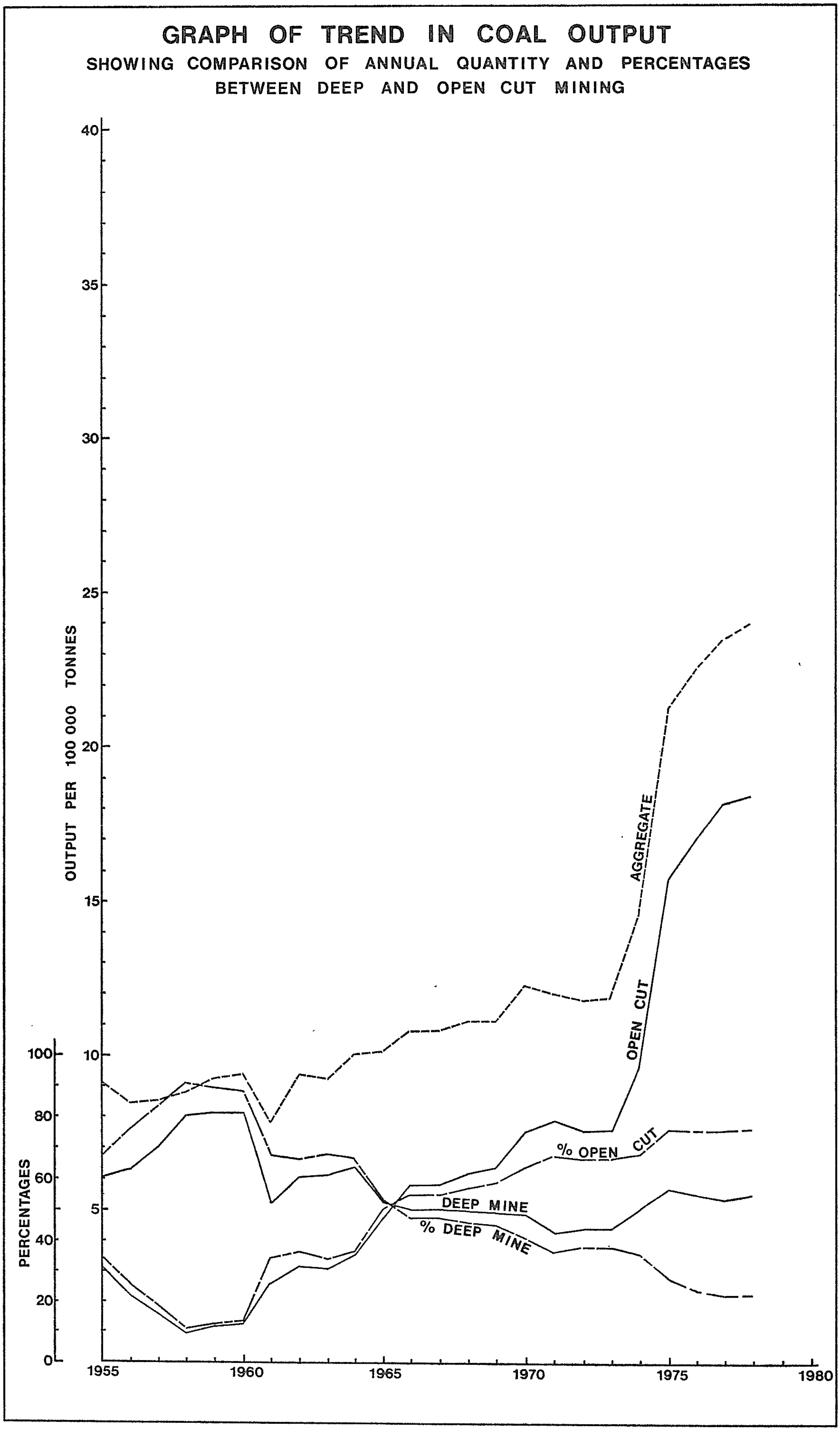
DIAGRAM OF GOLD OUTPUT
SHOWING QUANTITIES TREATED AS REPORTED TO DEPT. OF MINES, THE TOTAL OUTPUT OF GOLD BULLION CONCENTRATES ETC. ENTERED FOR EXPORT AND RECEIVED AT THE PERTH MINT AND THE ESTIMATED VALUE THEREOF IN AUSTRALIAN CURRENCY
TONNES TREATED
KILO-GRAMS
VALUE $A
1 UNIT - 1 000 000 (TONNES)
1 UNIT - 10 000 (KILOGRAMS)
1 UNIT - 2 000 000 ($A)
TONNES TREATED
KILOGRAMS
VALUE
YEAR
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980

GRAPH OF COAL OUTPUT

SHOWING QUANTITIES AND VALUES AS REPORTED TO DEPT. OF MINES



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



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

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 1978 *and in force as at* 31*st December*, 1978 (*compared with* 1977)

	Applied for				In Force			
	1977		**1978**		1977		**1978**	
	No.	Hectares	No.	Hectares	No.	Hectares	No.	Hectares
Gold—								
Gold Mining Leases	315	2 630	**701**	**5 979**	1 918	17 878	**2 309**	**18 556**
Dredging Claims	....	....	**75**	**2 810**	4	395	**16**	**159**
Prospecting Areas	227	1 805	**361**	**2 820**	207	1 646	**281**	**2 171**
Temporary Reserves	....	....	**32**	**3 751**	11	1 269	**52**	**6 080**
Totals	542	4 435	**1 169**	**15 360**	2 140	21 188	**2 658**	**26 966**
Coal—								
Coal Mining Leases	1 719	202 773	**129**	**15 051**	146	16 431	**121**	**13 579**
Prospecting Areas	7	6 876	**2**	**1 197**	2	2 384	**4**	**5 445**
Temporary Reserves	3	59 950	**3**	**58 500**	5	63 774	**11**	**171 508**
Totals	1 729	269 599	**134**	**74 748**	153	82 589	**136**	**190 532**
Other Minerals—								
Mineral Leases	25	1 936	**22**	**22 390**	730	69 038	**770**	**72 980**
Dredging Claims	49	3 379	**186**	**20 196**	215	9 028	**260**	**13 736**
Mineral Claims	3 657	408 944	**9 234**	**1 056 078**	13 264	1 370 745	**11 804**	**1 225 039**
Prospecting Areas	10	85	**20**	**173**	9	69	**16**	**127**
Temporary Reserves	116	1 696 950	**230**	**3 769 934**	395	5 417 943	**465**	**9 082 769**
Totals	3 857	2 111 294	**9 692**	**4 868 771**	14 613	6,866 823	**13 315**	**10 394 651**
Other Holdings—								
Miners' Homestead Leases	....	....	**2**	**284**	320	13 911	**314**	**12 810**
Miscellaneous Leases	4	17	**5**	**24**	95	729	**102**	**750**
Residential Areas	....	....	**1**	**1**	44	15	**45**	**16**
Business Areas	1	1	....	....	16	7	**16**	**7**
Machinery Areas	2	7	**1**	**2**	25	35	**24**	**34**
Tailings Areas	....	....	**4**	**36**	25	40	**19**	**28**
Garden Areas	6	10	**5**	**10**	84	138	**81**	**126**
Quarrying Areas	46	411	**78**	**685**	208	1 667	**247**	**1 990**
Water Rights	3	6	**11**	**33**	95	5 793	**95**	**5 802**
Licenses to Treat Tailings	73	....	**123**	....	68	....	**70**	....
Totals	135	452	**230**	**1 075**	980	22 335	**1 013**	**21 563**
Grand Totals	6 263	2 385 780	**11 225**	**4 959 954**	17 886	6 992 935	**17 122**	**10 633 712**

TABLE 5 (*a*)

SPECIAL ACTS

Leases applied for during 1978 *and in force as at* 31*st December*, 1978 (*Compared with* 1977)

	Applied for				In Force			
	1977		**1978**		1977		**1978**	
	No.	Hectares	No.	Hectares	No.	Hectares	No.	Hectares
Bauxite	....	....	....	....	7	1 269 618·00	**7**	**1 269 618·00**
Iron	....	....	....	....	10	365 361.00	**10**	**365 361.00**
Salt	....	....	....	....	5	257 465.96	**5**	**257 465.96**
Other	....	....	**1**	**1 709.38**	....	....	**1**	**966.20**
Totals	....	....	**1**	**1 709.38**	22	1 892 444.96	**23**	**1 893 411.16**

TABLE 5 (*b*)

PETROLEUM ACTS

Permits, Licenses and Leases applied for during 1978 *and in force as at* 31*st December*, 1978 (*Compared with* 1977)

Holding	Applied for				In Force			
	1977		**1978**		1977		**1978**	
	No.	Blocks	No.	Blocks	No.	Blocks	No.	Blocks
Onshore—								
Petroleum Act, 1967—								
Exploration Permits	1	1 285	**2**	**242**	35	2 037	**31**	**2 187**
Production Licenses	....	....	....	....	2	9	**2**	**9**
Petroleum Leases (Barrow Island)	....	....	....	....	1	8	**1**	**8**
Totals	1	1 285	**2**	**242**	38	2 054	**34**	**2 204**
Offshore—								
Petroleum (Submerged Lands) Act 1967—								
Exploration Permits	32	9 170	**10**	**1 320**	34	6 550	**41**	**7 633**
Production Licenses	5	22	....	....	....	....	....	....
Petroleum Leases (Barrow Marine)	....	....	....	....	1	12	**1**	**12**
Totals	37	9 199	**10**	**1 320**	35	6 562	**42**	**7 645**
Grand Totals	38	10 484	**12**	**1 562**	73	8 616	**76**	**9 849**

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

Holding	Applied for				In Force			
	1977		**1978**		1977		**1978**	
	No.	Km	No.	Km	No.	Km	No.	Km
Onshore—								
Petroleum Pipelines Act, 1969—								
Pipeline Licenses	....	....	....	....	5	444·87	**5**	**444·87**
Totals	....	....	....	....	5	444·87	**5**	**444·87**

TABLE 5 (*c*)

MINING ACT, 1904

Leases in Force as at 31*st December,* 1978 *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	12	93·01	10	1 082·39	....	....	....	....
Broad Arrow	51	367·23	26	2 735·94	....	....	....	....
Bulong	30	252·58	....	....	....	....	....	....
Collie	....	....	58	6 751·73	....	....	....	....
(Private Property)	....	....	2	210·43	....	....	....	....
Coolgardie	138	1 022·26	371	41 306·90	22	752·30	3	11·72
Cue	36	324·40	1	41·17	3	446·33	....	....
Day Dawn	27	248·69	....	....	1	8·09	....	....
Dundas	510	4 546·64	....	....	16	349·15	....	....
East Coolgardie	393	2 916·88	5	465·45	60	1 312·86	58	482·76
Gascoyne	1	9·71	....	....	....	....	....	....
Greenbushes	....	....	75	3 133·08	6	168·14	....	....
Kanowna	57	455·45	5	226·41	12	284·03	....	....
Kimberley	3	26·70	....	....	....	....	....	....
Kunanalling	23	173·28	....	....	2	211·43	1	0·25
Kurnalpi	8	77·12	....	....	....	....	....	....
Lawlers	54	414·80	....	....	5	449·16	....	....
Marble Bar	164	1 344·01	61	6 737·84	....	....	11	83·63
Meekatharra	111	882·74	....	....	9	512·07	1	0·04
Menzies	61	500·20	1	28·39	7	299·43	....	....
Mount Magnet	120	864·24	....	....	....	....	....	....
Mount Malcolm	56	431·35	....	....	8	311·57	1	0·30
Mount Margaret	57	534·78	59	6 011·61	7	23·43	....	....
Mount Morgans	39	337·92	....	....	....	....	....	....
Niagara	19	155·32	....	....	1	8·09	....	....
Northampton	....	....	3	25·07	....	....	....	....
(Private Property)	....	....	....	....	....	....	....	....
Nullagine	19	132·22	....	....	2	8·89	2	19·42
Peak Hill	20	142·38	6	274·35	4	99·94	....	....
Phillips River	4	21·36	24	1 297·39	105	5 620·52	1	2·42
(Private Property)	....	....	9	1 085·84	....	....	....	....
South West	1	4·04	35	3 590·81	....	....	1	2·00
(Private Property)	....	....	42	4 354·88	....	....	....	....
Ularring	31	255·91	....	....	....	....	....	....
West Kimberley	....	....	23	305·41	....	....	6	52·63
West Pilbara	12	109·82	24	582·41	2	4·44	8	69·16
Wiluna	2	19·30	22	2 648·60	17	1 569·07	2	1·20
Yalgoo	29	193·54	6	425·60	....	....	....	....
Yerilla	39	323·70	....	....	1	4·04	....	....
Yilgarn	159	1 190·95	10	940·11	24	366·51	7	24·07
(Private Property)	15	134·45	....	....	....	....	....	....
Outside Proclaimed	....	....	....	....	....	....	....	....
Totals	2 306	18 555·47	891	85 726·32	314	12 809·49	102	749·30

	No.	Hectares
Gold Mining Leases on Crown Land	2 291	18 421·02
Gold Mining Leases on Private Property	15	134·45
Mineral Leases on Crown Land	838	8 075·29
Mineral Leases on Private Property	53	5 651·15
Miner's Homestead Leases on Crown Land	314	12 809·49
Other Leases on Crown Land	102	749·30
Other Leases on Private Property	....	....

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TABLE 5 (*d*)

MINING ACT, 1904

Claims and Authorised Holdings in Force at 31*st December*, 1978 *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	1	9·71	....	....	243	24 904·18	....	....	....	....	....	....	....	....	....	....	2	16·70	....	....
Black Range	8	58·23	....	....	195	19 718·15	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Broad Arrow	25	192·59	....	....	66	7 174·37	1	0·40	....	....	....	....	....	....	....	....	2	10·00	5	4·83
Bulong	7	57·27	....	....	14	1 417·01	....	....	....	....	....	....	....	....	....	....	....	....	1	3·37
Collie	....	....	....	....	....	....	....	....	....	....	1	2·00	....	....	....	....	1	4·21	....	....
(Private Property)	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Coolgardie	83	611·28	....	....	332	32 269·45	3	1·20	....	....	1	2·02	....	....	7	11·73	32	268·72	4	27·37
Cue	7	43·17	....	....	300	32 035·24	1	0·10	....	....	1	2·02	....	....	....	....	1	9·71	1	1·00
Day Dawn	3	24·27	....	....	16	1 739·84	....	....	....	....	....	....	....	....	4	8·08	....	....	....	....
Dundas	....	....	....	....	179	13 078·06	....	....	....	....	....	....	....	....	....	....	....	....	....	....
(Private Property)	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
East Coolgardie	17	114·44	....	....	117	12 693·13	28	11·20	....	....	1	0·80	10	18·57	12	21·80	15	114·82	12	12·57
Gascoyne	2	10·92	2	165·91	263	24 266·41	....	....	....	....	....	....	....	....	....	....	4	37·22	....	....
Greenbushes	....	....	....	....	2	12·13	....	....	....	....	....	....	....	....	8	13·59	....	....	2	13·50
Kanowna	6	55·43	....	....	150	16 743·23	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Kimberley	....	....	....	....	1 354	154 972·72	....	....	....	....	....	....	....	....	3	4·03	12	84·05	....	....
Kunanalling	19	157·96	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Kurnalpi	5	48·54	....	....	99	11 475·37	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Lawlers	6	49·68	....	....	730	79 223·63	....	....	....	....	1	0·40	....	....	....	....	3	29·10	....	....
Marble Bar	14	96·76	246	11 087·12	874	80 819·38	1	0·20	2	0·80	8	12·21	1	2·02	18	30·87	51	443·81	30	5 675·78
Meekatharra	5	32·76	....	....	269	31 265·13	....	....	....	....	....	....	....	....	....	....	....	....	3	3·22
Menzies	4	33·98	....	....	183	19 464·69	....	....	....	....	....	....	....	....	1	0·40	....	....	....	....
Mount Magnet	10	83·28	....	....	103	12 210·09	1	0·40	....	....	....	....	....	....	7	3·60	....	....	3	3·62
Mount Malcolm	12	105·10	....	....	555	60 923·56	....	....	....	....	....	....	....	....	9	14·12	1	2·02	2	0·80
Mount Margaret	5	46·74	....	....	281	31 930·21	....	....	....	....	....	....	....	....	2	2·82	3	29·13	1	0·40
Mount Morgans	2	13·20	....	....	299	35 000·16	....	....	....	....	....	....	....	....	....	....	....	....	1	0·40
Niagara	3	24·27	....	....	40	5 229·50	....	....	....	....	1	1·80	....	....	....	....	....	....	3	2·40
Northampton	....	....	....	....	50	2 710·73	....	....	....	....	....	....	....	....	....	....	....	....	....	....
(Private Property)	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Nullagine	4	20·91	1	121·40	290	16 017·65	....	....	....	....	1	0·40	3	1·60	1	0·20	....	....	12	13·27
Peak Hill	3	29·10	....	....	290	29 492·90	....	....	2	0·80	3	5·02	2	3·30	2	3·96	7	67·97	2	8·53
Phillips River	....	....	....	....	127	10 100·71	....	....	....	....	1	0·80	1	0·80	....	....	1	2·02	....	....
(Private Property)	....	....	....	....	53	5 613·55	....	....	....	....	....	....	....	....	....	....	....	....	....	....
South West	3	2 484·37	14	1 297·12	212	28 834·15	....	....	....	....	....	....	....	....	....	....	2	12·70	1	2·42
(Private Property)	....	....	....	....	815	67 328·00	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Ularring	4	38·84	....	....	30	3 203·74	....	....	....	....	1	0·40	2	1·61	....	....	....	....	3	1·60
West Kimberley	....	....	1	121·40	1 153	131 001·17	....	....	....	....	5	4·04	....	....	....	....	23	137·53	2	19·42
West Pilbara	1	2·02	2	15·37	473	41 053·29	4	1·60	6	2·40	....	....	....	....	4	7·67	84	698·44	....	....
Wiluna	....	....	....	....	752	85 599·53	....	....	....	....	....	....	....	....	....	....	....	....	1	0·40
Yalgoo	10	86·89	....	....	443	46 548·48	....	....	6	2·40	....	....	....	....	....	....	2	11·73	....	....
Yerilla	8	62·88	....	....	198	22 814·55	....	....	....	....	....	....	....	....	....	....	....	....	5	4·82
Yilgarn	19	157·45	....	....	237	23 223·14	6	0·65	....	....	2	2·01	....	....	3	2·59	1	9·71	1	1·66
(Private Property)	....	....	....	....	6	554·44	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Outside Proclaimed	....	....	....	....	21	2 349·38	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Totals	289	4 752·04	266	12 808·32	11 804	1 225 038·29	45	15·75	16	6·40	24	33·12	19	27·90	81	125·46	247	1 989·59	95	5 801·38

TABLE 6

MEN EMPLOYED

Average number of Men employed in Mining during 1977 and 1978

Goldfield	District	Gold		Other Minerals		Total	
		1977	**1978**	1977	**1978**	1977	**1978**
Kimberley	....	....	....	....	....	....	....
West Kimberley	....	....	....	413	**444**	413	**444**
Pilbara	Marble Bar	104	**107**	943	**879**	1 047	**986**
	Nullagine	94	**91**	96	....	190	**91**
West Pilbara	....	....	....	2 574	**2 619**	2 574	**2 619**
Ashburton	....	....	....	101	**104**	101	**104**
Gascoyne	....	....	....	176	**178**	176	**178**
Peak Hill	....	....	**4**	1 378	**1 323**	1 378	**1 327**
East Murchison	Lawlers	....	**2**	....	....	....	**2**
	Wiluna	....	**1**	....	....	....	**1**
	Black Range	5	....	....	....	5	....
Murchison	Cue	2	**5**	7	**4**	9	**9**
	Meekatharra	22	**32**	....	....	22	**32**
	Day Dawn	....	....	....	....	....	....
	Mt. Magnet	15	**17**	....	....	15	**17**
Yalgoo	....	10	**14**	5	**8**	15	**22**
Mt. Margaret	Mt. Morgans	3	**4**	....	....	3	**4**
	Mt. Malcolm	28	**31**	....	....	28	**31**
	Mt. Margaret	6	**6**	364	**201**	370	**207**
North Coolgardie	Menzies	22	**10**	....	....	22	**10**
	Ularring	17	**16**	1	**1**	18	**17**
	Niagara	2	**4**	....	....	2	**4**
	Yerilla	4	**5**	....	....	4	**5**
Broad Arrow	....	19	**12**	65	....	84	**12**
North-East Coolgardie	Kanowna	1	**3**	....	....	1	**3**
	Kurnalpi	2	**3**	....	....	2	**3**
East Coolgardie	East Coolgardie	200	**224**	22	....	222	**224**
	Bulong	....	**3**	2	....	2	**3**
Coolgardie	Coolgardie	52	**90**	1 896	**1 560**	1 948	**1 650**
	Kunanalling	7	**12**	....	....	7	**12**
Yilgarn	....	31	**42**	154	**153**	185	**195**
Dundas	....	223	**222**	2	**2**	225	**224**
Phillips River	....	2	....	....	**2**	2	**2**
South-West Mineral Field	....	....	....	3 553	**3 621**	3 553	**3 621**
Northampton Mineral Field	....	....	....	....	....	....	....
Greenbushes Mineral Field	....	....	....	111	**134**	111	**134**
Outside Proclaimed Goldfield	....	....	....	....	**3**	....	**3**
Collie Coalfield	....	....	....	862	**870**	862	**870**
Total—All Minerals	....	871	**960**	12 725	**12 106**	13 596	**13 066**

Minerals Other than Gold—	1977	**1978**
Alumina (from Bauxite)	2 594	**2 804**
Antimony	94	....
Barytes	6	....
Building Stone	6	**6**
Clays	17	**14**
Coal	862	**870**
Diatomaceous Earth	2	....
Emeralds	8	**4**
Felspar	4	**4**
Garnet Sands	2	**2**
Glass Sand	11	**11**
Gypsum	14	**14**
Iron Ore	5 209	**5 151**
Limestone	24	**20**
Magnesite	2	....
Mineral Beach Sands	872	**736**
Nickel	2 333	**1 748**
Petroleum (Crude Oil)	101	**102**
(Natural Gas)	9	**9**
Ochre	....	**1**
Salt	383	**400**
Semi Precious Stones	18	**13**
Talc	23	**28**
Tanto/Columbite	3	**6**
Tin	128	**160**
Tungsten Ore (Scheelite)	....	**1**
Vermiculite	....	**2**
Total—Other Minerals	12 725	**12 106**

PART 3—STATE AID TO MINING

(A) STATE BATTERIES

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

From inception to the end of 1978, gold, silver, tungsten, lead, copper, tantalite, and garnet ores to the value of $49 746 539 have been treated at the State Batteries. $47 447 277 came from 4 051 043 tonnes of gold ore, $498 404 from 85 376·5 tonnes of tin ore, $71 384 from 5 026·3 tonnes of tungsten ore, $1 572 963 from 71 487 tonnes of lead ore, $11 932 from 224 tonnes of copper ore, $96 235 from 3 120·8 tonnes of tantalite ore (some from tin ore) $19 946 from 572·4 tonnes of garnet ore, and silver valued at $6 423 from the cyaniding of gold tailings.

During the year 56 282·15 tonnes of gold ores were crushed for 389·276 kilograms of bullion estimated to contain 329·904 kilograms of fine gold equal to 5·86 grams per tonne. The average value of Sands after amalgamation was 2·47 grams per tonne, making the average head value 8·33 grams per tonne. Cyanide plants produced 37·022 kilograms of fine gold, giving a total estimated production for the year of 366·926 kilograms of fine gold valued at $2 011 290.

The working expenditure for the year for all plants was $1 789 771 which does not include depreciation, interest or Superannuation. Since the inception of State Batteries, the Capital expenditure has been $2 093 411 made up of $1 505 663 from General Loan Funds; $502 932 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 $243 354 compared with $230 414 for 1977.

The actual expenditure from inception to the end of 1978 exceeds revenue by $14 504 256.

(B) PROSPECTING SCHEME

At the end of the year, one man was in receipt of prospecting assistance as compared with two at the end of 1977.

Total expenditure for 1978 was $1 515 and refunds amounted to $95.91.

Assisted Prospector crushed 40 tonnes of ore during the year for ·213 kilograms of gold.

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

Expenditure—$1 056 262
Refunds—$205 089
Ore Crushed—131 245 tonnes
Gold Won—1 813·275 kilograms

The rate of assistance remained at $17.50 per man per week in the more remote localities and $15.00 per man per week in the less isolated areas.

(C) GEOLOGICAL SURVEY OF WESTERN AUSRALIA

In addition to advice and information given directly to exploration companies, the Branch has published two bulletins and three reports on various geological subjects. These publications should be of assistance to exploration for groundwater, petroleum, and minerals.

In conjunction with the Bureau of Mineral Resources eight additional sheets of the 1:250 000 series geological maps were published.

A series of public lectures on geological topics was again presented and was well attended, and there has been strong demand for the newly opened microfilm library.

A review of the need for regional officers has been made. It is considered that such offices could bring geological assistance closer to prospectors and exploration geologists. The first will open at Kalgoorlie in mid-1979.

PART 4—GOVERNMENT CHEMICAL LABORATORIES

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

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

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

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

PART 5—EXPLOSIVES BRANCH

The functions of the Explosives 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 710 licences were issued for various purposes related to explosives, import, manufacture, storage and sale, and this represented a 3.6 per cent increase over licences issued during 1977.

A total of 1 226 permits were also issued, which included 1 146 Shotfirer's Permits, a rise of 183 on total permits issued during 1977.

Both general and professional officers of the Explosives Branch made more than 6 300 inspections during the year to give advice on the safe storage of flammable liquids at licensed and non-licensed premises and also check vehicles conveying flammable liquids in bulk throughout the State. A total of 5 259 licences were issued for the storage of flammable liquids.

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

Under arrangements with this Department, the State Public Health Department continued the periodic X-ray examination of mine workers throughout the year and some 18 mine sites were visited by the mobile X-ray unit.

A total of 6 923 examinations were made under the Mine Workers' Relief Act. Of the examinations under the Mine Workers' Relief Act, 3 134 were new applicants and 3 789 were re-examinees.

Compensation under the Miners' Phthisis Act paid during the year was $4 782 compared with $4 950 in the previous year. The number of beneficiaries under the Act as at 31/12/1978 was 19 being ex-miners and 17 widows.

PART 7—SURVEYS AND MAPPING DIVISION

With less funds available to the Survey Branch, tenement surveys were done on a more selective basis including control data. With additional computer equipment including a remote terminal at Mineral House from the M.R.D. Cyber 172, computing work was expanded. A major programme for the SME Branch involving dust sampling was set up as well as the usual survey work.

The Mapping Branch continued with a heavy programme of Geological Mapping aggravated by the withdrawal of Commonwealth funds for colour masking and printing of 1:250 000 series maps. This also added to the Photographic and Process work required. Other map work for recording of Mining Tenements continued.

The increase in mining activity was reflected in the Public Plans Branch having to process almost 11 000 tenement applications and 475 Temporary Reserves. Public enquiries were again heavy and over $14 000 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 Divisions II to IX.

B. M. ROGERS,
Under Secretary for Mines.

Department of Mines, Perth.

DIVISION II

Report of the State Mining Engineer for the Year 1978

Under Secretary for Mines:

For the information of the Hon, Minister for Mines, I submit the Annual Report for the State Mining Engineer's Branch which report is divided into six sections, namely:—

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

The value of mineral production (excluding petroleum) at $1 626 million was $15 million less than for the previous year. It is anticipated that production will increase in the coming year with renewed interest in nickel, gold, bauxite and ilmenite. The mining industry at present provides direct employment for over 21 000 persons.

Iron ore sales at $957 million accounted for nearly 59 per cent of the total value of mineral production for the year. At Tom Price and Newman, work is well advanced on the construction of concentrating plants at the two sites.

Alumina production valued at $278 million had the second highest value of production followed by nickel at $186 million, gold at $73 million, and coal at $29 million. It is pleasing to report that gold production increased 24 per cent and its total value was 55 per cent higher than that recorded for the previous year. An indication of the increased energy needs of the State is illustrated by the annual coal output more than doubling over the past five years.

ACCIDENTS

There were 7 fatal and 567 serious mining accidents reported during the year. In the previous year there were 13 fatal and 685 serious accidents. The accident rate per 1 000 men employed in 1978 was 0·33 for fatal accidents and 26·50 for serious accidents.

DRILLING

As part of the State-wide ground water investigation the Drilling Section completed 7 526 metres of exploratory drilling at sites in the Fortescue Valley and in the South West. In addition 736 metres of drilling was completed on an investigation to determine the effects of logging on the groundwater in the Manjimup area and to construct three bores, in the South Fremantle area, to be used to monitor groundwater quality.

STAFF

Appointments—

Collie, D., Mining Engineer—District Inspector of Mines	7/2/78
Dawson, M. W. Engineer Drilling	26/6/78
Duke, M. H., Engineer	3/7/78
Cedro, J. A. Mining Engineer-District Inspector of Mines	7/8/78
Austin, D. H., Ventilation Officer	30/10/78

Promotions—

Fraser, R. D. Mining Engineer—Special Inspector of Mines (Ventilation)	30/3/78

Resignation—

Bennett, M. G., Engineer Drilling	31/3/78

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

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.

This information has been obtained from the Statistical and Mine Inspection, Sections of the Department. Cobalt, copper metal, palladium and platinum are by-products of nickel mining, whilst silver is a by-product of both nickel and gold mining.

ACCIDENT STATISTICS

These statistics cover all classes of mining accidents, associated with mineral and metal production, which have been reported to the Mines Department. There were 7 (13) fatal and 567 (685) serious accidents in the year. (The figures for the previous year are shown in brackets). A diagram showing the fatal accidents segregated according to the class of mining operation and extending over the past twenty years is included in the 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 accident 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.

TABLE 1

Mineral and Metal Output (excluding Petroleum)

Mineral Production	1977		1978	
	Production	Value	Production	Value
	Tonne (t)	$A	Tonne (t)	$A
Alumina	3 456 987	276 558 960	3 470 380	277 630 400
Antimony	836	999 228	....	....
Barytes	7 117	21 750	....	....
Bentonite	147	1 470	....	....
Building stone	5 135	149 337	4 356	113 904
Clays	292 902	178 095	290 557	202 310
Coal	2 358 006	23 172 093	2 403 503	28 642 245
Cobalt	200·66	712 884	172·29	854 689
Copper—Metal	1 830·90	1 734 785	1 501·42	1 330 712
Diatomaceous Earth	20	500	....	....
Emeralds—Carats (cut)	13 830	12 182	7	875
Emeralds (grams)	739	5 803	668	5 346
Felspar	645	16 055	889	29 278
Garnet Sand	164	12 300	479	33 474
Glass Sand	137 181	Not Available	104 697	Not Available
Gold (kg)	10 747·37	46 961 828	13 332·42	72 882 596
Gypsum	105 102	282 038	159 537	588 660
Ilmenite (includes upgraded and reduced ilmenite)	1 164 299	21 666 789	1 039 331	23 687 589
Iron Ore	83 517 197	951 109 987	82 498 589	956 965 039
Iron Ore—Pig Iron	71 695	3 903 976	65 700	3 760 667
Leucoxene	7 106	1 058 892	13 273	1 773 702
Limestone	769 868	1 182 051	715 490	1 373 387
Magnesite	23 906	637 449	....	....
Manganese	2 267	39 663	922	16 140
Monazite	5 150	828 921	10 457	1 848 767
Nickel Ore and Concentrates	527 129	248 371 821	468 941	186 088 405
Ochre	42	717	281	4 776
Palladium (kg)	298·25	499 599	229·72	418 136
Platinum (kg)	114·89	527 666	92·10	557 698
Ruthenium (kg)	7·32	13 073	....	....
Rutile	89 873	18 920 888	114 643	22 422 136
Salt	3 705 476	26 138 310	3 888 065	27 410 412
Semi-precious Stones (kg)	42 293	24 374	11 523	10 575
Silver (kg)	2 087·98	184 548	2 178·11	203 253
Talc	90 466	Not Available	120 352	Not Available
Tanto-Columbite	156·74	2 124 638	138·52	2 751 264
Tin Concentrate	636·39	4 273 832	692·34	5 341 725
Tungsten Ores and Concentrates—Scheelite	....	....	·14	1 108
Vermiculite	716	7 160	244	2 440
Xenotime	....	....	13	12 138
Zircon	104 280	9 103 839	151 297	8 614 435
Totals	....	1 641 437 501		1 625 578 281

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	102	510	1 796	718	5 047	8 173
Dundas	Central Norseman Gold Corporation N.L.	....	....	139	331	16 353	16 823
North Coolgardie	Espacia Gold Mine	....	....	60	....	....	60
Murchison	Ingliston Gold Mine....	20	....	23	15	....	58
	Totals on Gold Mines	122	510	2 018	1 064	21 400	25 114
NICKEL—							
Coolgardie	Western Mining Corporation Ltd. (Kambalda Nickel Operations)	209	3 085	12 318	3 525	73 026	92 163
	Anaconda Aust. Inc.	....	....	237	80	....	317
	Metals Exploration N.L.	45	....	1 351	785	3 423	5 604
	Selcast Exploration Ltd.	....	....	1 116	187	469	1 772
Mount Margaret	Western Mining Corporation Ltd. (Windarra Project)	....	632	1 356	220	16 619	18 827
East Murchison	Agnew Mining Co.	273	842	1 368	404	8 582	11 469
	Totals in Nickel Mines	527	4 559	17 746	5 201	102 119	130 152

TABLE 3

Principal Gold Producers

Mine	1977			1978		
	Tonnes Treated	Yield † Kilograms	Grams Per Tonne	Tonnes Treated	Yield † Kilograms	Grams Per Tonne
Kalgoorlie Lake View Pty. Ltd.	....	....	....	....	*71·26	....
Kalgoorlie Lake View Pty. Ltd. (Mt. Charlotte)	549 717	2 354·62	4·3	636 153	3 089·26	4·8
Central Norseman Gold Corporation N.L.	155 517	2 908·13	18·7	149 813	2 710·10	18·1
Mulga Mines Ltd.	30 669	532·88	17·4	1 589	44·90	27·7
Newmont Pty. Ltd.	293 087	4 433·18	15·1	435 612	7 000·17	16·0
Minor Producers	42 990	487·67	11·3	57 005	368·43	7·3
Total State Production	1 071 980	10 716·48	10·0	1 280 172	13 284·12	13·6

* From mill clean-up.
† Does not include alluvial or dollied gold.
NOTE: The calculated value of the gold produced in 1978 was $72 882 596 which includes $58 340 909 distributed by the Gold Producers Association from the sale of 13 496·43 kilograms of gold at an average premium of $4 322.69 per kilogram.

TABLE 4

Overseas Iron Ore Exports

Company	Sales Tonnes	Grade % Fe
Hamersley Iron Pty. Ltd.	29 771 495	63·88
Mt. Newman Mining Co. Pty. Ltd.	24 055 334	63·00
Cliffs W.A. Mining Co. Pty. Ltd.	12 002 957	59·29
Goldsworthy Mining Ltd.	5 879 249	63·35
Dampier Mining Co. Ltd.	2 488 116	67·82
Total	74 197 151	62·94

TABLE 5

Nickel Producers

Product and Producer	Centre	Quantity Tonnes	Grade % Ni	Value $
NICKEL CONCENTRATES				
Western Mining Corporation Ltd.	Kambalda	307 896	13·07	146 046 772
Western Mining Corporation Ltd. (Windarra)	Windarra	76 677	10·60	22 154 466
Selcast Exploration Ltd.	Emu Rock	10 809	16·67	7 232 306
Anaconda Australia Inc.	Redross	9 146	13·09	4 196 699
Total Concentrates		404 528	12·70	179 630 243
NICKEL ORE				
Metals Exploration N.L.	Nepean	71 544	3·29	7 049 104

DIAGRAM OF FATAL ACCIDENTS

SEGREGATED ACCORDING TO CLASS OF MINING

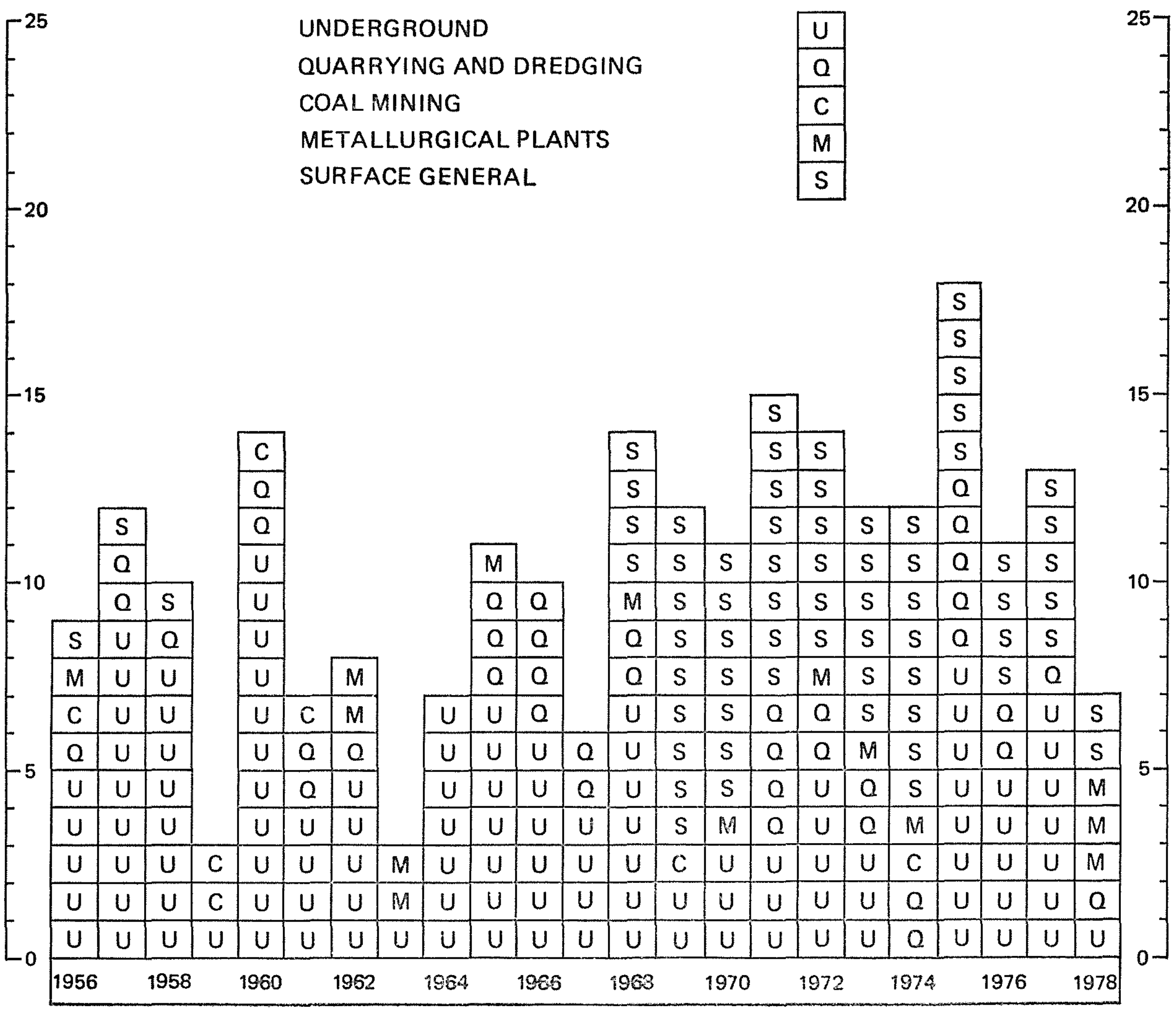

TABLE "A"

SERIOUS ACCIDENTS FOR 1978

Class of Accident	Pilbara	West Pilbara	Peak Hill	Gascoyne	Mount Margaret	East Coolgardie	Coolgardie	Dundas	South West	Greenbushes	Yilgarn	East Murchison	North East Coolgardie	Collie	Total
Major Injuries (exclusive of fatal)—															
Fractures—															
Head	1	....	....	....	....	....	....	....	....	....	....	....	....	....	1
Shoulder	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Arm	....	1	....	....	1	....	....	....	1	....	....	1	....	....	4
Hand	4	....	....	....	....	1	4	....	1	....	....	....	....	....	10
Spine	....	1	....	....	....	....	....	....	1	....	....	....	....	....	2
Rib	....	....	....	....	....	1	2	....	1	....	....	....	....	1	5
Pelvis	1	1	1	....	....	....	....	....	1	....	....	....	....	....	4
Thigh	....	1	....	....	....	....	....	....	....	....	....	....	....	....	1
Leg	2	....	1	....	1	2	....	....	2	....	....	....	1	1	10
Ankle	1	1	....	....	....	....	1	1	1	....	....	....	....	2	7
Foot	1	1	....	....	....	....	1	....	....	....	1	....	....	....	4
Amputations—															
Arm	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Hand	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Finger	1	1	....	....	....	1	1	....	....	....	....	....	....	2	6
Leg	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Foot	....	....	....	1	....	....	....	....	....	....	....	....	....	....	1
Toe	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Loss of Eye	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Serious Internal	....	....	....	....	....	....	1	....	....	....	....	....	....	....	1
Hernia	....	1	....	....	....	5	....	....	....	....	....	....	....	2	8
Dislocations	....	3	1	....	....	....	1	1	....	....	....	....	....	....	6
Other Major	....	3	....	....	....	....	3	....	1	....	....	....	....	....	7
Total Major	11	14	3	1	2	10	14	2	9	....	1	1	1	8	77
Minor Injuries—															
Fractures—															
Finger	1	2	1	....	....	3	6	....	3	....	....	....	....	2	18
Toe	1	....	....	1	....	....	1	....	1	....	....	....	....	....	4
Head	....	2	....	....	....	2	3	....	3	2	....	1	....	2	15
Eyes	1	1	1	....	....	1	7	....	5	1	....	....	....	....	17
Shoulder	1	....	....	....	....	5	4	2	2	....	....	....	....	10	24
Arm	1	6	....	....	1	3	2	3	6	....	....	1	....	....	23
Hand	6	13	....	....	2	3	23	2	4	....	....	....	....	8	61
Back	15	15	3	....	2	15	31	5	28	1	....	....	....	27	142
Rib	....	....	....	....	....	1	3	....	....	....	....	....	....	2	6
Leg	9	16	3	2	....	5	6	2	15	1	1	2	....	5	67
Foot	2	5	....	4	....	8	8	1	15	1	....	....	....	6	50
Other Minor	3	15	....	2	....	5	12	1	18	....	....	....	....	7	63
Total Minor	40	75	8	9	5	51	106	16	100	6	1	4	....	69	490
Grand Total	51	89	11	10	7	61	120	18	109	6	2	5	1	77	567

There were no serious accidents in the following Mining Districts:—North Coolgardie, Broad Arrow, 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)	3 132	1	59	171
Coal	871	....	77	494
Gold	968	....	69	188
Ilmenite etc.	874	2	19	75
Iron	11 387	....	149	591
Nickel	2 850	3	156	412
Salt	491	....	15	67
Tin	196	....	8	27
Other Minerals	242	....	2	11
Rock Quarries	383	1	13	37
Totals	21 394	7	567	2 073

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	....	....	....	....	....	....	....	....	....	....	....	51	....	51
West Pilbara	....	....	....	....	....	....	....	....	....	....	....	89	....	89
Ashburton	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Peak Hill	....	....	....	....	....	....	....	....	....	....	....	11	....	11
Gascoyne	....	....	....	....	....	....	....	....	....	....	....	10	....	10
Murchison	....	....	....	....	....	....	....	....	....	....	....	....	....	....
East Murchison	....	....	....	....	....	1	....	....	....	1	....	3	....	5
Yalgoo	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Northampton	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Mount Margaret	....	....	....	1	....	....	....	....	....	3	....	3	....	7
North Coolgardie....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Broad Arrow	....	....	....	....	....	....	....	....	....	....	....	....	....	....
North East Coolgardie	....	....	....	1	....	....	....	....	....	....	....	....	....	1
East Coolgardie	....	....	....	2	....	....	....	1	....	17	....	41	....	61
Coolgardie	....	1	1	13	....	7	....	....	....	75	....	24	1	120
Yilgarn	....	....	....	....	....	....	....	....	....	....	....	2	....	2
Dundas	....	1	....	....	....	1	....	....	....	7	....	9	....	18
Phillips River	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Greenbushes	....	....	....	....	....	....	....	....	....	....	....	6	....	6
South West	....	....	....	....	....	....	2	1	....	....	4	108	6	109
Collie	....	....	....	3	....	....	....	....	....	48	....	26	....	77
Nabberu	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Warburton	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Eucla	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Total for 1978	....	2	1	20	....	9	2	2	....	151	4	383	7	567
Total for 1977	....	5	1	33	5	14	....	....	1	173	6	460	13	685

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

Name and Occupation	Date	Mine	Details and Remarks
J. R. Marsden (Haulage contractor)	14/3/78	Jennings Industries (W.A.) Ltd (Mining Division) Geraldton Wharf storage shed	Whilst he was examining the axle housing, the tray of the tip truck suddenly descended and crushed his head.
D. D. Ramsay (Mechanical Loader Operator)	15/3/78	Western Mining Corporation Ltd (Kambalda Nickel Operations)—Silver Lake Mine	Crushed by large rock which fell from back of leading stope whilst he was using mechanical loader.
D. Orlando (Utility man)	26/4/78	Alcoa of Aust. Ltd.—Kwinana	He was run over by one of the rear wheels of a mobile crane. A fibre rope he was holding became entangled with the wheel and dragged him from his seat.
J. W. Bell (plant operator)	9/6/78	Western Mining Corporation Ltd	Bell was cleaning the Co. converter vessel in an unrespirable atmosphere. He collapsed due probably to a faulty seal on his face mask, lack of air from an air line and inhaled nitrogen gas. Haywood went to his assistance and inhaled nitrogen gas. Both were asphyxiated.
S. J. Haywood (operator)	9/6/78	(Nickel Refinery) Kwinana	
B. P. Byrne (Quarry Manager)	11/7/78 Died 12/7/78	Readymix Group (W.A.) Ltd—Gelorup Quarry	Died from fat embolism. Received fracture of neck of right femur when he overbalanced and fell from a platform whilst tightening bolts.
J. G. Wilson (plant operator)	29/8/78	Western Titanium Ltd—Capel	His clothing was caught by a revolving screw conveyor which dragged him into the trough and under the screw.

MINE INSPECTION

Winding Machinery Accidents

Accidents involving winding machinery and associated equipment were investigated. The actions necessary to repair the damage and remove any hazards were taken. Brief details are as follows:

Overwinds: There were no overwinding accidents.

Cage/Skip Hang-ups (3): The skip in the Jan shaft of Western Mining Corporation Ltd (KNO) was lowered onto a plat gate being installed on the 13 level. Slack rope and the capel caught on the shaft sets but no damage resulted.

A section of concrete formwork being lowered in the Long shaft of Western Mining Corporation (KNO) caught in the shaft and the winder driver, realising that something was wrong, brought the load to the surface. In so doing the formwork and the rope were damaged and debris was left in the shaft.

The ascending north skip in the underlay Regent shaft of Central Norseman Gold Corporation N.L. snagged the manway meshing which fouled the skip wheels resulting in the derailment of this skip.

Miscellaneous (5): The door of the cage in the Andrew shaft of Selcast Exploration Ltd was torn off when the cage moved away after the platman signalled to the next level but neglected to close the cage door. Similar damage resulted to the cage in this shaft later in the year during an attempt to adjust the cage at the No. 4 level plat either due to poor signalling by the platman or a misinterpretation of the signal by the winding engine driver.

The shafting for the door of the skip in the Juan shaft of Western Mining Corporation Ltd (KNO) broke due to excess pressure being exerted from a build-up of fines under the door. It was thus prevented from closing when the conveyance came out of the dump tracks after tipping.

The shaft supporting the sheave wheel in the Reward shaft at the Mt. Charlotte mine of Kalgoorlie Mining Associates failed during a normal hoisting cycle. The winding engine driver noticed a "whip" in the rope and stopped the engine before any damage occurred. The failure was apparently caused by the propogation of a crack at the cross-sectional change area of the shaft where welding had been used to build up the bearing shaft area.

The surface kibble trolley plummeted down the Main shaft of Agnew Mining Coy. Pty. Ltd. when the braceman inadvertently selected the wrong shaft protection door control lever. The trolley disintegrated when it struck the top of the sinking stage.

There were no accidents in Declines.

PROSECUTIONS

Complaints for breaches of the Mines Regulation Act and Regulations resulted as follows:

The hearing of complaints lodged in 1977 were heard on April 20th 1978. A winder driver was found guilty of breaching sub-section 46(1)(a) of the Mines Regulation Act and was fined $10.00 with costs of $4.10. He was also charged under Section 49 of the Act but was found not guilty. Two other winder drivers were charged with breaching Section 49 and on being found guilty were fined $10.00 with $54.10 costs, and $75.00 with $4.10 costs. This latter winder driver was also found guilty of a breach of Section 54 and was fined $50.00 with costs of $4.10. The contractor responsible for the shaft sinking was fined $100.00 with $4.10 costs for a breach of Section 46(2). The registered mine manager was found guilty of breaches of the regulations and was fined as follows:—$40.00 with $9.10 costs for Regulation 15.4, $20.00 with $9.10 costs for sub-regulation 15.6(1), $40.00 with $9.10 costs for Regulation 15.44, $40.00 with $9.10 costs for Regulation 15.64.

Two miners were prosecuted for breaches of sub-regulation 7.24(2) when, in separate instances, they were found to be drilling in a butt. They were each fined $25.00 with costs of $4.10.

A driller at a quarry pleaded guilty to operating an airtrac drill without appliances to control and suppress the emission of dust contrary to sub-regulation 8.8(1) and was fined $20.00 with costs of $2.00. Another driller was similarly charged but he denied the charge and the Magistrate, after hearing the evidence, dismissed the case.

CERTIFICATES AND PERMITS

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

Authorised Mine Surveyor's Certificates: The Survey Board issued five initial certificates. Certificates were issued as follows:

T. W. Giles—Certificate No. 035
M. Brecely—Certificate No. 036
W. I. Ronald—Certificate No. 037
R. H. N. Ebrall—Certificate No. 038
R. J. Colling—Certificate No. 039

Sunday Labour Permits: Fifteen permits covering forty-one shifts, involving a total of 88 men were issued to six of the mining companies. Safety, and to avoid loss of time in the subsequent working of the mine, were the main reasons for the permits and the following operations were conducted under the permits: removing pentices from shafts, removing the cuttings from a raise bore in an ore bin to prevent them consolidating, installing a power cable and a dust suppressing sprinkler system in a main decline, non destructive testing of the ropes to the sinking stage in a shaft, installing a transformer and commissioning a block lighting system which necessitated cutting off the electricity supply, installing a pump column, cable bolting part of a main decline, installing electrical connections requiring that the main ventilation be disrupted, removing large machinery from a mine through the man and supply shaft, and scaling and making the workings safe after a large pillar blast.

Premits to fire outside Prescribed times: Six permits were issued and all were conditional on the posting of warning notices to prevent persons entering the area, and the removal of resulting fumes. Three of these permits were granted to the Agnew Mining Co. Pty Ltd for the advancement of the Main decline and other associated development headings. Permits were granted to Western Mining Corporation Ltd. (Kambalda Nickel Operations) for developing the Nos. 9 and 13 level crosscuts off Jan shaft, working a surface winze at the McMahon mine, and for stripping the backs of the Fisher decline.

Inspection

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

All mining operations were inspected by Inspectors of Mines according to the requirements of the Mines Regulation Act.

It has not been possible to fill the vacant position for a District Inspector of Mines in the Port Hedland inspectorate but there is a full complement of Inspectors in the other inspectorates.

Ventilation

The ventilation staff inspected all mines throughout the State to determine that ventilation, and control of dust and atmospheric contaminants, was in accordance with the requirements of the Mines Regulation Act.

Both personal and positional dust sampling was undertaken to determine the concentration of dust in working places and a total of 897 gravimetric dust samples were collected from all sources. Twenty-three point Two per cent of these exceeded the standard of purity for the particular dust sampled. Six hundred and twenty-eight konimeter samples were taken in underground mines and of this number twenty per cent had a count in excess of 300 particles per cubic centimetre.

Temperature and humidity conditions were checked at the underground working places visited. The regulation relating to temperature and humidity requires that the temperature difference between wet and dry bulb readings shall be at least one degree Celsius but when the dry bulb reading is greater than 26.5 degrees Celsius for every half a degree Celsius rise in the wet bulb reading the dry bulb reading shall rise at least one degree Celsius.

The primary and secondary airflows in the underground workings where diesel engined equipment operated were measured regularly and measurements of the ambient air were made to determine that noxious or toxic gas levels were below the specified limits. Particular emphasis was given to determining the concentrations of undiluted gas from the exhaust of diesel engines and other conditions pertaining to the permits granted for the use of diesel engined equipment. Vehicles not complying with the conditions of the permit were sent to the surface or underground workshop for immediate attention to correct the faults.

Forty-seven permits for diesel engined equipment to be used underground were issued in the Kalgoorlie inspectorate in 1978. (Fifty-three permits were issued in 1977). Included in this number were permits for stationary diesel engined generators to provide auxillary power and a diesel fired steam cleaner to be used at an underground workshop. It was necessary to ensure that these units were installed in a strong through airway or forced ventilation was provided.

The undiluted exhaust emissions of 464 vehicles were tested and of these 1.5 per cent were found to have results exceeding the limit of 2 500 p.p.m. carbon monoxide, and 1.9 per cent exceeded the limit of 2000 p.p.m. for oxides of nitrogen. Mining companies are now making their own undiluted exhaust gas readings. Twenty-six sets of ambient gas concentrations were measured for atmospheric carbon monoxide and nitrogen dioxide and in no instances were they in excess of the limits of 50 p.p.m. carbon monoxide and 5 p.p.m. nitrogen dioxide.

Major problems with primary ventilation airflows occurred on three mines and assistance was given by the Branch's Ventilation officers in resolving them. It was necessary to provide a 1 800 mm raise bore hole between the 700 level and the surface to effect major improvement to the primary circuit on one mine. This raise-bore was completed in December 1978 and it is reported that conditions underground were improved greatly by this connection. At another mine complaints about dust problems on several levels were received and an investigation revealed that short circuiting of the primary airflow was responsible. The problem was resolved by the erection of several brattices. Recirculation of the primary airflow at the third mine was found to be due to short circuiting through open mill holes and was eventually solved when a major pillar blast effectively closed the mill holes. In the interim brattices were erected.

During inspections it was often found necessary to have the work in development headings stopped whilst ventilation ducting was extended closer to the working faces. It was felt that underground supervisors were not ensuring adequate secondary ventilation was maintained to these headings.

The control of dust emission in the crushing and screening plants at iron ore mines has improved considerably but it has become apparent that workmen engaged on maintenance are exposed to high concentrations of dust. It is advisable for the equipment to be cleaned down before maintenance is commenced. Almost all mobile plant are now fitted with a cab and an air conditioner which pressurises the cabin and minimises the amount of dust which can enter. When the plant is new the operators are only exposed to a moderate amount of dust but it is noticeable that when cabs etc. are fitted to older plant which has been in service for some time the dust concentrations are much higher.

The control of dust in crushing plants at hard rock quarries continues to be improved by the use of water sprays and dust collection systems. Screen washing is used to a limited degree but the large quantity of water required limits its wider use.

Two men died from asphyxiation due to inhaling nitrogen gas, two men were affected seriously by fumes and two other men were minimally affected by fumes. All fuming cases were investigated. One of those seriously affected was a long hole driller underground who inhaled fumes from a firing on the previous shift and contracted pneumonia. The other serious accident was to a rigger who was affected by an ammonia emission from the leach tail gas scrubber at a refinery.

Mine management have given support and co-operation to the Branch's Ventilation officers in their efforts to encourage the use of correct safety procedures in the handling of cyanide, xanthate, and litharge. All men involved with the handling of mercury, lead, and arsenic have been checked by means of urine samples to ensure that their health is not impaired. All samples were analysed.

Emissions of gases from treatment plants including smelters, pellet plants, refineries, blast furnaces, and up-grade plants, etc. were measured on a regular basis. The gases sampled were sulphur dioxide, hydrogen sulphide, carbon monoxide, hydrogen chloride and hydrogen fluoride. Organic vapours resulting from activities involving rubber lining of vessels etc. repairing conveyor belts, or cleaning (degreasing) were also sampled and determined.

Several new gravimetric dust sampling instruments were investigated and assessed for reliability of operation and comparison with instruments currently in use. Amongst these were a Simquad sampler, a petrol driven dust sampler and two digital instantaneous gravimetric dust samplers. Further testing will be conducted during 1979. Investigations, commenced in 1976 were continued in an endeavour to establish a factor, which could be used to convert the results of dust samples obtained with instruments designed to perform generally in accordance with the dust retention curve of the Atomic Energy Commission, to the same basis as the results obtained with the instruments designed to perform generally in accordance with the Mine Research Establishment dust retention curve. This latter dust retention curve is that specified in the regulations to the Mines Regulation Act.

GENERAL

There were four mine fires which were investigated. One occurred in a disused shaft, and three were on diesel engined equipment in use underground. The disused shaft was the Eclipse which is one of the leases held by North Kalgurli Mines Ltd. The fire was extinguished when the shaft was covered and a water line installed. An inspection after the fire had been extinguished revealed extensive damage of the timbers to a depth of 60 metres. A permanent fence has been erected around the shaft. Cause of the fire is not known. A Wigtruck caught fire in the Hunt decline of W.M.C. Ltd (KNO) when a flexible drive coupling between the converter and the transmission collapsed allowing the transmission fluid to leak from the coupling onto hot engine components. The fire was controlled by use of a chemical extinguisher. Two miners were inconvenienced by the resulting smoke and fumes and had to leave their respective working places until these were cleared. A hydraulic oil hose connecting the transmission control box to the transmission housing on a Caterpillar truck broke causing oil to spray on to the turbocharger and ignite. The fire was extinguished by the driver with a dry chemical extinguisher. This incident occurred in the McMahon decline of W.M.C. Ltd. (KNO). A fire on a load-haul-dump vehicle in the decline of Agnew Mining Co. Pty Ltd was caused by an alternator lead coming into contact with the engine breather resulting in a short circuit which ignited the electrical wiring. This was quickly extinguished.

Twenty Power Shovel Operator's Certificates of Competency were issued in 1978. Power shovel operators have previously operated under the authority of Crane and Hoist Driver's Certificate issued under the Inspection of Machinery Act, 1921. These certificates are still valid but operators who wish to take control of these shovels on mines in future will have to meet the requirements and comply with the conditions as specified in regulations 17.2 to 17.5 to the Mines Regulation Act. It is anticipated that the number of these Certificates issued will increase considerably next year.

The Department's seismograph was in regular use throughout the year to measure ground vibrations either as a result of complaints about blasting at quarries, blasting for construction works, or vibrations from trains. Blasting at a quarry near Dongara caused doubts about the safety of an adjacent major gas pipeline and checks were made to establish a safety limit for the quarry blasting operations. Complaints received about blasting in the quarry associated with the supply of rock for the Wungong Dam were investigated. Other complaints from quarry blasting at Gosnells and Albany were investigated. Many of these complaints originated from noise associated with the firing of explosives and the "startle" effects. Vibration measurements were taken at the request of the Metropolitan Water Board, and the Shire Council as the result of blasting for trench excavations at Armadale and Goomalling respectively. Vibration measurements were made for the Metropolitan Water Board at Scarborough where a tunnel excavation was in progress, and at Melville where vibrating rollers were used by the Board. The vibrations from underwater blasting were measured for the Public Works Department at the commencement of the deepening of the Albany Harbour by the Australian Dredging Co. Westrail had complaints about the vibrations from their trains passing through Kenwick and the use of the seismograph was requested. Checks on the vibration from major underground blasts at the Mt. Charlotte mine were also made in Kalgoorlie. Investigations into the suitability of various makes of seismographs were commenced as it will be necessary to obtain another, or replacement instrument to measure peak particle velocity which is to be the method used in amendments to the Explosives Code of the Standards Association of Australia.

Rehabilitation of mined areas is proceeding generally in a satisfactory manner and because of the current awareness of the need for an improved image for mining many of the companies who are not legally bound to rehabilitate the areas which they have mined are now doing so, and a better standard of "house-keeping" is evident in their operations. Matters relating to hard rock, limestone, clay and sand with a few exceptions, are generally controlled under Licenses issued by local governing authorities. The exceptions are those where mining proceeds on tenements issued under the Mining Act and rehabilitation conditions are specified under the Certificate of Title. Bauxite, iron ore and mineral sands (in particular areas) are controlled under the Agreement Acts.

The rehabilitation of areas in the Darling Range where bauxite is mined has to be done to the satisfaction of the Conservator of Forests and it is reported that the work undertaken by Alcoa of Australia (W.A.) Ltd exceeds the original requirement. Research carried out by this company's staff has resulted in advances to rehabilitation techniques in the Jarrahdale, Del Park and Huntly areas. Hamersley Iron Pty Ltd are conducting extensive trials with shrubs and trees at Paraburdoo and grassing and tree planting is undetaken at Tom Price operations, whilst grassing, shrub and tree planting is in progress at the Mt. Whaleback quarry of Mt. Newman Mining Co. Pty Ltd.

The mineral sands miners at Eneabba have carried out contouring, placing of top soil, and seeding of many hectares of mined area during this period which has been relatively inactive with respect to mineral production. Jennings Industries (W.A.) Ltd. Mining Group own the land which they mine and are endeavouring to return it to a condition suitable for cropping and grazing. Western Titanium Ltd have commenced backfilling tailings into part of their excavation but some time could elapse before this filled area is stable enough for topsoil to be spread. A small area which had been denuded by the traffic of earthmoving equipment and a back filled pit has been divided into four test areas which will be treated by different methods, and monitored. Allied Eneabba Pty Ltd have partly rehabilitated another 38.4 hectares of mined land by contouring and seeding it. This is in addition to top dressing 60 hectares of a previously sown area. Plantings of trees at the rate of about 160 per hectare have been made with the object of having clusters of low trees. Considerable areas have been set aside for growth trials.

At Jurien the area where W.M.C. Mineral Sands Ltd mined prior to 1977 is still being rehabilitated and a total of 89.4 hectares was levelled and sown with crops in 1978. A further 69 hectares remains to be rehabilitated before the ground is returned to the landowner.

The mining companies which operate in the area between Bunbury and Busselton have continued with satisfactory rehabilitation. Cable Sands Pty Ltd have ceased mining operations at Stratham and Wonnerup. Six point eight hectares were contoured and sown with seed at Stratham and 14 hectares were dealt with at Wonnerup. Further work will be done before rehabilitation is completed. The ground mined by Western Mineral Sands Pty Ltd has been rehabilitated except for a section of 1 000 metres which has been formed into a light aircraft landing strip. Westralian Sands Ltd rehabilitated and seeded 10 hectares at their Yoganup extended mine site whilst a further 20 hectares at Yoganup were seeded. At the treatment plant site in Capel 200 trees have been planted in the past three years. Western Titanium Ltd at Capel have a good record of mined land rehabilitation and this work is continuing. Since 1974 about 22 000 seedling trees have been planted and the survival rate is about seventy per cent. A number of native shrubs have re-established along the verges of some of the newly formed lakes on their holdings.

The rehabilitation work completed to date by Greenbushes Tin N.L. has been of good standard and currently efforts to rehabilitate the Kapunga pit, one of the larger pits, is in progress. Indications are that an appealing vista can be produced from what was a rather unsightly pit. The company is also venturing into refinements in their rehabilitation programme by establishing vegetable crops on some areas covered by tailings.

METALLIFEROUS MINING
PORT HEDLAND INSPECTORATE

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

EMPLOYMENT

Early in 1978 the closure of the Blue Spec mine caused a fall in employment in mining for gold. Employment figures also fell in the iron ore and crushed rock mining.

Increased employment was reported in activities for production of barite, mica, salt, tin and tantalite.

Employment figures reported are:—

Mineral	Employment: Full Year	Employment: Part Year
Barite	10	
Crushed Rock	....	48
Gold	182	....
Iron....	10 841	....
Lime Sands	....	6
Mica	....	6
Salt	385	....
Tin and Tantalite	52	....
Total	11 470	60

About 10 full time prospectors worked gold or tin shows while a number of other prospectors worked spasmodically, mining for gem stones, gold or tin.

EXPLORATION

Activity in the Kimberley and West Kimberley Mining Districts, mainly pegging claims for diamonds, reached "boom years" proportions and this office reported on some thousands of claims.

One visit was made to Sorby Hills, 50 km N.N.E. of Kununurra, where R.U.C. (Pacific) Pty. Limited constructed a decline for Aquitane Australia Minerals Pty. Limited, testing a silver-lead-zinc project.

A diesel Load-Haul-Dump machine was tested for underground use. The contractors, employing 11 men plus a manager, excavated a surface approach to the decline portal site, then advanced the decline 73 metres by the end of the year. Forty-eight metres advance was completed using an Alpine A.M. 50 Miner until more solid ground necessitated the use of the conventional drill and blast method for the remaining 25 metres advance. A sump of 80 cubic metres was excavated outside the decline portal.

This project was not declared to be a mine until early in 1979.

BARITE

Dresser employed 8 men at the North Pole mine and 2 at the grinding plant at Port Hedland.

At the North Pole a new jigging and dewatering plant was installed, replacing the old dry plant. An additional 320 kVA power plant was installed in the power house and additional housing and recreation facilities provided.

Mining commenced on the new ore body.

About 500 metres of blast hole drilling was completed and 3 500 kg of explosives used at the quarry.

After initial sorting, crushing, screening and jig treatment the barite was road hauled to Hedland where 3 117 tonnes of final ground product was produced, and 4 300 tonnes shipped.

CRUSHED ROCK

The Readymix Group (*W.A.*) operated at two sites during the year. At the Turner River Quarry, 10 men were employed for 8–9 months. Five hundred thousand tonnes of ballast being mined, crushed and screened, completing the contract in October.

At the Newman shingles quarry, 14 men were employed for 5 months. One hundred thousand tonnes of concrete and road sealing aggregate was crushed and screened.

Six other men were employed continually since April on other work at Newman.

Bell Basic Industries Limited employed 18 men at the Nickol Bay Quarry near Dampier and produced 130 000 tonnes of crushed and screened railway ballast. Twenty-two thousand metres of percussion drilling was completed and 95 tonnes of explosives used to break an equal amount of both product and waste.

GOLD

Mulga Mines Pty Limited ceased operations at the Blue Spec mine near Nullagine in the first quarter of the year. Little work was carried out underground and production came from treatment of surface stockpiles. On completion, the equipment was sold by auction in mid-March.

The Telfer Project near the Patterson Range and managed by Newmont Proprietary Limited, operated by open cut method throughout the year, employing 172 persons including Quest Mining contractors who removed the overburden prior to Newmont removing and treating the ore.

Mining on the Westerly side of the deposit commenced during the year.

A total of 7 190 524 tonnes of waste and 482 555 tonnes of ore were mined during the year.

New construction included a Dust Extraction System on the crusher and expenditure on the Trommel Return System.

Exploratory drilling continued, with further drilling for water to be used in dust suppression on roads and in the pits.

The *Comet* gold mine near Marble Bar employed 5 men on sands treatment, 6 629 tonnes of residues being treated.

Further equipment was purchased but has not yet been installed.

Prospectors: Few full time prospectors remain in the field, activities being restricted to the Marble Bar area.

IRON

Statistics from the five companies show that, compared with the previous year, there was: a drop of 906 in the number of employees; an increase in break of waste of 0·499 million tonnes; a decrease in ore broken of 2·420 million tonnes and total ore shipped fell by 1·109 million tonnes.

A workforce employed on large construction works at Tom Price and Newman where beneficiation plants are being erected is in addition to the employment figures shown in the table below.

Production and Shipping (Million Tonne Units)

Company	Persons Employed	Ore Broken	Ore Shipped			Total
			Lump	Fines	Pellets	
Hamersley Iron	4 128	53 514	13 993	15 192	2 059	31 244
Mt. Newman	3 327	43 655	16 579	14 687	....	31 266
C.R.R.I.A.	1 590	11 850	....	8 199	3 504	11 703
Goldsworthy Mining	1 263	5 974	2 922	2 959	....	5 881
Dampier Mining	533	2 333	0 683	1 631	....	2 314
Total	10 841	117 326	34 177	42 668	5 563	82 408

Hamersley Iron Pty Limited

The operations comprise of open cut mines at Tom Price and Paraburdoo. Crushing and screening plants at the mine sites produce lump and fine ore which is railed to Dampier port site where pellets are produced from some of the high grade fines.

At *Tom Price* mining took place over 11 operating benches, each of 15 m height. Material broken totalled 38·324 million tonnes and included 19·498 M.T. high grade and 14·401 M.T. low grade ore. Material movement included 15·581 M.T. high grade ore and 1·024 M.T. low grade ore move to the crusher and primary stockpile. Total movement was 32·899 Million Tonnes of material.

New plant and equipment included the commissioning of a bulk nitrate shed and a Marion 9m³ 191M Electric Shovel.

A 220 KV power line linking Dampier to Tom Price and Paraburdoo was completed and will be commissioned early in 1979. The power house at Tom Price will be dispensed with and two sources of power will be available for all three sites.

The construction of the concentrating plant at Tom Price was near completion.

At *Paraburdoo* mining took place over 7 operating benches, each of 14 m height. Material broken totalled 25·002 million tonnes and included 15·390 million tonnes high grade and 4·225 million tonnes low grade ore. Material movement included 13·962 million tonnes high grade ore moved to the crusher and primary stockpile. Total movement was 26·379 million tonnes of material.

New plant and equipment included a bulk nitrate shed.

At *Dampier* the port system comprises a pellet plant, stockpiling and shiploading facilities at Parker Point, with 1·4 million tonne capacity of stockpiles and a berth for ships up to 120 000 D.W.T. and the newer facilities at East Intercourse Island with 1·6 million tonne capacity of stockpiles and berthing for ships up to 160 000 D.W.T.

A total of 1·911 million tonnes of specification iron pellets were produced during the year.

Mt. Newman Mining Co. Pty Limited

The ore is mined on Mt Whaleback and the nearby Marra Mamba series orebody at the townsite of Newman, crushed through primary and secondary circuits then trained 420 km to Port Hedland where final tertiary crushing and shiploading is completed at Nelson Point.

At *Newman* two near new waste dumps and three low-grade stockpiles were started. Mining of the east end of Mt. Whaleback was accelerated to provide a slimes pond for the new beneficiation plant of 7 million tonnes per year capacity.

New development included 760 metres of new benches, two ramps totalling 2 580 metres and 2 270 metres of haulroads.

A major step forward in Pilbara iron ore mining was the acceptance by Japanese steel mills for large scale trials in their sinter plants for blended Brockman/Marra Mamba ore. The contract called for an initial 2.7 million tonnes of —6 mm fines with 15 per cent blended Marra Mamba.

Several shipments of blended fines were also shipped to European customers.

A rail spur line of 1.8 km was constructed from the Newman rail loop to the Marra Mamba mine and The Readymix Group (W.A.) installed a screening and crushing plant to produce —6 mm material into a rail load-out chute system.

This plant commenced operations in April and treated Marra Mamba ore mined by Mt. Newman Mining Co.

At *Nelson Point* in Port Hedland a hydrofine crusher was installed to reduce surplus lump ore to —6 mm.

In the railroad section, crew change-over facilities were installed at Bing siding 16 km from Port Hedland to provide a terminal for a revised operational system, a new track geometry recording car has been tested and commissioned while sensors to detect "dragging" ore cars have been installed and are under test.

Cliffs Robe River Iron Associates

The iron ore is mined from the limonitic mesa form deposits at Pannawonica in the Robe River Valley and railed direct to Cape Lambert where all crushing and processing is carried out to produce fines and pellets.

During the year, 11.850 million tonnes of ore was broken.

The second stage of the 19.8 M.T.P.Y. expansion commenced. A fifth P. & H. 2100 BL shovel and a fourth blast hole drill were commissioned. Nine workshop and amenities buildings were completed covering mine, rail, maintenance and marine areas.

Plant upgrade progressed with installation of new bins, apron feeders, repowering of conveyors and installation of secondary dust control units.

Three haulroads developed at the mine totalled 9 073 metres.

Twenty new houses were completed at Cape Lambert and 55 at Pannawonica.

Goldsworthy Mining Limited

The iron ore is mined and primarily crushed at Goldsworthy and Shay Gap then railed to Finucane Island where it is subject to secondary and tertiary crushing prior to ship-loading.

A total of 2.266 million tonnes of ore and 4.600 million tonnes of waste were mined at Goldsworthy, while 3.708 million tonnes of ore and 4.490 million tonnes of waste were mined at Shay Gap.

Ore shipped from Finucane Island included 2.922 million tonnes of lump ore and 2.959 million tonnes of fines.

One new Cat. 824 dozer was commissioned.

At Goldsworthy, 500 metres of new benches and 600 metres of new ramps were formed while at Shay Gap, 700 metres of new benches and 300 metres of new ramps were formed.

Dampier Mining Company Limited

The company operates on Koolan and Cockatoo Islands in Yampi Sound.

On *Koolan Island* material broken was 1 644.089 tonnes of ore and 6 447.585 tonnes of waste. A total of 1 606.089 tonnes of —64 mm ore was shipped.

Work is proceeding on a ramp access to the 62 metre R.L. bench on the Main Lode. Development included Benches, 950 metres; Ramps, 450 metres; and Haulroads, 600 metres.

New plant and equipment included: distillate and fresh water lines from wharf to service area around the western end of the quarry: parking and servicing area in quarry plus adjacent messroom: saltwater tanks and the PB6 water bore commissioned. Twenty-seven—3-bedroom houses, three blocks of flats and other community buildings were constructed.

On *Cockatoo Island* mining was confined to benches at the Western end of the quarry where 689 000 tonnes of ore plus 62 000 tonnes of waste were broken.

Ore shipped was 683 000 tonnes of lump plus 25 000 tonnes of fines.

Eleven thousand four hundred metres of blast holes were drilled using two primary drilling rigs and one secondary drilling rig.

New plant included a magnetometer at the shiploader and a new 20-tonne low loader.

LIMESAND

Bellway Pty Limited employed six men to excavate limesand several kms from Dampier and cart the screened material to a stockpile at the H.I. pellet plant.

Excavation by front end loader produced the required 60 000 tonnes plus 2 500 tonnes of oversized waste that was screened off.

MICA

Pilbara Mica Corporation Pty Limited tested their mica deposit situated South East of Pippingara homestead.

A crushing and screening plant in the Light Industrial Area near South Hedland with a capacity of 2.5 tonnes per day has been installed to process muscovite in various size specifications.

SALT

Production from the three salt deposits totalled 4.147 million tonnes harvested and 3.702 million tonnes shipped.

Texada Mines Pty Limited which operated the solar salt field at Lake MacLeod during 1978, was aquired by Dampier Salt Limited late in the year and the name of the company was changed to Dampier Salt Operations Pty Limited, a company which will now operate two divisions at Dampier and Lake MacLeod.

Dampier Salt Operations Pty Limited (Dampier Division)

Double shift harvesting required the employment figure to increase and an average of 179 men were employed throughout the year.

New plant aquired included 4 x 450 h.p. Kenworth prime movers and 1 x 375 h.p. JD 8630 tractor.

Dampier Salt Operations Pty Limited (Lake MacLeod Division)

No additional plant was added during the year when Texada Mines Pty Limited operated this field. An average of 162 men were employed.

Leslie Salt Co. (Port Hedland)

Major items of plant introduced were 1 x Cat. D8 dozer and 1 x John Deere 8630 tractor. An average of 44 men were employed.

TIN AND TANTALITE

Three companies were active mining alluvial tin deposits which also contain a percentage of tantalite.

The three companies are:—

Endeavour Resources Limited at Moolyella, near Marble Bar purchased the tin operations from Pilbara Concentrates on 1st June 1978. A complete upgrading of the plant and facilities has been undertaken. An average of 30 men were employed, some of them on the upgrading work.

A total of 138 850 tonnes of alluvial wash was mined.

Three surface dams have been completed.

Goldrim Mining Australia Limited at Wodgina increased the plant capacity by approximately 40 per cent after installing a fourth double cell concentrating jig.

Steady production began after good rainfall in February. After backhoe stripping of the overburden and loading out of the alluvium the ore is hauled 7 km to the plant on the west fork of the Turner River for treatment.

An average of 10 men were employed.

Pilgan Mining Pty Limited at Pilgangoora, mine and treat an alluvial tantalite and tin deposit. An average of eight men were employed and new plant included the treatment plant, workshop, power house, water circuit and accommodation units.

PERTH INSPECTORATE

G. J. Dodge

Mining Engineer/Senior Inspector of Mines

A gradual, but steady improvement in market potential was evident for mineral sands and nickel producers. Compared with 1977, mineral sands production increased by eight per cent and nickel by 11 per cent. End of the year activity indicates that the recovery will continue into 1979. Crushed stone producers had a buoyant year and talc production continued to improve.

ALUMINA

Alcoa of Australia Ltd: Alcoa's three mine sites produced 12 582 000 tonnes of bauxite from 138.9 hectares of land. The two refineries produced 3 460 000 tonnes of alumina being a slight reduction on 1977. The company is endeavouring to reduce the area of land laid open during the mining phase and has stepped up its rehabilitation programme. During the year 191.7 hectares of mined areas were rehabilitated.

At Pinjarra, a 600 000 m³ fresh water catchment dam was constructed to reduce the draw on state supplies. A furnace and plant for the production of sodium hydroxide from sodium oxalate and lime has been completed and a 100 000 tonne alumina storage bin was added to the rail-side storage complex.

An additional 50 000 tonne alumina storage bin has been completed at the Bunbury port facility.

During 1978 Alcoa received government approval to commence construction of the Wagerup refinery and mine site. Earthworks are expected to commence early in 1979.

Alwest Pty Ltd: A 20 000 tonne parcel of bauxite was mined and shipped overseas for testing and evaluation. The ore was taken from a company lease in the Boddington area.

BUILDING STONE

A very high demand for crushed aggregate and armour stone has given producers a very busy year. For a number of months a total of 16 individual quarries were in production throughout the inspectorate. An average of 302 persons were directly employed on mining operations.

Adelaide Quarry Industries: Quarries were operated at Brookton, Cranbrook and Moora. The Brookton quarry produced 72 000 tonnes of rail ballast, while at Cranbrook, a rail ballast plant and a road metal plant had together produced 56 000 tonnes of crushed products by the end of the year. Mining will continue into 1979. The Moora quarry was opened up to supply road material for the Main Roads Department.

Avon Quarries—Northam: This operation continued to meet local demand with a production of 13 900 m³.

Bell Group—Maddington quarry: Increased demand for road base material and a contract to supply core drainage material for the Wungong dam resulted in an eight per cent rise in production to 803 000 tonnes.

The plant is currently being expanded to permit further increases in production road base.

The Yatupa quarry closed down in December after producing 56 000 tonnes of granulite to complete the armour protection on the Port Denison harbour works.

Bruce Rock Shire Council: Council workmen produced 8 400 tonnes of crushed aggregate during the winter months. The Council has been under considerable pressure from inspectors to install an effective dust suppression system. A preliminary feasibility study was carried out an by inspector for the Council which must now either install dust suppression or close down the plant.

J. O . Clough & Son: After being awarded the contract to construct the Mullaloo Breakwater complex, Clough's purchased the monumental stone quarry at Mundaring. Large blocks of granite are being produced using a combination of very light blasting and hydraulic wedging tools. Although the operation is highly labour intensive, rock sizing is excellent with practically no waste.

John Holland (Constructions) Pty Ltd: Early in the year, John Holland's took over mining operations at the Wungong Dam. A second quarry was opened up and by the end of the year 1.7 million tonnes of rock had been produced. Mining will continue into the first quarter of 1979.

At Meckering John Holland's re-opened the old railway ballast quarry south of the town. The company has built a concrete sleeper factory adjacent to the quarry. The quarry is expected to operate for approximately four years and had produced 145 000 tonnes of aggregate by the end of the year.

Pioneer Concrete (W.A.) Pty Ltd: The Byford quarry commenced production in March with a steady workforce of 15 persons. The Herne Hill and Walkaway quarries operated throughout the year. Late in the year the Carnamah quarry was re-opened to produce 18 000 m³ of aggregate for the Main Roads Department. Pioneer directly employed some 70 men on mining operations and produced nearly a million tonnes of aggregate.

Roelands Quarry: The re-development of this quarry, which commenced in 1976, was advanced a stage further with a contract let to R. & N. Palmer for 69 000 tonnes of armour stone for Bunbury harbour works. One more sizeable contract should see the completion of the top bench.

The Readymix Group (W.A.): Readymix operated quarries at Gosnells, Albany and Gelorup. Gosnells and Gelorup operated continuously, while Albany closed down after eight months operation having completed its contract and replenished stockpiles.

CLAYS AND SHALES

Of the seven companies involved in mining clays and shales in and around the metropolitan area, Midland Brick continues to be the largest producer with 836 000 m³ or 47 per cent of the estimated 1 790 000 m³ total production.

Throughout country areas within the inspectorate, five small producers mined sufficient clays and shales to meet local demands for bricks and tiles. An average of 74 men were employed on mining for clays and shales.

GARNET

Target Minerals N.L. No full scale production has yet been commenced by this company. Activity was limited to one 500 tonne parcel of garnet sands being concentrated.

GOLD

Meekatharra District: The Ingliston Consols on G.M.L. 51/2139 treated 1 001 tonnes for a return of 27.334 kgms. The bulk of the ore being won by underhand stoping of the south ore body below the five level.

The syndicate has commenced developing the mine below the five level and to this end completed the following development.

Main shaft sinking	20 metres
Winzing	15 metres
Driving and cross cutting	23 metres

Modernisation and improvements included increasing the height of the headframe and installing a 37 kW electric winder. A new pumping system for mine dewatering was installed and a mechanical bogger has been introduced to speed up development.

Open cut ore from the Haveluck Goldmine, G.M.L. 50/2015 returned 2.016 kgm of gold from 1 181 tonnes.

Mt Magnet District: The Hill 50 Gold Mine remained on care and maintenance throughout the year. However a number of geophysical anomalies have been tested in an ongoing diamond drilling programme.

The Empress Gold Mine was abandoned when the syndicate's winze broke through into old workings where they expected to find a continuation of the main ore body. This syndicate then moved to the Mayflower leases (Alison) about 5 km east of Mt Magnet. They recovered 4.360 kgms of gold from 1 270 tonnes of oxidised ore mined by open cut.

Amoco held an option over the Mayflower leases and drilled a number of holes to test the ore body at depth. Insufficient ore was located and the option was dropped.

Paynes Find District: The Ark Gold Mine has been equipped with a new headframe, hoist and pumping equipment. It is expected to return to production in January 1979.

GYPSUM

Shark Bay Gypsum: This operation is a wholly owned subsidiary of Agnew Clough Ltd and operates in conjuction with the Shark Bay Salt Joint Venture at Useless Loop.

Increased demand for gypsum induced the company to upgrade its mining and treatment facilities during the year. A new 160 t/h crushing and screening plant was constructed. Excavators have been introduced to permit mining to a depth of three metres below water level. Drilling and blasting is necessary and an air trac has replaced the tractor mounted auger. One hundred and thirty-seven thousand tonnes were mined and treated.

Gypsum Industries of Australia Pty Ltd: This company produced 14 378 tonnes from Lake Cowcowing.

ILMENITE, LEUCOXENE, MONAZITE, RUTILE, XENOTIME AND ZIRCON

Mineral sands miners continued to operate under very tight budgets throughout the year. Indications were that sales are picking up gradually, but price rises are badly needed to return all operations to profitability.

Although total mineral production increased by 107 603 tonnes the average workforce decreased by 146 as the companies continued to economise.

MINERAL SANDS PRODUCTION STATISTICS

Company	Average Number of Persons Employed	Tonnes Ore Mined (Millions)	Minerals Produced (Tonnes) Ilmenite	Leucoxene	Monazite	Rutile	Xenotime	Zircon	Total
Allied Eneabba Pty. Ltd.	237	5·186	243 663	....	10 000	47 915	....	97 267	398 845
Cable Sands Pty. Ltd.	78	0·895	140 315	4 536	587	....	....	10 629	156 067
Jennings Industries Ltd.	120	0·950	107 522	....	201	22 705	....	14 991	145 419
Westralian Sands Ltd.	150	2·021	285 698	32 092	2 500	....	....	34 496	354 786
Western Titanium Ltd. (Capel)	180	1·885	285 502	4 125	1 444	....	22	15 168	306 261
Western Titanium Ltd. (Eneabba)	109	2·690	54 152	....	....	28 560	....	39 910	122 622
	874	13·627	1 116 852	40 753	14 732	99 180	22	212 461	1 484 000

Allied Eneabba Pty Ltd: Mineral production totalled 398 845 tonnes from the treatment of 504 500 tonnes of concentrates and retreatment of 12 560 tonnes of plant residues. The company mined and treated 5 186 000 tonnes of ore.

Allied expanded its monazite extraction plant and trebled production to 10 000 tonnes.

An additional 47 persons were employed throughout the year.

Cable Sands Ltd: Both the Stratham and Wonnerup ore bodies were depleted during the year, All production now comes from the Ambergate mine near Busselton.

The floating wet plant Stratham was relocated at Ambergate, as a land based unit. Treatment capacity was increased to 200 tph by the addition of two Reichert cones. All concentrates are road hauled to the Bunbury separation plant.

Mining at Ambergate is by front end loader which feeds an input trommel to screen out oversize material. Undersize is pumped to the wet concentrator. The ore body is very shallow, 1–4 metres, which necessitates constant shifting of screening, pumping and tails distribution equipment.

Cables mined and treated 895 000 tonnes of ore for a production of 156 000 tonnes of minerals. The three mine sites contributed as follows:—

Stratham 22 000 tonnes, Wonnerup 316 000 tonnes and Ambergate 557 000 tonnes.

At Bunbury, the ilmenite storage shed was extended and an overhead conveyor system added to transport ilmenite from the plant to the shed. The company is continuing with its programme to modernise the plant.

Jennings Industries W.A. Ltd—Mining Division: The operations of Jennings have been significantly affected by the downturn in the mineral sands industry. The Dunal plant remained closed throughout the year. In July the Strand plant was cut back to a one shift five day week. Cuts were also made at the Narngulu treatment plant. The combined workforce was reduced to 88 persons.

Ore production of 950 000 tonnes from the buried strand deposit necessitated the stripping of 2 664 000 tonnes of overburden. Mineral production totalled 145 419 tonnes.

A small monazite extraction circuit was installed at the Narngulu plant during the year.

Associated Minerals Consolidated Limited: During the year Western Titanium Ltd became a wholly owned subsidiary of A.M.C. Limited.

Capel operations: In January, a fire destroyed the primary wet concentrator. The fire which started as an electrical short circuit quickly spread to the fibreglass cones and plastic pipe work because the resulting power failure shut down the pumps supplying water to the cones.

A small plant was road hauled from the east coast and the company returned to partial production within a few weeks. A new wet concentrator was built and commissioned within four months. The electrical switching equipment has been separated from the main building.

Even with the fire induced production losses, the company exceeded the previous year's production. Minerals produced amounted to 306 261 tonnes from the treatment of 1 786 000 tonnes of ore.

Eneabba operations: Mineral production increased by 40 166 tonnes, or 49 per cent relative to 1977 output.

W.S.L. Group: The operations previously owned by Western Mineral Sands Pty Ltd have now been fully integrated within the operations previously owned by Westralian Sands Ltd. The combined operations together with the holdings of Ilmenite Pty Ltd are now known as the W.S.L. Group.

The company now identifies its current mining operations as Yoganup and North Capel (previously W.N.S. Ltd). The administrative and workshop facilities at North Capel have been closed down and moved to the Capel dry plant.

The combined output remained static with a production of 354 786 tonnes of minerals from the mining and treatment of 2 021 000 tonnes of ore and the retreatment of 25 000 tonnes of plant residues.

At the Capel dry plant, the concentrate drying kiln was converted from oil to coal firing.

IRON

Pig iron output regained most of last year's losses with an overall increase of 10 per cent.

Australian Iron and Steel: Pig iron production was 659 800 tonnes from the processing of 1 088 818 tonnes of iron ore. Personnel remained steady at 350.

Wundowie Iron and Steel. Forty-two thousand six hundred and ninety-one tonnes of pig iron were produced from the processing of 65 700 tonnes of iron ore.

LEAD

A two-man syndicate re-opened McGuires Lead Mine in the Northampton district. Their first parcel of 240 tonnes averaged only eight per cent Pb. As a consequence the mine was again closed down.

The Mary Springs Syndicate continued to upgrade and re-condition the shaft, headframe and winding equipment. Driving on the one level commenced in December with eight metres being completed by the end of the year.

The syndicate is still endeavouring to arrange finance so that the operation may continue.

LIMESTONE

Fourteen limestone pits operated in the metropolitan area. Most are operated to supply road base material. Cockburn Cement continued dredging lime sands from Cockburn Sound for cement production.

NICKEL

Western Mining Corporation Ltd. Nickel production increased by 11 per cent to 18 615 tonnes, but is still well below design capacity of the refinery. Higher production as a result of gradual market recovery is expected in 1979.

By-products produced were:—ammonium sulphate 99 669 tonnes, copper sulphide 2 278 tonnes and mixed sulphides 872 tonnes.

An economy drive resulted in rather severe staffing reductions during the year when the average number of employees fell by 59 to 385.

SALT

Shark Bay Salt Joint Venture: Operations at Useless Loop continued throughout the year. The new stacker and reclaim system has been completed allowing storage capacity on Topper Island of 90 000 tonnes.

SAND

Forty-two sand pits operated in the metropolitan area employing some 62 men in actual mining operations. The Readymix Group and Silicon Quarries continued to export silica sand.

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

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TALC

Three Springs Talc Pty Ltd: Production and sales continued to improve. Mining of ore and waste totalled 139 000 tonnes indicating that the major stripping programme of the last three years is nearing completion.

Talc production consisted of 69 073 tonnes of lump and 12 000 tonnes of washed fines which was recovered from old fines stockpiles.

The company is actively engaged in exploration drilling throughout the district.

Westside Mines N.L.: Westside mined 157 000 tonnes of ore and waste for a production of 50 400 tonnes of talc.

During the year, Bellway Pty Ltd acquired 54 per cent of the company.

TIN—TANTALITE

Greenbushes Tin N.L.: With the rising prices for tin and tantalite the company is continuing to lower the grade of ore mined. Ore mined and treated totalled 1 304 000 m^3 while 579 000 m^3 of waste was also removed. Concentrates recovered amounted to 531 tonnes of tin and 102.9 tonnes of tantalite.

A pilot plant for the extraction of tantalum and niobium was nearing completion at the end of the year.

Warda Warra Mining Company Pty Ltd: Mining operations ceased early in the year.

VANADIUM

Test work and studies into extraction from the Coates Siding deposit is continuing at the pig iron works of Wundowie Iron and Steel. A road has been constructed between the works and the deposit.

KALGOORLIE INSPECTORATE

J. J. Zuvich
Mining Engineer/Acting Senior Inspector of Mines

GENERAL

Nickel mining again dominated the mining scene in the Kalgoorlie Inspectorate. Although marketing of the product was tight, there were signs of recovery in the latter part of the year. Major progress included continued development of the Agnew Mining Company mine at Leinster and construction of a new furnace at the Kalgoorlie Nickel Smelter. However, complete closure of the Anaconda Aust. Inc. mine at Redross and the partial closure of the Windarra Nickel Mine reflected the downturn in the industry.

Continued steady increases in the price of gold to $200 per oz saw renewed activity in this field with prospectors and companies investigating formerly abandoned mines and retreating tailings dumps. The search for gold was given impetus by the fact that North Kalgurli Mines Ltd announced their intention to provide a custom mill. Feasibility studies on the re-opening of the Fimiston leases were not favourable but investigations are continuing.

Exploration for minerals was maintained at a moderate pace. Some of the ultra basic rock belts were repegged in search of colbalt which increased dramatically in price during the year. Although no uranium mining was initiated during the year, the search for these deposits continued in the East Murchison area.

The number of men engaged in mining in the Kalgoorlie Inspectorate is estimated at about 3 470, which is about 340 less than last year.

Principal activities are summarised under the headings of the mineral or metal mined and were as follows:

ARSENIC

A one man spasmodic operation produced about three tonnes of arsenic trioxide concentrate from treatment of mining residues at Wiluna.

CLAY

Chandler Clay Pty Ltd, utilising tailings from the former State potassium works at Chandler, produced 6 000 tonnes of absorbent clay which has found a ready state and interstate market in industry and the household pet trade.

COBALT

Cobalt prospecting received impetus from rising world prices for the metal. The search culminated in the discovery, by Western Mining Corporation at Siberia, near Kalgoorlie, of enriched cobalt zones within weathered ultrabasic rocks.

Up to the end of the year, 16 500 tonnes of cobalt-nickel ore was mined by open cuts and stockpiled for subsequent treatment at the Kalgoorlie Nickel Smelter. Substantial quantities continued to be produced in nickel matte form as a by-product of nickel concentrate smelting.

COPPER

No significant copper ore was mined except in conjunction with nickel mining operations where it is recovered in matte form with nickel.

CRUSHED ROCK

Crushed rock screenings for civil construction use were produced at several localities. At Kalgoorlie, the Kalgoorlie Quarry continued to crush mullock from the Mt Charlotte mine and the Readymix Group completed crushing from stockpiles at Boulder in February. The latter also completeted their rail ballast contract at Karonie in February. Quarry Industries Ltd completed a rail ballast contract at Kookynie during the year. At Koolyanobbing, Wundowie Iron and Steel utilised their plant for a short time to produce granite screenings for local consumption. The Esperance district continues to draw from the Readymix stockpile at Coramup Hill.

GYPSUM

The metropolitan market was supplied with gypsum from lakes in the Yilgarn Goldfield by two operators: W.A. Plaster Mills mined 27 680 tonnes from Lake Seabrook and H. B. Brady Co Pty Ltd mined 18 388 tonnes from Lake Brown.

GOLD

The main gold producers were Central Norseman Gold Corp at Norseman and Kalgoorlie Mining Associates at Kalgoorlie.

Central Norseman Gold Corp. enjoyed a very profitable year, treating 146 100 tonnes of ore for a recovery of 2 714.44 kg of gold. Both the Regent and North Royal shafts were worked for underground ore and the North Royal washing plant continued to treat clayey open cut ore from the No. 1 and newly excavated No. 2 pit. Portal construction commenced at the base of the No. 1 pit to obtain access to the Nos. 4 and 5 levels of the North Royal shaft, after which the headframe will be dismantled and a third pit excavated through the shaft area to join both the No. 1 and No. 2 pits. Ore reserves are quoted at 455 000 tonnes and an average of 252 personnel were employed.

Kalgoorlie Mining Associates' Mt Charlotte mine treated more ore and recovered more gold than in the previous year, being 628 130 tonnes for 3 087.91 kg of gold. An additional 115.99 kg of gold were recovered from the Chaffers Plant cleanup. An active development programme was pursued on both the main and southern ore bodies at Mt Charlotte which maintained ore reserves of 4.4 million tonnes averaging 5.2 gms/tonne. Major underground development consisted of completing the Reward Shaft sinking to the No. 17 level and connecting to the internal decline at this horizon; extending the decline from the No. 16 to near the No. 18 level; developing the southern orebody on the Nos. 11, 13 and 14 levels, and developing the main orebody on the 16 level. Installation of a new jaw crusher at the No. 15 level was under way at the close of the year. On the surface, a new crushing plant was commissioned near the mine. Continued upgrading of the Oroya treatment plant saw the introduction of a new ball mill. Some 365 persons were employed by the company.

A feasibility study by Kalgoorlie Mining Associates, released in November, showed that the re-opening of the Fimiston Mines would not be economical until the gold price exceeded $230 per oz. Part of their investigation entailed an underground inspection of the Perseverance workings. Further studies are in progress. Five tribute parties continued to work open cuts on the Company's leases and crushed some 10 700 tonnes of ore at the Kalgoorlie State Battery for a recovery of 46.06 kg of bullion by amalgamation.

North Kalgurli Mines Ltd ceased nickel ore treatment at their Croesus plant on May 31. After negotiating a loan of $500 000 from the State Government, work commenced to convert the plant into a custom mill for the treatment of non-refractory gold ores.

Also at Kalgoorlie, Occidental Minerals drilled three exploratory diamond drill holes in the Williamstown area to a vertical depth of about 500 metres. Results are being assessed before continuing.

At Menzies, the Aspacia Gold Mine, employing six men, continued to develop and mine ore at the No. 3 level. Some 1 260 tonnes were treated for a recovery of 8.61 kg of gold bullion. The Daisy gold mine at Mt. Monger was also a moderate producer, recovering 11.88 kg of bullion from 518 tonnes. Operations there had scaled down at the close of the year. Work has commenced at reopening the White Hope mine near Celebration by Hampton Areas Aust. Pty Ltd.

State Batteries at Kalgoorlie, Coolgardie, Menzies, Leonora, Ora Banda, Norseman and Marvel Loch were kept busy throughout the year operating on either two or three shifts per day. The Sandstone, Yarri and Laverton batteries were quiet. Prospectors ore came from a variety of localities but chiefly from Fimiston, Ora Banda, Kunanalling, Higginsville, Coolgardie, Gwalia, Darlot, Parkers Range and Bullfinch centres. Big parcels are being mined with earth moving equipment.

The number of individuals and small syndicates retreating tailings for gold rose during the year. These operations are now being conducted at Manxmans, Evanston, Westonia, Yunndaga, Kookynie, Grants Patch and Burbanks.

The use of electronic metal detectors in the search for alluvial gold increased during the year with some fine pieces being discovered.

IRON

Iron ore production from the two companies operating at Koolyanobbing in the Yilgarn Goldfield was marginally down from the previous year.

Dampier Mining Company Ltd railed 1 122 200 tonnes of ore averaging 60.6 per cent Fe to Kwinana. Most of the ore came from the Dowd's Hill deposit with small quantities from the "A" and "D" deposits. Three benches were worked and 126 personnel employed. Some exploratory drilling was done to test the Dow's Hill orebody at depth. Waste removal amounted to 2.6 million tonnes.

Wundowie Iron and Steel (a division of Agnew Clough Ltd) railed 57 400 tonnes of ore averaging 62 per cent Fe. Three benches were worked and a fourth developed. Eleven men were employed.

NICKEL

Western Mining Corp. Ltd—Kambalda Nickel Operations was the dominant nickel producer in the inspectorate, treating 1 237 200 tonnes of ore for a recovery of 313 562 tonnes of concentrate averaging 13.51 per cent Ni. Ore reserve estimates were down by one million tonnes to 21.2 million tonnes, but grade was marginally higher at 3.24 per cent Ni. An active development and drilling programme was pursued throughout the year with six surface diamond drills in operation. Encouraging new mineralisation was intersected in the Foster and Long shoot areas as well as beneath the lake bed between Kambalda and St Ives. An average of 1 214 persons were employed.

Of the four decline workings, the Otter Juan is the most extensive and extends down to the No. 15 level which is a driving distance of about four kilometres from the portal. Workings at the McMahon decline are down to the No. 10 level and to the 11 level at the Hunt decline. The Fisher decline was not worked except for stripping to provide access for larger vehicles in future.

The Silver Lake and Durkin shafts produced quantities of ore comparable to the previous year but a considerable proportion of the Durkin ore resulted from remnant mining. Ore from the small Edwin deposit at St Ives is almost exhausted and closure of the inclined shaft is imminent

Furnishing of the completed Jan shaft sink to the 14 level was completed during the year. Production and development is being undertaken on the 2, 3, 4, 5, 9 and 13 levels. Sinking of the Long shaft to 936 metres below the collar was completed in October and preparations made to commence lateral development.

A feature of the kambalda operation was the commissioning of a Robbins Co. raiseboring machine which was used to construct a three metre diameter hole from the surface to the 13 level of the Juan west wokrings.

The Kalgoorlie Nickel Smelter of W.M.C. Ltd treated 273 806 tonnes of concentrate for an output of 47 825 tonnes of matte containing 32 700 tonnes of nickel, 2 658 tonnes of copper as well as various by-products. A new flash furnace electrostatic precipitator and ancillary equipment to replace existing furnaces was commissioned towards the close of the year. Plant capacity now stands at 450 000 tonnes per annum. The bulk of the concentrate input came from Kambalda with some from the Croesus and Windarra plants until closure. Small initial shipments were received from Agnew Mining Co. Pty Ltd. A portion of the silica flux used in smelting was carted from stockpiles at Siberia and trials were conducted on treating cobalt rich ore from the same locality.

At Windarra, W.M.C. Ltd Windarra Nickel Project ceased production in June after treating 253 200 tonnes of ore for a recovery of 40 618 tonnes of concentrate averaging 10·35 per cent Ni. Although the south open pit was closed, a small workforce was kept on to deepen the decline and develop ore horizons underground in readiness for resumption of activities when the nickel market improves.

Depletion of developed ore reserves, coupled with an unfavourable economic situation led to the closure of the Redross mine of Anaconda Aust. Inc. Seventy-four men were dismissed and all equipment sold. Production before closure was 9 146 tonnes of concentrate averaging 13 per cent Ni from 35 400 tonnes of ore. This decision led to the closure of the Croesus concentrating plant at Kalgoorlie and forced Selcast Exploration Ltd, who were joint users of the plant, to arrange for treatment facilities at Kambalda.

Selcast Exploration Ltd at Spargoville, cut production and manpower compared with the previous year. Production was 147 000 tonnes of ore, of which 137 600 tonnes were treated for 18 273 tonnes of concentrate averaging 16·7 per cent Ni. Major ore development was completed and it is expected that all of the economic ore will be broken and extracted before the end of 1979.

Metals Exploration N.L. at Nepean, treated 79 500 tonnes of ore for a recovery of 19 117 tonnes of concentrate averaging 15·30 per cent Ni. Shaft sinking to the 13 level was completed and development commenced on the 11 and 12 levels. State Government assistance was granted to enable the company to continue with their development programme. Ore reserve is quoted as 246 000 tonnes of 4 per cent Ni which is sufficient for several more years of operation. The labour force was reduced from an average of 226 in 1977 to 176 in 1978.

Agnew Mining Co. Pty. Ltd. continued developing their mine via a vertical shaft and decline. Sinking is still progressing and the shaft reached a depth of 319 metres at the close of the year. The first plat was excavated at the 282 m horizon. The decline face advanced to 887 metres from the portal and lateral development on the orebody was undertaken on three horizons. The concentrating plant was commissioned during the year and treated 22 730 tonnes of development ore for a recovery of 4 184 tonnes of concentrate averaging 10 per cent Ni. Concentrates are hauled by road to Leonora, then railed to the Kalgoorlie Nickel Smelter. Some 194 men are employed and the number is increasing.

Some drilling was carried out at the Forrestonia nickel prospect but there was no activity at the Carr Boyd, BHP-INCO or Mt. Keith nickel mines.

SALT

Lefroy Salt Pty Ltd, harvesting salt from the bed of Lake Lefroy at Widgiemooltha, had a difficult year with marketing and although the average number of men employed was twenty-two, most had been retrenched by the end of the year. Production was down about 50 per cent from the previous year to stand at 116 300 tonnes. Exports through Esperance amounted to 211 900 tonnes.

W.A. Salt Supply rotated their workforce to harvest salt from the three localities of Widgiemooltha, Esperance and East Lake Deborah. Some 35 500 tonnes is reported to have been transported to the metropolitan area.

SCHEELITE

A trial parcel of 35 tonnes of scheelite ore from near Coolgardie was treated at the State Battery for a recovery of 0·75 tonnes of concentrates. No further work was done.

TIN

Poldark Mines Ltd constructed a small tin concentrating plant at Norseman to treat tin ore from the Mt. Deans area south of Norseman. A small quantity of concentrates was produced during trial runs.

VERMICULITE

The Young River mine was dormant for the year, but 224 tonnes of stockpiled material was carted to the treatment plant in the metropolitan area.

Consolidated Goldfields Aust. Ltd investigated a new vermiculite find near Coonana. Several pits were sunk to evaluate the deposits and to obtain samples for metallurgical and market research.

COAL MINING

R. S. Ferguson

Mining Engineer/Senior Inspector of Coal Mines

The trend in annually increasing outputs of coal from the Collie Coalfield continued with yet another record output produced during 1978 when, however, the output of 2 403 503 tonnes was only an increase of 45 497 tonnes or 1·89 per cent on the previous year's output of 2 358 600 tonnes. This was the fourth successive year in which over two million tonnes of coal were produced from the coalfield.

It is estimated that the strike by State Energy Commission Maintenance workers which had the effect of reducing coal deliveries to the power stations and, therefore, coal production from the mines during the latter part of the year, resulted in a decrease of 122 400 tonnes in output. In normal circumstances then, the output should have been nearly 2·5 million tonnes.

The open cut component of the total output from the field was won from the Muja and Western No. 5 Open Cuts and amounted to 1 849 654 tonnes or 76·96 per cent of the year's output. Again, the normal trends of the figures were distorted by the effects of the S.E.C. maintenance workers' strike and the underground mine output from Western No. 2 Colliery accounted for 23·04 per cent of the total output, an increase of 0·22 per cent when compared with the previous year.

The total value of the coal produced during 1978 was $28 642 245 an increase of $5 470 152, compared with the 1977 value of $23 172 093.

Western Colleries Limited Western No. 2 Mine

The output of 553 849 tonnes was the highest ever produced from this colliery and was 1 555 tonnes more than the previous annual record output of 552 294 tonnes produced in 1976 and 15 820 tonnes more than the 1977 output of 538 029 tonnes.

The method of "grunching" or firing coal off the solid faces preparatory to loading out continued to be used throughout the mine. This situation, together with the cyclic pattern of mining operations on the coal faces and the widespread use of diesel powered front end loaders for loading out coal, contrasted greatly with coal mining elsewhere in Australia where "grunching" is now practically non-existent and where nearly all of the coal is loaded out by electric powered continuous mining equipment.

Published figures show the estimated 1976 population of diesel powered equipment in underground collieries in Australia as 175. Since the end of that year when there were 30 diesel engined vehicles at Western No. 2 Colliery, another 15 such vehicles were introduced, including 11 during 1978. The relatively large number of diesel engined vehicles in use at this colliery relates to the system of mining where thirty-five of the machines are coal loading units.

To a great extent, the physical conditions at Collie, particularly very wet strata conditions and the soft floors and weak immediate roofs associated with these have inhibited the application of continuous mining methods which ceased on the field following poor results achieved with earlier equipment during the 1950s at collieries which closed nearly two decades or more ago.

The need for technological advances in undergound mining at Collie to complement the progress and achievements in the open cut mining sector is generally realized if underground mines are to improve productivity and coal recovery consistent with maintaining safe working conditions.

In this context, the management's planned trails of continuous mining methods in pre-drained areas are very important. These trails shall precede and be complementary to the long term research work and field trails to be undertaken at Collie by the Australian Coal Industry Research Laboratories Limited.

During the year, there was an average number of 150 coal face workers employed as composite miners at the widespread current workings of the mine. This number provided for fifteen crews of five face workers on each of the two shifts at the mine.

Pillar splitting to general overall retreating programmes continued in No. 4B East District and in No. 3B West District where percentages of extractions of approximatley 62 per cent (in plan) or 40 per cent (in volume) were achieved. Elsewhere, some of the coal winning was from areas where pillar splitting will not be undertaken or where development is in progress prior to opening out on first working.

Some quite difficult physical conditions were encountered in several areas, notably in the dip headings being developed down from No. 2B West District; in the workings being opened out in No. 3B West District and in the No. 6A West District, "D" Panel area. The adverse conditions generally resulted from hydraulically induced roof weight, sheared roof coal and excessive "makes" of water, with areas of soft floors.

New coal handling equipment, including a belt conveyor in the drift to the surface and a surface coal loading bin and ancillary equipment were installed for the South East Entries Area.

Western Collieries Limited. Western No. 5 Open Cut

The output of 758 466 tonnes was an increase of 40 975 tonnes or 5.71 per cent over the 1977 output of 717 491 tonnes.

By the end of the year most of the Cardiff Seam coal had been removed from Western No. 5A Excavations and the remaining reserves of this coal within the "C8" and "C10" Blocks were being exposed towards the fault separating these and the Western No. 5B Area where opening out and exposures along sub crop lines of the coal seams were quite impressive.

Exposed reserves of the relatively thin Neath Seam coal were being won out from the Western No. 5A Area and systematic backfilling of overburden from nearby excavations over the Cardiff Seam was in progress.

Backfilling featured prominently at the Main Excavations where a considerable area of previously mined land was reclaimed at the north end and where, apart from topsoil which was spread on contoured and graded dumps on the surface, all overburden removed was backfilled.

All of the Cardiff Seam coal was won out from the "C3" Block and at the end of the year work was well advanced on overburden removal down to this seam over "C5" Block at the extreme south of the excavations within currently held leases.

The overburden was quite dissimilar at the Main Excavations compared with the Western No. 5A and, so far, the Western No. 5B Areas. In the former case, it is relatively difficult to maintain a stable profile on the highwall from which slurry exudes in places and where the material is sometimes difficult to excavate and handle. At the latter two areas the overburden is relatively competent and it is easier to maintain satisfactorily good wall conditions.

This mine is now a very significant coal producer with a daily output of around 4 000 tonnes, practically all of which is mined from the generally 3.7 m thick Cardiff Seam and the 1.8—2.0 m thick Neath Seam. An output of this magnitude from thin seams necessitates a wide dispersal of plant, equipment and personnel and makes it imperative that planning be undertaken well in advance for overburden and coal removal activities.

Major extensions to the workshops building were completed for this mine where a wide range and variety of excavation and hauling equipment of increasing size is constantly being added to the existing equipment being used.

Work commenced on construction of extensions to the change house to meet the increasing needs of the mine where the labour force increased by 35 or from 147 to 182 men during the year.

Very impressive results are being achieved in areas where seeding and planting, mainly with native species but also with coniferous trees, have been undertaken as part of the ongoing rehabilitation work at this mine where approximately 40 hectares of areas in gravel pits, on dumps and around excavations have been treated and where a large programme of similar work is planned for the following planting season.

The Griffin Coal Mining Company Limited—Muja Open Cut

For the third year in succession, this colliery again produced over one million tonnes of coal. The output from this largest single producer on the field was, at 1 091 188 tonnes, 1.02 per cent or 11 297 tonnes less than the previous year's output of 1 102 485 tonnes. A significant increase should have been achieved but for the effects of the State Energy Commission maintenance workers' strike.

At the North Extension, exposure and winning out of the Galatea Seam was completed and the Hebe Seam was exposed down to the upthrow side of the major fault. Towards the end of December, the remaining 162 000 tonnes of exposed Hebe Seam coal in this area comprised the bulk of the total exposed reserves of 260 000 tonnes in various seams and areas of the widespread workings of the mine.

The final phases of coal winning from the Hebe Seam were completed on Bolck No. 7 where this work included excavating across old underground workings.

Very good progress was made on widesread excavations at various levels on Block No. 8 where the Ate, Bellona and Ceres Seams were fully exposed and won back to their face line positions along the high wall. Only a very small quantity of Diana Seam coal proved to be recoverable. Coal in the Eos, Flora, Galatea, Hebe and Iona Seams was won as the sub crop lines were intercepted during overburden removal. Benched working was necessary where the coal seams dip very steeply, particularly near the west wall.

Removal of the laterite capping was completed on East Section Panel No. 7 during the early part of the year and subsequently, following removal of sub soil or top overburden from the "Lake Beds", excellent progress was made on overburden removal within the coal measures with hydraulic excavators, rope shovels and front end loaders.

Very important hydrological investigations and monitoring procedures were undertaken and are continuing at the mine where the existence of high pressure acquifers in strata under the

Hebebe Seam is a matter for careful consideration now that the maximum depth of the workings is in excess of 100 m. Piezometers were placed in holes drilled for pressure testing and pump tests were carried out for the programme. In addition, dewatering of strata above the Hebe Seam through boreholes drilled into old underground workings resulted in improved conditions in the excavations on Block No. 8 Many of these procedures follow on from important recommendations by the Company's Consultants with regard to the geotechnical assessment of stability at the mine.

The planned expansion to double production rapidly at this mine is evidenced by the increasing numbers and sizes of various excavators, trucks and other items of equipment which are being put into service. Among significant new machines ordered is the Demag H 241 Hydraulic Excavator which with a service weight of 240 tonnes and bucket size of 11.7 m^3 is one of the largest units of its type in the world and is only the second of this particular model to be produced.

GENERAL

There were 571 reported accidents of which 494 were minor and 77 were classified as serious where an employee was absent from work for fourteen days or more.

There were 871 persons employed in the industry at Collie at the end of the year.

As the State was about to enter its 150 th Anniversary Year, the coal industry at Collie was completing its 80th year of operations. This industry which has existed for more than half of the duration of time since the founding of the State and which has produced over fifty-five million tonnes of coal is preparing to meet greatly expanded outputs and an unprecedented era of expansion and development.

DRILLING OPERATIONS

D. A. Macpherson
Drilling Engineer

During 1978 the Drilling Section was responsible for the drilling of 7 526 metres in 81 bores, the development of aquifers in 144 bores and the testing of aquifers in 16 bores. The work was carried out by Departmental employees and equipment except for 5 shallow bores which were drilled by a private contractor.

The total meterage drilled is 3 704 metres above the figure for 1977 and this is due in part to elimination of the backlog of testing of existing bores.

During the year G.S.W.A. increased projected depth on one of its main investigation jobs from 762 to 1 200 metres. This has presented the Section with various financial problems and has considerably increased the engineering work load.

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.

PICTON LINE

This job forms part of the statewide groundwater investigation conducted by the Geological Survey of Western Australia and is financed by the Department of Mines. The Picton Line commences in Bunbury and runs east through Picton Junction to the Collie river. Site 1 was completed in previous years.

The job was required to provide information on stratigraphy and groundwater conditions to a projected depth of 762 metres at selected sites on the line. This was generally effected by drilling one bore to target depth to provide strata samples, geophysical bore logs, and sidewall cores. This bore is cased to bottom and cemented, then perforated at 2 intervals. Each perforated interval is isolated by a packer and steel tubing, and separately developed and air lifted to provide accurate water samples and water levels. Additional bores may be drilled at the same site to provide water quality and water level measurements for aquifers at other levels. The bores are left in appropriate shape for long term water level observation.

During the year sites 2, 3, and 4 were completed with 2 bores on each site. Completion was delayed by a down hole casing failure during pressure cementing. During drilling of a deep bore on this line, some shallow coal seams were penetrated. These were further investigated during drilling of a shallow bore at the same location.

Results were inconclusive.

This line was completed during the year and the drilling unit moved to Quindalup Line.

QUINDALUP LINE

This job forms part of the statewide groundwater investigation carried out by the Geological Survey of Western Australia and is financed by the Department of Mines. The line commences west of Busselton and extends east through Quindalup towards Donnybrook. In previous years 6 sites were completed.

This job is required to provide information on stratigraphy and groundwater conditions to a projected depth originally of 762 metres but increased to 1 200 metres this year at selected sites on the line.

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

The move to Quindalup line was hampered by wet weather and boggy terrain and some equipment modifications and repairs were carried out during the move. Quindalup 7A, the deepest groundwater investigation bore drilled to date by the Department was completed. The additional depth of this bore and the next 2 to be drilled involve using stronger bore casing with considerable cost increase.

BUNBURY (Shallow Aquifers)

The job forms parts of the statewide groundwater investigation carried out by the Geological Survey of Western Australia and is financed by the Department of Mines. The work is being done in the Bunbury/Busselton area. The job is required to provide information on stratigraphy and groundwater conditions to a projected depth of 100 metres at selected sites in the area. This 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.

Part of this job was carried out during the first half of the year in which the unit was plagued by continual mechanical breakdowns.

Drilling was continued during the last month of 1978 after the unit returned from the North.

FORTESCUE VALLEY JOB

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

During 1978 a further 15 bores were drilled and 10 bores were pump tested. The work was held up on two occasions by local flooding caused by unusually heavy winter rains. Further work will be carried out in 1979.

MANJIMUP WOODCHIP INDUSTRY

This job forms part of an investigation into the effects of logging for the Manjimup Woodchip Industry on the groundwater regime in the area. The work is being carried out for an investigation committee and is financed by the Department of Mines. 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 groundwater 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.

During the year, 23 bores were drilled at selected sites in the area and 5 bores were tested. Pump testing will continue during 1979.

ALCOA—Del Park

This is an investigation into the effects of Bauxite mining on the groundwater regime in the Darling ranges. The work is being carried out for an investigation committee and is financed by the Department of Mines.

A small unit was set up using a tractor to clean out existing groundwater monitoring bores and was disbanded on completion of the job.

LAKE CLIFTON

This job is an investigation of the shallow groundwater resources of the Perth Basin in the Mandurah-Australind area. Lake Clifton is a dominant geographic feature in the area. The investigation is to provide sufficient information to assess the shallow groundwater resources of the coastal plain west of Harvey and Waroona between White Hill in the north and Binningup in the south and to establish approximate water balance for the coastal plain lakes. This job is being carried out for the Geological Survey of Western Australia and is financed by the Department of Mines.

The work consists of constructing 1 or more bores for water level and water quality monitoring purposes at selected sites on a number of east-west lines through the area.

The job was commenced late in the year and six bores were constructed on it. The work will be continued in 1979.

S.E.C.—Ash Dump Job

This job was carried out for, and is financed by the State Energy Commission.

This job was to construct 3 monitoring bores, with a projected depth of 35 metres each, and has been successfully completed.

This job was an environmental safeguard for a proposed ash dump to be located near the South Fremantle powerhouse. It was carried out for, and financed by the State Energy Commission. The work consisted of constructing 3 groundwater quality monitoring bores to detect possible pollution of the groundwater by a new ash dump for the powerhouse.

STAFF

On 31/3/78 the Engineer Drilling Mr. M. Bennett resigned and on the 26/6/78 Mr. M. Dawson was appointed to the staff in his place.

On 8/5/78 Mr. J. Young was appointed to the staff as an Assistant Drilling Supervisor to fill a newly created position.

On 3/7/78 Mr. M. Duke was appointed to the staff as a Level 1 Engineer to fill the newly created position of Engineer Electronics.

On 28/8/78 Mr. G. Dowdall was appointed to the staff as a Technical Officer.

On 22/12/78 Mr. N. Francis was reclassified from General Assistant to Transport Officer.

PLANT

Three vehicles were written off and sold due to poor mechanical condition. Various items of general equipment which had reached the end of their economic life were written off and sold, and replaced where necessary.

TABLE SHOWING WORK CARRIED OUT DURING YEAR ENDED 31/12/78

Place	Purpose	Type of Work	Done By	No. of Bores	No. of Aquifers	Meterage
Picton Line	Groundwater Investigation	Rotary Drilling	Dept. of Mines	6	....	2 870
		Development	Dept. of Mines	6	....	....
Quindalup Line	Groundwater Investigation	Rotary Drilling	Dept. of Mines	2	....	1 806
		Development	Dept. of Mines	1	....	....
Bunbury Shallow Job	Groundwater Investigation	Rotary Drilling	Dept. of Mines	14	....	923
		Development	Dept. of Mines	13	....	....
Fortescue Valley Job	Groundwater Investigation	Rotary Drilling	Dept. of Mines	20	....	931
		Development	Dept. of Mines	15	....	....
		Pump Test	Dept. of Mines	11	....	....
Manjimup	Investigation of the effects of logging on groundwater	Rotary Drilling	Dept. of Mines	23	....	417
		Pump testing	Dept. of Mines	5	....	....
		Diamond Drilling	Contractor	5	....	184
Del Park Bauxite	Investigation of effects of Bauxite Mining on groundwater	Development (reconditioning)	Dept. of Mines	100	....	....
Lake Clifton Job	Groundwater Investigation	Rotary Drilling	Dept. of Mines	8	....	260
		Development	Dept. of Mines	6	....	....
SEC Ash Dump	Groundwater Pollution Investigation	Rotary Drilling	Dept. of Mines	3	....	135
		Development	Dept. of Mines	3	....	....
			TOTALS:			
			Drilling	81	....	7 526
			Developing	144	....	....
			Testing	16	....	....

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 1978.

MINING LAW EXAMINATION

The examination in Mining Law for Mine Manager's Certificates of Competency was held on April 17, 1978. Details of this examination are as follows:—

Entries	14
Admitted	14
Pass	8
Did not sit	2

The names of the successful candidates were:—

D. H. Austin
D. Collie
A. R. Jackson
J. G. Seaward
G. G. Smith
P. C. Teasdale
J. K. Williams
B. J. Woolnough

UNDERGROUND SUPERVISOR'S EXAMINATION

The above examination was held on Monday, September 4, 1978 and attracted only three (3) applications, which is an all time record low of applications. This fact must relate to the down turn in gold mining in the State in 1978.

The three applications were accepted.

The only successful candidate was I. N. Vikis, and a Certificate was duly issued to him, dated 2/10/78.

In addition to the normal examination, the following persons were examined orally by members of the Board and subsequently were issued with Certificates, as follows:—

G. Hassan, G. B. Blackstock—Restricted to Shaft Sinking Operations.

B. J. Woolnough—Restricted to the Mining Operations of the Agnew Mining Coy. Pty. Ltd. at Leinster.

J. J. Claus—Restricted to Mining Operations with the exception of Shaft Sinking, of the Agnew Mining Coy. Pty. Ltd. at Leinster.

J. G. Green, F. Wood. B. J. Scholze—Restricted to the Blue Spec Operations of Mulga Mines Ltd.

K. D. Ross

J. Evans—Restricted to Agnew Mining Coy. Pty. Ltd. operations at Leinster.

F. J. Knaebler, D. F. H. Rahn—Restricted to the Exploration Decline and lateral Development being excavated by R.U.C. (Pacific) Pty. Ltd. at Sorby Hills.

MINE MANAGER'S CERTIFICATES

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

P. M. Bartlett
J. L. Blackburn
R. A. Dennis
R. B. Devereux
R. M. Harken
B. P. Micke
J. G. Seaward
B. J. Woolnough
D. Collie
P. C. Teasdale
K. J. Elvish
J. K. Williams
G. E. Robertson

GENERAL

Three normal meetings were held during the year on March 21, July 20 and October 2, 1978.

The Board was required to hold two Inquiries after representations had been made to the Minister by an Inspector of Mines under the provisions of Regulation 3.17 to the Mines Regulation Act, 1946–1974. These were held in Perth on June 19, 1978.

One inquiry was into the conduct of Mr. Robert John Lloyd, the holder of a First Class Mine Manager's Certificate of Competency, and the other was into the conduct of Mr. Theunis Louis Botha van der Merwe, the holder of an Underground Supervisor's Certificate of Competency. Both inquiries related to incidents associated with a multiple fatal accident which occurred in 1977.

A special meeting of the Board was held at Kalgoorlie on June 21, 1978 to consider the notes of the proceedings of the inquiries to prepare a report containing a statement of the case, and to arrive at its opinion thereon. The report was submitted to the Minister and the Governor, on the recommendation of the Minister, ordered that both of the Certificate holders be admonished.

BOARD OF EXAMINERS FOR QUARRY MANAGERS CERTIFICATES

J. A. Suda—Secretary

EXAMINATIONS

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

QUARRY MANAGER'S CERTIFICATES OF COMPETENCY

Mining Law examinations were held on 3rd April, 1978 and 20th October, 1978 and 15 applications were received and accepted.

Those successful in the April examination were:—

Curtis, R. E. S.
Markin, G. K.
Jamieson, J. K.
Morris, B. D.
Tejchman, L.
Kidman, V. T.
Osborne, T. R.
Cordy, R. C.
Purdy, G. H.
Leslie, W. E.
Lewis, P. A. P.

Those successful in the October examination were:—

M. Baron
R. De Jongh
J. Hughes

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

B. R. Gardiner
P. J. Jongen
J. K. Jamieson
R. E. Curtis
L. Tejchman
J. L. McIntosh
P. A. P. Lewis
J. Alderson
R. C. Cordy
G. H. Purdy
F. Sibbel
D. R. George
V. T. Kidman

RESTRICTED QUARRY MANAGER'S CERTIFICATES OF COMPETENCY

Mining Law and Quarrying examinations were held on 24th April, 1978 and 20th October, 1978 and 43 applications were received and accepted.

Those successful in the April examinations were:—

T. J. Honan
N. C. Halden
B. K. Spalding
W. D. Bentley
T. W. Sly
P. G. Stagbouer
M. J. Rumford
J. W. Gandy
S. Malinowski
F. M. Saliba
W. L. Gane
M. C. Welsh

Those successful in the October examinations were:

W. Kowalczuk
M. McKenzie
S. Kent
H. Steinkamp
J. P. Bulters
P. J. Titmus
P. V. McIntyre
L. G. Richardson
P. L. Tenardi
P. A. Williams
M. N. Hughes
M. G. Teague
R. H. Watson
C. P. Szolkowski
R. J. Meyer
M. T. Tate
W. R. McWhirter
R. H. Carroll
W. E. Leslie
A. S. Cooper

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

W. P. Gildare
N. C. Halden
A. S. Cooper
P. G. Stagbouer
T. W. Sly
B. T. Bertola
W. L. Gane
M. Rumford
W. E. Leslie
M. C. Welsh
W. Kowalczuk
S. Kent
J. P. Bulters
P. V. McIntyre
M. N. Hughes
S. Malinoski
M. Tate†
T. J. Honan
H. Steinkamp
K. W. Thomas*
B. K. Spalding
R. H. Watson†
R. H. Carroll†
M. McKenzie
J. W. Gandy
P. J. Titmus

* Valid only for Wungong Dam Quarry Operations.
† Valid only for Mineral Sands Mining Operations.

GENERAL

Nine meetings were held during the year and a total of 39 certificates were granted. Some members of the Board visited Newman, Tom Price, Goldsworthy, Koolyanobbing and Kalgoorlie to conduct oral examinations for the Restricted Quarry Manager's Certificate of Competency.

Members of the Board of Examiners (for 1978) were:—

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

BOARD OF EXAMINERS FOR COAL MINING CERTIFICATES OF COMPETENCY

R. S. Ferguson—Secretary

Following amendments to the Coal Mines Regulation Act and Regulations in sections and divisions relating to the Board of Examiners, the range of examinations conducted by the Board were extended to include the Open Cut Mine Managers and Deputy's (Open Cut) Certificates of Competency. In addition, the Board's powers to grant certificates of competency in respect of statutory qualifications gained elsewhere and to grant exemptions or partial exemptions from examinations for holders of approved academic or professional qualifications were extended.

Prior to amendments which came into effect on the 24th July, 1978, the Board of Examiners conducted examinations for candidates for First Class Mine Managers, Second Class Mine Manager's and Third Class or Deputies' Certificates of Competency.

The amendments provided for a reconstituted Board to include a nominee of the Association of Colliery Management and also, for a joint nominee of the Australian Collieries Staff Association and the Combined Mining Unions Council to assist the Board in the assessment of the practical experience of applicants.

Following the implementation of the amendments, the Board members were:—

A. Y. Wilson, Chairman.—Acting Chief Coal Mining Engineer.

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

H. W. Williams, Member.—Assocation of Colliery Management.

D. Forrest, Member.—Collieries Staff Association and Combined Mining Unions Council.

The appreciation by the continuing and new members of the Board of the very great contribution made to the work of the Board over many years by the Director of the Geological Survey, Mr. J. H. Lord, is recorded.

Statutory examinations for certificates of competency were held in October, 1978 when three candidates for Second Class Mine Manager's Certificates of Competency failed to pass the examinations and the following persons qualified for the types of certificates indicated:—

R. Stedman—Open Cut Mine Manager*

J. A Wall—Open Cut Mine Manager*

D. J. Atherton—Deputy (Open Cut)

W. B. Gillespie—Deputy (Open Cut)

* (Required to qualify in Mining Law only)

Mr. E. D. Morgan, the holder of a Limited Mine Manager's Certificate of Competency (Queensland) was granted an Open Cut Mine Manager's Certificate of Competency without further examination.

Twenty years ago, at a time when colliery closures were affecting employment, the Board reported on the then prevailing surplus of Managers, Under Managers and Deputies. The last published report of the Board appeared the following year and recorded that examinations were not held. A summary of the numbers of the various types of certificates of competency awarded during the period since the last published report is shown as follows:—

The situation is now that a definite shortage of statutorily qualified persons exists in the coal industry. Current and proposed developments indicate that this shortage could become very acute and that, necessarily, serious attention must be given to the availability of study courses leading to qualifications and also, to providing opportunities for intending candidates to acquire satisfactory practical experience.

The Board Members wish to record their appreciation of the generous assistance received from the New Zealand Technical Correspondence Institute in regard to co-operation with this Board by the provision of courses for students who are studying part time while working in the industry at Collie.

VENTILATION BOARD

J. A. Suda—Secretary

During 1978 the Ventilation Board met on eight occasions. The members of the Board were:—

Mr. A. Y. Wilson (Chairman), Dr. A. G. Cumpston, Mr. J. Faichney, Mr. R. Powell and Mr. I. Loxton.

DUST SAMPLING

All mining companies required to do so have commenced their dust sampling programmes and are now forwarding the results of dust sampling promptly and on a regular basis to the Mines Department. Due to a delay encountered in preparing a suitable computer programme to record and average the dust sampling results the Secretary manually processed the information available in order to overcome any further delay in examining the results and providing some comment to the companies. The Board anticipates that the preparation of a suitable programme will be completed by mid 1979 and that it will be able to provide information and comment on a regular basis.

All sample results received were placed into job categories or positional codes according to whether a personal or positional sample had been taken and calculations were made using a "Moving Average Method" taken over the last ten samples.

The Board was impressed with the results of positional sampling and are satisfied that this function will assist the mining companies to identify dust problem areas and take action to control these dust sources. On those mines where dust sampling has been in progress for about two years the results indicate a significant improvement in dust concentration.

Personal sampling results obtained from some categories of workers were unacceptable especially in the iron ore industry. The Board has made the companies concerned aware of the problem areas and expects improvements during 1979.

As soon as the computerised system is functional and the processed data is available for comparison by health officers, the related programme for monitoring health effects will be initiated.

TOXIC GASES

A walk-through survey was carried out by members of a technical sub-committee appointed by and responsible to the Ventilation Board. Their aim was to identify gases and fumes liberated from refineries, smelters and treatment plants

CERTIFICATES OF COMPETENCY 1958–1978

Certificate	Passed	Failed	*Awarded	†Refused	‡Mining Law	Total	Total Issued
First Class	5	1	3	1	....	10	8
Second Class	4	6	1	1	....	12	5
Third Class	26	....	1	3	....	30	27
Open Cut-							
Mine Manager	....	....	1	....	2	....	3
Deputy	2	....	....	....	....	....	2
Total Certificates Issued	....	....	....	....	....	....	45

* Awarded: On basis of Certificate of Competency from another approved Board.

† Refused: Application disallowed due to inadequate practical experience. Note: (Several other intending applicants were dissuaded from lodging applications as their experience was known to be inadequate.)

‡ Mining Law: One subject examination to qualify as academic qualification held.

The sub-committee made recommendations to the Board, however no further action will be taken to request companies to forward regular returns until the dust recording programme is operational. "Guidelines" on toxic gases will be prepared and a programme similar to that used for dust sampling is anticipated.

VISITS

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

The Board also visited Newmont Proprietary Limited's Telfer project to determine if the operations warranted a recommendation declaring that mine to be a "Class A mine". The analysis of personal dust sampling at this mine showed high percentages of free silica. A recommendation to have the mine reclassified as "Class A" was made to the Minister for Mines.

RAILWAY WORKERS

It was brought to the Board's attention that some railway workers loading, unloading and handling ballast on the iron ore railways were being exposed to high dust levels. The Board decided that some worker's health could be at risk and will arrange for Mines Department officers to conduct random dust sampling of these workers.

GENERAL

The Ventilation Board is concerned about the high dust levels encountered in certain sectors of the mining industry, however in the broad sense it is pleased with the overall results and the frequency of dust sampling undertaken by most companies.

Company dust sampling results will be further examined by the Ventilation Board during 1979, and comparison made with the results obtained by Mines Department officers when sampling the same areas.

DIVISION III

Report of the Superintendent of State Batteries—1978

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, 1978.

Crushing Gold Ores

One 20-head, five 10-head, and eight 5-head mills crushed 56 282·15 tonnes of ore made up of 439 separate parcels, an average of 128·2 tonnes per parcel. The bullion recovered amounted to 389·276 kilograms, estimated to contain 329·904 kilograms of fine gold, equal to 5·86 grams per tonne of ore.

The average value after amalgamation but before cyaniding was 2·47 grams per tonne, giving an average value of ore received of 8·33 grams per tonne, compared with 8·91 grams per tonne for 1977.

The cost of crushing 56 465·15 tonnes, which included 183 tonnes of Wolframite ore at Coolgardie was $25.81 per tonne. In 1977, 45 239·95 tonnes were crushed at the gold plants, for a cost of $28.74 per tonne.

Cyaniding

Six plants treated 14 625 tonnes of tailings from amalgamation for a product of 37·022 kilograms of fine gold. The average content was 3·42 grams per tonne before cyanidation, while the residue after treatment was 0·93 grams per tonne giving a theoretical recovery of 72·65 per cent. The actual extraction was 73·9 per cent. The cost of cyaniding was $19.68 per tonne, higher than the previous year when 11 886 tonnes were treated at a cost of $17.92 per tonne.

Silver recovered by the cyaniding of gold tailings was valued at $644.96.

TREATMENT OF ORE OTHER THAN GOLD

Lead Ores

The Northampton Battery crushed 279·84 tonnes of lead ore for the recovery of 31·33 tonnes of concentrates.

Tungsten Ores

The Coolgardie Battery crushed 183 tonnes of Wolframite ore for a recovery of 121 kilograms of concentrates.

Tin Ore

The Marble Bar Magnetic Plant treated 8·51 tonnes of tin ores for a recovery of 1·72 tonnes of concentrates.

Tantalum Ores

The Tin Ore treated at Marble Bar Magnetic Plant also produced 7·7 kilograms of tantalum concentrates.

Garnet Sands

The Northampton Battery treated 572·4 tonnes of Garnet Sands for the recovery of 415·9 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

	1978 $	Since Inception $
Gold	2 011 290	47 447 277
OTHER METALS		
Silver	645	6 423
Tin (Concentrate)	10 552	498 404
Tungsten (Concentrates)	967	*71 384
Copper (ores for Agricultural use)	....	11 932
Lead and Zinc (Concentrates)	11 429	1 572 963
Tantalite-Columbite (Concentrates)	189	96 235
Garnet-(Concentrates)	19 964	41 921
Total other metals	$43 746	$2 299 262
Grand Total	$2 055 036	$49 746 539

* Audit Correction for Tungsten 1977 Value $26 232.

FINANCIAL

	Tonnes	Expenditure $	Receipts $	Loss $
Crushing-Gold Mills	56 465.15	1 457 572	154 889	1 302 683
Crushing-Northampton Lead Plant	852.27	41 977	2 653	39 324
Magnetic Separator	8.51	2 387	106	2 281
Cyaniding	14 625.00	287 835	45 611	242 224
	71 950.93	1 789 771	203 259	1 586 512

The loss of $1 586 512 is an increase of $209 446 on the previous year. It does not include depreciation and interest on capital. Capital expenditure; was incurred as follows:—

	$
Meekatharra Extensions	22 845
Northampton (Gyrex Crusher)	4 000
	$26 845

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
1976	40 775.5	8 317.21	20.39
1977	46 469.5	7 957.9	17.12
1978	57 325.9	7 844.9	13.68

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

Administrative

Expenditure was $243 354, equal to $3.38 per tonne crushed and cyanided, compared with an expenditure of $230 414, $3.95 for 1977.

	1977 $	1978 $
Salaries	107 225	116 586
Pay Roll Tax	49 814	57 451
Workers Compensation	59 668	58 750
Travelling and Inspection	9 294	7 089
Sundries	4 413	3 478
	$230 414	$243 354

Staff

Senior Manager W. J. Crew retired in April, 1978 after thirty-three years of excellent service. He was appointed Manager in August 1950 shortly after re-joining the State Batteries in January 1950. After Managing in the Coolgardie and Cue areas Mr. Crew was transferred to Northampton where he remained until he accepted the Senior Management position at Kalgoorlie in 1975.

The position of Senior Manager at Kalgoorlie is now in the capable hands of Mr. D. Marr who was previously assisting Mr. Crew at Kalgoorlie.

State Battery Senior Clerk Mr. L. Abraham retired after twenty-five years of dedicated service. This position is now being managed by Mr. A. Bassett who was transferred from the Kalgoorlie State Battery Office.

The following operators were confirmed as foremen during the year—Mr. L. Zapelli, Mr. L. Colling, Mr. C. Solly, Mr. P. Tucker and Mr. R. Dellar.

General

The average price received for gold during the year was $170.50 an ounce. A rise of $37.50 on the previous year average. The tonnage of gold ore crushed (56 282·15 tonnes) increased to the highest since 1941 (72 807·25 tons)

Due to the relative high gold price some overloading of Batteries has occurred with the booking and crushing of low grade ores.

Several prospects have developed into producing mines with State Batteries aid, and others are in the process of development. With the general trend to higher mineral and metal prices confirmation of these developments should be achieved in the coming year.

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, 1978

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	29	1 849·05	10·644	9·019	4·897	13·916	7·52
Coolgardie	90	7 403·2	26·289	22·279	14·655	36·934	4·98
Kalgoorlie	117	16 725·3	148·077	125·494	41·715	167·209	9·99
Laverton	9	1 023	2·064	1·748	1·997	3·745	3·66
Leonora	38	7 003	39·071	33·112	17·124	50·236	7·17
Marble Bar	16	700·1	5·753	4·876	4·046	8·922	12·74
Marvel Loch	33	3 211	25·941	21·985	6·908	28·893	8·99
Meekatharra	19	3 461	49·746	42·159	10·446	52·605	15·19
Menzies	26	2 652·6	32·633	27·656	7·442	35·098	13·23
Norseman	21	2 643	14·150	11·992	12·930	24·922	9·42
Ora Banda	27	8 546·3	29·632	25·113	15·023	40·136	4·69
Paynes Find	6	336	2·579	2·186	0·676	2·862	8·51
Sandstone	2	145	0·206	0·174	0·149	0·323	2·22
Yarri	6	583·6	2·491	2·111	1·174	3·285	5·62
	439	56 282·15	389·276	329·904	139·181	469·085	8·33

Average Per Parcel .... 128·2 tonnes
Average Yield by Amalgamation (Fine Gold) .... 5·86 grams per tonne
Average Value of Tailings (Fine Gold) .... 2·47 grams per tonne

Schedule No. 2

DETAILS OF EXTRACTION—TAILINGS TREATMENT 1978

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	1 500	4·67	7·014	1·62	2·431	4·582	65·3	4·442	63·3
Kalgoorlie	2 990	4·17	12·480	1·04	3·113	9·367	75·02	9·430	75·5
Leonora	4 800	2·47	11·880	0·64	3·105	8·775	73·86	8·750	73·6
Marvel Loch	1 785	5·24	9·356	1·41	2·532	6·824	74·9	7·034	75·1
Menzies	1 150	2·79	3·212	0·85	0·985	2·227	69·3	2·583	80·3
Yarri	2 400	2·56	6·158	0·63	1·534	4·624	75·0	4·783	77·6
	14 625	3·42	50·1	0·93	13·700	36·399	72·6	37·022	73·9

Schedule No. 3

DIRECT PURCHASE OF TAILINGS YEAR ENDED 31st DECEMBER, 1978

Battery	Tonnes of Tailings Purchased	Initial Payment to $28.00 per ·0311 kg
Boogardie	34·7	335·78
Coolgardie	96·2	264·56
Kalgoorlie	2 314·4	3 720·73
Leonora	2 072·7	2 010·16
Marble Bar	85·5	133·21
Marvel Loch	236·7	327·67
Meekatharra	541·8	496·01
Norseman	223·5	4 969·67
Ora Banda	22·5	28·77
Paynes Find	22·5	20·70
	5 650·5	12 307·26

Schedule No. 4

STATEMENT OF RECEIPTS AND EXPENDITURE FOR YEAR ENDED 31st DECEMBER, 1978

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	1 849.05	18 165.89	30 786.66	11 899.85	60 852.40	32.91	5 693.15	14 382.32	80 927.87	43.76	5 594.20	3.02	....	75 333.67
Coolgardie	7 586.2	17 053.11	42 044.36	14 951.40	74 048.87	9.76	9 898.63	27 355.20	111 302.70	14.67	17 949.36	2.36	....	93 353.34
Cue	....	....	....	....	....	....	....	....	....	....	1 710.00	....	1 710.00	....
Kalgoorlie	16 725.3	31 326.82	227 976.96	56 356.88	315 660.66	18.87	36 602.64	100 258.23	452 521.53	27.05	46 781.30	2.79	....	405 740.23
Laverton	1 023.0	8 537.77	21 654.46	9 886.48	40 078.71	39.17	1 857.57	6 342.18	48 278.46	47.19	2 973.95	2.90	....	45 304.51
Leonora	7 003.0	22 463.81	43 984.24	16 819.09	83 267.14	11.89	8 417.68	27 351.26	119 036.08	16.99	19 343.65	2.76	....	99 692.43
Marble Bar	700.1	14 617.05	18 141.54	6 571.05	39 329.64	56.17	13 426.52	7 638.44	60 394.60	86.26	2 228.72	3.18	....	58 165.88
Marvel Loch	3 211.0	17 106.79	53 381.20	15 248.51	85 736.50	26.70	6 716.28	10 957.10	103 409.88	32.20	9 416.00	2.93	....	93 993.88
Meekatharra	3 461.0	23 397.82	60 812.05	17 363.73	101 573.60	29.34	16 212.05	14 881.22	132 666.87	38.33	8 574.24	2.47	....	124 092.63
Menzies	2 652.6	8 676.23	52 477.63	8 060.44	69 214.30	26.09	2 198.15	10 263.99	81 676.44	30.79	8 064.38	3.04	....	73 612.06
Norseman	2 643.0	19 093.78	35 875.54	8 492.87	63 462.19	24.01	3 154.78	10 255.69	76 872.66	29.08	7 125.50	2.69	....	69 747.16
Ora Banda	8 546.3	15 364.38	62 569.28	21 427.77	99 361.43	11.62	5 491.66	25 696.35	130 549.44	15.27	19 246.37	2.25	....	111 303.07
Paynes Find	336.0	5 791.77	9 004.69	2 766.03	17 562.49	52.26	1 616.00	1 575.22	20 753.71	61.76	1 036.10	3.08	....	19 717.61
Peak Hill	....	....	....	....	....	....	....	....	....	....	380.00	....	380.00	....
Sandstone	145.0	1 933.29	3 639.79	926.67	6 499.75	44.82	604.75	712.83	7 817.33	53.91	414.15	2.85	....	7 403.18
Yarri	583.6	5 201.68	13 856.31	4 478.51	23 536.50	40.33	3 893.43	3 934.18	31 364.11	53.74	1 776.10	3.04	....	29 588.01
Head Office	....	....	....	....	....	....	....	....	....	....	2 275.06	....	2 275.06	....
Sub total	56 465.15	208 730.19	676 204.71	195 249.28	1 080 184.18	19.13	115 783.29	261 604.21	1 457 571.68	25.81	154 889.08	2.74	4 365.06	1 307 047.66
Marble Bar (Mag. Plant)	8.51	....	2 249.80	119.60	2 369.40	278.42	....	17.79	2 387.19	280.51	106.40	12.50	....	2 280.79
Northampton	852.27	12 538.88	18 045.00	4 012.80	34 596.68	40.59	1 711.79	5 668.26	41 976.73	49.25	2 653.06	3.11	....	39 323.67
Total	57 325.93	221 269.07	696 499.51	199 381.68	1 117 150.26	19.48	117 495.08	267 290.26	1 501 935.60	26.20	157 648.54	2.75	4 365.06	1 348 652.12

Schedule No. 5

STATEMENT OF RECEIPTS AND EXPENDITURE FOR YEAR ENDED 31st DECEMBER, 1978

Cyaniding

Battery	Tonnes	Management and Supervision	Wages	Stores	Expenditure Total Working	Cost Per Tonne	Repairs and Renewals	Sundries	Gross Expenditure	Cost Per Tonne	Receipts	Receipts Per Tonne	Profit	Loss
		$	$	$	$	$	$	$	$	$	$	$	$	$
Boogardie	....	....	....	....	....	....	....	884.00	884.00	....	....	....	....	884.00
Coolgardie	1 500.0	856.70	18 623.44	8 094.09	27 574.23	18.38	1 916.42	6 861.81	36 352.46	24.23	3 143.08	2.09	....	33 209.38
Kalgoorlie	2 990.0	5 893.03	51 709.09	28 694.54	86 296.66	28.86	1 032.29	17 210.52	104 539.47	34.96	6 362.28	2.12	....	98 177.19
Leonora	4 800.0	....	34 085.65	10 487.33	44 572.98	9.28	10.12	16 695.00	61 278.10	12.76	9 175.37	1.91	....	52 102.73
Marvel Loch	1 785.0	....	13 882.05	577.51	14 459.56	8.10	....	5 241.60	19 701.16	11.03	17 627.67	9.87	....	2 073.49
Meekatharra	....	....	....	2.72	2.72	....	152.03	....	154.75	....	....	....	....	154.75
Menzies	1 150.0	3 760.18	8 422.16	5 261.27	17 443.61	15.16	165.87	3 391.91	21 001.39	18.26	1 439.03	1.25	....	19 562.36
Ora Banda	....	....	4 322.67	1 419.38	5 742.05	....	504.30	2 587.79	8 834.14	....	....	....	....	8 834.14
Yarri	2 400.0	....	17 707.66	8 642.66	26 350.32	10.98	1 456.80	7 282.63	35 089.75	14.62	12 183.41	5.07	....	22 906.34
Total	14 625.0	10 509.91	148 752.72	63 179.50	222 442.13	15.21	5 237.83	60 155.26	287 835.22	19.68	49 930.84	3.41	....	237 904.38
							Less Interest Paid to Treasury				4 320.00			4 320.00
									287 835.22		45 610.84			242 224.38

STATE BATTERIES
TRADING AND PROFIT LOSS ACCOUNT FOR THE YEAR ENDED 31st, DECEMBER, 1978

1977 $	1977 $		1978 $	1978 $
		Trading Costs—		
949 267		Wages	1 077 031	
161 541		Stores	262 561	
136 084		Repairs, Renewals and Battery Spares	122 733	
307 949		General Expenses and Administration	327 445	
	1 554 841			1 789 770
		Earnings —		
	177 782	Milling and Cyaniding and Mag Plant Charges		203 111
	1 377 059	**Operating Loss for Year**		1 586 659
		Other Charges—		
63 456		Interest on Capital	63 435	
27 227		Depreciation	28 968	
44 122		Superannuation—Employers Share	46 268	
	134 805			138 671
	1 511 864	Total Loss for Year		1 725 330

STATE BATTERIES BALANCE SHEET AS AT 31st DECEMBER, 1978

FUNDS EMPLOYED

1977		1978	1978
	Capital—		
1 505 663	Provided from General Loan Fund	1 505 663	
482 284	Provided from Consolidated Revenue Fund	502 932	
1 987 947			2 008 595
	Reserves—		
57 243	Commonwealth Grant—Assistance to Gold Mining Industry	57 243	
27 573	Commonwealth Grant—Assistance to Metalliferous Mining	27 573	
84 816			84 816
	Liability to Treasurer—		
2 951 355	Interest on Capital		3 014 789
	Other Funds—		
12 849 668	Provided from Consolidated Revenue Fund (Excess of payment over collections)		14 504 256
17 873 786			19 612 456
	Deduct—		
	Profit and Loss:		
16 274 968	Loss at Commencement of Year	17 786 832	
1 511 864	Loss for Year	1 725 330	
17 786 832	Total Loss from Inception		19 512 162
$86 954			$100 294

EMPLOYMENT OF FUNDS

1977		1978	1978
	Fixed Assets—		
1 977 865	Plant, Buildings and Equipment	1 997 513	
1 715 622	Less Depreciation	1 743 493	
262 243			254 020
	Current Assets—		
52 120	Debtors	66 598	
43 589	Stores	57 902	
28 262	Battery Spares	27 443	
	Purchase of Tailings:		
43 064	Treasury Trust Account	41 043	
53 334	Tailings not Treated	55 826	
14 877	Estimated Gold Premium	16 275	
235 246			169 087
497 489	Total Assets		519 107
	Deduct—		
102 571	Current Liabilities: Creditors	62 613	
292 788	Liability to Treasurer (Superannuation—Employers Share)	339 056	
	Purchase of Tailings:		
299	Creditors	869	
14 877	Estimated Premium Due	16 275	
410 535			418 813
$86 954			$100 294

DIVISION IV

Annual Report of the Geological Survey Branch of the Mines Department for the Year 1978

CONTENTS

REPORTS

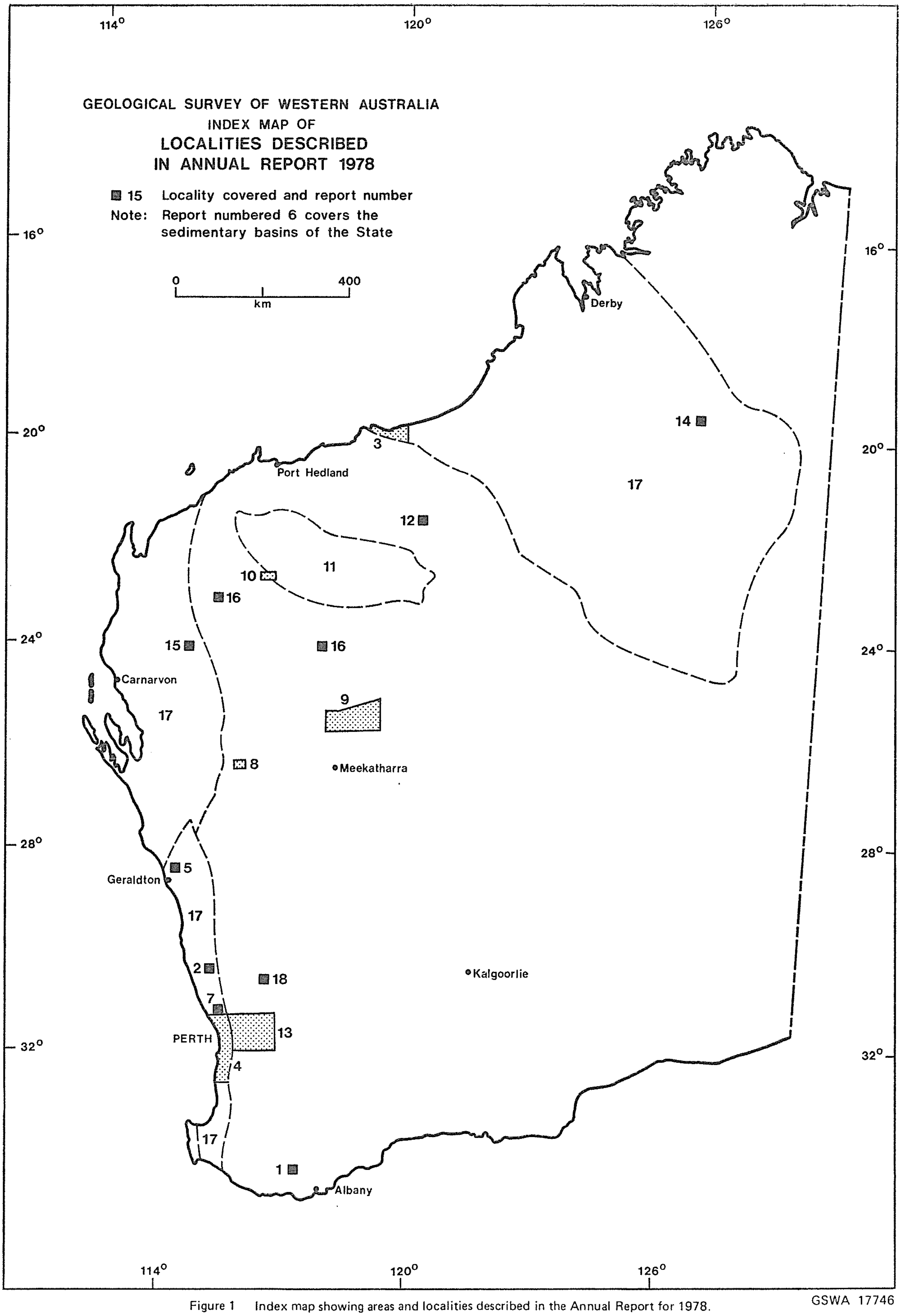

Figure 1 Index map showing areas and localities described in the Annual Report for 1978.

LIST OF FIGURES

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DIVISION IV

Annual Report of the Geological Survey Branch of the Mines Department for the Year 1978

Under Secretary for Mines:

My report for 1978 on the activities of the Geological Survey of Western Australia for the information of the Honourable Minister for Mines is forwarded herewith, together with selected reports on investigations and studies made for Departmental purposes.

INTRODUCTION

Previously it was reported that mineral exploration activity had levelled off in 1977, but in 1978 there was a rapid expansion in all exploration in this State, despite the fact that the world metal prices have not recovered to any great extent. The main search continued to be for uranium, but the diamond search, previously reported to be expanding, developed into a boom. Interest has been renewed in gold due to the increase in the world price, while the search for nickel, copper, zinc and other minerals continues on a limited scale.

This upsurge in exploration for minerals is illustrated in the statistics for temporary reserves granted.

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

Year	New applications	Renewals	Total
1973	182	—	182
1974	47	28	75
1975	20	18	38
1976	117	11	128
1977	92	37	129
1978	228	53	281

Of the 228 new applications for temporary reserves 101 included diamonds in the minerals sought, but uranium remained as the most often included in the minerals listed. These applications cover an area of 36 841 square kilometres with a minimum exploration expenditure commitment of $7 368 200 if the areas are held for the full tenure of twelve months.

Many companies continued the search for uranium throughout the State, both on the Precambrian areas and in the Phanerozoic basins. No new occurrences of economic importance were reported. The development of the Yeelirrie deposit should commence in 1979. Feasibility studies are being carried out on a deposit at Lake Way near Wiluna, and it should be known shortly if it is to be developed.

While the search for diamonds has been going on for many years in the Kimberley, it was not until 1978 that it became generally known that the consortium with Conzinc Riotinto of Australia (CRA), as operator, had found diamonds associated with kimberlitic plugs. CRA has reported a cluster of kimberlitic plugs covering in total some 610 hectares and located 120 km east-southeast of Derby, on and near Ellendale Station.

A substantial sampling plant was established during the year and 2 730 m^3 of kimberlitic material from pipe A yielded 966 stones and 4 170 m^3 from pipe B yielded 2 700 stones. Until the quality of the diamonds has been determined it is difficult to assess the value of these plugs.

Many companies and prospectors have been attracted to the diamond search, which has extended from the Kimberley to many other parts of the State. While prospecting for diamonds is very expensive, the companies remain undaunted having included diamonds in some 101 temporary reserve applications throughout the State, and having applied for 5 775 mineral claims in the Kimberley area.

Exploration for iron ore in the Hamersley Basin on incompletely tested temporary reserves continued, but interest in the Nabberu Basin has waned rapidly. Some 32 new temporary reserves for iron ore were granted and there were 127 in force at the end of the year.

The search for coal in this State, particularly in the northern portion of the Perth Basin, has decreased with no new finds being reported. The two active companies in the Collie coalfield continue their drilling programmes to delineate extractable reserves.

Due to the rise in price, the search for gold, particularly by prospectors, syndicates and small companies, has increased and the State Batteries are being kept fully occupied treating parcels of ore. No new finds of note have been reported but the Telfer, Central Norseman and Mount Charlotte mines continued to operate very profitably. Although the average price of gold is at a high level, it is not considered opportune to reopen the Golden Mile until current fluctuations stabilise at such a level.

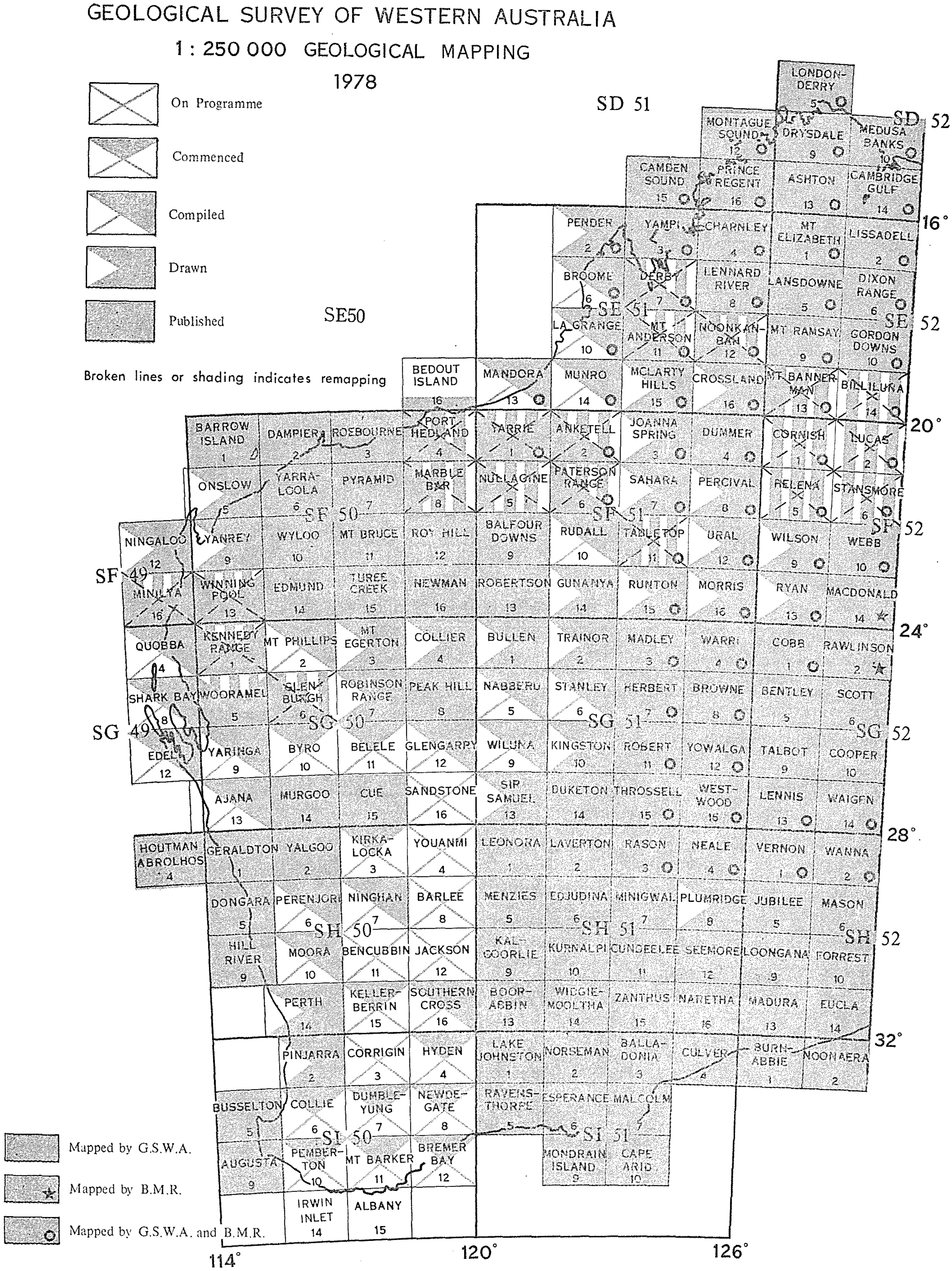
Over 4 000 enquiries from Metropolitan landholders for advice on the depth of water, strata and possible salinity were answered; in addition 224 country inspections were made by the Hydrogeological Division. Deep drilling in the Quindalup area and eastwards has disclosed major supplies of good water while further drilling in the Fortescue-Robe River area also continues to show valuable water resources for the Pilbara.

Regional geological mapping on 1:250 000 scale continues and the field work should be completed for the whole State by the end of 1979.

As anticipated, petroleum exploration was very active during 1978, particularly with marine seismic surveys on the Exmouth Plateau in preparation for drilling in 1979. There was a resurgence of onshore prospecting in the Canning Basin. The number of exploratory holes drilled in oil exploration also showed a marked increase.

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

There was no discovery of oil or gas of commercial interest made in 1978.



GSWA 17928

Figure 2 Progress of 1:250 000 or 4 mile geological mapping at the end of 1978

Public lectures: Public lectures were presented again in 1978 and on the first day (March 30) lectures with an emphasis on topics relating to the exploration of minerals within sedimentary rock environments were given. On the second day (April 1) lectures were confined to regional geology and mineralization of Precambrian rocks.

The attendance at the sessions varied according to the topics from 75 to 95 with persons attending the sessions appropriate to their interest.

Field excursions: No field excursions were held during 1978 as the required map sheets were not ready. It is proposed to visit the Nabberu Basin in April, 1979, and probably also to visit the Collie and Pemberton sheet areas later in the year.

Microfilm library: The microfilm library was described in last year's annual report, was opened and has operated very satisfactorily during the year. There was a strong demand for open file information released on 35 mm film and it was necessary to install a third reader printer midway through the year. At the end of 1978 there were 91 rolls of film of company reports on mineral exploration and 72 rolls on oil and gas exploration available in the library. Each film has about 500 frames, some of which display two pages of a report.

All the 1978 Records, as listed later, have been produced on microfiche and are readily available to the public. They are classed as publications. A start has been made on placing earlier Records on microfiche and these will become available as the project develops.

Regional offices: A review of the need for and possibilities of opening regional offices has been made. It is considered that such offices would, by the resulting decentralization, bring geological assistance closer to prospectors and exploration geologists. Such offices have been considered for Kalgoorlie, Karratha and Kununurra, and it is hoped that the first may open at Kalgoorlie about mid-1979.

STAFF

In addition to some resignations there were three retirements of officers who have given loyal and valuable service to the Geological Survey.

Mr Eugene O'Driscoll retired on March 17 after 15 years service. With academic qualifications in both geology and engineering he was appointed as chief hydrogeologist in 1962 to supervise the Hydrology and Engineering Geology Division. Early in 1978 his position was retitled Assistant Director. Eugene O'Driscoll, on joining the branch, had already established an internationally respected reputation in the field of groundwater study and this was enhanced during his service with this branch. He made a major contribution to the knowledge and development of groundwater in this State.

Mrs Sheila Fawcett retired on February 28 after nearly 12 years service. Mrs Fawcett joined the branch as a library assistant, was promoted to senior library assistant and later to librarian in 1969. Her efficiency and unfailing courtesy was greatly appreciated by all library users.

Mr Jack Dyer, stores and transport assistant, retired on November 9, after over 12 years of efficient and cheerful service.

A Ph.D. was conferred on R. Thom as a result of his studies at the Imperial College, University of London, London.

PROFESSIONAL

Appointments

Name	Position	Effective Date
Lavaring, I. H., B.Sc. (Hons)	Geologist L1	18/1/78
Whitfield, S. J., Grad.Dip.Lib.Stud.	Librarian L1	15/5/78
Moors, H. T., B.Sc., M.Sc., Ph.D. ..	Geologist L3	16/10/78
Johnstone, M. H., B.Sc. (Hons)	Geologist L5	13/11/78
Daetwyler, N. A., B.Sc. (Hons)	Geologist L1	22/11/78

Promotions

Hind, P.	Librarian L4	24/2/78
Playford, P. E.	Assistant Director L6	24/5/78
Denman, P. D.	Geologist L3	13/12/78

Retirements

Fawcett, S. M.	Librarian L4	28/2/78
O'Driscoll, E. P. D.	Assistant Director L6	17/3/78

Resignations

Klenowski, G.	Geologist L1	10/2/78
Harley, A. S.	Geologist L1	1/9/78
Van de Graaff, W. J. E.	Geologist L3	8/9/78

CLERICAL AND GENERAL

Appointments

May, Y.	Typist	16/1/78
Blight, E. K.	Clerical Assistant ..	20/2/78
Brown, T. H.	Geological Assistant	20/2/78
Stewart, F. W.	Geophysical Assistant	8/5/78
Monaghan, R. P.	Technical Assistant	22/5/78
Collier, J. M.	Geophysical Assistant	29/5/78
Prichard, D. E.	Technical Assistant	12/6/78
Donovan, G. K.	Laboratory Assistant	5/7/78
Evans, D. G.	Technical Assistant	20/11/78
Moore, B. J.	Stores and Transport Assistant	18/12/78
Paff, J.	Geophysical Assistant	18/12/78

Retirements

Dyer, J. M.	Stores and Transport Assistant	9/11/78

Transfers Out

Emery, L. S. G.	Laboratory Assistant	27/12/78
Willis, R.	Laboratory Assistant	22/12/78

Resignations

Elms, B.	Typist	10/1/78
Lutter, M. O.	Technical Assistant	19/1/78
Baggott, S.	Geophysical Assistant	9/2/78
Whiskin, M.	Laboratory Assistant	17/2/78
Quinn, P.	Technical Assistant	27/2/78
Slater, R.	Geophysical Assistant	28/2/78
Dickie, D. F. (nee Kelly)	Technical Assistant	31/8/78
Stewart, F. W.	Geophysical Assistant	3/11/78

ACCOMMODATION

There was no increase in the space allocated to the Branch in 1978. The most pressing need is for extension to the store building at Russell Street, Morley in which are stored the bulk supply of Branch publications and many of the original copies of company reports that have been recently microfilmed. Drawings for the extension are currently being prepared and it is hoped that the work will be carried out in 1979.

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. B. Hirschberg, E. H. Briese, D. P. Commander, L. J. Furness, R. E. J. Leech, J. S. Moncrieff, P. A. Wharton.

Despite cost inflation, exploratory drilling for water resource investigations was maintained at about the same level as last year. However, due to financial constraints, it remains at less than half of the level reached in 1974. Priority continues to be given to work in the Perth sedimentary basin. Six bores were drilled on three sites in, and east of, Bunbury on the Picton Line and two bores on Quindalup No. 7 site east of Busselton. One of the latter was drilled to a depth of 1 049 m and was the deepest hole yet to be constructed with departmental plant. The information collected further extends the substantial area known to be underlain by major groundwater resources. In the metropolitan area nine new bores have been drilled to explore the relationships between deep and shallow aquifers as part of the Artesian Monitoring program.

There has been further exploration of shallow aquifers with the drilling of 23 bores for the Yeal scheme north of Pinjar and 13 south and east of Bunbury. Work has also commenced on an evaluation of the water resources and water balance of the southwest coastal groundwater area between Bunbury and Mandurah. This area has experienced rapid development of groundwater for market garden and fodder irrigation.

Studies of the effects on stream and groundwater hydrology of the Manjimup woodchip industry and of bauxite mining in the Darling Range have continued on an interdepartmental basis. This year these have included the use of electronically recorded four-phase test pumping as an aid to the assessment of groundwater and salt discharges of catchments.

Drilling and test pumping have continued in the upper part of the Robe River catchment as part of the extended investigation of groundwater resources near the source of the west Pilbara water supply.

The continuation of water restrictions by the Metropolitan Water Board, which were necessitated by drought conditions, has encouraged landowners to seek independent sources of water for garden watering. Over four thousand enquiries for recommended bore depths and strata information were answered. The generally below average rainfall also resulted in an increase in other advisory work; 224 field investigations for bore site selection were carried out for landowners.

Liaison with other government departments regarding groundwater exploration and development, continues to be close. A number of investigations have been undertaken in reponse to applications for effluent disposal licences under the Rights in Water and Irrigation Act. Further reports have been written recording the results of hydrogeological studies of acid effluent disposal in the Leschenault dune system.

ENGINEERING GEOLOGY DIVISION

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

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 at Nunyerry dam site in the Pilbara.

(b) Geological reconnaissances made of the following dam sites: Kumina Creek and Munni Munni Creek in the Pilbara; Marrinup Brook, Kent River, and several in the Manjimup area in the southwest.

(c) Minor investigations carried out including foundation studies for tank sites at Sawyers Valley, Beacon, South Hedland and the wharf at Wyndham.

Metropolitan Water Board:

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

(b) Continued studies on South Canning and North Dandalup dam sites.

(c) Report completed for Burns Beach sewer tunnel and studies continued for Bibra sewer and Wungong water tunnels.

Westrail:

Geological advice given on selection and development of quarry sites.

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 continued on the Precambrian portion of the State for publication at a scale of 1:250 000 (Fig. 2). Field mapping on Albany, Belele, Bremer Bay, Byro, Hyden, Kennedy Range, Mount Barker, Newdegate and Winning Pool was completed. Mapping on Dumbleyung was 85 per cent completed.

The Bulletin on the Bangemall Basin was compiled and work continued on the Nabberu Basin Bulletin, which should be completed shortly.

SEDIMENTARY DIVISION

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

The processing of data submitted by petroleum companies continued. There was a considerable upsurge of seismic exploration during the year to delineate the regional structural style of the permit areas and to detail structures which would be targets for the drilling proposed for 1979. Onshore seismic surveys also increased in 1978 due to a renewal of interest in the northern Canning Basin.

Mapping continued in the Carnarvon Basin with the completion of compilation of the Phanerozoic portions of the Wooramel and Winning Pool 1:250 000 Sheets. Final editing of the compilations of the Ajana, Shark Bay-Edel, and Yaringa Sheets is in progress.

Editing of the comprehensive study of the southern and central Carnarvon Basin is in hand and a study of the economically important northern offshore portion of the basin is in progress.

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 Ninghan, Kirkalocka and the Precambrian portion of Pemberton 1:250 000 sheets was completed. The map compilation and explanatory notes for Perenjori and Ninghan were finished, and those for Collie continued.

A bulletin on the Pilbara Block was completed and work continued on a mineral resources bulletin on nickel.

Sundry field work included examinations of Ministerial Reserves for iron ore, an assessment of the possible effect on ore reserves at Eneabba caused by the mining of higher-than-average grade ore, and inspections of the Redross and Blue Spec mines prior to their closures.

A re-assessment of the State's iron ore resources was completed during the year and an assessment of nickel resources is nearing completion.

During 1978, 91 rolls of microfilm containing reports on some 600 exploration projects were placed on open file in the Branch library. The Division answered about 300 verbal enquiries from the pubic and other Government Departments and handled some 160 requests for access to company reports on surrendered tenements. About 725 new accessions were added to the Division's collection of mineral exploration reports, an increase of 65 on 1977.

COMMON SERVICES DIVISION

Petrology

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

One hundred petrological reports covering 1 677 thin sections and 57 other miscellaneous samples were completed during the year. Further thin sections were studied for incorporation into the computer based petrological data system.

The G.S.W.A./W.A.I.T. co-operative geochronology programme continued with the results of three projects published. Two further projects were completed during the year and are presently being prepared for publication. Sixteen projects were carried over to the 1979 programme.

During the year studies were completed on the geochronology of the Darling Range biotite, and an electron microprobe examination of amphiboles from the Wongan Hills was made.

The laboratory prepared 2 156 thin sections of which 2 130 were petrological; 77 polished sections were made; 88 rocks were crushed; and 262 rocks were cut and faced for examination. There were 76 mineral separations undertaken and 124 sieve analyses completed. Samples and thin sections stained for carbonate numbered 72, and 142 m of continuous peel was taken from core.

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

Palaentology

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

A total of 70 reports was written during the year. The reports covered three main areas of activity: (a) Mesozoic palynological studies of the Perth Basin for the Hydrogeology Division, (b) description of Precambrian stromatolites and microfossils, mainly from the Bangemall and Nabberu Basins, for the Regional Geology Division and (c) identification of Mesozoic and Tertiary fossils from the Carnarvon Basin for the Sedimentary Division.

Work on the Devonian faunas, especially the stromatoporoids, of the Canning Basin reef complexes continued. In conjunction with the Sedimentary Division a start was made on cataloguing palaeontological material from relinquished petroleum exploration permit areas.

Geophysics

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

Well-logging activity declined from 204 logging operations in 1977 to 144 in 1978 with a corresponding decrease in aggregate total depths from 43 210 m to 25 720 m.

Seismic refraction techniques were used to investigate several engineering project sites raging from the Nunyerry dam site in the Pilbara to a prospective siding for Westrail at Moondyne. Ground water surveys, again predominantly refraction work, were continued for the Albany Town Water Supply and in the Fortescue Valley near Mount Elvire.

Dolerite dykes, thought to indicate fracture zones in the granulite country rock near Northampton, and therefore possible sources of groundwater, were delineated with a magnetometer. An airborne proton precession magnetometer was adapted for ground measurements by the Commonwealth Bureau of Mineral Resources in an attempt to locate shell debris in a wartime gunnery range at Warnbro. Although successful in detecting shells to depths of about one metre the method proved too time-consuming and costly to use over large areas.

Field salinity measurements totalled about 1 050 of which 360 related to water samples submitted by the public and the remainder to continuing bauxite and other salinity monitoring projects.

Normal laboratory servicing was maintained and about 100 public enquiries on geophysical matters satisfied.

Environmental Geology

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

Work on the 1:50 000 urban geology map series was continued with the completion of two sheets (Roebourne and Baynton) and the addition of two part sheets to the Dampier Sheet (Eaglehawk and Rosemary Islands).

Geological information has been supplied for a variety of projects, including the System 6 study, Special Rural Zone proposals, an examination of the present and future requirements for aggregate in Perth, planning within Bunbury townsite and many others. This year, the appraisal of major environmental review and management programme reports has occupied a large segment of the section's activities, and committee and liaison meetings continue an important function.

A study has been made of the limesand and limestone resources of the islands of the Dampier Archipelago and adjacent mainland. Appraisal continues on applications for mineral tenements in the Southwest Mineral Field with a view to lessening adverse impacts of mining on the environment.

Geochemistry

R. Davy.

Studies on low-grade zinc mineralization in the Bangemall Basin, and on the use of B-Ga-Rb diagrams for determining depositional conditions in Phanerozoic rocks of W.A. have been completed.

Reports on geochemical exploration of the Saddleback greenstone belt and on the geochemistry of the Mount McRae Shale are in preparation.

Sampling of the Mount Edgar and Corunna Downs batholiths has been undertaken preparatory to detailed geochemical studies of rocks of these batholiths.

Co-operation was received in carrying out chemical work for the above projects from the Government Chemical Laboratories.

Technical Information

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

Budget restraints interfered with the printing of publications, and the withdrawal of the Bureau of Mineral Resources as publisher of the geological sheets mapped by the Survey has drastically curtailed the production of the 1:250 000 geological map and explanatory notes series. Only eight maps with explanatory notes were published.

This year two bulletins and three reports have been issued and three mineral resources bulletins and four reports were sent to press. Editing and proof reading of six explanatory notes has been carried out. Seventeen records have been edited. Three revised information pamphlets were edited.

Requisitions raised on the Surveys and Mapping Branch for drafting, photography and copying totalled 1 091. Photocopying for the public numbered 1 414 requisitions.

During 1978 this section answered 896 requests for information including rock identifications, 342 of which entailed some research; and 2 733 members of the public visited the library for research purposes. Book loans to the staff totalled 7 144, and loans to and from other libraries 598.

At the end of the first year of operation of the open file system for the "M" series, 548 users had visited the microfilm library.

ACTIVITIES OF THE COMMONWEALTH BUREAU OF MINERAL RESOURCES

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

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

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

(iii) Completing results of crustal study between Meekatharra and Mount Goldsworthy using seismic and gravity methods.

PROGRAMME FOR 1979

HYDROGEOLOGY DIVISION

1. Continuation of the hydrogeological survey of the Perth Basin including deep drilling and reports on Quindalup and Boyanup lines.
2. Hydrogeological investigations and/or exploratory drilling for groundwater in the following areas:
   (a) Fortescue River area—further investigations including Weelumurra and Robe River.
   (b) Re-assessment of the groundwater resources of the Gascoyne River.
   (c) Investigation of the water resources of the Collie Coal Basin.
3. Town water supply investigations and/or drilling for the following: Bunbury, Albany, Horrocks Beach, Brookton, Bindoon, Watheroo, Esperance (mallee), Port Gregory, Kalbarri and others as required.
4. Hydrogeological investigations for the Metropolitan Water Supply Board:
   (a) Deep drilling at Jandakot, Wanneroo, Mirrabooka.
   (b) Shallow drilling at Yeal, Lake Marginiup, East Mirrabooka.
   (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, salinity studies and supervising consultants work.
7. Miscellaneous investigations and inspections as required by Government departments and the public.

ENGINEERING GEOLOGY

1. South-West Division—continuing investigations on Wungong, South Canning, North Dandalup, Victoria, Manjimup, Kent River, Brunswick River and commencing investigations in Marrinup, Little Dandalup and Dirk Brook dam sites.
2. Investigation of tunnel lines at Bibra Lake and Wungong.
3. Review of dam sites in Pilbara and Kimberley.
4. Miscellaneous investigations as required by Government departments including quarry sites for Westrail.

SEDIMENTARY GEOLOGY

1. Maintain an active interest in the progress and assessment of exploration and potential for fossil fuels in Western Australia including the checking and assessing of all company reports on exploration.
2. Continuation of the surface mapping and sub-surface study of the Carnarvon Basin including the Kennedy Range and Wooramel 1:250 000 sheets.
3. Continuation of the compilation of a bulletin on stratigraphic studies of Devonian reef complexes in the Canning Basin.
4. Minor geological investigations as required.

REGIONAL GEOLOGY DIVISION

1. Continuation of mapping in the Great Southern portion of the South-West Division on Dumbleyung and Corrigin 1:250 000 sheets.
2. Mapping of portions of the Murchison and Yilgarn Goldfields on Sandstone, Youanmi, Barlee and Jackson 1:250 000 sheets.

3. Mapping the eastern wheatbelt Bencubbin and Kellerberrin 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 and resources in Western Australia.
2. Complete bulletin on the regional study of nickel resources in Western Australia.
3. Commence bulletin on the geology and bauxite occurrences in the Darling Range area.
4. Detailed mapping and study of the Warriedar fold belt.
5. Continue assessment of Ministerial Reserves for iron ore.
6. Examination and study of the talc occurrences near Three Springs.
7. Miscellaneous investigations as required.

COMMON SERVICES DIVISION

Petrology

1. Carry out petrological investigations as required by other Divisions.
2. The following topics to be investigated:
   (a) Petrology of the northern margin of the Yilgarn Block.
   (b) Petrological history and geochronology of the western margin of the Yilgarn Block.
   (c) Alkaline granitoids and possible extrusive equivalents, Eastern Goldfields.
   (d) Rb-Sr isotope distribution in the vicinity of the Black Range Dolerite.
   (e) A comparative study of the Archaean and Proterozoic geothermal gradients.
3. Miscellaneous minor petrological studies.

Palaeontology

1. Carry out palaeontological investigations as required by other Divisions.
2. Completion of a study of the Devonian stromatoporoids, Lennard Shelf, Canning Basin.
3. Continuing the palynological study of Early Cretaceous of Perth Basin.
4. Completion of study of Precambrian stromatolites and microfossils.
5. Miscellaneous minor palaeontological studies.

Geophysics

1. Well-logging on groundwater drilling projects as required.
2. Seismic surveys for
   (a) Dam sites in Pilbara and Darling Range as required.
   (b) Groundwater investigations at Manjimup, mouth of Robe and Fortescue Rivers and Horrocks Beach.
3. Miscellaneous geophysical investigations as required.

Geochemistry

1. Continuation of the study of the Corunna Downs and Mount Edgar batholiths to identify further potential tin/tantalum bearing rocks.
2. Completion of statistical studies on gossans/ ironstones with reference to the Yarri sheet.
3. Completion of the study of the geochemistry of the Mount McRae Shale.
4. Investigation of possible geochemical studies applicable to the Warriedar fold belt.

Environmental Geology

1. Completion of urban geology maps in the Roebourne and Port Hedland areas.
2. Field work and compilation for the urban geology of the Bunbury area.
3. Assessment of environmental reports and studies.
4. Miscellaneous environmental geological problems as required.

Regional Office

Kalgoorlie—it is hoped to establish this office about mid-year.

1. Re-mapping of the Widgiemooltha 1:250 000 sheet.
2. Detailed mapping and mineral investigation of an area near Kalgoorlie.
3. Study of the fossil drainages and Phanerozoic sediments in the Kalgoorlie area.

PUBLICATIONS

Issued during 1978

Annual Report, 1977.

Bulletin 124: The geology of the Perth Basin.

Bulletin 125: Quaternary molluscs of the western part of the Eucla Basin.

Report 4: A comparative study of the geochemistry of Archaean bedrock in part of the northeast Yilgarn Block.

Report 5: Devonian atrypid brachiopods from the reef complexes of the Canning Basin.

Report 7: Palynological zonation of the Late Jurassic and Early Cretaceous sediments of the Yarragadee Formation, central Perth Basin, Western Australia.

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

Geological map of Crossland 1:250 000 (SE/51-16 International Grid) with explanatory notes.

Geological map of Laverton 1:250 000 (SH/51-2 International Grid) with explanatory notes.

Geological map of Lennis 1 : 250 000 (SG/52-13 International Grid) with explanatory notes.

Geological Map of Lucas 1:250 000 (SF/52-2 International Grid) with explanatory notes (second edition).

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

Geological map of Throssell 1:250 000 (SG/51-15 International Grid) with explanatory notes.

Geological map of Waigen 1:250 000 (SG/52-14 International Grid) with explanatory notes.

Urban geological maps 1 : 50 000: Mandurah.

In press

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

Mineral Resources Bulletin 12: The tin deposits of Western Australia with special reference to the associated granites.

Mineral Resources Bulletin 13: Copper mineralization in Western Australia.

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

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

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

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

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

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

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

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

Geological map of Noonkanbah 1:250 000 sheet (SE/51-12 International Grid) with explanatory notes (second edition).

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

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

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

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

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

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

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

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

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

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

Geological map of Trainor 1:250 000 sheet (SG/51-2 International Grid) with explanatory notes.

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

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

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

In preparation

Bulletin 126: The Meckering and Calingiri earthquakes, October 1968 and March 1970.

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

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

Geological maps 1:250 000 with explanatory notes, the field work having been completed: Ajana, Albany, Anketell, Belele, Bremer Bay, Broome, Byro, Collie, Collier, Derby, Glenburgh, Glengarry, Gunanya, Hyden, Joanna Spring, Kingston, Kirkalocka, La Grange, Mandora, McLarty Hills, Moora, Munro, Mount Anderson, Mount Barker, Mount Phillips, Nabberu, Newdegate, Ningaloo-Yanrey, Ninghan, Onslow, Paterson Range, Pender, Perenjori, Pinjarra, Port Hedland, Quobba, Robinson Range, Rudall, Shark Bay-Edel, Southern Cross, Stanley, Trainor, Wiluna, Yampi, Yaringa, Yarrie.

Urban geological maps 1:50 000: Baynton, Boodarie, Dampier, Karratha, Port Hedland, Roebourne, Warambie-Picard.

Records produced (available in microfiche form)

1978/1 Wells drilled for petroleum exploration in Western Australia to the end of 1977, by K. A. Crank.

1978/2 Explanatory notes on the Moora 1:250 000 geological sheet Western Australia, by J. D. Carter, G. H. Low and S. L. Lipple (in prep.).

1978/3 Chronological bibliography of Western Australian Precambrian geochronology to 1977, by A. F. Trendall and J. R. de Laeter.

1978/4 Explanatory notes on the Bullen Western Australia 1:250 000 geological sheet, by R. E. J. Leech and A. T. Brakel.

1978/5 Explanatory notes on the Pinjarra Western Australia 1:250 000 geological sheet, by S. A. Wilde and G. H. Low.

1978/6 Dampier Archipelago limesand and limestone, by E. R. Biggs and P. D. Denman (in prep.).

1978/7 Geology and hydrogeology of the Eneabba Borehole Line, by D. P. Commander.

1978/8 Explanatory notes on the Collier Western Australia 1:250 000 geological sheet, by A. T. Brakel, M. Elias and J. C. Barnett.

1978/9 Explanatory notes on the Yaringa 1:250 000 geological sheet, Western Australia, by W. J. E. van de Graaff, R. M. Hocking, and B. P. Butcher (in prep.).

1978/10 Explanatory notes on the Wiluna 1:250 000 geological sheet Western Australia, by M. Elias and J. A. Bunting.

1978/11 Iron ore resources of Western Australia at 31 December 1977, by R. J. Morrison.

1978/12 Explanatory notes on the Nabberu 1:250 000 geological sheet Western Australia, by J. A. Bunting, A. T. Brakel, and D. P. Commander.

1978/13 Explanatory notes on the Mount Phillips 1:250 000 geological sheet Western Australia, by S. J. Williams, I. R. Williams, R. J. Chin, P. C. Muhling, and R. M. Hocking.

1978/14 Explanatory notes on the Trainor 1:250 000 geological sheet Western Australia, by A. T. Brakel and R. E. J. Leech.

1978/15 Explanatory notes on the Stanley 1:250 000 geological sheet Western Australia, by D. P. Commander, P. C. Muhling and J. A. Bunting.

1978/16 Explanatory notes on the Perenjori 1:250 000 geological sheet Western Australia, by J. L. Baxter and S. L. Lipple.

1978/17 Explanatory notes on the Rudall 1:250 000 geological sheet Western Australia, by R. J. Chin, S. J. Williams, and I. R. Williams.

Reports in other publications

Cockbain, A. E., 1977, The mathematical scientist, Volume 1: Jour. International Assoc. Mathematical Geol. v. 9, p. 656-657.

Davy, R., Whitehead, S. G., and Pitt, G., 1978, The Adelaide meteorite: Meteoritics v. 13, no. 1, p. 121-140.

Hickman, A. H., 1978, Recumbent folds between Glen Roy and Lismore: Scott. Jour. Geol. v. 14, p. 191-212.

Marston, R. J., 1978, The geochemistry of Archaean clastic metasediments in relation to crustal evolution, north-eastern Yilgarn Block, Western Australia: Precambrian Research, v. 6, p. 157-175.

23rd January, 1979.

J. H. LORD,
Director.

SALINIZATION AND THE APPROXIMATE SALT BALANCE OF LAKE POORRARECUP

by T. T. Bestow

ABSTRACT

Lake Poorrarecup is a high-level lake sustained by rainfall and groundwater inflow. Clearing of native vegetation for farming since 1958 has resulted in the release of salt stored in the soil profile, with consequent increases in groundwater salinity. This has produced the steep rise in lake salinity of some 230 mg/L per year which has been experienced since about 1964.

The suggestion is made that the salinity of the lake may be stabilized by artificially discharging about 86 000 m^3 of lake water into one of the surrounding drainages each year.

LOCATION AND TOPOGRAPHY

Lake Poorrarecup is situated 33 km west-southwest of Cranbrook and is the largest of nearly one hundred lakes and swamps in an area of about 270 km^2. This area is on the watershed between the Kent and Frankland River catchments and the Gordon River, which is a tributary of the Frankland River (Fig. 3). The lake area is generally flat or gently undulating and contains relatively few well-defined drainage courses. In contrast to this the surrounding catchments, although exhibiting quite mature landforms, display a degree of dissection with moderately well-defined drainages. The lake area occupies a similar position in the landscape to a comparable, but smaller, lake area west of Lake Matilda, and a very much larger area centred on Lake Balicup, respectively south and east of Cranbrook. They appear to lie on a relatively high-level erosion surface at much the same topographic elevation.

Lake Poorrarecup has an average surface area of about 1.94 km^2. This varies somewhat in response to seasonal changes in rainfall. The shore is mainly sandy and appears to shelve quite gently (from minimum seasonal levels) towards the lake centre. At higher (flood) levels the lake shore steepens. However, no bathymetric or hydrographic details are available, except that a Department of Agriculture file report indicates that lake levels were exhibiting a rising trend in 1973 which prompted an investigation into the possible effects of overflow.

The lake provides the habitat for a variety of bird life and is a popular venue for recreation in the Cranbrook district.

GEOLOGY

The Lake Poorrarecup area is underlain by sediments of Tertiary or Quaternary age, which rest on Precambrian granites and migmatites which are not known to crop out. The form of the bedrock surface is not known but it is probable that erosion has produced a floor of variable relief. Without data from bores or deep sections it is not possible to estimate how thick such sediments might be. The low hills or rises in the landscape are generally capped with pisolitic laterite, but sandy ridges having the form of lunettes frequently occur parallel to lake margins, for example at Lake Poorrarecup itself. These appear to be ancient dunes.

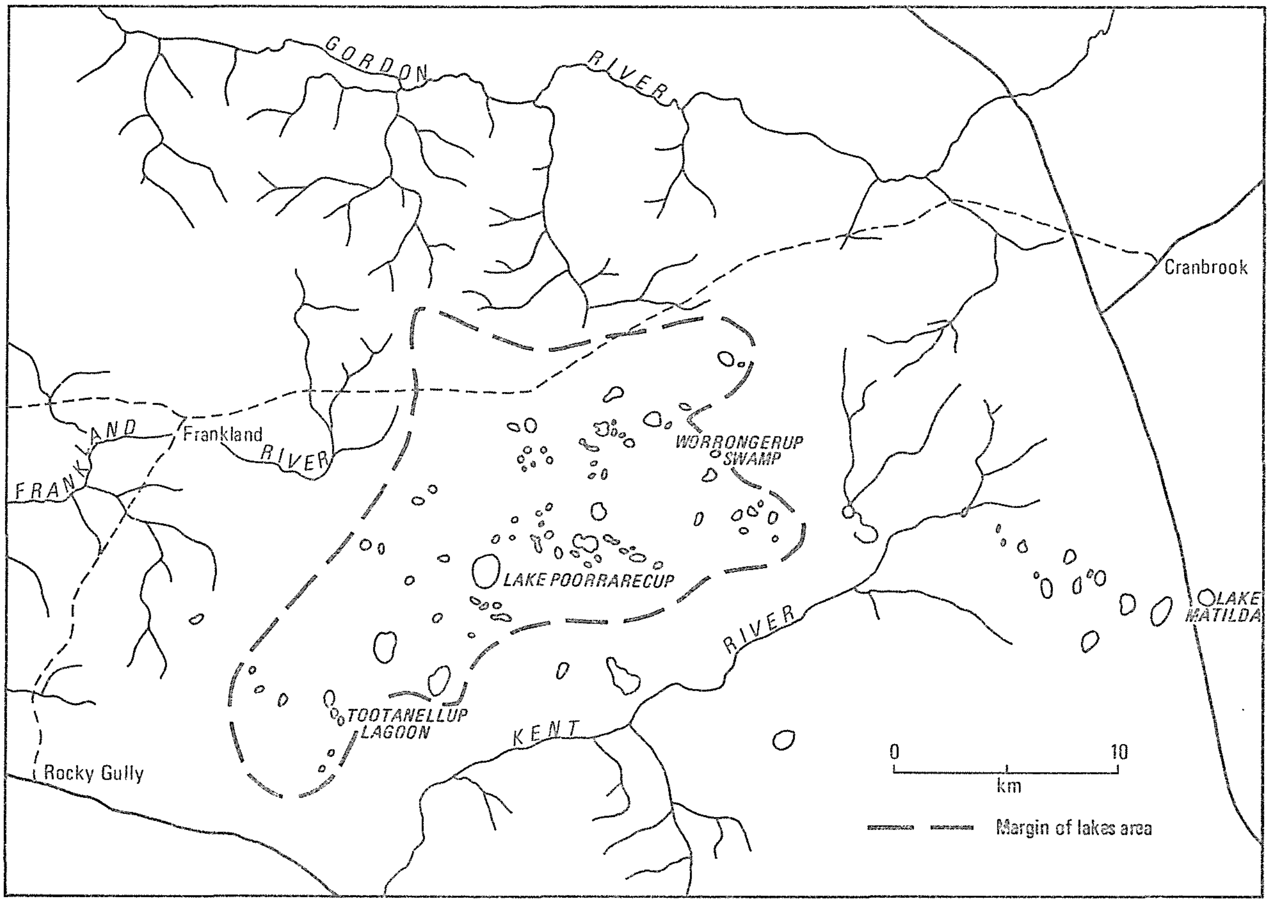
HYDROGEOLOGY

Lake Poorrarecup and other lakes and swamps within the study area exist because the hydrogeological conditions differ fundamentally from those in the surrounding catchments. The general lack of stream channels in the lake area is an obvious major difference and it points to a relatively high rate of infiltration by rainwater to replenish the groundwater system. This appears to be extensive, in that each lake or swamp is at least partially sustained by groundwater inflow as well as by direct rainfall and a limited amount of run-off. However, the pattern of groundwater movement and the extent to which each lake is connected with the groundwater cannot be defined without detailed and accurate groundwater levels. Similarly it is not possible to indicate whether the groundwater exists in an essentially closed system or whether it discharges into the surrounding catchments. As there are no obvious barriers to groundwater discharge it seems probable that the system as a whole is an open one. However, the possibility of parts of the system being closed due to the presence of hydraulic boundaries created by recharge mounds should not be excluded.

HYDROLOGY

RAINFALL

Long-term rainfall records are available for three stations in the vicinity of Lake Poorrarecup: Cranbrook, Rocky Gully and Mount Barker. Monthly averages for these stations are listed in Table 1.



GSWA 17703

Figure 3 Lake Poorrarecup and associated lakes.

TABLE 1. MONTHLY RAINFALL, EVAPORATION, AND RAINFALL EXCESS (mm)

Month	Rainfall				Evaporation		Rainfall excess or deficiency
	Observed			Estimated			
	Mount Barker	Rocky Gully	Cranbrook	*Lake Poorrarecup	Open pan	Estimated lake surface (0·8 x O.P.)	
Jan.	22	15	14	14·5	175	140	—125·5
Feb.	24	20	17	18·5	155	124	—105·5
Mar.	37	29	25	27	119·5	95·5	—68·5
Apr.	57	53	36	44·5	66	53	—8·5
May	86	89	61	75	61	49	+26·0
June	100	111	75	93	35·5	28·5	+64·0
July	108	123	78	100·5	33	26·5	+74·5
Aug.	94	87	65	76	35·5	28·5	+47·5
Sept.	82	72	53	62·5	61	49	+13·5
Oct.	74	65	45	55	89	71	—16·0
Nov.	42	38	25	31·5	117	93·5	—62·0
Dec.	30	21	17	19	165	132	—113·0
Total	756	723	510	617	1 112·5	890·5	—273·5

* The averages of the Cranbrook and Rocky Gully monthly means have been taken to approximate the rainfalls at Lake Poorrarecup, which is nearly midway between the two. The monthly figures indicate that about two-thirds of the rainfall occurs in the five months May to September which is also the period of rainfall excess over evaporation. The mean annual rainfall at the lake is estimated to be about 617 mm.

WATER AND SALT BALANCE

If lake levels are to remain within a reasonably narrow range over a period of years then the input of water from all sources must equal the losses. In the absence of overland flow and in the presence of groundwater inflow and outflow, the water-balance equation for a defined period is:

$$P + G_{in} + V_1 = E + G_{out} = V_2 \qquad (1)$$

where

P is the direct rainfall on the lake (m^3)
G_{in} is groundwater inflow (m^3)
G_{out} is groundwater outflow (m^3)
E is the open-water surface evaporation (m^3)
V_1 is the initial volume of the lake (m^3)
V_2 is the final volume of the lake (m^3).

In an average year there is an excess of evaporation over rainfall of about 273.5 mm (Table 1) which must be made up by the difference between groundwater inflow and outflow for the lake volume to remain fairly constant.

The salinity balance of the flow system associated with Lake Poorrarecup for a defined period may be determined from the equation:

$$P\,C_p + G_{in}\,C_{g1} + V_1 C_{L1} = G_{out}\,C_{g2} + V_2 C_{L2} \qquad (2)$$

where

C_p is the concentration of salt (NaCl) in rainfall
C_{g1} is the concentration of salt in groundwater input
C_{g2} is the concentration of salt in groundwater output
C_{L1} is the initial concentration of salt in the lake
C_{L2} is the final concentration of salt in the lake
All are expressed as mg/L = g/m^3.

A lake will normally exhibit a seasonal fluctuation in its salinity depending very largely on the amount of the level fluctuation and hence the lake volume. Thus a shallow lake showing a seasonal fluctuation equivalent to half its maximum depth might double its salinity in the course of a summer but would later return to its initial salinity when the lake level rose during the following winter.

Obviously during years of below-average rainfall, salinities will tend to be higher than the average and vice versa.

In an open groundwater system which resulted in the quantity of salt being discharged from the lake equating with the combined input of salt from rainfall and groundwater, the long-term average lake salinity would remain constant. This situation almost certainly existed prior to the commencement of farming in the district.

In the event of Lake Poorrarecup lying in a closed groundwater system the annual accession of salt with rainfall could be expected to result in a progressively increased salinity. An additional contribution of salt could result from the release of salt stored in the soil profile above the water table in the area surrounding the lake. This is known to have occurred in other areas where clearing of native forest has resulted in a reduced transpirative loss and an increased infiltration of rainfall to groundwater (Peck and Hurle, 1973). As the salt content of rainfall in that area is about 13 mg/L (Hingston and Gailitis, 1977) the mean annual input to the lake from this source is about:

$1.94 \times 10^6 \times 0.617 \times 13$ g or 15.5 t
where $1.94 \times 10^6 m^2$ is the area of the lake, and
0.617 is the annual precipitation.

It has already been noted that to sustain lake levels a mean net groundwater input of 273.5 mm is required additional to the mean annual rainfall. In the absence of salinity data from suitably sited boreholes less direct information may be used to estimate the salt concentration of this groundwater inflow. Thus it is reasonable to expect it to approximate to the salinities of springs which flow into swamps in the lakes area. A water sample collected from Worrongerup Swamp in December 1976 had a salinity (TDS) of 390 mg/L and another swamp 2 km east of Tootanellup Lagoon contained water having a TDS of 1 700 mg/L. Both of these samples came from areas in which clearing commenced in 1922. The average of the two values is 1 045 mg/L (TDS) or very approximately 785 mg/L NaCl (derived by applying a NaCl/TDS ratio of 0.7513) (Table 2).

The contribution of salt from groundwater inflow at this salinity would therefore be of the order of $1.94 \times 10^6 \times 0.2735 \times 785$ g. This amounts to 416.5 t, making a total annual input of 432 t.

If the lake is assumed to have a mean depth of 1.0 m then the annual salinity increase which would result from a lack of salt discharge becomes—

$$\frac{432 \times 10^6}{194 \times 10^4 \times 1.0} = 223 \text{ mg/L}$$

This may be compared with the approximate quantity of salt stored in the lake waters at the salinity (NaCl) measured in November 1978 of 3 381 mg/L (Table 2). If the lake is one metre deep then this is $1.94 \times 10^6 \times 1.0 \times 3381$ g or 6 559 t. This is equivalent to only 15 times the estimated annual input, which implies that much of the salt has accumulated in the lake over a relatively short period.

Figure 4 Percentage of land released for farming within 2 km of Lake Poorrarecup.

Clearing of native vegetation for farming is known to have started in the Lake Poorrarecup area in 1919 but it was not until 1958 that large-scale clearing occurred. The pattern of land release for farming within 2 km of

TABLE 2. LAKE POORRARECUP SALINITY

Sample No.	Date	pH	TDS	NaCl	Ratio NaCl/TDS
1636	3/4/67	7·8	1 970	1 390	·7056
	28/4/69		1 659	1 246*	·7513
	29/12/72		2 715	2 040*	·7513
	31/1/75		3 174	2 385*	·7513
	2/4/75		3 890	2 923*	·7513
	7/5/75		4 290	3 223*	·7513
	13/6/75		3 805	2 859*	·7513
	9/7/75		3 737	2 808*	·7513
	11/8/75		3 098	2 328*	·7513
	8/9/75		2 764	2 077*	·7513
	12/10/75		3 045	2 288*	·7513
	17/11/75		3 251	2 442*	·7513
	5/1/76		3 184	2 392*	·7513
	29/2/76		4 075	3 062*	·7513
	18/3/76		3 892	2 924*	·7513
	19/5/76		4 097	3 078*	·7513
	27/7/76		4 290	3 223*	·7513
	3/9/76		4 001	3 006*	·7513
	1/11/76		4 000	3 005*	·7513
18765	14/12/76	8·5	4 300	3 427	·7970
	24/1/77		5 170	3 884*	·7513
	15/4/77		5 459	4 101*	·7513
	10/7/77		5 250	3 944*	·7513
	31/8/77		4 729	3 553*	·7513
	14/11/77		4 515	3 392*	·7513
	11/1/78		6 020	4 523*	·7513
	3/2/78		5 720	4 297*	·7513
	3/3/78		6 101	4 564*	·7513
	5/4/78		5 370	4 034*	·7513
	5/5/78		5 870	4 410*	·7513
	27/6/78		6 522	4 900*	·7513
	4/8/78		5 123	3 849*	·7513
	11/9/78		4 642	3 488*	·7513
	13/11/78		4 500	3 381*	·7513

* Calculated from given NaCl/TDS ratio derived by averaging the analyses of sample numbers 1636 and 18765.

the lake shore is indicated in Figure 4. The maximum occupancy of 64.7 per cent of the area was reached in 1963 but not all of this would have been fully cleared until later. A Department of Agriculture study in 1973 records that 63 per cent of a 3 950 ha area adjoining the northern side of the lake had been cleared at that time.

There is no precise historical information available regarding the level of Lake Poorrarecup, although a Department of Agriculture report indicates that the lake level has tended to rise in recent years. However, some salinity data have been obtained (Table 2, Figure 5). It is clear

evapotranspirative losses, i.e. it is unaffected by any solution of stored salt in the soil. The proportion of the annual rainfall which reaches groundwater is then $\frac{13}{390 \times 0.7513}$ or 4.44 per cent. As the mean annual rainfall is 617 mm, the area required to provide the groundwater inflow into Lake Poorrarecup is 1 940 ha ($= \frac{530\ 590}{0.617 \times 0.0444}$ ha) which is rather less than the area

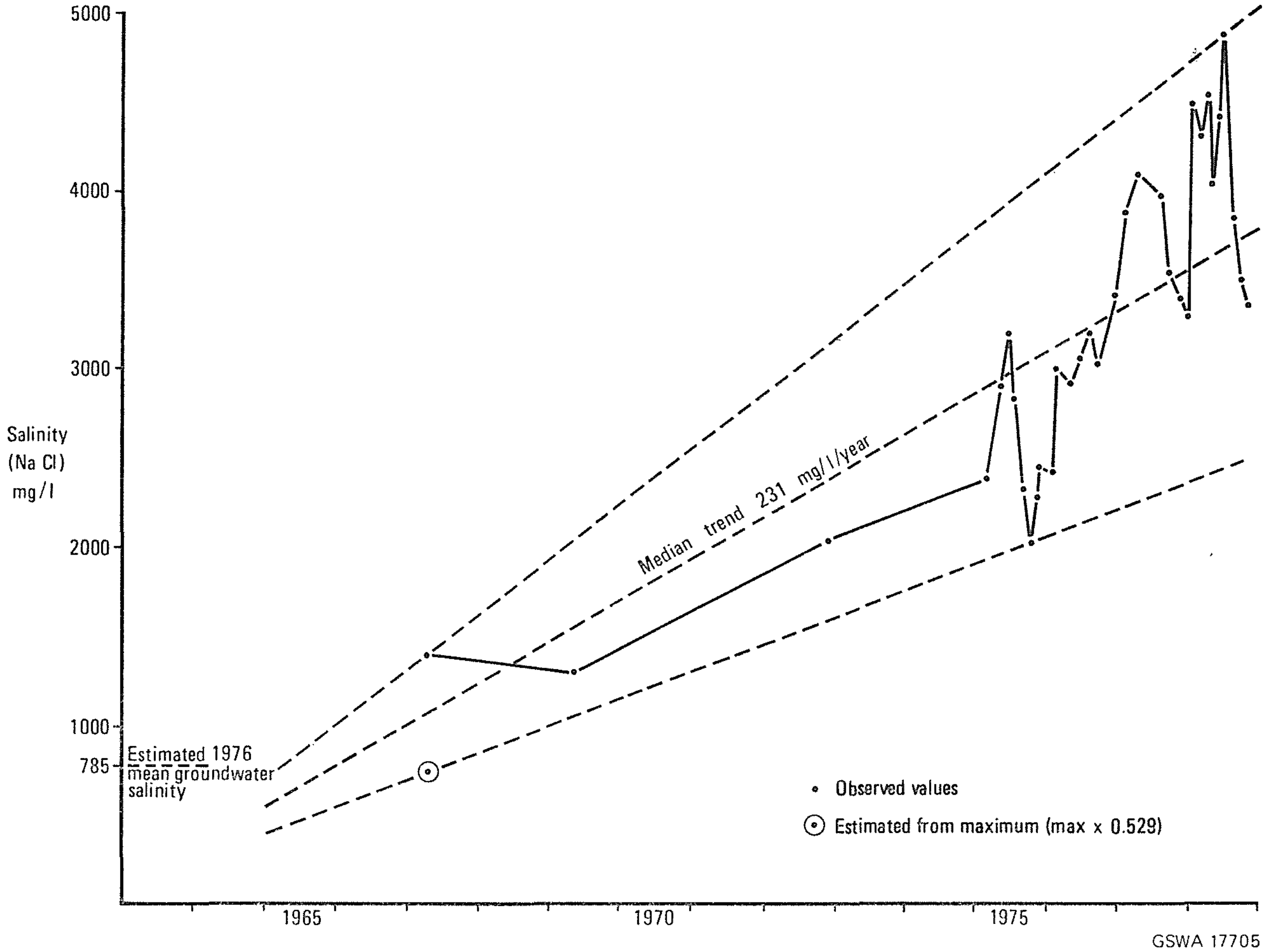


Figure 5 Variations in the NaCl salinity of Lake Poorrarecup.

from these data that the lake is increasing in salinity at a rate of 231 mg/L per year (NaCl), which is close to the figure calculated above on theoretical grounds.

When this trend is extrapolated back in time to 1965 it falls below the presently estimated mean groundwater salinity of 785 mg/L (NaCl) and it is probable that the salt storage of the lake would have been close to stability in 1964. It may therefore be inferred, by comparison with the clearing pattern broadly indicated by Figure 4, that less than 6 years elapsed between the clearing of vegetation and the resultant onset of salinity increases.

Clearing between 1919 and 1958 would appear either to have had negligible effect on the recent salinity record or that its influence was confined to the period before 1967 when salinity records began.

An approximation of the recharge area required to sustain the estimated average groundwater inflow to Lake Poorrarecup of 530 590 m^3 (273.5 mm over the lake area), may be calculated from the rainfall/groundwater salinity ratio. The salinity of the rainfall is 13 mg/L NaCl and the lower of the two observed groundwater salinities (390 mg/L TDS) may be assumed to represent the resultant salinity after infiltrating rainfall has been subjected solely to

of about 2 300 ha encompassed by a 2 km radius from the lake shore. It therefore seems probable that unless the lake is receiving runoff from areas at greater distances, the bulk of the salt contributing to the salinity increase of the lake is coming from stored salt in soil in the immediate vicinity of the lake itself and may be directly attributed to clearing in the peripheral area.

CONCLUSION

It is most probable that the present salinity trend involving an annual average increase of 231 mg/L per year (NaCl) will continue until the surrounding catchment ceases to yield salt from the soil store. Unless remedial measures are taken, this increase in salinity will reduce the utility of the lake as a sanctuary for a wide range of wildlife and as a public amenity.

To stabilize the salinity at its present level, it would be necessary to effect the discharge of about 430 t of salt per annum from the lake into one of the surrounding drainages. This would best be achieved at minimum lake levels during the summer, when the salinity could now be expected to be at about 5 000 mg/L. At this concentration the volume of water required to be removed annually would be about 86 000 m^3 ($= \frac{432 \times 10^6}{5000}$) which would represent only about 5 per cent of the mean annual inflow to the lake from all sources. The resultant reduction in level, of 40 to 60 mm, may be regarded as negligible, especially as the lake has shown a tendency to rise in level in recent years.

ACKNOWLEDGEMENTS

The writer is indebted to Mr A. L. Prout of the Department of Agriculture for most of the Lake Poorrarecup salinity record quoted in Table 2, and the Department of Lands for the data on which Figure 4 is based.

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THE GEOLOGY AND HYDROGEOLOGY OF THE MOORA BOREHOLE LINE

by E. H. Briese

ABSTRACT

The Moora Line consists of 19 bores located at 9 sites and ranging in depth from 25 m to 801 m. These have an aggregate depth of 8 767 m and were drilled to explore the geology and hydrogeology of an east-west section of the Perth Basin approximately 150 km north of Perth.

Drilling encountered continental and marine sediments of Late Triassic to Holocene age and confirmed that the structure consists of a deep basin (Dandaragan Trough) bounded to the east by the Darling Fault and to the west by the Beagle Ridge.

The Otorowiri Siltstone Member of the Yarragadee Formation was intersected in bores to the east of the Dandaragan Scarp. In this area it is a thick siltstone-claystone unit, and is unconformably overlain by the Leederville Formation.

Large groundwater resources occur in the Leederville Formation (444 m thick) and in the Yarragadee Formation. Groundwater of less than 1 000 mg/L T.D.S. was encountered almost throughout the Leederville Formation, and extends at least to the maximum depth of 800 m drilled in the Yarragadee Formation. The Otorowiri Siltstone Member acts as an aquiclude between the two aquifers and maintains a head difference of 70 m.

West of the Warradarge Fault, the Cockleshell Gully Formation and Lesueur Sandstone contain reserves of brackish water. The Tamala Limestone is an important source of potable groundwater along the coast.

Recharge to the aquifers is by infiltration of rainfall in their outcrop areas, and by leakage from overlying formations. The barrier boundaries of the Darling Fault in the east and impermeable Triassic sediments in the west constrain groundwater movement into a southward-flow direction.

INTRODUCTION

LOCATION AND TOPOGRAPHY

The Moora Line of bores is situated about 150 km north of Perth (Fig. 6). They are sited about 6 km apart across the width of the Perth Basin, from 8 km west of Moora to Grey townsite on the coast.

The area through which the line passes has been divided into four physiographic regions by Playford and others (1976) (Fig. 7). The Swan Coastal Plain extends from the coast to the Gingin Scarp and is a Cainozoic marine erosion and construction feature. It has been divided into the Coastal Belt consisting of calcarenite dunes and beach ridges, and the Bassendean Dunes, consisting of leached Pleistocene quartz sands. The Arrowsmith Region to the east of the Gingin Scarp is a dissected area with hills of Mesozoic strata commonly capped by laterite. East of the Arrowsmith Region, and separated from it by the topographic feature of the Dandaragan Scarp, is the Dandaragan Plateau, a sand- and laterite-covered plateau overlying Cretaceous sediments. The Yarra Yarra Region, between the Dandaragan and Darling Plateaus, is a flat low-lying region characterized by essentially internal drainage with intermittent streams feeding into numerous swamps and salt lakes.

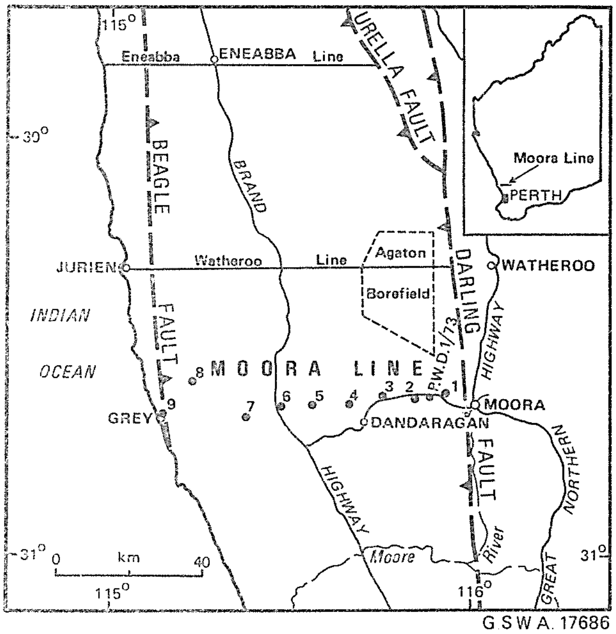

Figure 6 Location map, Moora Line.

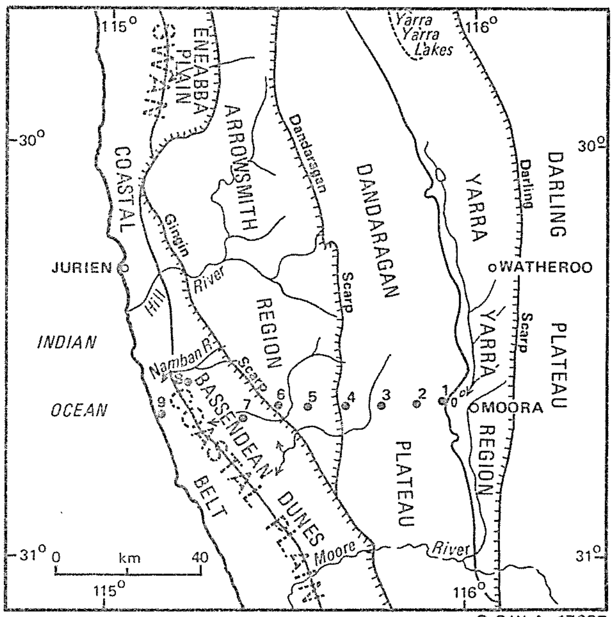

Figure 7 Physiographic regions.

PURPOSE AND SCOPE

The Moora Line of bores is part of a long-term programme, commenced by the Geological Survey in 1961, of drilling a series of east-west lines of bores across the Perth Basin to obtain information on its stratigraphy, structure and hydrogeology to a depth of about 800 m. The information obtained from the Moora Line has been correlated with that from other projects to derive a broader stratigraphic and structural picture than would otherwise be possible. All bores are completed for long-term monitoring of water levels and salinity changes.

Exploratory drilling in the northern Perth Basin has been carried out at Arrowsmith River (Barnett, 1969), Agaton Borefield (Balleau and Passmore, 1972), the Watheroo Line (Harley, 1975) and the Eneabba Line (Commander, 1978).

DRILLING AND TESTING

Drilling of the Moora Line commenced in December 1974 and was completed in December 1977 after several interruptions totalling 15 months during which time the drill rig was employed elsewhere. All bores were drilled by the mud-flush rotary technique. Sludge samples were taken every 3 m, and on reaching total depth, gamma-ray, long- and short-normal resistivity and caliper wire-line logs were run. These were used to select sidewall-coring targets for palynological samples, and aquifer intervals for sampling and observation.

Generally three aquifer intervals were sampled at each site. At sites 1-4 a separate bore was drilled for each interval, but on the remaining sites two intervals were tested in each deep bore. This was achieved by installing large-diameter (155 mm) casing to total depth and explosively perforating it at the deepest interval to be tested. The interval was then airlifted until the true static water level and a representative water sample had been obtained. A shallow interval was then explosively perforated and developed. It was then separated from the lower interval by inserting a string of 76 mm pipe and a compressible packer which was designed to seat between the two intervals. The shallow interval was then airlifted from the annulus of the pipe and casing. Slots in the 76 mm pipe below the compressible packer allow the water level of the deep interval to be monitored from inside the pipe. The water level of the shallow interval is monitored from the annulus.

A summary of the data from the exploratory bores is given in Table 3, together with information from the Moora town water supply bore 1/73 which was drilled between Moora Line sites 1 and 2. All potentiometric levels are related to Australian Height Datum (A.H.D.).

TABLE 3. SUMMARY OF MOORA LINE BORE DATA

Name	Latitude S	Longitude E	Drilling		Elevation (m) A.H.D.		Depth (m)	Com-pleted depth (m)	Tested in-terval (m)	Head (m) A.H.D.[1]	Salinity T.D.S. by evap. (mg/L)	Status
			Com-menced	Com-pleted	Surface	Casing						
ML 1A	30°37′04″	115°55′21″	11/11/74	27/11/74	213·250	213·810	756	648	622–629 (P)	198·090	1 300	obs—Lower Leederville Fm
ML 1B	....	....	4/12/74	10/12/74	213·460	213·810	399	391	312–320 (P)	....	460	abd—blocked with sand
ML 1C	....	....	13/12/74	18/12/74	213·035	213·425	222	207	187–195 (P)	....	....	abd—blocked with sand
ML 1D	....	....	17/2/77	3/3/77	214·108	214·548	356	326	316–322 (S)	195·288	410	obs—Leederville Fm
ML 1E	....	....	16/3/77	21/3/77	213·881	214·181	205	201	189–195 (S)	194·031	6 800	obs—Leederville Fm
PWD 1/73	30°36′51″	115°52′28″	7/9/73	22/9/73	243·032	243·451	434	350	333–350 (S)	190·937	450	Moora town water—Leederville Fm
ML 2A	30°36′19″	115°49′22″	14/1/75	30/1/75	205·950	206·650	464	292	273–281 (P)	148·900	430	obs—Leederville Fm
ML 2B	....	....	30/1/75	24/2/75	205·950	206·490	762	733	713–721 (P)	124·110	3 650	obs—siltstone, mudstone unit
ML 2C	....	....	26/2/75	27/2/75	205·855	206·395	100	95	66–72 (P)	146·785	....	obs—Leederville Fm
ML 3A	30°37′22″	115°44′15″	7/3/75	26/3/76	192·948	193·383	762	750	730–740 (P)	122·773	2 340	obs—siltstone, mudstone unit
ML 3B	....	....	14/4/75	23/4/75	192·820	193·405[2]	280	252	228–235 (P)	198·025[3]	820	obs—Lower Leederville Fm
ML 3C	....	....	24/4/75	28/4/75	193·190	193·550	117	112	88–95 (P)	149·590	490	obs—Leederville Fm
ML 4A	30°37′55″	115°38′18″	1/4/76	21/5/76	284·628	285·153	731	664	644–652 (P)	80·228	820	obs—Yarragadee Fm
ML 5A	30°37′55″	115°32′22″	15/6/77	5/7/77	204·261	204·801	772	760	741–749 (P)	88·941	390	obs—Yarragadee Fm
ML 5A (annulus)	....	....	15/6/77	5/7/77	204·261	204·761	772	760	458–466 (P)	....	450	obs—Yarragadee Fm
ML 5B	....	....	26/7/77	27/7/77	204·216	204·766	146	146	134·146 (S)	89·806	770	obs—Yarragadee Fm
ML 6A	30°38′48″	115°27′43″	28/5/76	16/8/76	114·759	116·004[2]	772	761	723–733 (P)	117·214[3]	350	obs—Yarragadee Fm
ML 6A (annulus)	....	....	28/5/76	16/8/76	114·759	115·349[2]	772	761	493–503 (P)	117·359[3]	330	obs—Yarragadee Fm
ML 6B	....	....	18/8/76	27/8/76	114·164	114·699	170	168	147–157 (P)	111·699	450	obs—Yarragadee Fm
ML 7A	30°39′36″	115°22′24″	30/3/77	13/5/77	69·479	70·059	801	759	695–703 (P)	55·199	610	obs—Yarragadee Fm
ML 7A (annulus)	....	....	30/3/77	13/5/77	69·479	69·929	801	759	318–326 (P)	55·189	630	obs—Yarragadee Fm
ML 7B	....	....	2/6/77	3/6/77	69·429	69·929	86	81	75–81 (S)	68·321	480	obs—Yarragadee Fm
ML 8A	30°45′05″	115°13′25″	3/10/77	10/11/77	38·546	39·186	770	674	642–651 (P)	34·626	5 770	obs—Lesueur Sandstone
ML 8A (annulus)	....	....	3/10/77	10/11/77	38·546	39·096	770	674	446–456 (P)	35·306	4 790	obs—Lesueur Sandstone
ML 8B	....	....	8/12/77	12/12/77	38·446	38·746	103	103	91–103 (S)	35·926	4 570	obs—Cockleshell Gully Fm
ML 9A	30°39′28″	115°08′08″	2/8/77	31/9/77	8·702	8·702	25	22	open hole	0·530	930	abd—Tamala Limestone

[1] Readings in April 1978
[2] Elevation to top of valve
[3] Artesian flow

A.H.D.—Aust. Height Datum
P—Perforated
S—Screened

obs—observation bore
abd—abandoned bore

GEOLOGY

STRATIGRAPHY

The area lies within the Perth Basin, a sedimentary trough over 950 km long, on the western side of the Precambrian Yilgarn Block. In this area the basin has been divided into two structural subdivisions: the Dandaragan Trough and the Beagle Ridge.

The Dandaragan Trough is bounded in the east by the Darling Fault and in the west by the Beagle Fault. The deepest part of the trough is west of Moora where it contains about 15 000 m of Phanerozoic (predominantly Mesozoic) sediments resting on Precambrian basement.

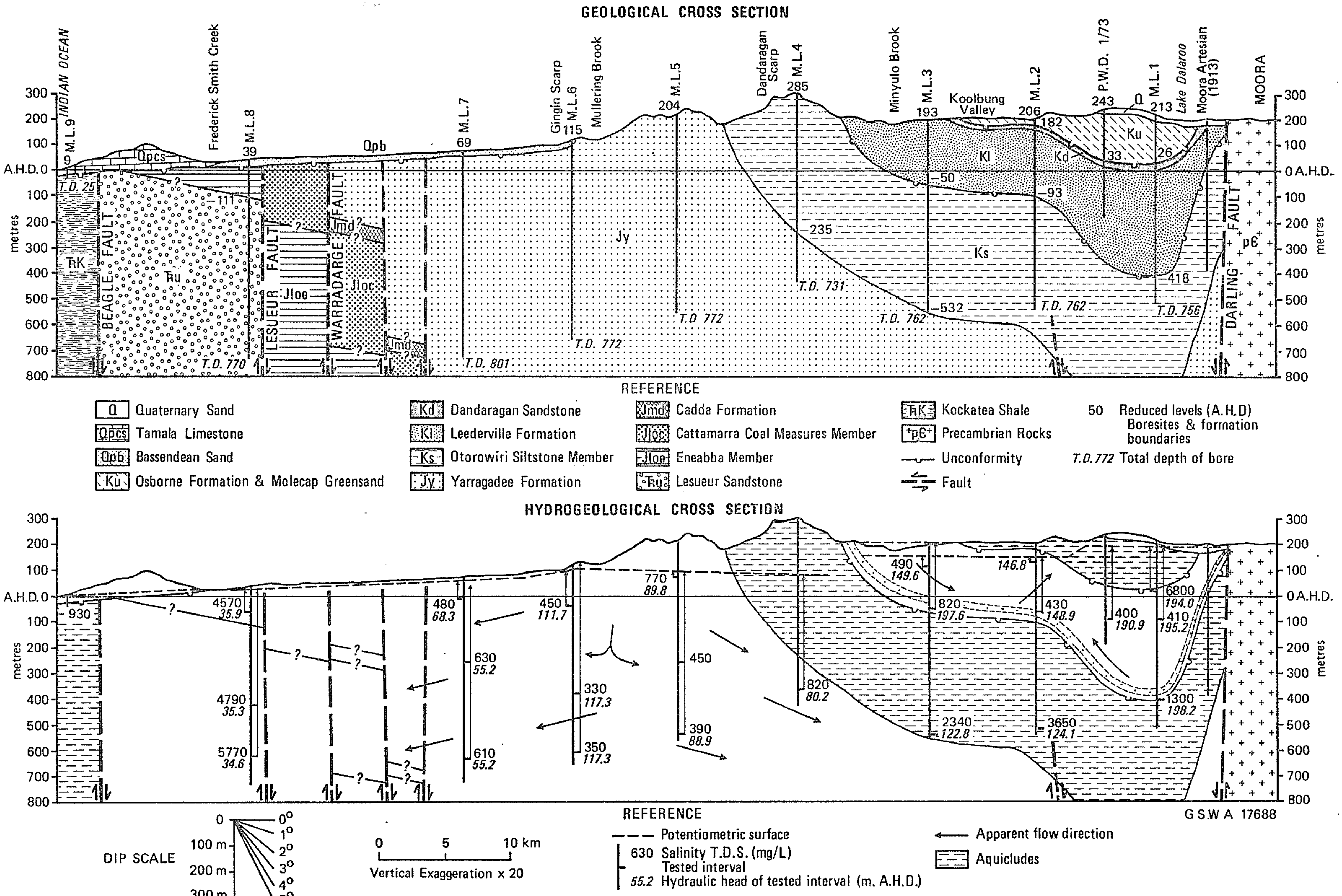

Figure 8 Geological and hydrogeological cross sections of the Moora Line.

The Beagle Ridge is a mid-basin ridge of relatively shallow basement covered by Permian and Triassic sediments and separated from the Dandaragan Trough by the Beagle Fault.

Cainozoic sediments mantle much of the surface in the area, obscuring the underlying geology. Table 4 summarizes the Mesozoic and Cainozoic stratigraphy intersected by drilling, and a cross-section of the borehole line is shown in Figure 8.

Palynology indicates that the section intersected at site 8 is of Late Triassic or Early Jurassic age, which is consistent with the basal section of the formation. It was deposited under non-marine conditions.

Yarragadee Formation: An aggregate thickness of 2 524 m of Yarragadee Formation was intersected at sites 4, 5, 6 and 7.

TABLE 4. STRATIGRAPHIC SEQUENCE—MOORA LINE

Formal age	Group	Formation	Maximum thickness (m)	Summary lithology	Remarks
CAINOZOIC Quaternary		"Superficial formations"*	36	Sand, limestone, silt, clay	Major and minor aquifers
		UNCONFORMITY			
MESOZOIC Early Cretaceous	Coolyena Group	Poison Hill Greensand .... Gingin Chalk .... Molecap Greensand .... Osborne Formation	34 } 168	Sand, clay .... Chalk .... Siltstone, minor sand	Not definitely intersected Not intersected Aquiclude
		UNCONFORMITY			
Middle to Early Cretaceous	Warnbro Group	Dandaragan Sandstone .... Leederville Formation	33 411	Sandstone, siltstone .... Sandstone, siltstone	Major aquifer Major aquifer
		UNCONFORMITY			
		Otorowiri Siltstone Member	507+	Siltstone, claystone	Aquiclude
Late Jurassic		Yarragadee Formation....	2 524+	Sandstone, minor siltstone	Major aquifer
Middle Jurassic		Cadda Formation		Sandstone, siltstone	Not intersected
Early Jurassic		Cockleshell Gully Formation .... Cattamarra Coal Measures Member Eneabba Member	 134+	Siltstone, sandstone, shale Coal measures	 Not intersected Aquifer
Late Triassic		Lesueur Sandstone	620+	Sandstone, minor siltstone	Major aquifer
Middle Triassic		Woodada Formation		Sandstone, siltstone	Not intersected
Early Triassic		Kockatea Shale	5+	Shale, siltstone	Aquiclude

* Informal name for various recognized Quaternary formations.

Triassic

Kockatea Shale: Five metres of Kockatea Shale was intersected below the Tamala Limestone at site 9 on the Beagle Ridge. It consists of finely laminated siltstone and very fine-grained sandstone.

The formation occurs in fault blocks in juxtaposition with the Lesueur Sandstone to the east. Palynological examination of the bottom hole core from site 9 indicated an Early Triassic age and a marine depositional environment. The fossel assemblage suggest a correlation with the upper part of the formation.

Lesueur Sandstone: The uppermost 620 m of the Lesueur Sandstone was intersected at site 8. It consists of thick beds of sandstone composed of fine- to very coarse-grained angular and sub-rounded quartz sand. It includes some feldspar and intergranular clay (which appears to be kaolinized feldspar), and accessory heavy minerals and pyrite. Interbeds of grey, micaceous, laminated claystone up to 6 m thick, occur infrequently.

The Lesueur Sandstone occurs in fault blocks which bring it into juxtaposition with the Cockleshell Gully Formation to the east. This sandstone disconformably overlies the Woodada Formation which was not intersected in the Moora Line bores, and is conformably overlain by the Cockleshell Gully Formation.

Palynology indicates the Lesueur Sandstone to be of non-marine origin and Late Triassic age.

Jurassic

Cockleshell Gully Formation: The bottom 134 m of the Eneabba Member of the Cockleshell Gully Formation was intersected below the Bassendean Sand at site 8. This formation is an interbedded siltstone-sandstone sequence. The siltstones are multicoloured, laminated and moderately lithified. The sandstones are composed of fine to very coarse angular to sub-rounded quartz with rare feldspar, accessory pyrite, heavy minerals and mica.

The formation occurs in fault blocks faulted against the Yarragadee Formation to the east. A complete section of the formation is believed to occur in a fault block to the east of site 8. The Cockleshell Gully Formation is conformably overlain by the Cadda Formation, which was not encountered in the Moora Line bores.

It is composed predominantly of thick-bedded sandstone with subordinate conglomerate and siltstone interbeds. The sandstones vary from pink (in weathered sections) to grey; they are generally poorly sorted and consist of fine to very coarse, sub-angular to sub-rounded quartz. Varying proportions of intergranular clay and feldspar are present, together with accessory heavy minerals, garnet and pyrite. Sandy conglomerates intersected in the upper part of the formation at site 5 consist of quartz and grey to pink feldspar ranging in size from fine sand to pebbles up to 10 mm in diameter. The siltstone interbeds which constitute about 25 per cent of the formation are light to dark grey, micaceous, and vary from laminated to fissile. The formation is argillaceous in its upper section which subcrops between site 5 and the Dandaragan Scarp. It also becomes argillaceous and contains minor lenses of coal at site 7, where the bore probably penetrated almost to the base of the formation.

The Yarragadee Formation outcrops or subcrops between the Warradarge Fault and Dandaragan Scarp and conformably overlies the Cadda Formation. In Wapet's Walyering No. 1 well 9 km south of site 6, the Yarragadee Formation is 2 686 m thick (Bird and Moyes, 1971).

The sediments are fluviatile deposits of Late Jurassic age ranging from Tithonian at site 5 to Callovian at site 7.

Cretaceous

Otorowiri Siltstone Member: A siltstone-claystone unit which outcrops in the Dandaragan Scarp was intersected in all bores to the east of the scarp. The unit has a maximum thickness of 507 m and can be correlated on palynological evidence with the Otorowiri Siltstone Member of the Yarragadee Formation of the northern Perth basin. The unit can also be traced in outcrop south to the Moore River and then in the subsurface in deep bores, to the Gingin Brook Line, where it is possibly represented in Gingin Brook bores 1 and 5 (J. Backhouse, pers. comm., 1978).

In the Moora Line bores the unit is a thick interbedded siltstone and claystone with minor thin clayey sandstone interbeds. The siltstone is olive brown, fissile, moderately lithified and micaceous; it also contains rare lignite and pyrite. The claystones are more massive; they are grey and contain rare lignite and mica. The rare clayey sandstone interbeds are light grey and consist of fine- to medium-grained quartz with accessory heavy minerals, garnet, mica and lignite.

The unit is the top member of the Yarragadee Formation. It is unconformably overlain by the Leederville Formation.

Palynological examination of side-wall cores indicate the unit is of Early Neocomian age and was deposited under non-marine (lagoonal) conditions.

Leederville Formation and Dandaragan Sandstone: The Dandaragan Sandstone has been grouped with the Leederville Formation for the purpose of this paper as they have similar lithologies, are conformable, and the Dandaragan Sandstone has a maximum thickness of only 33 m.

The formations were intersected at sites 1, 2 and 3. The Leederville Formation consists of an interbedded sandstone-siltstone sequence.

The sandstones are grey, and consist of fine to very coarse angular to sub-rounded quartz and rare feldspar, commonly in a clayey matrix. The siltstones are grey, micaceous, and moderately lithified. Individual beds of both the argillaceous sediments and sandstones are up to 20 m thick; however, they are lenticular and correlation of these beds between distant bores is not possible. Correlation is therefore based on broad gamma-ray log characteristics and stratigraphic relationships with adjoining formations.

A maximum thickness of 444 m was intersected at site 1, the centre of the Dandaragan Trough at the time of deposition. The formations thin to the west and have a combined thickness of 237 m at site 3, but part of the Dandaragan Sandstone has been eroded away.

Palynology indicates that the Leederville Formation is of Early Cretaceous (Neocomian to Aptian) age and was deposited in a non-marine environment.

Osborne Formation and Molecap Greensand: The Molecap Greensand has been grouped with the Osborne Formation for the purposes of this paper, as they are neither lithologically nor geophysically distinguishable in the Moora Line bores. The Osborne Formation was intersected at site 1, PWD 1/73 and possibly site 2. It consists of black to grey-green glauconitic shales and siltstones with thin sandier interbeds, and contains rare pyrite and phosphate, the latter occurring as a coating on the glauconite grains.

The Osborne Formation disconformably overlies the Dandaragan Sandstone and is conformably overlain by the Molecap Greensand. A maximum thickness of 168 m was intersected at site 1. Marked thinning occurs towards the margin of the trough so that near Dandaragan townsite, the formation is only 6 m thick (Low, 1965).

The glauconitic sequence was deposited in a marine environment and as palynological determinatons also indicate a Middle Cretaceous (Albian-Cenomanian) age, most of the section intersected by drilling is apparently Osborne Formation rather than Molecap Greensand, which is considered to be Coniacian to possibly Late Cenomanian in age (Playford and others, 1976).

Gingin Chalk and Poison Hill Greensand: The Gingin Chalk crops out along the sides of Koolbung Valley, but was not intersected in the Moora Line bores as sites 2 and 3 are at a lower elevation than the formation. As the formation lenses out east of site 2 it was not intersected in the more easterly bores. The Gingin Chalk conformably overlies the Molecap Greensand and is itself conformably overlain by the Poison Hill Greensand, which was only tentatively recognised from gamma-ray logs as occurring in PWD 1/73. These three formations are marine deposits of Late Cretaceous age.

Quaternary

'Superficial formations': The 'superficial formations' comprise the following: laterite and associated sand, which are widely developed over the Mesozoic sediments east of the Gingin Scarp; Bassendean Sand, consisting of low irregular quartz sand dunes; Tamala Limestone, which is a lithified dune system parallel to the coast, and consisting of calcarenite and quartz sand; and Safety Bay Sand, consisting of coastal dune and shallow-marine to littoral sand overlying the Tamala Limestone.

STRUCTURE

Faulting and Folding

The geological section illustrated in Figure 8 suggests that the Mesozoic structure is characterised by faulting rather than folding. The Darling Fault forming the eastern boundary has a displacement of up to 15 000 m west of Moora. This has imposed a predominantly easterly dip on the sediments.

An asymetric syncline has developed near the axis of the Dandaragan Trough and there is marked thinning of the Warnbro Group and Osborne Formation from east to west (Fig. 8). This may be interpreted as being caused by differential compaction across, and in association with, growth faults (Cope, 1972), and suggests that movement on the underlying faults continued to Late Cretaceous times.

On the western side of the Dandaragan Trough there are a series of faults, the most important being the Beagle Fault which has a throw of about 2 000 m.

HYDROGEOLOGY

INTER-RELATIONSHIP OF AQUIFERS

Perched aquifers and unconfined aquifers in weathered sediments and Quaternary sand occur on the Dandaragan Plateau. They are separated over most of the area from the underlying Dandaragan Sandstone and Leederville Formation aquifers by the impermeable Osborne Formation, but are in direct contact where the Osborne Formation has been eroded away and where the Dandaragan Sandstone and Leederville Formation subcrop at the margins of the basin.

The main groundwater flow system is divided into two parts by the thick Otorowiri Siltstone Member which maintains a head difference of up to 70 m between the systems. The upper part comprises the Leederville Formation and Dandaragan Sandstone, together with Quaternary sand where it is in hydraulic connection with these formations. The lower part comprises the superficial formations of the Bassendean Sand and Tamala Limestone and the Mesozoic aquifers of the Yarragadee Formation, Cockleshell Gully Formation, and Lesueur Sandstone. These Mesozoic aquifers are considered to be in hydraulic continuity both vertically and across fault planes.

The barrier boundaries of the Darling Fault in the east and impermeable Triassic sediments of the Beagle Ridge in the west impart an overall southward flow in the aquifers.

AQUIFERS

'Superficial formations'

Small supplies of groundwater occur in perched and unconfined aquifers in the Quaternary sand and associated weathered sediments of the Dandaragan Plateau. Recharge is by infiltration of rainfall and movement is downward and laterally to discharge via springs along the sides of the valleys or in topographic depressions. However, where the impermeable Osborne Formation is absent the perched aquifers may discharge by downward infiltration into the underlying Mesozoic aquifers.

The groundwater salinity is generally less than 1 000 mg/L T.D.S., but where springs have given rise to large areas of swampy ground, concentration by evapotranspiration has increased salinities up to 7 000 mg/L T.D.S.

On the Swan Coastal Plain, the Bassendean Sand and Tamala Limestone constitute unconfined aquifers. The former is up to 21 m thick and is recharged by direct infiltration of rainfall and streamflow. A number of westward-flowing water courses dissipate into the Bassendean Sand. Groundwater movement is to the west, under the influence of a gentle hydraulic gradient between the Gingin Scarp and the Coastal Belt. Discharge is by evapotranspiration from numerous interdunal swamps, by flow into the Tamala Limestone, and by leakage into the underlying Mesozoic aquifers. Groundwater salinity is generally less than 1 000 mg/L T.D.S.

The Tamala Limestone covers an elongate area along the coastline and extends as far as 10 km inland. It is up to 36 m thick in the vicinity of the Moora Line. Recharge is directly from rainfall through solution tubes, cavities, and intergranular porosity within the linestone; outflow from the Bassendean Sand; and the infiltration of stream flow from the east. The Namban River discharges into a cave system within the limestone. Groundwater movement is predominantly westwards with discharge into the ocean and lakes. There is also potential for vertical leakage into the underlying Mesozoic aquifers.

Groundwater with a salinity of less than 1 000 mg/L T.D.S. can generally be obtained at distances greater than 1 km from the coast. Closer to the sea the near-surface water is potable, but the salinity increases rapidly with depth as the zone of mixing of fresh and salt water is penetrated.

The Tamala Limestone is generally a high-yielding aquifer and has considerable importance as a source of freshwater to the fishing communities along the coast.

Leederville Formation

The Dandaragan Sandstone is in hydraulic connection with the Leederville Formation and the two units are lithologically similar. It also has a common area of recharge and extends over essentially the same area. They are therefore regarded as being a single multi-layered aquifer system consisting of about equal proportions of sandstone and siltstone.

This aquifer underlies an area from the Dandaragan Scarp to the Darling Fault (Fig. 8). Recharge is by infiltration of rainfall via the overlying 'superficial formations' where the Osborne Formation is absent. The Leederville Formation ranges from about 200 m to 444 m thick and contains a large volume of water in storage.

Isopotential contours drawn from water levels measured on the Agaton Borefield (Balleau and Passmore, 1972) and the Moora Line indicate the regional flow to be towards the south or southwest. However, the elevation of the potentiometric surface declines from east to west along the Moora Line, from 190.9 m in PWD 1/73 to 147.9 m at site 2 (Fig. 8). This is possibly caused by the marked thinning of sediments from east to west resulting in changes in vertical hydraulic conductivity. Where the Osborne Formation is thickest it effectively confines the Leederville aquifer, but conditions become unconfined to the west where the Osborne Formation has a much thinner section (Fig. 8).

Most discharge presumably occurs south of Moore River in the low-lying areas west of the Gingin Scarp and offshore; however, there is minor evaporative discharge from permanent pools in the Moore River and possibly some contribution to river base-flow.

The salinity of groundwater from the Leederville Formation along the Moora Line is generally less than 1 000 mg/L T.D.S. A local area of 6 800 mg/L T.D.S. in the Dandaragan Sandstone at site 1 is probably due to local intake from the saline drainage of the Yarra Yarra Region.

The Leederville Formation contains major resources of low-salinity groundwater. Present development is very limited and there is scope for considerably increased production for town and agricultural water supplies.

A 30 m thick sandstone bed at the base of the Leederville Formation, confined by a siltstone of similar thickness, has a hydrostatic head of about 198 m, which is higher at site 3 than the hydrostatic heads in either the upper part of the Leederville Formation or in the Yarragadee Formation. This sandstone is considered to be of local significance only, but gives rise to small artesian flows in some areas. An increase in salinity from west to east suggests recharge is along the topographic high of the Dandaragan Scarp where it is thought this sandstone outcrops.

Yarragadee Formation

The Yarragadee Formation extends westwards to the Warradarge Fault, eastwards to the Yilgarn Block beneath the cover of younger sediments, and to the north and south throughout the Dandaragan Trough (Fig. 8). The formation consists predominantly of sandstone; the aquifer is unconfined west of the Dandaragan Scarp and is confined beneath the thick Otorowiri Siltstone Member at the top of the formation to the east.

Recharge to the formation is by infiltration of rainfall into the weathered sediments and by leakage from the overlying Bassendean Sand. A groundwater mound has developed beneath the Arrowsmith Region.

Although the Moora Line bores were drilled to a maximum depth of 800 m they did not intersect the base of the groundwater body having a salinity of less than 1 000 mg/L T.D.S. However, the Wapet well, Walyering No. 1, has shown that groundwater of less than 1 000 mg/L T.D.S. extends to a depth of 1 500 m (Nowak, 1978). An extremely large volume of low-salinity groundwater is therefore contained in storage.

Groundwater movement is radial from the apex of the mound. To the east it becomes confined beneath the Otorowiri Siltstone Member and to the west it discharges laterally across the Warradarge Fault into the Cockleshell Gully Formation. Data from surrounding bores indicate the regional flow direction to be to the south where offshore discharge may be expected.

The groundwater salinity from the intervals tested in the Moora Line bores ranged from 330 to 770 mg/L T.D.S. An unusual feature at sites 5 and 6 is that the water quality improves with depth. This may result from variation in hydraulic conductivity, or source and time of recharge.

The large volume of low-salinity groundwater, very thick sandstone beds and the large recharge area indicate that the Yarragadee Formation is a major potential source of groundwater. It exists within the central part of the coastal plain and extends well beyond the vicinity of the Moora Line. This source is virtually undeveloped.

Cockleshell Gully Formation

The base of the Eneabba Member, the lower member of the Cockleshell Gully Formation, was intersected at site 8. The formation consists of alternating sandstones and siltstones and occurs in a series of north-south fault blocks which have been faulted against the Yarragadee Formation.

Recharge is presumably by direct infiltration of rainfall where the sandier sections of the formation crop out, by leakage from the overlying Bassendean Sand and Tamala Limestone, and by westward outflow from the Yarragadee Formation. Flow is south to southwest following the same general direction as the Yarragadee Formation. Discharge presumably is by outflow across fault boundaries into the Lesueur Sandstone and offshore.

A salinity of 4 570 mg/L T.D.S. was recorded from 103 m at site 8, and high salinities were also recorded from the Watheroo Line (Harley, 1975).

Test results, geophysical logs and the generally silty nature of the formation, all indicate that the Cockleshell Gully Formation is unlikely to be a major source of low-salinity groundwater in this area; it is mainly prospective for stock water.

Lesueur Sandstone

The Lesueur Sandstone occurs in a fault block faulted against the Cockleshell Gully Formation. The aquifer is confined beneath the Eneabba Member of the Cockleshell Gully Formation at site 8, but is unconfined further north where it crops out in the Gairdner Range. At site 8 it is a thick coarse sandstone.

Recharge is by infiltration of rainfall where the formation outcrops, by underflow from the Cockleshell Gully Formation and by leakage from the overlying Eneabba Member. Groundwater flow probably does not occur into the impermeable Kockatea Shale on the west and is therefore most likely to be southwards, eventually discharging offshore as for the other Mesozoic aquifers.

Groundwater salinity at site 8 is over 4 500 mg/L T.D.S. throughout the thickness penetrated and is probably due to lack of surface recharge close to the site sampled. However, in the outcrop area to the north the salinity is generally less than 500 mg/L T.D.S. (Harley, 1975).

In the vicinity of the Moora Line the Lesueur Sandstone contains large volumes of brackish groundwater prospective for stock supplies only.

HYDROCHEMISTRY

All groundwater in the area is classified as being of sodium-chloride type, and there is no significant difference in chemical composition between water from different aquifers.

Iron concentrations are known to be high in the Leederville Formation (8.9 mg/L in Dandaragan town water supply bore) and appear to be variable in the Yarragadee Formation. Treatment of the groundwater will therefore be necessary if used for domestic or town water supply.

GROUNDWATER TEMPERATURE

Temperature logs were run on the Moora Line bores 12 months after completion of the last bore. They indicate a range at site 2 of from 25°C at the water table to 42°C at a depth of 600 m. The corresponding range at site 5 in the west was 21°C to 27.5°C. These ranges indicate the existence of a low temperature gradient in the west, and a high gradient in the east across the thick Otorowiri Siltstone Member, which may act as a thermal insulator. Actual gradiants are about 2.3°C per 100 m in the Lesueur Sandstone, 1.5°C per 100 m in the Yarragadee Formation, 3.5°C per 100 m across the Otorowiri Siltstone Member, and 2.5°C per 100 m in the Leederville Formation.

CONCLUSIONS

The Moora Line of bores has provided valuable new geological and hydrogeological data in the northern Perth Basin. Drilling has confirmed the basic structure of the

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basin; the sediments are block faulted on the western side of the Dandaragan Trough and have a gentle east dip towards the Darling Fault which forms the eastern edge.

Fault-controlled subsidence during the Middle to Late Cretaceous and associated differential compaction of the sediments, resulted in a thick sequence of Osborne Formation and Warnbro Group being deposited in the axis of the Dandaragan Trough.

The groundwater flow system is separated into two parts by a thick siltstone-claystone unit, which has been correlated with the Otorowiri Siltstone Member of the northern Perth Basin. Very large volumes of low-salinity groundwater are available from the Leederville and Yarragadee Formations. The Cockleshell Gully Formation and Lesueur Sandstone both contain brackish groundwater; however, the Lesueur Sandstone is a major aquifer and contains potable water to the north of the area of investigation. The Tamala Limestone is an important source of low-salinity shallow groundwater for coastal communities.

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GEOLOGY AND GROUNDWATER RESOURCES OF THE SOUTHWESTERN CANNING BASIN, WESTERN AUSTRALIA

by R. E. J. Leech

ABSTRACT

A hydrogeological study was conducted to assess the stratigraphy and groundwater potential of 3 500 km^2 of the southwestern part of the Canning Basin. Forty-seven bores were constructed with an aggregate depth of 6 790 m. Two major aquifers have been defined, the shallowest being the Broome Sandstone, which supports an unconfined groundwater system, and the other is the Wallal Sandstone, which contains a largely confined system separated from the Broome Sandstone by the almost impermeable Jarlemai Siltstone.

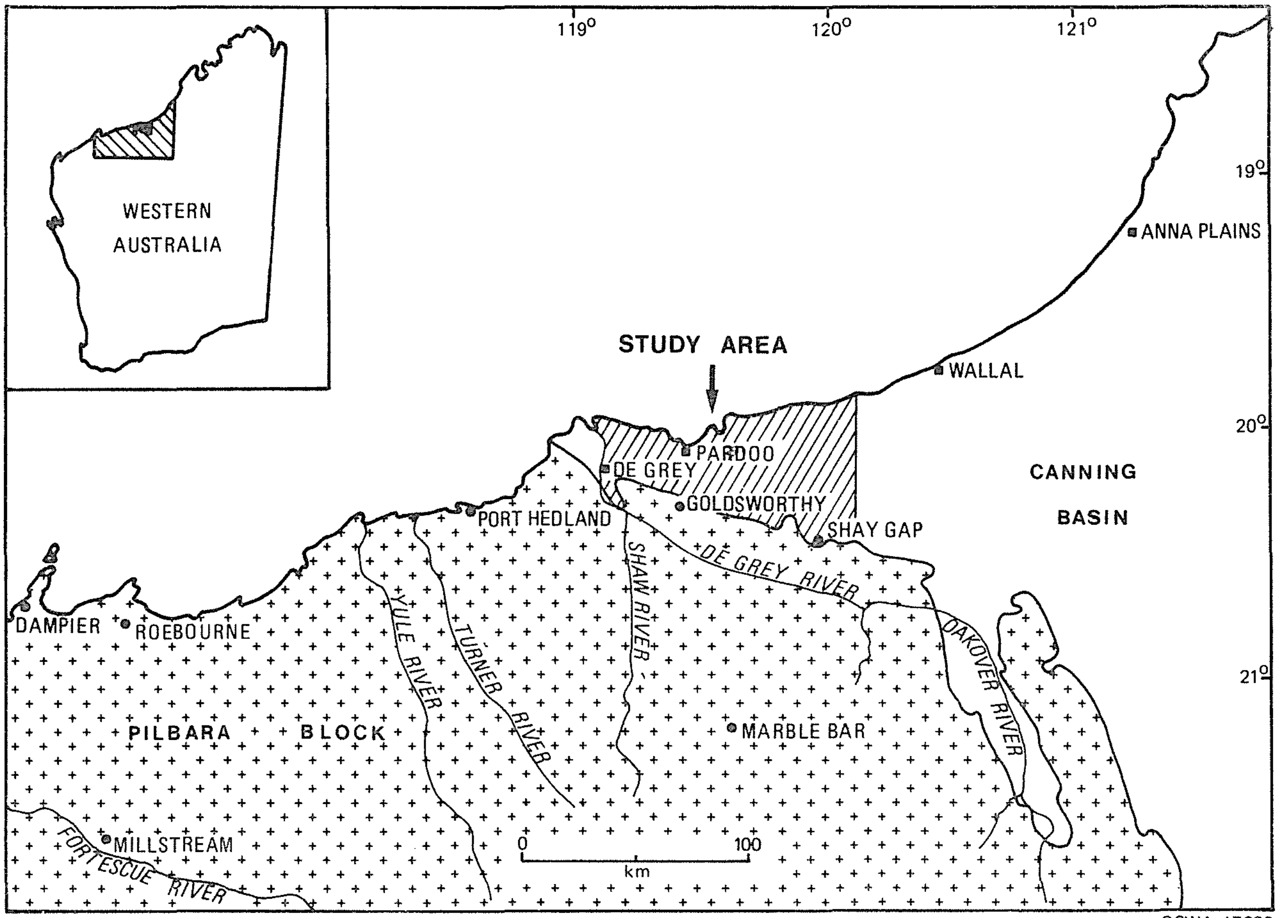

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Figure 9 Location plan, southwestern Canning Basin.

The Broome Sandstone has an areal extent of about 1 575 km² and a saturated thickness of from 0 to 61 m. This aquifer is estimated to contain about 3.2 × $10^9 m^3$ of groundwater in storage. Yields of up to 1 000 m^3/day of potable water have been obtained from suitably constructed bores. The groundwater salinity (TDS) in this formation ranges from 380 mg/L in the east to more than 3 000 mg/L in the west. Nitrate concentrations are locally higher than the accepted limit for human consumption. Recharge to the Broome Sandstone is by direct percolation from rainfall. Groundwater movement is towards the north where it is discharged into the Indian Ocean.

The Wallal Sandstone extends over about 2 100 km² and has a saturated thickness of from 14 to 218 m. The estimated groundwater storage in this aquifer is 54.9 × $10^9 m^3$. Close to the coast hydraulic heads may exceed 30 m above ground level, and artesian flows from individual bores range up to 3 000 m^3/day. The salinity of groundwater in the Wallal Sandstone ranges from 240 to 13 000 mg/L. Recharge to this aquifer takes place outside the area investigated, towards the east and southeast, and is by direct percolation from rainfall in areas where the Jarlemai Siltstone is absent. Groundwater movement is towards the northwest where it discharges into the Indian Ocean.

INTRODUCTION

LOCATION

The investigation area is located in the southwestern Canning Basin, about 100 km east of Port Hedland (Fig. 9). The area is approximately 3 500 km² in extent and

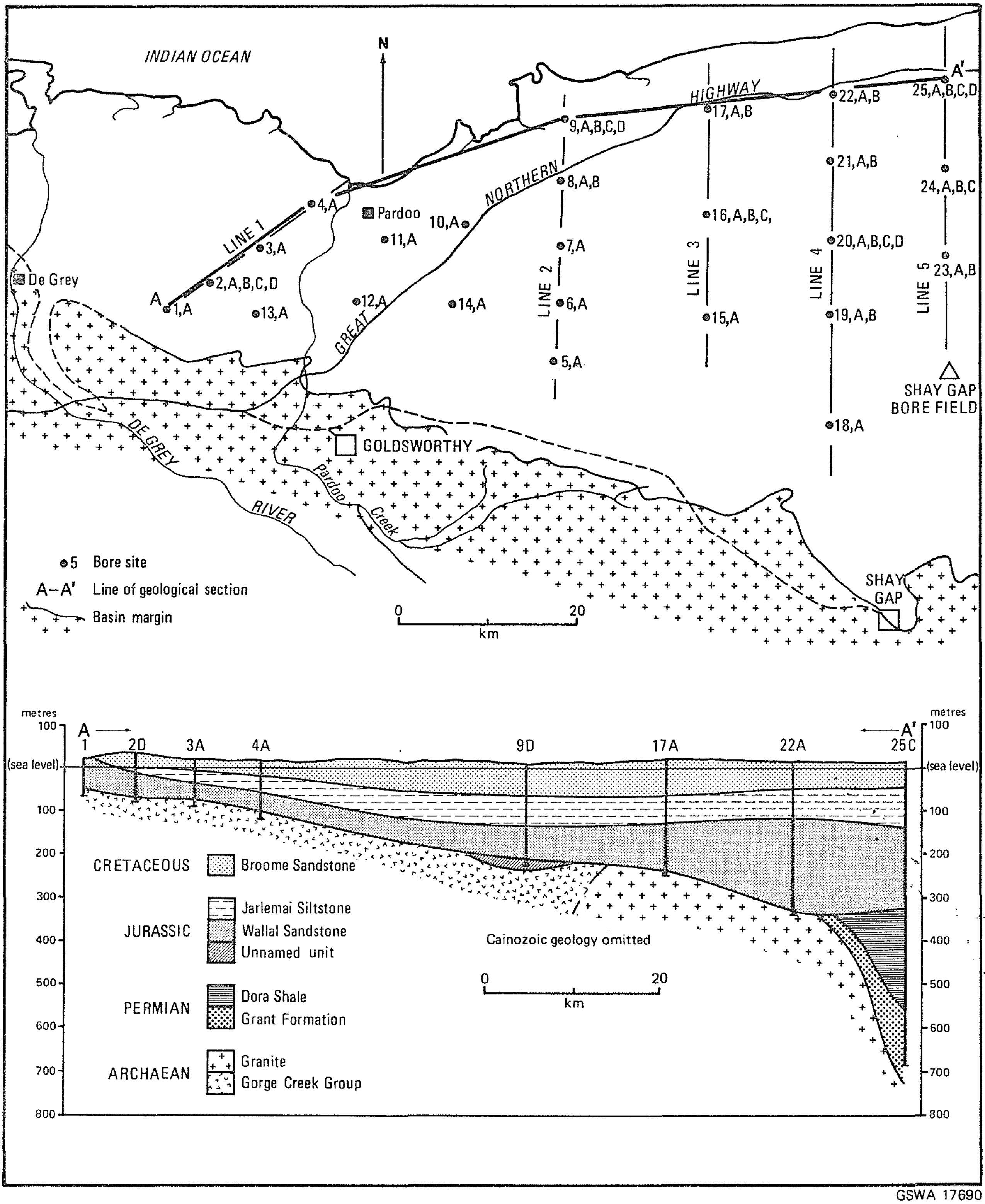


Figure 10 Bore locations and geological cross section.

is bounded by the Pilbara Block to the south, the Indian Ocean to the north and by lines of investigation bores to the west and east.

DRILLING AND BORE CONSTRUCTION

All drilling was completed by the Mines Department Drilling Section using Jacro 1500 and Mayhew 2000 rotary drilling rigs. Forty-seven bores with an aggregate depth of 6 790 m were drilled. Their locations are shown on Figure 10. Drilling difficulties were encountered when aquifers with large positive heads were intersected at sites 4, 9, 17, 22 and 25. These were overcome by the addition of barytes or a salt/sugar mixture to the drilling mud. This increased its density sufficiently to raise the pressure exerted by the mud column to that of the formation water.

Details of bore construction and test data are given in Table 5.

GEOLOGY

GENERAL

The Canning Basin is the largest sedimentary basin in Western Australia and extends over 630 000 km², of which two-thirds is onshore. The sediments that it contains

TABLE 5. SUMMARY OF PROJECT BORE DATA

Bore	Reduced level natural surface AHD* (m)	Total depth (m)	Casing		Screens†		Reduced water level AHD (m)	Discharge and drawdown at eight hours		Transmissivity (m²/day)	Salinity TDS (mg/L)	Aquifer
			Length (m)	Diameter ID (mm)	Interval (m)	Diameter ID (mm)		Discharge (m³/day)	Drawdown (m)			
1	19·666	83·2	60·0	206	Open hole		9·96	....	....	....	790	Wallal
2A	31·030	65·0	52·0	206	52·0–58·0	200	9·90	....	....	....	1 590	Wallal
2B					bore abandoned							
2C					bore abandoned							
2D	31·062	104·0	84·0	143	84·0–102·0	100	9·87	....	....	....	....	Wallal
3A	19·170	103·4	5·0 64·5	206 143	64·5–82·5	76	11·18	614	4·3	145	1 860	Wallal
4A	12·675	133·5	5·4 67·4	206 143	67·4–109·4	76	19·22‡	199	4·7	69	1 680	Wallal
5A	64·712	43·5	6·0 26·3	206 143	37·1–43·1	76	30·81	....	....	....	....	Wallal
6A	48·269	78·5	6·2 50·0	206 143	50·7–74·7	76	30·17	650	4·4	129	490	Wallal
7A	34·229	125·0	6·0 91·0	206 143	91·7–115·7	76	29·76	641	2·7	204	360	Wallal
8A	15·115	183·0	6·0 137·5	206 143	138·1–150·1	76	31·24‡	1 464	4·8	40	1 010	Wallal
8B	14·982	103·0	6·0 82·0	206 143	82·7–100·7	76	31·26‡	939	3·3	104	960	Wallal
9A					bore abandoned							
9B	5·875	120·0	65·0 74·4	206 143	74·4–95·4	143	32·85‡	....	....	....	860	Jarlemai
9C					bore abandoned							
9D	7·075	224·0	43·9 130·0 168·0	259 189 143	193·0–211·0	50	27·70‡	508	15·5	10	1 190	Wallal
10A	20·975	116·4	41·0 71·0	206 143	71·1–113·1	76	25·74‡	769	1·7	272	1 120	Wallal
11A	19·732	129·7	35·0 55·0	206 143	61·0–85·0	76	22·20‡	....	....	....	1 160	Wallal
12A	32·168	45·7	26·0 31·0	206 143	31·0–43·0	76	18·26	....	....	....	1 180	Broome
13A	46·100	69·7	41·0 71·0	206 143	42·0–54·0	76	11·05	....	....	....	820	Broome
14A	53·704	77·1	35·0 55·0	206 143	57·7–70·1	100	25·78	....	....	....	770	Wallal
15A	84·314	120·5	26·0 31·0	206 143	101·0–113·0	100	38·01	....	....	....	240	Wallal
16A	41·976	184·0	29·0 42·0	206 143	138·0–153·0	100	38·22	672	6·1	145	310	Wallal
16B	41·792	45·0	6·0 57·7	189 143	37·0–43·0	100	30·43	393	5·6	222	440	Broome
16C	41·772	155·0	30·0 101·0	206 143	135·2–153·4	76	38·24	....	....	....	....	Wallal
17A	18·750	259·0	29·0 220·0	206 143	220·0–244·0	100	37·17‡	2 100	6·9	142	420	Wallal
17B	18·558	70·0	29·0 64·0	206 143	64·0–70·0	100	2·95	632	5·0	854	720	Broome
18A	157·641	126·5	106·0	143	108·7–120·7	100	45·60	....	....	....	310	Wallal
19A	105·918	176·0	21·0 158·0	189 143	158·0–176·0	100	43·86	532	2·8	54	330	Wallal
19B	105·878	54·0	45·0	143	45·0–51·0	100	Dry	....	....	....	....	Broome
20A					bore abandoned							
20B	77·000	56·0	50·0	143	50·0–54·5	100	Dry	....	....	....	....	Broome
20C	78·164	190·0	169·0	143	169·5–187·5	76	43·50	....	....	2 490	....	Wallal
20D	76·949	185·0	167·0	143	167·0–183·8	100	43·39	626	2·7	720	300	Wallal
21A	37·877	235·0	29·0 200·0	189 143	200·0–224·0	104	43·64‡	247	0·7	409	320	Wallal
21B	37·552	42·0	30·0	143	30·0–39·0	104	14·35	29	0·03	159	380	Broome
22A	11·081	344·0	36·7 278·0	237 143	278·0–296·0	100	38·74‡	3 030	10·0	279	320	Wallal
22B	11·078	55·0	49·0	143	49·0–55·0	100	7·82	626	5·6	138	430	Broome
23A	70·912	210·0	96·9	143	96·9–114·9	100	46·60	645	1·3	569	290	Wallal
23B	70·481	122·0	97·0	143	97·0–114·5	100	46·60	....	....	....	....	Wallal
24A	43·768	267·0	32·0 170·7	259 143	170·7–179·0	100	45·99‡	69	0·5	200	240	Wallal
24B	43·807	45·0	34·0	143	34·0–40·0	100	10·70	....	....	....	480	Broome
24C	43·822	47·0	34·0	143	34·0–40·0	100	10·70	....	....	....	....	Broome
25A					bore abandoned							
25B					bore abandoned							
25C	16·212	696·0	34·0 231·0 286·0	259 143 105	286·0–310·0	100	41·99‡	1 394	14·7	130	300	Wallal
25D	16·158	102·0	30·9	143	30·9–36·9	100	3·62	735	3·0	250	830	Broome

* AHD—Australian Height Datum.
† The interval between the top of the screen and the base of the casing is occupied by either a packer or blank casing.
‡ Flowing bore.

range from Ordovician to Recent in age, and reach a maximum thickness of over 8 km. The area included in the current investigation, 3 500 km^2, covers but a small portion of the basin and is confined to the western part of the Anketell Shelf which includes the Wallal Platform to the west of the Willara Sub-basin. The maximum thickness of sediments penetrated by boring was 696 m at site 25. trough to the northeast named the Willara Sub-basin. The Wallal Platform is a basement-high in this area, and all project bore sites with the exception of site 25 are drilled on this platform. The gradient of the bedrock floor steepens between sites 24 and 25 which suggests that this structure may be an ancient fault scarp, or a hinge line with greater subsidence to the northeast (Fig. 10).

TABLE 6. STRATIGRAPHIC UNITS IN THE SOUTHWESTERN CANNING BASIN

Age		Rock unit	Lithology
CAINOZOIC	Quaternary	Bossut Formation	Alluvium—clay, sand and gravel Sand—wind-blown, red residual soil Tidal Flat Deposits—clay, silt and sand Calcarenite—sandy, cross-bedded
	Tertiary		Calcrete—white, calcareous rock Laterite—pisolitic, ironstone, unconsolidated
		UNCONFORMITY	
MESOZOIC	Cretaceous	Broome Sandstone	Sandstone—with rare siltstone interbeds
	Jurassic	Jarlemai Siltstone .... Wallal Sandstone .... Unnamed unit	Siltstone—claystone and rare sandstone interbeds Sandstone—with rare siltstone and conglomerate interbeds Claystone—with rare lignite
		UNCONFORMITY	
PALAEOZOIC	Permian	Dora Shale .... Grant Formation	Shale—with siltstone interbeds Glacigene deposits—interbeds of siltstone, sandstone and claystone
		UNCONFORMITY	
ARCHAEAN		(Muccan Batholith) .... Gorge Creek Group	Granite—weathered; quartz, biotite and kaolinized feldspar Metasediments and volcanic rocks—shale, amphibolite, schist and quartzite

The geological succession and a brief lithological description of each geological unit encountered during this investigation either in bores or during mapping is given in Table 6. The main stratigraphic problem was to establish the correct Mesozoic succession. Several authors (Elliott, 1957; Australia Bureau of Mineral Resources, 1958; McWhae and others, 1958; Veevers and Wells, 1961; and the Geological Survey of Western Australia, 1975) had all produced conflicting geological successions; their stratigraphy together with the sequence adopted in this report are shown in Table 7.

STRUCTURE

The drilling programme has defined the geology and also allows accurate construction of structure contour and isopach maps. These indicate that the Mesozoic sediments are essentially flat lying with presumed depositional dips of less than 1° to the north. There is no evidence of folding and faulting.

Two structurally controlled subdivisions which affect the Canning Basin sediments in this part of the basin are the northwesterly trending Wallal Platform and an adjacent

GEOLOGICAL HISTORY

There are no indications of Palaezoic sedimentation in the investigation area prior to the Early Permian. It is therefore likely that either this part of the basin was a land mass before this time or, if sediments had been deposited, they had already been removed by erosion. During Permian times the glacigene Grant Formation, of Sakmarian age, was deposited unconformably on the Archaean basement rocks, and this was followed in the Late Sakmarian or Early Artinskian by deposition of the Dora Shale, a continental sequence of claystone, siltstone and sandstone. At the end of the Permian an interval of uplift occurred and sedimentation ceased.

During Middle Jurassic times renewed subsidence resulted in a marine transgression, which by the Bajocian had reached the study area. An unnamed claystone unit (Backhouse, 1978) was then deposited locally on Archaean basement. Further subsidence occurred in the Callovian, and the Wallal Sandstone was deposited. Over most of the Canning Basin this sandstone is the basal unit of the Jurassic marine transgression, and was deposited unconformably on Archaean or Permian rocks. By Oxfordian

TABLE 7. MESOZOIC STRATIGRAPHIC NOMENCLATURE IN THE SOUTHWESTERN CANNING BASIN

Age	Elliott Wallal core hole No. 1 (1957)	BMR 4 and 4A Wallal (1958)	McWhae and others (1958)	Veevers and Wells (1961)	GSWA Memoir 2 (1975)	This Report
Neocomian	Broome Sandstone	Broome Sandstone	Anketell Sandstone Callawa Formation	Broome Sandstone	Broome Sandtsone	Broome Sandstone
			Broome Sandstone	Jarlemai Silstsone		
Tithonian	Jarlemai Siltstone	Jarlemai Siltstone	Jarlemai Silststone	Anketell Formation	Jarlemai Siltstone	Jarlemai Siltstone
Kimmeridgian	Alexander Formation and Jururra Sandstone Equivalent	Alexander Formation		Callawa Formation		
Oxfordian		Wallal Sandstone	Alexander Formation		Alexander Formation ? Wallal Sandstone	
Callovian						Wallal Sandstone
Bathonian						
Bajocian						Unnamed unit
Toarcian						

times the sea had moved further inland and the marine Jarlemai Siltstone was deposited disconformably on the Wallal Sandstone in a relatively low-energy environment. During Upper Jurassic and Early Cretaceous times the regressive Broome Sandstone was deposited in a non-marine high-energy environment.

From the Early Cretaceous to the present, uplift and erosion has taken place with only very minor deposition.

HYDROGEOLOGY

AQUIFER RELATIONSHIPS

The Broome and Wallal Sandstones which comprise the main aquifers, support two flow systems that are separated by the Jarlemai Siltstone. The flow system in the Broome Sandstone is essentially unconfined, and recharge is either by direct percolation from rainfall or indirectly through the thin Tertiary or Quaternary sediments. This may take place over quite large areas. In contrast, groundwater flow in the Wallal Sandstone takes place under confined conditions and recharge from rainfall is only possible over the limited area where the Jarlemai Siltstone is absent. A limited interconnection between the two aquifer systems may occur in this area; however, elsewhere, groundwater movement in each aquifer is separate and differs markedly in direction. Thus, groundwater in the Broome Sandstone moves towards the north and is discharged into the Indian Ocean at beach seepage faces; whereas groundwater in the Wallal Sandstone moves almost westwards and probably discharges mainly as sub-ocean springs, but some minor discharges take place at springs along the coastal strip.

The Tertiary and Quaternary deposits, including the Bossut Formation, contain small groundwater storages that are probably in hydraulic continuity with the Broome Sandstone. The hydrogeology of these superficial deposits will not be discussed further as they are only of local importance for stock supplies.

BROOME SANDSTONE

Introduction

The Broome Sandstone, which reaches a thickness of up to 71 m, is the largest unconfined aquifer in this part of the Canning Basin. Recharge is by direct percolation from rainfall, and groundwater movement is generally towards the north. The water-table contour map, Figure 11, is drawn from measurements taken from private bores and wells, together with project bores which were constructed in the Broome Sandstone.

Hydraulic testing and results

Test pumping was undertaken on five single bores completed in the Broome Sandstone. As observation bores were not provided, drawdown and recovery records were only available from the pumping bores. The raw drawdown data were corrected for bore inefficiency and partial penetration effects. No dewatering correction was needed as the dewatered depth of aquifer was small when compared to the aquifer thickness.

The analytical results for the unconfined Broome Sandstone are given in Table 8. Transmissivity values varied from 138 to 854 m²/day, and averaged 325 m²/day. Hydraulic conductivity values ranged from 2.6 to 15 m/day, and averaged 7.5 m/day. The aquifer consists of a fine-to coarse-grained, moderately sorted sandstone for which the published results for similar rocks (Krumbein and Monk, 1943; Turneaure and Russell, 1947; Johnson, 1963; and Lovelock, 1970) suggest a hydraulic conductivity of between 5 and 15 m/day. The average values for transmissivity and hydraulic conductivity therefore appear to be of the correct order.

TABLE 8. GENERAL BORE INFORMATION AND TEST PUMPING RESULTS

Bore	Saturated aquifer thickness (m)	Pumping test discharge (m³/day)	Corrected drawdown at 1 hour (m)	Transmissivity (m²/day)	Hydraulic conductivity (m/day)
16B	34·2	393	1·91	222	6·5
17B	56·9	632	0·85	854	15
21B	19·9	29·4	0·05	159	8·0
22B	53·1	626	3·10	138	2·6
25D	48·1	735	1·27	250	5·2
Average	....	....	....	325	7·5

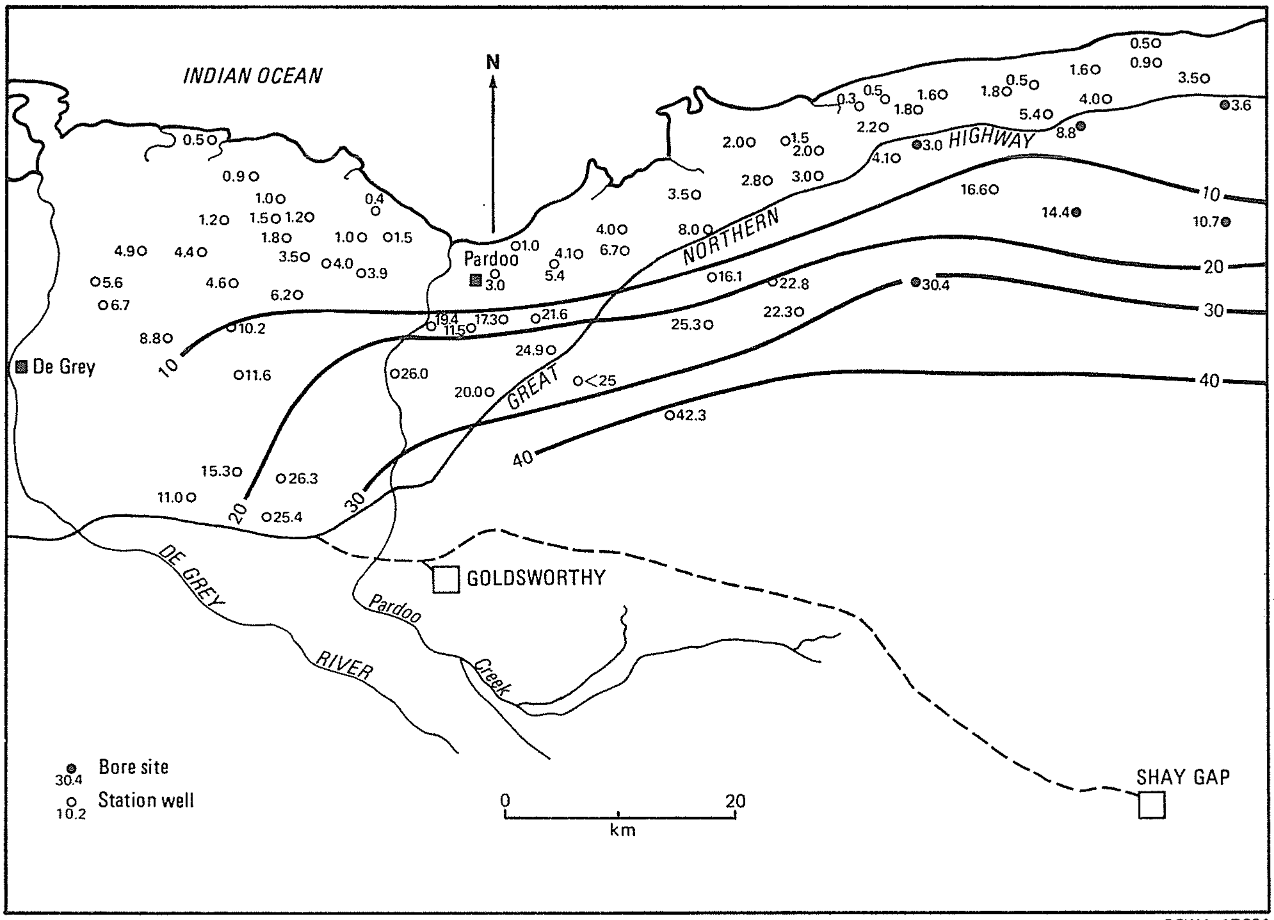


Figure 11 Water-table contours, measured on 24th August 1977 – mAHD (Contour interval 10m).

The specific yield of the Broome Sandstone aquifer could not be determined as observation bores were not installed in the cones of depression of the pumping bores.

Storage

The groundwater stored in the Broome Sandstone (Q_s) can be estimated as the product of the saturated volume (V) and the specific yield (S_y). The volume is the product of the aquifer's areal extent and the average saturated thickness. These parameters have been estimated from known geological and hydrological data to be 1 575 km² and 20 m respectively. As a specific yield could not be calculated from test pumping a value of 0.1 has been adopted for this calculation. Thus:

$$Q_s = VS_y$$
$$Q_s = 1575 \times 10^6 \times 20 \times 0.1$$
$$= 3.2 \times 10^9 m^3$$

Throughflow

The rate of throughflow in the Broome Sandstone aquifer at the 10 m water-table contour (Fig. 11) may be calculated from the following version of the Darcy equation:

$$Q = Kbil$$

where Q is the throughflow (m³/year)
K is the hydraulic conductivity (m/day)
b is the saturated aquifer thickness (m)
i is the hydraulic gradient (dimensionless)
and l is the length of section (m)

The average hydraulic conductivity of 7.5 m/day has been derived from pumping-test results and by considerations of the aquifer lithology. The hydraulic gradient has been estimated from Figure 11 as the average of the shallowest and steepest gradients and is 2.5×10^{-3}; and the aquifer width is taken as the length of the 10 m contour (Fig. 3), which is 100 km. The mean saturated thickness along the 10 m contour was derived from this contour and the contours on the base of the Broome Sandstone, and is 29.3 m. Therefore:

$$Q = 7.5 \times 29.3 \times (2.5 \times 10^{-3}) \times 100 \times 10^3 \times 365$$
$$= 20 \times 10^6 \ m^3/year$$

This annual throughflow volume represents about 0.6 per cent of the aquifer storage calculated above.

Hydrochemistry

The isohalines for the unconfined aquifers including the Broome Sandstone, the Bossut Formation and superficial deposits are shown in Figure 12. Salinities in the Broome Sandstone east of drill line 2 are less than 1 000 mg/L, but to the west rise to more than 3 000 mg/L. Salinities from wells constructed in the coastal dunes are generally less than 2 000 mg/L. Further inland, on the coastal plain, salinities from the alluvium rise appreciably and may reach 15 000 mg/L. This may be due to a high soil salt content caused by a Holocene high sea level.

In general the concentrations of total soluble salts and the common ions in water from the Broome Sandstone make it acceptable for domestic use.

However, the nitrate ion is commonly present in greater concentrations than the recommended limit of acceptance in Australia (Hart, 1974) of 23 mg/L, and that set by the World Health Organization (1971) of 45 mg/L.

WALLAL SANDSTONE

Introduction

The Wallal Sandstone occurs in the subsurface over most of the area, and consists of a fine- to very coarse-grained, poorly to well sorted, unconsolidated sandstone. This aquifer provides large artesian flows from bores drilled into it along the coastal plain, where positive heads in excess of 30 m have been measured. The potentiometric contours for this aquifer (Fig. 13) indicate that recharge takes place in the southeast and that groundwater movement is to the west and northwest. Recharge is by infiltration of rainfall south of the Jarlemai Siltstone subcrop where the aquifer becomes unconfined, and to the southeast outside the investigation area. Groundwater discharge is mainly offshore towards the northwest except for a few small springs in the Pardoo area (Fig. 13).

Hydraulic testing and results

Pump or flow tests were conducted on 18 bores screened in the Wallal Sandstone. Only one test was successfully completed with an observation bore. Drawdown data from each test were corrected for bore inefficiency and in some cases for barometric pressure changes.

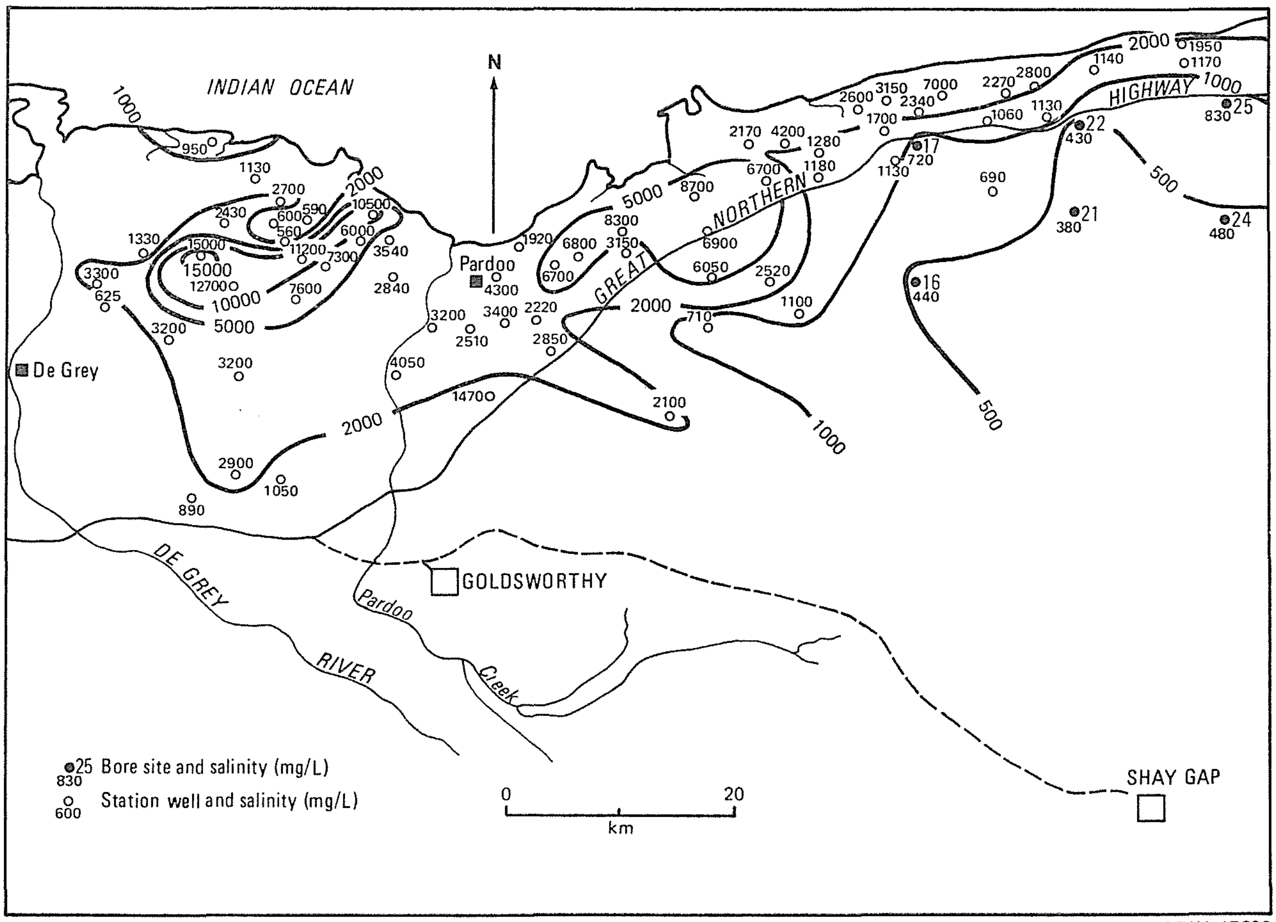


Figure 12 Isohalines in the unconfined aquifers (mg/L T.D.S.).

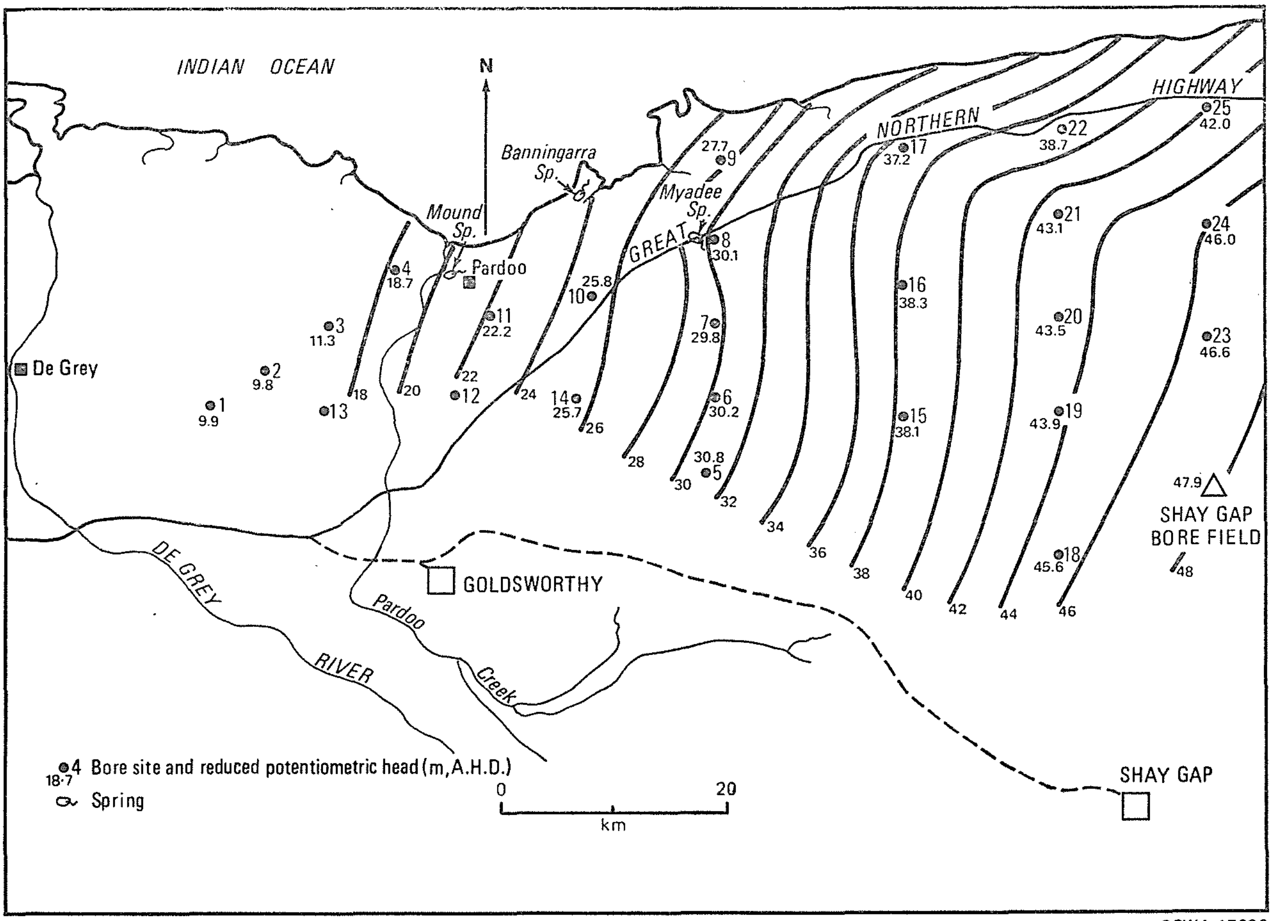


Figure 13 Wallal Sandstone potentiometric contours 13th May 1977 (contour interval 2m).

Analytical results for the confined Wallal Sandstone aquifer are given in Table 9. Transmissivity values range from 10 to 2 490 m²/day and average 340 m²/day. The corresponding range of hydraulic conductivity values is 0.6 to 138.3 m/day, and the average is 18.5 m/day (Table 9).

TABLE 9. PUMP AND FLOW TEST RESULTS FROM THE WALLAL SANDSTONE AQUIFER

Bore	Bore status	Aquifer thickness (m)	Screen length (m)	Discharge* (m^3/day)	Transmissivity† (m^2/day)	Hydraulic conductivity (m/day)	Storage coefficient
3A	Pump	35	18	614	145	8·1	
4A	Flow	42	42	199	69	1·6	
6A	Pump	28	24	650	129	5·4	
7A	Pump	62	24	641	204	8·5	
8A	Flow	14	12	1 464	40	3·3	
8B	Flow	24	18	939	104	5·8	
9D	Flow	99	18	508	10	0·6	
10A	Flow	72	42	769	272	6·5	
16A	Pump	89	15	672	145	9·7	
17A	Flow	116	24	2 100	142	5·9	
19A	Pump	96	18	532	54	3·0	
20C	Obs. bore	107	18	626	2 490	138·3	$2{\cdot}0 \times 10^{-4}$
20D	Pump	107	16·8	626	720	42·9	
21A	Flow	115	24	247	409	17·0	
22A	Flow	218	18	3 030	279	15·5	
23A	Pump	104	18	645	569	31·6	
24A	Flow	151	8·3	69	200‡	24·1	
25C	Flow	189	24	1 394	130	5·4	
Average	....	100	....	....	340	18·5	$2{\cdot}0 \times 10^{-4}$

* Discharges shown are those for the constant discharge test.
† Transmissivity values are for the screened interval only.
‡ Estimated from specific capacity calculation.

The analysis from the observation bore gave a storage coefficient of 2.0×10^{-4}.

All plots of drawdown against time showed steady-state conditions after about three minutes. These plots were matched to leaky artesian-type curves. The lithology of the Jarlemai Siltstone, a thick impermeable clayey formation, suggests that the vertical leakage from this confining bed would be too small to allow steady-state conditions to be reached in such a short time after the start of pumping. Further, the potentiometric head of the Wallal Sandstone, where it is confined, was above the water table throughout the flow and pumping tests. This means that during the test there was a potential for upward groundwater movement from the Wallal Sandstone to the confining bed. The observed respone indicates that the cone of influence has ceased expanding and that the discharge is sustained by a recharge boundary or by leakage. There is no geological or hydrological evidence to support the presence of recharge boundaries. Therefore it is concluded that the observed response results from leakage within the aquifer, caused by inhomogeneity and stratification of the sediments which together produce anisotropic conditions. This would result in greater hydraulic conductivities in a horizontal direction than occurs in the vertical. If this is the case the transmissivities derived from the analyses of hydraulic tests are applicable only for the screened interval and a corresponding mean hydraulic conductivity can be derived for that interval. This figure may then be applied to the entire aquifer thickness to derive the aquifer transmissivity.

Storage

The interstitial aquifer storage is the product of the aquifer volume and the specific yield. To derive an accurate estimate of the aquifer volume the area between adjacent isopachs of the Wallal Sandstone is multiplied by the mean thickness, and the incremental volumes are then summed to give the total volume. Table 10 shows the data required to calculate the volume of the Wallal Sandstone. The area considered is bounded on the west by line 1, on the north by the Indian Ocean, on the east by line 5, and on the south by the 20 m isopach and an east-west line from the eastern end of the 20 m isopach to line 5. This excludes the area over which the aquifer is not fully saturated and conditions are unconfined.

TABLE 10. WALLAL SANDSTONE—DATA REQUIRED TO CALCULATE THE VOLUME OF WATER HELD IN INTERSTITIAL STORAGE

Isopach interval (m)	Mean aquifer thickness (m)	Incremental area (km^2)	Incremental volume x 10^9 (m^3)
20–40	30	289·88	8·696
40–60	50	225·13	11·257
60–80	70	298·38	20·887
80–100	90	460·13	41·412
100–120	110	483·75	53·213
120–140	130	57·88	7·524
140–160	150	62·88	9·432
160–180	170	51·00	8·670
180–200	190	46·88	8·907
>200	210	123·50	25·935
Total	....	2 099·41	195·933

The specific yield was estimated to be 0.28 from laboratory experiments conducted on recompacted aquifer samples; this figure compares favourably with that quoted by Hazel (1973) of 0.27 for a medium-grained sandstone. Therefore, for estimating the volume of groundwater in storage (Q_s), specific yield (S_y) of 0.28 is adopted.

Therefore:

$$Q_s = VS_y \text{ where V is the aquifer volume}$$
$$= 195.933 \times 10^9 \times 0.28$$
$$= 54.9 \times 10^9 m^3$$

This is a very large storage, and is equivalent to approximately 275 times the annual water consumption of the Perth metropolitan supply (based on 1975-1976 figures).

Throughflow

A throughflow can be estimated for the Wallal Sandstone across the 44 m potentiometric contour using the equation Q = Kbil; the notation is given above. The mean hydraulic conductivity derived from pumping-test analyses is rounded off to 20 m/day for this calculation. The aquifer thickness along the 44 m potentiometric contour is estimated from the isopachs and Figure 13 to be 117 m, and the hydraulic gradient from Figure 13 is 4.2×10^{-4}. The length of section considered here is 58.5 km.

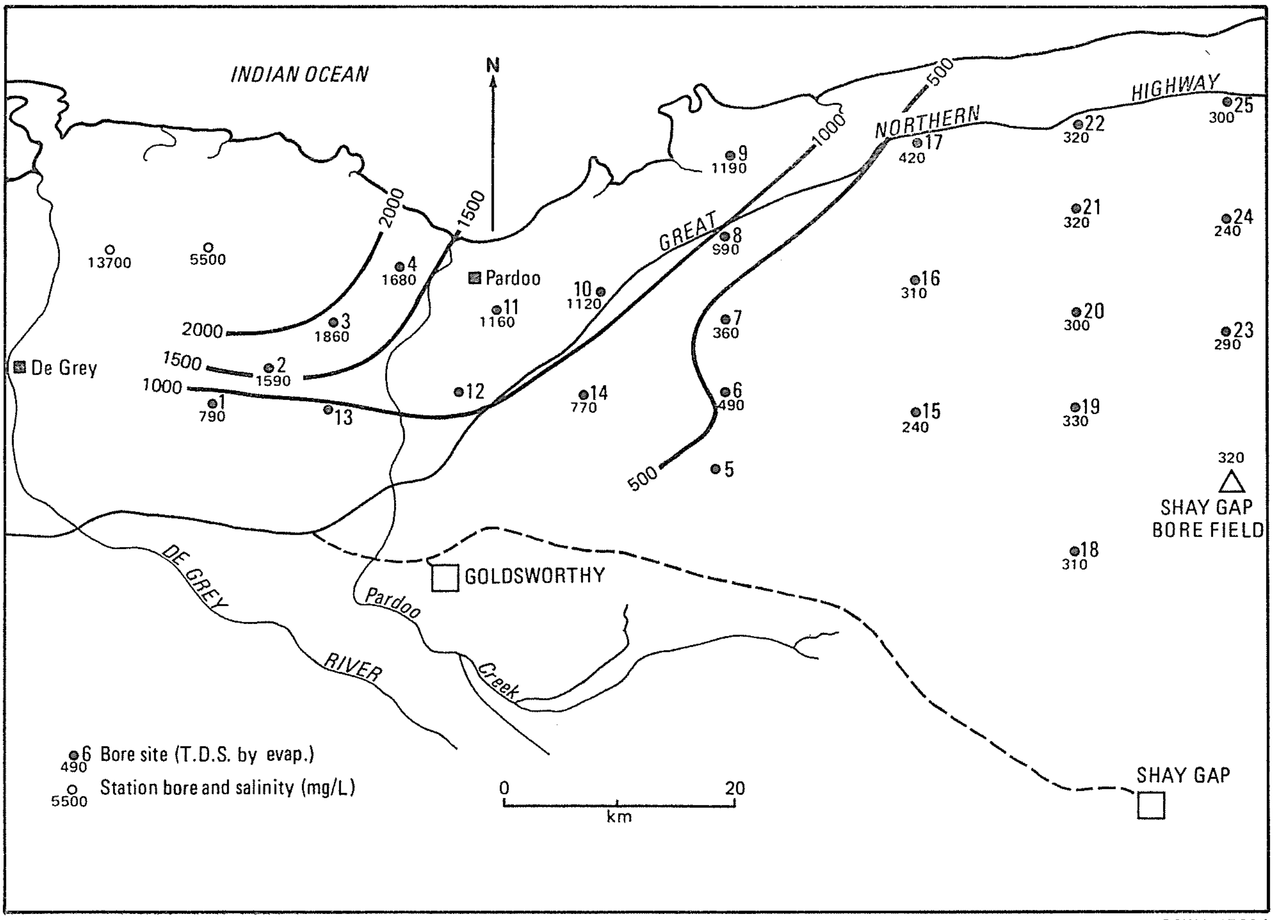
Therefore:

$$Q = 20 \times 117 \times (4.2 \times 10^{-4}) \times 58.5 \times 10^3 \times 365$$
$$= 21.0 \times 10^6 m^3/year$$

This figure for throughflow can be regarded as the annual safe yield as it must be supported by the average long-term recharge to the aquifer system.

Hydrochemistry

The isohalines for the Wallal Sandstone confined aquifer are shown in Figure 14. The salinity increases from about 300 mg/L TDS in the east to 13 700 mg/L TDS (private bore) in the extreme western part of the area. The sharp increase in salinity gradient in the west is thought to be



GSWA 17694

Figure 14 Isohalines in the Wallal Sandstone aquifer (mg/L T.D.S.).

due to the displacement of the saline water by fresher recharge water. It is not known whether the saline water was introduced during a high Quaternary sea level which encroached into the recharge area; or whether the aquifer was previously subjected to another source of saline intrusion.

The confined groundwater is a sodium-chloride type, with somewhat more bicarbonate in the east towards the recharge area. East of the 500 mg/L isohaline the groundwater quality is wholly acceptable for domestic consumption. However, a zone of high nitrate ion concentration does occur in an area bounded by the Shay Gap bore field and project sites 19 and 23. In this zone the nitrate concentration ranges from 23 to 26 mg/L; this is just above the acceptable limit for human consumption as defined by Hart (1974).

DEVELOPMENT

The Broome Sandstone and Wallal Sandstone aquifers contain large volumes of groundwater, much of which is suitable for domestic, irrigation or industrial use. The main constraints imposed on developing these aquifers are the remoteness of the area and the quality of the groundwater for a given use. If a production bore field is to be constructed it should develop both the Broome Sandstone and Wallal Sandstone aquifers. Besides more fully developing the total water resources this would have the effect of bringing the average nitrate concentration down to an acceptable level (subject to appropriate management). Production bores should be designed to intercept the throughflow by locating them parallel to the water table or potentiometric contours. Rates of abstraction should be appropriate to the throughflow in their vicinity.

CONCLUSIONS

This project has elucidated the stratigraphic sequence in the southwestern part of the Canning Basin and indicated the western limit of the Permian subcrop. It has also led to the discovery of an unnamed claystone unit of Bajocian age.

The major aquifers in the area are the Wallal and Broome Sandstones. The Wallal Sandstone has the greater volume of groundwater in storage and in general this is of better quality than that of the Broome Sandstone.

The full extent of the Wallal Sandstone has not been determined, but it is known to occur from De Grey Station to at least as far northeast as Anna Plains Station, a distance of 270 km. Groundwater quailty from this aquifer is acceptable for domestic purposes over more than half of the area, but varies from 300 mg/L in the southeast nearest the recharge area, to 13 000 mg/L at De Grey Station. This confined aquifer is a substantial resource and has a larger storage than any other known aquifer within the Pilbara and West Kimberley Regions of Western Australia.

The Broome Sandstone occurs throughout the investigation area and extends further east into the basin. Much of the groundwater stored in this formation is of marginal quality for domestic consumption by reason of its high salinity or nitrate content, but could be used for some industrial processes, or mixed with other water of lower salinity and nitrate content.

The large-scale development of groundwater resources in the Canning Basin sediments is unlikely in the near future due to its remote location. However, when major abstraction does take place it would be advantageous to utilize conjunctively the groundwater from the Wallal and Broome Sandstones.

Production borefield design and management, and the determination of recharge areas would be assisted by further exploratory drilling to the east and southeast. Further test pumping, under controlled conditions is also desirable to better quantify aquifer parameters and hence rate of underflow through the different parts of the area to be developed.

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AN OUTLINE OF THE CONFINED GROUNDWATER RESOURCES IN THE VICINITY OF PERTH, WESTERN AUSTRALIA

by A. D. Allen

ABSTRACT

Near Perth large confined groundwater resources occur in the Leederville, Yarragadee and Cockleshell Gully Formations of Mesozoic age. They have localized intake areas and receive recharge from rainfall and stream runoff via immediately overlying aquifers where confining beds are absent. The confined aquifers may be able to provide 50 to 80 x 10^6 m^3/y of groundwater with a salinity of less than 1 000 mg/L T.D.S. compared with a present yield of about 30 x 10^6 m^3/y. A more reliable assessment of the resources will be possible when drilling of the artesian monitoring network is completed.

INTRODUCTION

LOCATION AND TOPOGRAPHY

Confined (artesian) groundwater resources are being investigated for Perth's water supply on the Swan Coastal Plain between Gingin Brook in the north and

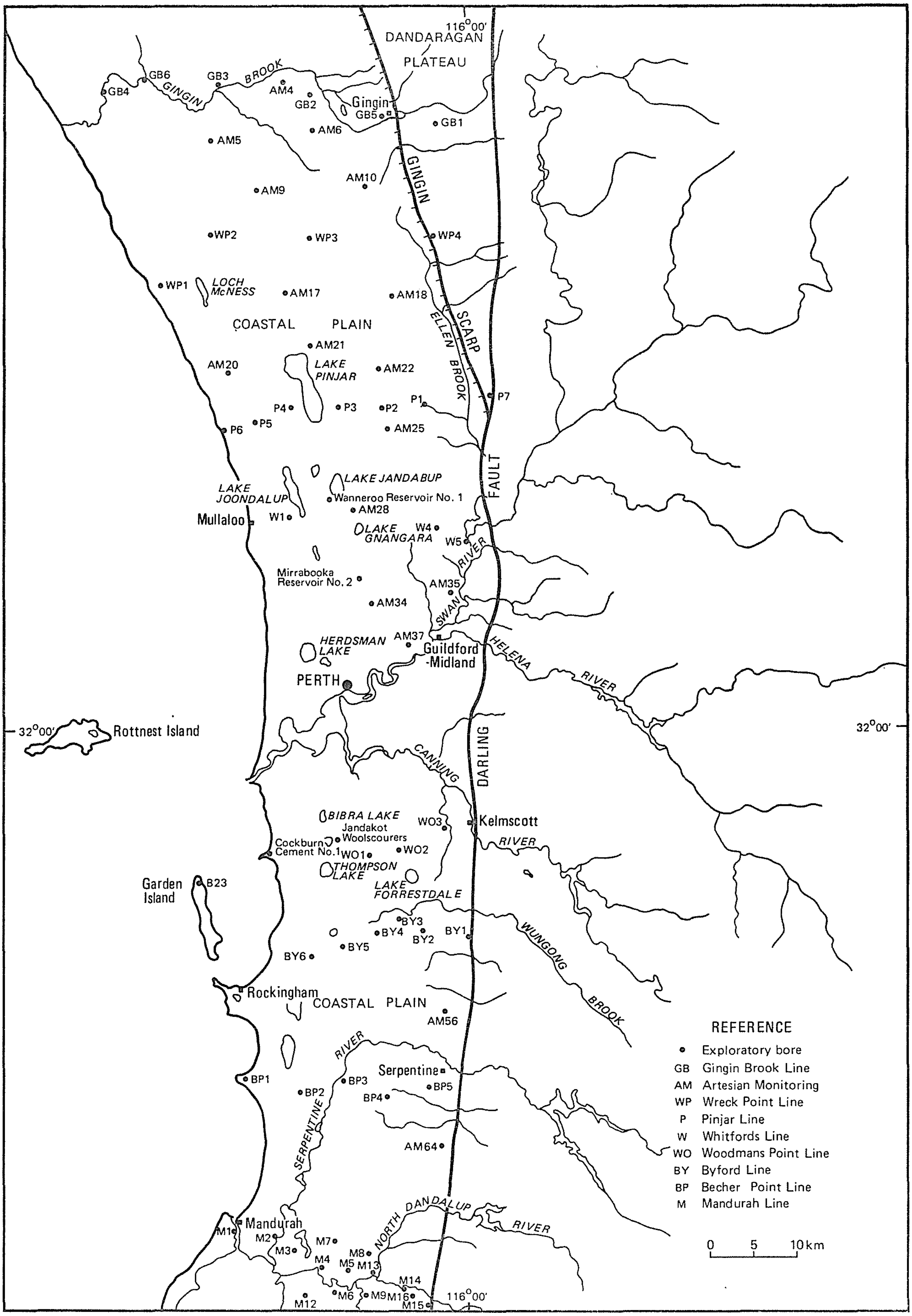

Figure 15 Locality map. GSWA 17706

the North Dandalup River in the south. The area extends for about 65 km to the north and south of Perth, averages 25 km in width and has an area of about 3 600 km^2 (Fig. 15).

For convenience the area is referred to as the Perth area, while the areas to the north and south of the Swan River are called the northern and southern Perth areas respectively.

In the northern Perth area the Swan Coastal Plain consists of a coastal belt, about 10 km wide, of dune limestone with an irregular topography. This borders a broad ridge which reaches an elevation of about 100 m in the central part of the plain and which is flanked on the east and south by extensive low-lying areas associated with the Swan River and its tributary Ellen Brook. In the southern Perth area there is also a coastal belt which borders a gentle ridge with an elevation of about 30 m in the northern half of the area. This is bordered by low-lying areas associated with the Swan, Canning and Serpentine Rivers. In the rest of the area between the Helena and Canning Rivers and the Serpentine and North Dandalup Rivers, the coastal plain rises gently to about 70 m adjacent to the Darling Scarp.

PURPOSE AND SCOPE

The purpose of this paper is to provide an interim account of the occurrence, size, and extent of the confined groundwater resources near Perth. A more comprehensive account, possibly modifying the interpretations given in this paper will be published on completion of the exploratory drilling.

HISTORY

Artesian water (from the Leederville Formation) was first discovered in the Perth area in an exploratory bore, drilled in 1871 for coal, adjacent to the Canning River near Kelmscott (Passmore, 1912). Further drilling for artesian water was discouraged by a report by Hardman (1885). Despite this report an exploratory bore was drilled at Midland Junction by the Government in 1894-95 and encountered an artesian flow at 152 m. As a result, about 40 artesian bores were drilled in Guildford, Midland and Perth between 1895 and 1905 (Maitland, 1913).

The first artesian bore for public water supply (West Perth Station Yard bore) was drilled in 1897, and subsequently up to 1932 a further 20 bores were drilled. These produced 60 to 70 per cent of Perth's water supply until the completion of Canning Dam in 1940. A further 15 artesian bores have been drilled since 1954 and others are planned.

Systematic exploratory drilling to assess the confined groundwater resources in the Perth Basin, near Perth, was commenced by the Mines Department (G.S.W.A.) in 1961, and up to 1969 four lines of deep exploratory bores had been drilled (Table 11). At about this time it was realized that the proven surface and groundwater resources were inadequate to meet Perth's projected requirements (Hillman, 1971; O'Hara, 1973). It was also recognized that there were many advantages in having a water supply based both on surface and groundwater resources; and being able to develop groundwater resources near developing areas.

To meet increasing demand the Metropolitan Water Supply Sewerage and Drainage Board (M.W.B.) commenced a comprehensive drilling programme in 1969 to evaluate the confined and unconfined groundwater resources. The confined groundwater resources have been investigated by drilling lines of deep exploratory bores as well as a network of artesian monitoring bores which are planned to be completed by 1986.

PREVIOUS WORK

There are numerous reports which give details of the first deep bores or discuss early concepts about the geology and confined groundwater resources near Perth. Most of these are of historical interest and are not reviewed, although where relevant they are cited in this paper.

The first attempt at correlating the confined aquifers was made by Forman (1933) who distinguished three distinct 'horizons' on the basis of chemical analyses and groundwater temperatures. They were the Claremont-South Perth Horizon (equivalent to the Yarragadee Formation) and the Leederville and City Horizons (equivalent to the Leederville Formation). The City Horizon contains a mixture of water from *both* the Leederville and Yarragadee Formations; hence it was mistakenly thought to be a separate unit.

Pudovskis (1962) correlated the deep water bores with the established stratigraphy. He gave an interpretation of the structure and recognized that the Kings Park Formation filled a deep channel.

Subsequently, the most important information is given in the descriptions of the various deep drilling projects: Byford Line (Berliat, 1964), Pinjar Line (Whincup, 1966), Gingin Brook Line (Sanders, 1967), Mandurah Project (Commander, 1974), Becher Point Line (Allen, 1978), and in a general account of the hydrogeology of the Perth area by Allen (1975).

DATA

Since 1895 about 50 bores over 300 m deep and 400 bores 90 to 300 m deep have been drilled for public water supply, irrigation and exploratory projects.

The main data from the early bores are drillers' logs, head measurements, water analyses, and a few samples. Gamma logs are also available from some of these bores that are still accessible.

Geophysical logs (gamma ray, long and short normal resistivity and others), sludge samples, conventional cores and sidewall cores have been obtained from all recent exploratory and production bores. These logs, together with palaeontological results from the cores, have been used to delineate the major aquifers and to make estimates of the salinities of the groundwater that they contain.

Chemical analyses of groundwater from the production and observation bores have been made and monthly head measurements from the observation bores have been measured and are recorded in the M.W.B. computerized groundwater levels retrieval system.

GEOLOGY

SETTING

The Perth area is situated on the eastern onshore edge of the Perth Basin (Playford and others, 1976). It is underlain by more than 10 000 m of sedimentary rocks

TABLE 11. SUMMARY OF EXPLORATORY DRILLING PROJECTS

Project	Commenced	Completed	Authority	No. of bores	Range of depth (m)	Aggregate depth (m)	Remarks
Byford Line	1961	1963	G.S.W.A.	6	183–265	1 351	One bore used for observation
Mandurah Project	1961	1969	G.S.W.A.	18	96–610	3 920	Exploratory project to locate Mandurah water supply
Pinjar Line	1964	1965	G.S.W.A.	7	348–699	3 839	Bores abandoned
Gingin Brook Line	1965	1966	G.S.W.A.	6	522–796	3 982	Bores abandoned
Whitfords Line	1973	1975	M.W.B.	8	90–800	3 298	Three sites; incorporated data from existing bores; observation bores in major aquifers
Woodmans Point Line	1975	1976	M.W.B.	8	67–800	3 196	Three sites; incorporated data from existing bores; observation bores in major aquifers
Becher Point Line	1976	1977	M.W.B.	10	71–810	4 588	Five sites; observation bores in major aquifers
Artesian Monitoring Network	1976	Continuing	M.W.B.	17	116–623	6 852	Sixty-eight sites proposed; observation bores in major aquifers
Wreck Point Line	1977	1977	M.W.B.	6	165–839	3 720	Four sites; observation bores in major aquifers

separated by the Darling Fault from crystalline rocks of the Darling Scarp. The area overlies the southern end of the Dandaragan Trough, a major structural subdivision within the basin.

STRATIGRAPHY

The sequence of formations in the Perth area has been established from deep water bores, regional geological mapping and oil exploration. Those formations occurring within the upper 1 000 m of the basin and which may contain, or affect the occurrence of, low-salinity confined groundwater are given in Table 12, together with a summary of their lithology and groundwater potential.

Formation into the Cockleshell Gully and Yarragadee Formations at sites where the South Perth Shale is thin or was not deposited.

Confined groundwater may be found locally in all the formations on the coastal plain. However, in this paper only the major aquifers in the Mesozoic formations are described.

The formations containing major confined groundwater resources are, in descending order, the Leederville, Yarragadee and Cockleshell Gully Formations. The formations are multilayer aquifer systems composed of interbedded sandstone, siltstone and shale and are separated from one

TABLE 12. NEAR-SURFACE STRATIGRAPHIC SEQUENCE—PERTH AREA

Formal age		Group	Formation	Maximum thickness m)	Lithology	Groundwater potential
Cainozoic	Quaternary–Late Pleistocene	Kwinana	Various	90	Sand, limestone, clay	Major non-artesian aquifer
			UNCONFORMITY			
	?Quaternary		Rockingham Sand	110	Sand	Non-artesian aquifer
			UNCONFORMITY			
	Early Tertiary		Kings Park Fm	240	Siltstone, shale, minor sand	Confining bed
			UNCONFORMITY			
Mesozoic	Late Cretaceous	Coolyena	Poison Hill Greensand	?10	Glauconitic sand, minor silt	Minor aquifer
			Gingin Chalk	55	Chalk—fossiliferous and glauconitic	Confining bed
			Molecap Greensand	?20	Glauconitic sand	Minor aquifer
			Osborne Fm	160	Glauconitic shale and siltstone; minor sand	Major confining bed; local aquifers near base
			?UNCONFORMITY			
	Early Cretaceous	Warnbro	Leederville Fm	300	Sandstone, siltstone, shale	Major artesian aquifer
			South Perth Shale (incl. Gage Sandstone member)	300	Shale, siltstone, minor sand at base	Major confining bed; minor aquifer at base
			UNCONFORMITY			
	Early Cretaceous–Early Jurassic		Yarragadee Fm	2 000	Sandstone, siltstone, shale	Major artesian aquifer
	Middle Jurassic		Cadda Fm	?350	Shale, siltstone	Confining bed, not definitely known
	Early Jurassic		Cockleshell Gully Fm	2 000	Sandstone, siltstone, shale	Local artesian aquifer

STRUCTURE

The Cockleshell Gully and Yarragadee Formations have a regional dip to the east. They have been extensively faulted and occur as a complex set of fault blocks.

The Warnbro and Coolyena Groups rest unconformably on the Cockleshell Gully and Yarragadee Formations. They appear to occupy synclinal basins which have been controlled by subsidence rather than by folding. The largest of these is the Swan Syncline separated by the Pinjar Anticline from the Yanchep Syncline (Fig. 16). The structures have a northeast-southwest trend and are not known to be faulted.

The Kings Park Formation is flat-lying and occupies deep channels (probably related to former positions of the Perth Canyon) locally eroded, to a depth of about 550 m below sea level, through the Coolyena and Warnbro Groups into the underlying Yarragadee Formation.

The Rockingham Sand also occupies channels eroded into the Kings Park Formation and the Coolyena and Warnbro Groups.

The flat-lying Kwinana Group rests unconformably on the post-Early-Cretaceous formations. It conceals them, so that the distribution and nature of the underlying formations have to be obtained by geophysical methods or from boreholes.

The subcrop of the various formations beneath the Kwinana Group, and sections illustrating the structure are given in Figure 16.

HYDROGEOLOGY

RELATIONSHIP OF AQUIFERS

The Perth area has an annual rainfall of about 865 mm. This, together with local run-off from the Darling Scarp and areas to the east, maintains regional bodies of unconfined groundwater in the Kwinana Group (Allen, 1976). From these, infiltration takes place into the Leederville Formation at sites controlled by the topography and the geological structure, and in turn from the Leederville another by thick confining beds formed by the Osborne Formation and South Perth Shale. They may be in hydraulic interconnection as a result of erosion, faulting, or non-deposition at recharge and discharge areas but elsewhere they form discrete flow systems.

The groundwater in the formations is under pressure except locally at the intake. In low-lying areas, especially near the major rivers, flowing artesian bores may be encountered.

LEEDERVILLE FORMATION

Description of aquifer

The Leederville Formation is a predominantly non-marine formation becoming marine in the southwestern part of the area. It is up to 300 m thick and consists of sandstone, siltstone and shale. Beds of conglomerate are common in the formation near the Darling Scarp, and in its marine facies it contains some limestone and glauconitic sand. The lenticular beds of sand in the formation usually do not exceed a thickness of 10 m and do not persist over large areas. They comprise about half the formation and vary considerably in sorting, grain size, and clay content.

In hydraulic connection and included within the aquifer are beds of glauconitic sand locally present at the base of the Osborne Formation.

The aquifer system may be confined above by thick shales and siltstones of the Osborne Formation and below by the South Perth Shale. The aquifer extends throughout the coastal plain except near the Swan Estuary where it has been eroded out prior to deposition of the Kings Park Formation.

The Leederville Formation subcrops beneath the Kwinana Group over about half of the coastal plain where the Osborne Formation has been removed by erosion (Fig. 16). In these areas it is in direct contact and hydraulic connection with the Kwinana Group.

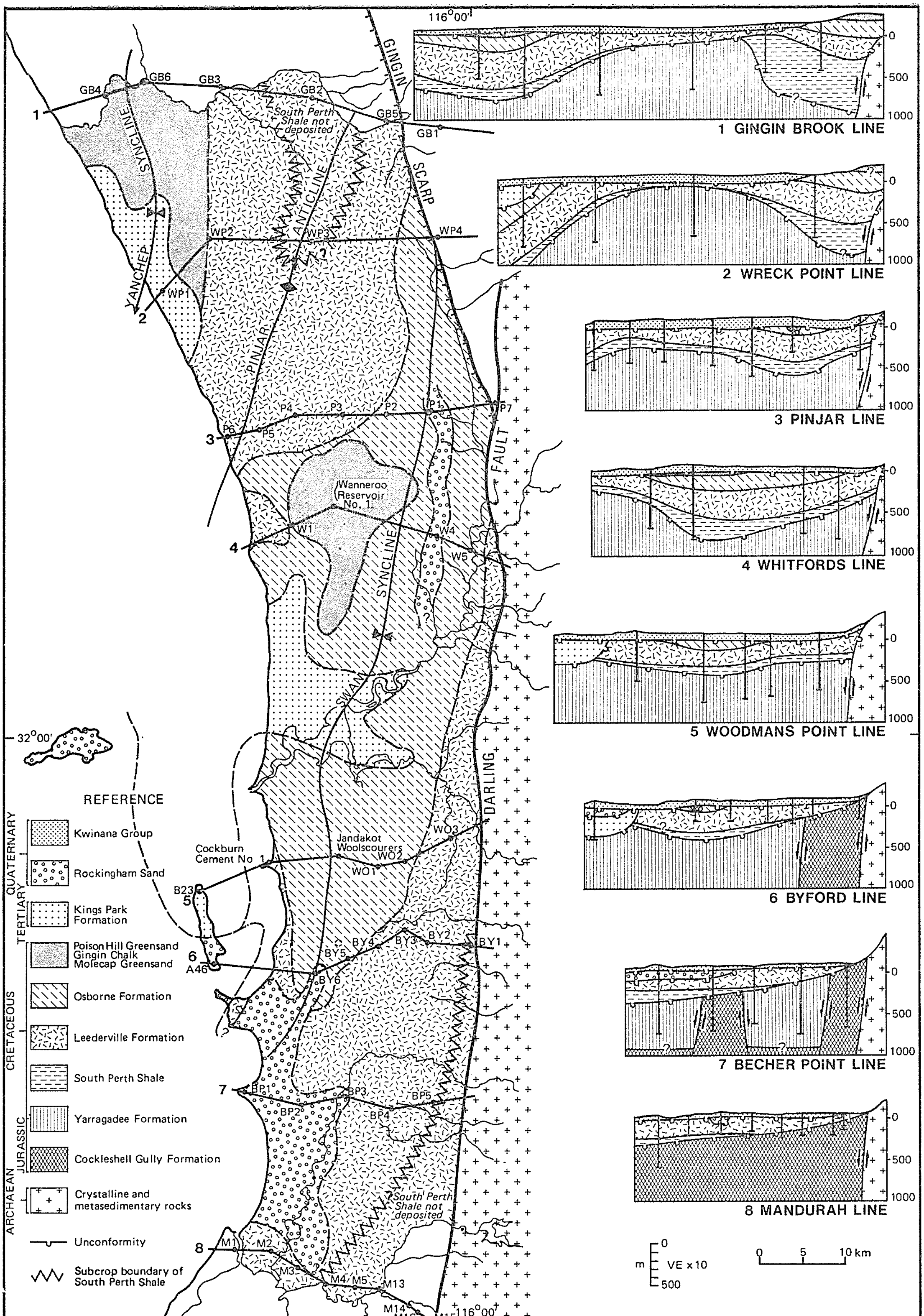

Figure 16 Subcrop map and sections. GSWA 17707

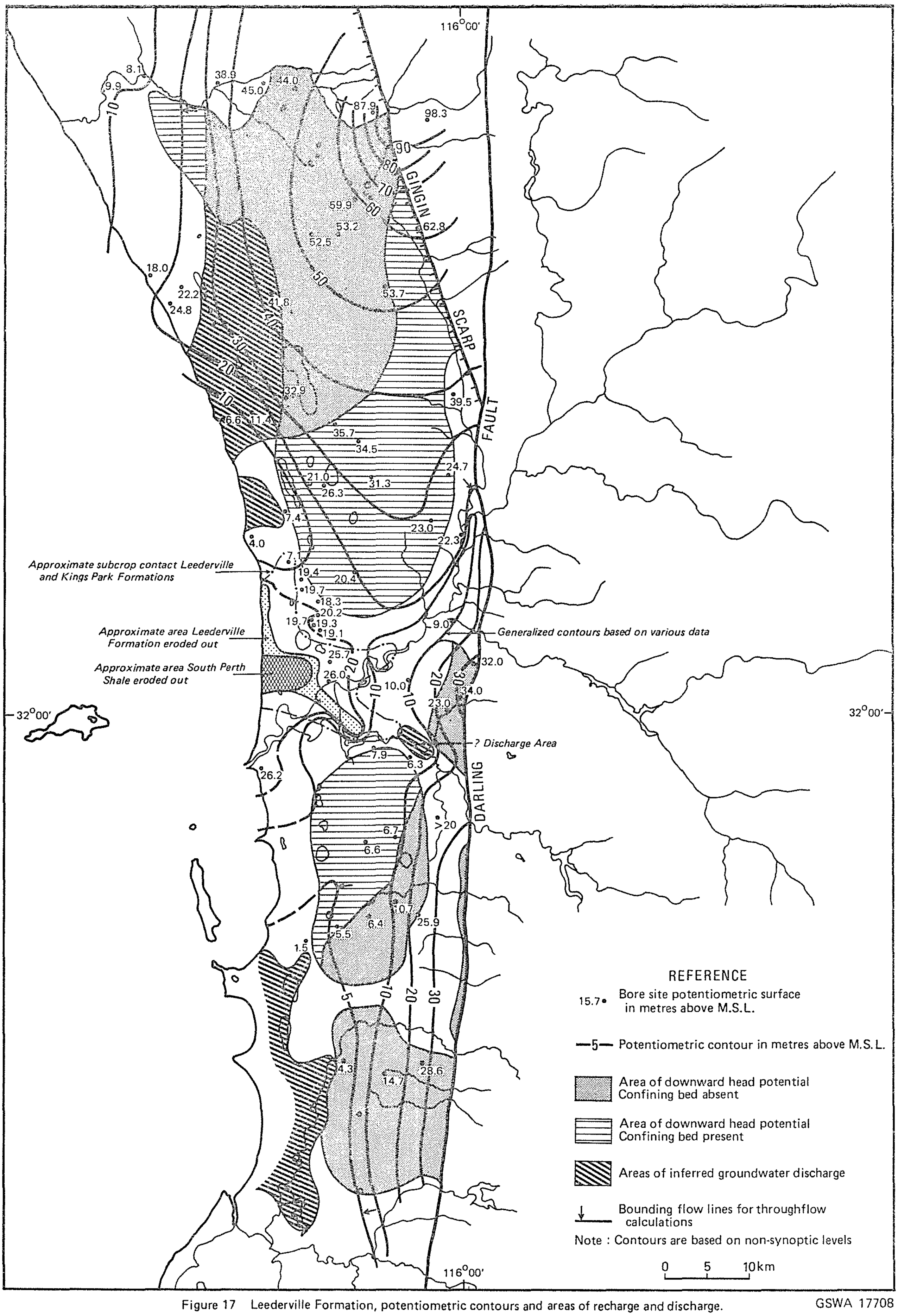

Figure 17 Leederville Formation, potentiometric contours and areas of recharge and discharge. GSWA 17708

On the crest of the Pinjar Anticline in the northern Perth area, and along the foot of the Darling Scarp in the southern Perth area (where the South Perth Shale was not deposited) it is in direct contact with the Yarragadee or Cockleshell Gully Formations (Fig. 31 Sections).

Recharge

Recharge to the formation is from the overlying Kwinana Group. The main recharge areas have been identified by overlaying the water table map for the Kwinana Group (Allen, 1976), potentiometric contours for the Leederville Formation, and the subcrop map. In the northern Perth area these occur in the northern central part of the coastal plain (600 km^2) and in the southern Perth area near the Darling Scarp (420 km^2). Small streams debouching on the Coastal Plain in the vicinity of Gingin and Serpentine may also provide recharge (Fig. 17). Other recharge occurs by upward leakage of groundwater from the Yarragadee Formation where the South Perth Shale has been eroded out near Perth. This is evident from equalized pressures in the two formations (Figs. 17 and 18) and from the chemical composition and temperature of groundwater from the Leederville Formation (Parr, 1927; Forman, 1933).

Reliable estimates of the recharge are not yet possible. In the northern Perth area the groundwater throughflow past the 20 m isopotential contour is estimated to be 75×10^6 m^3/y assuming half the formation is sand with an hydraulic conductivity of 10 m^2/d. Based on the same assumptions, groundwater flow past the 5 m contour in the southern Perth area is about 40×10^6 m^3/y. These estimates are considerably greater than would be expected from rainfall infiltration over the known recharge areas, suggesting that local streams may contribute substantially to recharge.

Storage

The area, thickness, and proportion of sand in the formation indicate that a very large volume of groundwater of variable quality is in storage within the aquifer. From isopachs of the formation (not given) the volume of the formation is estimated to be $650\,000 \times 10^6$ m^3. Assuming that half of this is sand with a specific yield of 0.10 then the volume of groundwater in storage in the formation is about $33\,000 \times 10^6$ m^3 of which about a third, $11\,000 \times 10^6$ m^3, may have a salinity less than 1 000 mg/L T.D.S.

Movement

The isopotential map (Fig. 17) indicates that groundwater flow is generally westward except near Perth and along the Swan River where there is eastward flow toward apparent discharge areas along the Swan and Canning Rivers. The configuration of the potentiometric surface is not well known in these areas and other interpretations may be possible.

The head in the aquifer system has a seasonal fluctuation of 1.5 m to 7.5 m. It is lowest in April-May and highest in October-November.

Discharge

Groundwater discharge from the Leederville Formation (Fig. 17) probably occurs between Lake Pinjar and Loch McNess, and near Mullaloo where the Osborne Formation has been removed by erosion and there is an upward head potential between the otherwise confined groundwater, and unconfined groundwater in the Kwinana Group. Other apparent discharge areas occur along the Swan valley near the Darling Scarp and in the vicinty of the Canning River. The most likely sites are at the contact between the Osborne Formation and Leederville Formation (Fig. 16). The apparent discharge area along the Canning River coincides with a notable area of saline groundwater in the Kwinana Group (Allen, 1976).

Groundwater discharge also takes place where the Rockingham Sand is deposited in a deep channel incised into the formation between Rockingham and Mandurah (Fig. 16, Section 7).

Artesian flows can be obtained along the lower areas associated with the Swan and Canning Rivers; the depression containing the linear lakes between Lake Joondalup and Loch McNess; and between Wungong Brook and Serpentine River.

Quality

Groundwater in the Leederville Formation ranges in salinity from about 180 to 3 000 mg/L T.D.S. The groundwater salinity is lowest at the intake areas and increases with depth and distance from these areas.

TABLE 13. SELECTED WATER ANALYSES

Bore Name	Chemical Lab. number	Sampling date	Conductivity mS at 20°C	pH	Turbidity APHA units	Colour HAZEN units	Odour	milligrams per litre																					
								Free CO_2	T.D.S. Evap.	T.D.S. Cond.	Total hardness as $CaCO_3$	Total alkalinity as $CaCO_3$	Ca	Mg	Na	K	HCO_3	CO_3	SO_4	Cl	NO_3	SiO_2	Fe	Mn	Cu	Pb	As	F	B	P
YARRAGADEE FORMATION																														
Whitfords No. 1	2335/75	5/2/75	340	9·0	10	<10	Oily	Nil	210	220	65	125	16	6	46	9	134	9	3	34	<1	18	·05	<·05	<·05	<·02	<·02	0·2	·10	·28
Mt. Yokine No. 1	6377/74	....	1 300	8·2	....	....	Nil	....	780	780	41	150	10	4	274	10	183	Nil	23	337	<1	19	·49	<·05	....	....	....	0·6	....	·28
Balcatta No. 1	6376/74	....	1 060	8·2	....	....	Nil	....	640	640	51	153	12	5	219	9	186	Nil	18	260	<1	21	·10	<·05	....	....	....	0·6	....	·10
Woodman Point No. 3	16524/76	14/7/76	5 450	7·5	<5	<5	Nil	17	3 000	3 490	203	273	30	31	1 070	32	332	Nil	144	1 520	<1	15	·15	<·05	<·02	<·01	<·01	1·3	<·05	·70
LEEDERVILLE FORMATION																														
Wanneroo No. 25	7961/73	12/4/73	700	6·6	<5	<10	Nil	28	420	490	91	57	17	12	113	10	70	Nil	25	190	<1	17	2·4	·15	<·05	<·02	<·02	0·2	·4	·23
Gwelup No. 135	13606/73	19/7/73	870	6·5	<5	<10	Nil	32	540	610	128	53	25	16	135	11	64	Nil	21	255	<1	19	13	·15	<·05	<·02	<·02	0·2	<·1	·01
Mounts Bay No. 1	4626/73	28/2/73	2 310	7·6	....	....	Nil	....	1 350	....	135	160	31	14	465	16	195	Nil	37	683	<1	18	·10	....	....	....	....	0·5	....	·01
Woodman Point No. 3	16042/76	8/7/76	400	6·5	<5	<5	Nil	41	230	260	31	65	4	5	66	4	79	Nil	8	75	<1	43	4·4	·28	<·02	<·01	<·01	0·1	·04	·14

The groundwater usually contains dissolved iron (0.2-15.0 mg/L) and may also contain manganese, both of which may require treatment before the water can be used for public water supply. Four selected analyses of groundwater from the Leederville Formation are given in Table 13.

The temperature of the groundwater in the Leederville Formation varies from 23.0 to 32.0°C. It shows a general increase with depth but is warmest near Perth as a result of mixing with warm water from the Yarragadee Formation.

Development

There are currently 15 M.W.B. production bores in the formation and about 400 private bores, principally in low-lying areas such as the Swan Valley where large supplies of unconfined groundwater are not available. The formation is about 100 m to 300 m deep through most of the Perth area. Bores in it are usually constructed to produce moderate to large supplies for public water supply, reticulation of public reserves, irrigation and industry. Annual usage varies with the seasonal conditions but is estimated to average about $18 \times 10^6 m^3/y$, of which about $10 \times 10^6 m^3/y$ are pumped by the M.W.B.

The present abstraction is only about 15 per cent of the estimated throughflow and consequently production from the aquifer could be considerably increased.

YARRAGADEE FORMATION

Description of aquifer

The Yarragadee Formation is about 2 000 m thick. It consists of non-marine interbedded sandstone, siltstone and shale. The beds of sandstone are frequently up to 30 m thick and usually consist of medium to very coarse, feldspathic, subangular weakly-cemented sand. The formation also contains thick pyritic and micaceous siltstone as well as thin-bedded sections of rapidly alternating sandstone and siltstone.

The discontinuous Gage Sandstone Member at the base of the South Perth Shale contains groundwater in hydraulic connection with the Yarragadee Formation and for this reason is considered as part of the Yarragadee aquifer system.

Groundwater in the formation is possibly confined below by the Cadda Formation, and is confined above by the South Perth Shale. It is in hydraulic continuity with groundwater in the Leederville Formation where the South Perth Shale is absent on the crest of the Pinjar Anticline, and adjacent to the Darling Scarp in the southern Perth area. In the latter area there is probably also hydraulic continuity between adjacent fault blocks of the Yarragadee and Cockleshell Gully Formations.

The Yarragadee Formation extends throughout the Perth area at a depth of 200 m to 500 m below sea level, except in part of the southern Perth area, where it has been removed by erosion (Fig. 18).

Recharge

Recharge to the Yarragadee Formation is by downward leakage from the Leederville Formation where the South Perth Shale is absent. The approximate extent of the intake areas was determined by overlaying the isopotential maps for the Yarragadee and Leederville Formations and comparing them with the known extent of the South Perth Shale. The only intake area that has been identified is approximately 80 km² on the crest of the Pinjar Anticline (Fig. 18). In this area groundwater throughflow past the 40 m isopotential is about $13 \times 10^6 m^3/y$, assuming the low-salinity groundwater occurs in the upper 200 m of the aquifer, and that half the formation was sand with an hydraulic conductivity of $10 m^2/d$. This throughflow appears too large to result only from recharge over the intake area, and presumably some of the groundwater is derived from further north or from recharge by local streams.

Storage

There is insufficient data to estimate the very large volume of groundwater in storage in the Yarragadee Formation. Most of this groundwater is brackish except in the northern Perth area where the upper 200 m (Whincup, 1966) of the Yarragadee Formation over an area of about 750 km² contains groundwater with a salinity less than 1 000 mg/L T.D.S. Assuming that half the formation is sand with a specific yield of 0.10 then the volume of groundwater in storage less than 1 000 mg/L T.D.S. is about $7\,500 \times 10^6 m^3$.

Movement

The regional groundwater movement is toward the south-west (Fig. 18). The configuration of the potentiometric surface near Perth is uncertain but does not appear to reflect any major lowering of the potentiometric surface resulting from pumping or discharge into the Leederville Formation.

The potentiometric surface is generally 5 m to 25 m higher in the northern Perth area than in the southern Perth area reflecting the effect of the regional topography. In the southern Perth area the potentiometric surface has a very low gradient, probably reflecting slow rates of recharge and a high transmissivity for the formation (Allen, 1978).

The potentiometric surface varies in phase with the rainfall. It reaches its lowest level in March-April and highest level in September-October. Under natural conditions it may vary seasonally by about 5 m.

Discharge

The chemical composition and temperature of the groundwater (Forman, 1933) together with equalization of potentiometric heads between the Yarragadee and Leederville Formations near Perth (Figs. 17 and 18) indicate that groundwater discharge takes place possibly along preferred paths around the contact with the Kings Park Formation where the South Perth Shale has been eroded away.

Groundwater discharge may also occur offshore. A large submarine spring reported at 'Fish Rock' or 'The Dummies' on the Fremantle side of the Parmelia Bank near Woodman's Point (Christie, 1912a, b) may be a discharge site. The spring is reputed to have been seen disturbing the surface of the sea between 1879 and 1907 and to have ceased flowing as a result of pumping artesian bores around Perth. Its reported location is close to the inferred contact with the Kings Park Formation.

A hot 'spring' formerly located on the foreshore of the Swan River near Sunset Men's Home in Dalkeith resulted from the escape of groundwater from a bore completed in the Yarragadee Formation. The bore was drilled in 1908 and was finally plugged in 1956.

Flowing artesian bores can be expected at most sites with an elevation less than 25 m R.L., with the exception of parts of the southern Perth area.

The upward head differential between the Yarragadee and Leederville Formations has caused some interaquifer flow within boreholes. Changes in salinity described by Parr (1927) occurring in Loftus Street No. 1 and No. 2 bores may be attributed to this, as well as variations in salinity observed in Mounts Bay No. 1 bore.

Quality

Groundwater in the Yarragadee Formation ranges in salinity from 120 to 7 500 mg/L T.D.S. with an average salinity of about 3 000 mg/L T.D.S. Groundwater with a salinity less than 1 000 mg/L is restricted to the northern Perth area in a poorly defined strip extending from about Perth northwards to near Gingin. The distribution of the low-salinity groundwater may result from a preferred flow path between the intake area and the discharge area near Perth.

The low-salinity groundwater occurs in the upper 200 to 500 m of the formation. The lowest salinity groundwater obtained is 120 mg/L T.D.S. from near Lake Pinjar. This is the lowest salinity groundwater known from any aquifer in the Perth area and may be groundwater recharged during past conditions of higher rainfall.

In offshore oil exploration wells and beneath Rottnest Island the groundwater in the formation is believed to have a salinity of 7 500 to 60 000 mg/L T.D.S. (Playford and Leech, 1977).

Unlike groundwater from the other major aquifers in the Perth area the groundwater from the Yarragadee Formation usually has a very low concentration of dissolved iron and does not require treatment. Selected analyses from the Yarragadee Formation are given in Table 13.

The temperature of groundwater from the formation ranges from 21° to 44°C. It is warmest in the vicinity of Perth and coolest in bores of the Becher Point Line in the southern Perth area.

Development

The depth at which the Yarragadee Formation occurs, and legislation restricting depth of bores to 150 m below sea level in the Metropolitan area, have ensured that the formation is mainly used for public water supply. The

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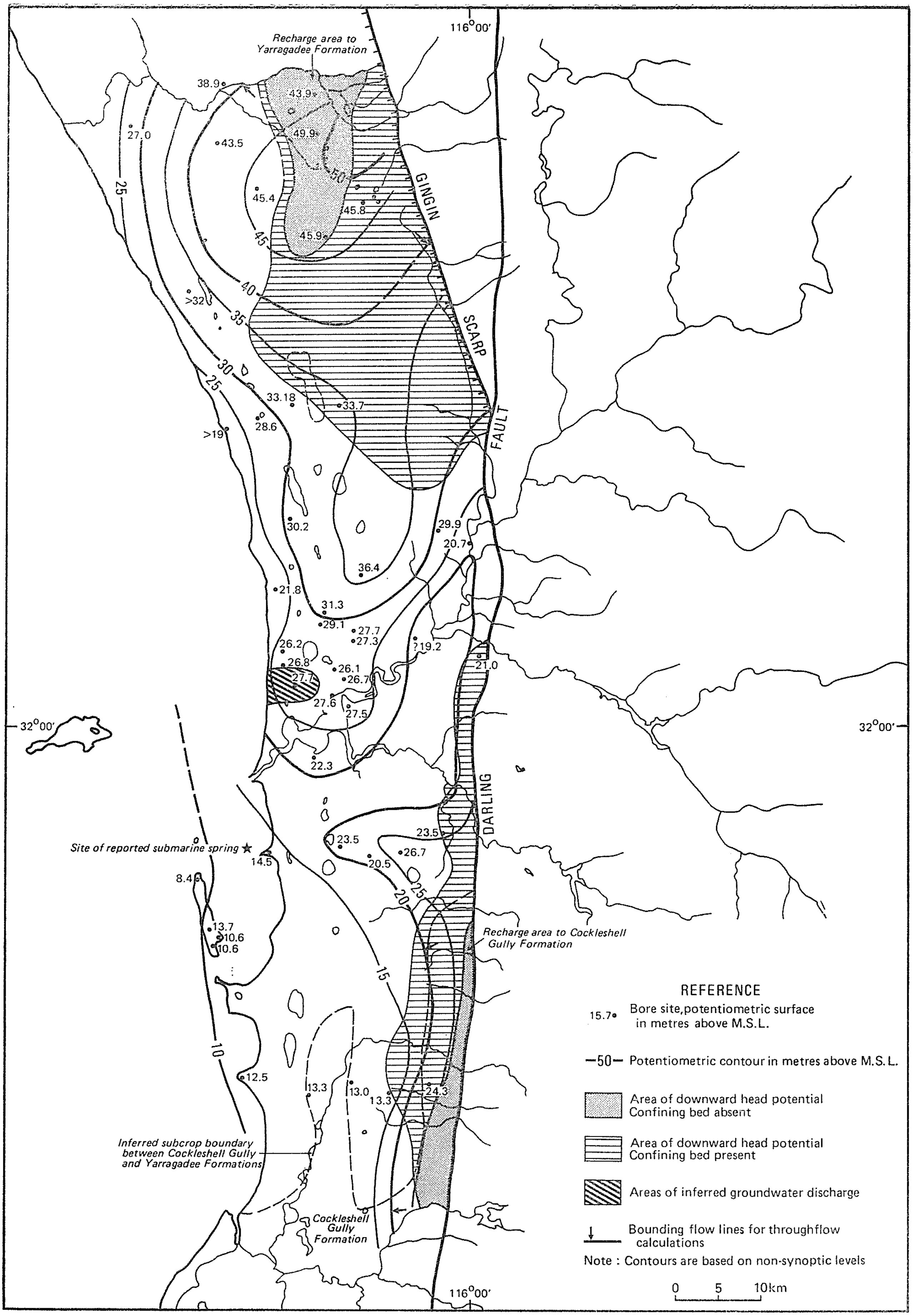

Figure 18 Yarragadee Formation, potentiometric contours and areas of recharge and discharge. GSWA 17709

M.W.B. has 12 production bores in the formation and there are 4 private bores. Six former deep bores in the formation have been plugged and abandoned.

The present annual abstraction from the formation varies depending on seasonal conditions. It is estimated that the present average production is about 10 x 10^6 m^3/y of which 8 x 10^6 m^3/y is by the M.W.B.

Since 1970 abstraction has caused the potentiometric head in the aquifer to decline at a rate ranging from 0.2 to 2.3 m/y. The cause of this has been the commissioning of new bores and the fact that abstraction is concentrated within an area of only 300 km^2. Some pumping water levels are below sea level but on cessation of pumping the potentiometric head recovers to above sea level. This indicates that there is only localized lowering of the potentiometric surface and no immediate danger of sea-water intrusion.

The exploratory drilling has proven the existence of a large volume of groundwater with a salinity less than 1 000 mg/L T.D.S. in the northern Perth area. The throughflow calculations indicate scope for further abstraction from this resource. In addition there are extremely large brackish-water resources which may also be developed.

COCKLESHELL GULLY FORMATION

Description of aquifer

The Cockleshell Gully Formation is about 2 000 m thick. It consists of non-marine interbedded sandstone, siltstone, coal measures, and shale which locally may be up to 300 m thick. The sandstones are usually slightly clayey, medium to coarse, and occur in beds up to 30 m thick.

The formation extends at depth throughout the Perth area but is at shallow depth and prospective for groundwater only in the south and southeast of the southern Perth area. It is extensively faulted so that the Yarragadee Formation may be brought into juxtaposition with it as shown by drilling on the Becher Point Line (Fig. 16). Near Mandurah the Cockleshell Gully Formation is overlain by the South Perth Shale, while further to the east it is directly overlain by the Leederville Formation (Allen, 1978).

Recharge

Recharge to the aquifer is by vertical leakage from the Leederville Formation and is inferred to occur over an area of about 60 km^2 (Fig. 18) adjacent to the Darling Scarp between about Serpentine and Pinjarra (Allen, 1978). Groundwater throughflow past the 25 m contour is estimated to be 35 x 10^6 m^3/y assuming the low salinity groundwater is in the upper 300 m of the formation (Allen, 1978), and that half the formation is sand with an hydraulic conductivity of 10 m^2/d. Some of the throughflow may originate from additional recharge from streamflow, and possibly a small amount from lateral leakage across the Darling Fault.

Storage

The subsurface area of the Cockleshell Gully Formation which contains groundwater with a salinity less than 1 000 mg/L T.D.S. is not known. In Becher Point No. 5 low salinity water extends to a depth of about 300 m in beds of sandstone with an aggregate thickness of about 100 m. This suggests that a fairly substantial groundwater resource may be present in the vicinity.

Movement

Groundwater in the Cockleshell Gully Formation is believed to be in hydraulic continuity with groundwater in the Yarragadee Formation (Fig. 18). Groundwater movement is presumably westward though it is possible that faulting may have produced a groundwater compartment in which the flow may be southwestward towards Pinjarra.

Discharge

Groundwater discharge occurs, via the Yarragadee Formation and overlying formations, offshore.

Quality

Groundwater in the formation on the Becher Point Line ranges from about 270 to 3 000 mg/L T.D.S. (Allen, 1978). Uncontaminated samples from the formation have not yet been obtained and consequently the dissolved iron content is not known.

Development

Apart from about 6 low-yielding private bores the formation is undeveloped. Further south near Pinjarra (Forth, 1974) the Alcoa Alumina Refinery abstracts about 2 x 10^6 m^3/y and has caused a large and widespread lowering in the potentiometric surface.

CONCLUSIONS

The assessment of the exploratory drilling carried out so far has provided a general understanding of the geology and the occurrence, size and extent of the confined groundwater resources. More reliable quantitative assessment of the resources and the solution of some remaining hydrogeological problems should be possible when drilling is completed for the artesian monitoring network.

Tentative calculations indicate that the confined aquifers have an aggregate throughflow of about 163 x 10^6 m^3/y and contain, in storage, more than 18 500 x 10^6 m^3 of groundwater with a salinity less than 1 000 mg/L T.D.S. In addition there are extremely large brackish groundwater resources, particularly in the Yarragadee Formation.

On the basis of the throughflow calculations possibly 50 to 180 x 10^6 m^3/y of groundwater could be abstracted from the confined aquifers, compared with the present abstraction of about 30 x 10^6 m^3/y. The remainder would be necessary to stabilize the saltwater interface. Considerably larger volumes of groundwater could be obtained if there was deliberate mining of the resources.

ACKNOWLEDGEMENTS

The assistance of colleagues at the Metropolitan Water Board is gratefully acknowledged.

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SEDIMENTOLOGY OF THE TUMBLAGOODA SANDSTONE (SILURIAN) IN THE LOWER MURCHISON RIVER AREA, WESTERN AUSTRALIA: A PRELIMINARY INTERPRETATION

by R. M. Hocking

ABSTRACT

The Tumblagooda Sandstone is a thick sandy "red-bed" sequence of Silurian age which is present in the northern Perth Basin and most of the western portion of the Carnarvon Basin. Sedimentation was dominated at all times by terrigenous clastic material, which in the southern Carnarvon Basin was derived from a tectonically active source to the southeast on the Yilgarn Block. Varied sedimentary structures, trace fossils, and grain-size characteristics enable four broad facies to be distinguished. These can be equated to low-input braided fluviatile, high-input braided fluviatile, high-input tidal-flat, and tidally influenced shallow-marine environments. Sedimentation oscillated between these environments and produced a sequence greater than 3 000 m thick before the advent of chemical and evaporite sedimentation in the Late Silurian.

INTRODUCTION

The Tumblagooda Sandstone is a "red-bed" sequence which consists of feldspathic to quartz arenites with subordinate siltstones and granule to pebble conglomerate. It is only exposed in the northern Perth and southern Carnarvon Basins between the Geraldton and lower Murchison River areas (Fig. 19), and has only been penetrated by bores north of the area of outcrop, the northernmost being Wandagee 1 in the central Carnarvon Basin. The overlying Dirk Hartog Formation was penetrated in Marrilla 1 and Pendock 1, suggesting that the Tumblagooda Sandstone may extend as far north as Exmouth Gulf. It has been studied by several workers (Clarke and Teichert, 1948; Condon, 1965; Johnstone and Playford, 1955; Playford and others, 1976) as part of regional projects, but no detailed or semi-detailed analysis of sedimentary structures and depositional environments has been attempted apart from the unpublished thesis of Mandyczewsky (1973). The present paper presents a preliminary interpretation of the depositional environments of the Tumblagooda Sandstone as exposed on the Ajana Sheet.

No body fossils are known from the Tumblagooda Sandstone in outcrop. The Dirk Hartog Formation overlies the Tumblagooda Sandstone with apparent conformity in Dirk Hartog 17B and is of Late Silurian age (Philip, 1969). Microfossils from the upper part of the Tumblagooda Sandstone in Wandagee 1 are of probable Silurian

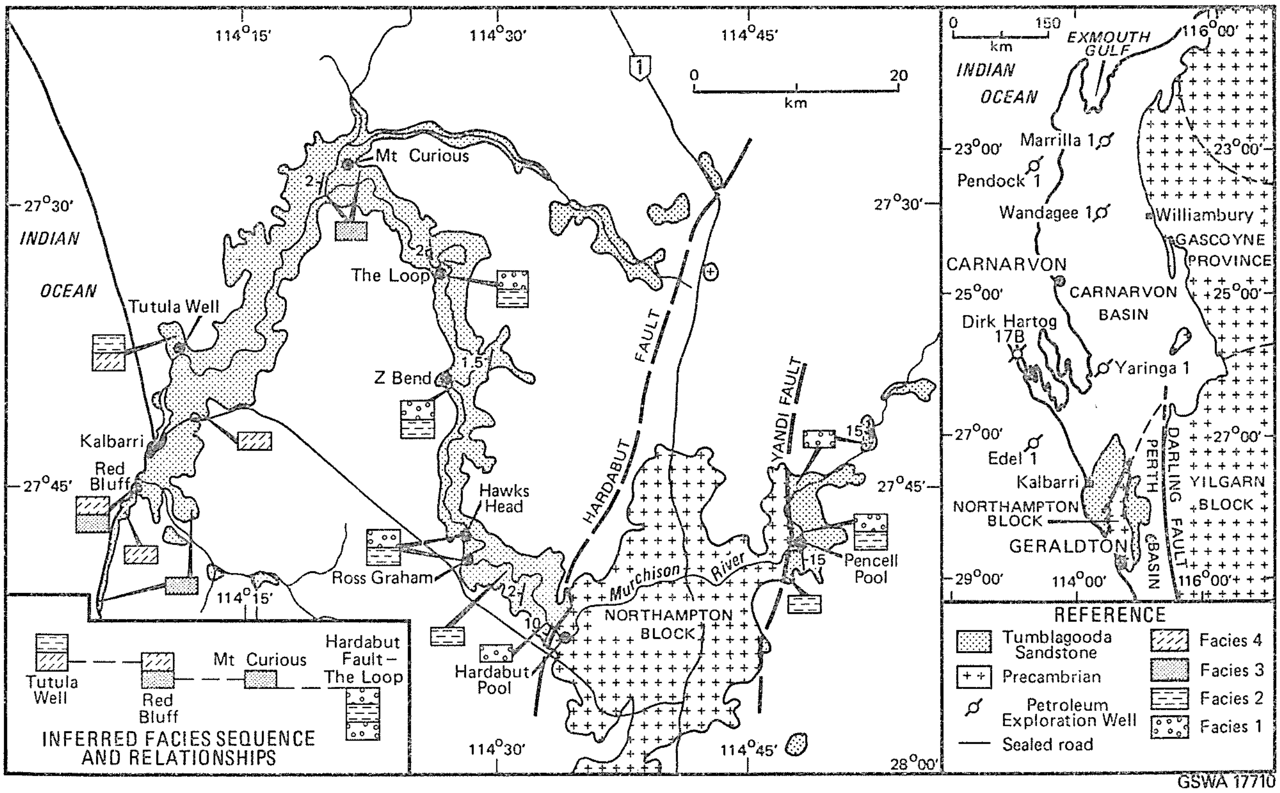

Figure 19 Outcrop distribution of the Tumblagooda Sandstone in the Perth and Carnarvon Basins, and constituent facies (where known) on Ajana Sheet.

age (B. E. Balme, *in* Playford and others, 1976), but the lower parts of the Tumblagooda Sandstone have not been dated and may conceivably be as old as Ordovician.

The base of the Tumblagooda Sandstone has not been penetrated by any oil or water wells, and is not exposed on the Ajana Sheet. On the Geraldton Sheet to the south, the Tumblagooda Sandstone crosses the Hardabut Fault (Fig. 19) without disruption, to rest directly on rocks of the Northampton Block, but a gravity survey indicates a significant thickness of sediments on the western, downthrown side of the fault beneath the outcropping Tumblagooda Sandstone (Playford and others, 1976). Thus the onlap of Tumblagooda Sandstone onto the Northampton Block might represent a limited transgression across the Hardabut Fault after cessation of the major period of movement on this fault. (As expressed now on Ajana Sheet, the Hardabut Fault reflects a later, but minor, period of reverse movement during Cainozoic times, which uplifted the block west of the fault and formed the Hardabut Anticline.)

The type section, along the Murchison River downstream from the Hardabut Fault, is 1 070 m thick, and the thickest drilled section, 2 500 m, is in Edel 1, where the depth to magnetic basement is about 4 000 m (Megallaa, in prep.). East of the Northampton Block, Johnstone and Playford (1955) measured a poorly exposed section of Tumblagooda Sandstone more than 3 500 m thick.

FACIES WITHIN THE TUMBLAGOODA SANDSTONE

The Tumblagooda Sandstone is divisible into four broad facies, based on exposures west of the Hardabut Fault. Diagrammatic sections of these facies, showing significant sedimentary features, and their distribution, relationships and order of succession (where known) are shown in Figures 19 and 20. Palaeocurrent patterns for each of the facies are shown in Figure 21. There is a fault south of Mount Curious, of unknown magnitude, which may affect the relationships between the eastern and western parts of the sequence, but movement on the fault is here assumed to be minor, and facies are extrapolated across it.

Facies 1

This consists of medium-grained, well-sorted and rounded, felspathic sandstone to quartz sandstone, with sporadic quartz granules and pebbles in more westerly exposures. In eastern exposures, as at Pencell Pool, the grain size and pebble content is greater, and some coarse lenses are present. The facies is ubiquitously crossbedded, with foresets in places oversteepened. Crossbedding is at two scales: small cross-sets 20 cm thick, and large troughs up to 10 m thick consisting of a number of smaller cross-sets. Palaeocurrents, measured mostly on trough cusps, are very consistent and have a mean direction of 315°. Scouring at the base of cross-sets is common, but there is minimal scouring on a local scale at the basal contact of the facies with the underlying Facies 2 between the Loop and Hawks Head. No trace fossils have been found.

The unimodel, low-scatter palaeocurrent pattern of this facies is suggestive of a low-sinuosity, braided fluviatile environment (Selley, 1968). The textural maturity of the sandstone is atypical of fluviatile deposits, but the hydrologic conditions which prevailed in the Silurian offer one explanation. Schumm (1968) argued that in these conditions, prior to the appearance of significant terrestrial vegetation, wide braided streams proliferated with unconfined channels downstream from source areas. With only moderate sediment input, alluvial deposits would have been constantly levelled and sorted as streams moved over and down the slopes, producing relatively mature sands. This process would have been accentuated in the Tumblagooda Sandstone, which with its large areal extent could not have had a consistently high palaeoslope. Oversteepening of cross-sets could be partially due to downcurrent drag during flooding, and partially due to earthquake shocks temporarily fluidizing waterlogged sand (Hendry and Stauffer, 1977; Allen and Banks, 1972).

A second explanation is to consider that some of the sand in Facies 1 was derived from the weathering of already mature sandstones of the Badgeradda Group or other Proterozoic sandstones marginal to the Yilgarn Block, although the feldspar content of Facies 1 sandstones renders this explanation less likely.

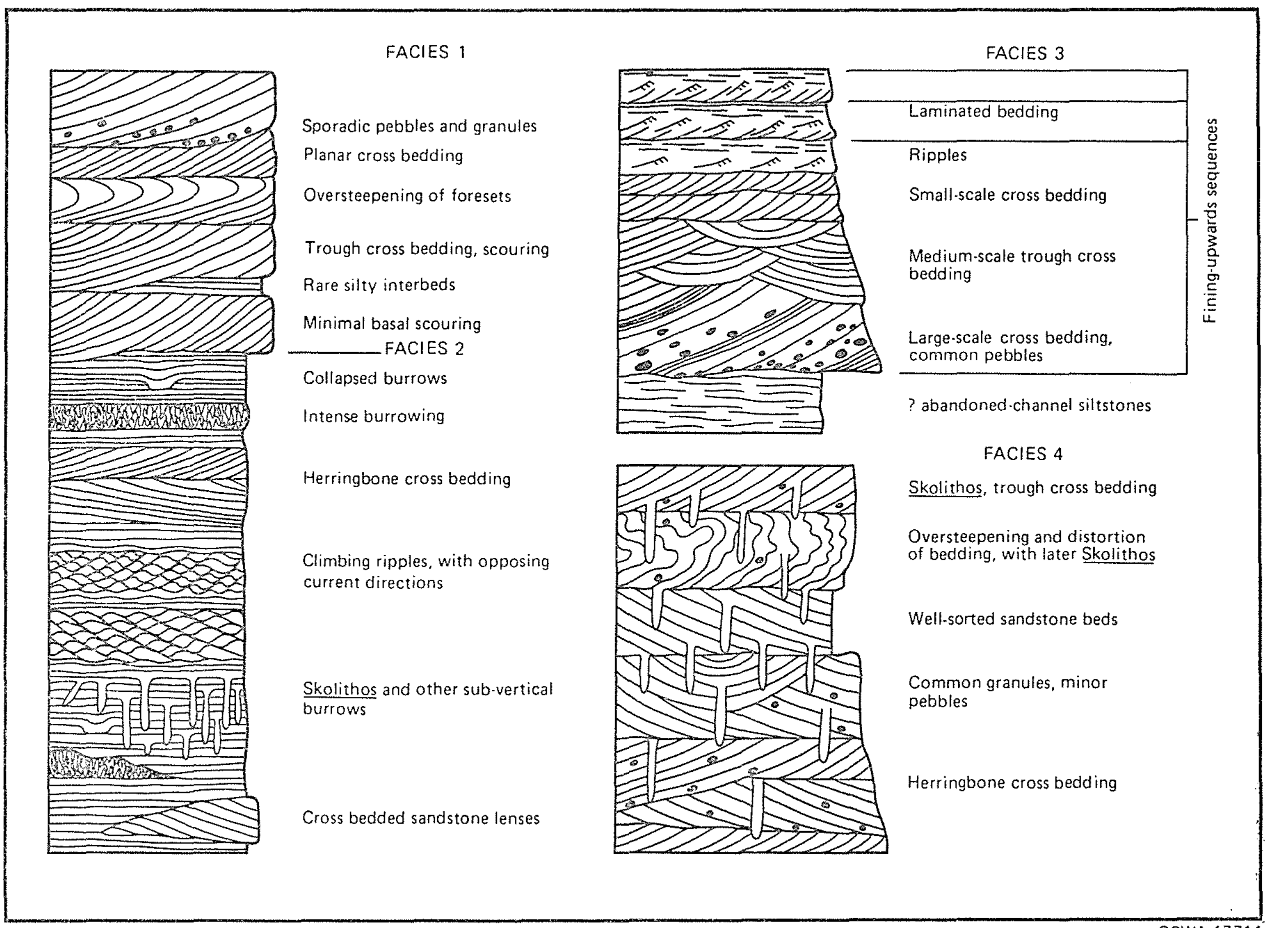

Figure 20 Diagrammatic sections of facies within the Tumblagooda Sandstone, showing diagnostic features. Scale variable.

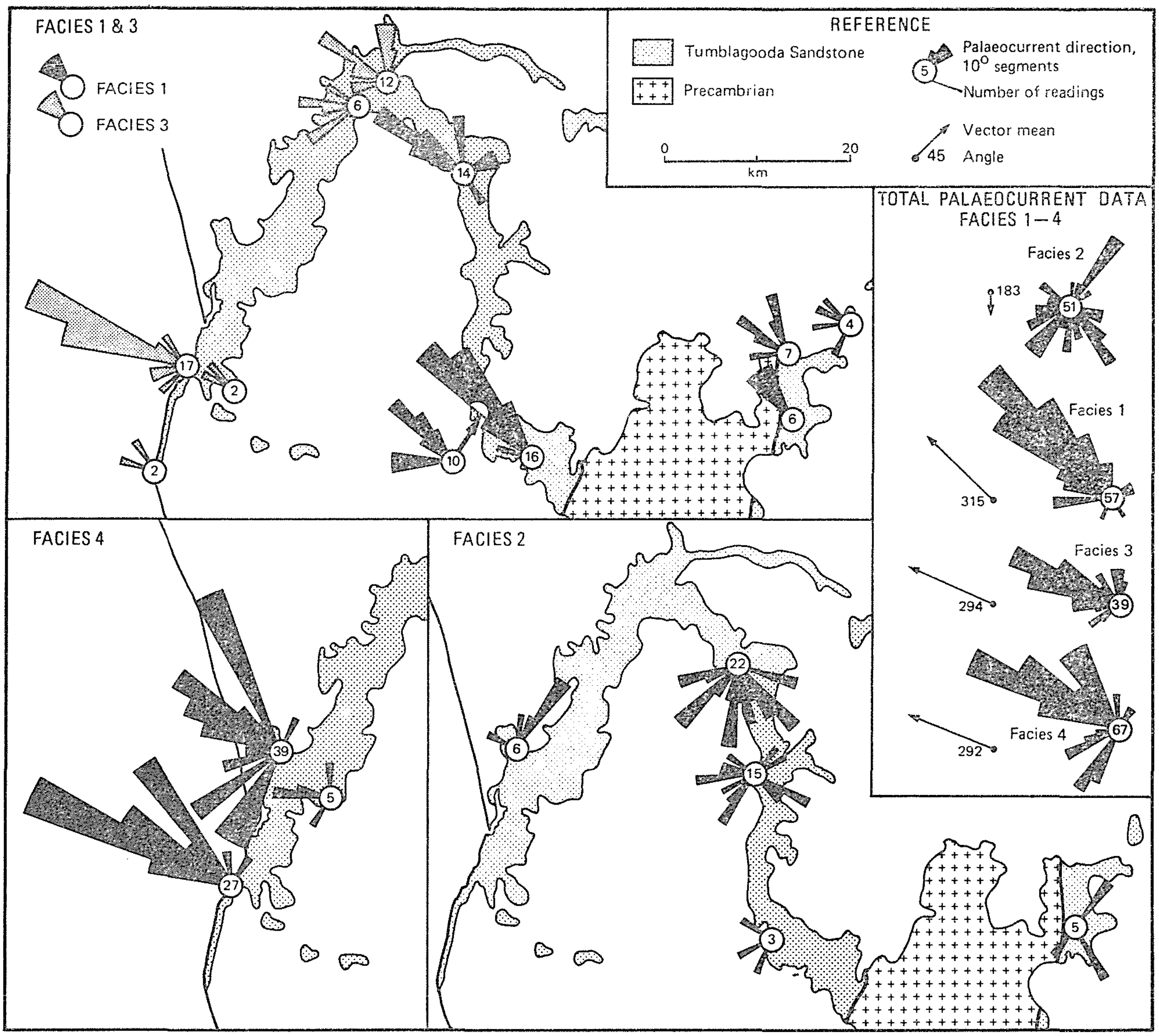

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Figure 21 Palaeocurrent patterns within the Tumblagooda Sandstone. Length of arc segments proportional to number of readings.

Facies 2

This consists of thin-bedded, red and white silty sandstone and fine-grained sandstone, with some cross-bedded lenses. Some beds are intensely bioturbated, mostly by vertical and subvertical burrows, and discrete *Skolithos* tubes, *Cruziana* furrows, *Protichnites* trails, *Rusophycus* resting hollows, *Teichichnus* burrows and *Diplocraterion* tubes (Opik, 1959) are present within the facies. Sedimentary structures not shown in Figure 20, and exposed at the Z Bend, include setulfs, which are similar to flutes but with positive relief from the bedding plane (Friedman and Sanders, 1974), and considerably distorted bedding within a sandstone lens. "Windmarks" described by Mandyczewsky (1973) are probably setulfs.

Trace fossils in Facies 2 belong to the *Skolithos* and *Cruziana* ichnofacies of Seilacher (1967). All burrows are high-angle shelter burrows, and trails show no systematic grazing pattern. These suggest shallow-marine conditions, near to and above wave-base, grading into intertidal conditions, using the modified ichnofossil zonation of Heckel (1972). The sedimentary structures support this interpretation. Herringbone cross-stratification indicates opposing current directions (Klein, 1977) which in Facies 2 are probably tidal. The composite palaeocurrent rose for Facies 2 (Fig. 21) clearly illustrates the multiplicity of opposing current directions, and sheds further light on the depositional environment of Facies 2 when compared to the roses for the fluviatile-dominated portions of the Tumblagooda Sandstone. Assuming that the dominant fluviatile trend reflects the palaeoslope, and that the coastline was perpendicular to the palaeoslope, the southeasterly pointing trend of Facies 2 suggests currents normal to the shoreline during deposition. The southwest-northwest trend may reflect alternating longshore currents, and combined with the small southerly vector mean (Fig. 21) suggests that currents during deposition moved primarily north-south at a low angle to the shoreline, rather than directly onshore. Climbing ripples indicate a periodically strong sediment supply, and herringboned climbing ripples a periodically strong supply in a tidal situation. The setulfs described by Friedman and Sanders occurred on emergent tidal flats, and those in the Tumblagooda Sandstone may also indicate subaerial exposure, but there is no other evidence of emergence within Facies 2. Cross-bedded sandstone lenses within the facies may be winnowed tidal-channel sands, and the distorted bedding within one at the Z Bend possibly resulted from an earthquake which triggered gravity sliding.

Facies 3

This consists of coarse- to fine-grained, generally poorly sorted sandstone, with significant siltstone and claystone interbeds, and contains several fining-upwards cycles. These cycles fine upwards both in grain-size and in the scale of the bedding. Palaeocurrents are unimodel, with a vector mean of 294° (Fig. 21). The poor sorting, variable grain size, and fining-upwards sequences in this facies suggest a fluviatile environment. The section exposed at Red Bluff is very similar to one figured in Reineck and Singh (1973, Fig. 358) from a braided-alluvial environment, and siltstone beds were probably abandoned channels. Less reworking of the sediments occurred than in Facies 1 because of higher sediment input. This may have resulted from greater tectonic activity in the source area, or from subsidence of the depositional area, which would have increased stream energy.

Facies 4

This consists of medium- to coarse-grained, poorly sorted feldspathic to quartzose sandstone, with common quartz granules and minor siltsone. It is ubiquitously trough cross-bedded, with some cross-sets oversteepened and distorted, and through most of the facies palaeocurrents were to the northwest. However, cross-sets in sporadic better sorted sand lenses indicate opposing palaeocurrents which trend north-northeast and south-southwest (Fig. 21). Large-scale scouring at the base of the troughs is visible at Red Bluff. *Skolithos* tubes are common, and near Tutula Well they cut through oversteepened cross-sets.

The presence of *Skolithos* tubes indicates that there was marine influence during deposition of this facies, but the coarse grain-size and poor sorting indicate significant differences between this environment and that of Facies 2. A high-energy, braided transport system with heavy sediment load and some marine influence appears necessary. This could occur where a braided fluviatile system was partially drowned by marine incursion, offering enough marine influence to support the animals which made *Skolithos* tubes and to occasionally rework some sediment, but not enough to rework the poorly sorted deposits.

Hereford (1977, facies E) postulated a tidal flat environment, as a whole, with high-energy braided streams continuing from nearby rivers, for apparently similar parts of the Tapeats Sandstone. Fining-upwards sequences at the top of this facies near Tutula Well may have formed in semi-confined tidal channels similar to Hereford's facies D, and represent a transition into the overlying, well-sorted, tidally deposited sandstones and siltstones of Facies 2.

SILURIAN PALAEOGEOGRAPHY

The palaeocurrent pattern for Facies 1, 3 and 4 of the Tumblagooda Sandstone is unequivocal (Fig. 21). The palaeoslope was to the northwest, and the Tumblagooda Sandstone in the area of the outcrop had a southeasterly source. In marine parts of the unit, the dominant current and sediment transport direction was subparallel to the presumed coastline (a line from south-southwest to north-northeast), with tidal influence more in a north-south than in an east-west direction. Mandyczewski (1973) obtained similar results, with a palaeocurrent azimuths of 282°, 20° and 169°, and 303° respectively in his equivalents of Facies 1, 2 and 3, and 4.

With the high feldspar content of much of the sandstone, a granitic source on the Yilgarn Block can be postulated, possibly with some input from Gascoyne Province rocks as significant tourmaline is present and the Gascoyne Province is tourmaline-rich. Streams feeding the Tumblagooda Sandstone may also have passed through some Proterozoic sandstones and provided second-generation sand which was incorporated in the texturally mature sandstone of Facies 1.

There is no apparent deflection of palaeocurrents around the Northampton Block, and no trace of garnet within the Tumblagooda Sandstone. As the Northampton Block is garnet-rich (Prider, 1958), traces of garnet could reasonably be expected in the Tumblagooda Sandstone if the block was exposed to erosion during deposition of the formation. These two facts indicate that the Northampton Block was not a major topographic feature which influenced sedimentation of the Tumblagooda Sandstone. However, rates of deposition may have been less on the block than in surrounding areas if the bounding faults moved during deposition, as seems likely.

The red colouration of much of the Tumblagooda Sandstone is, as Playford and others (1976) noted, one of its most distinctive features. This indicates that during deposition sediments were subject to strongly oxidizing conditions (Reineck and Singh, 1973). The continental origin postulated for many red-bed sequences cannot be applied to the Tumblagooda Sandstone, as the marine sediments of Facies 2 are among the reddest parts of the sesquence.

On Ajana Sheet, the throw of the Darling Fault exceeds 3 000 m, and the time of movement is probably entirely pre-Permian (Playford and others, 1976; Hocking and others, in prep.), but at least some movement postdates deposition of the Proterozoic Badgeradda Group and Nilling Beds. It seems reasonable that much of the movement took place during the deposition of the Tumblagooda Sandstone, as Playford and others (1976) suggested, and that the Darling Fault where present marked the eastern margin of the Silurian depositional basin. This fault trends approximately north-south, and palaeocurrent data indicate a palaeoslope oblique to this line. With the absence of the Tumblagooda Sandstone from bores south of Geraldton, this suggests that the present area of outcrop was quite close to the southern end of the depositional basin. In this area, streams would approach the basin from the south as well as the east, and palaeocurrent directions are interpreted as showing this.

GEOLOGICAL HISTORY

The lowermost exposed sediments of the Tumblagooda Sandstone on Ajana Sheet are relatively mature, syndepositionally reworked sandstones (Facies 1) which were deposited in a braided fluviatile environment. Much if not all of the underlying sequence was probably deposited by braided streams, and may be less mature.

A marine transgression ended this fluviatile phase, and deposition commenced in a broad, shallow-marine basin, primarily above wave-base and frequently in tidal conditions (Facies 2). There was considerable biological activity on the sea-floor, although all body fossils were destroyed, probably by the strongly oxidizing conditions.

Marine sedimentation waned, and was followed by a second phase of braided fluviatile deposition (Facies 1, repeated). The topmost marine sediments may have been removed by erosion and planation on a regional scale, because the contact is abrupt although only minimally scoured on a local scale. During this fluviatile phase, rejuvenation of the source area occurred and stream power increased. Less reworking of previous deposits took place, and less mature fluviatile sediments were deposited (Facies 3).

Subsequently, the sea level rose, relative to the land, either through eustatism or as a result of basin subsidence, and high-energy paralic sediments were deposited (Facies 4). This period was relatively brief, and transitional into another phase of shallow-marine, tidally influenced sedimentation (Facies 2, repeated).

Terrigenous input continued to dominate sedimentation until the Late Silurian, when supply waned, and chemical sediments of the Dirk Hartog Formation were deposited. These are predominantly dolomitic, but contain some evaporites, limestone and mudstone (Shannon, 1966). They are probably near-shore to sabkha deposits.

CONCLUSIONS

Present evidence suggests the Tumblagooda Sandstone was deposited in mixed shallow-marine and terrestrial environments, with deposition oscillating between high-input braided fluviatile, and tidally influenced, shallow-marine environments.

Palaeocurrents in fluviatile portions of the formation are very consistent and unimodel, indicating a northwesterly facing palaeoslope, whereas palaeocurrents in the marine portions are polymodal, and suggest that the dominant tidal influence was oblique rather than perpendicular, to the shoreline.

Sedimentation was at all times dominated by terrigenous clastics, which in the southern Carnarvon and northern Perth Basins initially originated from a southeasterly source on the Yilgarn Block, as palaeocurrent and compositional data do not indicate that the Northampton Block influenced sedimentation. The Darling Fault probably formed the eastern margin of the basin, and the main tectonic activity during sedimentation was probably centres on this fault.

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PETROLEUM EXPLORATION IN WESTERN AUSTRALIA IN 1978

by K. A. Crank

ABSTRACT

There was a significant increase in petroleum exploration activity in Western Australia during 1978.

Fifteen exploration wells were completed compared with eight in 1977, and one was drilling ahead at the end of the year, for a total penetration of 48 100 m, an increase of 12 771 m, or 36 per cent, compared with the previous year. Expressed in rig months, however, drilling operations were 10.3 per cent less than in 1977. Drilling was mainly offshore, in the Perth, Carnarvon, Canning, Browse and Bonaparte Gulf Basins, although three onshore wells were completed, one in the Perth Basin and two on Barrow Island. Seven development wells were completed on Barrow Island. No major discoveries were made during the year although gas shows were reported in several wells.

Geophysical activity, consisting mainly of marine seismic surveys, increased about 700 per cent compared with 1977. This increase occurred mainly on the newly granted deep-water Exmouth Plateau permits, where 25 314 line kilometres of seismic surveys were shot.

INTRODUCTION

Exploratory drilling for petroleum in Western Australia over the past two years is illustrated in the following table (excluding the aborted Geelvink No. 1 well, which was abandoned at 1 268 m and was replaced by Geelvink No. 1A). No discovery wells were drilled in 1978.

Type of Well	Wells completed		Wells drilling on 31 December	
	1977	1978	1977	1978
New Field Wildcats	7	13	3	0
New Pool Wildcats	0	2	0	0
Extension Tests	1	0	0	1
Total	8	15	3	1

Total effective drilling: 1977—35 339 m
1978—48 110 m

Geophysical survey and surface geological survey activity for 1978 is shown below. Figure 22 summarizes the seismic activity since 1967.

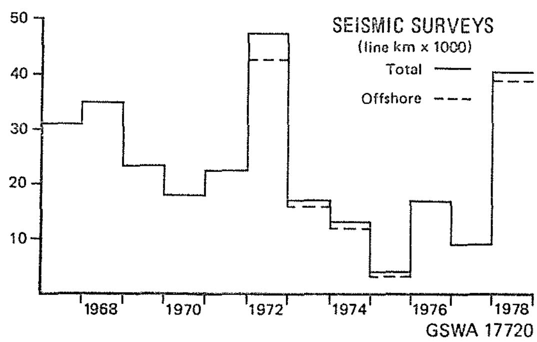

Figure 22 Seismic surveys since 1967.

Type of Survey	Line kilometres		Party months or geologist months	
	1977	1978	1977	1978
Land seismic	0	1 143	....	....
Marine seismic	5 994	38 996	....	....
Land gravity	0	459	....	....
Marine gravity	147	1 023	....	....
Aeromagnetic	0	1 847	....	....
Marine magnetic	579	2 336	....	....
Oceanographic	....	....	0	3·5
Geological	....	....	0	2
Geochemical	....	....	0	2

DRILLING

DRILLING OPERATIONS

Expressed in rig months, overall exploration operations declined by 10.3 per cent to 24.3 rig months in 1978 compared to 21.1 rig months in 1977. Offshore operations increased by 15.2 per cent compared with 1977 (21.2 compared with 8.7 rig months), and onshore exploration activity declined by 64 per cent (3.1 compared with 8.7 rig months). In addition, 4.7 rig months were spent on a seven-well development program on Barrow Island in 1978. There was no development drilling in 1977.

A total of six rigs, 4 offshore and 2 onshore, were operated. During the first half of the year, the 3-leg jack-up rig Maersk Endurer drilled the last 3 holes of a 4-well program initiated by WAPET in 1977, after which it left Western Australian waters. The drillship Regional Endeavour was active in Western Australia throughout the year except for a period in Northern Territory waters from mid-May to the end of July. Other details of rig deployment are shown in Figure 23.

Three tropical cyclones affected the Regional Endeavour operations for Woodside Petroleum Development Pty Ltd (Woodside) at the beginning of the year. The first, "Vern", caused work loss of 7 days during late January and Early February whilst drilling Jarman No. 1. Cyclone "Alby" caused a loss of 2¼ days work at the end of March whilst drilling Miller No. 1, and a week later cyclone "Brenda" caused a loss of 6½ days operational time.

productive area in WA-28-P. Gas-bearing sandstones were penetrated between 3 046 and 3 066 m, and between 3 111 and 3 232 m, but the well was abandoned as non-commercial.

Brigadier No. 1, in WA-90-P, was the first well to be drilled in the newly awarded permits on and adjoining the Exmouth Plateau. It was drilled on the Brigadier Trend,

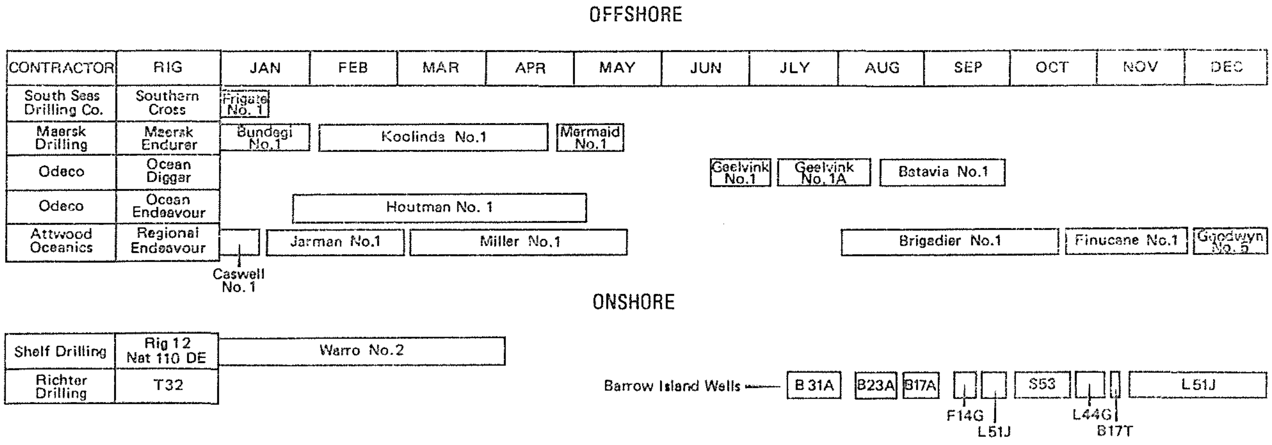

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Figure 23 Rig utilization, 1978.

Figure 24 is a summary comparison of drilling operations for the 12-year period 1967-78.

WELLS COMPLETED IN 1978

The positions of wells drilled for petroleum exploration in Western Australia during 1978 are shown in Figure 25. Details relating to wells drilled during the year are given in Table 14. All petroleum exploration wells drilled in Western Australia up to the end of 1978 are listed in the Geological Survey Record 1979/1 (Crank, 1979). A summary of the principal results of drilling in each basin during the year is as follows:

Bonaparte Gulf Basin

Arco Australia Ltd completed one well, Frigate No. 1, in the offshore Bonaparte Gulf Basin in 1978. This was drilled, in WA-18-P, on a large, faulted anticlinal structure and was located 68 km southeast of Petrel No. 1 and 14 km west of Tern No. 1. No shows of gas or oil were encountered, and the well was plugged and abandoned in the Triassic at a total depth of 1 584 m.

Browse Basin

One well, Caswell No. 1, was completed in the Browse Basin by the Woodside group. It was drilled on a pre break-up horst overlain by Middle Jurassic sediments, located about 410 km north of Broome in Exploration Permit WA-34-P. The well, which was drilled in 345 m of water, reached a total depth of 4 097 m in the Lower Cretaceous. The only hydrocarbons of significance were encountered between 3 606 and 3 611 m, but testing indicated the presence of overpressured streaks, not in vertical communication, and the well was plugged and abandoned.

Canning Basin

The Woodside group also drilled one well in the Canning Basin during the year, Jarman No. 1 in WA-1-P. This was located in the Beagle Sub-basin on the north-west flank of the Cossigny Trough. It was drilled to test a very large anticlinal structure and reached a total depth of 2 906 m in the Middle Jurassic, but no significant hydrocarbon shows were encountered.

Carnarvon Basin

As has been the case over the last ten years the most active drilling area has been the offshore Carnarvon Basin. Seven exploration wells were completed and one extension test, Goodwyn No. 5, was drilling at the end of the year. Two onshore new pool wildcats were drilled on Barrow Island, as well as seven development wells within the Barrow Island field.

Three exploration wells were drilled by Woodside: Miller No. 1, Brigadier No. 1, and Finucane No. 1. Miller No. 1 was drilled to 3 520 m to test the potential of Upper Triassic sands on the eastern side of the North Rankin

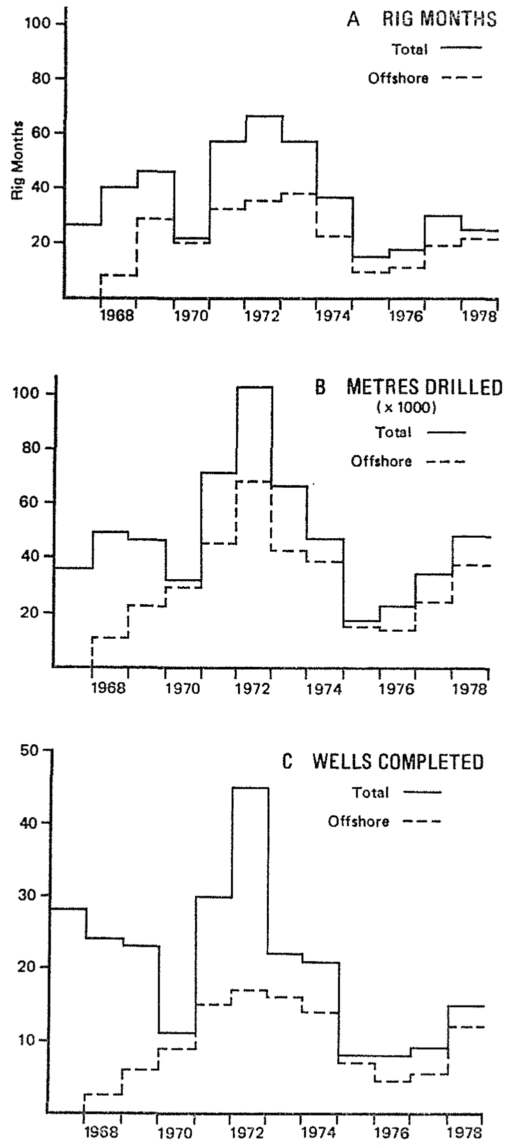

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Figure 24 Drilling operations since 1967.

TABLE 14. WELLS DRILLED FOR PETROLEUM EXPLORATION IN WESTERN AUSTRALIA DURING 1978

Basin	Well	Tenement	Operating company	Type	Position		Elevation and water depth (m)			Dates			Total depth (m)	Bottomed in	Status on 31 Dec.
					Latitude South	Longitude East	GL	RT	WD	Com-menced	Reached TD	Rig released			
Perth	Warro No. 2	EP24	WAPET	NFW	30°10′05″	115°44′03″	291	299	....	20/11/77	20/2/78	5/4/78	4 854	L. Jurassic	Gas shows, p & a
	Houtman No. 1....	WA-59-P	Esso	NFW	28°39′55″	113°34′35″	....	25	152	27/1/78	5/4/78	6/5/78	3 860	L. Jurassic	Gas shows, p & a
	Geelvink No. 1	WA-13-P	WAPET	NFW	29°05′47″	114°17′55″	....	30	50	30/5/78	10/6/78	13/6/78	1 268	L. Jurassic	Mechanical problems, p & a
	Geelvink No. 1A	WA-13-P	WAPET	NFW	29°05′47″	114°17′53″	....	30	51	14/6/78	2/7/78	10/8/78	3 053	? Permian	Dry, p & a
	Batavia No. 1	WA-59-P	Esso	NFW	28°53′59″	114°15′36″	....	31	53	13/8/78	20/9/78	28/9/78	2 941	? Permian	Dry, p & a
Carnarvon	Bundegi No. 1	EP41	WAPET	NFW	22°01′06″	114°09′33″	....	31	16	4/12/77	21/1/78	31/1/78	1 584	U. Triassic	Dry, p & a
Canning	Jarman No. 1	WA-1-P	Woodside	NFW	19°07′23″	117°20′42″	....	8	134	17/1/78	28/2/78	3/3/78	2 906	M. Jurassic	Dry, p & a
Carnarvon	Koolinda No. 1	WA-24-P	WAPET	NFW	21°23′46″	115°03′13″	....	31	18	4/2/78	1/4/78	24/4/78	3 732	Jurassic	Gas and oil shows, p & a
	Miller No. 1	WA-28-P	Woodside	NFW	19°34′45″	116°09′55″	....	8	121	6/3/78	12/5/78	20/5/78	3 520	U. Triassic	Gas shows, p & a
	Mermaid No. 1	WA-23-P	WAPET	NFW	20°41′55″	115°57′39″	....	31	25	27/4/78	9/5/78	16/5/78	1 271	Precambrian	Dry, p & a
	Brigadier No. 1	WA-90-P	Woodside	NFW	19°05′49″	116°08′09″	....	8	312	2/8/78	9/10/78	19/10/78	4 292	Triassic	Dry, p & a
	Finucane No. 1	WA-1-P	Woodside	NFW	19°17′25″	116°45′54″	....	8	139	21/10/78	29/11/78	3/12/78	3 301	M. Jurassic	Dry, p & a
	Barrow S53	PL1H	WAPET	NPW	20°49′05″	115°22′22″	27	38	....	7/10/78	20/10/78	22/10/78	802	L. Cretaceous	Oil shows, p & a
	Barrow L51J	PL1H	WAPET	NFW	20°49′05″	115°22′22″	40	43	....	11/11/78	18/12/78	....	2 135	U. Jurassic	Waiting on completion
	Goodwyn No. 5	WA-28-P	Woodside	EXT	19°40′42″	115°53′45″	....	8	129	5/12/78	....	....	2 917	....	Drilling
Browse	Caswell No. 1	WA-34-P	Woodside	NFW	14°14′29″	122°28′04″	....	8	345	16/8/77	2/1/78	13/1/78	4 090	L. Cretaceous	Gas and oil shows, p & a
Bonaparte Gulf	Frigate No. 1	WA-18-P	ARCO	NFW	13°10′48″	127°55′25″	....	2	91	4/1/78	13/1/78	17/1/78	1 584	Triassic	Dry, p & a

Woodside: Woodside Petroleum Development Pty Ltd
WAPET: West Australian Petroleum Pty Ltd
ESSO: Esso Exploration and Production Aust. Inc.
ARCO: Arco Australia Ltd

NFW: New field wildcat well
EXT: Extension test well
NPW: New pool wildcat well
p & a: Plugged and abandoned

a large structure on the northwestern edge of the Carnarvon Basin between the Victoria and Kangaroo Synclines. The total depth was 4 292 m in the Upper Triassic, but no significant shows of oil or gas were detected.

Finucane No. 1, located 25 km north-northeast of the Angel gasfield, was drilled to test a drape-closed fault block in WA-1-P, similar to those present on the Rankin Trend. Total depth was 3 301 m in probable Middle Jurassic sediments, but no hydrocarbon shows were recorded.

West Australian Petroleum Pty Ltd (WAPET) completed three offshore wells in 1978: Koolinda No. 1, Mermaid No. 1, and Bundegi No. 1, although the latter was technically located on an onshore permit, EP41.

Koolinda No. 1 was located in the Barrow Sub-basin on a large reversal on the downthrown side of the Flinders Fault System in WA-24-P. The well was drilled to a total depth of 3 732 m in the Middle Jurassic. Hydrocarbon-bearing sandstones, encountered between 2 100 and 2 305 m, were extensively drillstem tested, but the results were disappointing as no formation fluids were recovered.

The formation was considered to be tight and non-productive, and the well was abandoned.

Mermaid No. 1 was drilled to a depth of 1 271 m on the outer edge of the Lambert Shelf at the eastern margin of the Barrow Sub-basin, in Permit WA-23-P. The well was drilled to evaluate postulated stratigraphic traps in the Triassic and Upper Permian. It was drilled into Precambrian basement and no hydrocarbon shows were encountered.

Bundegi No. 1 was drilled in the shallow waters of the Exmouth Gulf within EP41 about 20 km east-northeast of Cape Range No. 1. The structure tested was an anticlinal feature on the west side of and adjacent to, the north-northeast-trending Paterson-Learmonth Fault. Possible gas-bearing sandstones were detected between 2 606 and 2 679 m. Formation-interval tests of this zone indicated multiple gas-water contacts. The gas sands were too thin to be considered economic so the well was plugged and abandoned at a total depth of 3 096 m.

Barrow L51J, drilled within PL1H (Barrow Island), was classed as a new pool wildcat and had as its main objective an extension of the "6 700-foot sand". The total depth of 2 135 m was reached on 18 December, 1978, and at the end of the year preparations were being made to test upper zones between 1 806 and 1 809 m and between 1 842 and 1 844 m, after the lower part of the well including the "6 700-foot sand" had been plugged as a dry hole.

Barrow S53 was completed on a possible closure to the northwest of the main "Windalia sand" pool on PL1H and was also classed as a new pool wildcat. The Windalia reservoir, however, did not contain significant oil saturation and the well was plugged and abandoned.

Barrow Island Development Wells

During the year seven development wells were drilled by WAPET within the Barrow Island oilfield. Three of these B17A, B23A and B31A, were completed as infill wells evaluating the "Windalia sand" reservoir. F14G, L44G and L82G were drilled to evaluate the potential of the Upper Cretaceous Gearle Siltstone, and B17T was a 76 m test of "oil shows" previously encountered in shallow Tertiary rocks in B17A.

The status of these wells at the end of the year is shown below:

Well	Total depth (m)	Status at 31 December 1978	
		(bbls oil per day)	(bbls water per day)
B17A	680	196	5
B23A	727	224	135
B31A	758	100	13
F14G	412	0	0
F82G	514	30	0
L44G	543	115	0
B17T	76	waiting on pump	
Total development drilling	3 710	....	....

Perth Basin

One onshore and three offshore wells were drilled in the Perth Basin in 1978, two by Esso and two by WAPET.

Warro No. 2, located 240 m west-northwest of Warro No. 1, was drilled by WAPET in the onshore permit EP24, to evaluate the hydrocarbon potential of Jurassic gas sands encountered in the first well, testing results

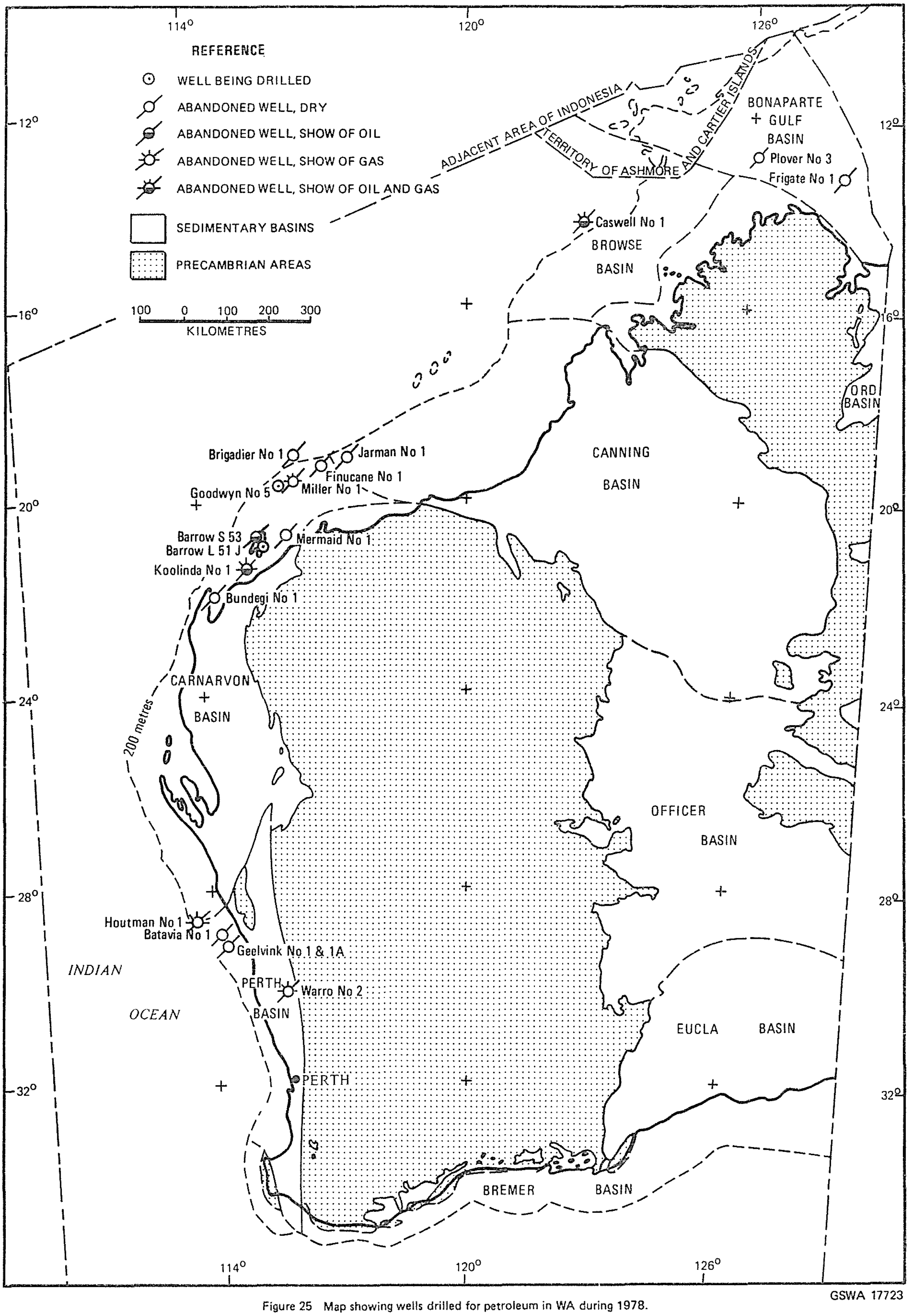

Figure 25 Map showing wells drilled for petroleum in WA during 1978.

of which had been inconclusive. The No. 2 well was abandoned at 4 854 m after testing two zones, 3 977 to 4 016 m and 4 086 to 4 120 m, which yielded only very small gas flows, 2.27 × 10^3 m^3/day and 2.94 × 10^3 m^3/day maximum respectively.

Three wells were drilled in the offshore Abrolhos Sub-basin: Houtman No. 1 and Batavia No. 1 by Esso, and Geelvink No. 1A by WAPET. Houtman No. 1 was drilled on a complex, faulted anticline west of the Abrolhos Islands in WA-59-P, with target horizons Lower Jurassic to Upper Triassic sandstones. The well did not reach these objectives and was completed at 3 860 m in the Upper Jurassic. Possible gas-bearing sandstones were penetrated between 3 340 and 3 486 m, but wireline tests, confirmed later by drillstem test results, suggested that these sandstones are low-permeability reservoirs, and the well was abandoned as uneconomic.

Esso's second well, Batavia No. 1, was drilled to the east of the Abrolhos Islands, also in WA-59-P, on a north-northwest-trending antithetic fault closure. The principal objective was basal Triassic sandstone similar to that which produces in the onshore Dongara gasfield 80 km to the southeast. No permeable reservoir sandstones were encountered and the well was plugged and abandoned at a total depth of 2 941 m.

Geelvink No. 1A was drilled by WAPET in the central part of the Abrolhos Sub-basin to test a faulted anticlinal closure with Triassic and Permian objectives. Geelvink No. 1 was abandoned at 1 268 m because of mechanical problems. The basal Triassic sandstone encountered at 2 149 to 2 169 m proved to be tight, as were the Permian sandstones below. No significant shows of oil or gas were encountered and the well was plugged and abandoned at 3 053 m.

GEOPHYSICAL SURVEYS

Geophysical surveys consisted mainly of seismic surveys which increased about 700 per cent compared to 1977. Other surveys conducted were gravity, magnetic, aeromagnetic and uphole velocity surveys.

SEISMIC

During 1978 offshore seismic surveys were conducted in the Perth Basin (809 km), Carnarvon Basin (5 028 km), Browse Basin (349 km), Canning Basin (3 073 km), Bonaparte Gulf Basin (4 420 km), and the Exmouth Plateau area (25 314 km). Onshore seismic surveys were conducted in the Perth Basin (51 km) and the Canning Basin (1 092 km). Details are as follows:

SEISMIC SURVEYS

Basin	Tenement	Company	Line (km)
Perth	PL2	West Australian Petroleum Pty Ltd	51 (onshore)
	WA-59-P	Esso Exploration and Production Aust Inc	809 (offshore)
Carnarvon	WA-1-P	Woodside Petroleum Development Pty Ltd	271 (offshore)
	WA-28-P	Woodside Petroleum Development Pty Ltd	910 (offshore)
	WA-23-P	West Australian Petroleum Pty Ltd	346 (offshore)
	WA-25-P	West Australian Petroleum Pty Ltd	424 (offshore)
	WA-58-P	Western Energy Pty Ltd	710 (offshore)
	WA-80-P	Otter Exploration NL	414 (offshore)
	WA-81-P	Continental Oil Co of Australia Ltd	1 950 (offshore)
Canning	EP97	Amax Iron Ore Corp	18 (onshore)
	EP101	Amax Iron Ore Corp	151 (onshore)
	EP102	Amax Iron Ore Corp	140 (onshore)
	EP103	Whitestone Petroleum Pty Ltd	150 (onshore)
	EP104	Esso Exploration and Production Aust Inc	633 (onshore)
	WA-79-P	Getty Oil Development Co Ltd	3 073 (offshore)

SEISMIC SURVEYS—*continued*

Basin	Tenement	Company	Line (km)
Browse	WA-33-P	Woodside Petroleum Development Pty Ltd	121 (offshore)
	WA-34-P	Woodside Petroleum Development Pty Ltd	162 (offshore)
	WA-35-P	Woodside Petroleum Development Pty Ltd	31 (offshore)
	WA-37-P	Woodside Petroleum Development Pty Ltd	34 (offshore)
Bonaparte Gulf	WA-70-P	Getty Oil Development Co Ltd	4 420 (offshore)
Exmouth Plateau area	WA-84-P	Phillips Aust Oil Co	5 344 (offshore)
	WA-90-P	Woodside Petroleum Development Pty Ltd	1 011 (offshore)
	WA 93 P	Hudbay Oil (Aust) Ltd	2 214 (offshore)
	WA-96-P	Esso Exploration and Production Aust Inc	8 980 (offshore)
	WA-97-P	Esso Exploration and Production Aust Inc	7 765 (offshore)
Total			40 139

GRAVITY

Gravity surveys carried out in conjunction with seismic surveys were as follows:

GRAVITY SURVEYS

Basin	Tenement	Company	Line (km)
Carnarvon	WA-1-P	Woodside Petroleum Development Pty Ltd	86 (offshore)
	WA-28-P	Woodside Petroleum Development Pty Ltd	248 (offshore)
Canning	EP97	Amax Iron Ore Corp	18 (onshore)
	EP101	Amax Iron Ore Corp	151 (onshore)
	EP102	Amax Iron Ore Corp	140 (onshore)
	EP103	Whitestone Petroleum Aust Ltd	150 (onshore)
Browse	WA-37-P	Woodside Petroleum Development Pty Ltd	20 (offshore)
Exmouth Plateau area	WA-93-P	Hudbay Oil (Aust) Ltd	669 (offshore)
Total			1 482

MAGNETIC

One aeromagnetic survey was flown and other magnetic surveys were conducted in conjunction with seismic surveys as follows:

MAGNETIC SURVEYS

Basin	Tenement	Company	Line (km)
Carnarvon	WA-58-P	Western Energy Pty Ltd (Aero-magnetic Survey)	1 847 (offshore)
Exmouth Plateau area	WA-84-P	Phillips Aust Oil Co	1 421 (offshore)
	WA-93-P	Hudbay Oil (Aust) Ltd	915 (offshore)
Total			4 183

OTHER SURVEYS

Esso Exploration and Production Aust Inc carried out a geological survey in the Canning Basin totalling 4 geologist months. North West Mining NL conducted a geochemical survey in the onshore Perth Basin totalling 2 party months. Other surveys included oceanographic surveys by Esso and Phillips on WA-84-P, WA-96-P and WA-97-P (3.5 party months), and an uphole velocity survey in the Perth Basin by WAPET on EP23.

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THE STRATIGRAPHY OF GINGINUP NO. 1 CENTRAL PERTH BASIN

by B. S. Ingram* and A. E. Cockbain

ABSTRACT

Ginginup No. 1, sited 3.5 km north of Gingin, was drilled in 1969 to obtain a continuously cored section through the Coolyena Group. The section penetrated was: Poison Hill Greensand (0-53.57 m), Campanian and possibly Maastrichtian; Gingin Chalk (53.57-74.75 m), Santonian-Campanian; Molecap Greensand (74.75-87.02 m), late Cenomanian-early Santonian; and Leederville Formation (87.02-102.26 m T.D.), Neocomian-Aptian.

INTRODUCTION

Ginginup No. 1 was drilled in 1969 by the Mines Department drilling section, and was sited on Mount Ginginup, some 3.5 km north of Gingin (Fig. 26). The site was selected, by G. H. Low, to provide a representative section through the Coolyena Group. The purpose of drilling the hole was to obtain a sequence of samples suitable for palaeontological (especially palynological) examination.

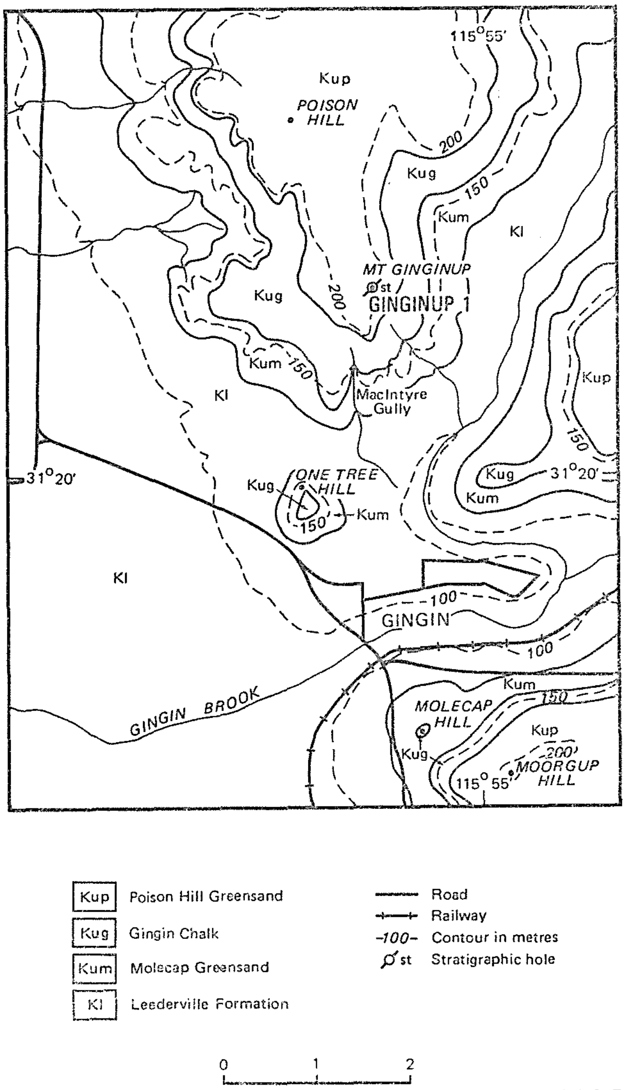

Figure 26 Solid geology sketch map of Gingin area showing position of Ginginup No. 1.

The Coolyena Group (Cockbain and Playford, 1973) consists of the Poison Hill Greensand, Gingin Chalk, Molecap Greensand and Osborne Formation. Prior to drilling Ginginup No. 1, the Gingin Chalk was considered to be of Santonian age, mainly on the evidence of pelagic-crinoid fossils (Withers, 1924; 1926). The ages of the Molecap and Poison Hill Greensands were only poorly known from internal evidence. Although the Osborne Formation had been assigned to the Albian-Cenomanian on the basis of plant microfossils obtained from boreholes, the relationship between it and the Molecap Greensand was uncertain.

In order to clarify these age relationships, it was decided to drill a continuously cored hole through the Coolyena in its type area. The site selected (Fig. 26) is 1 km north of the type section of the Gingin Chalk (MacIntyre Gully) and less than 5 km from the type sections of the Poison Hill Greensand (Poison Hill) and the Molecap Greensand (Molecap Hill).

Preliminary results obtained by Ingram were used by Playford and others (1978); these included lists of plant microfossils and ages for the Molecap and Poison Hill Greensands. The Campanian to possibly Maastrichtian age of the Poison Hill Greensand is now confirmed and the Molecap Greensand is considered to be late Cenomanian to possibly early Santonian. The Santonian-Campanian age of the Gingin Chalk suggested by Playford and others (1978) is confirmed by Rexilius' (1974) detailed analysis of the planktonic foraminifers from Ginginup No. 1. Although we now know that the Molecap Greensand and Osborne Formation both extend into the Cenomanian and are therefore, in part, equivalent in age, their stratigraphic relationships are still not fully understood.

This paper summarises the stratigraphy of Ginginup No. 1. The ages of the formations are based on an examination of the microplankton by Ingram (using Evans' (1966) zonation established in the Otway Basin) and for the Gingin Chalk, on Rexilius' (1974) study of the planktonic foraminifers. Additional biostratigraphic studies of the benthonic foraminifers (N. Marshall of the University of Western Australia) and the calcareous nannofossils (S. Shafik of the Bureau of Mineral Resources) are in progress. It is hoped that all these palaeontological studies will be published shortly.

DRILLING

Ginginup No. 1 was drilled from 12 November to 16 December 1969 with a small rotary drilling rig. The hole was situated near the summit of Mount Ginginup at latitude 31°19'00"S., longitude 115°54'15"E. The hole was continuously cored to a total depth of 102.27 m using a triple-barrelled split-inner-tube core barrel. Core recovery in the relatively soft sediments averaged 64 per cent in the unweathered section below 25 m. Detailed core-recovery figures are given in Figure 27. All core is stored in the Geological Survey core library at Dianella; there is 37.8 m of 50 mm diameter core and 7.9 m of 35 mm diameter core.

STRATIGRAPHY

The sequence penetrated in Ginginup No. 1 is shown in the composite log (Fig. 27) and is summarised below:

Formation	Borehole depth (m)	Elevation (m)	Thickness (m)
Poison Hill Greensand	surface	227·18	53·57+
Gingin Chalk	53·57	173·61	21·18
Molecap Greensand	74·75	152·43	12·27
Leederville Formation	87·02	140·16	15·24+
Total depth	102·26	124·92	....

Poison Hill Greensand (0-53.57 m): The Poison Hill Greensand is weathered from the surface to a depth of about 25 m and consists of very poorly sorted, often pebbly, sandstone, which is reddish brown in colour to about 15 m, and yellowish brown below 15 m. Up to 10 per cent of clay occurs. There are some unconsolidated

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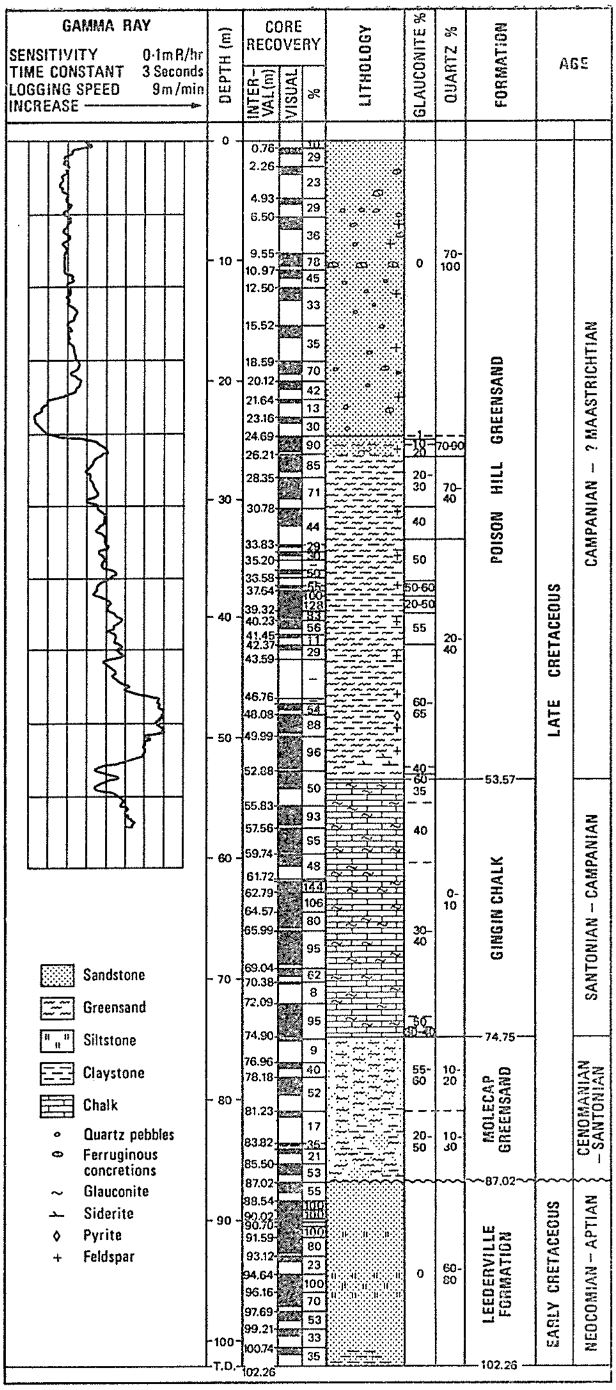

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Figure 27 Ginginup No. 1 composite log.

bands of very coarse quartz sandstone and a few hard ferruginised bands of very coarse sandstone between 30 and 80 mm thick.

Below 25 m, unweathered greensand is present. The greensand is poorly sorted (20 per cent coarse sand, 10 per cent medium sand, 50 per cent fine sand, 20 per cent silt and clay), and yellowish brown to greenish brown to greyish green in colour. Glauconite makes up to 65 per cent of the rock, and occurs mainly in the fine and medium sand fractions. Grey claystone is rare and usually occurs in lenses up to 300 mm thick. Traces of feldspar, limonite and pyrite are present and there is a 350 mm thick band near the base which contains about 30 per cent siderite.

The Poison Hill Greensand contains microplankton belonging to the *Nelsoniella aceras* and the *Xenikoon australis* zones and possibly the *Deflandrea pellucida* zone and is of Campanian age, possibly extending into the Maastrichtian.

Gingin Chalk (53.57-74.75 m): The Gingin Chalk is a greenish-grey glauconitic chalk. Glauconite ranges from 30 to 50 per cent and there is a low (less than 10 per cent) but variable amount of quartz in the rock. *Inoceramus* prisms are common at the top of the formation, but are rare elsewhere. Foraminifers are frequent; brachiopods, ostracods and crinoid and bivalve fragments were also noted. Traces of siderite and coprolites occur.

On the basis of the planktonic foraminifers the unit is Santonian-Campanian in age (Rexilius, 1974). Microplankton of the *Deflandrea cretacea* and *N. aceras* zones occur in the formation, the boundary between the two zones being about 6 m above the base of the chalk.

Molecap Greensand (74.75-87.02 m): The Molecap Greensand is divisible into two units in Ginginup No. 1. (a) 74.75-81.23 m greenish-grey poorly sorted greensand. (b) 81.23-87.02 m greensand with lenses of black claystones and coarse quartz sand.

The greensand contains up to 60 per cent glauconite, and consists of 15-25 per cent coarse sand, 25-35 per cent medium sand and 30-40 per cent fine sand. There are traces of siderite.

Microplankton from the formation belong to the *Ascodinium parvum* and *D. cretacea* zones with an unnamed assemblage between them, probably representing part of the "unclassified gap" of Evans' (1966) zonal scheme. The unit is considered to be late Cenomanian in age at the base, possibly extending into the early Santonian at the top.

Leederville Formation (87.02-102.26 m total depth): The Leederville Formation is a moderately well-sorted (5-25 per cent medium sand, 65-75 per cent fine sand, 5-25 per cent silt clay) grey silty sandstone. It is micaceous and carbonaceous and contains rare carbonaceous siltstone and silty shale.

Microfloras from the unit are poor and the age is Neocomian-Aptian.

CONCLUSIONS

The prime purpose of drilling Ginginup No. 1 was to obtain a complete sequence of samples through the Coolyena Group. This was achieved and the biostratigraphic information resulting from examination of these samples promises to be very useful. Other contributions to geology include:

1. The great depth of weathering (25 m) in the Poison Hill Greensand is confirmed. The corehole represents the thickest section (53 m) of the formation yet recorded.
2. The two-fold subdivision of the Molecap Greensand was not previously known. The lower, claystone-rich, unit is lithologically like the Osborne Formation, although the significance (if any) of this resemblance is not clear.

Comparison of Ginginup No. 1 with Gingin Brook No. 1, situated 6.7 km to the south-east, is instructive. In the latter hole, the top of the Leederville Formation is at an elevation of 9 m above sea level, and is overlain by 95 m of Osborne Formation. This is in contrast to the absence of the Osborne Formation in Ginginup No. 1, where the top of the Leederville Formation is 131 m higher. Clearly there are still gaps in our knowledge of the stratigraphy of the Coolyena Group in the Gingin area.

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RECENT FAULT SCARPS IN THE MOUNT NARRYER AREA, BYRO 1:250 000 SHEET

by I. R. Williams

ABSTRACT

Two prominent curvilinear photo-lineaments, identified as eroded fault scarps, occur near Mount Narryer, 60 km north-northeast of Meeberrie homestead.

Large mulga trees *(Acacia aneura)*, which are confined to alluvium at the base of eroded fault scarps, were sectioned for dendrochronology (counting of annual growth rings) in order to establish a minimum age for the faults. The scarps are at least 90 years old, hence the Mount Narryer fault traces are older than the Meeberrie earthquake of 1941 whose computed epicentre plots 21 km south of the fault traces. It is suggested that surface faulting of the hardpan produced favourable soil and seed-trapping conditions which induced coeval germination of mulga seeds. Consequently, the fault scarps may be little more than 90 years old.

Empirical relationships between earthquake magnitude (energy released) and surface dimensions of the fault scarp, suggest an earthquake magnitude of 6 to 7 for the faulting. Historical records describe a strong earthquake in 1885 which was felt in the Geraldton-Northampton district, about 280 km southwest of Mount Narryer (Everingham, 1968). In view of the comparable times, it is likely that this earthquake resulted from the faulting near Mount Narryer.

The discovery of similar tree-lined lineaments within 200 km of Mount Narryer and the matching of some lineaments with computed, recent earthquake epicentres suggests that the Meeberrie Seismic Zone may be more active than previously supposed.

INTRODUCTION

During routine regional mapping of the Byro 1:250 000 sheet an investigation was made of two curvilinear photo-lineaments situated 30 km east and 50 km east-northeast of Mount Narryer homestead, and roughly 60 km north-northeast of Meeberrie homestead. Reference has already been made to these lineaments by Gordon (1972, p. 31), who speculated that they represented fault scarps produced by the Meeberrie earthquake of 1941.

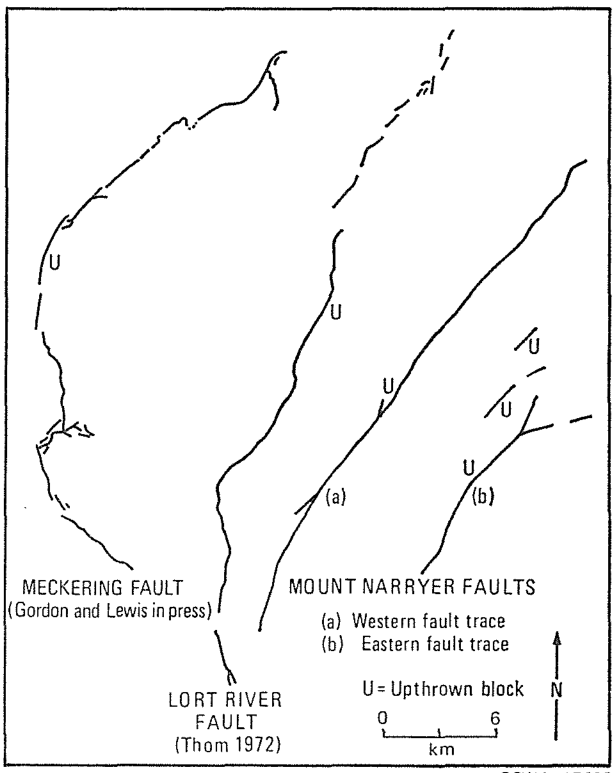


Figure 28 Comparison of fault traces.

Knowledge of such features on the Precambrian Shield of Western Australia has been increased in recent years by studies of the Meckering (1968) and Calingiri (1970) fault traces, (Gordon and Lewis, in press). Thom (1972) has identified a comparable photo-lineament, in the Lort River area near the south coast, as a scarp generated during a recent, but unrecorded, seismic event. The similarities between the Meckering and Lort River fault scarps and the two Mount Narryer scarps are shown in Figure 28.

The discovery that the Mount Narryer lineaments did coincide with a break in slope, that their dimensions and photo-expression resembled known fault scarps, and that there is recorded evidence of active seismicity in this region (Everingham, 1968), leads to the conclusion that the lineaments are eroded fault scarps.

The dark photo-expression of the lineaments is due to dense growth of large mulgas (*Acacia aneura*) in deep alluvium at the base (downthrown side) of the eroded scarps (Fig. 30 shows the eastern fault trace). This vegetation contrasts with the open shrub and grassland on the sheet-wash colluvium adjacent to the fault traces. The fault-scarp vegetation resembles the taller and denser vegetation of the stream courses. However, in contrast to the variable size of the stream mulgas, the scarp mulgas show a uniform size that would suggest coeval germination, in which case the age of the mulgas would give a minimum age for the earthquake scarp, which may be only a few years older than the tree age.

REGIONAL GEOLOGY

Both fault traces are confined to alluvium and colluvium over hardpan in broad valleys west of the Murchison River. The underlying bedrock consists of banded gneiss (mainly paragneiss), migmatite, amphibolite and iron-formation into which is intruded various types of granitoid and mafic rocks. The Mount Narryer area, between the western and eastern fault traces, is a north-trending belt of high-grade garnet quartzite, a meta-conglomerate, and garnet-sillimanite gneiss.

The trend of the fault traces (040°) is oblique to the regional foliation in the gneiss (355-025°). The western fault trace is parallel to quartz-filled shear zones in the banded gneiss and these also extend south and north from the terminations of the western fault scarp. These shear zones (including the western fault trace) separate granulite-facies rocks to the east from amphibolite-facies rocks to the west. It is possible that the recent fracturing follows the older fractures in the gneiss-migmatite basement (Fig. 29).

SURFACE CHARACTERISTICS OF FAULT TRACES

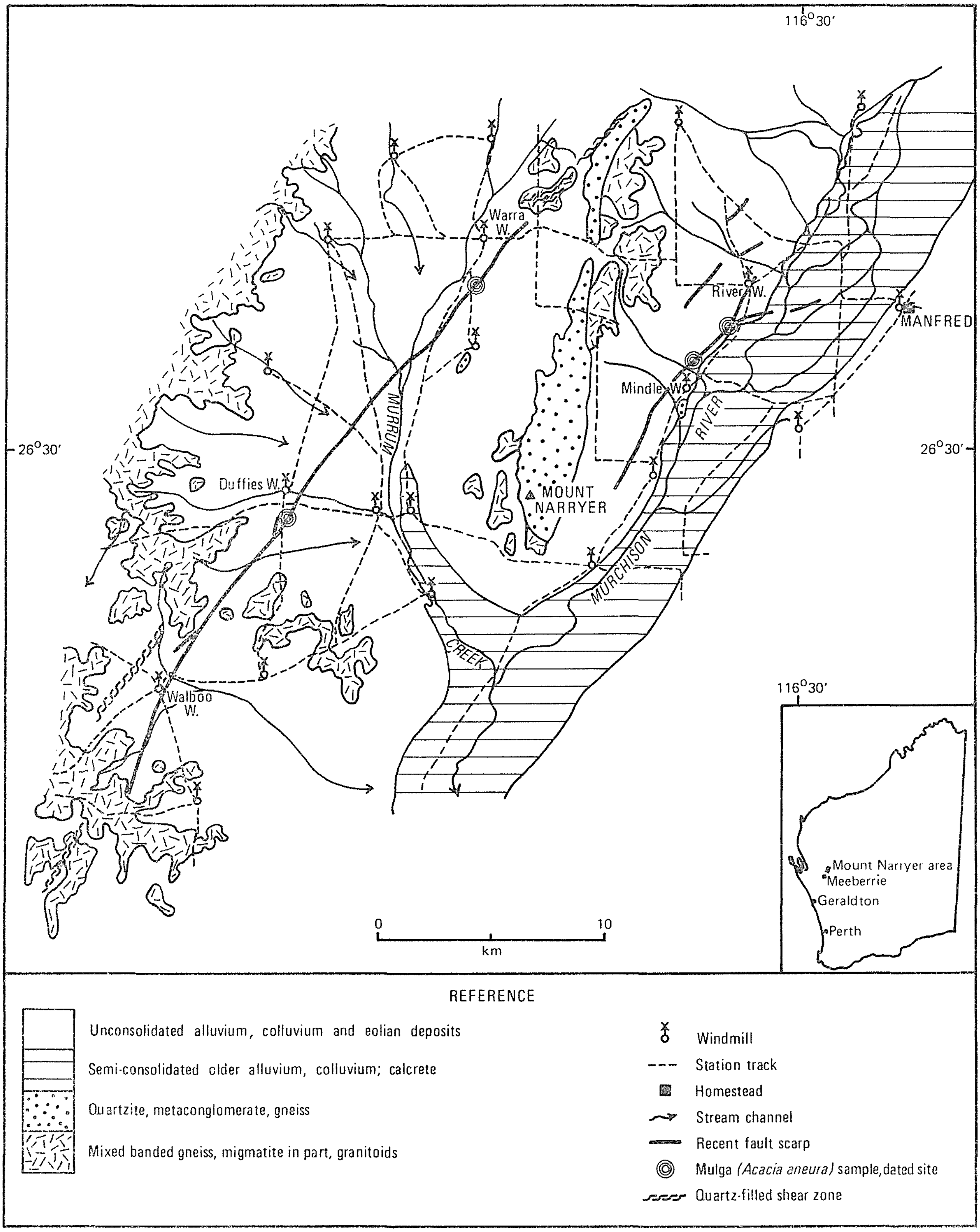
The dimensions and salient features are summarized in the following table:

Name	Length (km)	Estimated vertical displacement	Trend	Remarks
(a) Western fault trace	32·7	1–1·5	040°	Downthrown to east
(b) Eastern fault	11·0	1·2	040°	Downthrow to east small; separate faults at northern end downthrown to west

The western fault trace lies 9.5 km west of Mount Narryer, where it passes obliquely across the Murrum Creek drainage. It is a gently arcuate trace, convex to the west. Two short faults, both about 1 km in length, splay from the western side between Walboo Well and Duffies Well.

The eastern fault trace lies 4 km east of Mount Narryer, along the west bank of the Murchison River. Again, it is convex westward, but is more arcuate than the western fault trace, and bifurcates towards the northern end.

Three short (2 km) lineaments northwest of River Well appear to be fault traces which are downthrown to the west.



GSWA 17701

Figure 29 General geological sketch, Mount Narryer area.

The strip of dense vegetation which marks both fault traces varies from 10 m to 500 m in width. The western edge of the vegetation is very abrupt (Fig. 30) and presumably marks the actual trace of the fault. The eastern edge of the vegetation is irregular, the lineament being widest where water courses cross the scarp, and narrowest in colluvial areas close to outcrop.

Schematic cross sections of the fault including the distribution of the vegetation are given in Figure 31.

DENDROCHRONOLOGY

Four large mulga trees (*Acacia aneura*) were sampled, two from each fault trace. Polished, unvarnished sections were prepared from each tree and submitted to Mr. A. J. Hart, Forests Department, Kelmscott, for counting of annual growth rings. Check counts were carried out by Mr. B. Rockel, Forests Research Division, CSIRO, Kelmscott. The results of repeated counting are given in Table 15.

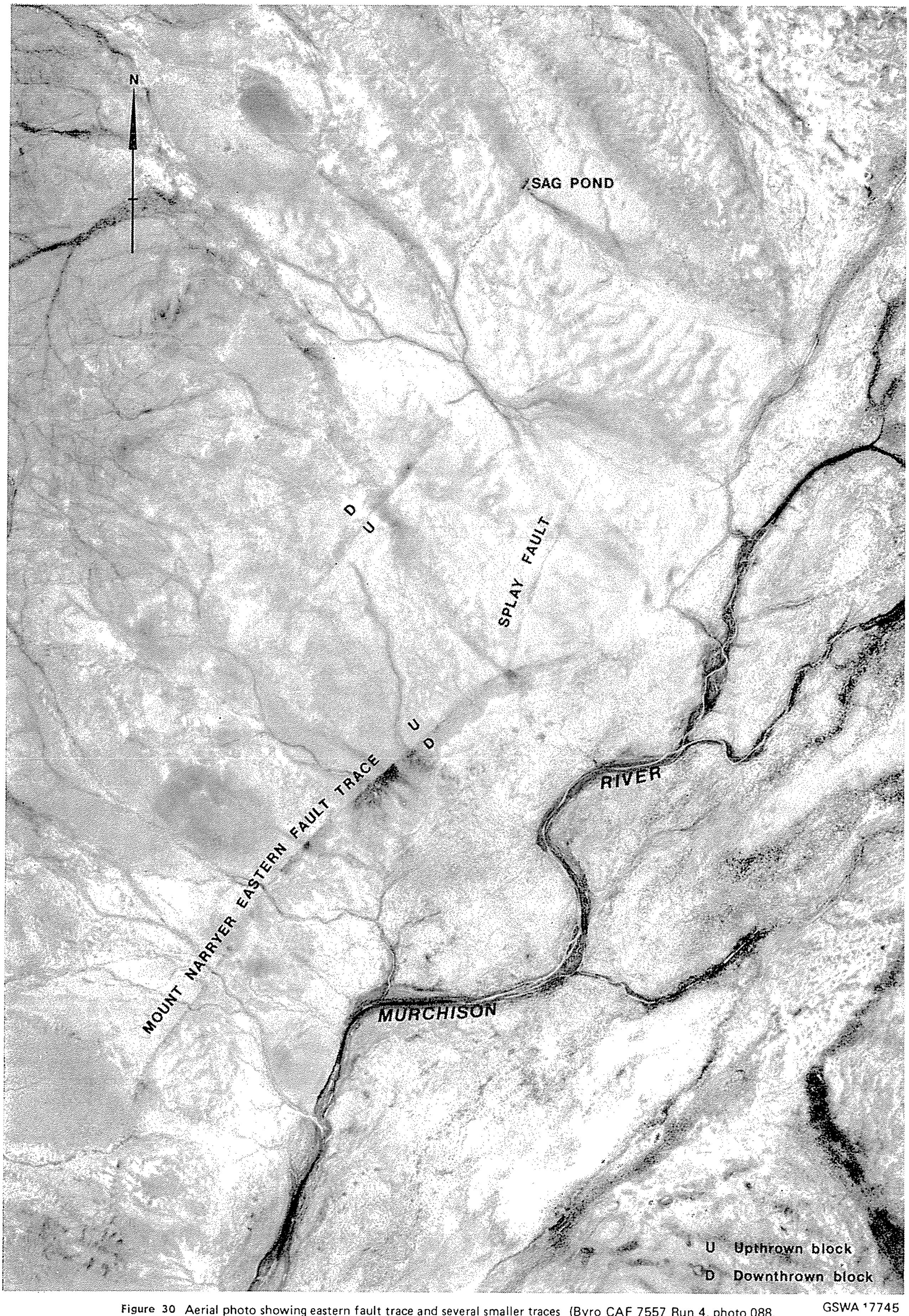


Figure 30 Aerial photo showing eastern fault trace and several smaller traces (Byro CAF 7557 Run 4, photo 088. Scale enlarged to approximately 1: 57000). GSWA 17745

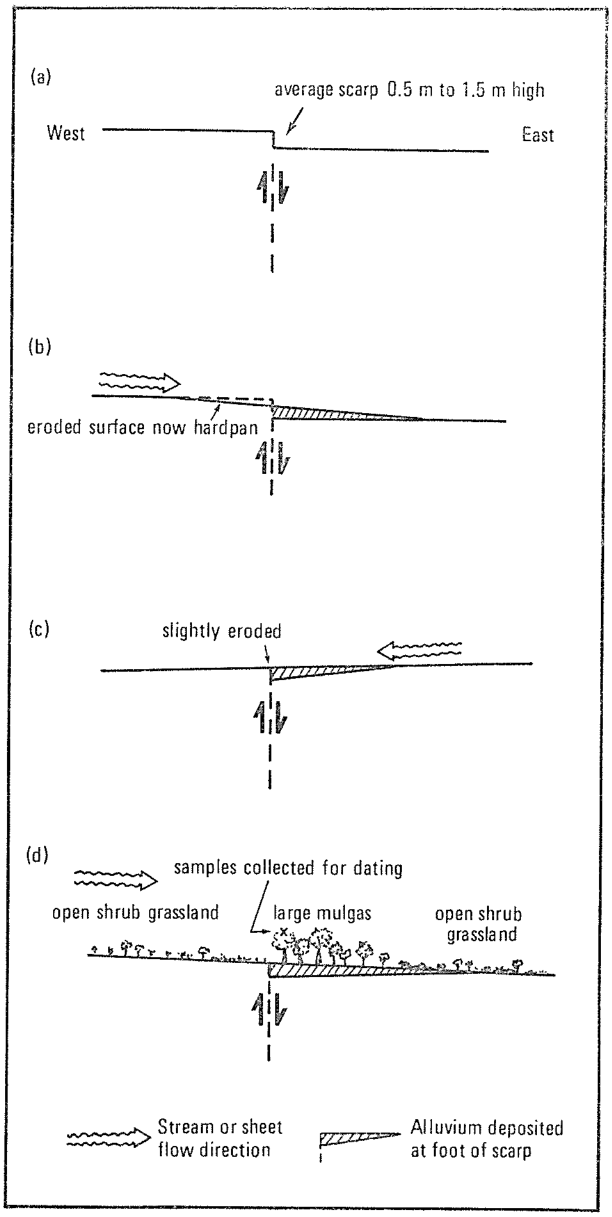


Figure 31 Schematic cross sections of eroded fault scarps, Mount Narryer area.

The estimated age range of each tree is a preferred age, or age range, subject to the constraints imposed by the difficulty of ascertaining the significance of some growth rings. Climatic variations of the Murchison area, particularly the irregular summer rainfall seem to have produced some 'false' growth rings, which have grown outside the normal growth season. Although the individual counts are not precisely consistent, even on the one sample, they all are clustered in the range of 70 to 90 years, suggesting that the fault scarps are closely related in time, if not coeval. The surface expressions of both fault traces show similar degrees of erosion.

It is concluded that the fault scarps are at least 90 years old and, subtracting from 1978, would have formed prior to 1888. Therefore the fault traces cannot be related to the Meeberrie earthquake of 1941 whose epicentre plots only 21 km south-southwest of the Mount Narryer faults (Gordon, 1972, p. 31; Denham, 1976).

SEISMIC HISTORY

The Mount Narryer area falls within seismic zones variously called Zone C (Everingham and Gregson, 1970), Zone 2—Meeberrie (Gordon, 1972), or the Meeberrie-Onslow Zone (Denham, 1976). Although it has not been as active as the South West Seismic Zone over the past 30 years (Doyle, 1971) this zone included the Meeberrie earthquake in 1941, one of the largest (magnitude 6.8) and deepest (33 km focal depth) earthquakes recorded on the Australian continent (Denham, 1976).

Besides the Meeberrie event four other computed epicentres lie within a 200 km radius of Mount Narryer (Fig. 32). Two epicentres plot near Coordewandy Hill, 85 km north of Mount Narryer. The other two epicentres both plot 180 km north-northeast of Mount Narryer (Everingham, 1968; Everingham and Parkes, 1971).

Inspection of 1972 CAF aerial photography covering these two areas revealed tree-lined lineaments similar in trend and size to the Mount Narryer fault traces. All these lineaments occur in areas of sheet wash over consolidated hardpan. These localities have not been inspected in the field.

Other probable recent fault traces have been checked in the field 30 km east-southeast of Byro homestead (20 km north of Mount Narryer). They are considered to be older than those at Mount Narryer as they strongly control the local drainage on the older colluvial hardpan unit.

M. Elias (pers. comm.) pointed out the occurrence of similar tree-lined lineaments near Wilyun Bore, 90 km east of Mount Narryer. Unlike all the other lineaments, which trend northeasterly, the Wilyun Bore lineaments trend northwesterly.

The localities of all these probable fault traces are shown in Figure 32. It is not specifically suggested that the plotted epicentres produced the visible lineaments, but merely that their close spatial relationships point to active seismic areas within the Meeberrie Seismic Zone.

An account in Geraldton and Northampton newspapers of an earthquake in January, 1885 raises some interesting speculations, particularly in view of the age of the Mount Narryer faulting. These reports indicated a felt intensity of about MMV-VI, (Modified Mercalli scale, Gordon, 1972, p. 36), and that the noise and shaking came from a northeasterly direction (Everingham and Tilbury, 1972).

TABLE 15. DENDROCHRONOLOGY, MOUNT NARRYER FAULT TRACES—AGE OF MULGA (*ACACIA ANEURA*) FROM RING COUNTING

G.S.W.A. Sample No.	Byro 1:250 000 CAF air-photo data (Run No., photo point)	Locality		Estimated age (in years)		Estimated age range (preferred) age (in years)
		Co-ordinates	Description	Observer I*	Observer II	
			Western fault trace			
60119	4–086–1022	26°26′30″S 116°21′00″E	2·5 km S Warra Well, Mount Narryer Station	88, 79	94, 72	80–85
60120	5–204–456	26°31′45″S 116°16′00″E	1·5 km S Duffies Well, Mount Narryer Station	86, 78, 83, 79	61, 76, 69	70–80
			Eastern fault trace			
60115	4–086–1018	26°27′15″S 116°28′15″E	2 km SSW River Well, Manfred Station	70	68–70	70
60116	4–086–1019	26°28′00″S 116°27′00″E	1·5 km N Mindle Well, Manfred Station	90	70–80	90

* Ring counting of prepared mulga samples carried out by Mr. A. J. Hart, Forest Department and Mr. B. Rockel, Forests Research Division, C.S.I.R.O.

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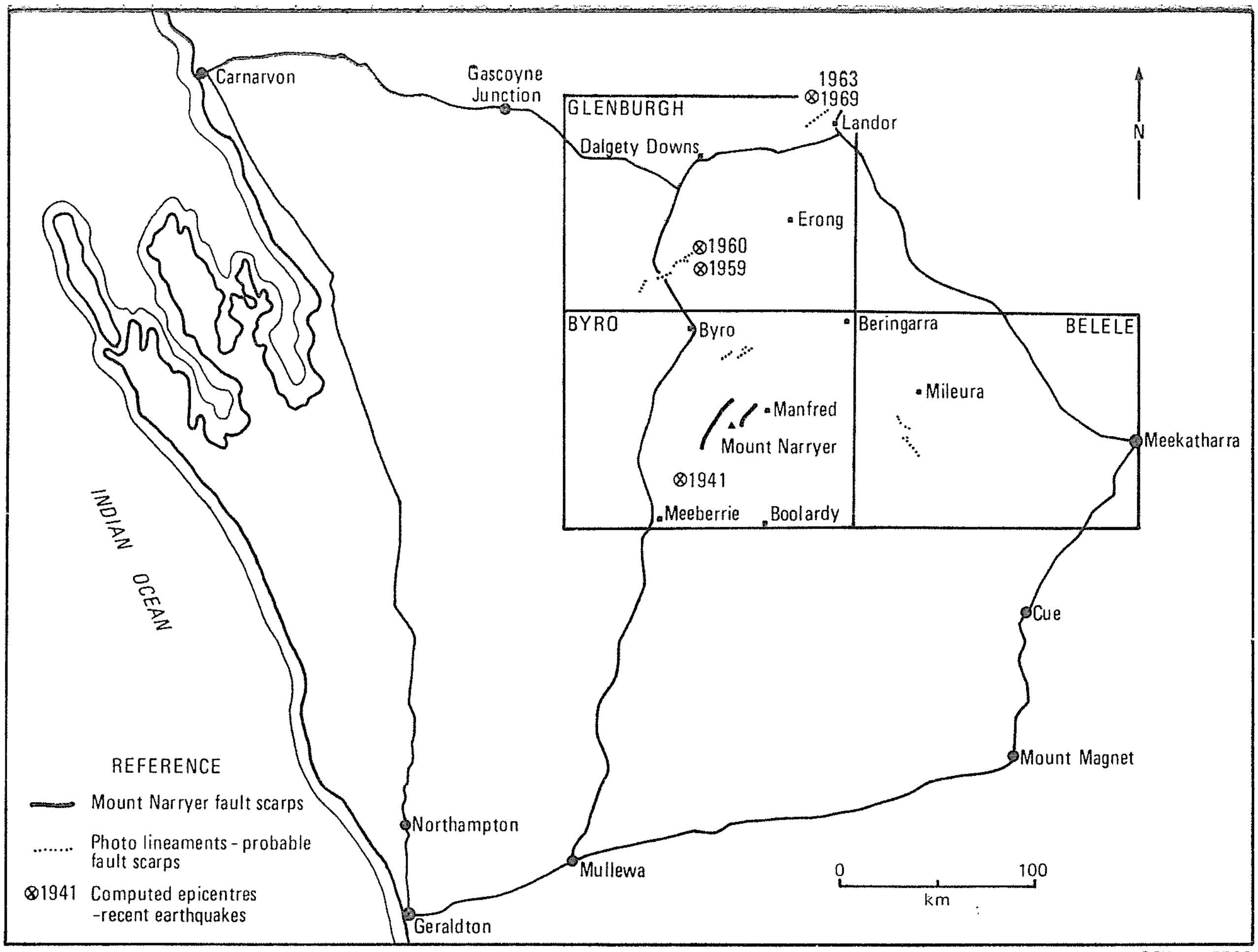

Figure 32 Location map of Mount Narryer faults, computed epicentres and photo-lineaments in relation to 1:250 000 sheets.

DISCUSSION AND CONCLUSIONS

The magnitude of an earthquake is an expression of the energy released. The Richter Scale is the best known scale for magnitude, which is measured from seismic records. Seismologists have also developed empirical relationships between earthquake magnitude and fault characteristics, based on shallow earthquakes in California and Nevada (Tocher, 1958; Bonilla, 1970), and these have been used for calculations involving the Mount Narryer faults.

In the following equations, L is the length of the fault trace in kilometres, D the maximum displacement in centimetres, and M the magnitude:

$$M = 5.65 + 0.98 \text{ Log } L$$
$$M = 5.22 + 0.53 \text{ Log } LD \quad \text{(Tocher, 1958)}$$
$$\text{Log } D = 0.57\, M - 1.91 \quad \text{(Bonilla, 1970)}$$

A fourth formula is based on 42 world-wide events:

$$\text{Log } LD^2 = 1.90\, M - 7.65 \quad \text{(King and Knopoff, 1968)}$$

The western fault trace of Mount Narryer is 32.7 km long and has an estimated maximum vertical displacement of about 1.5 metres. Substituting these values in any of the above formulae gives a magnitude of between 7.1 and 7.2.

Gordon and Lewis (in press), using these relationships for the Meckering earthquake, calculated a magnitude of 7.2-7.9 against a known magnitude (measured) of 6.8. This suggests that in the Precambrian Shield there is a tendency for the formulae to overestimate the magnitude by up to one unit.

The question now arises, would a 6 to 7 magnitude earthquake at Mount Narryer be felt in Geraldton? Richter (1958) has shown that an earthquake of such magnitude would be felt up to 400 km away, and Geraldton is only 280 km from Mount Narryer. The Meeberrie earthquake, which had a magnitude of 6.8, was felt in Geraldton with an intensity of VI on the Modified Mercalli Scale (Denham, 1976). From this it is deduced that an earthquake of estimated magnitude 6 to 7 at Mount Narryer should have been felt in Geraldton with an intensity of V-VI.

If the oldest tree growing along the degraded scarp was 90 years old in 1978, it would have germinated in 1888, only three years after the known earthquake.

The mulgas at Mount Narryer grow in alluvium derived either by erosion of the scarp and/or by ponded deposition against the scarp. During heavy rain the mixed colluvial-eolian deposits, intersected by the fault scarps, are flooded to a depth of several centimetres. This surface is underlain, at shallow depths, by an impermeable clay hardpan which is not conducive to germination. Hence, during heavy rain, seeds would normally wash across this surface into stream channels. The ruptured hardpan exposing sterile subsoil (A. J. Hart, pers. comm.) and the newly deposited alluvium would act as a seed trap and seed bed, and germination could commence following the first heavy seasonal rain after the faulting occurred.

The absence of dead trees along the eroded scarp, and the deliberate sampling of the oldest mulgas, supports the contention that the age of about 90 years is close to the initial germination of vegetation along the scarp. The time lag of mass germination after faulting would be three years, which is the average frequency of heavy cyclonic rains in this area.

It is not unreasonable to suggest, but by no means proven, that the Geraldton-Northampton earthquake of 1885 was caused by the Mount Narryer faulting.

ACKNOWLEDGMENTS

The author thanks Mr. R. P. Groom of Domus Furniture for the preparation of the mulga samples. Counting of rings was undertaken by Mr. B. Rockel, Forest Research Division, CSIRO, and Mr. A. J. Hart, Forests Department, Kelmscott, whose helpful discussions are also acknowledged.

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THE GEOLOGY OF THE PEAK HILL AREA

by R. D. Gee

ABSTRACT

A thick geosynclinal sequence of arkose, conglomerate, basalt, greywacke, sandstone and shale, possibly as much as 20 km thick, occurs in the Glengarry Sub-basin of the Nabberu Basin. This sequence is called the Glengarry Group, and eight of its constituent formations are defined and described. It is probably 2.0-1.8 b.y. old. A shallow-water clastic facies, a thick volcanic pile, and a deep turbidite trough are identified.

This sequence is unconformably overlain by the Padbury Group (probably 1.7-1.6 b.y. old), which is a chemogenic sequence with a coarse basal conglomerate called the Wilthorpe Conglomerate. The Wilthorpe Conglomerate was the coarse conglomeratic part of the Labouchere Formation as originally defined. The Labouchere Formation was previously assigned to the Padbury Group, but the revised formation is now placed in the Glengarry Group.

Metamorphosed sedimentary rocks in the vicinity of Peak Hill townsite are called the Peak Hill Metamorphic Suite, and are unconformable beneath the Glengarry Group. These metamorphics form a mantle of the Marymia Dome, which has a core of reworked Archaean basement. In the Glengarry Sub-basin, deformation is by crumpling between basement domes.

Regional correlations suggest that the Glengarry Group forms part of an ensialic geosyncline, now largely covered by the Bangemall Group, between the Hamersley Basin and the Yilgarn Block.

INTRODUCTION

Two main problems outlined by Bunting and others (1977) in their preliminary synthesis of the Proterozic stratigraphy and structure along the northern margin of the Yilgarn Block were the relationship of the Padbury Group to the older rocks of the Glengarry Sub-basin, and the stratigraphic relationships within that older sequence. In an attempt to clarify these problems, the area surrounding Peak Hill has been re-mapped, and the Proterozoic stratigraphy in the eastern part of Robinson Range Sheet has been re-examined. This paper summarizes this reappraisal, and establishes a stratigraphic framework which should serve as the basis for continuing studies in the western part of the Nabberu Basin.

EVOLUTION OF STRATIGRAPHIC CONCEPTS

MacLeod (1970) erected the first stratigraphy for the area when he introduced the terms "Peak Hill, Horseshoe, Labouchere and Robinson Range Beds". Although recognizing the possibility of a Proterozoic age, he opted for an Archaean age. During mapping of the Robinson Range Sheet, Barnett (1975) identified this entire succession as having the overall features of a Proterozoic basin. He formalized some of the stratigraphic units, and included them in the Padbury Group, which was defined to include only those units which formed a continuous sequence.

Subsequently, evidence emerged for the existence of a thick sequence older than the Padbury Group, which until its stratigraphy could be clarified, was termed the "pre-Padbury" by Elias and Williams 1977, Williams and others 1978, and the "Glengarry axial sequence" by Bunting and others (1977). The most compelling evidence at that stage was the exposed unconformity between conglomerate assigned to the Labouchere Formation and granitoid of the Yarlarweelor Gneiss Belt. Williams and others (1978) also pointed out that the "pre-Padbury" displayed a more complex structure and a higher grade of metamorphism than the Padbury Group.

During selective remapping on the Peak Hill sheet, it became evident that an unconformity lay *within* rocks assigned to the Labouchere Formation, and as the type section of the Labouchere Formation falls within the "pre-Padbury", some terminological revision is now necessary.

PROTEROZOIC STRATIGRAPHY

EARLY PROTEROZOIC METASEDIMENTARY INLIERS

Peak Hill Metamorphic Suite

This is the metasedimentary sequence in the area within a 7 km radius of the Peak Hill townsite. It occurs unconformably below the Glengarry Group, and does not display the high metamorphic grades and the advanced gneissic fabrics of the Archaean parts of the Marymia Dome. The suite corresponds more-or-less to the "Peak Hill Beds" of MacLeod (1970). It represents a sequence of terrigenous clastics, chert and carbonate, which have been repeatedly deformed and metamorphosed to upper greenschist facies. Its age is uncertain, but is presumed to represent Early Proterozoic sedimentation, tectonism, and metamorphism.

The western part of the exposed area is quartz-muscovite-magnetite schist, interlayered with flaggy quartzite. The quartzite is fine grained, has lepidoblastic texture (elongate quartz in a metamorphic mosaic), and contains minor amounts of potash feldspar, biotite, and muscovite. Lamination is defined by grain-size variations on a millimetre scale, and by stylolitic carbonaceous stringers. No evidence of cross-bedding is evident. A distinctive feature is the presence of moulds of a fibrous lenticular mineral having a radiating habit similar to gypsum (selenite). These features suggest that the quartzite is metamorphosed chert.

Calc-silicate schist and granofels contain albite, calcite, epidote and quartz in a granoblastic mosaic. Biotite and chlorite impart a foliation. Poikiloblastic garnet and magnetite are also present. These rocks are metamorphosed calcareous siltstones, and indicate upper greenschist facies.

The eastern part of the Peak Hill Metamorphic Suite is more homogeneous than the western part, and is not so obviously metasedimentary. Mostly the rocks are retrogressed and granulated quartz-muscovite-plagioclase-sericite gneiss, some of which is banded paragneiss and some of which is probably sheared granitoid. Porphyritic adamellite occurs 15 km east of Peak Hill townsite, but its relationship to the metasedimentary sequence, whether intrusive or unconformable, is unknown.

Sequence at Horseshoe Lights

Stratigraphically below the Thaduna Greywacke at Horseshoe Lights is a sequence that does not fit conveniently into the regional stratigraphy. The rocks here are quartzite, quartz-muscovite-sericite schist, garnetiferous felsic agglomerate and lapilli tuff of mafic composition. The fabric in the pelitic schist demonstrates repeated deformation, and together with the metamorphic grade suggests that the pelites and volcanics correlate with the Peak Hill Metamorphic Suite.

It is possible that the quartzite at the Horseshoe Lights Mine is equivalent to the base of the Glengarry Group, and that the overlying arkose and greywacke are the Doolgunna Arkose and Thaduna Greywacke respectively. There is certainly a contrast in deformation and fabric on either side of the quartzite; and an unconformity is inferred,

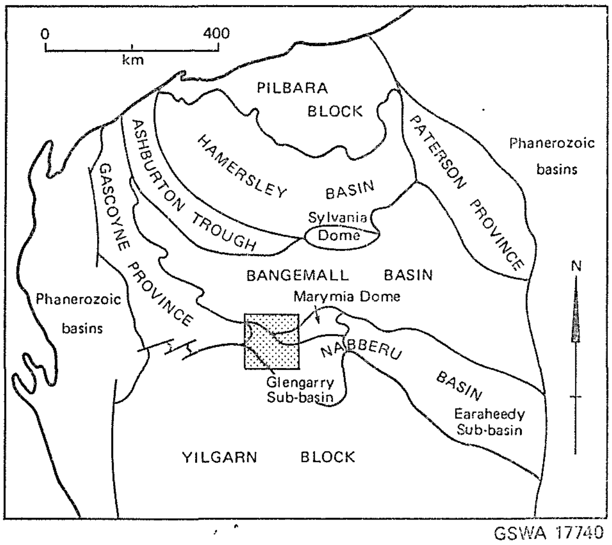

Figure 33 Location diagram showing relation of area to tectonic units in the northern part of the Western Australian Shield.

although there is no direct evidence of this. Nevertheless, this is the interpretation placed on Figure 33, but the metamorphic rocks are not specifically assigned to the Peak Hill Metamorphic Suite.

GLENGARRY GROUP

Definition

The Glengarry Group is a newly defined group, of greywacke, terriginous clastics, carbonate and volcanics that unconformably overlies Archaean basement, and is unconformably overlain by the Padbury Group in the Glengarry Sub-basin. It includes what has been informally termed the "Axial Sequence" and "pre-Padbury" by previous writers, and also includes most of what has previously been termed the Labouchere Formation.

Basal formations of the Glengarry Group

The base of the Glengarry Group is exposed more or less continuously along the southern margin of the Glengarry Sub-basin, where the orthoquartzitic Finlayson Sandstone (Elias, Bunting, and Wharton 1979) rests unconformably on Archaean granite of the Yilgarn Block. Over most of its extent, the Finlayson Sandstone is overlain by the Maraloou Formation—a calcareous shale sequence. Together, these two formations constitute the shelf facies of the Glengarry Group in the southern part of the sub-basin.

Within the Glengarry Sub-basin is a basement high of Archaean granite, called the Goodin Dome. This is unconformably overlain by a sandstone similar to the Finlayson Sandstone. Physical continuity cannot be established between them, and furthermore the sandstone at Goodin Dome is overlain by a thick arkose unit, which marks the appearance of the axial sequence in the northern part of the Glengarry Sub-basin. For these reasons, this sandstone blanketing the Goodin Dome is given a new name, Juderina Sandstone.

On the northern margin of the Glengarry Sub-basin a continuous basal orthoquartzite unconformably overlies the basement, and is conformably overlain by the same arkose unit as around the Goodin Dome. This orthoquartzite is also placed in the Juderina Sandstone. Previously this northern boundary has been interpreted as a fault (Bunting and others 1977), but in view of the stratigraphic consistency, it is more properly regarded as a folded, but essentially intact, unconformity.

The Juderina Sandstone on the edge of the Marymia Dome extends westerly toward the Peak Hill mine area, where it passes into a boulder conglomerate of comparable thickness to the Juderina Sanstone and retains the same stratigraphic position. This unit is termed the Crispin Conglomerate.

Crispin Conglomerate

The Crispin Conglomerate is that formation of boulder pebble and granule conglomerate and coarse sandstone which occurs at the base of the Glengarry Group, where it overlies the Peak Hill Metamorphic Suite. It extends in an arc of continuous exposure from a point 5 km south of Peak Hill townsite, eastward to the vicinity of the old Saint Crispin gold mine. It is about 200 m thick.

The lower part is schistose, sericitic granule conglomerate and coarse sandstone, which contains abundant pebbles and boulders of metamorphic-textured quartzite averaging 0.1 m in diameter and ranging up to 1.5 m in diameter. The matrix is schistose, and the generally well-rounded boulders are now prolate ellipsoids because of tectonic flattening and stretching in the cleavage.

Toward the top of the formation, pebbles become sparse, and the rock is simply a schistose, sericitic granule conglomerate and sandstone, in which low-angle trough cross-bedding is recognizable. The sericite is mainly derived by granulation of abundant detrital muscovite. A fluvial origin is envisaged for the Crispin Conglomerate.

Juderina Sandstone

The Juderina Sandstone is a well-bedded orthoquartzitic sandstone at the base of the Glengarry Group around the northern part of the Goodin Dome. Its type area is 3 km north of Juderina Bore (119°12'E, 25°53'S), where it is 30 m thick.

Around the Goodin Dome, the bedding in the sandstone is strictly conformable with the contact over a distance of 3 km, and is only disturbed by post-depositional faulting. Where visible, the contact is sharp, non-conglomeratic, and totally without intrusive features. Dolerite dykes occur in the granite, but are absent in the Juderina Sandstone.

The correlate of the Juderina Sandstone, along the southern margin of the Marymia Dome is 50 m thick. The beds in the lowermost metre are of feldspathic sandstone containing small pebbles of vein quartz, which are now flattened and stretched. Angular discordance occurs between the underlying gneiss and the sandstone.

The sandstone has a recognizable sedimentary texture, together with cross-bedding and ripple marks. In the region adjacent to the Marymia Dome, it appears to be a facies variant of the Crispin Conglomerate, the facies change correlating with a change of basement type from Archaean gneiss to the Peak Hill Metamorphic Suite. The Juderina Sandstone is interpreted as a transgressive shoreline deposit developed on a flat unconformity surface.

Finlayson Sandstone

The Finlayson Sandstone (Elias, Bunting and Wharton, 1979) extends into the area of Figure 33 only at the locality 10 km southwest of Mikhaburra where it is a ripple-marked and cross-bedded orthoquartzite 10 m thick resting unconformably on granite of the Yilgarn Block.

At this locality, the basal orthoquartzite is overlain by an alternation of sandstone and slaty siltstone about 100 m thick. Overlying this is magnetite-bearing sandstone and quartzose-feldspathic microconglomerate, which marks the appearance of the Doolgunna Arkose.

Doolgunna Arkose

The Doolgunna Arkose is a thick sequence of medium- to coarse-grained arkose and minor quartz-pebble conglomerate and argillaceous siltstone, which on the southern side of the Glengarry Sub-basin appears to lie conformably above the basal orthoquartzite, and which is conformable with the overlying Karalundi Formation. Around the northern margin of the Goodin Dome, there is a gap in exposure between the Juderina Sandstone and the arkose, but on the northern side of the sub-basin, the correlate of the Juderina Sandstone passes upward into arkose by the appearance of arkose beds within the sandstone.

In the type area, 14 km southeast of Ruby Well Find, arkose is spectacularly exposed in breakaway country, as it is in the area 13 km northeast of Doolgunna (off the area of Fig. 34). It is invariably deeply weathered and has the topographic expression of deeply weathered granite. It weathers in buff and reddish-brown colours.

Individual arkose beds may be stacked one upon the other, or separated by thin shale beds. Arkose beds range in thickness from less than 1 m up to 4 m, and display gross upward-fining grading, bottom scouring of the shale,

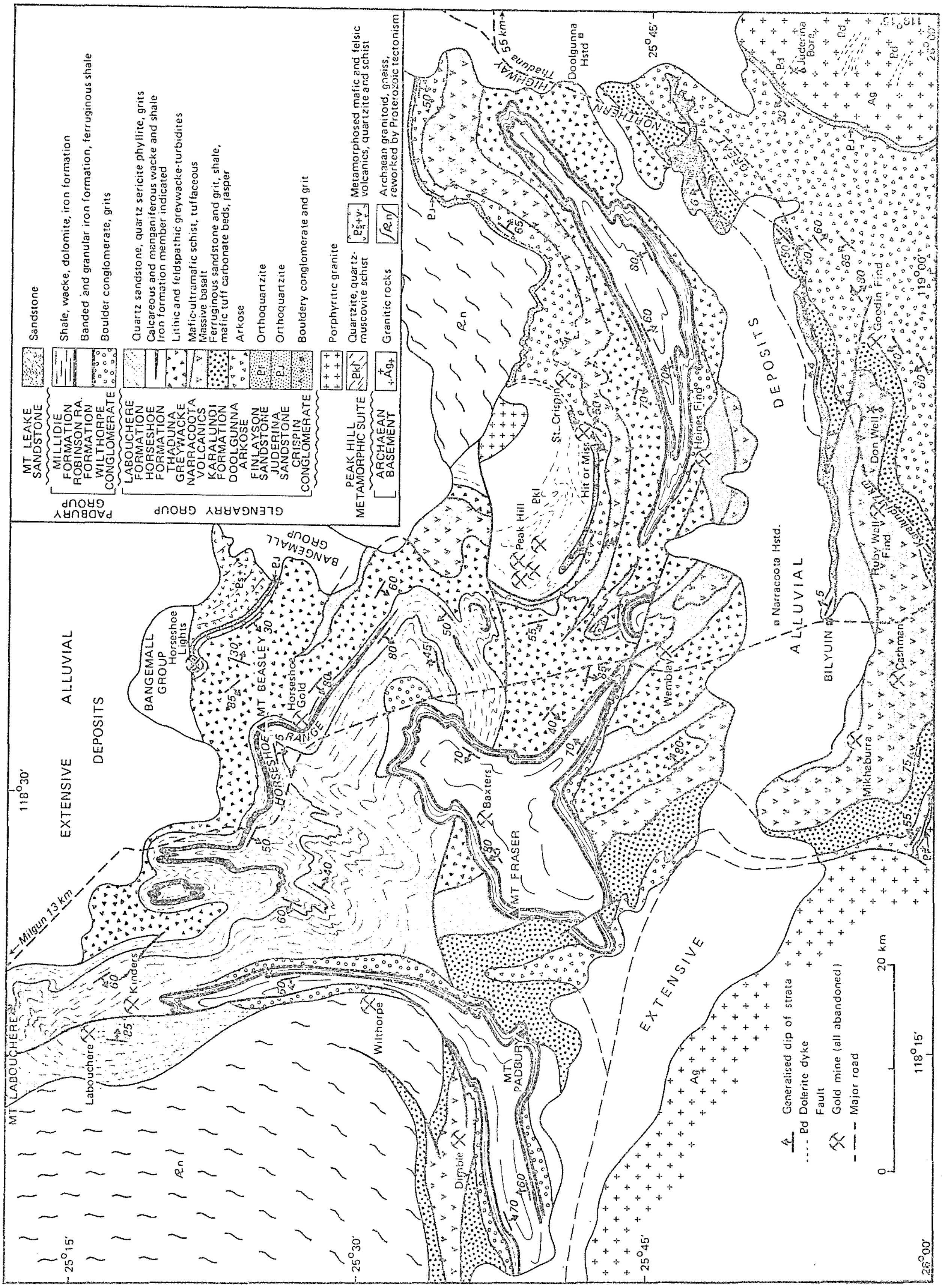

Figure 34 Geological map of parts of Peak Hill and Robinson Range 1:250 000 sheets

and diffuse, trough-type cross-bedding. The lower parts of the arkose beds may contain rounded clasts of vein quartz, up to 20 mm in diameter, and fragments of the underlying shale, but the bulk of each bed consists of angular quartz, microcline and plagioclase up to 10 mm in diameter. Feldspar grains are as abundant as quartz, and the rocks are true arkose.

Strangely, no granite clasts are found, and it appears that the source granite was disaggregated into consituent crystals, perhaps by a balance of deep chemical leaching and rapid mechanical breakdown.

The Doolgunna Arkose is continuous throughout this part of the Glengarry Sub-basin, but there are rapid thickness variations. It is possibly 5 km thick around the northern part of the Goodin Dome, about 1 000 m thick along the southern margin of the Marymia Dome, and only a few hundred metres thick at the western end of the Marymia Dome. East of the area of Figure 34, in the Doolgunna-Thaduna area, mapping has established that the Doolgunna Arkose passes laterally into the Thaduna Greywacke.

The Doolgunna Arkose is considered to be a thick clastic wedge emanating from the Goodin Dome, and spreading extensively through the Glengarry Sub-basin. It is interpreted as a complex piedmont deposit, involving fluvial, shallow-marine and possibly lacustrine processes. Although a close spatial connection exists between the arkose and the granite, the two rocks have not been found in contact. Presumably the Juderina Sandstone must be missing in some areas.

Karalundi Formation

The Karalundi Formation is a mixed clastic-carbonate-chert-tuff sequence, about 1 500 m thick, lying conformably between Doolgunna Arkose and the Narracoota Volcanics in the southern part of the Glengarry Sub-basin. The type area is along the east-west fence line 11 km north-northwest of Karalundi (south of the area of Fig. 34), and good exposures occur adjacent to the Great Northern Highway between 8 and 12 km north from Karalundi along the highway.

The base is the single layer of fine-grained, massively bedded orthoquartzite which is exposed 3 km southwest of Don Well. Above this is an interbedded sequence of feldspathic sandstone, kaolinitic siltstone and thin orthoquartzite. This association becomes more ferruginous higher in the sequence.

Medium- to fine-grained, poorly sorted, ferruginous, black sandstone is the most distinctive rock in this formation. It contains both well-rounded and angular quartz grains, and feldspar clasts set in a hard, black cement. Upward-fining beds, convolute lamination, and cement angle cross-bedding are common in these beds, which appear to be shallow-water marine deposits. These rocks are interbedded with ferruginous and siliceous shales, which commonly contain silty lenses with ripple-drift lamination.

Basaltic tuff, minor pillow basalt, and carbonate beds appear in the upper part, being conspicuous in the section 11 km north-northwest of Karalundi. The tuffs are clearly waterlain, being well bedded, with upward fining grading, and planar and ripple-drift lamination. They contain fragments of shale and basalt in a matrix of fine chlorite, epidote, saussuritized plagioclase, calcite, ilmenite, and magnetite. Calcite also occurs as large idioblastic authigenic crystals.

Carbonate beds range from only a few centimetres to several metres thick, and are either finely laminated (commonly with cross-lamination) or oolitic.

Another distinctive rock is hematite-magnetite jasper, which occurs as steeply inclined pipes up to 20 m in diameter. It has a distinctive colloform texture due to grain-size differences in the cherty material, these differences being outlined by cellular patterns of hematite staining. Euhedral magnetite is abundant, commonly forming clusters within or around the cellular structures. Veins of identical material also penetrate the interpillow material in the basalt. These jasper pipes are interpreted as colloidal hydrothermal deposits formed in fumarolic pipes associated with the basalt volcanism.

The top of the formation is taken as the continuous bed of ferruginous, cherty sandstone which extends for 10 km southwest from Ruby Well Find.

The Karalundi Formation represents a transition from fluvial to shallow-water marine environments, and records the commencement of basalt volcanism.

Narracoota Volcanics

At the lower stratigraphic levels, the Narracoota Volcanics is a massive basalt, and at upper levels mafic-ultramafic phyllite. It conformably overlies the Karalundi Formation in the type area which is specified as the Mikhaburra-Cashman area, 10 to 15 km south of Narracoota.

Basalt, about 4 km thick, is exposed in this area. It is generally massive, but is sheared in some places. Pillowed and fragmental types are also present. The basalts are usually altered; the clinopyroxene shows varying degrees of alteration to actinolite, and the plagioclase to saussurite. More advanced alteration produces actinolite, epidote, clinozoisite, albite and calcite.

At Mikhaburra, at the top of the main pile of massive basalt, is a volcanoclastic sequence of quartz-chlorite phyllite which displays clastic textures, interbedded with clay-pellet quartz sandstone and feldspathic-lithic greywacke. This horizon seems to mark a change to predominantly mafic-ultramafic pyroclastic volcanics, which occur extensively in the general area northeast and northwest of Narracoota.

Although some of this rock is simply sheared basalt, much of it is talc-tremoite-chlorite phyllite with only minor amounts of altered feldspar, and characterized by a fragmental texture on a scale of millimetres. The fragments are usually of similar material to the matrix. Despite the intense shearing, some of these rocks still exhibit remnants of devitrified glass fragments.

The total thickness of the Narracoota Volcanics is about 6 km, but the complex deformation in the upper part makes an accurate estimate impossible. However, the formation does seem to have its maximum thickness along an axis from Ruby Well Find through Mikhaburra, perhaps extending into the Dimble area. In this latter area, Elias and Williams (1977) record considerable amounts of magnesian lavas, containing olivine, skeletal clinopyroxene, and devitrified glass. The Narracoota Volcanics lens out in the Doolgunna and Horseshoe areas by interfingering with Thaduna Greywacke.

Thaduna Greywacke

Extensive areas of greywacke, covered by a thin veneer of alluvium, but excellently exposed in water courses, have been encountered within and to the north of the major synclinorial axis (Fig. 34). These rocks, which bear a striking resemblance to the Thaduna Beds (MacLeod, 1970), hold a constant stratigraphic relationship to the Narracoota Volcanics in the area shown in the central part of Figure 33, and interfinger with the greywacke in the distal parts of the volcanic pile.

Additional field investigations between Doolgunna and Thaduna show that the Doolgunna-Karalundi-Narracoota stratigraphic interval passes laterally into a thick sequence of greywacke. Consequently the greywacke discussed here appears to be the same litho-stratigraphic unit as the undefined Thaduna Beds. For the present, it is convenient to use Thaduna Greywacke as a formal term to include all this greywacke in the Glengarry Sub-basin. The type locality of the Thaduna Greywacke is taken as the area surrounding the Thaduna Mine.

The Thaduna Greywacke is a thick turbidite sequence consisting of graded beds of coarse- to fine-grained lithic and feldspathic wacke with subordinate interbedded slaty mudstone. Like the arkose, the greywacke is invariable deeply weathered, exhibiting red, purple, buff and chocolate colours. The wacke beds contain a variety of sedimentary structures, such as single and multiple graded cycles, shale intraclasts, flute marks, load casts, convolute lamination and slumping. Individual wacke beds are generally of the order of 1 to 2 m thick.

Identifiable lithic fragments include basalt, jasper and shale, but the deep weathering limits petrographic study. Feldspar is abundant as discrete clasts and as matrix, but the relative contributions of microline and plagioclase are unknown. The only petrological descriptions of these rocks are of drill core from Thaduna by Trendall (1970). He described: lithic fragments of shale, tuff, lava, and siltstone; clasts of epidote, amphibole, quartz and albite; and matrices rich in chlorite and hematite. Such assemblages are consistent with derivation from the Narracoota Volcanics.

These rocks are interpreted as proximal turbidites marking a deep trough marginal to a rapidly accumulating submarine basalt pile.

Horseshoe Formation

The Horeshoe Formation is the unit of carbonate-cemented greywacke, shale and banded ironstone that occurs in a section extending for 3 km west from the Horseshoe gold mine, across the Horseshoe Range. It is used in the same sense as the 'Horseshoe Beds' of MacLeod (1970). No specific base is defined, as it is transitional upwards from the correlate of the Thaduna Greywacke, but for mapping puroses it is taken as the sudden break in slope at the eastern side of the Horseshoe Range. The top is taken as the base of the prominent orthoquartzite which marks the base of the conformably overlying Labouchere Formation. It is about 1 000 m thick.

The lowermost 300 m on the eastern slopes of Horseshoe Range is an interbedded dark-grey-green greywacke and chloritic shale, interbedded on a scale of centimetres up to about one metre. A typical greywacke bed is graded in the lower part, and planar laminated in the upper part. Rare fragments of chert, gneiss and sericitic shale occur up to one centimetre in diameter. The rock is composed of about equal proportions of quartz, microcline, and lamellae-twinned albite-oligoclase, in single-crystal grains up to 2 mm in diameter. Detrital flakes of muscovite and biotite are also present. The matrix contains fine chips of all the above minerals, together with opaques, chlorite and sericite and abundant carbonate cement.

The interbeds are of laminated green shale composed of fine quartz, biotite, chlorite and magnetite. Both greywacke and shale are stained by manganese dioxide. These rocks differ from the Thaduna Greywacke because of their finer bedding features, their darker colour, and a modal composition which indicates derivation from granitic and metamorphic terrain, rather than from mafic volcanics.

The most prominent member at Horseshoe Range is an iron-formation. At Mount Beasley, it is 250 m thick, and consists of three bands of iron-formation, each about 40 m thick, intercalated in quartz-chlorite-magnetite shale. These prominent bands consist of beds of chert-magnetite-?stilpnomelane iron-formation, green shale, and chert, alternating on a scale of 20 to 100 mm. Each bed shows lamination on a scale of millimetres.

Above the iron-formation is about 500 m of more calcareous, manganiferous shale and greywacke, which at Horseshoe Range is heavily replaced by supergene manganese and iron oxides. This upper part is better exposed in the areas 10 to 15 km to the south, where there is calcareous greywacke and shale similar to the lower part.

The iron-formation member has a limited strike extent of 50 km, and 25 km south-southeast of Mount Beasley, it thins to a number of beds or iron-formation less than 1 m thick.

The Horseshoe Formation marks the filling of the deep geosynclinal trough, the cessation of volcanogenic sedimentation, and a transient period of quiet shallow-water sedimentation during which chemical sediments precipitated in isolated depressions.

Labouchere Formation

The unconformity that marks the top of the Glengarry Group is now known to occur within what has previously been called the 'Labouchere Formation' within the Padbury Group. The major part of this formation is in conformable sequence with the Glengarry Group, and the coarse conglomerate at the top of the formation as originally defiined is now regarded as the basal unit of the Padbury Group, the Wilthorpe Conglomerate.

In accordance with the original usage of MacLeod (1970) and the intention of Barnett (1975) the name Labouchere Formation is now applied to the thick sequence of sandstone and slaty sericitic siltstone that can be traced from the type area at Mount Labouchere to the Horseshoe Range, where it conformably overlies the Horseshoe Formation.

At Mount Labouchere, the formation consists of medium- to coarse-grained orthoquartzite at the base, overlain by an interbedded sequence of quartzose feldspathic wacke and phyllitic shale, in which the wacke becomes better sorted and the shale proportion increase at higher levels. The term 'wacke' was used to indicate sandstones containing more than 10 per cent matrix, which in this rock is sericitic and argillaceous. However, they are not related in any way to greywacke turbidites, and in order to preserve the distinction, the term sandstone is used in this paper.

The section is 5 000 m thick in the Mount Labouchere area but is incomplete because of faulting. The greatest thickness occurs in the area 30 km south-southeast of Mount Labouchere, where an additional 2 000 m of sericitic slate with siltstone and sandstone appears, before being cut out by the unconformity at the base of the Padbury Group.

The sequence on the western side of the Horseshoe Range is comparable to that at Mount Labouchere. The basal quartz, which is the most conspicuous marker horizon in the Glengarry Group, is again about 300 m thick, but has become better sorted and contains thin, shale interbeds. It is medium grained, with well-rounded quartz grains and sparse feldspar in a siliceous cement. The beds range from 0.1 to 3 m in thickness, and low-angle trough cross-bedding and linguoid ripple marks are present.

The overlying sequence consists of beds of argillaceous sandstone, some with detrital muscovite and feldspar, intervals of sericitic quartz siltstone with thin interbeds of ripple-marked clean sandstone, and fine-grained sericitic and laminated mudstone (now phyllite in places).

Cross-bedding of various types, such as small linguoid ripples, and planar and tangential megaripples occur within normally planar beds which range from 0.1 up to 1.5 m in thickness. These features, together with the presence of shale, indicate that the Labouchere Formation was deposited on a marine shelf. The sedimentary structures record sediment-dispersal currents.

PADBURY GROUP

The definiton of the Padbury Group (Barnett, 1975) is amended to exclude the Labouchere Formation (and the Horseshoe Formation) and to include the newly defined Wilthorpe Conglomerate. Barnett (1975) noted that the topmost 1 000 m of what he refferd to as the "Labouchere Formation" consisted of conglomerate and quartzose-feldspathic granule sandstone, and it is only this conglomeratic unit, the Wilthorpe Conglomerate, that remains in the Padbury Group.

Evidence for regional unconformity below the Padbury Group

Unconformity between the Padbury and Glengarry Groups is indicated by the following evidence.

1. A proven unconformity lies between the Wilthorpe Conglomerate and basement gneiss at locality 118° 18′20″E, 25°28′40″S.
2. Discontinuous lenses of boulder conglomerate (correlated with the Wilthorpe Conglomerate) occur at several other localities (Fig. 34) immediately below the Robinson Range Formation.
3. Angular discordance on the local and regional scale, between bedding in the Wilthorpe Conglomerate and cleavage in underlying phyllite is observable, although the unconformity surface itself is not exposed.
4. The Wilthorpe Conglomerate and the Robinson Range Formation overlie a variety of rock types which represent different stratigraphic levels in the Glengarry Group.
5. The Wilthorpe Conglomerate contains clasts of distinctive rocks which can be matched with particular stratigraphic units low in the Glengarry Group.
6. There is a contrast between the Glengarry Group which contains several generations of cleavage and phyllitic schistosity, as well as metamorphic garnet, muscovite, biotite and tremolite, and the Padbury Group which generally has only one cleavage and is unmetamorphosed.

Wilthorpe Conglomerate

The type area of the Wilthorpe Conglomerate lies 5 km east-northeast of the Wilthorpe Mining Centre. Here it consists of boulder and cobble conglomerate, passing upward through feldspathic sandstone with abundant pebble beds into siltstone and shale with thin, white chert layers, and is finally conformably overlain by the Robinson Range Formation. This predominantly conglomeratic unit occurs more or less continuously around the Padbury Syncline.

At the unconformity locality on the western side of the Padbury Syncline large boulders up to 1 m in diameter directly overlie the unconformity, and together with granite clasts form a conglomerate with a matrix of feldspathic sandstone containing abundant detrital muscovite. Clasts within the body of the Wilthorpe Conglomerate consist predominantly of fine-grained silica- or hematite-cemented orthoquartzite, that can be matched with the Karalundi Formation, and with Finlayson-type sandstone. Clasts of vein quartz and lepidoblastic-textured metamorphic quartzite are also common. Seldom do the coarse conglomerates actually outcrop; they are usually expressed as talus slopes of well-rounded boulders up to 3 m in diameter. The coarse conglomerate beds appear to be up to 100 m thick.

The conglomeratic sandstone occurs in lensoid units, several metres thick, which define a crude stratification. Imbrication of pebbles and low-angle trough-type cross-bedding are evident. There is commonly an upward fining of all clasts within the sedimentation unit.

The conglomeratic rocks have a cleavage, and the pebbles are deformed by brittle-style cracking, a feature common to all occurrences of the Wilthorpe Conglomerate. Some pebbles, however, show some evidence of stretching, flattening, and mineral lineation, but their fabric is not consistent with respect to the cleavage, and some of these deformed pebbles also participated in the sedimentary imbrication. It is suggested that at least some of these pebbles are recycled from an older, previously stretched conglomerate.

The Wilthorpe Conglomerate has its maximum thickness of about 1 000 m around the Padbury Syncline, an area adjacent to the Yarlarweelor Gneiss Belt. It is only intermittently exposed beneath the Robinson Range Formation further east, and is commonly covered by scree of iron-formation.

One area of reasonably good exposure below the Robinson Range Formation on the northern side of the Robinson Syncline consists of finely interbedded white chert and hematitic and sericitic shale with rare pebbles, which passes conformably up into the iron-formation. At another locality in the southeast part of the Millidie Syncline (118°34'00"E, 25°42'30"S) a similar chert-shale sequence contains interbeds up to 10 m thick of flaggy cross-bedded sandstone and pebbly siltstone containing well-rounded clasts of orthoquartzite up to 0.1 m in diameter.

These features suggest a discontinuous development of the conglomeratic phase, and furthermore, the fluvial features lead to the suggestion that the Wilthorpe Conglomerate records the position of large rivers that spread out over a peneplaned surface over which chert and ferruginous silts were elsewhere being deposited.

Robinson Range Formation

In the western part of the area, the Robinson Range Formation consists of a prominent layer of finely laminated chert-magnetite banded iron-formation, underlain by hematitic shale, which contains thin beds of banded iron-formation, and overlain by laminated chlorite-hematite shale. Barnett (1975) noted an upper zone in the main iron-formation layer in which bedding is indistinct, and clastic textures are apparent.

This feature is most characteristic of the Robinson Range Formation in the Robinson Syncline, where two regionally concordant ridges are separated by magnetite-bearing hematite-sericite shale. The lower unit is a true banded iron-formation, but the upper unit is a granular iron-formation with discontinuous bedding on the outcrop scale.

The granular iron-formation is characterized by lenses of granular and oolitic chert 10-20 mm thick, more continuous beds of the same thickness or red jasper, and beds of clastic ironstone up to 1 m thick. Clasts in the ironstone include spherical granules of chert 0.5 mm in diameter, fine grained hematitic shale, green chloritic shale, chert, and specular hematite up to 10 mm in diameter, and larger fragments of jasper. All clasts appear to have been derived from the immediate sedimentary environment. None of the original Fe-silicate mineralogy is preserved.

These rocks bear a striking similarity to the granular iron-formations of the Frere Formation in the eastern part of the Earaheedy Sub-basin, rock which Hall and Goode (1978) interpret as precipitates of iron silicates and chert in a shallow-marine environment disturbed by current activity. The lithological similarity is the basis of the proposed correlation of the Padbury and Earaheedy Groups (Bunting and others, 1976).

Millidie Formation

This is the higest stratigraphic unit of the Padbury Group, and is best exposed in the Millidie Syncline, where there is at least 1 500 m of feldspathic wacke, with sandstone, chert, dolomite, sericitic and hematitic shale and granular iron-formation. Exposure in the Padbury and Robinson Synclines is particularly poor, there being only iron- and manganese- stained shale and sandstone, with extensive developement of calcrete, presumably over dolomite.

Mount Leake Sandstone

Gently dipping beds of orthoquartzitic sandstone occur in a line of exposures from Bilyuin to Mount Leake. These beds unconformably overlie the vertically dipping Glengarry Group, the unconformity being well exposed on the southern slopes of Mount Leake. This unit is defined as the Mount Leake Sandstone and has its type section at Mount Leake (119°09'30"E, 25°47'00"S) where it is 15 m thick.

Characteristically it supports a chalcedonic cap with large colloform and breccia structures of uncertain origin, but it is suggested that the rock originally had a carbonate cement. Below this cap, the rock is a silica-cemented, fine-grained, well-sorted and well-rounded orthoquartzite, commonly containing small rounded flakes of glauconite. It is flaggy bedded, and abounds in trough crossbedding. Resting directly on the unconformity at Mount Leake is a thin stromatolite layer that has been totally replaced by chert.

The stratigraphic relations of the Mount Leake Sandstone are unknown; it could be an outlier of Bangemall Group, or part of a westerly extension of the Earaheedy Group, or a remnant of a new sedimentary sequence, as yet unidentified in the Glengarry Sub-basin.

TECTONIC DEVELOPMENT

Geosynclinal phase

Reconstruction of the Glengarry Sub-basin is shown in Figure 35. It is postulated that the almost continuous blanket of basal sandstone and conglomerate is broken

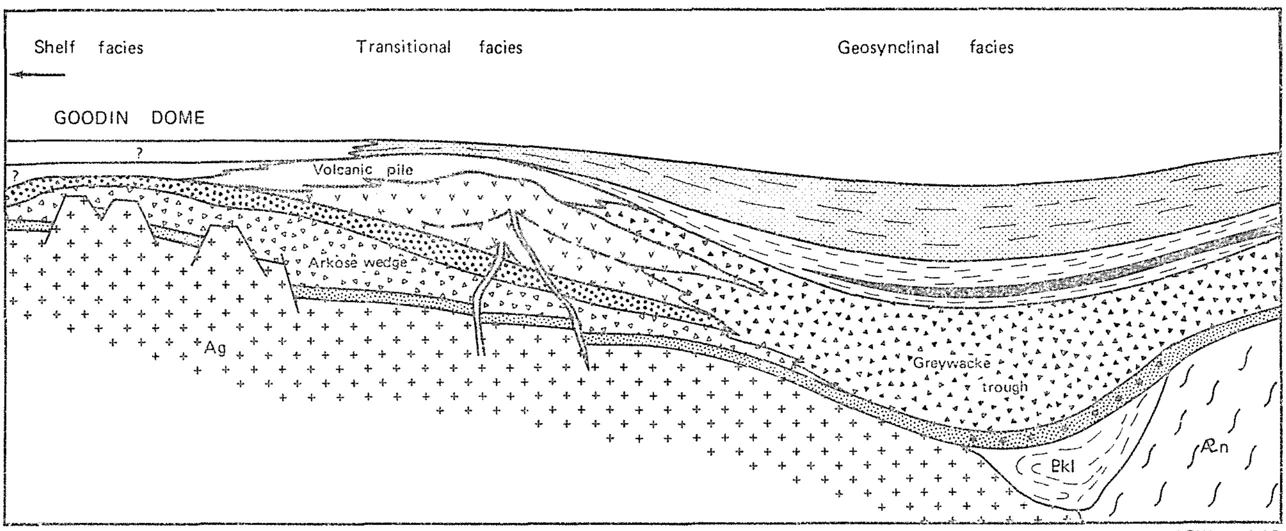

Figure 35 Diagrammatic section of the Glengarry Sub-basin from Goodin Dome northward to Horseshoe area, showing distribution of facies, and relationship of arkose wedges, volcanic pile and greywacke trough. Symbols are same as in Figure 34.

only over the Goodin Dome, where block-faulting elevated granite into a palaeo-high which was the source for the arkose wedges.

A deep geosynclinal trough developed across the northern margin of the cratonic Yilgarn Block, possibly located on a major crustal suture between different types of Archaean basement. The relationship between the geosynclinal and stable-shelf facies is not discussed here, however, it is worth noting that the Karalundi Formation appear to mark the transition from shelf to trough. The thick volcanic pile is localized along the hinge line of basin development. Calcareous shale, shallow-water conglomeratic sandstone, tuff and basalt lava were laid down here. At the same time, volcanogenic debris slumped off the volcanic pile, and was transported into the trough by dense turbidity currents to form greywacke.

The deposition of carbonate-cemented greywacke and a lens of banded iron-formation marks the termination of rapid subsidence and the filling of the trough. Then followed a period of vigorous fluvial and near-shore arenaceous sedimentation.

Main Deformation Phase

Bunting and others (1977) and Williams and others (1978) have previously interpreted deformation in terms of Archaean basement domes, driven by upward-rising Proterozoic granites. This picture is consistent with the revised stratigraphy, and it is further evident from the complex depositional and deformational history that this was a long-continuing episodic process.

Identification of an overall coherent structure in the Glengarry Group is obscured by the strong deformation, both before and after deposition of the Padbury Group. However, regional facings reveal a synclinorium more-or-less coincident with the synclinorium expressed by the Padbury Group. Contacts of the Glengarry Group with the metamorphic rocks of the Marymia Dome are still intact, but possibly as much as 10 km of stratigraphic thickness is absent adjacent to the bulbous end of the Yarlarweelor Gneiss Belt; this points to the region being a major shear zone. Infolded and metamorphosed remnants of the Glengarry Group occur in this reworked basement area. A 1.7 b.y. age for metamorphic muscovite (Williams and others, 1978) dates the main metamorphic event of the Glengarry Group. Consistent with the polyphase deformation, evidence of strain-slip and crenulation cleavage overprinting slaty cleavage is ubiquitous, but regional examples of refolded structures have not been identified. One of the most conspicuous pre-Padbury structures is the major east-west fault that emanates from a strong shear zone between the Yarlarweelor Gneiss Belt and the Yilgarn Block and extends to the western end of the Marymia Dome (Fig. 36). The nature of displacement on this fault is uncertain.

Second phase sedimentation and deformation

Following the orogenic climax, there was a period of uplift, erosion, and peneplanation, and then the Padbury Group was deposited as an upward-fining sequence of fluvial clastics and chemogenic rocks. The appearance of greywacke in the Millidie Formation indicates a return to active basinal sedimentation, but the record of this is incomplete.

Deformation of the Padbury Group followed the same earlier pattern—compression between reactivated basement domes and the stable basement of the Yilgarn Block (Fig. 36). Upright, near-isoclinal folds, spectacularly outlined by the Robinson Range Formation, are clearly related to basement domes. The Padbury Syncline is arcuate around the end of the Yarlarweelor Gneiss Belt; the Robinson Syncline is arcuate about the Marymia Dome; and the amoeba-shaped Millidie Syncline is crumpled between the two domes.

The last recorded tectonic event in the Yarlarweelor Gneiss Belt is the emplacement of Proterozoic granite dated about 1.6 to 1.5 b.y. (Williams and others, 1978). This event dates the deformation of the Padbury Group, and hence places a younger age limit on Padbury Group sedimentation.

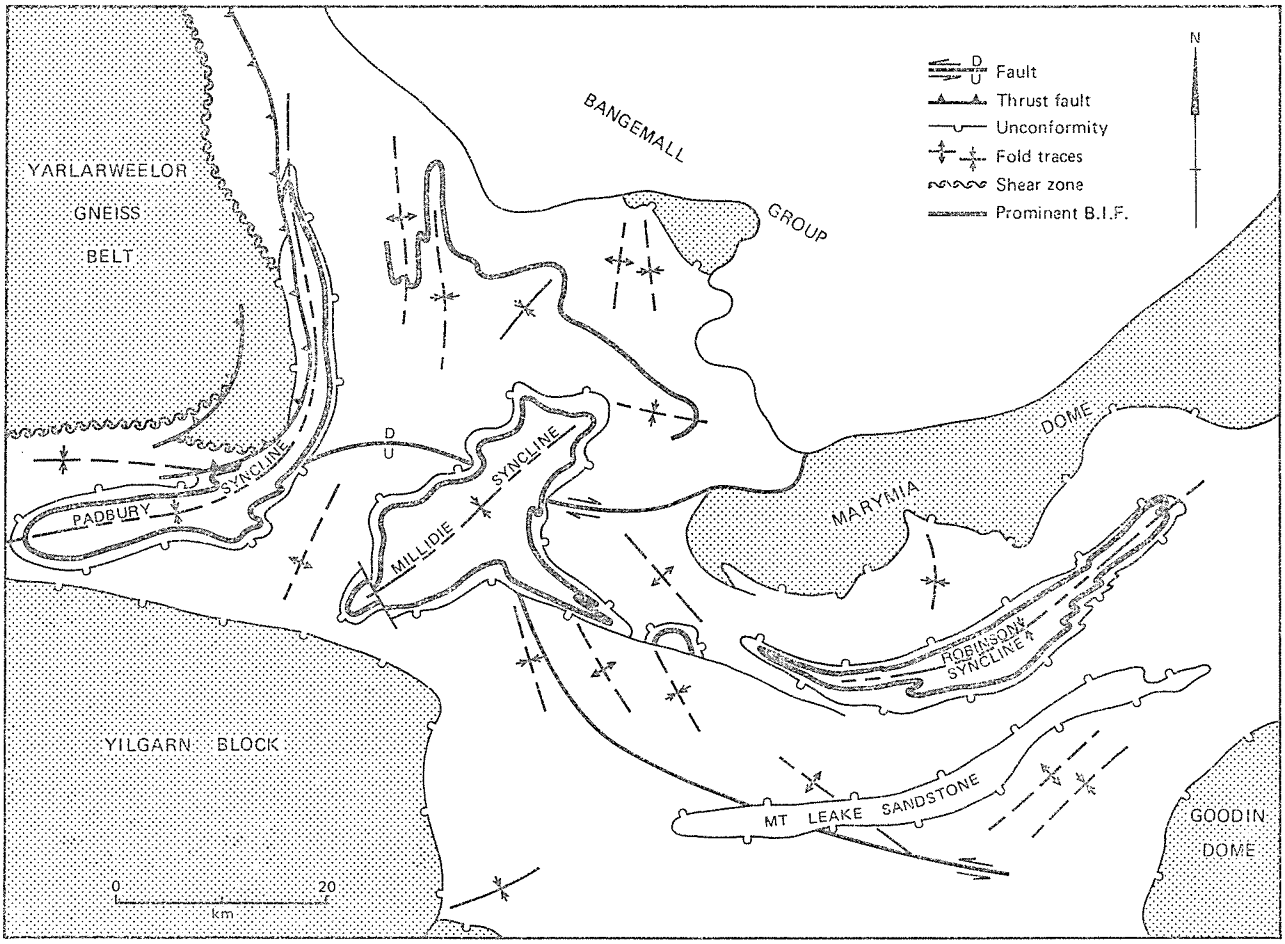

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Figure 36 Structural map, showing relationship of regional folds to basement highs and domes (shaded). The area of this figure is the same as Figure 34.

IMPLICATIONS FOR THE PROTEROZOIC GEOLOGY OF W.A.

The identification of a major unconformity between the Padbury Group and the Glengarry Group, and the discovery of abundant granular iron-formations in the Padbury Group, which are similar to those in the Earaheedy Group, supports the proposal of Bunting and others (1977) that the Earaheedy Group in the eastern part of the Nabberu Basin unconformably overlies the Glengarry Group. No additional evidence is forthcoming from this present study to clarify the ages of the various sedimentary sequences, but the conclusions are consistent with the previously suggested ages of 1.7 to 1.6 b.y. for the Padbury Group and 1.8 to 2.0 for the Glengarry Group (Williams and others, 1978).

It is not the intention of this paper to present a tectonic synthesis of the northern margin of the Yilgarn Block, as this requires elucidation of the relationships between the geosynclinal and stable-shelf facies of the Glengarry Group, and an examination of the easterly extension of the Glengarry Group toward the Earaheedy Group. However, it is appropriate to examine possible relationships with other major sequences on the Precambrian Shield of Western Australia.

Most striking is the gross lithological similarity of the Glengarry and Wyloo Groups, both of which are thick geosynclinal sequences containing arkose, greywacke, carbonates and basalt. These two sequences have a comparable age, the Wyloo Group being later than the Woongarra Volcanics (Trendall, 1979), and hence younger than 2.0 b.y. (Arriens, 1976). Furthermore, there is almost a physical continuity between the two sequences, expressed by the infolded belts of Proterozoic metamorphic rocks throughout the Gascoyne Province Williams and others, 1979). This reconstruction points to an elongate belt of thick greywacke and volcanic fill of geosynclinal dimensions occupying the broad area between the Hamersley Basin and the Yilgarn Block, and suggests the emergence of a major, and hitherto unrecognized, tectonic element in the Western Australian Shield.

Relatively small elongate belts of fluvial sandstone and conglomerate occur throughout the Gascoyne Province (Williams, Williams, and Chin, 1979). They uncoformably overlie the metamorphic rocks, and clearly post date the orogenic climax, however they have been deformed during the emplacement of the Proterozoic orogenic granitoids. These sediments may correlate, by virtue of their similar tectonic setting, with the Padbury Group.

These broad chronostratigraphic relations, together with the currently accepted ages for the basement units in the Western Australian Shield, are shown diagramatically in Figure 37. This figure presents a model for the Proterozoic tectonic evolution for the region between the two stable Archaean cratons in the Western Australian Shield.

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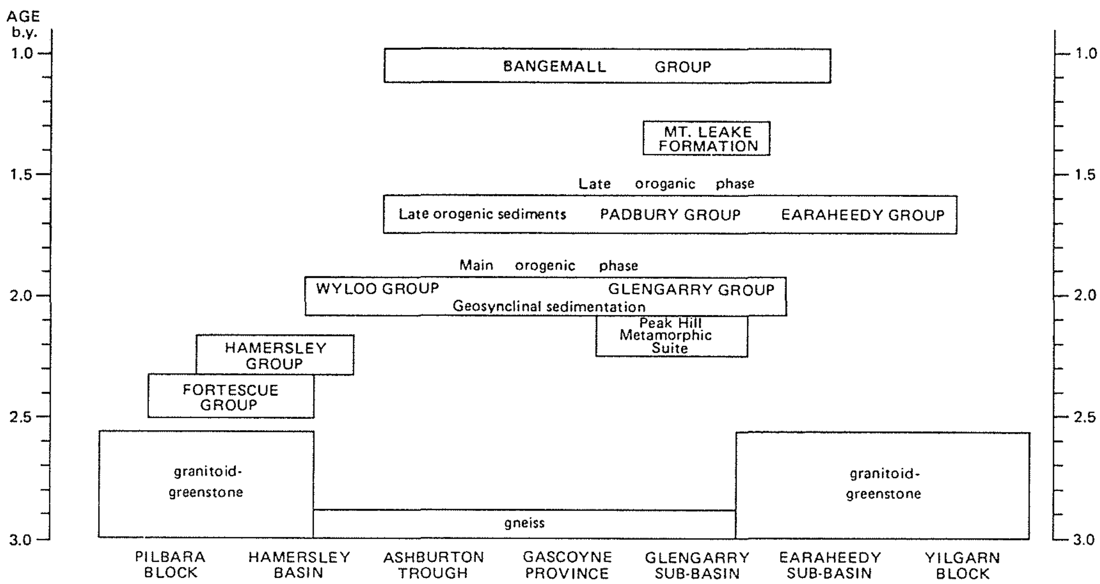


Figure 37 Diagram showing relationships of Padbury and Glengarry Groups to other major sedimentary and tectonic events in the region between the Pilbara and Yilgarn Blocks

A REVISION OF THE MOUNT BRUCE SUPERGROUP

by A. F. Trendall

ABSTRACT

All published accounts of the Proterozoic Hamersley Basin accept the stratigraphic framework established by MacLeod and others (1963), in which three consecutive groups, in ascending order the Fortescue, Hamersley, and Wyloo Groups, together constitute the Mount Bruce Supergroup, and represent the total content of the basin. Re-examination of the stratigraphy of the lower part of the Wyloo Group within a small area at the southwestern margin of the basin has revealed complexities which prevent continuing and consistent use of the established nomenclature, and the following revisions are proposed:

1. The lowest formation of the original Wyloo Group, the Turee Creek Formation, is raised to group status.
2. The lowest formation of the newly erected Turee Creek Group, locally containing the boulder-bearing and possibly glacigene Meteorite Bore Member, is defined as the Kungarra Formation.
3. The lowest formation of the revised Wyloo Group is the newly defined Beasley River Quartzite, the basal Three Corner Conglomerate Member of which marks the unconformity between the Wyloo Group and the underlying Hamersley and Turee Creek Groups.
4. The Mount Bruce Supergroup is consequently revised to exclude the revised Wyloo Group.

These revisions are consistent with the concept that the revised Wyloo Group (which constitutes the greater part of the Wyloo Group as hitherto accepted) was laid down in the Ashburton Trough (Gee, 1979), a belt of crustal subsidence to the south of, younger than, and tectonically distinct from the Hamersley Basin.

INTRODUCTION

In a initial report of striated and faceted boulders from the "Wyloo Group" (Trendall, 1976), it was noted that further work was planned in support of a more complete description of the occurrence. It was envisaged that this would include details of the stratigraphic status and extent of the mixtite containing the boulders. Work in 1976 showed that the stratigraphy of the mixtite could not adequately be described within the existing nomenclature of the "Wyloo Group", and in 1977 and 1978, the lower units of the group were re-examined over a slightly wider area, extending from the southwestern corner of the Mount Bruce 1:250 000 Sheet area to the adjacent southeastern part of the Wyloo Sheet area.

The purpose of this paper is to report the results of this wider study, which has led to a substantial stratigraphic revision of the lower part of the "Wyloo Group", and in consequence to a reassessment of the "Mount Bruce Supergroup".

In order to avoid confusion as to whether a revised stratigraphic name is used in this paper with a pre-revision or post-revision connotation, all revised names used in a pre-revision sense are placed between inverted commas. Thus "Beasley River Quartzite" means some or all, according to context, of the rocks represented on a map as such or referred to as such, in a previous publication. Beasley River Quartzite, without inverted commas, means the rocks defined and represented as such in this paper.

This revision is made at a time when the Council of the Geological Society of Australia has accepted a recommendation from its Stratigraphic Nomenclature Committee to replace the Australian Code of Stratigraphic Nomenclature (GSA, 1964) by the International Stratigraphic Guide (Hedberg, 1976). At the time of writing the procedural details of this transition are unclear, and for the purpose of this paper the requirements of the Australian Code are accepted as the criteria for determining the present validity of names already in use, while the International Guide is employed in the process of revision.

PRESENT STATUS OF THE "WYLOO GROUP"

Attention has previously been drawn (Trendall, 1975) to the fact that the constituent formations of the "Wyloo Group", the uppermost of the three groups which form Halligan and Daniels' (1964) "Mount Bruce Supergroup", have never been properly established in accordance with the Australian Code of Stratigraphic Nomenclature (GSA, 1964). Article 19 of this Code required that a new formation be 'explicitly defined at the time of its proposal'. A critical omission from all early references to these formations was that of any described type sections or localities. In terms of Articles 11 and 12 of the Code, none is therefore a valid unit, or can consequently be regarded as validly or formally named. It follows that the "Wyloo Group" itself has the same status.

The name "Wyloo Group", and the names of many of its constituent units, have nevertheless been widely and usefully applied since their roughly concurrent introduction by MacLeod and others (1963), Halligan and Daniels (1964), and de la Hunty (1965). These authors' stratigraphic intentions were generally clear through the representation of their named units on accompanying maps. From these publications, and from the later publication of further 1:250 000 scale maps with extensive "Wyloo Group" outcrop (Daniels, 1968, 1970), the name came to cover all the sedimentary and associated volcanic rocks stratigraphically above the Hamersley Group and below the Bangemall Group, with the exception of certain specifically separated groups such as the Bresnahan and Mount Minnie Groups.

In this sense the group reached the state of subdivision shown in the left hand column of Table 16, in which the revisions made in this paper are also summarised.

JUSTIFICATION FOR REVISION

Within the area whose re-examination is reported here:

(i) the "Turee Creek Formation" is overlain with marked unconformity by the "Beasley River Quartzite",
(ii) parts of the "Beasley River Quartzite" are continuously mappable into the underlying "Turee Creek Formation", and
(iii) different parts of the "Beasley River Quartzite" are separated by a major unconformity.

The first point formally precludes the permissibility of retaining both formations within the same group (GSA, 1964), while the second two points make it essential that some defining type sections be established.

THE AREA USED AS A BASIS FOR REVISION

The geology of the area selected as a basis for "Wyloo Group" revision is shown in Figure 38. The map there presented is generalized from the published Wyloo (Daniels, 1970) and Mount Bruce (de la Hunty, 1965) 1:250 000 Sheets, with boundaries interpolated across areas of Tertiary or later cover. The dominant structure of the area is the east-west anticline which culminates in the Wyloo and Rocklea Domes; the name Wyloo-Rocklea Anticline is suggested for it. Its northern limb forms the south limb of a complementary syncline, the Duck Creek-Brockman Syncline, which has a sub-parallel, but more irregular, axial trend. Similarly, its southern limb forms, in the east of the illustrated area, the northern limb of the complementary Hardey Syncline. All these folds are cut by southwesterly trending faults. Two of these, which together exert a stronger effect than others on the structural trends shown, are here called jointly the Menindee Fault Zone. Two subareas, whose outlines are shown on Figure 38 are described in more detail below and are used as a basis for definition of the new stratigraphic names used in this paper. The western subarea is called the Wyloo Dome subarea, and that to the east the Hardey Syncline subarea.

Within the area of Figure 38 no lateral stratigraphic variation is known to exist within the Hamersley Group, as established by MacLeod and others (1963) and elaborated by Trendall and Blockley (1970), other than local absence of the uppermost part caused by the unconformable overlap of the Wyloo Group. Although the thicknesses of some Hamersley Group formations are obviously reduced locally, this occurs where it is credibly attributable to tectonic strain, as for example along the eastern margin of the Menindee Fault Zone.

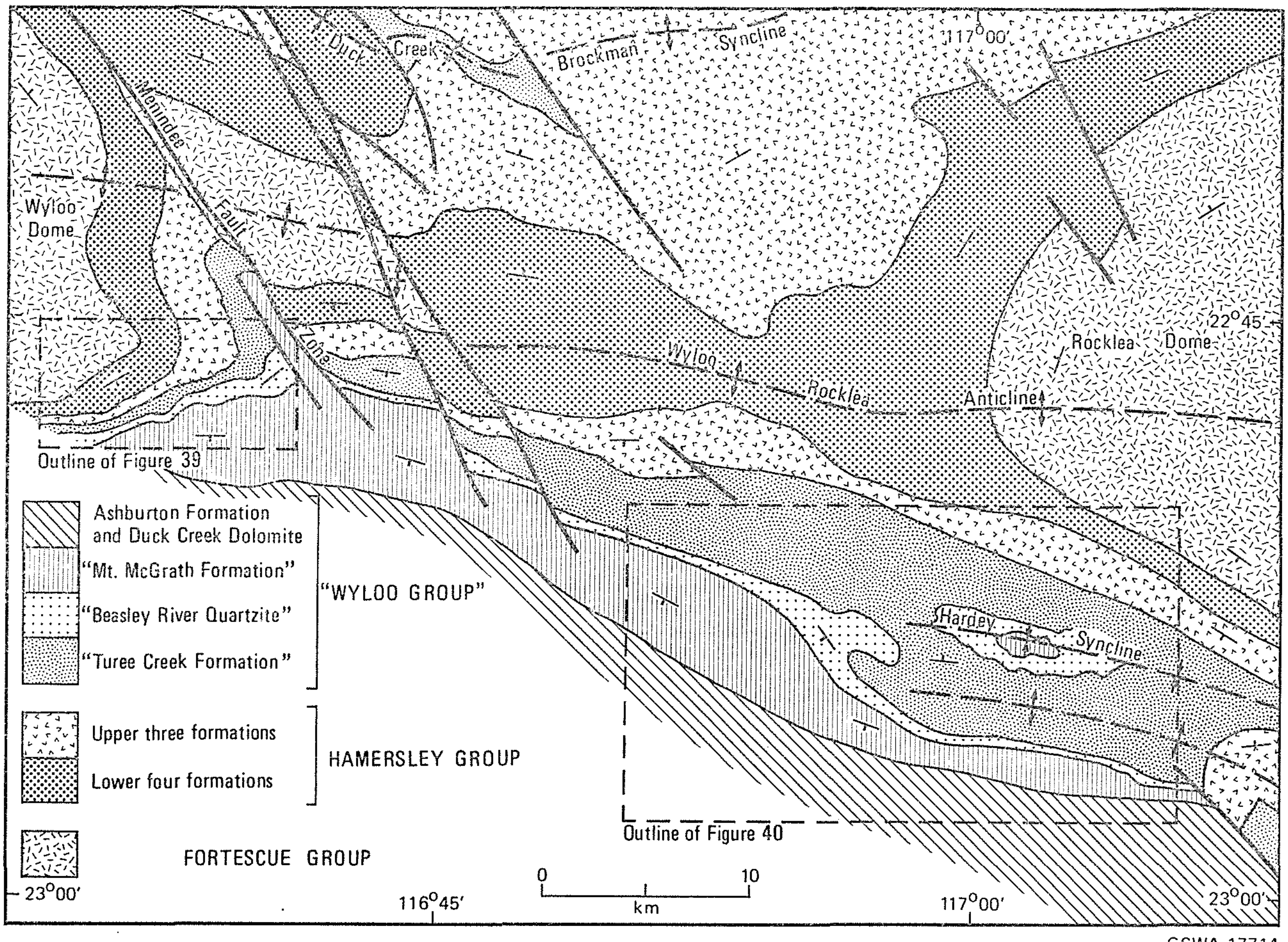


Figure 38 Geological map of the area in this paper as basis for revision of the Mount Bruce Supergroup. The outlines of the Wyloo Dome (Fig. 39) and Hardey Syncline (Fig. 40) subareas are also shown.

WYLOO DOME SUBAREA

A revised geological map of this area appears in Figure 39. For this map, the nominal 1:50 000—scale (airphoto) line compilations used for reduction to the 1:250 000 scale of the published map (Daniels, 1970) were used as a base, and alterations were made only to re-examined boundaries. Consequent modifications, apparent from a comparison of Figures 38 and 39, affect mainly the "Turee Creek Formation" and "Beasley River Quartzite" of Figure 38, which are there represented as stratigraphically concordant and continuous. The revised geological map of Figure 39 serves as a basis for definition below of the revised Beasley River Quartzite and its basal Three Corner Conglomerate Member, which unconformably overlies, from west to east and in ascending stratigraphic order, the Woongarra Volcanics and the Boolgeeda Iron Formation of the Hamersley Group, and the newly established Kungarra Formation of the Turee Creek Group.

BEASLEY RIVER QUARTZITE

Preliminary note

The type section defined here is, in fact, a 'lectostratotype' in the sense of Hedberg (1976, p. 26): a stratotype selected later in the absence of an adequately designated original stratotype.

Type section (stratotype)

The position of the designated type section is shown on Figure 39. Its base is in a deeply incised valley which drains south-southeast at 22°46′50″ South, 116°37′47″ East. This point is 86 mm on a bearing of 350°50′ from the principal point of 1957 air photo, Wyloo, Run 15 No. 5817. From it, the section extends for a distance of about 700 m on a bearing of approximately 160°; for the first 500 m, the excellent exposures along the sides and in the floor of the valley define the type section, but the remaining part of the section then continues over a sharp ridge while the valley bends abruptly westwards.

The basal 100 m of the Beasley River Quartzite consists of the Three Corner Conglomerate Member, details of which appear further below. This conglomerate is succeeded upwards by 240 m of massive, white or pale-green, well-cemented orthoquartzite, with an average dip of about 35° to the south-southeast. The quartzite is well bedded in units mainly 0.2 to 1 m thick, but some sections are more flaggy, and in others the quartzite is glassy with barely detectable bedding. Cross-bedding is common, with sets mainly 0.2 to 0.4 m thick, and ripple marks are locally present. The quartzite is well jointed, but forms steep cliffs on either side of the valley. This continuous section of massive quartzite is succeeded by about 12 m of greenish-grey, very finely laminated shale. This is in turn overlain by about 8 m of conglomerate with closely packed angular and rounded pebbles of black and white chert up to 80 mm across. Above this conglomerate, a further 50 m of massive white quartzite is lithologically similar to that of the main central quartzite.

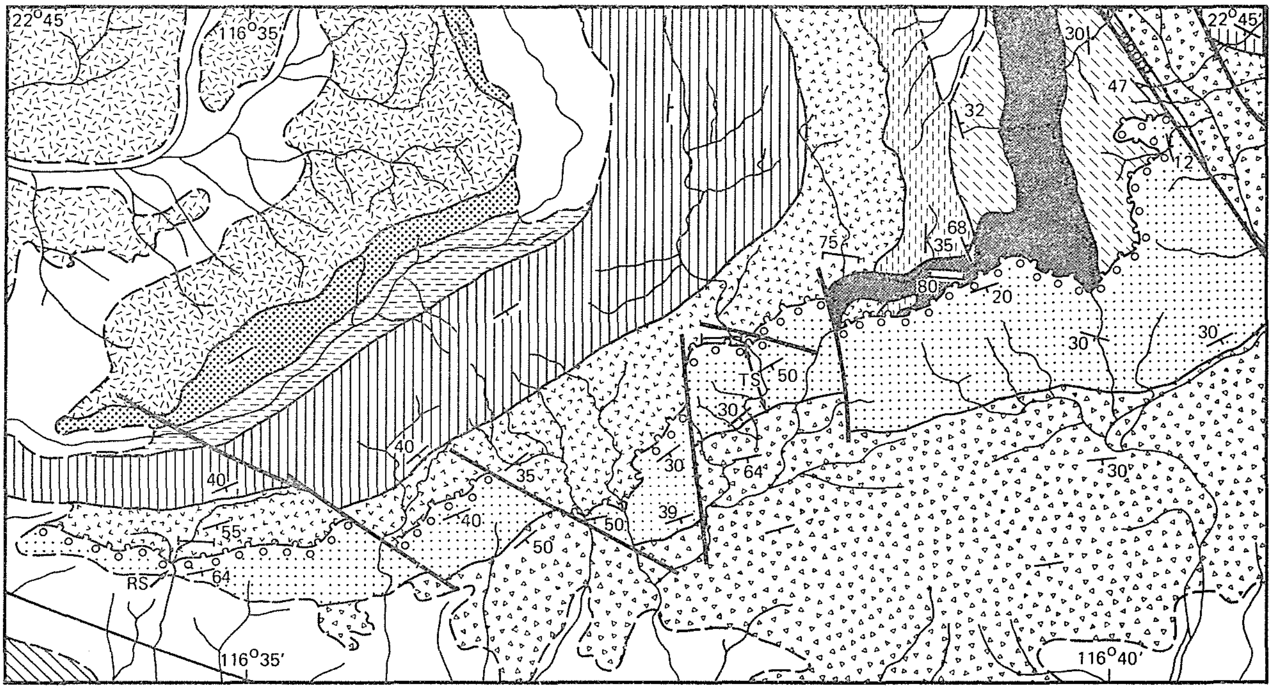
The total thickness of the Beasley River Quartzite in the type section is thus about 400 m, including the basal Three Corner Conglomerate Member. Some minor folding in the upper part, and uncertainties in determination of the true average dip, give this figure an uncertainty of about 10%.

To the south of the type section, the uppermost quartzite of the Beasley River Quartzite is separated from a thick well-exposed dolerite sill by an exposure gap of a few metres. South of this, only thin, grey, silty quartzite and shale associated with the lower part of the Cheela Springs Basalt are present; no discordance has been shown to exist between the two units.

The type section is most conveniently reached by leaving the main Nanutarra-Tom Price road about 4 km west of the turn-off to Meningee Well and driving about 3 km across country in a north-northeasterly direction; it is then necessary to walk for about 2 km to the top of the type section.

Derivation of name

Although the selected type section lies some 35 km west-northwest of the lower part of the Beasley River, there is little doubt either of its correlation with the reference section established below, which is closer to the river, or



REFERENCE

Dip of bedding
Vertical bedding
Dip of overturned bedding
Dip of cleavage
Vertical cleavage
Geological boundaries
Limits of superficial cover
Geological boundaries extrapolated beneath superficial cover

Fault
Unconformity
Syncline
Anticline
Watercourse
Windmill
Main road
Track

TS Type section of Beasley River Quartzite
RS Reference section for Three Corner Conglomerate Member
BRQ Comparative section of Beasley River Quartzite
MB Type section of Meteorite Bore Member

0 — 3 km

WYLOO GROUP
- Duck Creek Dolomite
- Mt. McGrath Formation
- Cheela Springs Basalt Member
- Beasley River Quartzite
- Three Corner Conglomerate Member

unconformity

- 3 Unnamed quartzite unit 3

unconformity

TUREE CREEK GROUP
- 2 Unnamed quartzite unit 2
- Unnamed carbonate unit
- 1 Unnamed quartzite unit 1
- Kungarra Formation, with Meteorite Bore Member and dolerite sills

conformable contact

HAMERSLEY GROUP
- Boolgeeda Iron Formation
- Woongarra Volcanics
- Weeli Wolli Formation and Brockman Iron Formation
- Mt McRae Shale, Mt Sylvia Formation and Wittenoom Dolomite
- Marra Mamba Iron Formation

conformable contact

FORTESCUE GROUP

major regional unconformity over Archaean rocks

MOUNT BRUCE SUPERGROUP

GSWA 17715

Figure 39 Geological map of the Proterozoic rocks of the Wyloo Dome subarea; superficial deposits are left blank. See Figure 38 for location.

that it represents the "Beasley River Quartzite" as stratigraphically intended by Daniels (1970). The name is therefore retained.

THREE CORNER CONGLOMERATE MEMBER

Type section (stratotype)

The Three Corner Conglomerate Member forms the lower-most part of the Beasley River Quartzite, the base of which has been specified above, and is marked on Figure 39. Although the member at the type section is known from regional stratigraphy to be unconformable over the Woongarra Volcanics, this relationship cannot be established at the contact: the underlying Woongarra Volcanics consist of autobrecciated rhyolite with a strong, vertical, east-west cleavage, and no disconcordantly truncated primary structure can be seen. The contact can be established on both slopes of the valley to within a few metres, and dips south-southwest at about 40°.

The conglomerate immediately above the base consists almost entirely of close-packed fragments of cherty, banded iron-formation (BIF) characteristic of that present in the Weeli Wolli Formation of the Hamersley Group. Striking red and black, or red and white definition of both mesobands and microbands is common. Most such fragments are between 0.02 and 0.1 m across, but some reach a length of about 0.2 m. They are mainly platy, with their length parallel to both the bedding of the conglomerate and the internal banding, but the latter may be oblique or perpendicular to the clast length. All are angular, with somewhat abraded edges. Clasts not clearly identifiable as derived from the Weeli Wolli Formation include boulders derived from the Woongarra Volcanics, and clasts possibly derived from other (lower) iron-formations of the Hamersley Group. The clasts of Woongarra Volcanics tend to be more rounded than the BIF fragments, and reach a greatest length of 0.4 m. All the clasts are strikingly close packed, and pressure-solution embayment is common between fragments of differing type. The interstices are occupied by a coarse angular sand of BIF debris.

Apart from its expression by a long-axis orientation of the clasts there is no clear stratification in the lower parts of the conglomerate, although a blocky parting in beds 2 to 4 m thick may represent a primary bedding structure. However, with increasing distance above the base there is a gradual increase in frequency of partings of coarse, often cross-bedded, ferruginous sandstone 0.1 to 0.3 m thick. The appearance of these beds is associated with a steady but slight decrease in the average clast size to about 50 mm, due mainly to a decrease in the largest size fraction.

Within the lower 60 m of the member these textural transitions are gradual, but above this interval there is a relatively abrupt change in facies. The upper 40 m of the member consists of coarse-grained, often cross-bedded grey quartzite with scattered pebbles of BIF debris, interbedded with pebbly conglomerate. Measured dips range from 35° to 44° to the south-southeast throughout the type section. At the top of the member, the transition to the white or pale-green orthoquartzite of the main body of the Beasley River Quartzite is again relatively abrupt.

Reference section (hypostratotype)

The following reference section is established because of the relative inaccessibility of the type section, which was selected because the complete thickness of the Beasley River Quartzite is exposed there. At this reference section the Three Corner Conglomerate Member is as well exposed, and stratigraphically almost identical to, the type section, but the overlying quartzite is truncated.

The base of the reference section (Fig. 39) lies in a deeply incised valley draining southwards at 22°47′58″ South, 116°34′36″ East. This point is 72 mm on a bearing of 300° from the principal point of 1957 air photo, Wyloo Run 15, No. 5816. As at the type section, the conglomerate unconformably overlies intensely cleaved rhyolite of the Woongarra Volcanics; the cleavage dips at 75° to the south. The contact dips at about 60° to the south-southeast. The lithology of the member is as described for the type section. However, the lower unstratified or weakly stratified conglomerate is here 80 m rather than 60 m thick; the upper, pebbly quartzite and conglomerate is 40 m thick at both localities. Dip is consistently concordant with the lower contact, at 60° to the south-southeast. Conformably overlying the member are about 50 m of flaggy yellow and brown quartzite terminated by a fault contact exposed in the right bank of the creek.

This reference section lies about 800 m north of the main Nanutarra-Tom Price road, 8 km west of the Menindee Bore turn-off, and is very easily accessible from it.

Derivation of name

The name is derived from Three Corner Bore, which lies 6 km from this reference section on a bearing of 282°; note that this bore is shown about 1 km too far east on the published 1:250 000 map (Daniels, 1970).

KUNGARRA FORMATION

On Figure 38, the siltstone, fine sandstone, and greywacke which concordantly overlie the Boolgeeda Iron Formation are correlated with the Kungarra Formation of the Turee Creek Group. These respectively new and revised names are defined below.

HARDEY SYNCLINE SUBAREA

A revised geological map of this area appears in Figure 40, the Reference column for which is included on Figure 39. Like Figure 39, this map is based on the airphoto-scale line compilations of Daniels (1970) west of longitude 117° East and of de la Hunty (1965) east of this longitude, with amendments only in restricted re-examined areas. The stratigraphy and structure of this subarea are clear from the map and the accompanying cross-sections of Figure 41. From the comparison of Figures 38 and 40 the amendments on the latter map involve, as for the Wyloo Dome subarea, a reinterpretation of the simple, stratigraphically concordant, and continuous relationship of the "Turee Creek Formation" and "Beasley River Quartzite". This subarea serves as a basis for upgrading the earlier "Turee Creek Formation" to group status and for establishing newly named units within it, as set out below.

TUREE CREEK GROUP

This major unit, herein raised to group from formation status, is defined as including the Kungarra Formation, which is defined below, and other sediments which overlie that formation in this subarea. These include the unnamed quartzite units 1 and 2, and the unnamed carbonate unit shown in Figures 40 and 41. They are not formally named and defined here because sufficient work has not yet been done to support full descriptions and some details of relationships remain uncertain. Unnamed quartzite unit 1 consists of both massive and flaggy white to pale-brown quartzite, locally with festoon cross-bedding. Quartzite unit 2 is more massive and glassy, and shows sporadic development of pebble conglomerate with abundant red chert debris. The estimated thicknesses of these unnamed units are shown graphically in Figure 42.

KUNGARRA FORMATION

Preliminary note

This formation is equivalent to most of the rocks represented as "Turee Creek Formation" on published 1:250 000 maps covering the Hamersley Basin.

Type area

Because of the normally poor exposure of this formation it is impracticable to designate a single type section. A type area is therefore defined as that part of the northern limb of the Hardey Syncline, between the vicinity of the Beasley River to the east and that of the Kungarra Gorge to the west, and between the top of the south-dipping Boolgeeda Iron Formation to the north and the base of the ridge-forming quartzite shown as unnamed quartzite unit 1 on Figure 40 to the south. The greater part of this area appears in Figure 40.

The lower part of the formation is particularly poorly exposed. The base crops out immediately south of Woongarra Pool, on the Beasley River at 22°53′ South, 117°06′ East (Trendall, 1976, pp. 38-39). Here 3 to 4 m of greenish flaggy siltstone dips south-southwest at 80° and conformably overlies the top of the Boolgeeda Iron Formation. The upper part of the formation is well exposed at the western end of the type area (Fig. 40) and also at the eastern end in the axial part of the Hardey Syncline. Apart from the Meteorite Bore Member, described below, the formation consists of a monotonous sequence of greyish-green siltstone, fine-grained greywacke, and fine-grained sandstone, in which the normally thin bedding is weakly defined by slight colour changes. Thin carbonates

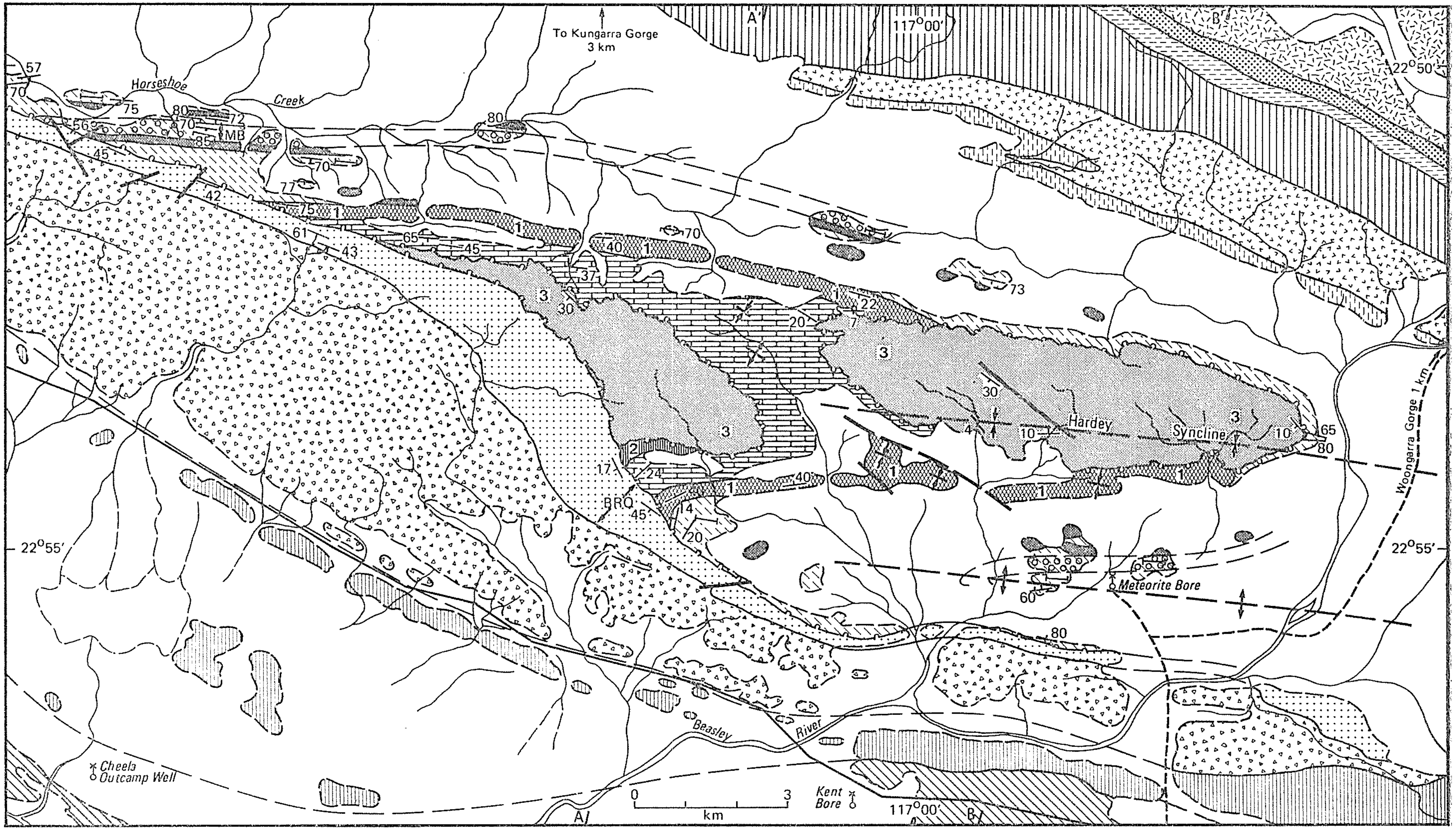


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Figure 40 Geological map of the Proterozoic rocks of the Hardey Syncline subarea; superficial deposits are left blank. See Figure 38 for location. The reference for this figure is included on Figure 39.

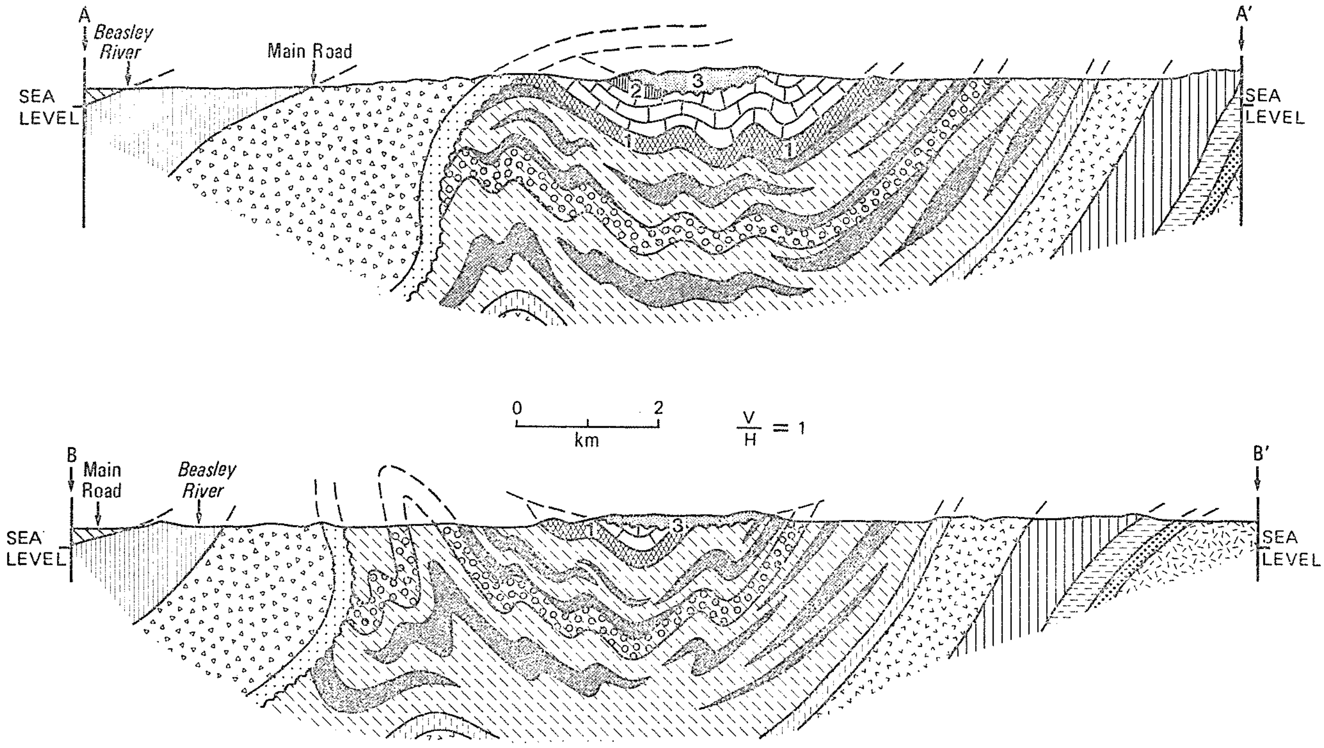

Figure 41 Vertical cross-sections along the lines marked A-A' and B-B' on Figure 40. Stratigraphic units are marked as in the reference of Figure 39.

are interbedded with siltstones in the higher parts of the formation. Throughout the type area, the formation has a strong cleavage, close to vertical and striking roughly east-west, which is normally more conspicuous than the bedding. The transition at the top of the formation to the unnamed quartzite unit 1 shown on Figure 40 is taken to be a stratigraphically concordant one because of its parallel outcrop with the Meteorite Bore Member. Dolerite sills are abundant within the formation, and probably form between 10 and 20% of its thickness.

Although minor folding is present locally, it is likely from the width of the outcrop area and the likely average dip that this formation has a total thickness of about 3 km.

Local correlation

The folding of the Kungarra Formation with the underlying Hamersley Group defines the Hardey Syncline, and the formation together with the Meteorite Bore Member, is continuously mappable, over the south side of the Syncline, as shown in Figures 40 and 41. Within the area of Figure 38, but *excluding* the area of Figures 39 and 40, the Kungarra Formation is probably equivalent to the previously mapped "Turee Creek Formation". This equivalence outside the area of Figure 37 has already been mentioned above.

Derivation of name

The name is derived from Kungarra Gorge (Fig. 40).

METEORITE BORE MEMBER

Type section

The type section is located at 22° 50′ 48″ South, 116° 52′ 12″ East, among steep rocky exposures on the south side of Horseshoe Creek; its position is marked on Figure 40. The member consists of mixtite (Schermerhorn, 1966), a form of conglomerate in which scattered boulders with a wide size range are sparsely and randomly distributed within a matrix of greenish-grey siltstone. In the type section, bedding is not visible, but bedding in the siltstone and fine sandstone of the Kungarra Formation, above and below the member, dips steeply to the south. The outcrop width of about 320 m gives a true stratigraphic thickness for the member of about 300 m.

The lithology of the mixtite at the type section is closely similar to that of the mixtite near Meteorite Bore described by Trendall (1976b), except that the contained clasts are smaller and less abundant. Boulders of fine sandstone, and a lesser proportion of acid volcanic rock, are evenly scattered through the silty matrix. Most of the sandstone boulders are tabular; the remainder, and all of the volcanic boulders, are roughly equant. They reach a length of up to 0.3 m, but most have greatest dimensions in the range 0.05 to 0.1 m. All have their shortest dimension perpendicular to the roughly vertical and east-west striking cleavage which is strongly developed at this locality.

A small proportion of both sandstone and volcanic clasts exhibit striation or grooving of a type suggestive of glacial origin.

Local correlation

The constant thickness and lithology of this member from its point of emergence from beneath the basal unconformity of the Beasley River Quartzite, eastwards through the type section (Fig. 40), and the close correspondence in both thickness and lithology between this mixtite on the north limb of the Hardey Syncline with that of the south limb, in the vicinity of Meteorite Bore, make it reasonable to suggest that a single continuous mixtite bed exists, as shown in Figures 41 and 42. Although the member may be expected to crop out in the hillslope exposures of the Kungarra Formation below the cliffs formed by the unnamed quartzite unit 3 in the axial area of the Hardey Syncline, it has not so far been seen, or sought, there.

Derivation of name

The name is derived from Meteorite Bore (Fig. 40).

STRATIGRAPHIC SYNTHESIS

The newly named units described above are displayed in column format in Figure 42, where approximate thicknesses and nominal lithologies of other stratigraphic units included on Figure 40 are also shown. The relationships of these are apparent from these two figures and from the cross-sections of Figure 41.

A key point in the comparative columns of Figure 42 lies in the correlation of the Beasley River Quartzite between the Wyloo Dome and the Hardey Syncline subareas. Although the basal Three Corner Conglomerate Member is almost continuous within the Wyloo Dome subarea it can be seen from Figure 39 that there is a central part of the outcrop of the Beasley River Quartzite, just east of a fault, from which it is absent. It is not certain whether this absence is a tectonic effect related to the fault, or whether this part of the quartzite was draped

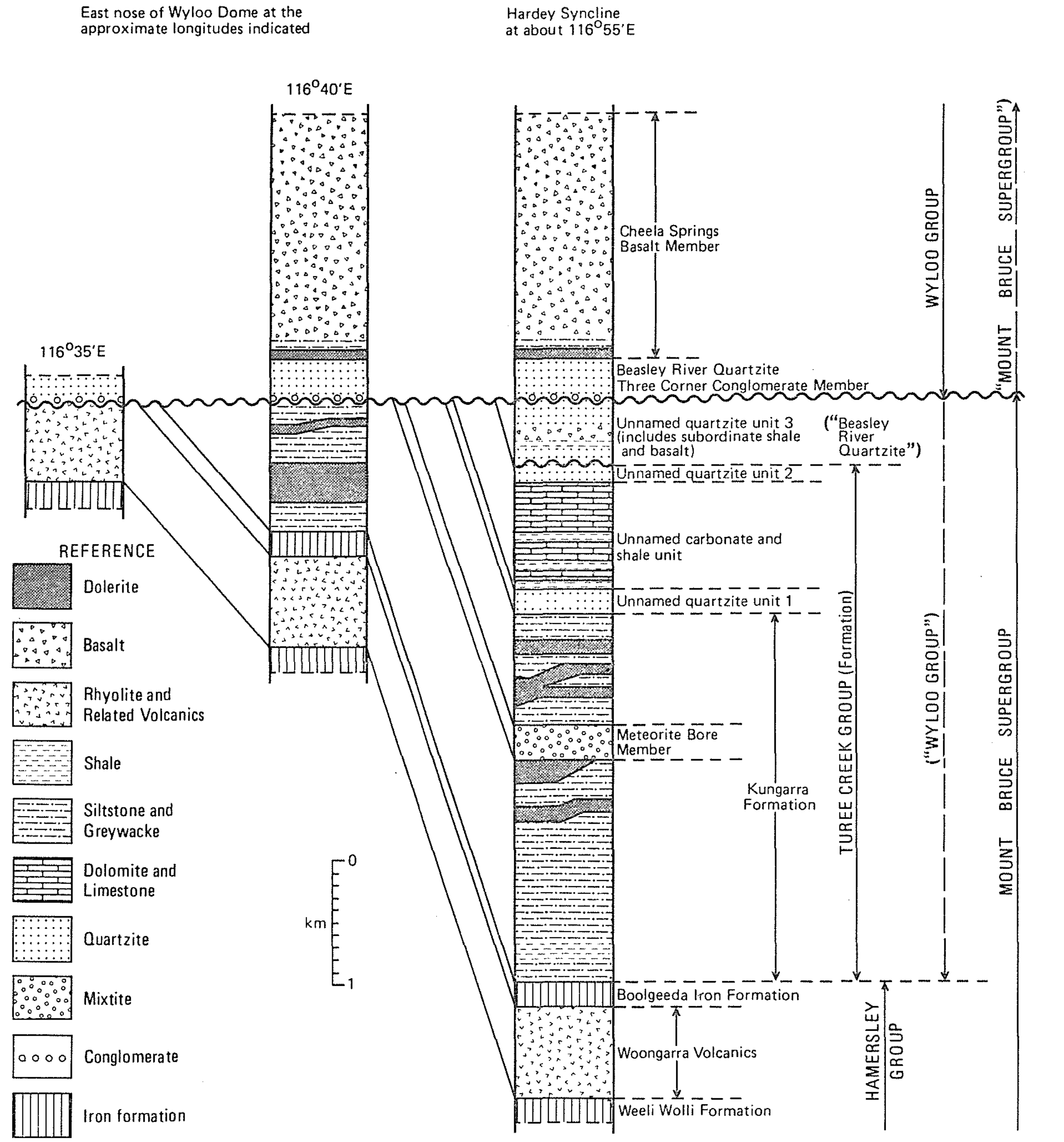

Figure 42 Comparative stratigraphic columns for two localities of Figure 39 and one of Figure 40. The nomenclatural revisions of this paper are displayed by showing the pre-revision nomenclature within brackets, and by pecked lines.

over a hill on an irregular palaeosurface of the Woongarra Volcanics. It may be that both possible reasons are partly true. However that may be, its absence indicates that the presence of the basal Three Corner Conglomerate Member is not an indispensible requirement for correlation of the Beasley River Quartzite beyond the area of Figure 39. An immediate difficulty occurs in eastward correlation of the quartzite across the Menindee Fault Zone. Slivers of conglomerate are preserved within the multiple bounding faults marking the western edge of this zone. One of them appears on Figure 38. Immediately east of the Menindee Fault Zone, no conglomerate is present at the base of the quartzite immediately succeeding the Kungurra Formation, but pervasive strain adjacent to the fault makes it uncertain whether the exposed succession is complete. Farther east, more faults prevent continuous lithostratigraphic correlation, and it is not until the northwestern part of the Hardey Syncline subarea (Fig. 40) is reached that there is reasonable stratigraphic continuity. The correlation with the Beasley River Quartzite of the quartzite marked as such on Figure 40 is based on the close lithological correspondence of the section marked "BRQ" with the type section. Although this section was not measured on the ground, the total thickness of the formation is estimated from air photos as 370 m, within which the basal coarse conglomerate, which is lithologically indistinguishable from the material of the lower part of the Three Corner Conglomerate type and reference sections, has an estimated thickness of 20 m. The continuity of this conglomerate has not been examined in detail, but it is certainly absent where the Beasley River Quartzite overlies the unnamed quartzite unit 1, one kilometre to the southeast of the base of the "BRQ" section, and also to the northeast, for at least 7 km eastwards from the western edge of Figure 40; it is possible either that the dolomite below the "BRQ" section formed a valley in which conglomerate was preferentially deposited, or that the basal conglomerate has been sheared out by faulting at a shallow angle to the bedding during folding.

Two other stratigraphic amendments within the two subareas which will be apparent by comparison of Figures 39 and 40 with Figure 38 are both concerned with the identity of the "Mount McGrath Formation". The absence of a defined type section for this formation is particularly confusing, as preliminary work suggests that there is even more doubt about the correlation between its different

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outcrop areas than there has been for the "Beasley River Quartzite". Horwitz's (1978, Fig. 1) omission of the "Mount McGrath Formation", in displaying the stratigraphy of a part of the Wyloo Dome to the west of Figures 38 and 39, and outside the scope of this paper, appears to reflect a similar doubt concerning its status. It is likely that what appears on published maps as the "Cheela Springs Basalt Member" of the "Mount McGrath Formation" will need to be defined with formation status.

STRUCTURE AND SEDIMENTATION

Although it appears complex in detail, the structure of the area of Figure 37 may be envisaged simply as related to a system of open east-west folds of the granitic crust underlying the whole supracrustal sequence, and the *concurrent* development of a set of northwest-southeast faults, representing one of the two sets of oblique conjugate fractures that may be expected to develop. A diagrammatic simplification of the Wyloo-Rocklea Anticline illustrates this concept in Figure 43A. The real structural situation may be developed from this simple model by providing for branching or anastomosing of the faults, and for movement on them to be variously right-lateral vertical or with a rotational component due to fold shape differences between adjacent fault-bounded blocks. These possibilities are shown in Figure 43B.

An advantage of the model of Figure 43B, is that it provides an explanation both for the Menindee Fault Zone, as explained in the caption, and for the way in which many of the faults parallel to it (Figs. 39 and 40) die out along their length. Where this takes place towards the northwest it is seen as a result of rotational movement; where

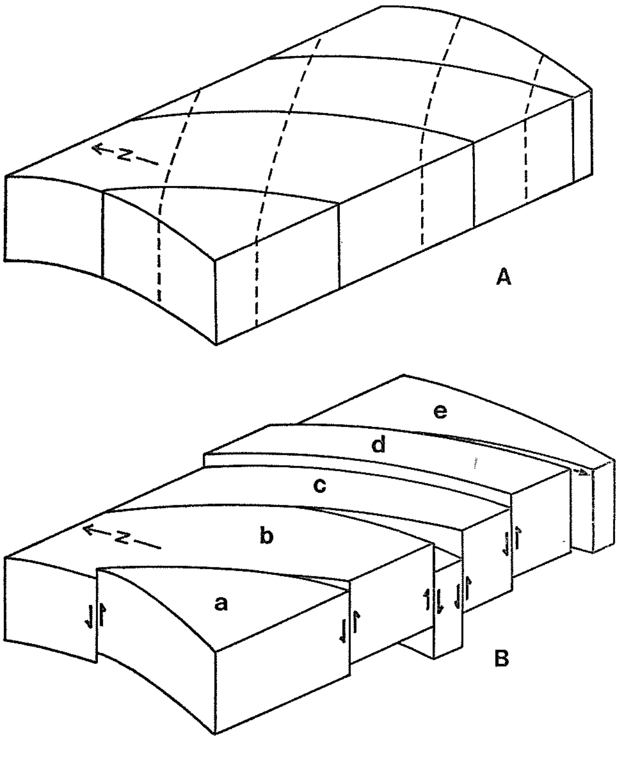

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Figure 43 Block diagrams showing the suggested general relationship between folding and faulting in the area described. The Minindee Fault Zone is interpreted as a pinched graben akin to that between the blocks marked 'b' and 'c'.

it takes place toward the southwest this may additionally be due to the contemporaneity of faulting and deposition, higher formations of the Wyloo Group covering faulted lower formations.

The concept of tectonic and depositional contemporaneity gains support from the Hardey Syncline subarea, where it appears that the preservation of a thick section of the Turee Creek Group above the Kungarra Formation, and of a still higher quartzite (unnamed quartzite 3) below the Beasley River Quartzite, is related to continuing intensification of the Hardey Syncline from its initiation, probably during deposition of the Kungarra Formation, up to and beyond the deposition of the Beasley River Quartzite.

The presence of the volcanic clasts, almost certainly derived from the Woongarra Volcanics, in the Meteorite Bore Member indicates that, locally, deposition was not continuous during the transition from the Hamersley Group into and through the Turee Creek Group. However, it is not known whether the Kungarra Formation was deposited over the whole of the southwestern part of the Hamersley Basin, and the boulders in the Meteorite Bore Member came from the northern part, or whether, within the southwestern part, there was some degree of concurrent erosion of continuously developing anticlinal areas during deposition in the synclines. Certainly, in the Wyloo Dome subarea (Fig. 39), the most complete stratigraphic section occurs in the crestal area of the anticline, while the southern limb shows erosion to successively lower stratigraphic levels, so that the relationship between deposition and structure may not be simple.

Whatever the detailed nature of this relationship, the lithology and extent of the Three Corner Conglomerate Member argue strongly for its status as the record of a unique catastrophic event, involving the abrupt deposition of an enormous volume of coarse, angular, iron-formation debris. Both the coarseness and the angularity of this debris preclude the possibility of transport over a substantial distance, and a debris slide off the crest of a nearby rapidly rising anticline seems the best explanation of these features.

With the necessary exclusion of the "Turee Creek Formation" from the Wyloo Group, the stratigraphic record of this event is now seen as an appropriate marker for the base for the revised Wyloo Group, and for the initiation of the main tectonism accompanying the development of the Ashburton Trough, in which it was deposited. The Mount Bruce Supergroup, if it is to continue to designate the contents of the Hamersley Basin, is consequently revised to exclude the revised Wyloo Group, and to include the Turee Creek Group and higher unnamed units below the Beasley River Quartzite.

REGIONAL IMPLICATIONS

The new definitions presented above, taken together with the demonstration that within the limited area of Figure 38, the Beasley River Quartzite is markedly discordant over the Turee Creek Group, and the unnamed quartzite unit 3 raise problems for future application of stratigraphic nomenclature to other areas of "Wyloo Group" outcrop. In the initial regional mapping of the Wyloo (Daniels, 1970), Mount Bruce (de la Hunty, 1965), and Turee Creek (Daniels, 1968) Sheets, it was accepted that within the "Wyloo Group" the "Beasley River Quartzite" everywhere overlay the "Turee Creek Formation" conformably. As this concept must now be abandoned, the grounds for correlation of any outcrop of "Beasley River Quartzite" with the Beasley River Quartzite as here defined need careful individual appraisal, especially where there is no prospect of mappable continuity or near-continuity. In the outlier of "Wyloo Group" rocks forming the core of the Turee Creek Syncline, for example, the quartzite units cannot be correlated confidently with either the Turee Creek Group or the Wyloo Group as here defined, and judgement on their stratigraphic position must be withheld until more detailed work has been carried out.

ACKNOWLEDGEMENTS

Mr. R. Halligan, who was responsible for the initial 1:250 000 mapping of the southeast part of Wyloo (Daniels, 1970), observed and noted the discordant base of the Beasley River Quartzite in the Hardey Syncline subarea in 1962; his helpful comments and advice during preparation of this paper are acknowledged with thanks.

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TABLE 16. SUMMARY OF STRATIGRAPHIC REVISIONS IN THIS PAPER

"Wyloo Group" of MacLeod and others (1963), Halligan and Daniels (1964), de la Hunty (1965) and Daniels (1968, 1970)	Names applied in this paper to outcrop areas allocated in published maps to the units of the "Wyloo Group" shown in the left hand column	
	Wyloo Sheet (Daniels, 1970)	Mount Bruce Sheet (de la Hunty, 1965)
Capricorn Formation	Not on these sheets	
Ashburton Formation (including Mudong Member)	Part re-allocated (Fig. 40) to Mount McGrath Formation	No change
Duck Creek Dolomite	No change	No change
Mount McGrath Formation, locally subdivided into:	Incorporated into Cheela Springs Basalt Member	
"Karlathundra Conglomerate Member"	Not used by Daniels (1970)	Combined as Mount McGrath Formation on Figure 40.
"Coolbye Shale Member"	Not used by Daniels (1970)	
"Cheela Springs Basalt Member"	No change other than inclusion of undifferentiated Mount McGrath Formation	No change
"Nummana Member"	Not used by Daniels (1970)	Included with unnamed quartzite unit 3 on Figure 40.
"Beasley River Quartzite"	Part unchanged; part now unnamed quartzite unit 3	Part unchanged; part now unnamed quartzite unit 3
"Turee Creek Formation"	Part now Beasley River Quartzite; part now Turee Creek Group	Turee Creek Group

A CONTRIBUTION TO THE STRATIGRAPHY OF THE MARRA MAMBA IRON FORMATION

by J. G. Blockley

ABSTRACT

Inspection of company gamma-ray logs and eight artificial and natural exposures indicates that there are six identifiable 'shale' horizons in the upper banded iron-formation member of the Marra Mamba Iron Formation which can be traced for at least 300 km along the length of the Hamersley Basin.

Some 'shale' horizons within the middle shaly member may also have a similar lateral persistence.

INTRODUCTION

During inspections of a number of iron-ore exploration projects within the Lower Proterozoic Marra Mamba Iron Formation in 1977, it became apparent that there is a remarkable similarity between sections of the upper banded iron-formation (BIF) member in widely separate parts of the Hamersley Basin. This similarity indicates that within this member, 'shale' bands have the same basin-wide lateral persistence as was previously found in the stratigraphically higher Dales Gorge Member of the Brockman Iron Formation (Trendall and Blockley, 1970). There is also a suggestion that a similar lateral continuity may be found for 'shales' within the middle shaly member of the Marra Mamba Iron Formation, but there is as yet insufficient information to confirm this possibility.

The results presented in this report are based on sections of mineralized Marra Mamba Iron Formation measured at the Newman, West Angelas, Marandoo and Nammuldi deposits, and on a well-exposed natural section in Kungarra Gorge. Additional information was obtained from gamma-ray logs of holes drilled in these deposits and in others at Tom Price and Paraburdoo. In fact, for some deposits, the 'shales' show rather better on the logs than in the available exposures.

The various locations mentioned in the text are shown in Figure 44, which also indicates the area containing the main outcrops of the Marra Mamba Iron Formation.

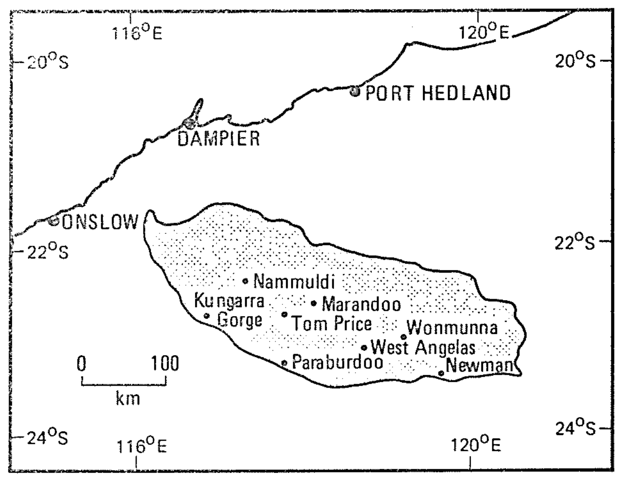

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Figure 44 Locality map showing positions of sections examined, and area containing main outcrops of the Marra Mamba Iron Formation.

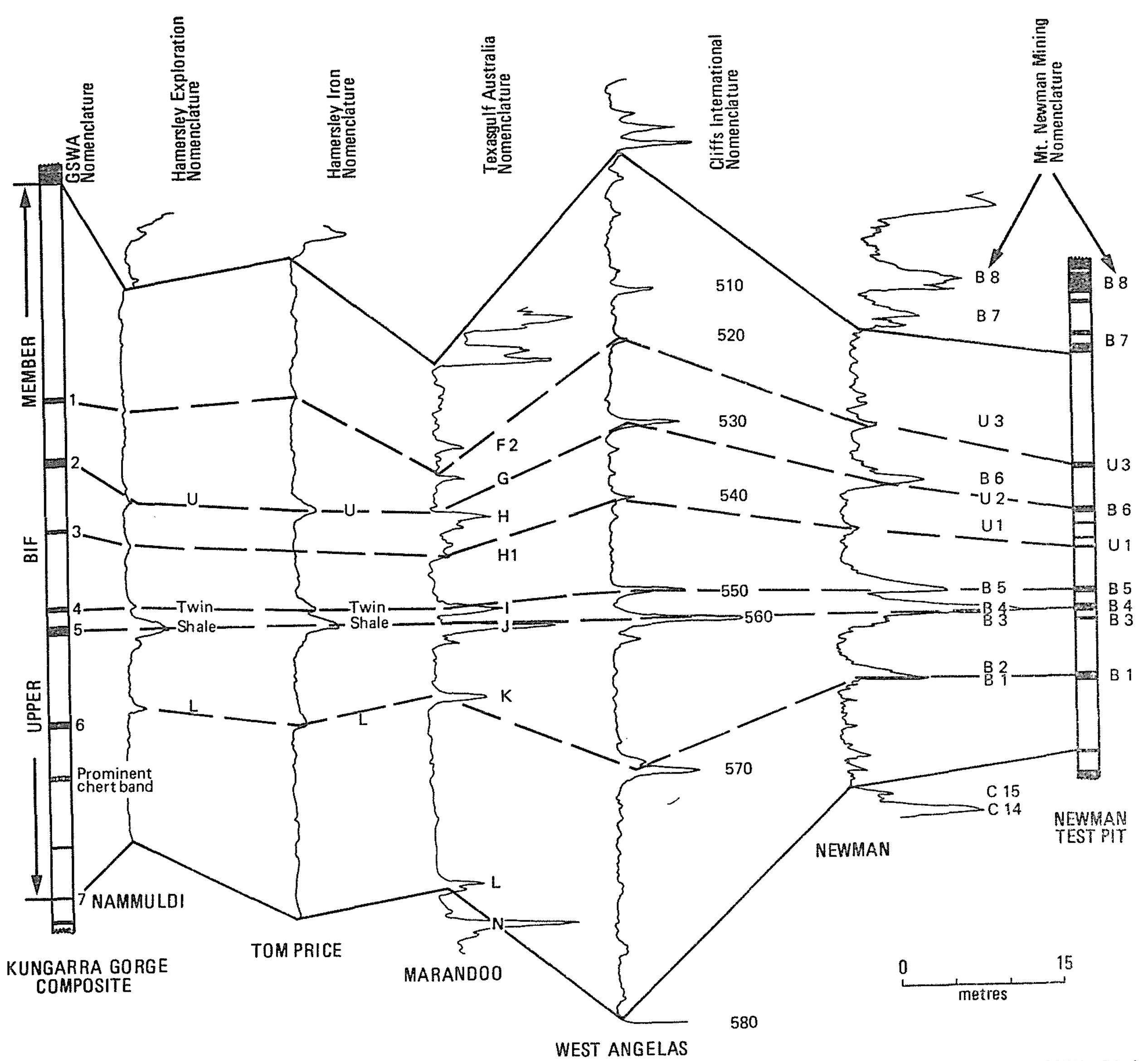

Figure 45 Comparison of gamma-ray logs and measured sections, upper BIF member, Marra Mamba Iron Formation, showing company nomenclature and correlations. Thickness variations are thought to be mainly due to thinning during mineralization of iron formation to iron ore.

Previous descriptions of the stratigraphy of the Marra Mamba Iron Formation can be found in MacLeod and others (1963), Ryan and Blockley (1965), Blockley (1967) and Trendall and Blockley (1970).

Thanks are due to the geological staffs of Mt Newman Mining Co Pty Ltd, Texasgulf Australia Ltd, Cliffs International Inc, Goldsworthy Mining Co Ltd, Hamersley Iron Pty Ltd and Hamersley Exploration Pty Ltd for facilitating access to drill cores and exposures, and permitting publication of drill-hole gamma-ray logs.

UPPER BIF MEMBER

Figure 45 compares gamma-ray logs of the upper BIF member obtained from Nammuldi, Tom Price, Marandoo, West Angelas, and Newman with one another and with lithological sections measured at Newman and Kungarra Gorge. The various nomenclatures in use are indicated alongside each column, that adopted in this paper being shown beside the Kungarra Gorge section. Figure 46A shows the typical appearance of the 'shales' in man-made exposures. It should be noted that the 'shale horizons' contain not only true shale, but also closely associated massive stilpnomelane and, in some fresher sections, thin beds of dolomite. In some cases true shale is the subordinate lithology. These 'shale horizons' are equivalent to the S macrobands of Trendall and Blockley (1970), but the term 'shale' is used here because of its wide acceptance by the iron-ore industry.

Correlations between the sections on Figure 45 are indicated by the dashed lines. Although based in the first instance on similarities of spacing and gamma-ray log traces, they are confirmed by certain lithological features described below.

'Shale 1' generally gives a poor response on gamma-ray logs. Its thickness is typically about 30 cm, with a range of 10 to 60 cm. Apart from 2 or 3 cm of yellow to pink bedded material at its top, the 'shale' consists entirely of massive stilpnomelane which locally weathers to massive goethite. Exposures in Kungarra Gorge have a distinctive 'limestone weathering' appearance.

'Shales 2 and 6' are very similar bands each ranging from about 20 to 60 cm thick. Typically the lower two thirds of the units consist of massive, unctuous, khaki-weathering stilpnomelane (or goethite) and the upper one third comprises well-bedded pink, red and yellow shale. Each gives a prominent peak on most gamma-ray logs.

'Shale 3' is of similar composition to 'shale 1', but is normally thinner, averaging about 20 to 25 cm in thickness. Like 'shale 1' it has a poor gamma-ray log response.

'Shales 4 and 5' are typically 1.5 to 2 m apart and give a distinctive double peak on gamma-ray log traces. They are widely used as stratigraphic markers by the iron-ore explorers, being represented by a 3- or 4-m wide exposure gap in most natural outcrops. 'Shale 4' is 30 to 50 cm thick and 'shale 5' is typically 50 cm to 1 m thick. Both consist of finely laminated, yellow, pink and red shale interbedded with thin bands of massive stilpnomelane. Near

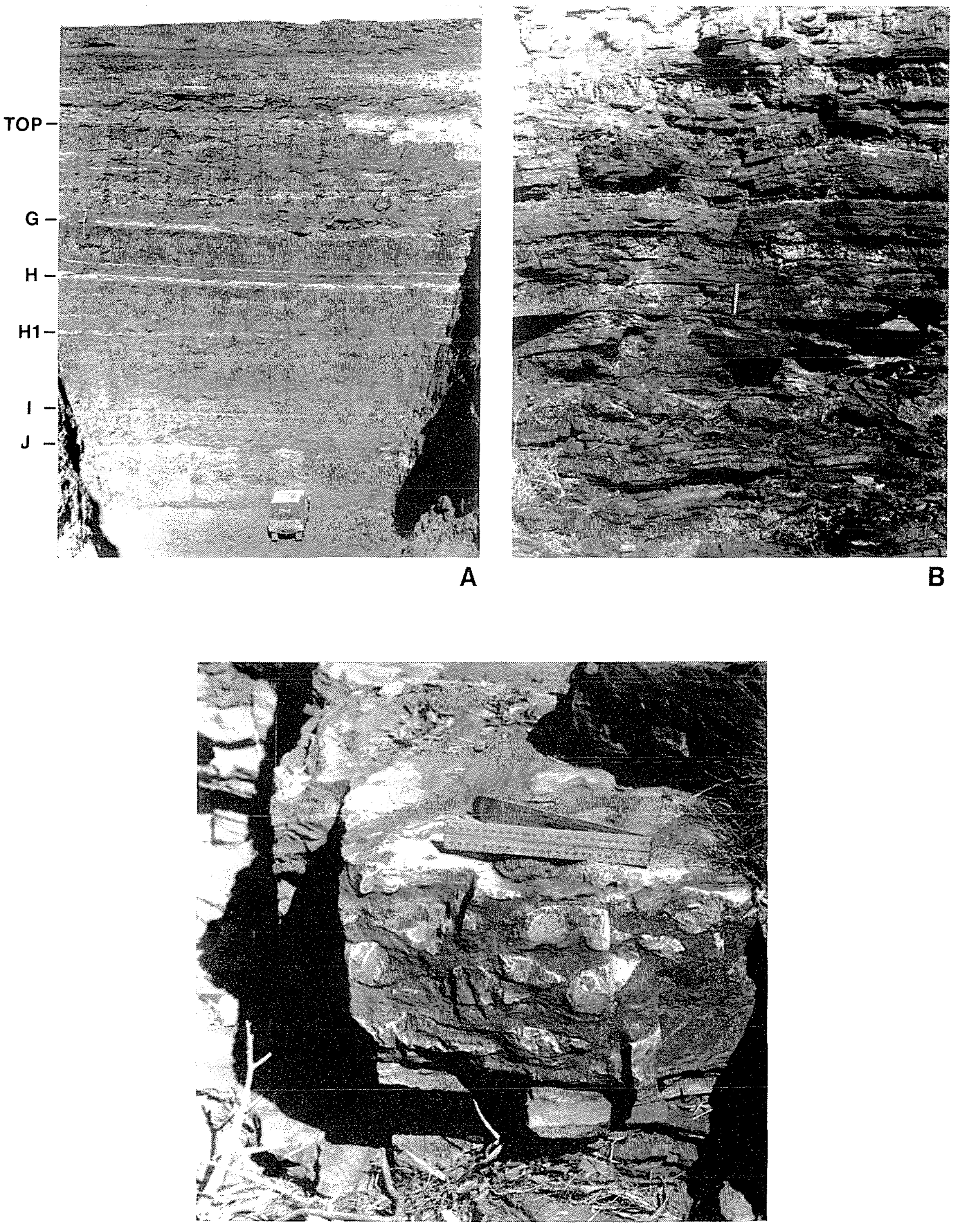

Figure 46 Photographs of the upper and middle members of the Marra Mamba Iron Formation.
A. Section of mineralized upper BIF member exposed in the test pit at Marandoo. The 'shale' horizons are numbered according to the scheme used by Texasgulf Australia Ltd. White appearance of 'shales' is due to efflorescence.
B. Distinctive podded chert horizon 4·5m below 'shale 6' in Kungarra Gorge.
C. Interbedded stilpnomelane (blocky appearance) and cherty iron formation (well-bedded appearance) typical of the middle shaly member in Kungarra Gorge.

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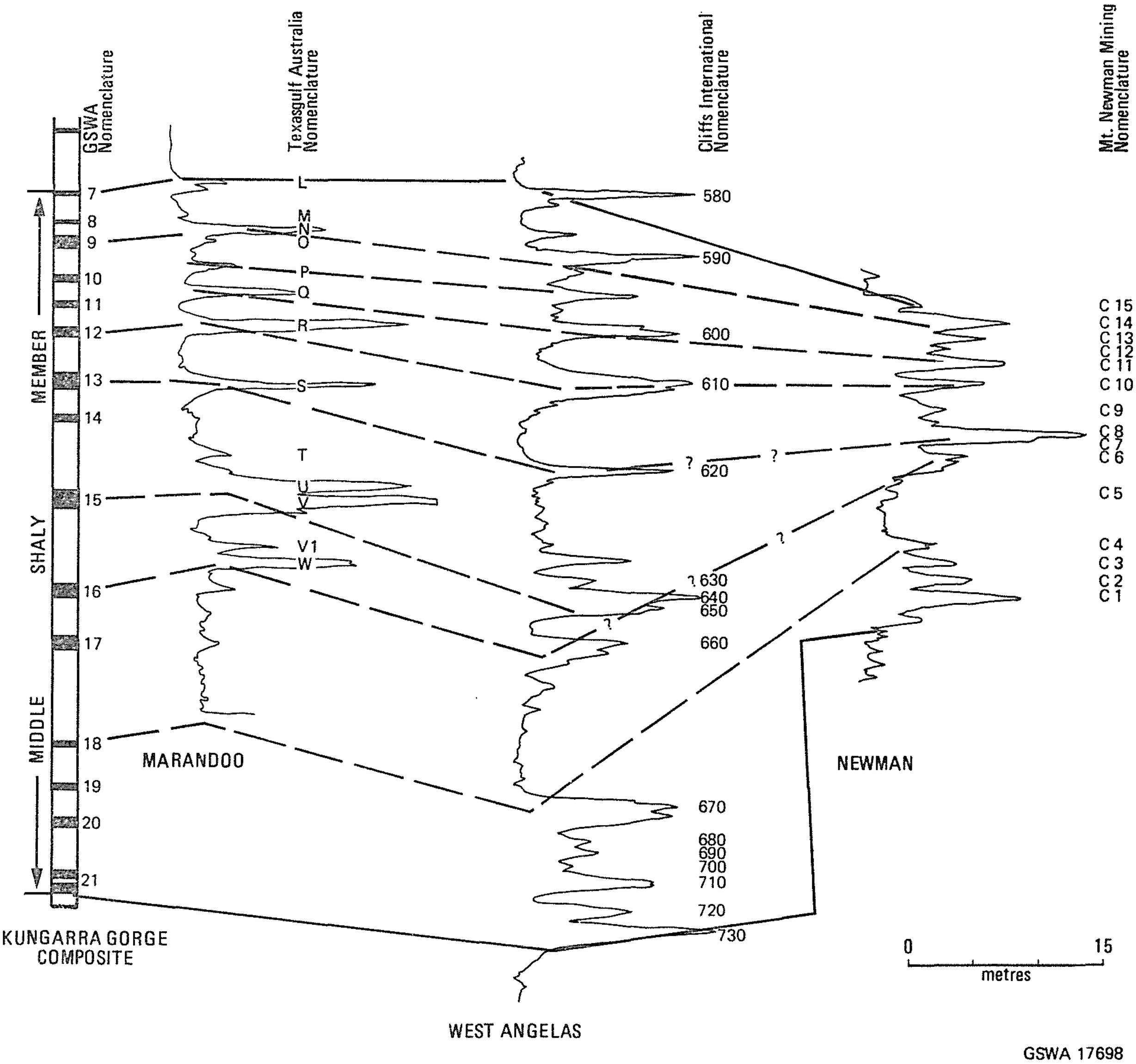

Figure 47 Comparison of gamma-ray logs and a measured section of the middle shaly member of the Marra Mamba Iron Formation, showing company nomenclature and some tentative correlations. As all sections are stated to be unmineralized, the thickness variations may be primary.

the centre of 'shale 5' is a band about 5 cm thick containing hematite nodules 3 to 5 mm in diameter. This band, first observed at West Angelas, was later recorded at Newman, Marandoo, Nammuldi and Kungarra Gorge.

An important feature of the 'shale' bands is that they retain their distinctive lithologies even where the surrounding iron formation has been converted to iron ore, although locally there may be difficulty in recognizing them due to slumping or squeezing of the units.

Another marker horizon of potential use in less weathered sections is a 40-cm band of distinctively podded chert occurring about 4.5 m below 'shale 6' in Kungarra Gorge (Fig. 46B). A smiliar band was noted about 6 m below 'shale 6' in a section measured in the Wonmunna area.

MIDDLE SHALY MEMBER

Figure 47 compares three gamma-ray logs of the middle shaly member with a well-exposed section in Kungarra Gorge. A suggested correlation, based on spacing and estimated thicknesses of the 'shales', is indicated by the dashed lines. Further information, particularly the matching of lithogolical sections and gamma-ray logs from several localities, is needed to confirm or modify the suggested correlations. An exposure of the member in Kungarra Gorge is shown in Figure 46C.

CONCLUSIONS

Although the stratigraphic subdivision of the upper BIF member of the Marra Mamba Iron Formation has been recognized independently by several operators, its basin-wide application may not have been appreciated by all of them.

The presence of indentifiable 'shale' bands within mineralized Marra Mamba Iron Formation has already been used in structural interpretations and ore-reserve calculations. In the future the 'shale' markers will almost certainly prove useful for grade control during mining operations. The knowledge that these 'shale' units extend for at least 300 km should add to the confidence with which they are employed as stratigraphic markers.

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THE BLUE SPEC GOLD–ANTIMONY MINE

by R. J. Morrison

ABSTRACT

The Blue Spec gold-antimony mine is located east of Nullagine, Western Australia, on a major shear zone which lies parallel to the regional strike of the Archaean Mosquito Creek Formation. During renewed operations from 1976 to 1978 a total of over 723 kg of gold and 690 t of antimony in concentrates were recovered from 47 422 t of ore with an average head grade of 30.9 g/t gold and 2.9 per cent antimony. Tailings assays indicate that the ore may average 0.1 per cent tungstic oxide.

The mineralization occurs in a complex, narrow, steeply plunging lode system which has a strike length of 70 to 100 m and is known to a depth of 350 m. The dominant ore minerals are stibnite, aurostibite and gold, which occur associated with quartz with or without carbonate veins. Sediments adjacent to the mine workings contain 10 to 20 per cent carbonate.

The lodes have proved to be unpredictable. Variograms of lode-width measurements indicate that the lodes maintain a measure of continuity to about 12 m along strike. Assays show no correlation at the mine sample scale, gold values having a log-normal distribution and antimony values having an anomalous log-normal distribution above a threshold of 5 per cent antimony.

INTRODUCTION

The Blue Spec mine is located on GML 46/404, 19 km north-northeast of Nullagine (230 km southeast of Port Hedland) at approximately lat. 21°49′S., long. 120°16′E. In October, 1978, the lease was registered jointly in the names of Mulga Mines Pty. Ltd. (50 per cent) and Metramar Minerals Ltd. (50 per cent).

The mine was visited from February 21st to 25th, 1978, to obtain representative samples of drill core and other material, and to collect data available at the termination of mining to assist any future evaluations. Unfortunately, the underground workings proved to be inaccessible at the time of the inspection.

The mineralization was discovered in 1905 and named after the winner of the 1905 Melbourne Cup. Because of difficulties in recovering gold from the antimony-rich ore, commercial production did not begin until 1935. After initial gold production, wartime demand for antimony led to the Wiluna Gold Corporation producing stibnite concentrates from the ore from 1945 to 1956. During 1956-57 the leases were held by the Western Australian Development Syndicate N.L., and the Golden Spec mine and the area east of Blue Spec mine were drilled with Government assistance (Ellis, 1957). North West Mining N.L. began operations in 1960 with the hope of increasing gold recoveries; however, metallurgical problems were not overcome. In 1962, after selective mining of high-grade areas, the mine closed with a substantial debt remaining to the Government, which then took over the property (Fitch, 1970).

The Metal Traders group acquired the mine in July, 1968, passing it to their subsidiary, Western Alluvials Pty. Ltd., in February, 1969. Investigations, commencing in 1970 after Metramar Minerals Ltd. was floated, initially concentrated on the antimony mineralization. When antimony prices returned to more normal levels after the 1970 boom the mineralization was re-examined for its gold potential. After considerable work had been carried out, Metramar was joined in 1972 by the Australian Anglo American subsidiary Mulga Mines Pty. Ltd. A minor interest in Mulga Mines Pty. Ltd's interest was purchased by Australian Consolidated Minerals Ltd. in December, 1975.

Up to November, 1972, $2 million had been spent on the mine and on feasibility studies. Capital expenditure after that date included $1 million on risk exploration and about $6.7 million on fixed capital items.

Just prior to the end of operations at Blue Spec mine, a proposal was made to extend the mine life by producing from the Golden Spec mine, 1 km west of Blue Spec mine. This proposal was found to be economically unattractive and consequently the mine closed on January 10th, 1978. An auction of all plant and equipment at the mine was held in March, 1978.

The total production reported to the Mines Department from the leases is summarized in Table 17.

TABLE 17. BLUE SPEC MINE PRODUCTION FIGURES

Period	Ore (t)	Gold (Au		Antimony (Sb)
		Production (kg)	Recovery (g/t)	Production (t Sb in concentrate)
1935–1975	64 200	1 187·748	18·5	798·85
1975–1978	47 422	723·973	15·3	690·8
Total	111 622	1 911·721	17·1	1 489·65

GEOLOGY

Blue Spec mine lies within the thick Archaean Mosquito Creek Formation. Hickman (1975) has described the geology of the formation which consists of metamorphosed greywacke and siltstone. The geology of the upper sections of the mine has previously been described by McKeown (1953).

LITHOLOGY

Inspection of rock types on the mullock dumps show that the country rocks are dominantly coarse- to fine-grained metasediments. The finer sediments tend to have a strong fabric giving rise to slaty cleavage which locally has been crenulated by later deformation. In places a phyllitic sheen has developed. The coarser sediments vary from sandy siltstone to coarse greywacke and have a more poorly developed fabric but a greater tendency to contain irregular carbonate, quartz-carbonate, or quartz veins.

An unexpected feature of the geology is the widespread presence of carbonate, both associated with quartz in the veins, and in the matrix of the country rocks. On the mullock dumps the carbonate in the quartz-carbonate veins weathers to a characteristic cream colour. On the surface, approximately 100 m west of the old main shaft, coarse-grained carbonate was found outcropping at the western end of the mineralized shear zone.

All sediments examined in thin section (Blight, 1978) contain significant quantities of carbonate in the groundmass, typically 10 to 15 per cent. The clastic fragments are mainly quartz or quartzite with some coarse detrital muscovite flakes and cherty fragments. Pyrite occurs locally both as disseminated grains and in quartz veins and veinlets. Despite their appearance in hand specimen, the shales are not particularly graphitic or chloritic, the dark colouring being due to minute specks of rutile and pyrite together with fine flaky opaque material interleaved with mica (unpublished Mulga Mines petrographic report).

MINERALIZATION

The mineralization which has been defined to date is associated with veins of quartz with or without carbonate, and sheared metasediments. Carbonate minerals are not normally abundant in the main orebody, but petrographic examination has demonstrated that they do occur in close association with the ore in some samples (Blight, 1978). Typically, quartz and quartz-carbonate veins are intruded by veinlets of stibnite in fine microstockworks adjacent to patches of massive stibnite. The characteristic mottled grey colour of the Blue Spec stibnite-quartz mineralization is caused by the variable intensity of these microfractures. Individual stibnite-bearing fractures usually cut across both the grain boundaries and the carbonate cleavage. The massive stibnite is commonly partially recrystallized from typical fine- to medium-grained material into coarse tabular crystals over 30 mm long.

Normally economic mineralization is confined within the veins, assays having a sharp cutoff at vein contacts (A. C. Gifford, pers. comm.). Gold is not always intimately associated with stibnite, and high gold assays have been recorded in some pyritic quartz lodes. There is currently no evidence of vertical mineralization zoning.

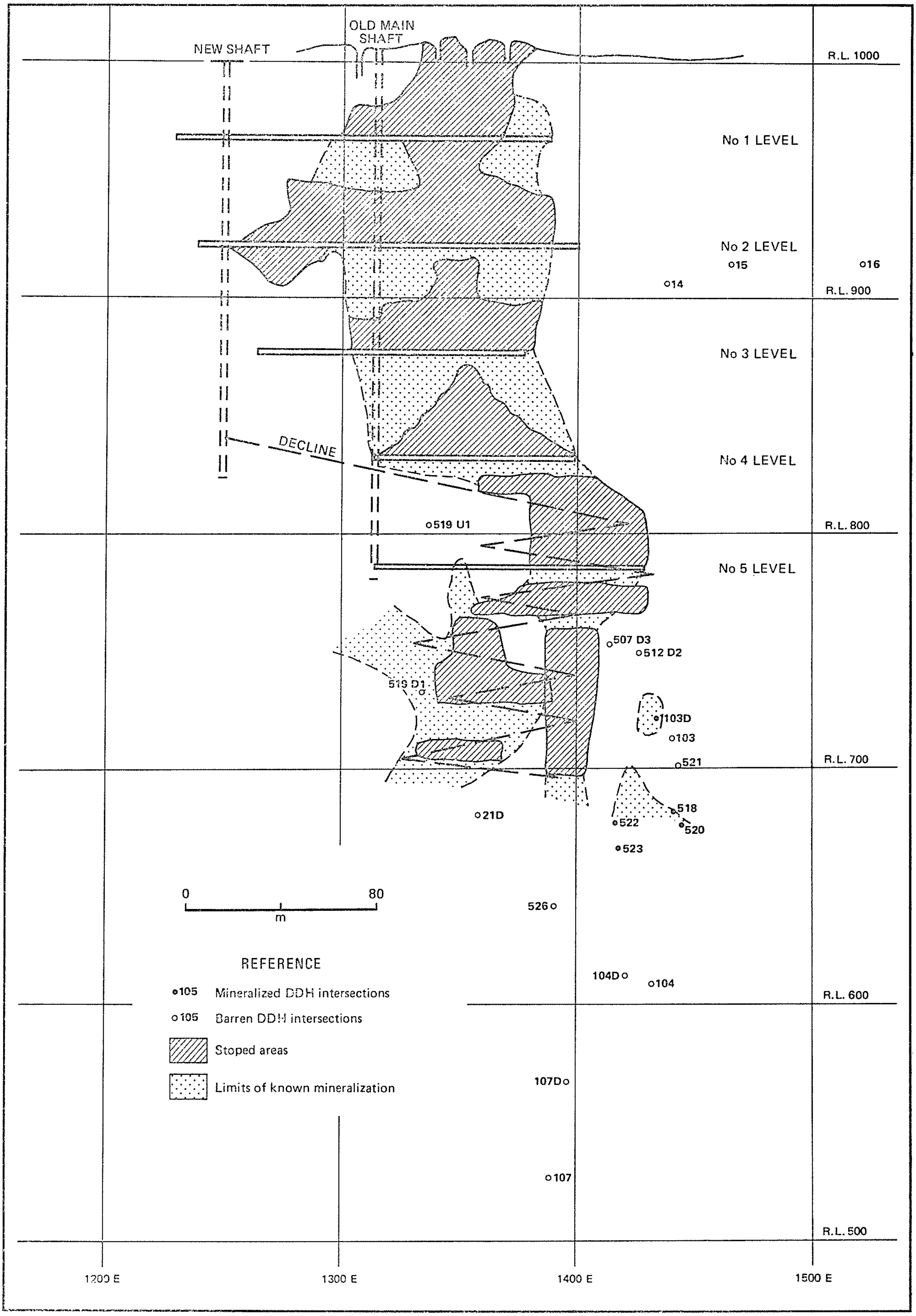

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Figure 48 Generalized longitudinal projection, Blue Spec mine (many stope outlines are not precisely known).

Although in many parts of the mine scheelite mineralization is negligible, it is locally abundant in the lode channel where it is said to correlate closely with gold. For example, samples taken by the company from a crosscut in the vicinity of 1370E at RL810 assayed up to 2.29 per cent tungstic oxide (WO_3), averaging 0.33 per cent WO_3, 23.3 g/t gold (Au), and 2.4 per cent antimony (Sb). However, analyses of samples from the upper sections of the tailings dams (Table 18) encountered only low tungsten values and it is concluded that the scheelite mineralization is very sporadic and may average about 0.1 per cent WO_3.

STRUCTURE

The Blue Spec mine lies near the western end of an easterly trending strike-fault zone which has gold and antimony mineralization intermittently associated with it over 17 km. In the immediate vicinity of the mine the Mosquito Creek Formation is dominantly south dipping, with a number of drag structures developed at intervals. A complex system of shears cuts across the area. Company mapping in 1971 showed that the mine is located near the junction of the main east-northeasterly trending Blue Spec shear with a more northeasterly trending fault system.

The mineralization occurs in a complex shear zone which strikes 080° and has a near-vertical dip. This lode system plunges at approximately 80°E and typically has a strike length of 70 to 100 m (Fig. 48). Within the shear zone irregular mineralized veins range up to 5 m in width but average about 1 m.

Individual lodes (referred to by the operators as "elements") usually dip vertically and are typically bounded on one side by a strong shear (A. C. Gifford, pers. comm.). Two or more lodes are usually present on any given level and are found in various positions, end to end, overlapping, and sometimes branching or folded (Fig. 49). The lodes tend to vary through the mine and may show local reductions in strike length and locally increased variation in grade.

Structure contours were constructed from company mapping of the lower levels in an attempt to define the lode structure and to predict any extensions to, or repetitions of, the mineralization (Morrison, 1978). No significant correlation appears to exist between "element 3" and the structure contours, although the axis of greatest thickness is subvertical, parallel to the trend of the structure. The "element 1" and "2" lodes have a complex structure, being separate units above RL 780, below which they join and reduce in strike length to become the vertically plunging "element 1-2".

Despite negative results in several deep drill holes, the mineralization is still open at depth. Drill holes 518, 520, and 523 intersected mineralization to a maximum depth of 350 m below the mine workings, close to reference plane 1400N. This suggests that the "element 1-2" shear zone either continues or is repeated down plunge. Work carried out by the company showed that mineralization indicated by these drill holes was of insufficient tonnage and grade to warrant further development and mining (Douglas, 1978).

STATISTICAL TREATMENT OF SAMPLING DATA.

McKeown (1953) noted that crossfolding gave rise to dispersed and erratic mineralization and to the formation of relatively small bodies of high-grade stibnite. Because the orebody has proved to be relatively unpredictable the available sampling data were examined in some detail to assist in any future evaluation of the mineralization.

SAMPLING

Examination of the diamond drill core showed that most shear zones produced very broken core and that some friable sections were present. In general the quartz reefs and massive stibnite cored well. Reliable sampling of faces underground proved to be difficult because of the different hardnesses of various mineralized and unmineralized rock types.

Figure 50A compares cumulative frequency plots for three groups of gold and antimony samples, that is, No. 5 level horizontal DDH assays, No. 5 level crosscut assays, and channel samples from drives below No. 5 level. The smaller diamond drill core samples have a greater spread of values, 90 per cent lying between 2 g/t and 380 g/t about a median of 17 g/t Au. In comparison 90

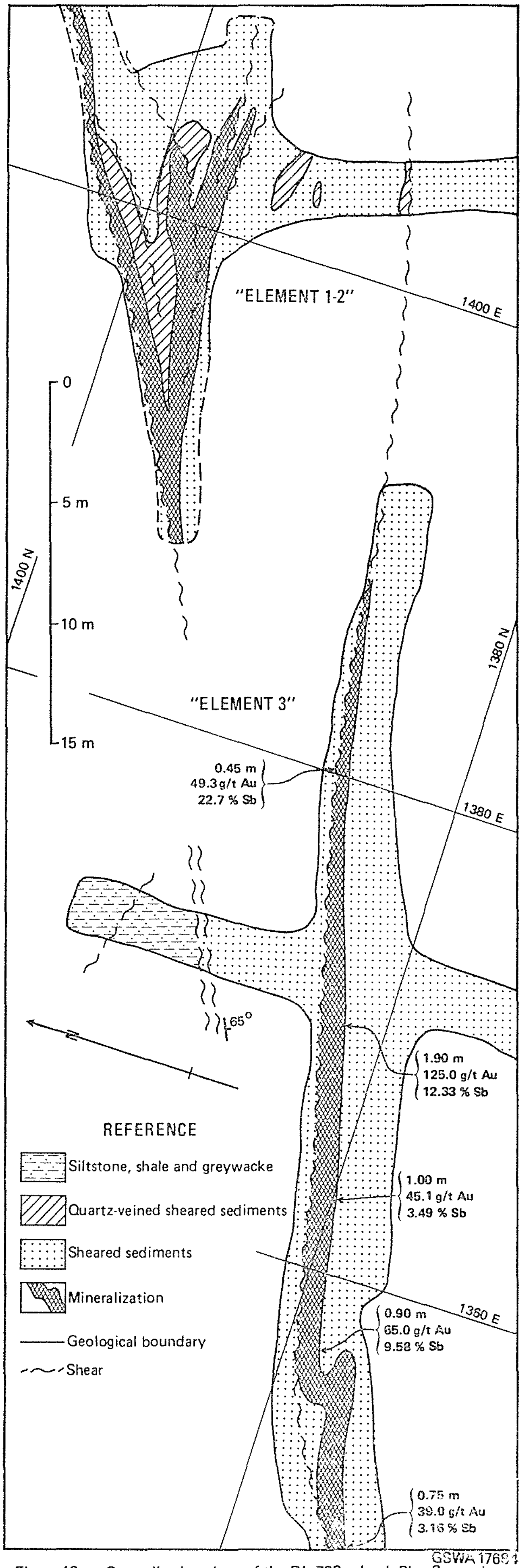

Figure 49 Generalized geology of the RL 722m level, Blue Spec mine (after mapping by A.C. Gifford for Mulga Mines Pty Ltd).

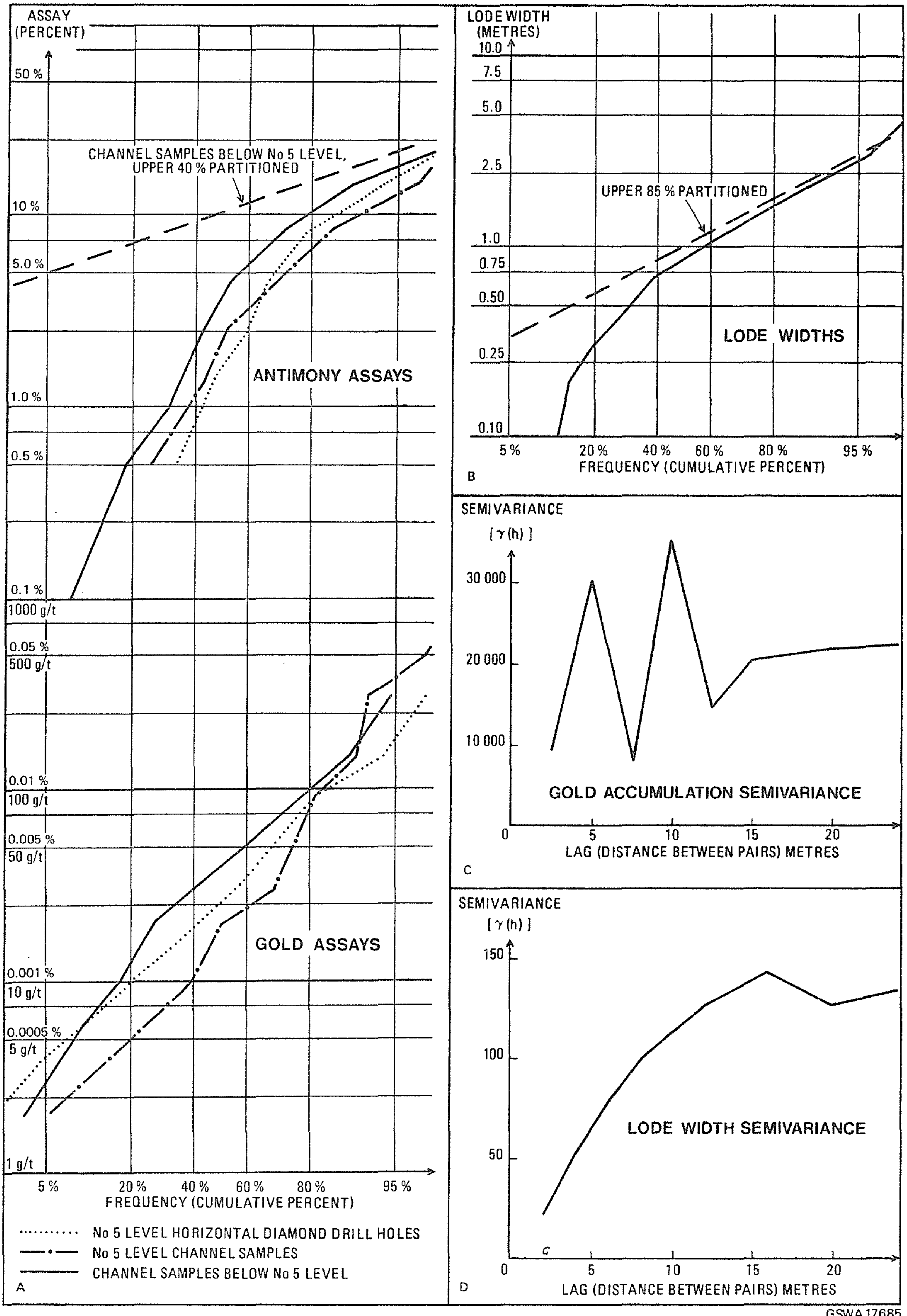

Figure 50 Cumulative frequency plots and variograms of sampling data, Blue Spec mine.

A. Cumulative frequency plots of gold and antimony assays on logarithmic probability paper.
B. Cumulative frequency plots of mapped lode widths below No.5 level on logarithmic probability paper.
C. Variogram of gold accumulations (metres width of samples x average assay in g/t) in channel samples below No.5 level. (A variogram is plot of the semivariance between pairs of samples against the distance (lag) between the pairs).
D. Variogram of mapped lode widths RL 697-702, RL 722, RL 754-757.

per cent of the No. 5 level channel samples, which tested the same area, lie between 4 and 174 g/t about a median of 25 g/t Au. Channel samples below the No. 5 level taken by different personnel tend to be higher grade, having a median of 39 g/t, with a 90 per cent spread from 3 g/t to over 300 g/t Au. The smaller drill core samples also tend to have a greater variance than the channel samples. When using a particular cut-off grade the smaller samples indicate a higher average assay than is suggested by larger volume samples (Krige, 1977).

GRADE DISTRIBUTION

The approximately linear plot of gold on log probability paper suggests that the distribution is log normal (Fig. 50A). This is best demonstrated by the No. 5 level channel samples. Antimony values on the other hand show a negative skew and obviously do not represent a single log normal distribution. Partitioning (Sinclair, 1974) of the upper 40 per cent of the antimony values suggests that a log normal distribution with a median value of 10 per cent Sb is present, having a threshold at about 5 per cent Sb.

With one exception (RL 757) the mean Au:Sb ratios in drive samples below No. 5 level showed little variation with depth and remained consistently close to the 1:900 Au:Sb ratio encountered during the 1976-78 mine production. Correlograms of individual sample ratios of Au:Sb, however, show extreme variation.

A variogram (David, 1977) of gold accumulations of mine channel samples was constructed to determine the dimensions of the zone of influence of the samples (Fig. 50C). In this case the variogram, which is a plot of semivariance ($\gamma(h)$) against lag (h), was constructed from pairs of samples of lag (i.e. distance) h apart, along the strike of the lode. The semivariance, $\gamma(h)$, was calculated from the formula:

$$\gamma(h) = \frac{1}{2N} \sum_{i=1}^{n-h} \{g(x_i) - g(x_{i+h})\}^2,$$

where N is the number of samples, h is the distance between pairs of samples, $g(x_i)$ is the gold accumulation (m.g/t) at position x_i, and $g(x_{i+h})$ is the gold accumulation at distance $_h$ beyond x_i. Figure 50C shows that the semivariances of the gold accumulations are high and that there is little evidence of continuity within the mineralization, even over short distances.

The semivariances of gold assays between adjacent and next but adjacent samples (i.e. lag of 1 and 2) for both diamond drill hole (DDH) and channel samples on No. 5 level were also calculated to determine whether any correlation could be found over shorter distances. These indicated that there is no correlation between adjacent samples and thus classical satistics rather than geostatistics should be applied to the gold assays. Antimony assays in No. 5 level diamond drill holes were also examined and there is only a slight possibility of a weak correlation between adjacent samples.

LODE WIDTH

A cumulative frequency plot of the width of lodes below No. 5 level (Fig. 50B) was based on measurements taken from company mapping. Partitioning of the dominant log normal distribution, represented by a straight line between 40 per cent and 96 per cent cumulative frequency, suggests that about 85 per cent of the measured points lie within this distribution which has a median of 1 m width.

A variogram of lode widths (Fig. 50D) was constructed from mapping on RL 697-702, 722, and 754-757. This has characteristics of the spherical model (David, 1977) and shows decreasing continuity up to its range of approximately 12 m after which the lode widths are independent of distance. Thus in the area studied, the maximum distance which a lode width measurement can be projected and still retain any degree of correlation with the sampling point is about 12 m along strike. (Variograms for individual levels showed some variation about this figure.) No data are available to construct a vertical variogram and thus to test for anisotropy within the deposit.

MINING

The main shaft used in the first phase of mining down to No. 4 level proved to be unsuited to further production. After drilling in 1970-71 had indicated additional reserves at depth, General Mining and Finance sank a new shaft to the northwest of the main shaft. The old main shaft was later deepened to No. 5 level and an exploratory drive was cut to provide a bulk sample of the mineralization and to give access for underground drilling.

The mining method was mechanized cut-and-fill, with stope access off a 1 in 7 decline. The decline was chosen because of considerations of both mining efficiency and the extra capital cost and delay involved in shaft sinking. It was extended for a length of approximately 1 km from near the base of the new shaft.

The final stoping procedure adopted was a flat back resue method, the mineralized vein being mined first and walls stripped later where necessary. The minimum stoping width was 1 m. Attempts to fill stopes with wet tailings were not successful because the very sheared wall rock became unstable when wet. Dry river gravel was used as fill in the latter stages of mining.

Typical production figures for the mine are illustrated by the period from April to November 1977 when the median weekly tonnage extracted was 660 t, 90 per cent of the weekly production being between 470 t and 770 t. The median head grades for this period were 29.5 g/t Au and 3.25 per cent Sb, 90 per cent being between 20 and 40 g/t Au, and 1.7 and 4.6 per cent Sb.

A. C. Gifford (pers. comm.) indicated that at the cessation of mining operations in January 1978 little mineralization remained readily accessible for underground inspection. Virtually all the blocked out ore reserves had been extracted from the workings, which persist to 310 m below the original surface. The mined ore bodies have averaged 360 t per vertical metre.

METALLURGY

The concentrating process was based on gravity tabling followed by cyanidation and carbon absorption of gold, and flotation of antimony concentrates.

Recoveries of both gold and antimony were low, the average recovered grade from all operations at the mine being about 17 g/t Au and 1.5 per cent Sb. A number of factors appear to have contributed to the problem. Ores containing aurostibite ($AuSb_2$) are notoriously difficult to treat commercially, being virtually unattacked by mercury or cyanide solutions (Henley, 1975). In addition, arsenic and antimony sulphides cause difficulties in cyanidation, reducing gold extraction, and themselves being dissolved while at the same time increasing reagent consumption. Other factors may have been important such as the low head grades caused by the unavoidabily high dilution. Typical analyses of grab samples of stibnite concentrates (unpublished Mulga Mines Pty Ltd data) were:

antimony >60%
sulphur 24.0%
iron 1.24%
lead 0.10%
arsenic 0.0255%
gold 0.0044% (44 g/t)
mercury 0.00015% (1.5 ppm)

Because of the known high losses of gold and antimony from the mill, and the presence of significant WO_3 within the ore, shallow samples were taken from each of the five main tailings dams (Table 18).

TABLE 18. ASSAY RESULTS OF TAILINGS SAMPLES, BLUE SPEC MINE

Sample No.	Locality	Au g/t	Sb %	W %
55022	SE tailings composite	4·7	0·24	0·054
55023	E tailings composite	6·9	0·48	0·090
55024	S tailings composite	8·9	0·34	0·091
55025	N tailings composite....	12·4	0·31	0·062
55026	W tailings composite	4·7	0·18	0·094

It should be emphasized that the samples were designed only to provide an indication of tailings values. Any future economic evaluation of this material should be based on a comprehensive sampling programme.

The Government Chemical Laboratories used x-ray powder photographs, scanning-electron microscopy and other means in an attempt to identify the gold, antimony and tungsten minerals present in the tailings. The minerals could not be definitely identified, but the evidence suggested that tungsten may be present as scheelite, and antimony as stibiconite.

ACKNOWLEDGEMENTS

The assistance of Mulga Mines Pty Ltd, Metramar Minerals Ltd and Australian Anglo American Ltd is gratefully acknowledged. Particular thanks are also due to Dr Tony Gifford, and Messrs Bruce Mellor and Bruce Jannson who provided much useful information on the mine geology and recent operations.

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BIOTITE DATES AND COOLING HISTORY AT THE WESTERN MARGIN OF THE YILGARN BLOCK

by W. G. Libby and J. R. de Laeter*

ABSTRACT

Twenty-eight rubidium-strontium whole-rock-biotite two-point isochrons give dates which regularly decline from typical Yilgarn Block ages of about 2 500 m.y. near Meckering, to about 500 m.y. at the western limit of the Yilgarn Block, 70 km to the west. In contrast, four whole-rock isochrons supported by additional model dates suggest that whole-rock dates maintain the typical Yilgarn Block level (2 500-2 700 m.y.) to the western limit of the block.

The only whole-rock date younger than Archaean is from Bald Hill quarry in the Avon Gorge, where an isochron from six samples gives a date of 1 566 ± 302 m.y. with an initial $^{87}Sr/^{86}Sr$ ratio (R_i) of 0.722 6 ± 0.005 3. Whole-rock dates somewhat older than 2 700 m.y. seem typical of the Avon Valley between Toodyay and York, in keeping with the earlier determinations of Arriens (1971).

INTRODUCTION

Mapping of biotite Rb-Sr dates throughout Western Australia was suggested by W. Compston (written communication) in 1969, apparently as an outgrowth of discussions he had in the field with A. F. Trendall, P. A. Arriens and J. L. Daniels. By 1971 plans for mapping biotite Rb-Sr dates were formalized within the Geological Survey. For convenience and significance the Perth 1:250 000 Sheet was chosen as a pilot area to be studied in conjunction with the biotite isotope data from the Gascoyne Province (de Laeter, 1976). Accordingly, samples were collected by W. G. Libby and S. A. Wilde, beginning in March, 1972. The location of the study area within the tectonic framework of the Yilgarn Block is shown in Figure 51 and the locations of samples within the study area are shown in Figure 52.

The samples were prepared mechanically in the laboratory of the Geological Survey for chemical and isotopic analysis in the Department of Physics, Western Australian Institute of Technology. Samples are briefly described in Petrology Report no. 945 on file with the Geological Survey.

The petrographic conventions of Streckeisen (1973) are followed, with the addition of fields for adamellite, quartz monzonite, and monzonite. In an attempt to follow

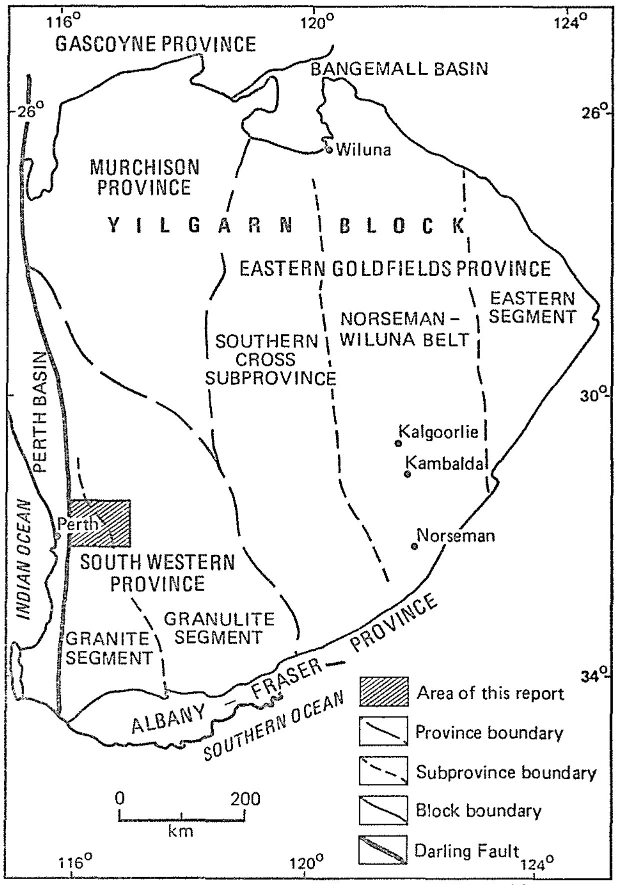

Figure 51 Index map and tectonic subdivisions of the Yilgarn Block.

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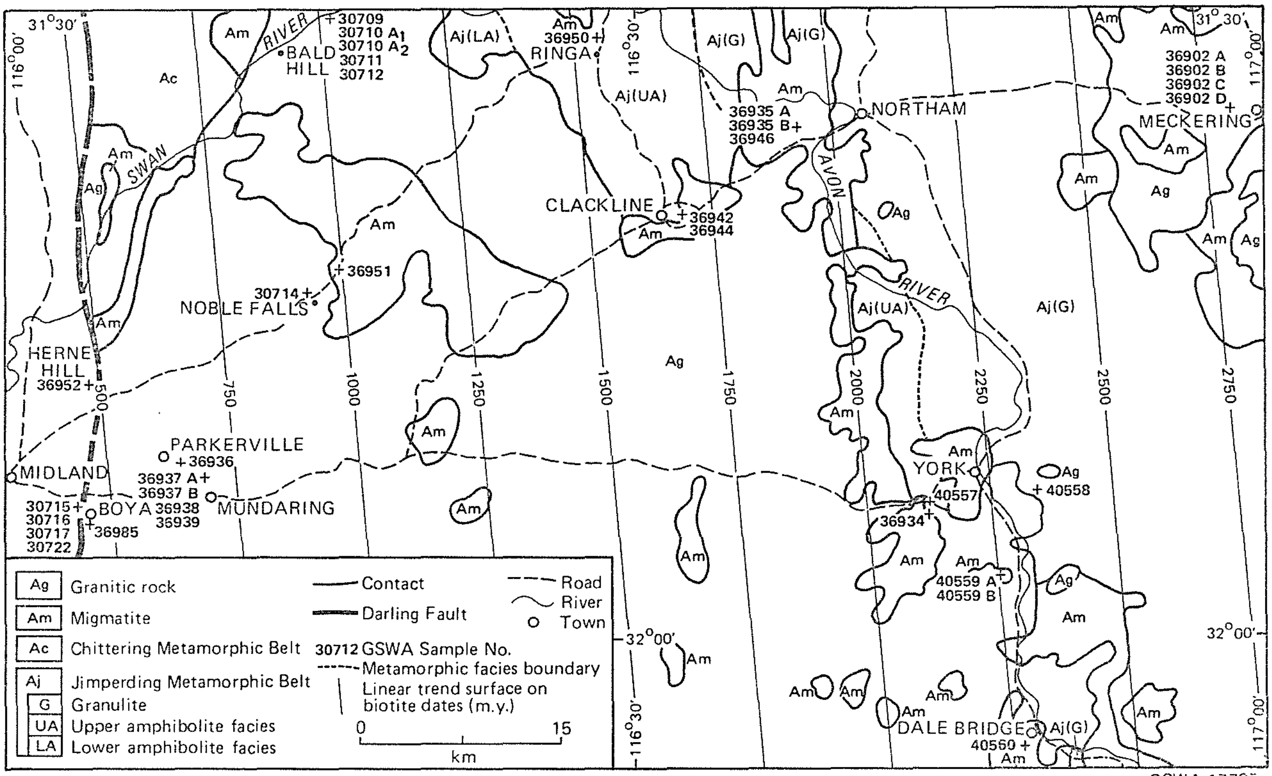

Figure 52 Locality index, linear trend surface on biotite Rb-Sr dates, and bedrock geology.

the convention of Faure and Powell (1972), 'age' is applied to the time that a real event occurred whereas 'date' is applied to the result of a calculation based on analytical data expressed in years before present, which may or may not correspond with a geological event.

This pilot study of biotite Rb-Sr dates is limited to a portion of the western margin of the Yilgarn Block, extending from the Darling Fault, where the Archaean Yilgarn Block terminates against the Phanerozoic Perth Basin, eastward for about 100 km into the Yilgarn Block. All localities except Dale Bridge lie within the Perth 1:250 000 map sheet. Dale Bridge is on the adjacent Pinjarra Sheet.

The project has shown that whole-rock Rb-Sr dates of about 2 500 m.y. tend to persist to the western edge of the Yilgarn Block whereas biotite Rb-Sr dates decline regularly westward in the western 70 km of the block from about 2 500 m.y. at Meckering to about 500 m.y. at the Darling Scarp near Perth. A single anomalous whole-rock date of 1 600 m.y. at Bald Hill suggests that at least one local high-grade Proterozoic event affected the area in addition to the pervasive low-grade effects recorded by biotite.

REGIONAL GEOLOGY

The Yilgarn Block, about 350 000 km^2 of almost exclusively Archaean rock, has been divided into three sections: the Eastern Goldfields Province in the east, the Murchison Province in the northwest, and the Southwestern Province. Outside the Southwestern Province most of the Yilgarn Block is granite-greenstone terrain. Within the Southwestern Province metamorphic grade is higher, rocks are more coarsely crystalline, and distinct greenstone belts are more difficult to define (Trendall, 1975; Williams, 1975). The Southwestern Province has been subdivided (Gee, 1975) into a granulite segment in the east and a granite segment in the west. The line separating the two segments passes from northwest to southeast across the middle of the area chosen for the pilot study of biotite ages. Gneisses of the Toodyay, Northam, York and Dale Bridge areas belong to the granulite segment whereas gneisses and granitoids of Bald Hill, Noble Falls, Boya, Parkerville, Mundaring and Clackline belong to the granite segment.

Most of the Precambrian rocks from the Perth and Pinjarra Sheets described by Wilde (1974, 1976) can be classified in one of four associations, the Chittering Metamorphic Belt, the Jimperding Metamorphic Belt, plutonic rocks of the granite segment between these belts, and migmatite and granitoid northeast of the Jimperding Metamorphic Belt. The geology of the study area is outlined in Figure 52.

Apart from weakly metamorphosed Proterozoic rocks of the Cardup Group along the Darling Scarp, metamorphosed supracrustal Precambrian rocks in the vicinity of Perth belong to one of two suites, the Jimperding metamorphics in the northeast and the Chittering metamorphics in the west. The Jimperding Metamorphic Belt consists of pelitic to arenaceous schists and gneisses up to granulite facies. The belt trends south-southeasterly along the Avon River valley in the vicinity of Toodyay, Northam, York and Dale Bridge. The Chittering Metamorphic Belt to the west consists of gneiss with intercalated amphibolite and pelitic schist. The schists contain kyanite, staurolite and sillimanite but, unlike the Jimperding Metamorphic Belt, are limited to grades below granulite facies. The Chittering Metamorphic Belt trends southward along the Darling Fault eventually pinching out against the fault in the southern third of the Perth Sheet.

The two belts of metamorphosed supracrustal rocks are separated by a wedge of complex granitic and gneissic rock which widens southward to form the granitic segment of the Southwestern Province described by Gee (1975).

Within the area of study metamorphic grade tends to decrease from east to west, reversing the more general westerly increase in grade across most of the Yilgarn Block (Wilde, 1974, 1976).

EARLIER ISOTOPIC STUDIES NEAR PERTH

Several earlier geochronological studies in the Perth area have been published (Compston and Jeffery, 1959; Compston and others, 1960; Wilson and others, 1960; Compston and Arriens, 1968; and Arriens, 1971). Unfortunately, much of the earlier data are not directly comparable with the whole-rock isochrons used in this work. Analytical data for three whole-rock samples published by Compston and others (1960) would, if combined with our data from Mundaring (Fig. 53C), slightly raise the date and lower the $^{87}Sr/^{86}Sr$ initial ratio (R_i). A whole-rock isochron date from York (Compston and Arriens, 1968) of 2 690 ± 210 m.y. ($\lambda = 1.39 \times 10^{-11}\ yr^{-1}$) is consistent with our dates in the area. Seven dates determined by Arriens (1971) are plotted in the time-distance graph, Figure 56.

Additional biotite data, mostly east of the area of specific interest, are provided by Wilson and others (1960) and Aldrich and others (1959). These data also are plotted on the time-distance graph (Fig. 56). A mildly disturbing biotite date by Mullumby is quoted by Compston and Arriens (1968). Mullumby determined a date of 1 070 m.y. (probably $\lambda = 1.39 \times 10^{-11}\ yr^{-1}$) from biotite at South Chittering, well west of biotites of this age found in the present study, but direct comparison is not possible as the present study did not reach north to the Chittering area.

Total rock, mineral dates between 560 and 590 m.y. ($\lambda = 1.39 \times 10^{-11}\ yr^{-1}$) were measured on metasomatized and sheared edges of basic dykes near Mundaring (Compston and Arriens, 1968). When adjusted for a decay constant equal to $1.42 \times 10^{-11}\ yr^{-1}$ (548 m.y. and 577 m.y., respectively), these dates are close to the biotite ages we determined in the same area.

Modern whole-rock data are provided by Arriens (1971) including eight dates from localities within our area of interest. Five localities are on the Perth Sheet, and three

TABLE 19. ANALYTICAL DATA FOR WHOLE-ROCK SAMPLES AND BIOTITE CONCENTRATES FROM LOCALITIES MENTIONED IN THE TEXT

Locality	Sample Number	Rock Type	Material Analysed	Rb (ppm)	Sr (ppm)	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
Bald Hill Quarry	30709	bgd	wr	123	294	0·417±0·005‡	1·21±0·02	0·750 09±0·000 31
			btt			33·6±0·7	113±2	2·352 4±0·002 4
	30710 A*	bgd	wr	142	290	0·489±0·005	1·42±0·02	0·753 87±0·000 28
			btt			26·2±0·5	82±1·5	1·609 8±0·001 3
	30710 A†	bgd	wr	136	250	0·545±0·006	1·58±0·02	0·757 10±0·000 41
			btt			16·8±0·4	51±1	1·266 6±0·001 5
	30711	bgd	wr	135	262	0·514±0·006	1·49±0·02	0·754 62±0·000 37
			btt			42·6±0·8	143±2	2·348 1±0·002 7
	30711†	bgd	wr	115	252	0·453±0·005‡	1·31±0·02	0·750 60±0·000 42
			btt			26·9±0·5	85±1·5	1·641 5±0·002 0
	30712	msgd	wr	115	364	0·316±0·004	0·92±0·01	0·742 52±0·000 31
			btt			60±1·2	230±5	4·088 7±0·003 9
Noble Falls	30714	adgn	wr	159	205	0·775±0·008	2·25±0·03	0·782 75±0·000 43
			btt			116±2	547±10	7·182 7±0·007 3
	36951		wr	145	184	0·789±0·009	2·30±0·04	0·786 88±0·000 42
			btt			26·2±0·5	81±1·5	1·424 9±0·001 1
Boya Quarry	30715	bgd	wr	114	168	0·678±0·007	1·97±0·03	0·768 64±0·000 39
			btt			63±1·2	211±4	2·401 3±0·002 8
	30716	bgd	wr	106	107	0·99±0·01	2·88±0·04	0·795 09±0·000 28
			btt			31·9±0·7	99±2	1·495 8±0·001 9
	30717	bgd	wr	148	114	1·30±0·02	3·79±0·05	0·824 08±0·000 53
			btt			39·4±0·8	124±3	1·598 0±0·001 8
	30722		wr	167	134	1·25±0·02‡	3·64±0·05	0·832 69±0·000 55
Meckering Quarry	36902 A	bad	wr	244	376	0·665±0·007	1·93±0·03	0·774 76±0·000 33
			btt			45±0·9	247±5	9·673 4±0·008 4
	36902 B	bgt	wr	327	270	1·21±0·02	3·54±0·05	0·831 29±0·000 50
	36902 C	bgt	wr	225	278	0·808±0·009	2·35±0·03	0·791 05±0·000 62
			btt			68±1·3	614±12	22·482±0·020
	36902 D	bad	wr	180	318	0·565±0·006	1·64±0·03	0·764 31±0·000 37
			btt			30·6±0.6	126±3	5·060 8±0·005 1
York area	36934	adgn	wr	177	74	2·40±0·03	7·1±0·1	0·990 77±0·000 71
			btt			59±1	376±7	13·039 9±0·010 3
	40557	bgn	wr	200	101	1·99±0·02	5·88±0·08	0·938 78±0·000 85
			btt			36±0·6	163±4	6·554 2±0·005 4
	40558	mig	wr	121	269	0·451±0·005	1·31±0·02	0·754 04±0·000 38
			btt			28·1±0·6	114±2	4·837 0±0·003 8
	40559 A		wr	71	695	0·102±0·002‡	0·296±0·005	0·714 10±0·000 35
	40559 C		wr	68	686	0·010±0·001‡	0·288±0·004	0·713 78±0·000 39
Northam Quarry	36946	adgn	wr	148	155	0·95±0·01	2·78±0·04	0·813 79±0·000 47
	36935 A	htgn	wr	151	168	0·91±0·01	2·64±0·04	0·788 70±0·000 46
			btt			69±1·4	600±10	21·251±0·019
	36935 B	bsch	wr	612	16·6	36·7±0·5‡	169±3	6·820 0±0·003 4
			btt			94±2	1 710±30	54·900±0·044
Parkerville Quarry	36936	bgd	wr	197	130	1·52±0·02	4·45±0·06	0·878 10±0·000 55
			btt			143±3	599±10	5·267 6±0·004 3
Mundaring Quarry	36937 A	bgd	wr	230	130	1·76±0·02‡	5·18±0·07	0·896 23±0·000 61
			btt			90±2	325±6	3·284 0±0·002 1
	36937 B	bgd	wr	233	134	1·74±0·02	5·11±0·07	0·896 13±0·000 57
			btt			193±4	955±20	8·008 6±0·007 4
	36938	bgd	wr	218	129	1·69±0·02	4·96±0·07	0·890 96±0·000 53
			btt			82±1·5	290±5	3·005 0±0·001 9
	36939	bgd	wr	190	133	1·43±0·02	4·19±0·06	0·860 41±0·000 71
			btt			76±1	266±5	2·895 1±0·002 2
Clackline	36942	gdgn	wr	132	369	0·357±0·004	1·04±0·02	0·746 98±0·000 28
			btt			32·2±0·6	123±2	3·978 4±0·002 5
	36944	gdgn	wr	259	343	0·754±0·008	2·19±0·05	0·788 65±0·000 53
			btt			62±1·2	322±6	9·352 6±0·008 5
Ringa	36950	gtgn	wr	270	144	1·88±0·02	5·53±0·08	0·929 05±0·000 61
			btt			36±0·6	144±3	5·065 7±0·003 7
Herne Hill Quarry	36952 A	bgd	wr	151	94	1·61±0·02	4·70±0·07	0·832 86±0·000 49
						148±3	633±12	5·587 6±0·004 2
Helena Valley Quarry	36982		wr	208	104	1·99±0·02	5·85±0·08	0·907 20±0·000 82
Dale Bridge Quarry	40560 B	bgn	wr	104	267	0·389±0·004	1·13±0·02	0·748 04±0·000 41
	40560 B†	bgn	wr			0·204	0·590	0·725 54
	40560 C(L)	btgn	wr			0·142	0·410	0·719 577
	40560 C(D)	htgn	wr			0·506	1·46	0·756 18

Rock type codes:

bgd biotite granodiorite
msgd mafic schlieren in granodiorite
adgn adamellite gneiss
bad biotite adamellite
bgt biotite granite
bgn biotite gneiss
mig migmatite

htgn hornblende tonalite gneiss
bsch biotite schist
gdgn granodiorite gneiss
gtgn granite gneiss
btgn biotite tonalite gneiss
wr whole rock
btt biotite

* first subsample
† second subsample
‡ average of two analyses
(L) Light phase
(D) dark phase

on the Pinjarra Sheet. Using a decay constant of 1.39 x 10^{-11} yr^{-1}, dates range from about 2 200 to about 3 600 m.y. though the extreme dates are poorly controlled. A pooled date on 23 gneiss samples from the Avon River valley and near the Darling Scarp is about 3 100 m.y. A date on 7 samples of microgranite dykes near Northam is about 2 300 m.y. The gneisses, principally in the Avon River valley (Dale Bridge, York, Northam and Toodyay) give dates of about 3 100 m.y., systematically older than granitic rocks of the Yilgarn Block as a whole. Most dates from Yilgarn Block granitic rocks lie between 2 600 and 2 700 m.y. (Arriens, 1971).

SUMMARY OF GEOPHYSICAL DATA ON CRUSTAL STRUCTURE NEAR PERTH

Bouguer gravity anomalies are higher in the Darling Range than across most of the Yilgarn Block (Everingham, 1965, plates 8 and 9; Mathur, 1974, Figure 7). Everingham suggested that the general rise in Bouguer anomalies takes place across the Yandanooka-Cape Riche lineament (west of Meckering), as illustrated by his plate 9. Mathur (1974), on the other hand, suggests that the observed increase in Bouguer anomalies across the Yandanooka-Cape Riche lineament is part of the regional increase from the Eastern Goldfields to the Southwestern Provinces.

Everingham attributed the high Bouguer anomaly of the Darling Range to shallowing of intermediate crustal layers, despite deepening of the Mohorovicic discontinuity, and to an increase in mafic dykes near the Darling Scarp. A change in crustal structure along the Yandanooka-Cape Riche lineament is appealing as the lineament coincides with changes in surface rock types, topography, and metamorphic grade, and is defined as an active seismic zone.

Gravity, reflection and refraction data were interpreted by Mathur to show three crustal layers, a top layer at a density of 2.78 g/cm^3, a middle layer of 2.91 to 2.94 g/cm^3, and a lower layer of 3.04 to 3.10 g/cm^3. The two upper layers become shallower and thinner to the west whereas the lower layer thickens to the west, resulting in an overall westward thickening of the crust. The crustal thickness near Kalgoorlie is about 34 km, and under the Yilgarn Block near Perth it is about 44 km.

Thus the Southwestern Province has an anomalous crustal structure but it is not clear whether the anomaly is limited by the Yandanooka-Cape Riche lineament or whether it is the culmination of a regional trend.

EXPERIMENTAL PROCEDURE

About 500 grams of each sample was crushed to pea size and split. The split for whole-rock analysis was reduced to –200 mesh in a Tema-style mill. Three to five grams of biotite were separated from the remaining split, mainly with a Frantz magnetic separator, and reduced to –200 mesh in an automatic agate mortar. The procedure for Rb-Sr analysis was essentially as described by Lewis and others (1975), de Laeter and Abercrombie (1970) and de Laeter (1976).

Measured Rb and Sr values and measured Rb/Sr ratios, determined by X-ray fluorescence spectrometry, are listed with mass spectrometric determinations of $^{87}Sr/^{86}Sr$ in Table 19. We believe the measured values of Rb and Sr are accurate to ±7 per cent; however, the measured Rb/Sr ratios should not be expected to correspond precisely with ratios which would be derived from the separate Rb and Sr values listed. Errors are reported at the 95 per cent confidence level. The value 1.42 x $10^{-11}yr^{-1}$ was used for the decay constant of ^{87}Rb (Steiger and Jäger, 1977).

ANALYTICAL RESULTS AND REGIONAL PATTERNS

WHOLE-ROCK RESULTS

The results of whole-rock analyses are listed in Table 19. Although whole-rock data are used primarily to support one end of the whole-rock-biotite isochron for each sample, at four localities sufficient samples were collected to form whole-rock isochrons independent of biotite data. These isochrons are plotted at a single scale in Figures 53 A to D. The isochron from Bald Hill is also plotted at an expanded scale in Figure 54. The data for these samples have been regressed using the least-squares program of McIntyre and others (1966). Results are listed in Table 20. Whole-rock model ages are mapped on Figure 55.

The results from Bald Hill are of particular interest as they imply a Proterozoic age in an area conventionally considered Archaean.

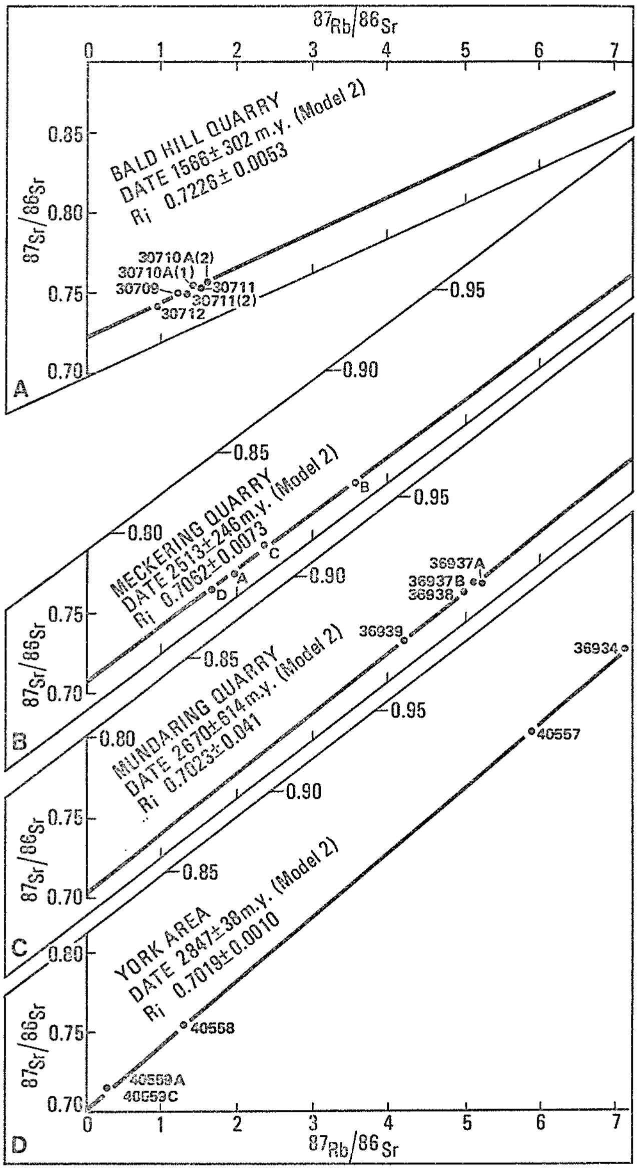

Figure 53 Biotite – whole-rock isochrons.
A. York area
B. Meckering quarry
C. Bald Hill quarry
D. Mundaring quarry

Figure 54 Bald Hill quarry, whole-rock isochron at an expanded scale.

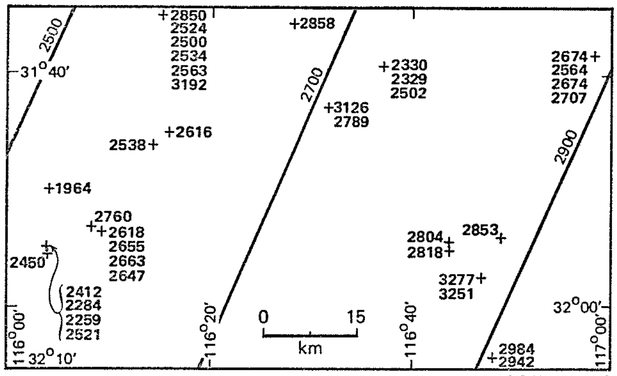

Figure 55 Map of whole-rock model ages with an assumed initial ratio of 0.700.

BIOTITE RESULTS

Biotite analytical results are listed with the whole-rock results in Table 19. Ages for each biotite, formed by joining the analysis at each separated biotite with that of a whole-rock split from the same sample, appear in Table 21 and are plotted in Figure 56. Biotite ages decrease regularly from Meckering (about 2 500 m.y.) westward for 70 km to the edge of the Yilgarn Block at the Darling Scarp (about 500 m.y.). This strong age gradient contrasts with whole-rock ages which, apart from the Bald Hill site, are consistent across the entire area.

Apart, possibly, from the Bald Hill site, there is no clear relation between either biotite or whole-rock dates and geology. Samples from the most westerly and most easterly localities are from granitoid rocks; intermediate samples are from migmatite and, possibly, Jimperding metamorphics (Fig. 52). However, the oldest whole-rock dates are from the Avon River valley area from which old dates have been previously recorded (Arriens, 1971).

TABLE 20. DATES FROM WHOLE-ROCK SAMPLES

Locality	No. of samples	MSWD*	Date (m.y.)	Ri	Model
Bald Hill Quarry	6	6·9	1 555±130 1 566±302	0·722 8±0·002 4 0·722 6±0·005 3	1 2†
Meckering Quarry	4	3·3	2 508±131 2 513±246	0·706 4±0·004 0 0·706 2±0·007 3	1 2†
Mundaring Quarry	4	3·0	2 678±362 2 670±614	0·701 7±0·024 2 0·702 3±0·041	1 2†
York area	5	1·4	2 844±35 2 847±38	0·702 0±0·000 7 0·701 9±0·001 0	1 2†

* Mean square of weighted deviates. † Preferred model.

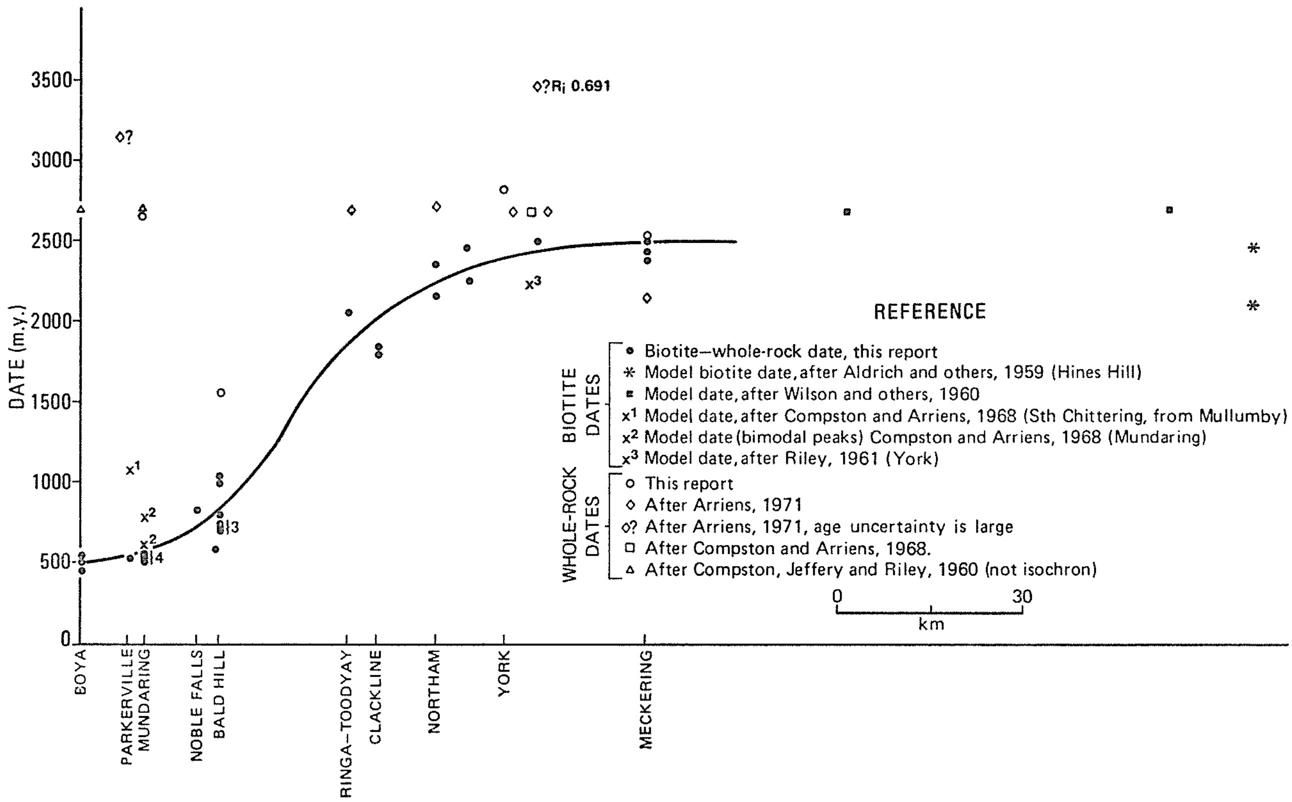

Figure 56 Plot of dates against distance east of the Darling Scarp, measured normal to isopleths on the linear trend surface of biotite Rb-Sr dates.

TABLE 21. DATES FROM BIOTITE SAMPLES

Locality	Sample	Date (m.y.)	Locality	Sample	Date (m.y.)
Bald Hill Quarry	30709	1002	York	36934	2264
	30710A*	744		40557	2473
	30710A†	722		40558	2506
	30711	789			
	30711†	746	Northam Quarry	36935A	2372
	30712	1021		36935B	2164
Noble Falls	30714	823	Parkerville Quarry	36936	518
	36951	569	Mundaring Quarry	36937A	524
Boya Quarry	30715	548		36937B	525
	30716	512		36938	520
	30717	452		36939	545
Meckering Quarry	36902A	2512	Clackline	36942	1842
	36902C	2454		36944	1805
	36902D	2392			
			Ringa	36950	2073
			Herne Hill	36952	531

* First subsample. † Second subsample.

REGIONAL BIOTITE DATES

Biotite dates from the current study plus 33 Yilgarn Block biotite dates from other sources (Aldrich and others, 1959; Wilson and others, 1960; Turek, 1966; Compston and Arriens, 1968; and Roddick and others, 1976) along with dates from adjacent areas are plotted on Figure 57. All of the dates in the southwestern part of the Yilgarn Block are less than 2 000 m.y.; all those elsewhere in the Yilgarn exceed 2 000 m.y. In the western part of the Perth Sheet the transition from dates above 2 000 m.y. to dates below this figure approximates the boundary between the granulite and granite segments of the Southwestern Province.

Biotite data are not available for the south-central part of the Yilgarn Block or from a very large area in the northwestern part; however, biotite dates are available from the adjacent Gascoyne Province where they have a westward-decreasing trend similar to the pattern on the Perth Sheet, though less steep. Data from the east Gascoyne are from Williams and others (1978); those from the west Gascoyne have been drawn from de Laeter (1976) but recalculated to $\lambda = 1.42 \times 10^{-11}yr^{-1}$, the decay constant which we have used. Both data sets are plotted on the map, Figure 57. Three dates in the southwestern part of the Yilgarn Block similarly define a westward-sloping trend surface: (a) Wellington Dam (Compston and Arriens, 1968), 675 m.y. at $\lambda = 1.39 \times 10^{-11}yr^{-1}$; (b) Donnybrook (Compston and Arriens, 1968), 500 m.y. at $\lambda = 1.39 \times 10^{-11}yr^{-1}$; and (c) Hester (Wilson and others, 1960), 760 m.y. at $\lambda = 1.386 \times 10^{-11}yr^{-1}$. Adjusted for $\lambda = 1.42 \times 10^{-11}yr^{-1}$, these dates become, respectively, 661 m.y., 489 m.y., and 742 m.y. Although the three points are insufficient in themselves to provide confidence in a trend, it may be significant that the trend is consistent with the data from the Perth Sheet and the Gascoyne Province.

Although broad areas are devoid of Rb-Sr data on biotite, the reasonably continuous set of data between Perth and Kalgoorlie provides some constraint on proposed models for the Yilgarn Block. A model consistent with current data shows random variations in dates above 2 000 m.y. over most of the Yilgarn Block, decreasing rapidly but regularly in a westerly direction to about 500 m.y. along the western margin of the block. The decrease in dates may be reflected in the Gascoyne Province as well as in the adjacent Yilgarn Block.

Material is now being collected for a similar study of biotite dates along the western margin of the Yilgarn Block between Perth and the Gascoyne Province.

INTERPRETATION

DATING OF UPLIFT

Rubidium-strontium dates from biotite commonly are younger than whole-rock Rb-Sr isochron dates from the same rocks. The relatively late biotite date is commonly attributed to a metamorphic event which expelled Sr from biotite but failed to homogenize strontium among the whole-rock samples. However, an alternative interpretation was suggested by Hurley and other (1962). In their view biotite K-Ar and Rb-Sr dates may reflect time of uplift rather than time of thermal climax. This interpretation is particularly attractive if the rocks can be shown to have been at such a depth that a reasonably normal geothermal gradient would have brought them to a temperature above the blocking temperature of Sr for biotite.

Armstrong (1966) suggested the contouring of mapped biotite dates. Each contour would represent the intersection of the surface of the earth with a surface bearing a particular biotite age. The surface was formed at the depth of the regional blocking temperature for biotite. The biotite in deeper rocks lost the radiogenic Sr daughter product, those above retained it. On cooling associated with uplift and erosion the radiogenic isotope was frozen into the lattice and the date of uplift recorded. A succession of such surfaces, each younger than the previous, would be formed as long as uplift and erosion continued to bring new rock through the level in the crust at which Sr was frozen in biotite. On exposure these surfaces can be contoured. The conturs may outline the original shape of the isothermal surface if uplift has been uniform over the region or may reflect relative amounts of uplift if the original surface was flat. Armstrong called contours on biotite dates 'chrontours', Harper (1967) preferred 'thermochrons'.

Dates of uplift have been inferred from biotites using both K-Ar data (Armstrong and Hansen, 1966; Harper, 1967; and Krummenacher and others, 1975) and Rb-Sr data (Jäger, 1965; and Armstrong and others, 1966).

BIOTITE ^{87}Sr BLOCKING TEMPERATURE

A low ^{87}Sr diffusion blocking temperature in biotite is necessary for the interpretation of biotite dates as age of uplift. The blocking temperature should be equivalent to ambient temperatures well within the crust under a normal geothermal gradient.

Hanson and Gast (1967) calculated that biotite lost radiogenic Sr at temperatures down to 350°C near the Duluth Gabbro and down to 450°C at a quartz dolerite dyke, 50 m thick, near Christmas Lake Wyoming. They concluded that temperatures in excess of 300°C are necessary to effect complete radiogenic Sr daughter loss in biotite. Jäger and Zwart (1968) assume a 300°C blocking temperature for Rb-Sr in biotite from the Pyrenees. Dodson (1973) calculated that the 300°C estimate for Sr biotite closure derived by Jäger and others (1967) from mineralogical data in the Alps is reasonable. Williams and others (1975) accept the temperature of about 300°C; and Roddick and others (1976) accept a blocking temperature near 250°C on the basis of the work of Hart (1964) and Hanson and Gast (1967). Thus the consensus of observation and acceptance places the biotite blocking temperature near 300°C for an environment of regional heating. This is equivalent to a depth of 15 km at the modest rate of 20° C/km. The data of Hanson and Gast from Christmas Lake, suggesting somewhat higher temperatures, may be influenced by kinetic effects associated with the contact environment which they studied.

MODELS OF CRUSTAL DEVELOPMENT

The results of the botite analysis probably cannot now be given a unique interpretation. Various assumptions are necessary to arrive at any model. Apart from the fundamental assumption that the pattern of westward-decreasing biotite dates reflects a real, simple cause rather than fortuitous sampling one may assume:

(model 1), that each reported date closely approximates the age of a short-lived thermal event in the area;

(model 2), that the dates closely approximate the age of closure of the biotite system after an extended period above closure temperatures; or

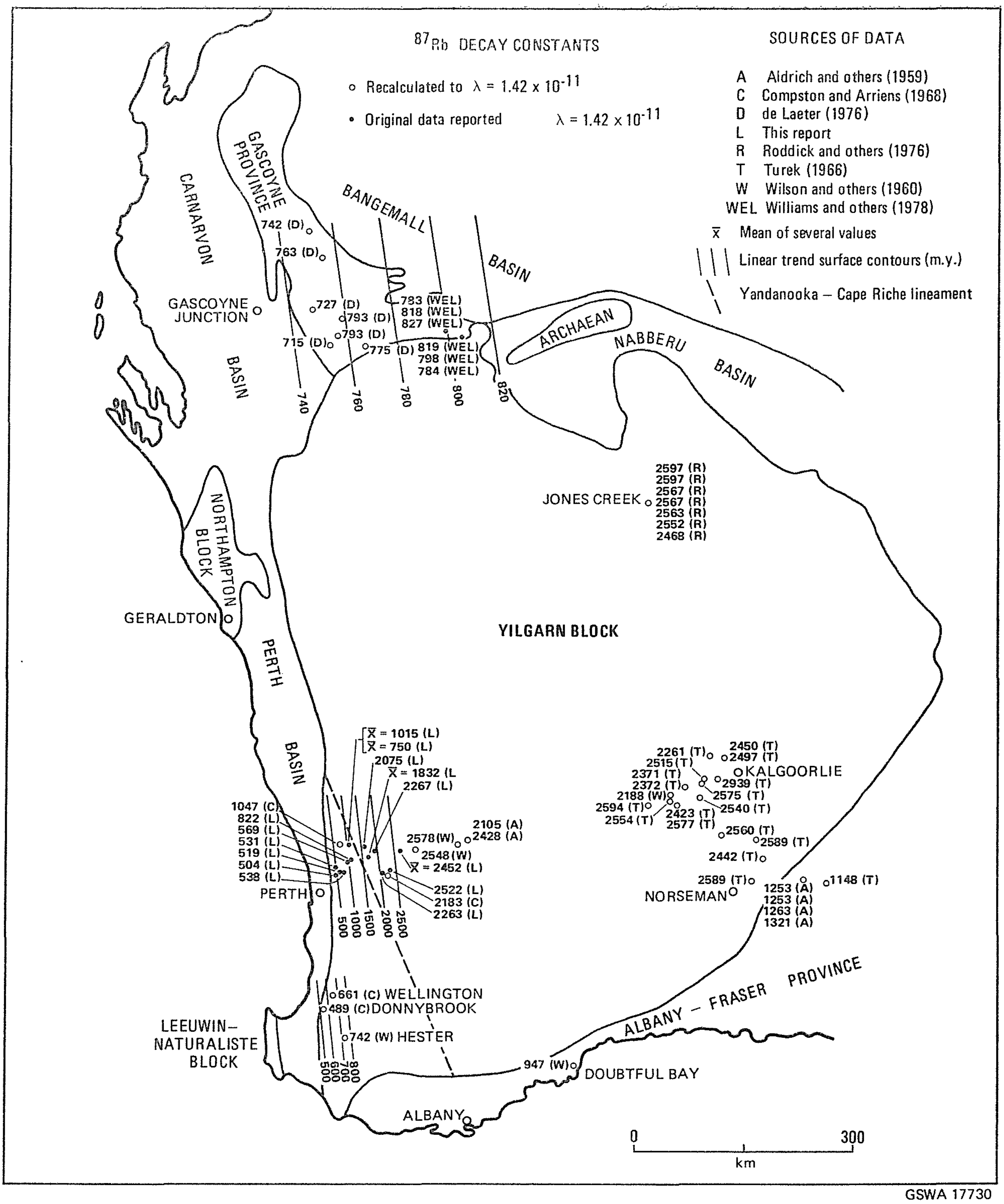

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Figure 57 Regional biotite Rb-Sr dates, Yilgarn Block, with local linear trend surfaces.

(model 3), that the range in dates is due to variable expulsion of radiogenic ^{87}Sr from the biotite lattice near the closure temperature of ^{87}Sr in biotite.

Model 1 would require a wave, continuous or in discrete steps, of thermal activity passing from the Meckering area to the Darling Fault, or progressively contracting in that direction, over a period of 2 000 m.y., from 2 500 m.y. to 500 m.y. In the absence of precedent for this type of process elsewhere or necessity to invoke it here, model 1 seems less attractive than models 2 and 3. Nevertheless, the possibility of discrete thermal events draws some support from whole-rock Rb-Sr data. There are whole-rock dates which span much of the time interval involved. A date of 548-577 m.y. on basaltic dyke margins in the Mundaring area (Compston and Arriens, 1968) has already been mentioned. Assuming that this is an igneous date, an igneous event is provided to account for the western, young, biotite dates. Various dates on dykes from the Perth area, from 750 m.y. to 1 500 m.y., are quoted by Giddings (1976) from unpublished work by Compston and Crawford. The six-point whole-rock isochron from Bald Hill (Fig. 54) indicates a substantial mid-Proterozoic igneous or metamorphic event near the centre of the zone of transition of biotite dates. A high $^{87}Sr/^{86}Sr$ initial ratio (R_i), large mean square of weighted deviates, and large error limits favour a metamorphic origin for the Bald Hill whole-rock date although the rock appears no more metamorphosed than others which give an Archaean date. However, regardless of igneous or metamorphic origin of the date, a very substantial mid-Proterozic event is indicated.

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Thus there is plentiful evidence for discrete events capable of resetting biotite throughout the range of dates observed.

Apart from evidence from whole-rock data, a few biotite results seem to support multiple discrete events. Inspection of biotite results from Bald Hill suggests two ages. Figure 58 is a plot of biotite-whole-rock isochrons from Bald Hill, translated in the manner of van Schmus (1965) for more ready comparison of slopes. The clustering of slopes about 1 000 m.y. and 750 m.y. confirms the bimodal distribution of dates, though their statistical significance is not established.

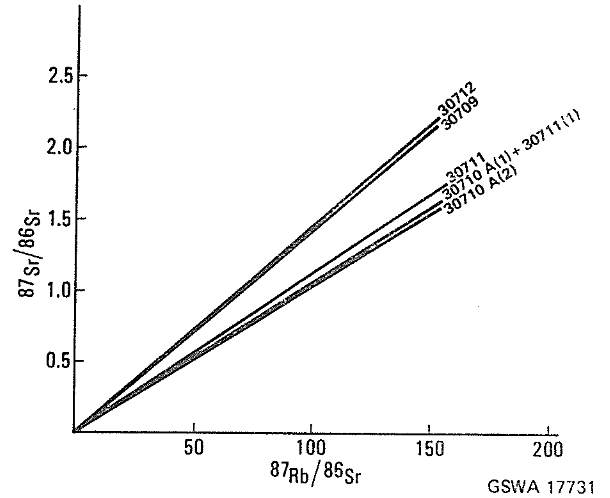

Figure 58 Bald Hill quarry, isochrons from biotite to associated whole-rock points, translated to pass through a common origin (O,O).

Despite suggestions of multiple discrete events the most direct interpretation of the data is a smooth progression of dates from 2 500 m.y. to 500 m.y. A mechanism for triggering discrete events sequentially to give the observed gradient in biotite dates remains difficult to find. Thus until better correlation between biotite dates and igneous or metamorphic events is established, or the regular progression of dates is shown to be spurious, models 2 and 3 are preferred.

Model 2 has substantial appeal as the steady march of events for 2 000 m.y. can be attributed to erosion and isostasy, processes which conceivably could have acted uniformly over the required period. In this model, slow and steady uplift of crustal material through the 300°C isotherm, accompanied by erosion, sets the sequence of dates. The truncated edges of surfaces of equal date are exposed successively either by uniform uplift and erosion of originally sloping paleo-isothermal surfaces or by erosion after continuous or episodic tilting of these surfaces. In any of these cases, erosion truncates the surfaces of equal date, giving the observed geographic spread of dates. This model would seem to be consistent with the geophysical pattern of westward-shallowing of the intermediate crustal layer. However, to explain the westward thickening of the total crust as well as to account for continued uplift of the magnitude assumed, crustal underplating would seem to be required.

In model 3, the disequilibrium model, only the oldest and youngest dates have age significance. The intermediate dates reflect incomplete expulsion of strontium from the biotite lattice. The appeal of this system is that a uniform succession of events spanning 2 000 m.y. is not required. A principal objection is that the entire 70 km from the Darling Scarp to Meckering would need to have been poised in the presumably small temperature range of partial discharge of ^{87}Sr from biotite. It seems unrealistic to propose vertical isotherms with the required temperature range spread from Meckering to the Darling Scarp, but gently eastward-dipping isotherms might be acceptable. Here, however, model 3 begins to converge on model 2. Truth may lie in this area.

The critical area for testing model 1 against models 2 and 3 seems to be the zone of steep gradients in dates between Toodyay and Bald Hill. Further samples have been collected in this area and are being analysed.

In summary, whole-rock Rb-Sr dates appear to average about 2 700 m.y. throughout the Southwestern Province whereas biotite Rb-Sr dates fall regularly westward from about 1 500 m.y. at Meckering to about 500 m.y. at the Darling Scarp, 70 km to the west. The succession of dates may be attributed either to a series of discrete events, the gradual elevation of the rock mass through the 300°C isotherm, or the increased completion of expulsion of radiogenic ^{87}Sr from the biotite lattice upon westward approach to a source of heat less than 500 m.y. ago. No choice is made among the 3 models, but the last two are favoured over the first.

ACKNOWLEDGEMENTS

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INTRACOENOSTEAL VARIATION IN A SPECIMEN OF *ACTINOSTROMA*

by A. E. Cockbain

ABSTRACT

Six variables have been measured in 6 thin sections cut from one coenosteum of *Actinostroma papillosum*. Ten measurements were made of each variable in each thin section and the results statistically analysed. The median test suggests that lamina thickness, number of laminae in 5 mm and distance in which 15 pillars occur, show significant intracoenosteal variation at the 0.05 level while the other 3 variables—pillar thickness, number of pillars in 5 mm and distance in which 15 laminae occur—show no variation. The Kruskal-Wallis test suggests that only pillar thickness shows *no* variation at this level. Fagerstrom and Saxena's (1973) data on intracoenosteal variation in *Syringostroma sherzeri* were re-examined and significant variations were found to occur in 2 of their 4 variates. It is concluded that intracoenosteal variation is higher than previously believed. The treatment of tied median values in the median test is discussed in an appendix.

INTRODUCTION

Measurement of variables, for example the spacing of laminae and pillars, is an important aspect of the description of stromatoporoid specimens. Such measurements are usually few in number and are often made on only one thin section from a coenosteum. The assumption that such measurements are representative of the variation throughout the coenosteum has been tested by Fagerstrom and Saxena (1973). They showed that in a specimen of *Syringostroma sherzeri* from the Devonian of Ontario, 3 out of 4 variables showed no significant variation within the coenosteum.

In the course of a study of Devonian stromatoporoids from the reef complexes of the Canning Basin, numerous specimens of *Actinostroma* were observed. In the form of the 'Art-Diagram' (Flügel, 1959), measurements have been considered especially critical in differentiating species of *Actinostroma* and it was decided to extend Fagerstrom and Saxena's work to see how much intracoenosteal variation there is in this genus.

MATERIAL AND METHODS

Actinostroma is one of the commonest stromatoproids in the Pillara Limestone (Playford and Lowry, 1966; Playford and Cockbain, 1976). Several species are present and the most abundant one is identified as *A. papillosum* Bargatzsky. Specimen F9861 from sample no. 18660 is a large, well-preserved example of *A. papillosum* and was collected from reef facies of the Pillara Limestone at the southern end of McWhae Ridge (Fossil locality MRM 2; Mount Ramsay 1:250 000 map sheet, grid reference (yards) E 408 900; N 649 610). It is hemispherical in shape with a diameter of 350 mm and a height of 250 mm. The coenosteum was cut vertically through the middle and 6 thin sections were made from different parts of cut surface (Fig. 59). The cut surface has an area of about 600 cm^2 and the thin sections ranged in area from 14.5 to 30 cm^2.

Ten measurements of 6 variables were measured on each thin section. The variables are:

1. Number of laminae in 5 mm (L5)
2. Number of pillars in 5 mm (P5)
3. Lamina thickness (in mm) (Lt)
4. Pillar thickness (in mm) (Pt)
5. Distance (in mm) occupied by 15 laminae (15L)
6. Distance (in mm) occupied by 15 pillars (15P)

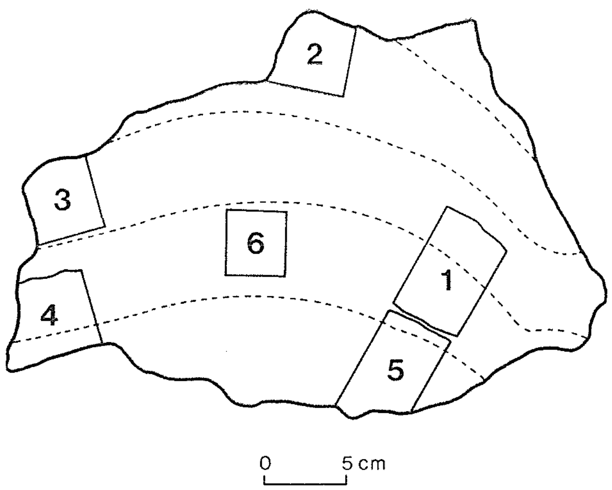

Figure 59 Sketch of vertical section through coenosteum F9861 showing position of slides (1-6) and course of selected laminae (- - - - - -).

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Variables 5 and 6 are equivalent to variables 1 and 2. However, measuring the distance in which a number of laminae and pillars occurs, rather than the number of laminae and pillars in a particular distance, gives a more continuous variate and (incidentally) simplifies the calculation of the gallery index. By way of emphasising the small sample size that these thin sections represent, it was calculated that the coenosteum had a volume of 12.3 x 10^3 cm^3 and possessed about 100 laminae and around half a million pillars.

The original data are on file at the Geological Survey of Western Australia.

STATISTICAL ANALYSIS

The amount of intracoenosteal variation may be analysed stastistically by determining the probability that, for any variable, the measurements in each of the 6 samples (thin sections) are drawn from the same population (coenosteum). This may be re-phrased: taking a probability of 0.05 as the rejection level, do the samples come from the same population?

Three tests were carried out on the data, the F test, extension of the median test, and the Kruskal-Wallis one-way-anova test. Fagerstrom and Saxena (1973) argued that the F test was inappropriate because the data are (a) discontinuous variates and (b) are not necessarily normally distributed. They preferred to use the distribution-free median test. Their reasoning is accepted here and the F test is included purely for comparative purposes and will not be discussed further.

The results of the tests are tabulated below:

Variate	F test	Median test *	Kruskal-Wallis test †
L5	3·55	13·04	14·71
P5	4·61	9·57	16·77
Lt	2·42	11·20	11·07
Pt	1·02	1·94	3·91
15L	2·75	9·60	12·46
15P	3·83	12·00	14·07
Significance level:			
0·05	2·37	11·07	11·07
0·01	3·34	15·09	15·09

* See Appendix for tied median values
† Corrected for ties.

INTERPRETATION

Two features stand out from the above table. Firstly the difference between the two distribution-free tests and secondly the high values of the test statistics. At the 0.05 probability level the median test shows that for only 3 of the variates are the samples drawn from the same population (P5, Pt and 15L). The Kruskal-Wallis test indicates that this is true for only one variate (Pt). Hence there is considerable intracoenosteal variation in L5, Lt and 15P, much less in P5 and 15L and least (negligible) in Pt.

Intracoenosteal variation in the lamina characters (L5, Lt) could be explained by the presence of latilaminae, which do occur in this specimen; however, it is strange that latilamination does not affect 15L to the same extent. The great variation in pillar spacing (15P) is hard to account for and is not reflected in the P5 variate.

Which of the two distribution-free tests to prefer is a difficult problem. The Kruskal-Wallis test uses more information than the median test and has a higher asymptotic relative efficiency (0.955 as compared with 0.637 for the median test; see Gibbons, 1971, p. 202). Conover (1971, p. 256) states that the median test is preferable to the Kruskal-Wallis test if there are too many tied observations. Here the most favourable test outcome is accepted, that is that the samples are drawn from the same population and hence the results of the median test are preferred. At the same time a note of caution should be sounded and perhaps variable Pt is the only one that has an acceptably small amount of variation.

RE-EXAMINATION OF FAGERSTROM AND SAXENA'S DATA

The conclusion that half of the variables studied showed considerable intracoenosteal variation is quite different from Fagerstrom and Saxena's results. In *Syringostroma sherzeri* they found that only 1 of the 4 variables studied showed appreciable intracoenosteal variation.

Through the courtesy of J. A. Fagerstrom I have been able to re-examine their data. The variables measured in *S. sherzeri* were:

1. Number of microlaminae in 2 mm (L2)
2. Megapillar diameter (MPd)
3. Megapillar spacing (MPsp)
4. Number of galleries encircling each megapillar (EG)

The data were tested in the same way as for *Actinostroma* with the following results:

Variate	F test	Median test*	Kruskal-Wallis test†
L2	2·85	9·91	16·97
MPd	3·21	10·88	16·75
MPsp	6·65	14·63	27·94
EG	4·45	20·00	22·21
Significance level:			
0·05	2·17	14·07	14·07
0·01	2·95	18·48	18·48

* See Appendix for tied median values.
† Corrected for ties.

The values for the results of the median test differ from those published by Fagerstrom and Saxena (1973) because of the different way of resolving tied median values (see Appendix for discussion of this problem). Again the two distribution-free tests give different results. Accepting the more favourable results of the median test, the thin sections do not come from the same population with respect to variables MPsp and EG. Hence there is considerable intracoenosteal variation in these two variables. Fagerstrom and Saxena recognised considerable variation only in EG.

CONCLUSIONS

Of the 6 variables examined in *A. papillosum* and the 4 in *S. sherzeri*, only half show no intracoenosteal variation at the 0.05 probability level using the median test. The Kruskal-Wallis test would reduce to one the variables showing no such variation at the same level of acceptance. The variates showing no intracoenosteal variation are, in *A. papillosum:* P5, Pt and 15L; in *S. sherzeri:* L2 and MPd.

Three things emerge from this analysis: (a) variation in one thin section may not reflect the variation throughout the coenosteum; (b) more measurements of coenosteal variables should be made, preferably on more than one thin section; (c) caution should be exercised in differentiating species solely on the basis of small differences in coenosteal variables.

ACKNOWLEDGEMENTS

I thank J. A. Fagerstrom for supplying the data from his measurement on *S. sherzeri* and I thank both him and K. M. L. Saxena for their helpful comments on the whole question of the analysis of intracoenosteal variation.

APPENDIX

THE TREATMENT OF TIED MEDIAN VALUES IN THE MEDIAN TEST

Tied observations do not affect the median test except where the median value is tied. Gibbons (1971, p. 137) suggests that such ties should be broken in all possible ways, and the minimum computed test value accepted.

The *Actinostroma clathratum* P5 data will be taken as an example.

No. of pillars	Frequency	Cumulative frequency
14	1	1
15	4	5
16	8	13
17	15	28
18	16	44
19	10	54
20	5	59
21	1	60

Here the median is 18 and the number of tied median values is 16.

The median test may be calculated as follows:

χ^2 with m–1 df = $N^2/R(N-R)\ (\Sigma(Om^2/n)-R^2/N)$

where N is the grand total of measurement (here 60)
n is the number of measurements in each sample (10)
m is the number of samples (6)
Om is the number of measurements below the median in each sample
R is the grand total of measurements below the median (=ΣOm)

The χ^2 values for R=28 and R=44 (i.e. for values <Md class and for values ⩽Md class) are calculated. Then χ^2 for R between 28 and 44 is calculated by breaking the ties. The following will show the method:

R	Sample No. 1	2	3	4	5	6	χ^2
28	7·0	2·0	2·0	4·0	7·0	6·0	10·98
30	7·38	2·25	2·75	4·13	7·0	6·5	10·16
32	7·75	2·5	3·5	4·25	7·0	7·0	9·63
34	8·13	2·75	4·25	4·38	7·0	7·5	9·57
36	8·5	3·0	5·0	4·5	7·0	8·0	9·79
38	8·88	3·25	5·75	4·63	7·0	8·5	10·55
40	9·25	3·5	6·5	4·75	7·0	9·0	11·68
42	9·63	3·75	7·25	4·88	7·0	9·5	13·54
44	10·0	4·0	8·0	5·0	7·0	10·0	16·02
(Ties 16	3·0	2·0	6·0	1·0	0	4·0)	

In this example χ^2min lies at R=34. Note that two obvious choices of R, namely R=30 (the mid point or median) and R=36 (allocating half the tied median values to <Md class) do not give minimum values of χ^2 in this case, although either may do so in other examples.

When χ^2 is plotted against R values for the median class, a smooth 2nd degree polynomial curve is obtained and this is true for all cases where the median values are tied. This suggests that χ^2min can be calculated from the polynomial equation and that the minimum need not lie at an integer value of R.

If $\chi^2 = aR^2 + bR + c$
then $\chi^2min = c-(b^2/4a)$
and occurs where $R = -b/2a$

It is relatively easy to fit a 2nd degree polynomial to the calculated χ^2 values using a programmable calculator (although the R values may have to be restored from O to n, where n = number of ties, in order to avoid rounding errors in the calculation). A good approximation to χ^2min can be obtained by finding χ^2 for R<Md class and R⩽Md class and for the mid-point between these R values, and then determining the polynomial equation for these three pairs of values.

The following table compares χ^2min calculated by three different methods.

	by iteration (breaking ties)	by polynomial	by polynomial approximation
L5	13·04	13·00	12·98
P5	9·57	9·41	9·36
Pd	1·94	1·93	1·89
MPd	10·88	10·88	10·90
L2	9·91	9·91	9·91
MPsp	14·63	14·59	14·59

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PALAEOECOLOGICAL AND PALAEOGEOGRAPHIC IMPLICATIONS OF *RHIPIDOMELLA MICHELINI?* (LEVEILLE) IN THE CARBONIFEROUS OF THE CARNARVON BASIN

by I. H. Lavaring

ABSTRACT

Shelly coquinoid deposits in the middle and upper parts of the Lower Carboniferous Moogooree Limestone are dominated by shells of *Rhipidomella michelini?* (Leveille). Tho separate biofacies are identified within the coquinas: (1) *Syringopora* biofacies consisting of coral, bryozoan and brachiopod debris, and (2) *Rhipidomella michelini?* biofacies consisting of brachiopod shells and crinoid ossicles. Taphonomic evidence suggests they are postmortem, transported assemblages and not *in situ* benthic communities. The morphology of *Rhipidomella michelini?* reflects adaptation to turbulent, shallow marine conditions similar to those experienced by its Visean homoeomorph from eastern Australia, *Rhipidomella fortimuscula* Cvancara. A westerly deepening palaeobathymetry, evident from the coquinas, differs from the Early Carboniferous palaeogeography of the Carnarvon Basin proposed by Condon (1965, 1968), and provides further evidence of shoreline positions during this time.

INTRODUCTION

The major Carboniferous marine invertebrate fauna of the Carnarvon Basin is preserved in the middle and upper parts of the Moogooree Limestone. Glenister (1955), Veevers (1959), and Thomas (1971) described brachiopod species from the fauna, and Thomas (1971) considered it to be Tournaisian in age. Roberts (1971) and Thomas (1971) compared the fauna to others of the same age and similar faunal composition in the Canning and Bonaparte Gulf Basins.

Detailed mapping of outcrop of the Moogooree Limestone carried out during 1978 has shown that shelly faunas are limited to several stratigraphic horizons, and are dominated by shells of *Rhipidomella michelini?*. Condon (1965) considered the unit to be a shallow-marine sequence and noted that fossils were restricted in occurrence. Examination of the fossiliferous horizons has revealed that the faunal content of each horizon is facies dependent. Further, the distribution, orientation, and preservation of *Rhipidomella michelini?* provides an indication of sedimentary conditions prevalent during deposition of the sequence.

The Tournaisian age given to the fauna of the Moogooree Limestone by Thomas (1971) provides the only definite age determination for the Carboniferous sequence in the Carnarvon Basin; the Visean age for the Yindagindy Formation is less certain. *Rhipidomella* is one of the few genera represented by different species in the Carboniferous faunal successions of eastern and western Australia. The stratigraphic range of species such as *Rhipidomella michelini?* provides the basis for the biostratigraphic zonations proposed for the Carboniferous system of Western Australia by Roberts (1971) and Thomas (1971). The present study provides the first evidence of palaeoecological factors influencing the geographic and stratigraphic distribution of brachiopod species within the faunal succession. The shallow-marine environment postulated for the Moogooree Limestone by Condon (1965) is supported, and the palaeobathymetry established from the position and environment of deposition of the coquinas. These show a westward-deepening trend during deposition of the upper part of the Moogooree Limestone.

STRATIGRAPHIC SETTING

The Moogooree Limestone is the basal unit of the Carboniferous sequence in the Carnarvon Basin; it crops out as a series of north-trending strike ridges near the eastern edge of the basin on Williambury and Moogooree Stations (Fig. 60). Teichert (1949) originally named the unit, but Condon (1954, 1965) redefined and described it, and proposed a type section southeast of Williambury Homestead.

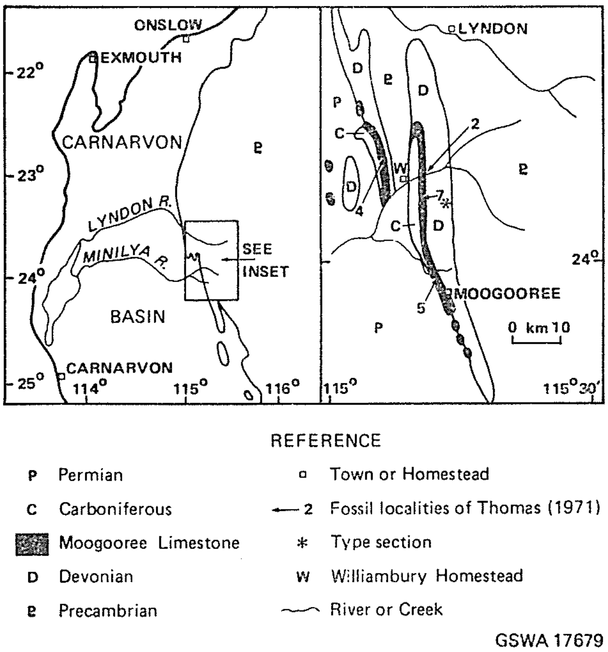

Figure 60 Location of Moogooree Limestone outcrop and fossiliferous horizons.

The sequence within the type section is calcarenite, quartz sandstone, calcilutite, dolomite and oolite. Shelly coquinoid deposits are limited to calcarenite beds in the middle and upper part of the sequence, and extend along strike north and south of the line of section.

The Moogooree Limestone lies disconformably on the Willaraddie Formation, or unconformably on the Munabia Sandstone. Where the complete Lower Carboniferous sequence is present, the Moogooree Limestone is conformably overlain by the Williambury Formation; elsewhere it is unconformably overlain by the Lower Permian Lyons Formation. The Tournaisian age assigned to the Moogooree Limestone is the basis for ages Condon (1965) assigned to the other unfossiliferous units in the sequence: the Willaraddie Formation, Munabia Sandstone, and Williambury Formation.

Condon (1965) suggested that the Moogooree Limestone is a shallow-marine shelf sequence. The presence of corals and other shallow-marine invertebrates supports this interpretation. Low-angle planar cross-stratification is evident within the coarse-grained calcarenite which contains shell-rich coquinas. Fine-grained, well-sorted calcarenite contains some sets of trough cross-stratification and a fauna of corals, brachiopods, and bryozoans. The calcilutite is planar bedded, and generally devoid of macrofossils. Few of the macrofossils, except colonies of *Syringopora* sp., are preserved *in situ*. Abrasion and transportation of the fossiliferous debris has resulted in damage to specimens, which are scattered along bedding planes in dense layers. Marine conditions appear to have prevailed during deposition of the sequence, and a turbulent shallow-marine environment is envisaged.

Dolomite comprises a significant proportion of the unfossiliferous part of the Moogooree Limestone, but is not as common in other marine units of the Devonian or Carboniferous sequence.

BIOFACIES

Two biofacies are distinguished within fossiliferous horizons of the sequence: (1) the *Syringopora* biofacies which consists of *in situ* colonies of *Syringopora* sp., small pedunculate brachiopods, and bryozoan fragments; and (2) the *Rhipidomella michelini?* biofacies which consists of whole shells and disarticulated valves of *Rhipidomella michelini?*, *Unispirifer fluctuosus* (Glenister), *Syringothyris spissus* Glenister, other brachiopod species, crinoid ossicles, and occasionally, coral debris, all of which are significantly damaged and abraded.

Each biofacies is characterized by its distribution as well as its faunal content: the *Syringopora* biofacies occurs northwest of Williambury Homestead, in beds of fine-grained well-sorted calcarenite (Thomas, 1971, Fig. 1, locality 4). The *Rhipidomella michelini?* biofacies is present at the same stratigraphic level in coarse-grained, well-sorted calcarenite that is exposed on the northern and southern banks of the Minilya River (Veevers, 1959, Fig. 1, CC120; Thomas, 1971, locality 2) and the upper part of the sequence within the type section (Thomas, 1971, locality 7).

TAPHONOMY

Shells comprising coquinas of the *Rhipidomella michelini?* biofacies are oriented parallel to bedding planes and exhibit evidence of abrasion, such as wear on the umbo and rounding of shell edges, features typical of movement and winnowing in nearshore areas. Many complete valves of *Rhipidomella michelini?* exhibit fracture patterns consisting of three linear or curvilinear fractures which intersect at or near the centre of each valve at angles of approximately 120°. Crushing after burial is interpreted to be the cause.

The absence of juvenile shells indicates either a continued winnowing and removal prior to burial, or a low juvenile mortality rate in the living population. The first alternative is favoured because of the damaged and abraded nature of the shells, and because present-day marine invertebrates inhabiting turbulent environments generally possess high juvenile mortality rates (Valentine, 1973).

Specimens of *Syringopora* sp, exhibit few signs of turbulent conditions such as damaged colonies or broken corallites and are present northwest of Williambury Homestead in fine-grained, well-sorted calcarenite. Coarse-grained calcarenite is lacking and this occurrence which is interpreted as a sublittoral assemblage of both *in situ* and transported remains, formed below wave base.

The *Rhipidomella michelini?* biofacies was formed as a littoral accumulation of shelly debris, built up in nearshore areas by progressive deposition of live and dead shells by wave action. Living shells detached from the substrate by rupture of the pedicle, were then transported shorewards with dead shells, many being disarticulated or otherwise damaged during the process.

FUNCTIONAL MORPHOLOGY OF *RHIPIDOMELLA MICHELINI?*

Shells of the species were anchored to the substrate, or other hard objects, by means of a muscular pedicle (Fig. 61). A low lateral profile was thus attained, minimizing the possibility of detachment.

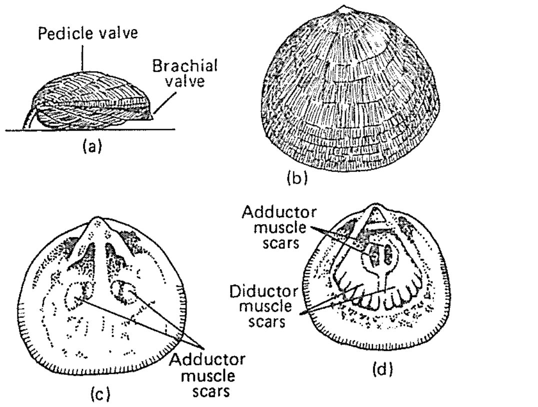

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Figure 61 A. Living orientation of Rhipidomella michelini? (Leveille).
B. Pedicle valve exterior, F10288 (x 1).
C. Brachial valve exterior, F10281 (x 1).
D. Pedicle valve interior, F10287 (x 1).

The external surface of some valves contain elliptical borings, up to 5 mm long and 2 mm wide, which are similar to acrothoracic barnacle borings described by Rodriguez and Gutschick (1970). As no indication of host response is evident, boring may have taken place after death. Present-day populations of encrusting barnacles are known to be limited to the intertidal zone (Valentine, 1973), but it is not known if Carboniferous forms were distributed in this manner.

Distinctive features of the internal surface of the pedicle valve of *Rhipidomella michelini?* are the large muscle scars which served as a base for the attachment of the diductor muscle system. Confined space within the shell and the anterior position of the hinge line necessitated development of a large muscle system with a wide base of attachment, to ensure fast and efficient opening and closure of valves. Fine rounded costae on the external surface of both valves served as structural reinforcement, strengthening the shell without significantly increasing weight.

Of the three described species from eastern Australia *Rhipidomella australis* (M'Coy) (Mid-Tournaisian to Mid-Visean), *Rhipidomella myosa* Campbell (Mid-Visean), and *Rhipidomella fortimuscula* Cvancara (Late Visean), the latter species is most similar to *Rhipidomella michelini?*

Considerable variability is apparent in the specimens of *Rhipidomella michelini?* figured by Thomas (1971), particularly in the size and shape of the diductor muscle scars (Thomas, 1971, pl. 21, fig. 46, 6). They are larger in *Rhipidomella fortimuscula*, and may be an adaptation for living in turbulent shallow-marine conditions as Lavaring (1974) indicated.

PALAEOGEOGRAPHIC SIGNIFICANCE

Devonian sedimentation along the eastern margin of the Carnarvon Basin commenced with a marine invasion which penetrated well to the east of the present basin margin and formed a shallow sea which received little terrigenous material. Sediments deposited include a basal transgressive unit, the Nanyarra Greywacke, and the carbonate-rich shelf sequence of the Gneudna Formation. Regression occurred during the Late Devonian, with deposition of the shallow-marine Munabia Sandstone, which infilled the marine basin. Uplift along the eastern margin of the basin and deposition of the non-marine Willaraddie Formation followed.

Marine transgression during the Early Carboniferous (Tournaisian) initially penetrated beyond the present basin margin, but was restricted during deposition of the upper part of the Moogooree Limestone (Fig. 62). The presence of littoral shell deposits, *in situ* coral colonies, and the absence of tidally influenced sedimentation is the basis of the palaeogeography shown in Figure 62. The sharp lateral transition between the biofacies indicates a well-defined but

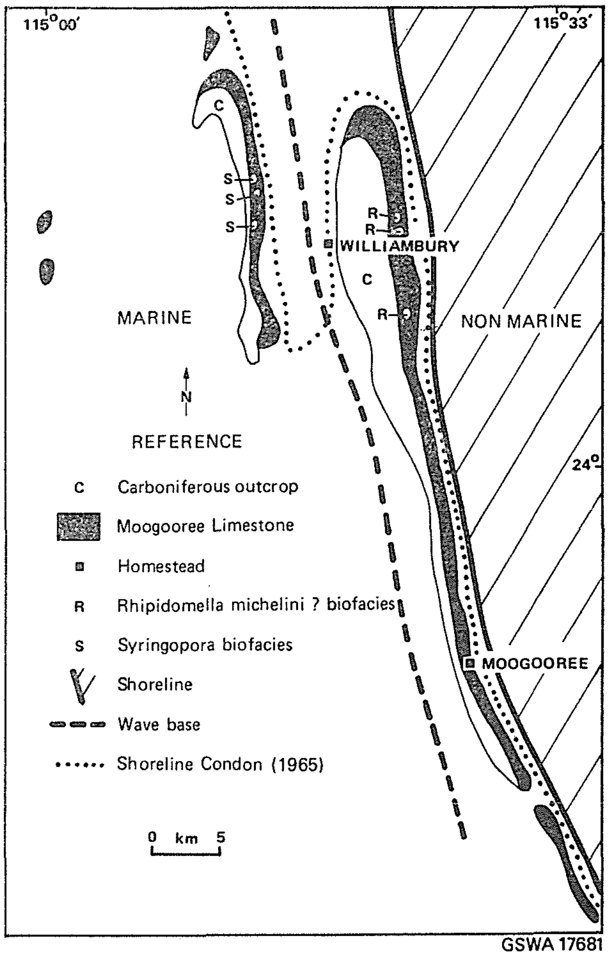

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Figure 62 Early Carboniferous palaeogeography of the eastern margin of the Carnarvon Basin during deposition of the upper part of the Moogooree Limestone.

gentle bathymetric slope and a shoreline adjacent and parallel to the *Rhipidomella michelini?* biofacies (Fig. 62). A north-south shoreline is evident from the biofacies; this conflicts with the indented coastline postulated by Condon (1965) and provides further evidence that the "abutment" unconformities he postulated to account for the discrepancy, are faults as Playford and others (1975) suggested. The limit of wave agitation is the boundary between the two biofacies, and is placed mid-way between them, parallel to the shoreline.

CONCLUSION

Shelly coquinoid layers in the Moogooree Limestone are dominated by *Rhipidomella michelini?*, and were formed by deposition of shelly material between wave base and the strand line. Less disturbed fossiliferous remains and *in situ* colonies of *Syringopora* sp. were preserved below wave base. Compared to the three known species from the Carboniferous of eastern Australia *Rhipidomella fortimuscula* is most similar to *Rhipidomella michelini?* and populated similar sedimentary environments. Palaeobathymetric trends evident from the distribution of biofacies show a straight north-south oriented shoreline during deposition of the fossiliferous upper parts of the Moogooree Limestone, whereas the shoreline was further east during deposition of the lower part of the unit.

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EXPLORATION GEOCHEMISTRY AT THE MOUNT PALGRAVE AND MOUNT VERNON Cu–Zn LOCATIONS, BANGEMALL BASIN

by R. E. Smith* and R. Davy

ABSTRACT

Geochemical exploration surveys carried out by Westfield Minerals (W.A.) N.L. and Union Minière Mining and Development Corporation Limited show that both the Mount Palgrave and Mount Vernon locations have strong surface geochemical expression.

Regional stream-sediment surveys which included the region about Mount Palgrave show Cu and Zn anomalies relatable to outcrops of shale in the Jillawarra Formation. A multi-element investigation of leached shale outcrops and microgossans shows a Cu-Mo-Ag association at Westfield Minerals' Cu-shale location. A similar investigation of thin, Zn-sulphide intersections from their diamond-drill core showed only a weak Mo-Ag pathfinder signature. The copper-rich shale outcrops appear to be unrelated to the weak Zn-sulphide mineralization.

In the region of the Mount Vernon Syncline, a stream-sediment geochemical survey by Westfield Minerals defined Zn-Cu anomalies, most of which were related to outcrops of shale in the Kiangi Creek Formation, which in turn carry Cu and Zn anomalies. Systematic chip sampling of stratigraphic sections by UNIMIN closely defined the anomalies. Multi-element analyses of the mineralization, a low-grade Zn-Cu-sulphide zone in black shale, showed a Cd-Mo-Ag pathfinder signature. Investigation showed the same association to be recognizable as a surface anomaly in the leached shale outcrops of the mineralized zone. Hydromorphic dispersion has enlarged the anomaly size in the down-hill direction, particularly for Zn, less so for Cu, and intermittently for Cd, Mo and Ag.

Stream-sediment surveys are confirmed as being valid exploration procedures for regions of the Bangemall Basin with good outcrop. Rock-chip and gossan sampling provide follow-up data. Cd, Mo and Ag are shown to be pathfinder elements for the known types of mineralization in the Bangemall Basin. However, the known mineralization is subeconomic, and it is unlikely that future exploration will be specifically directed at this style of mineralization. It is recommended, therefore, that a comprehensive suite of potential pathfinder elements be determined in future exploration programmes.

INTRODUCTION

Systematic exploration of the Bangemall Basin by Westfield Minerals (W.A.) N.L. (Westfield) in the early 1960s revealed low-grade stratiform Zn-Cu mineralization in the lower part of the Bangemall Group, in stratigraphic units, dominantly shales, which are now called the Jillawarra Formation and the Glen Ross Shale Member of the Kiangi Creek Formation. Subsequent exploration by Union Minière Development and Mining Corporation Limited (UNIMIN) during 1970-72 confirmed the widespread nature of surface indications of Zn and Cu over these two units.

This paper compares the results of surface geochemical exploration by the two companies with the chemistry of mineralized drill cores obtained by Westfield at two localities (Fig. 63), in the Mount Palgrave area (grid reference

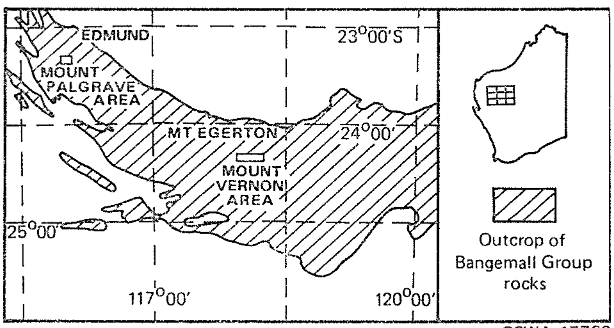

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Figure 63 Location diagram.

395088, Edmund 1:250 000 sheet), and the Mount Vernon area (grid reference 644973, Mount Egerton 1:250 000 sheet). Additional multi-element geochemical work on both core and surface material has been carried out by the authors. The purpose of this paper is to review the effectiveness of exploration methods in the Bangemall Basin with particular emphasis on the trial use of multi-element geochemical methods.

In this paper the terms 'pathfinder elements' or 'pathfinders' are used for minor and trace elements that accompany, or have close associations with, base-metal sulphide mineralization. A distinction exists between this usage and that where the term 'pathfinders' is used for relatively more mobile elements than the element(s) being sought.

REGIONAL GEOLOGICAL SETTING

The stratigraphy, sedimentation and structure of the central and western parts of the Bangemall Basin has been presented by Brakel and Muhling (1976). These authors correlate the stratigraphy established on the Edmund 1:250 000 sheet (Daniels, 1969) across the Mount Egerton and Collier 1:250 000 sheets. The rocks of interest are

* CSIRO, Division of Mineralogy, Floreat Park, Western Australia.

those of the Bangemall Group, which were deposited in shallow-water marine to terrestrial alluvial conditions and which are characterized by lensing, interfingering, and lateral gradations (Brakel and Muhling, 1976).

Throughout the west and central Bangemall Basin, the most widespread rock unit carrying indications of Cu or Zn mineralization is the shale underlying the Discovery Chert, a prominent marker horizon in the western Bangemall Basin. This unit has previously been referred to as the "Prospect Shale" at Mount Palgrave, but it is now formally referred to as part of the Jillawarra Formation (Muhling and others, 1976), and is the host of the drilled mineralization at Mount Palgrave.

At Mount Vernon, shale of the Jillawarra Formation immediately below the Discovery Chert shows weak surface indications of Cu and Zn. However, a lower shale unit, the Glen Ross Shale Member of the Kiangi Creek Formation (Muhling and others, 1976) shows stronger surface indications of the same elements.

Detailed investigation of the mineralization at these two locations has recently been carried out by Davy and Marshall (in prep.).

SURFACE EXPLORATION

Stream-sediment geochemistry has been used by both Westfield and UNIMIN. In both cases samples were collected from the upper 0.1 m of the sediment and sieved at 80 mesh (177 μm). Cu, Pb and Zn were determined by atomic absorption spectrophotometry following digestion in perchloric acid. In addition, UNIMIN determined cold-extractable Cu following digestion with cold, dilute HCl.

UNIMIN's stream-sediment programme was restricted to the Edmund Sheet. Approximately 4 000 sites were sampled covering all the Bangemall Group rocks. The survey was designed to give a linear sample density of 1 sample per 1.6 km (1 mile) down all appropriate stream channels. The Mount Palgrave area was included within this survey (Fig. 64B).

Subsequently UNIMIN changed their emphasis to the collection of weathered shales as a continuous series of chip samples from measured stratigraphic sections. In addition numerous ironstones were sampled separately.

For interpretation, stream sediments derived from each rock unit or formation were considered separately. The 95th and 98th percentile derived from histograms or cumulative-frequency curves were arbitrarily used to define 'threshold' and 'strongly anomalous' levels respectively. Threshold levels used (in ppm) are given in Table 22.

TABLE 22. THRESHOLD VALUES OF UNIMIN STREAM-SEDIMENT SAMPLES (-177 μm) TAKEN ON THE EDMUND SHEET, (HERBERT AND OTHERS, 1972)

Formation	Threshold Values (—177μm fraction)			
	Cold copper (ppm)	Total copper (ppm)	Lead (ppm)	Zinc (ppm)
Irregully Formation	13	70	52	128
Kiangi Creek and Jillawarra Formations	22	73	67	115
Devil Creek Formation and Discovery Chert	10	74	40	125
Ullawarra Formation	13	91	47	99
Fords Creek Shale	10	69	40	96
Curran and Coodardoo Formations	13	80	43	110
Kurabuka Formation	16	101	48	125

Values are the 95th percentile for geological domains (defined as areas based on rock units—mostly formations) mapped on the Edmund Sheet, Daniels (1969).

Other aspects of exploration in the Bangemall Basin are discussed by Smith (in press).

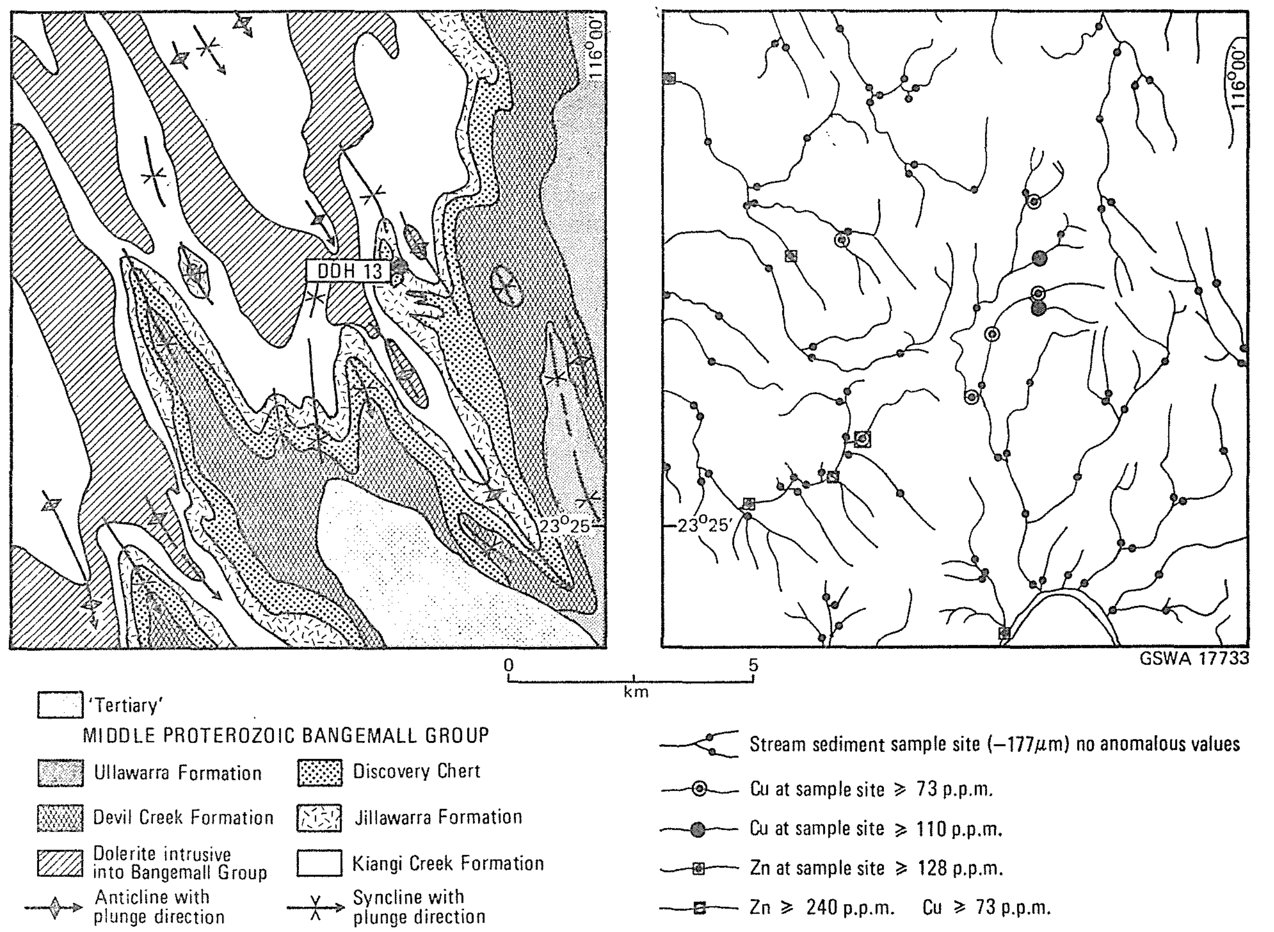

Figure 64 A. Geology of the region about Mount Palgrave from mapping by Herbert and others (1972) following regional mapping of the Edmund Sheet by Daniels (1969).
B. Regional stream-sediment Cu and Zn geochemistry of region shown in (A), part of a regional geochemical survey of the Edmund Sheet by UNIMIN.

MOUNT PALGRAVE AREA

Physical features

Relief is moderate; the softer sedimentary rocks, such as shale, dolomitic shale and siltstone, erode to produce valleys bounded by cliffs, and the area is dissected by gullies which limit vehicular access. Ridges are governed by resistant rocks such as quartzite, dolerite and the Discovery Chert. These resistant rocks control both the position of the major drainages and the sediments contained in them.

Most of the stratigraphic units crop out extensively, although shales are commonly weathered, and form white, buff or chocolate-coloured outcrops, except in cliff faces where they can be black. Mafic igneous rocks are fresh. Soils are poorly developed or absent on most slopes. Skeletal soils predominate, but loamy soils are also present.

The climate is arid to semi-arid. The vegetation consists of sclerophyll shrub-land with scattered tall shrubs and stunted trees *(Eucalyptus, Hakea* and *Grevillia* sp.). Taller eucalypts occur along stream channels.

Erosion is both chemical and mechanical: the depth of weathering is variable, but extends to several tens of metres, and most soils and exposed rocks are leached. Mechanical erosion has taken place mainly as a result of torrential rain and soil creep, and the upper part of the weathering profile has been removed in many places.

Geological setting

The surface geology of the Mount Palgrave area is shown in Figure 64A. Mineralization occurs in shale and siltstone of the Jillawarra Formation, which was deposited on a shallow-marine shelf (Brakel and Muhling, 1976). The shales hosting mineralization are black and pyritic when fresh. The mineralization is stratabound and of probable syngenetic origin (Davy and Marshall, in press).

Following deposition, the sedimentary rocks were folded and intruded by semi-concordant dolorite sills. The metamorphic grade is either low greenschist or just below the greenschist facies, as authigenic actinolite is present in the mafic rocks.

Malachite and, less commonly, azurite were observed at the surface in shale underlying the Discovery Chert (Westfield Minerals, 1967). Goethite pseudomorphs after pyrite occur in many outcrops of shale, but fresh sulphides tend to be present at the surface only where protected by resistant minerals such as quartz.

Mineralization

Drilling by Westfield encountered three sulphide zones containing Zn. All are 3 m thick and appear to be separate lenses (Fig. 65). The grades for Zn are 0.8%, 1.4% and 2.4%. Zn occurs mainly in veinlets of quartz, pyrite and sphalerite, which appear to have been derived from syngenetic, disseminated mineralization by diagenesis or metamorphism (Davy and Marshall, in press). Cu-values in the Zn-rich zones are 110 ppm or less. Elsewhere in the black shale, chalcopyrite and covellite are associated with pyrite and marcasite, but Cu values are low, commonly between 100 and 300 ppm, but isolated values up to 800 ppm are found (Westfield Minerals, 1967).

The profile revealed by Westfield's drilling included a weathered, 'bleached zone' of white or buff-weathered shale containing irregularly distributed Cu-carbonate concentrations. Analyses showed low values ($<$100 ppm) of Zn Cu-sulphide minerals occur in accessory amounts in the underlying fresh black shale, and the Cu carbonates may represent enrichment as a result of weathering of these minerals. It is just possible, however, that Cu-sulphide mineralization occurs in the top 20 m of the 60 m thick shale, as fresh rock from this zone does not appear to have been tested by drilling.

The multi-element spectrographic scan of the drill-core samples showed only a weak association of other trace elements, namely Mo and Ag, with the Zn mineralization. The maximum value of Mo was 80 ppm and of Ag 0.4 ppm. Cd was not detected (Table 23).

Geochemistry of weathered shale

Ten stratigraphic sections crossing shale of the Jillawarra Formation were chip sampled as part of UNIMIN's exploration programme. Cu anomalies were found in six of these sections. In three traverses, over a length of 1 km along the east side of the syncline at Mount Palgrave, the anomalies were very pronounced. All of the Cu anomalies lie within the top 45 m of the Jillawarra Formation (using the base of the Discovery Chert as a marker), and within this sequence the uppermost 18 m contained Cu values greater than 1 000 ppm. Section ED 17, illustrated in Figure 66, displayed the second strongest anomaly. In section ED68 (not illustrated), 400 m to the south, copper values averaged several per cent (maximum 13.5%) over half the 18 m interval.

A Zn anomaly, revealed in a stratigraphic section 1 km to the east of the known mineralization (section ED73, not illustrated), is present some 67 m stratigraphically below the Discovery Chert. This position corresponds approximately to the position of the highest Zn mineralization encountered in the drill core.

Multi-element analysis of the weathered shale samples taken in section ED17, revealed a Cu-Ag-Mo association with values of Cu, Ag and Mo up to 6 000 ppm, 10 ppm and 30 ppm respectively (Table 23).

A Zn anomaly, also 67 m below the Discovery Chert, is present in a section (ED76, not illustrated) 1 km east of the known Zn mineralization. Its position relative to the Discovery Chert corresponds approximately to the position of the first Zn-rich zone met in the drill core. Multi-element analysis of the samples from ED73 has not been carried out.

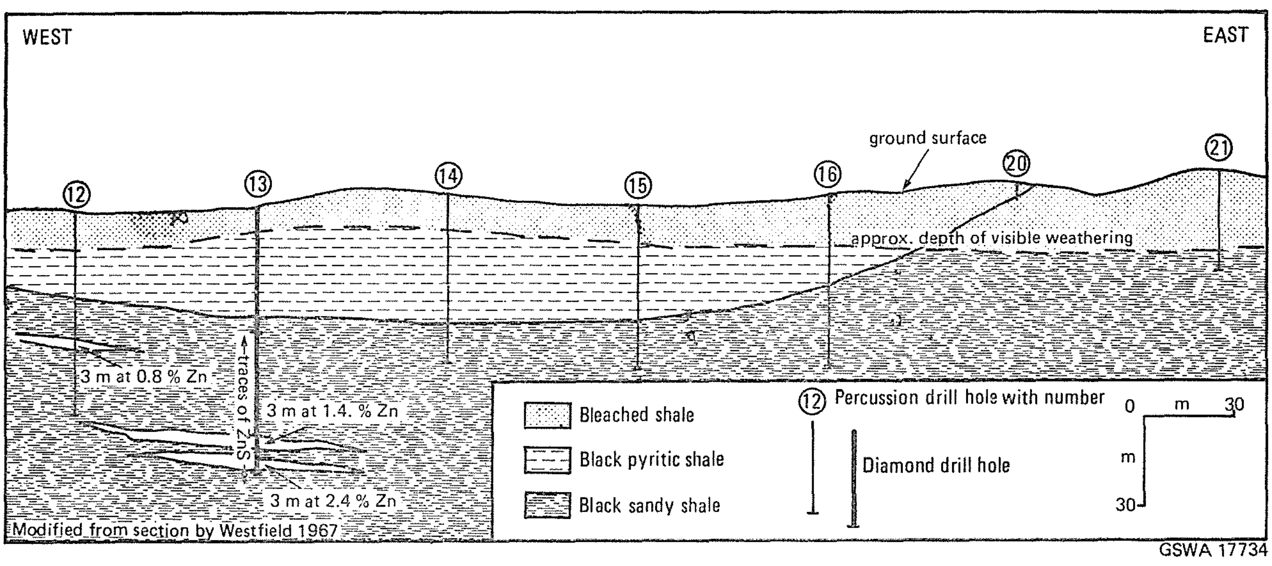

Figure 65 Cross-section showing the relationships at the Mount Palgrave location. The section is taken between chip-sampled stratigraphic locations ED 17 and ED 68 approximately 150 to 250 m to the north and 140 to 200 m to the south respectively.

TABLE 23. RANGES IN VALUES FOR ELEMENTS IN DIAMOND-DRILL CORE, MICROGOSSANS, WEATHERED-SHALE AND ANOMALOUS STREAM-SEDIMENT SAMPLES AT MOUNT PALGRAVE

Element	Diamond-drill core sulphide zone DDH 13	Microgossans ED 17	Weathered shale samples			Anomalous stream sediments
			Cu anomaly ED 17	Cu anomaly ED 68*	Zn anomaly ED 73*	
Cu	<525	0·059%–15·1%	800–6 000	2·5%–13·5%	10–110	73–150
Pb	<30	20–200	20–30	20	30–80	<35
Zn	to 2·4%	<20–300	<20–50	20–200	300–2 600	to 260
Ni	500–1 400	20–200	10–50	....	....	30–50
Co	100–300	<5–300	<5–10	....	....	5
As	to 50	<50–200	<50	....	....	<50
Sb	<30	<30	<30	....	....	<30
Bi	<1	<1	<1	....	....	<1
Cd	<3	<1–3	<1–3	....	....	<3
In	<10	<10	<10	....	....	<10
Mo	to 80	<3–100	<3–30	....	....	10
Ag	to 0·4	0·1–10	0·1–10	....	....	1
Tl	to 10	<1	<1	....	....	<1
Sn	<1	<1–1	<1–3	....	....	1
Ge	to 1	<1	<1–5	....	....	<1–5
Ga	to 7	1–50	3–50	....	....	10–20
W	<50	<50	<50	....	....	<50

Values in ppm unless marked %. * Samples not available for multi-element analyses.

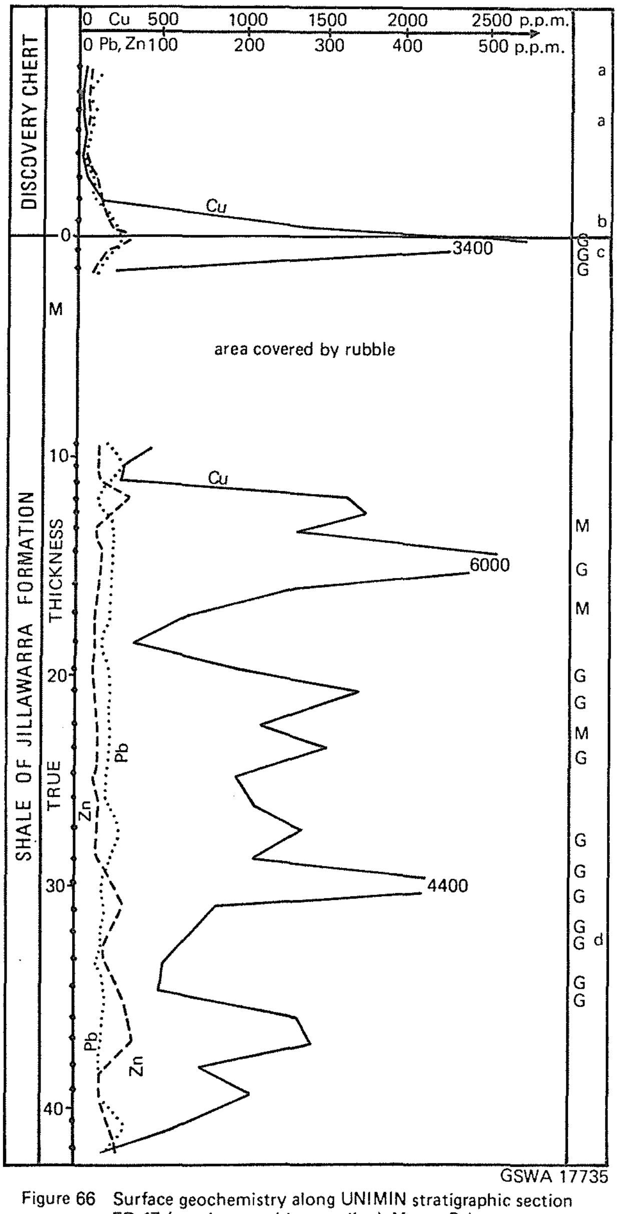

Figure 66 Surface geochemistry along UNIMIN stratigraphic section ED 17 (continuous chip sampling), Mount Palgrave area. All samples were analyzed for a wide range of elements. In last column: G – microgossan grab samples, M – malachite-stained shale, a – surface chips contain 3 ppm Ag, b – surface chips contain 30 ppm Mo and 10 ppm Ag, c – microgossan contained 800 ppm Cu and 10 ppm Ag, d – microgossan contained 8000 ppm Cu, 100 ppm Mo and 10 ppm Ag, e – microgossan contained 2000 ppm Cu, 20 ppm Mo and 3 ppm Cd.

Microgossans

Massive, iron-rich gossans are not present at the Mount Palgrave location. At the surface, the leached shales are impregnated with malachite along bedding and joint planes. However, the shale outcrops do contain thin ferruginous horizons, 2 to 20 mm thick, containing pseudomorphs after sulphides. These are referred to as microgossans, and were sampled separately from the chip sampling of the weathered shales as part of UNIMIN's exploration programme.

In section ED17 many microgossans carried visible malachite. Trace-element values obtained from multi-element analysis are shown in Table 23. They are anomalous in Cu, Mo and Ag. Discussion on the use of microgossans in exploration will be found in Smith (in press).

Stream-sediment geochemistry

Threshold values for Cu, Pb and Zn in stream sediments in the Mount Palgrave area are 73 ppm, 67 ppm and 128 ppm respectively. No Pb anomalies were detected.

Anomalies for both total and cold-extractable Cu clearly relate to outcrops of the Jillawarra Formation, and very strong anomalies occur near the site drilled by Westfield.

Anomalous Zn values, which are also related to outcrops of the Jillawarra Formation, lie to the west of the main Mount Palgrave prospect. Drilling by Westfield of one Zn-anomalous zone showed that the shale contained weak mineralization with up to 1.3% Zn and 0.67% Cu over 2 m intervals. There is no Zn stream-sediment anomaly over the main Mount Palgrave prospect, suggesting that the Zn-rich zones intersected by diamond drilling do not reach the surface. Anomalous stream sediments at Mount Palgrave carry as pathfinders Mo (10 ppm) and Ag (1.0 ppm).

MOUNT VERNON AREA

Physical features

Alternating resistant and softer rock units control the stream-sediment pattern of the Mount Vernon Syncline. Quartzite, chert and dolerite form the ridges; shale, dolomitic shale and siltstone, the valleys. A thick quartzitic sandstone unit marking the top of the Kiangi Creek Formation governs the local drainage around the syncline. Remnants of a colluvial (possibly Tertiary) conglomerate are commonly found flanking the resistant quartzite ridge on both the north and south sides of the syncline. Further remnants of the possibly Tertiary depositional surface are seen in the mesas around Glen Ross Gorge and on the plateaux rising from the flat country around Mount Vernon Station. Some of the mesas are capped by calcrete and represent former valley deposits.

Weathering is intensive, and extends in shales to 30 or 40 m, where determined by drilling. Outcrops of mafic igneous rocks are fresh.

Geological setting

Rocks in the Mount Vernon Syncline consist of shallow-marine, brackish-water and continental sediments of the Kiangi Creek and Jillawarra Formations, the Discovery Chert, and the Devil Creek Formation (Fig. 67A). The Kiangi Creek Formation consists of sandstone, siltstone, shale and quartzite; the Jillawarra Formation (in this area) of shale and the Devil Creek Formation of shale, dolomitic shale, dolomite and siltstone.

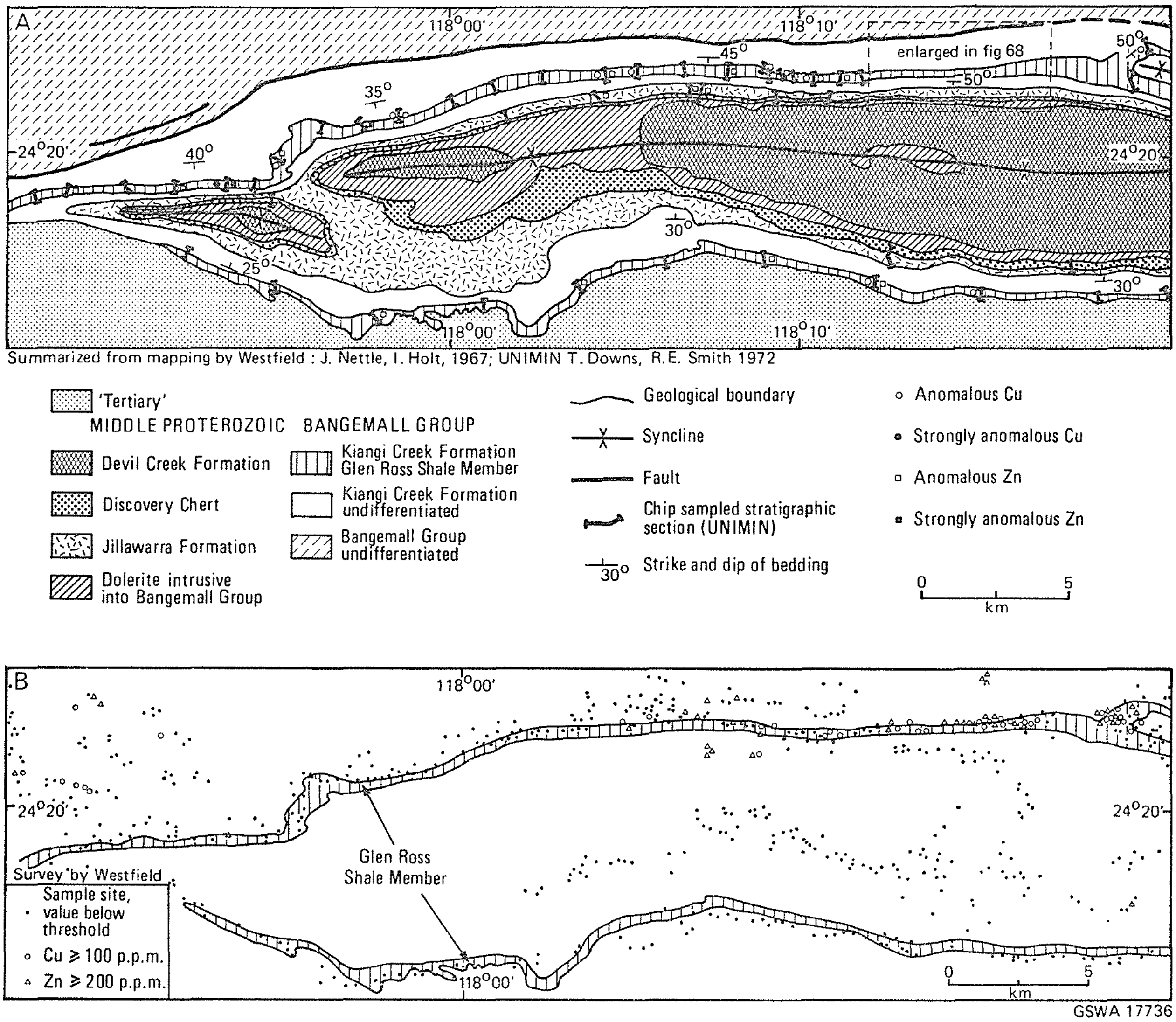

Figure 67 A. Geological map of the Mount Vernon area.
B. Cu and Zn stream-sediment geochemistry of the Mount Vernon area showing locations of anomalies in -177μm fraction.

Dips on each side of the syncline range from 25° to 55°, and the fold axis is subhorizontal. The sequence is truncated to the north by a regional fault which has caused local structural complexity. Metamorphism of the rocks is approximately greenschist facies, based on the occurrence of metamorphic actinolite in the mafic rocks.

Low-grade Zn mineralization occurs in black pyritic shale in the Glen Ross Shale Member of the Kiangi Creek Formation. Anomalous Cu-Zn values have been found in the Jillawarra Formation. These are generally subordinate to those in the Glen Ross Shale Member. Mineralization in the Glen Ross Shale Member is syngenetic; the only alteration since deposition has been local recrystallization, and the mobilization of some of the sphalerite and pyrite into veins (Davy and Marshall, in prep.).

Shales in the weathered zone are bleached, buff or cream in colour and do not contain fresh sulphide.

Stream-sediment geochemistry

The mineralized rocks were identified by Westfield following stream-sediment geochemistry. Sample sites are shown in Figure 67B together with Zn and Cu anomalies. The main shale horizon (the Glen Ross Shale Member) was sampled from gullies separated by 300 m to 1 km. Thresholds for Zn and Cu in the -177μm fraction were 200 ppm and 100 ppm respectively.

Mineralization

Two diamond-drill holes drilled by Westfield tested the main Zn-Cu stream-sediment anomaly, and a third hole tested an anomaly approximately 2.5 km to the west (Fig. 68). All holes were drilled into the Glen Ross Shale Member (Figs. 68 and 69). A 7.3 m intersection of Zn-Cu sulphides, with average values of 1.8% Zn and 0.15% Cu, was found in diamond-drill hole No. 2 (DDH2) under the main anomaly. Weaker base-metal sulphide mineralization was encountered in the third hole, including 2.4 m at 0.8% Zn and 860 ppm Cu. This mineralization appears to occur in a horizon equivalent to that of the main intersection of DDH2.

Multi-element analysis has been carried out on core from DDH2 and 3 (Table 24). Significant traces of Cd (100 ppm), Mo (70 ppm), Sb (150 ppm) and Ag (15 ppm) accompany the main Zn-Cu mineralization.

Most of the black shale contains pyrite, ranging from a trace to 20%, and also contains traces of copper sulphides (mainly covellite). Sphalerite is almost wholly restricted to about 100 m of the black shale (approximately half the total thickness), and the main mineralized zone (40 m in true thickness) lies in the middle.

Geochemistry of weathered shale

Sites for diamond drilling were selected by Westfield on the basis of anomalous Zn-Cu in rock-chip sampling as a follow-up to the stream-sediment investigation. UNIMIN extended exploration by systematic chip sampling of stratigraphic sections in a programme designed to test for a possible extension of the mineralization found by Westfield. All the shale units around the syncline were systematically sampled: sections on the north side were about 1.6 km apart, and, on the south side about 3.2 km apart (Figs. 67A, B).

Detail of several of the chip-sample traverses in the vicinity of the main Zn-Cu anomaly is given in Figure 70. Surface indications of mineralization were shown by thin

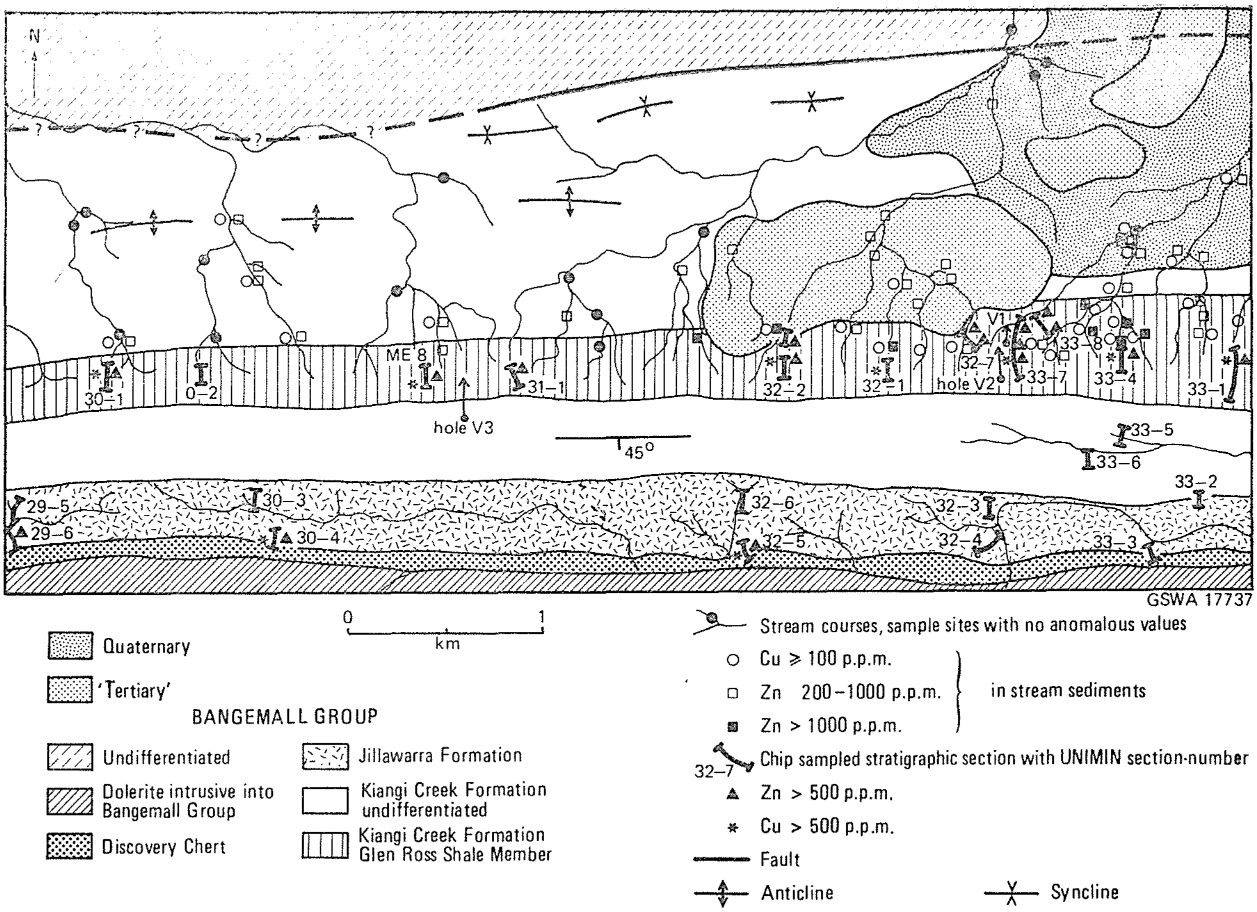

Figure 68 Geological map of the detail of the area indicated in Figure 67A – this zone displays a continuous Cu-Zn anomaly. Detail of Westfield's stream-sediment sampling is superimposed. Strong Cu-Zn anomalies in both stream sediments and weathered shale are shown.

TABLE 24. RANGES IN VALUES FOR ELEMENTS IN DIAMOND-DRILL CORE AND WEATHERED-SHALE OUTCROP AT MOUNT VERNON

Element	Sulphide zone of DDH 2‡	Values in weathered stratigraphic section 33–7			‡Stream-sediment anomaly*
		In situ Zn-Cu anomaly‡	Solution-transported Zn-Cu anomaly‡	Solution-transported Zn anomaly‡	
Cu	1 500	400–850	200–700	50–400	100–1 600
Pb	20	10–40	10–40	10–40	†
Zn	1·8%	500–1 800	600–5 000	0·3%–1%	200–3 000
As	400	50–600	50–100	50–100	....
Sb....	150	30–50	<30–50	<30–30	....
Bi	<1	<1	<1	<1	....
Cd	100	<1–10	<1–10	<1–300	....
In	<10	<10	<10	<10	....
Mo	70	10–300	5–300	<5–100	....
Ag	15	2–20	0·5–10	0·1–10	....
Tl	<1	<1–50	<1–50	<1	....
Sn....	<1	<1	<1	<1	....
Ge	<10	5–15	5–15	3–8	....
Ga	10	8–10	8	5–15	....
W	<75	<50	<50	<50	....

Values are shown for mineralization, its surface expression as weathered shale, and the anomalous stream sediments derived from the surface expression.
* Sample not available for multi-element analyses. † Pb values not available. ‡ refers to figure 69. Values in ppm unless marked %.

coatings of Cu-carbonates along joint and bedding planes in isolated outcrops. The extent of this 'Cu-staining' is less than that exposed at Mount Palgrave.

Chip sampling showed the main anomaly to extend continuously over 4 km of strike, and discontinuously to a total length of about 8 km. The chip samples indicated a coincident Zn-Cu anomaly starting approximately 100 m stratigraphically below the overlying quartzite. The maximum Zn values were in the range 2 000 ppm to 6 000 ppm and Cu values in the range 1 000 ppm to 2 000 ppm. Zn is anomalous for over 100 m in stratigraphic thickness, the top 50 m being also anomalous in Cu (Fig. 68).

The surface expression of the uppermost mineralized shale met in DDH2 coincides with the top of the Zn-Cu anomaly in the rock-chip sample traverse (Fig. 69). The surface anomaly in addition probably reflects, in part, the 40 m thick zone of weakly disseminated Zn mineralization. However, the northern part of this anomaly represents shale, which in DDH2 has most Zn values less than 500 ppm and most Cu values less than 100 ppm. The northern part of the anomaly lies down-hill from the main mineralization, and it is concluded that tbe anomalous Zn-Cu values in this area reflect down-hill seepage (in solution) of these elements during weathering.

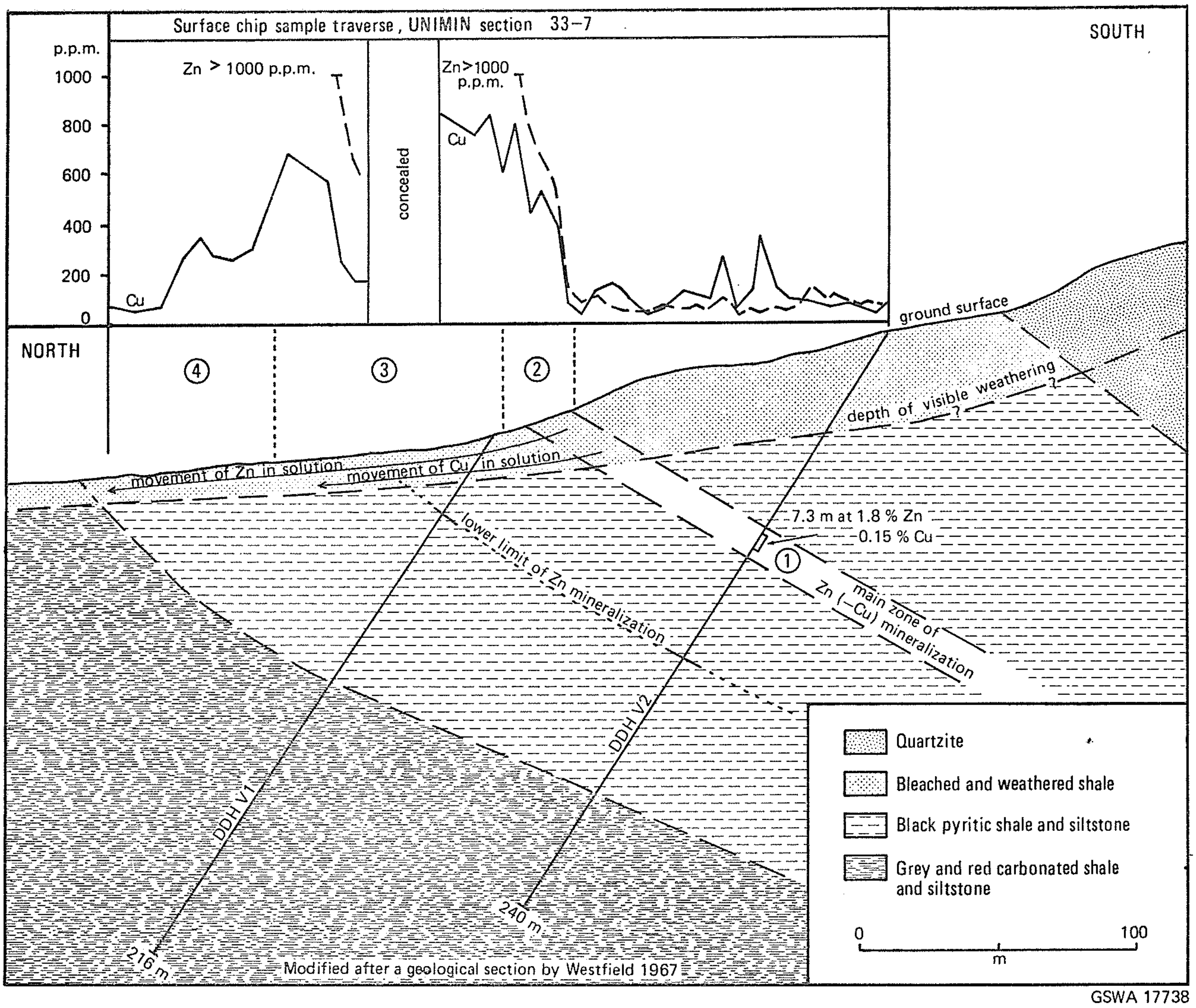

Figure 69 Cross-section along the line of Westfield's diamond-drill holes 1 and 2 at the Mount Vernon location, together with surface geochemistry along UNIMIN's section 33-7 which lies approximately along the cross-section. The numbers 1, 2, 3 and 4 refer to data summarized in the respective columns of Table 24.

Multi-element analyses have been carried out on the weathered shales over selected parts of the main anomaly. Results for Section 33-7 are listed in Table 24, columns 2-4. Mo and Ag are commonly anomalous, and there are isolated high values of Cd and Sb (Fig. 70).

DISCUSSION

Choice of exploration techniques

Both Westfield's and UNIMIN's exploration programmes showed that stream-sediment sampling of appropriate density is a valid exploration procedure that detects even low-grade mineralization. For this type of terrain, outcrop, and degree of weathering, sediment sampling at 1.6 km intervals along streams appears adequate for reconnaissance exploration where the expected mineralization has wide lateral extent. For the two areas studied here, rock-chip sampling is no improvement on stream-sediment sampling as a first reconnaissance exploration tool.

Chip sampling of rock units is a more specialized technique than stream-sediment sampling, and, even though the rocks are weathered, it provides information more directly related to the target mineralization. Chip sampling of both gossans and rock units is also necessary to identify the source rocks of anomalies defined by stream-sediment geochemistry.

Pathfinder elements

The confirmation of a base-metal anomaly in weathered outcrop by pathfinder elements is particularly important because it adds weight to the interpretation that the base metals may be derived from a base-metal sulphide source.

Of the selection of common pathfinder elements that accompany copper, lead or zinc-sulphide mineralization (Table 25), Sb, Cd, Mo and Ag are present in the Mount Vernon mineralization in sufficient quantities to be useful in exploration geochemistry. Bi, In and Sn were undetected in the observed mineralization and their dispersion during weathering was, therefore, precluded. Of the four pathfinder elements present (Sb, Cd, Mo and Ag) all are anomalous in the chip-sample traverse at the mineralized location, though not continuously. By way of contrast, spurious anomalies of Cu, Pb or Zn (false gossans) so far investigated do not contain anomalous pathfinder elements where their metal content is not related to base-metal sulphide sources (Smith, in press).

Microgossans and weathered shale at Mount Palgrave contain, besides their very high Cu values, anomalously high values of Mo and Ag but negligible Sb or Cd. The intersected mineralized zone is characterized by high Zn and anomalous Mo, though Cd and Ag are scarcely anomalous. The microgossans and anomalous copper-shale outcrop do not appear to relate to the mineralization intersected.

For exploration samples of gossans, microgossans and other weathered rock materials, low-cost multi-element analysis of the elements listed in Table 25 is recommended as an integral part of the exploration. Elimination of pathfinder elements from the comprehensive list should only be done after careful thought, because it is unlikely that the character of mineralization can be assumed with certainty, and the mineralization governs the pathfinder elements present.

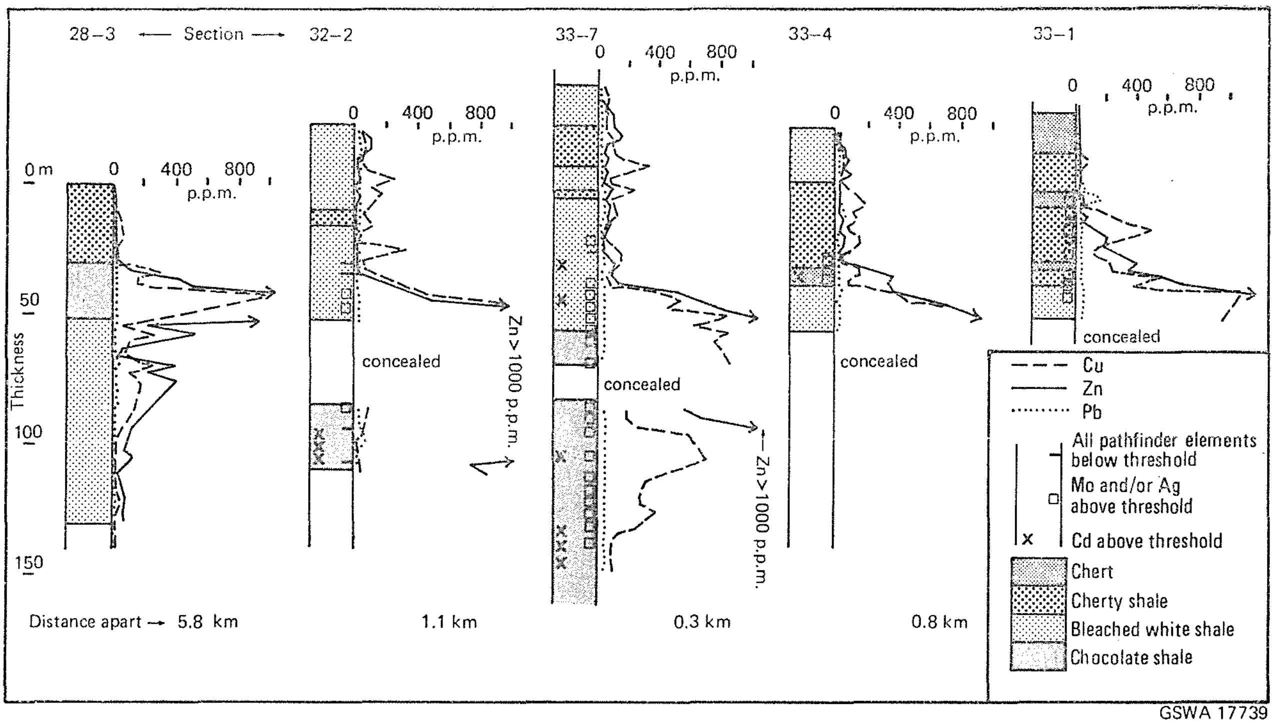

Figure 70 Geochemical information from UNIMIN rock-chip sampled stratigraphic sections along shale outcrops in the main Mount Vernon anomaly. For comparison, the mineralized contact has been placed in an equivalent position for each section. Some samples were subject to spectrographic multi-element analysis; the position of anomalous samples is shown.

To the list of elements (Table 25) several others can be added (Hg, Au, Se and Te), but their present comparatively high cost of analysis probably restricts their general use to the follow-up geochemical stage.

SUMMARY AND CONCLUSIONS

1. Anomalous Cu values in exploration stream-sediment surveys in the Mount Palgrave area outline a significant zone of interest in shale of the Jillawarra Formation. Drill sites selected on the basis of follow-up rock chip sampling failed to intersect Cu mineralization, but did encounter three intersections of low-level Zn-sulphide mineralization. The intersections do not appear to have surface expression where drilled. Further west, Zn anomalies were related to additional low-grade Zn mineralization.

2. At Mount Vernon, exploration stream-sediment sampling with sample sites 0.3 km to 1 km along strike outlined a Cu-Zn-anomalous area in the Kiangi Creek Formation which was accurately defined by a chip-sampling programme. Hydromorphic dispersion downhill within the weathered shales extended the surface area of the anomaly to about twice its original size, and perhaps more.

3. The mineralization at both localities is accompanied by anomalous values of other trace elements. These are Mo, Ag, Cd and Sb, at Mount Vernon, and Mo and possibly Ag at Mount Palgrave. These elements are retained at the surface in both leached shales and, at Mount Palgrave, in ferruginous microgossans, though at Mount Palgrave a direct relationship between drilling and the surface Cu anomaly is unclear.

TABLE 25. THRESHOLDS AND LEVELS OF INTEREST FOR MULTI-ELEMENT GEOCHEMISTRY OF GOSSANS, MICROGOSSANS, GENERAL FERRUGINOUS OUTCROPS AND WEATHERED SHALE IN THE BANGEMALL BASIN

Pathfinder elements used and lower limit of detection†	Gossans, microgossans and general ferruginous outcrops		Weathered-shale geochemistry	
	Threshold (ppm)	Moderately anomalous level (ppm)	Threshold (ppm)	Moderately anomalous level (ppm)
Cu (1)	400	900	200	500
Pb (1)	400	1 200	?	?
Zn (20)	2 000	8 000	200	500
Ni (5)	*	*	*	*
Co (5)	300	500	Element levels inadequately known, levels as for gossans etc. tentatively applied	
As (50)	n.k.	300		
Sb (30)	n.k.	50		
Bi (1)	3	10		
Cd (3)	5	10		
In (10)	5	15		
Mo (3)	20	100		
Ag (0·1)	2	5		
Tl (1)	n.k.	?5		
Sn (1)	3	5		
Ge (1)	‡	‡		
Ga (1)	‡	‡		
W (50)	....	100		

† Analysis by semiquantitative optical emission spectrography, AMDEL; high values of interest confirmed by appropriate analytical technique, predominantly by X-ray fluorescence, CSIRO.
* Element may not be applicable to mineralization sought.
‡ Insufficient comparative data available.
n.k. not known.

4. Exploration results showed that stream-sediment surveys with samples taken at 1.6 km intervals along appropriate drainages are valid exploration procedures for reconnaissance exploration in the Bangemall Basin. Rock-chip sampling will be needed to identify those rocks causing metal anomalies in the streams.
5. It is considered that pathfinder elements (Table 25) are invaluable in discriminating between barren and mineralized gossans, ironstones and weathered rocks. For the type of mineralization in the Mount Vernon and Mount Palgrave areas, the pathfinder elements appear to be Cd, Mo and Ag. However, since other types of Cu, Pb, or Zn deposits would be sought in most exploration programmes, the comprehensive list is recommended.

ACKNOWLEDGEMENTS

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BORON-GALLIUM-RUBIDIUM STUDIES IN PHANEROZOIC BASINS ON THE WEST COAST OF WESTERN AUSTRALIA

by R. Davy and J. Backhouse

ABSTRACT

Following apparently successful use of boron-gallium-rubidium ratios (expressed as triangular diagrams) in estimating depositional conditions in the Proterozoic Bangemall Basin (Davy and others, 1978) tests have been carried out to see whether these ratios give equally consistent predictions when used on rocks whose depositional histories are better known.

Ninety core samples of shales and siltstones, and one of halite, taken from the Canning, Carnarvon and Perth Basins have been studied. Conditions of deposition predicted from boron-gallium-rubidium analyses have been compared with those deduced from mineralogical and palynological studies.

The hypothesis proposed for the use of these ratios (Degens and others, 1958) is unacceptable for the Carnarvon Basin since it cannot be demonstrated that boron is located in illite.

In the Canning and Perth Basins boron correlates with illite as expected. However, a possible line of separation between rocks of marine and of freshwater deposition lies close to the gallium-rich part of the diagram in a position far removed from that suggested in the original hypothesis.

It is concluded that boron-gallium-rubidium diagrams cannot by themselves be used to predict the environment of deposition of sediments.

INTRODUCTION

Following apparently successful use of boron-gallium-rubidium (B-Ga-Rb) ratios (expressed as triangular diagrams) in estimating depositional conditions in the Proterozoic Bangemall Basin (Davy and others, 1978), it was decided to see whether these diagrams give equally consistent predictions when drawn for more recent rocks whose depositional histories are better known.

Initially 15 samples of shales from the Perth Basin, 8 of marine origin and 7 of freshwater origin (GSWA, 1975) were analysed and plotted on the ternary diagram (included in Fig. 71). The result indicated that, on the basis of interpretation using the original hypothesis (Degens and others, 1958), 14 of the 15 samples could have been deposited in fresh water.

It was therefore decided to examine the depositional conditions further by adding samples from the Canning and Carnarvon Basins and further samples from the Perth Basin, and by carrying out mineralogical and palaeontological investigations as well as chemical analysis. A total of 90 core samples of shales and siltstones, and one of halite, taken from bores drilled for petroleum exploration have been studied.

THE HYPOTHESIS

The hypothesis behind the use of B-Ga-Rb ratios was postulated by Degens and others (1958). In essence these workers suggest that differential partitioning of the three elements takes place between clay minerals at the time of the formation of the sediments. The main clay minerals of interest are illite and kaolinite. The former is more common in marine sediments, the latter in freshwater (continental) sediments, although the two minerals are not mutually exclusive (Grim, 1968). According to Degens and others (1958) marine sediments commonly contain larger absolute amounts of B and Rb and a higher B/Ga ratio than freshwater sediments. This was inferred to reflect a higher original illite/kaolinite ratio. B and Rb collect preferentially in illite where they replace Al and K respectively. Ga substitutes for Al wherever it occurs and is concentrated in kaolinite compared with illite by virtue of the higher Al content of the kaolinite.

The use of ratios rather than absolute amounts removes the need to separate pure clay fractions, since components such as quartz and carbonates are simply diluents as they do not contain significant amounts of B, Ga or Rb.

This hypothesis has been tested in four ways:

(i) establishment that B and Rb are located in illite and that Ga is located in both kaolinite and illite. These relationships have been tested using correlation coefficients (using K_2O as a measure of the illite content).

(ii) recognition of glauconite and foraminifera as indicators of marine origin.

(iii) palynological examination for marine acritarchs and dinoflagellates.

(iv) by determining the proportions of illite and kaolinite in the samples to see if illite is more common in marine sediments.

Chemical and X-ray diffraction studies were carried out at the WA Government Chemical Laboratories, and grainmount mineralogical and palynological examinations at the Geological Survey. All mineralogical data are semiquantitative.

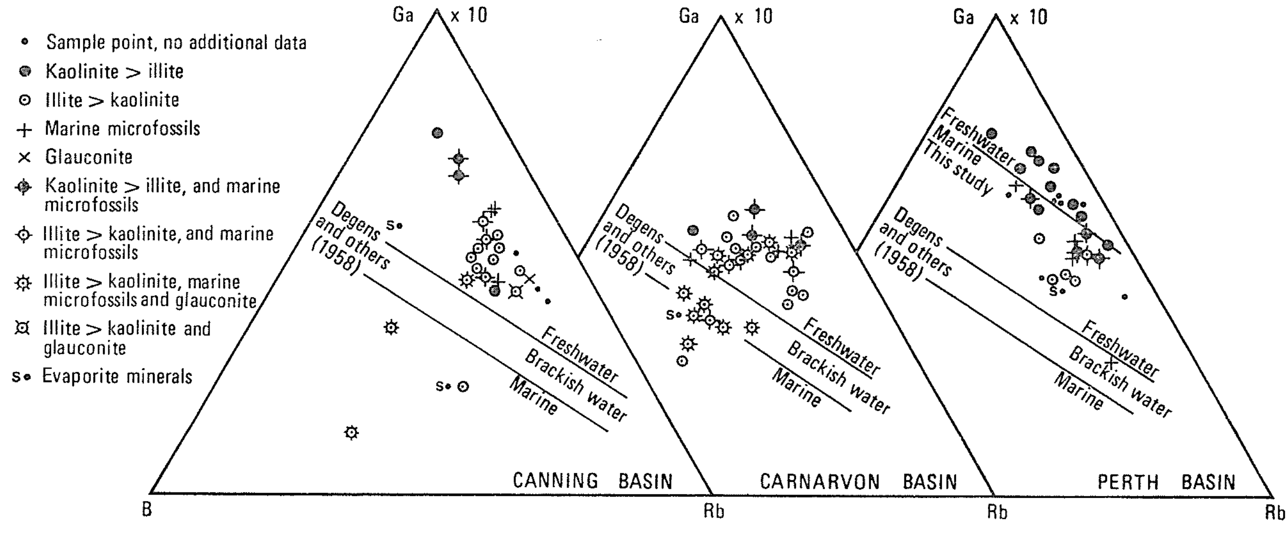

Figure 71 B-Ga-Rb plots for rocks from the various basins.

RESULTS

Results for individual samples are presented in Tables 26-28. The chemical, illite and kaolinite data have been summarized for each basin (Table 29) and appropriate Pearson correlation coefficients calculated (Table 30).

In addition to illite and kaolinite other clay minerals are present. Chlorite is relatively abundant in all basins, montmorillonoids feature in a few samples in each basin and small amounts of glauconite occur in a few samples from the Carnarvon and Canning Basins. Illite is the most common clay mineral in the Carnarvon and Canning Basins, kaolinite in the Perth Basin.

The mean absolute amount of B is higher in the Carnarvon Basin than in the other basins. The absolute amounts and standard deviations of the other chemical constituents are closely similar for all three basins.

TABLE 26. SUMMARY TABLE OF CHEMICAL AND MINERALOGICAL DATA—PERTH BASIN

Sample and Well	Depth (m)	Chemistry B	Ga	Rb	K_2O	Mineralogy KA	IL	CL	MD	GL	TO	Fossils P	F
PERMIAN													
Holmwood Shale													
52169 Abbawardoo No. 1	237·7–240·8	15	4	32	0·95	5	1						
52170 Abbawardoo No. 1	225·6–228·6	65	18	150	3·7	1	35	20			*		
52171 Arrowsmith No. 1	3 303·1	65	22	190	4·3	10	35	20			T		
52172 Arrowsmith No. 1	3 301·3	65	22	200	4·4	1	40	20					
42694B Abbawardoo No. 1	225·6–228·6	65	18	150	3·8	20	20	15					
Irwin River Coal Measures													
42691 Arrowsmith No. 1	2 939·2	55	20	115	2·8	1	30	20					
42694A Abbawardoo No. 1	153·3–156·4	25	21	90	2·0	40	10						
42699 Mungarra No. 5	536·4–539·5	20	10	45	0·9	20	5						
TRIASSIC													
Kockatea Shale													
42690A Arrowsmith No. 1	2 265·0	30	6	120	3·3	20	1				T	M	
42690B Arrowsmith No. 1	2 265·9	50	26	200	3·7	40	20					M	
42692A Eneabba No. 1	3 904·5	50	28	220	3·8	20	30	20				M	
42692B Eneabba No. 1	3 904·5	40	20	155	3·2	30	25					M	
42695 Eurangoa No. 1	1 599·6–1 607·2	35	24	200	3·8	50	10					M	
42696 Cadda No. 1	1 700·2	45	27	190	3·6	30	20	20				M	
JURASSIC													
Cockleshell Gully Formation													
42499 Badaminna No. 1	1 546·3	20	20	125	2·8	45	5						
42697 Bookara No. 1	278·6–278·9	30	18	55	1·1	35	5						
42698 Mungarra No. 3	448·0–451·1	5	3	5	0·12	15	1						
52179 Eganu No. 1	597·4–600·5	10	10	30	0·6	15	3		15				
52180 Eganu No. 1	246·9–249·9	10	8	40	0·95	10	10						
Cadda Formation													
52173 Badaminna No. 1	1 036·3–1 039·4	10	10	70	2·1	15	5					M	
52174 Badaminna No. 1	1 543·8	25	30	110	2·1	55	25						
52175 Badaminna No. 1	1 546·3	15	18	100	2·9	35	1						
52176 Bookara No. 2	719·0–721·8	10	8	100	3·1	10	5						
Yarragadee Formation													
42500 Cockburn No. 1	1 190·9	30	31	100	1·5	60	10						
CRETACEOUS													
Yarragadee Formation													
52177 Charlotte No. 1	2 131·4	15	20	160	5·0	20	10	15					
52178 Charlotte No. 1	2 431·2	20	30	170	3·6	40	30						
52183 Roe No. 1	1 360·6	35	25	120	2·6	20	20	15					
52184 Roe No. 1	1 363·3	30	25	120	2·8	20	20	15					
South Perth Shale													
42693 Gage Roads No. 1	1 518·5	45	19	65	1·3	30	25						
52181 Gage Roads No. 1	1 521·3	40	20	70	1·4	20	10		45		T	M	
Leederville Formation													
52182 Quinns Rock No. 1	770·2	50	25	100	2·3	45	15					M	

Mineralogy:—
KA: Kaolinite
IL: illite
CL: Chlorite
MD: montmorillonoid
GL: glauconite
TO: Tourmaline
T: trace

Fossils:—
P: palynology
F: foraminifera
M: marine forms present

* Gypsum present.

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TABLE 27. SUMMARY TABLE OF CHEMICAL AND MINERALOGICAL DATA—CARNARVON BASIN

Sample and Well	Depth (m)	Chemistry				Mineralogy						Fossils	
		B	Ga	Rb	K_2O	KA	IL	CL	MD	GL	TO	P	F
PERMIAN													
Lyons Group													
52050 Remarkable Hill No. 1	1 070·8	70	18	160	4·5	5	25	20					
Kennedy Group													
52032 Direction No. 1	522·1	75	18	110	3·8	25	40						
52033 Direction No. 1	671·5	90	20	180	5·4	15	30						
52040 Hope Island No. 1	1 250·0	75	20	130	6·6	15	30	15					
"Unspecified"													
52034 Flinders Shoal No. 1	3 030·9	50	20	130	3·5	10	45	15					
52035 Flinders Shoal No. 1	3 505·5	105	24	140	4·2	5	50	10					
52036 Flinders Shoal No. 1	3 507·9	100	24	120	2·7	1	50	15					
TRIASSIC													
Locker Shale													
52038 Hope Island No. 1	926·6	65	22	150	3·8	40	30					M	
52039 Hope Island No. 1	927·8	60	22	140	3·6	35	30					M	
52046 Mary Anne No. 1	464·2–465·4	70	30	130	3·2	45	20					M	
52047 Mary Anne No. 1	531·3–532·5	80	22	120	3·6	35	20					M	
Mungaroo Formation													
52053 Sandy Point No. 1	3 042·5	120	30	260	7·2	10	80						
JURASSIC													
Dingo Claystone													
52049 Peak No. 1	2 138·8	125	20	85	1·8	25	20	15				M	
Learmonth Formation													
52052 Sandy Point No. 1	1 230·5	110	22	70	1·6	45	15	5					
CRETACEOUS													
"Neocomian"													
52023 Angel No. 3	2 607·0	50	16	110	3·6	25	25	5		T	T	M	
52024 Angel No. 3	2 613·3	70	20	120	3·5	15	25	20		T		M	
52030 Dampier No. 1	2 834·6–2 838·3	85	20	120	5·6	15	35	15		T		M	
52031 Dampier No. 1	2 837·7	90	20	120	3·2	15	20	15		T		M	
Winning Pool Group, Mardie Greensand													
52041 Mardie No. 2	147·5	75	10	110	3·2	5	40	5		5		M	
Muderong Shale													
52037 Glenroy No. 1	493·5	75	6	55	1·4	5	30			5		M	
52045 Marilla No. 1	350·5–353·6	70	20	130	4·0	30	30	10		T		M	
52054 Trimouille No. 1	2 433·5	95	30	120	3·8	10	45	10		T			
52055 Trimouille No. 1	2 432·3	95	20	120	3·8	15	35	15		T		M	
Lower Gearle Siltstone													
52025 Cape Cuvier No. 1	335·3–338·4	50	14	110	3·4	1	25	5	50			M	
52042 Marilla No. 1	84·7–87·8	100	12	85	2·2	1	15		15	5		M	
52043 Marilla No. 1	126·5–129·6	130	14	100	3·2	1	30		20	5	*	M	
52044 Marilla No. 1	217·9–221·0	110	12	100	2·1	5	20		50			M	
52048 Minderoo No. 1	88·4	120	8	85	2·0	5	20		10				
52051 Rough Range No. 1	1 061·3–1 065·6	90	10	95	2·1	5	55			T		M	
Toolonga Calcilutite													
52026 Dampier No. 1	2 368·3	60	12	65	1·5	1	15	5	45	T		M	M
52027 Dampier No. 1	2 370·4	70	12	65	1·6	1	20	5	45	T		M	M
52028 Dampier No. 1	2 372·6	100	12	65	1·6	1	20	10	45			M	
52029 Dampier No. 1	2 621·3–2 624·6	105	20	90	2·1	35	20	5				M	M

* Gypsum present. Other symbols as in Table 26.

TABLE 28. SUMMARY TABLE OF CHEMICAL AND MINERALOGICAL DATA—CANNING BASIN

Sample and Well	Depth (m)	Chemistry				Mineralogy						Fossils	
		B	Ga	Rb	K_2O	KA	IL	CL	MD	GL	TO	P	F
PRE-PERMIAN UNASSIGNED													
52019 Willara Hill No. 1	759·6–763·5	30	12	110	3·4	10	15	10			T		
52020 Willara Hill No. 1	1 602·3	10	2	6	0·1						△		
PERMIAN													
Grant Formation													
52186 Crossland No. 2	410·3	75	22	230	5·4	1	50	25		T			
Poole Sandstone, Nura Nura Member													
52194 Frome Rocks No. 2	630·9–634·0	40	20	160	3·0]	20	25	15			T		
Noonkanbah Formation													
52012 Meda No. 1	592·2–598·4	65	25	160	4·7	15	40	20				M	
52191 Frome Rocks No. 2	513·4–216·5	60	16	140	4·0	20	20					M	
52192 Frome Rocks No. 2	335·0–338·1	85	20	150	3·7	15	25	15					
52193 Frome Rocks No. 2	457·2–460·3	25	6	55	1·5	15	1						
52195 Jurgurra Creek No. 1	57·0	80	20	140	3·7	15	25	15					
52196 Jurgurra Creek No. 1	149·4	80	25	160	3·9	20	40	15					
52197 Jurgurra Creek No. 1	210·0	60	25	160	4·8	20	40	20					
52198 Jurgurra Creek No. 1	246·9	50	16	120	3·4	15	25	15					
52199 Kemp Field No. 1	137·2	35	14	140	4·5	20	20	5		T			
52200 Meda No. 1	429·8–435·9	60	24	170	4·2	15	35	25					
Liveringa Formation													
52013 Myroodah No. 1		65	16	130	3·8	10	30	15			T	M	
Dora Shale													
52022 Willara No. 1	1 742·8	60	4	80	3·6	1	25	5			T*		
52190 Fraser River No. 1	572·4–574·5	15	6	65	1·9	1	5	10					

TABLE 28. SUMMARY TABLE OF CHEMICAL AND MINERALOGICAL DATA—CANNING BASIN—*continued*

Sample and Well	Depth (m)	Chemistry B	Ga	Rb	K_2O	Mineralogy KA	IL	CL	MD	GL	TO	Fossils P	F
JURASSIC													
Jarlemai Siltstone													
52014 Roebuck Bay No. 1	149·4–152·4	70	6	45	1·1	5	15			5		M	
52015 Roebuck Bay No. 1	176·8–179·8	50	24	130	3·5	15	25	20				M	
52016 Roebuck Bay No. 1	179·8–182·9	55	25	140	4·2	15	35	20				M	
52021 Willara No. 1	1 147·6	10	4	50	1·4	1	1						
52185 Chirup No. 1	156·1–156·7	550	12	280	5·6	5	1			80		M	
52187 Dampier Downs No. 1	18·3–21·3	25	16	28	0·6	35	10			T	T		
52188 Dampier Downs No. 1	48·8–50·3	50	24	130	6·6	20	20	20			T	M	
52189 Fraser River No. 1	59·4–62·5	90	18	140	5·3	15	25	5	5	T		M	
"EARLY JURASSIC"													
52017 Ronsard No. 1	2 844·5	55	30	95	1·7	55	15	5				M	
52018 Ronsard No. 1	2 843·8	50	30	85	1·6	55	15					M	

* Gypsum present. △ Rock salt. Other symbols as in Table 26.

TABLE 29. A SUMMARY OF MEAN VALUES AND STANDARD DEVIATIONS FOR EACH BASIN FOR CHEMICAL DATA, KAOLINITE AND ILLITE

(Values of B, Ga, Rb, in ppm, remainder as percentages)

	Boron $\bar{x}$	Boron s	Gallium $\bar{x}$	Gallium s	Rubidium $\bar{x}$	Rubidium s	K_2O $\bar{x}$	K_2O s	Illite $\bar{x}$	Illite s	Kaolinite $\bar{x}$	Kaolinite s
PERTH BASIN 31 samples	33	19	19	8	116	58	2·6	1·3	15	12	25	16
CARNARVON BASIN 33 samples	86	22	18	6	115	38	3·2	1·3	31	14	15	14
CANNING BASIN* 25 samples	53	21	18	8	121	47	3·2	1·3	22	13	16	14

* Halite sample and sample with 550 ppm B omitted.

TABLE 30. PEARSON CORRELATION COEFFICIENTS BETWEEN ELEMENTS, ILLITE AND KAOLINITE FOR EACH SEDIMENTARY BASIN

(Underlined figures are those significant at the 1% probability level)

	Ga	Rb	K_2O	Il	Kaol
PERTH BASIN					
B	$\underline{0·48}$	$\underline{0·62}$	$\underline{0·54}$	$\underline{0·78}$	—0·14
Ga	....	$\underline{0·67}$	$\underline{0·47}$	$\underline{0·61}$	$\underline{0·57}$
Rb	....	....	$\underline{0·92}$	$\underline{0·66}$	0·13
K_2O	....	....	....	$\underline{0·55}$	—0·05
Il	....	....	....	....	—0·17
CARNARVON BASIN					
B	0·05	—0·01	—0·08	0·13	—0·14
Ga	....	$\underline{0·64}$	$\underline{0·59}$	0·36	$\underline{0·52}$
Rb	....	....	$\underline{0·91}$	$\underline{0·64}$	0·15
K_2O	....	....	....	$\underline{0·59}$	0·11
Il	....	....	....	....	—0·22
CANNING BASIN*					
B	—0·01	$\underline{0·64}$	0·46	$\underline{0·76}$	—0·13
Ga	....	0·49	0·39	0·40	$\underline{0·65}$
Rb	....	....	$\underline{0·91}$	$\underline{0·91}$	—0·10
K_2O	....	....	....	$\underline{0·84}$	—0·24
Il	....	....	....	....	—0·14

* Halite sample and sample with 550 ppm B omitted. Il—illite, Kaol—kaolinite.

RELATIONSHIPS OF B, Ga, AND Rb WITH ILLITE AND KAOLINITE

Correlation coefficients (Table 30) indicate essential similarities of element behaviour in the Perth and Canning Basins. However, B and Ga behave differently in the Carnarvon Basin. In the Perth and Canning Basins, B, Rb and K_2O are closely associated with illite and Ga with both illite and kaolinite. In the Carnarvon Basin B is associated with neither illite nor kaolinite and Ga is dominantly related to kaolinite.

The Carnarvon Basin

The absolute value of B is higher in the Carnarvon Basin than in the other two basins. This is attributed to a different source area for the sediments. Sedimentary rocks of the Bangemall Basin and gneisses and granitoids of the Gascoyne Province are known to be richer in tourmaline than, for example, equivalent rocks in the Yilgarn Block. The highest values of B in the Carnarvon Basin occur, in general, in those samples of undoubted marine origin.

The lack of a relationship between B and illite is unusual and implies that B is concentrated elsewhere. There is no close association of B with kaolinite. Chlorite and montmorillonoids are not present in every sample. There is no correspondence of B with the total proportion of the clay minerals. B is present in tourmaline; this mineral has been identified in grain mounts of the Muderong Shale and other Early Cretaceous rocks, but the samples with the highest B values are marine siltstones and calcilutites with no visible tourmaline. However these samples do contain opal, glauconite, zeolites or montmorillonoids in small (<5 per cent) to moderately large (50 per cent) amounts and it seems likely that B is present in more than one mineral and is partitioned between them.

It is clear that the hypothesis of Degens and others (1958) is inapplicable to sedimentary rocks of the Carnarvon Basin.

Perth and Canning Basins

The highly significant degrees of correlation between B and Rb with illite and Ga with kaolinite in these basins support the original hypothesis of the location of these elements.

There is a clear separation of samples with a low illite: kaolinite ratio (<2:3) from those with a high illite:kaolinite ratio (>3:2) on the triangular diagram (Fig. 71) for the Perth Basin. Although there are fewer samples with the low ratio an almost identical line of separation is possible for samples from the Canning Basin.

In addition to those samples which contain one dominant clay mineral many samples, particularly in the Perth Basin, have approximately equal proportions of illite and kaolinite. These samples fit well into the overall clusters on the triangular plots but occur on both sides of the line of separation noted above. They lessen the possible significance of using simple illite:kaolinite ratios as a separator of samples deposited in marine and freshwater conditions.

The wide range of illite:kaolinite ratios differs from that of Degens and others (1957). These authors found the range of ratios for most samples deposited in fresh water to be 0.8 to 1.9, in brackish water 1.0 to 2.1, and in sea water 1.2 to 2.3. Though mineral results in this study are semiquantitative the range is 0.2 to 11 overall. For sediments recognized as of marine origin the range of the ratios is 0.2 to 1.5 in the Perth Basin, in the Carnarvon Basin 0.4 to 11, and in the Canning Basin 0.3 to 3.

EVIDENCE OF DEPOSITION FROM GLAUCONITE AND FORAMINIFERA

The only identified mineral indicator of depositional conditions is glauconite. This mineral is considered to have formed only in marine sediments (Deer and others, 1962). One sample from the Canning Basin, a greensand, is composed largely of glauconite, and has a very high B content (550 ppm). This value supports Harder (1970) who noted that the B content in glauconite is higher than in illite.

The presence of this mineral may therefore distort the B-illite relationship, though there is no apparent systematic variation due to glauconite.

Glauconite is present in most Cretaceous samples in the Carnarvon Basin and in isolated samples from Permian and Jurassic rocks in the Canning Basin. For the most part it occurs in rocks low in kaolinite. In one sample from Dampier Downs No. 1 the glauconite present may have been reworked from previously deposited marine sediments.

Foraminifera were observed in grain mounts of the Toolonga Calcilutite (Canning Basin) confirming a marine deposition of this rock.

PALYNOLOGY

The presence of dinoflagellates or acritarchs is also considered generally conclusive of open-marine origin. An exception occurs in the Yarragadee Formation (Early Neocomian) of the Perth Basin (Table 26) which contains dinoflagellates regarded as representing a restricted marine environment and probable brackish-water conditions. Species known to occur in open-marine deposits of similar age are not present in this formation. Rare marine forms within the Yarragadee Formation are of apparent Triassic age and are derived from pre-existent sediments.

A number of samples contained no palinomorphs of either marine or non-marine origin.

B-Ga-Rb TRIANGULAR DIAGRAMS

The trace-element chemical data together with observations concerning the illite:kaolinite ratio and inferences of depositional conditions based on mineralogical and palaeontological evidence have all been plotted on triangular diagrams (Fig. 71) showing the lines of separation between freshwater and marine deposition suggested by Degens and others (1958).

The plots show the samples clustering in different positions in the three basins. Those for the Perth and Canning Basins are similar except for ioslated samples in the Canning Basin rich in B. The plot for the Carnarvon Basin reflects the high overall B content relative to the other two basins.

It is immediately apparent that the boundary of depositional conditions suggested by Degens and others (1958) bears no resemblance to the actual depositional conditions in any of the three basins.

The diagrams suggest that if there is a separation between marine and freshwater deposition the line of demarcation lies much closer to the Ga-Rb boundary of the triangular diagram than it did for the samples studied by Degens and others (1958). A possible line of separation is shown in Figure 71 (Perth Basin). The line is close to but not exactly the same as the line of separation of kaolinite-rich from illite-rich samples.

PROBLEM OF IDENTIFICATION OF NON-MARINE SAMPLES

In an exercise of this kind it is easier to positively identify rocks which were deposited in marine conditions. In this study this has been done by the identification of glauconite, foraminifera, marine acritarchs or marine dinoflagellates in the sample. It has proved impossible to identify rocks deposited in fresh water in this way, since no indicator minerals or fossils have been found. The absence of marine fossils is not a certain indication of non-marine origin since some marine sediments are unfossiliferous.

Only those samples demonstrably of marine origin have been plotted as such in Figure 71. Non-marine sediments and those with no clear indication of origin have been plotted without interpretation.

CONCLUSIONS

These studies have shown difficulties in using B-Ga-Rb ratios to determine environments of deposition without other geological, mineralogical or palaeontological controls. They immediately raise doubt as to the validity of the conclusions drawn in Davy and others (1978). It may be fortuitous that there was agreement in the earlier study between the depositional conditions suggested by B-Ga-Rb diagrams (using Degens and others (1958) as a basis for interpretation) and those deduced on geological grounds.

It appears that provenance plays an important part in determining the absolute amounts of the trace elements. Since provenance appears to control B more than Ga or Rb, the provenance indirectly controls the position of the plotted point on the triangular diagram.

The present studies have shown that the hypothesis of Degens and others (1958) is untenable for the Carnarvon Basin since B is not correlated with illite. They have confirmed, however, that illite is in general more abundant than kaolinite in rocks of undoubted marine origin.

A consistent pattern has emerged in the Perth and Canning Basins. There is a reasonably sharp division between kaolinite-rich and illite-rich samples, and the kaolinite-rich samples, as expected, are located in the Ga-rich rather than the B-rich parts of the triangular diagrams. However, palynological studies on Perth Basin samples, whilst not conclusive for all samples, indicate a line of demarcation between marine and brackish water deposition far away from that proposed by Degens and others (1958), close to the Ga-rich part of the diagram (Fig. 71). This suggests that, once adequate parameters are established for a restricted area of deposition, such as one of the basins studied here, the triangular diagrams may be of use for characterizing conditions for samples of unknown origin but from the same general area. The same line of separation may also apply in the Canning Basin; however this basin contains few sedimentary rocks of undoubted freshwater origin.

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ASPECTS OF AMPHIBOLE CHEMISTRY AND METAMORPHIC GRADIENT IN THE WONGAN HILLS, WESTERN AUSTRALIA

by D. F. Blight

ABSTRACT

Ten metamorphic amphiboles from the Wongan Hills area of Western Australia were chemically analysed. A study of their TiO_2 content and the amount of alkalis in relation to silicon suggests a dominantly temperature-controlled metamorphic gradient; rocks formed under higher temperatures occur in the south.

INTRODUCTION

The Wongan Hills, centred at latitude 30°50′S longitude 116° 38′E (Moora 1:250 000 Sheet), are approximately 150 km northeast of Perth. They are approximately 20 km long and 6 km wide. The rocks have been described by Carter, Low and Lipple (in press), and are of metamorphosed and deformed Archaean supracrustal rocks. There are mafic and felsic volcanics, intercalated with sedimentary rocks ranging from banded iron-formation to pelitic schist. Porphyritic and even-grained Archaean granitoids intrude the sequence. The structure of the area is complex, and at least two tectonic events are megascopically visible. Presumed Proterozoic dolerite dykes intrude faults and northeast-trending fractures.

METAMORPHIC GRADE

During the course of service petrology associated with the regional mapping of the Moora 1:250 000 Sheet, the following metamorphic assemblages were recognised within the supracrustal rocks of the Wongan Hills.

Basic rocks

Plagioclase (An >25) + hornblende + opaques ± quartz ± sphene with secondary chlorite, clinozoisite and sericite.

Aluminous rocks

Microcline + andalusite + fibrolite + muscovite + biotite + quartz ±garnet, and
cordierite (altered) + garnet + quartz + biotite + opaques.

Banded iron-formations

Quartz + grunerite + opaques

Ultramafic rocks

Garnet ± grunerite ± hornblende + opaques

The unusual assemblage, cordierite + cummingtonite, was also noted. Rocks of similar composition have been described by many other workers, including Prider (1944), Starmer (1969), Lal and Moorehouse (1969), and Beeson (1976); the consensus favours non-isochemical metamorphism to account for the unusual chemistry. Evidence of metasomatism associated with the copper mineralization in the Wongan Hills supports such a suggestion. All the assemblages mentioned above are characteristic of the amphibolite facies at medium pressures (Turner, 1968).

When the areal distribution of the minerals was examined no definite mineral isograds were found. However, garnet appears to be confined to the south (field observation by S. Lipple during regional mapping), and andalusite was only visible in thin sections collected from the southern regions. This latter observation may well be a function of the composition of the rocks sampled. The assemblage, cordierite + cummingtonite, was noted from all areas of the Wongan Hills. On the basis of subtle colour changes of amphiboles, Blight (1977, unpublished GSWA Petrology Report 783) suggested that a regional metamorphic gradient, increasing to the north, may be evident in the rocks of the Wongan Hills. It was stressed that a detailed chemical study of the amphibole minerals was needed to substantiate such a suggestion. This report deals with such a study.

ELEMENTAL VARIATIONS

Petrographic descriptions of the rocks used in this study are detailed in Appendix I, and analytical techniques are discussed in Appendix II. Analysed amphiboles and structural formulae are listed in Table 31. Sample locations are given in Figure 72. As can be seen from Table 31, all analysed amphiboles, apart from the rim of sample 44045, are hornblendes.

Raase (1974) has demonstrated a good distinction between hornblendes of low-pressure (less than 500 MPa) and high-pressure type of regional metamorphism by using a plot of Al^{VI} against Si. Figure 73 is a similar plot for the hornblendes of the Wongan Hills. All plot in the low-pressure regions, and thus support the estimate of metamorphic grade based on mineral assemblages.

The TiO_2 content of hornblendes and biotites has been considered responsible for colour charges of the minerals which correlate with variations in metamorphic grade (Leake, 1965; Binns, 1969). Furthermore Leake (1965), Binns (1969), and Raase (1974) have demonstrated that, with increasing metamorphic grade, the TiO_2 content of hornblendes also increases. Leake (1965) and Binns (1969) consider that increasing temperature is the important factor in these correlated changes. A visual inspection of location versus the TiO_2 content for the Wongan Hills hornblendes suggests a tendency towards a lower TiO_2 content in the north. The influence of host-rock chemistry may have masked this trend, so a second-order trend-surface analysis was applied to the data. Figure 72 clearly demonstrates that such a trend, of lower TiO_2 values to the north, exists; this suggests that the hornblendes of the southern region were formed at higher temperatures than those in the north.

The charge on silicon ions is different from that on aluminium ions and results in a charge imbalance where aluminium replaces silicon in the anion part of the silicate lattice. Binns (1965) showed that this charge imbalance is rectified differently at high metamorphic grade than at low grade. At low grade, a charge balance is maintained by additional cationic aluminium, whereas at high grade, the charge balance is maintained by additional alkali cations. Thus at

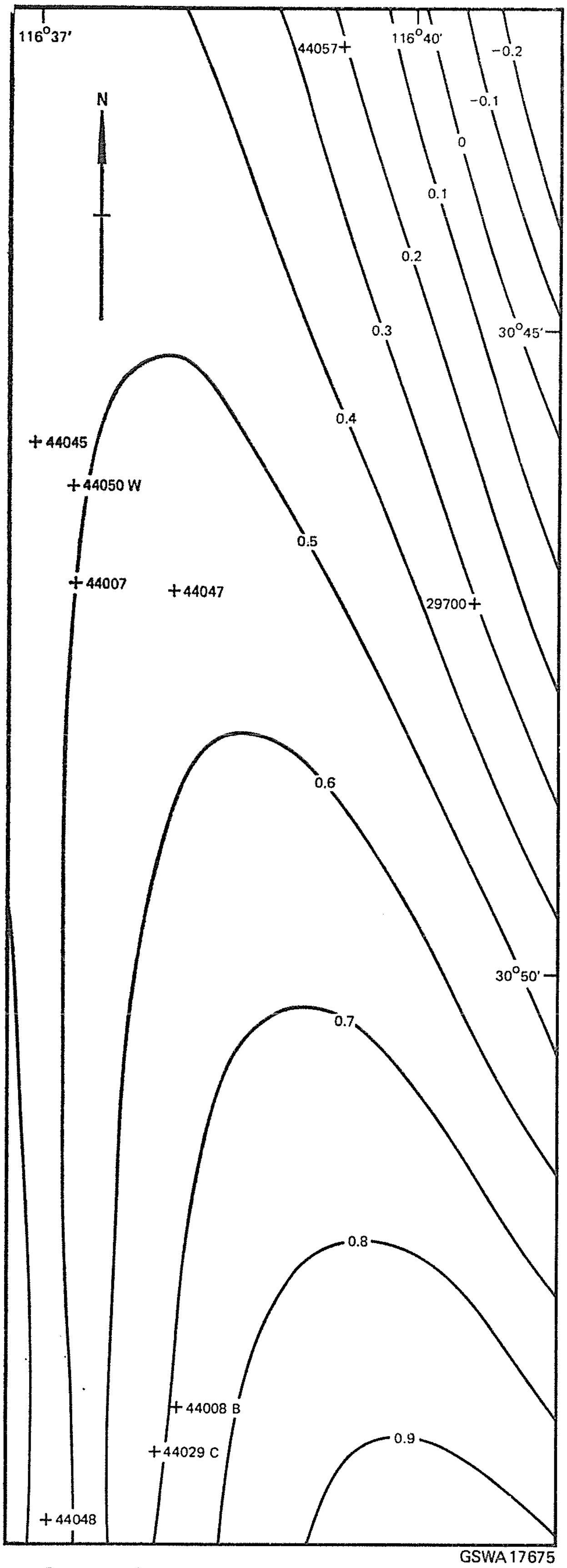

Figure 72 Second order trend surface analysis of TiO_2 content of Wongan Hills amphiboles in relation to location.

higher metamorphic grade, the amphibole contains more "edenitic" alkalis and less Al^{VI}. Binns (1969) further demonstrated this observation with a study of 180 hornblendes from different terrains, and concluded that these types of ". . . changes in amphibole composition appear more highly influenced by temperature than pressure".

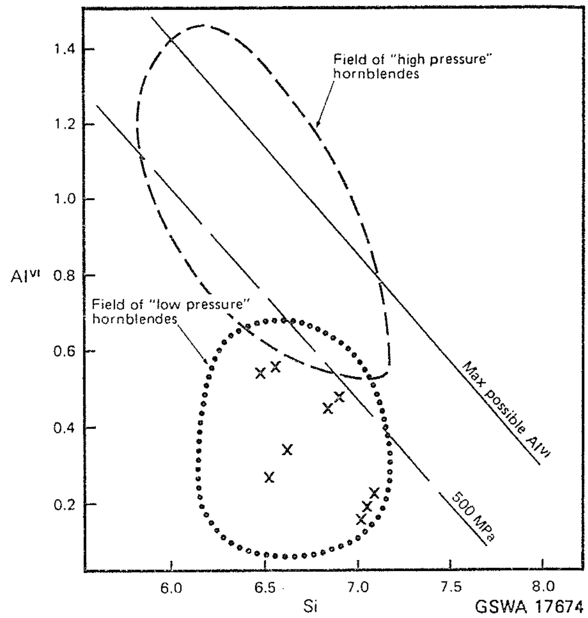

Figure 73 Wongan Hills amphiboles plotted on a Si against Al^{VI} diagram after Raase (1974).

The hornblendes of Wongan Hills have been plotted on Figure 74, Al^{VI} against "edenitic" alkalis (cf. Binns, 1969, page 326). While these amphiboles do not plot within the fields indicated by Binns, they nevertheless show a trend which, in the light of the previous discussion, suggests that those rocks to the south are higher grade, and consequently formed at higher temperature, than those to the north.

CONCLUSIONS

It is apparent from this study of hornblendes that there is a variation of metamorphic grade in the Wongan Hills, from low in the north to higher in the south. Furthermore, it is probable that this variation is a response to temperature and not pressure. This finding is consistent with that of an earlier study (Blight, 1977), which showed, using petrological evidence, that an unusually high geothermal gradient existed in the southern region of the Wongan Hills.

ACKNOWLEDGEMENTS

Assistance with the microprobe analyses, by Dr. J. Graham and Mr. B. Robinson of the CSIRO, Floreat Park, Western Australia, is gratefully acknowledged.

APPENDIX I—PETROGRAPHY OF ANALYSED SAMPLES

29700 Texture: Granoblastic, seriate with a very weak fabric overprinting a faint relict igenous texture.
Mineralogy: Coarse green hornblende (55%) up to 2.0 mm in size with finer grained plagioclase (40%) minor opaques and a trace of apatite.
Name: Meta-Dolerite.

44007 Texture: Fine grained, lepidoblastic, equigranular with a moderate layering and a strong fabric.
Mineralogy: Green hornblende (45%) about 0.1 mm in size, plagioclase (45%) rarely weakly saussuritized, chlorite (10%), and some minor opaques.
Name: Amphibolite.

44008B Texture: Fine grained, granoblastic, equigranular, interlobate.
Mineralogy: Green hornblende (10-15%) scattered throughout a matrix of plagioclase and quartz (?) with minor opaques.
Name: Meta-Dacite.

44029C Texture: Medium to fine grained, moderately lepidoblastic, inequigranular with a moderate fabric. There is a relict but unrecognizable (possibly basaltic) texture.

TABLE 31. ANALYSES OF AMPHIBOLES FROM THE WONGAN HILLS

	29700	44007	44008B	44029C	44045 *core*	44045 *rim*	44047	44048B	44050W	44057
SiO_2	46·42	43·11	47·48	42·40	43·25	52·46	43·72	48·44	47·99	48·64
Al_2O_3	9·28	11·65	6·44	9·69	11·85	·97	9·74	6·26	9·14	6·66
Fe_2O_3	4·98	5·53	5·55	6·61	5·33	2·91	5·68	5·30	3·87	3·86
FeO	13·44	14·93	14·99	17·85	14·39	23·57	15·33	14·32	9·46	10·41
MgO	11·60	8·37	10·40	6·58	9·66	16·00	9·15	11·19	14·10	15·60
CaO	11·62	12·16	12·10	11·76	10·69	·70	11·29	11·84	12·10	10·51
Na_2O	1·01	1·19	·61	1·07	1·51	·24	1·31	·60	1·01	·73
K_2O	·14	·53	·16	·75	·17	....	·32	·42	·14	....
TiO_2	·31	·66	·55	·87	·51	....	·54	·41	·29	·22
MnO	·21	·30	·32	·52	....	·37	·35	·63	·16	·25
H_2O+	1·50	1·57	1·50	1·90	2·00	2·00	2·00	1·50	1·74	2·00
Total	100·51	100·00	100·10	100·00	99·36	99·22	99·43	100·91	100·00	98·88
STRUCTURAL FORMULAE ON THE BASIS OF 24 OXYGENS										
Si	6·853	6·506	7·104	6·509	6·473	7·799	6·604	7·091	6·945	7·138
Al^{IV}	1·147	1·494	·900	1·491	1·527	·170	1·396	·909	1·055	·862
Al^{VI}	·468	·578	·236	·262	·563	....	·338	·171	·504	·283
Fe^{2+}	1·659	1·884	1·876	2·292	1·801	2·930	1·937	1·753	1·145	1·270
Fe^{3+}	·553	·628	·625	·764	·600	·325	·646	·584	·421	·427
Mg	2·553	1·883	2·320	1·506	2·155	3·545	2·060	2·442	3·041	3·391
Ca	1·838	1·966	1·940	1·934	1·714	·112	1·827	1·857	1·876	1·642
Na .... {	·162	·034	·060	·066	·286	·069	·173	·143	·124	·206
Na .... {	·127	·314	·117	·253	·152	....	·211	·027	·159	....
K	·026	·102	·031	·147	·032	....	·062	·078	·026	....
OH	1·477	1·581	1·497	1·946	1·997	1·983	2·015	1·953	1·680	1·946
Ti	·034	·075	·062	·100	·057	....	·061	·045	·032	·024

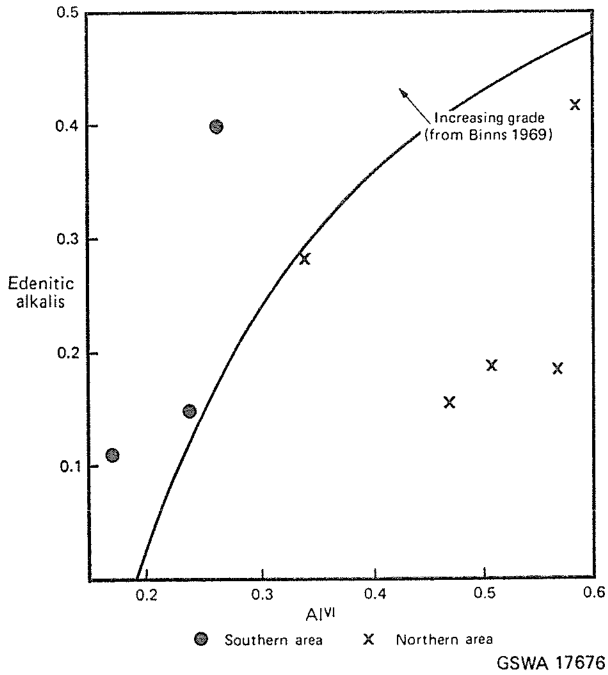

Figure 74 Edenitic alkalis against Al^{VI} for Wongan Hills amphiboles.

Mineralogy: Green hornblende (45%) up to 0.3 mm in size, slightly saussuritized plagioclase (55%) with minor sphene (1%) and a trace of opaques.

Name: Meta-Basalt.

44045 Texture: Fine grained, lepidoblastic, poorly equigranular with a strong fabric.

Mineralogy: Colourless to pale green cummingtonite-grunerite with a green hornblende core (50%) up to 0.6 mm long but averaging about 0.2 mm, plagioclase (50%) and minor opaques.

Name: Amphibolite (Schist).

44047 This rock is similar to 29700 but the fabric is a little more penetrative.

Name: Meta-Dolerite.

44048B Texture: Fine grained, poorly lepidoblastic, equigranular with a weak layering and a moderate fabric—possibly a relict vesicular texture.

Mineralogy: Green hornblende (60%) up to 0.4 mm, totally saussuritized plagioclase producing clinozoisite and muscovite, and minor quartz and opaques.

Name: Amphibolite (Meta-Basalt).

44050W Texture: Medium to fine grained, granoblastic, poorly equigranular.

Mineralogy: Pale green hornblende (99%) averaging about 0.5 mm in size and minor opaques.

Name: Meta-Pyroxenite.

44057 Texture: Barely discernible relict sub-ophitic igneous texture.

Mineralogy: Coarse grained green hornblende (55%) up to 3.0 mm, medium grained calcic plagioclase (45%) up to 1.0 mm in size and minor opaques.

Name: Meta-Dolerite.

APPENDIX II—ANALYTICAL DETAILS

The amphiboles were analysed at the CSIRO, Floreat Park, using a MAC electron microprobe. Determinations were made on a number of grains per sample at different places within the one grain, the results were then averaged. Initially, manually operated wavelength spectrometers were used for detection but later a quantitative energy dispersive multichannel analyser was installed and utilized. The results from both these systems were found to be comparable. The probe analyses did not distinguish between Fe^{2+} and Fe^{3+} so, after examination of other published amphibole analyses, corrections were applied as follows:

$$Fe_2O_3 = \frac{\text{total Fe (as FeO)}}{4} \times 1.1113$$

FeO values were then obtained by difference. H_2O^+ was considered to lie between 1.5 and 2.0, the value assumed gave a total closest to 100.00%. Structural formulae were calculated on the basis of 24 Oxygens.

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DIVISION V

Report of the Director of The Petroleum Branch for the Year 1978

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Under Secretary for Mines

I hereby submit my Annual Report for the Petroleum Branch for 1978.

PETROLEUM TENEMENTS

Status on 31st December 1978 (Figure 1, Table I)

Petroleum tenements current on 31st December 1978 cover an area totalling 173 540 square kilometres onshore and 614 280 square kilometres offshore. The total area still available for application, i.e. onshore and offshore combined, is almost 1 200 000 square kilometres (Figure 1). Table 1 sets out the details of the various holdings.

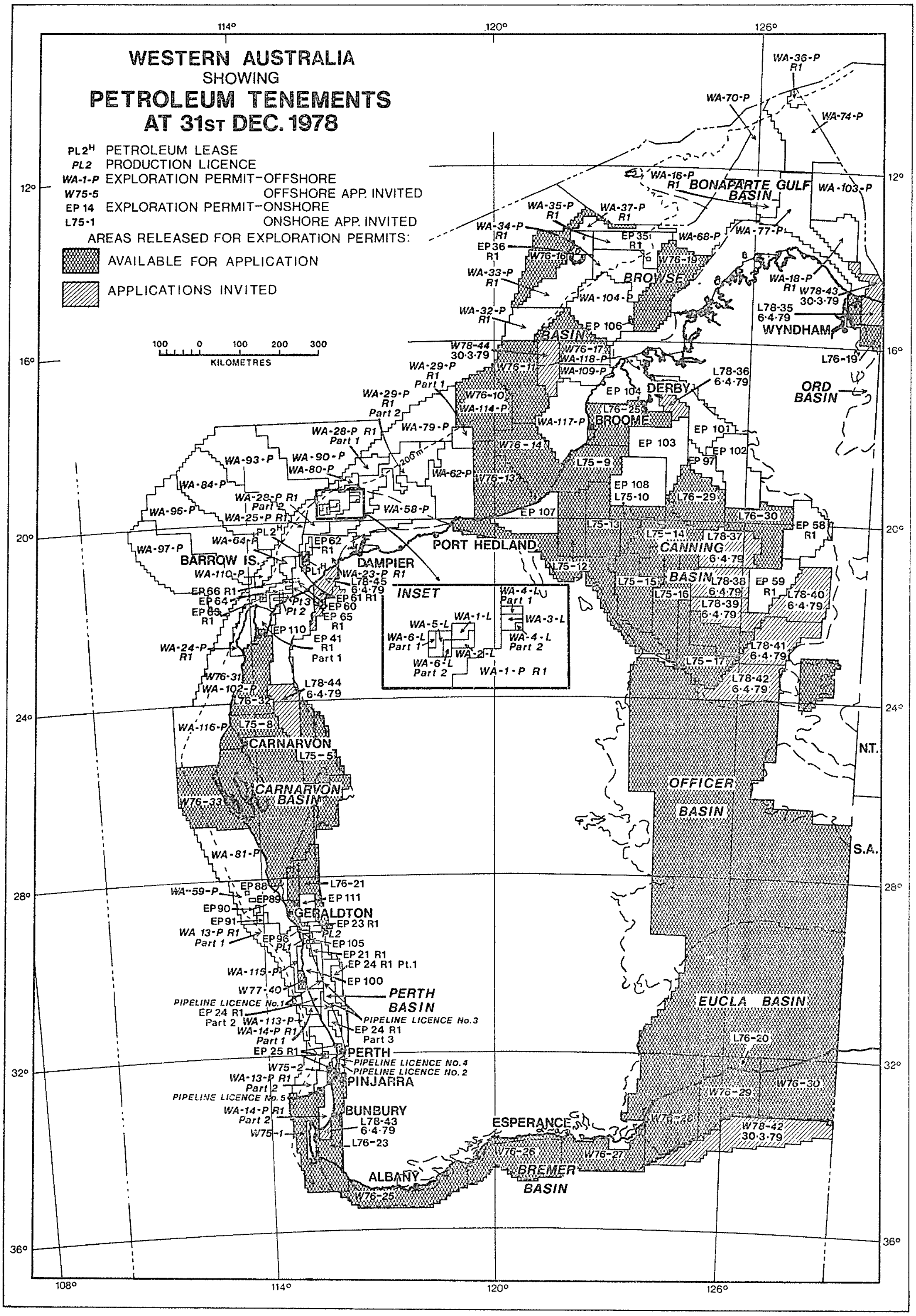

Figure 1 Petroleum Tenements on 31st December, 1978.

TABLE I

A. 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			
R 1	178	14/11/79	Woodside Oil Ltd, Woodside Petroleum Development Pty Ltd, Mid-Eastern Oil Ltd, North West Shelf Development Pty Ltd, B.P. Petroleum Development Aust. Pty Ltd, California Asiatic Oil Co.
WA-13-P			
R 1 Part 1	110 } 194	29/8/79	
R 1 Part 2	84		
WA-14-P			West Australian Petroleum Pty Ltd
R 1 Part 1	77 } 198	29/8/79	
R 2 Part 2	121		
WA-16-P			
R 1	40	16/4/80	Arco Aust. Ltd
WA-18-P			
R 1	105	16/4/80	Arco Aust. Ltd, Australian Aquitane Petroleum Pty Ltd
WA-23-P			
R 1	199	3/10/79	
WA-24-P			
R 1	104	17/10/79	West Australian Petroleum Pty Ltd
WA-25-P			
R 1	128	16/10/79	
WA-28-P			
R 1 Part 1	52 } 178	24/3/80	
R 2 Part 2	126		
*WA-29-P			
R 1 Part 1	36 } 120	18/5/80	
R 1 Part 2	84		
WA-32-P			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.
R 1	100	2/7/80	
WA-33-P			
R 1	194	18/5/80	
WA-34-P			
R 1	149	2/7/80	
WA-35-P			
R 1	123	2/7/80	
WA-36-P			
R 1	18	18/5/80	Woodside Oil Ltd, Woodside Petroleum Development Pty Ltd, Shell Development (Aust) Pty Ltd, Mid-Eastern Oil Ltd, North West Shelf Development Pty Ltd, B.P. Petroleum Development Aust. Pty Ltd.
WA-37-P			
R 1	59	2/6/80	
WA-58-P	222	11/7/82	Western Energy Pty Ltd, Stirling Petroleum N.L.
WA-59-P	190	18/6/82	Esso Exploration & Production Aust. Inc., Western Mining Corp. Ltd.
WA-62-P	226	7/3/83	Oxoco-International Inc., 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-84-P	400	18/11/83	Mobil Oil Aust. Ltd., Phillip Aust. Oil Co., Australian Gulf Oil Co., M.I.M. Investments Pty Ltd., B.P. Petroleum Development Aust. Pty Ltd.
WA-90-P	400	18/11/83	Woodside Petroleum Development Pty Ltd., Woodside Oil Ltd., Mid-Eastern Oil Ltd., B.P. Petroleum Development Aust. Pty Ltd., California Asiatic Oil Co., The Shell Co. of Aust. Ltd., Hematite Petroleum Pty Ltd.
WA-93-P	400	18/11/83	Hudbay Oil (Aust) Ltd., Canadian Superior Oil International Ltd., Pan Canadian Petroleum Ltd., Australian Oil and Gas Corp. Ltd.
WA-96-P	400	18/11/83	Esso Exploration and Production Aust. Inc., Hematite Petroleum Pty Ltd.
WA-97-P	400	18/11/83	
WA-102-P	234	15/3/84	Canada North West Land Ltd., Star Oil & Gas Ltd., Oakwood Petroleums Ltd., Cultus Pacific N.L.
WA-103-P	247	29/12/83	Natomas of West. Aust. Inc., Wainoco International Inc., Bonaparte Petroleum Ltd., Petro Energy Ltd., Lennard Oil N.L., White Pine Mining Pty Ltd.
WA-104-P	242	7/3/84	Oberon Oil Pty Ltd
WA-109-P	75	4/7/84	Esso Exploration and Production Aust. Inc.
WA-110-P	25	24/7/84	Cultus Pacific N.L., C.N.W. Oil (Aust) Pty Ltd., Oakwood Petroleums Ltd., Star Oil & Gas Ltd.
WA-113-P	44	22/9/84	Haoma Gold Mines N.L.
WA-114-P	239	Appln	Era South Pacific Pty Ltd., E.S.P. Exploration Pty Ltd., Carr Boyd Minerals Ltd., Hill Minerals N.L., Western Queen (1936) N.L., Attock Petroleum Ltd.
WA-115-P	14	9/11/84	Geo Metals N.L.
WA-116-P	250	9/11/84	
WA-117-P	248	15/11/84	Pursuit Exploration Pty. Ltd.
WA-118-P	173	Appln	Conex Aust. N.L., Pennant Oil & Gas Pty Ltd

* Surrender Pending

TABLE I—*continued*

A. 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
PRODUCTION LICENCES			
WA-1-L	5	Appln	Woodside Oil Ltd., Woodside Petroleum Development Pty Ltd., Mid-Eastern Oil Ltd., North West Shelf Development Pty Ltd., B.P. Petroleum Development Aust. Pty Ltd., California Asiatic Oil Co.
WA-2-L	4	Appln	
WA-3-L	5	Appln	
WA-4-L	4	Appln	
WA-5-L	5	Appln	
WA-6-L	4	Appln	

B. PETROLEUM TENEMENTS UNDER THE PETROLEUM ACT, 1936

PETROLEUM LEASES

Number	Aera (square kilometres)	Expiry Date of Current Term	Holders
1H	259	9/2/88	West Australian Petroleum Pty Ltd
2H	259	9/2/88	

C. PETROLEUM TENEMENTS UNDER THE PETROLEUM ACT, 1967

EXPLORATION PERMITS

Number	No. of Graticular Sections	Expiry Date of Current Term	Registered Holder or Applicant
*EP 21			
R 1	32	26/7/80	West Australian Petroleum Pty Ltd
EP 23			
R 1	33	6/8/80	
EP 24			
R 1 Part 1	39		
R 1 Part 2	24 } 85	6/8/80	
R 1 Part 3	22		
*EP 25			
R 1	36	6/8/80	
EP 35			
R 1	1	15/4/81	Woodside Oil Ltd., Woodside Petroleum Development Pty Ltd., Mid-Eastern Oil Ltd., North West Shelf Development Pty Ltd., B.P. Petroleum Development Aust. Pty Ltd., California Asiatic Oil Co.
EP 36			
R 1	1	15/4/81	
EP 41			
R 1 Part 1	102		
R 1 Part 2	1 } 106	18/7/81	West Australian Petroleum Pty Ltd
R 1 Part 3	3		
EP 58			
R 1	150	20/7/81	A.A.R. Limited, Pursuit Oil N.L.
EP 59			
R 1	139	18/7/81	
EP 60	2	Appln	West Australian Petroleum Pty Ltd
EP 61			
R 1	4	19/9/81	
EP 62			
R 1	8	19/9/81	
EP 63			
R 1	4	19/9/81	
EP 64	1	Appln	
EP 65			
R 1	2	19/9/81	
EP 66	1	19/9/81	
R 1	1	19/9/81	
EP 88	1	18/6/81	Esso Exploration & Production Aust. Inc., Western Mining Corp. Ltd.
EP 89	2	18/6/81	
EP 90	4	18/6/81	
EP 91	7	18/6/81	
EP 96	3	3/11/81	X.L.X. N.L.
EP 97	64	16/9/81	Whitestone Petroleum Aust. Ltd., Amax Iron Ore Corp., Pennzoil Producing Aust. Ltd., Australian Consolidated Minerals Ltd.
EP 100	163	3/10/82	Agha-Jahri Exploration Co., North West Mining N.L., 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.

C. 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 101	172	24/6/82	Whitestone Petroleum Aust. Ltd., Amax Iron Ore Corp., Pennzoil Producing Aust., Ltd., Australian Consolidated Minerals Ltd.
EP 102	200	24/6/82	
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	7/3/83	Oberon Oil Pty Ltd.
EP107	146	30/6/83	Era South Pacific Pty Ltd., Era West. Aust. Inc., E.S.P. Explorations Pty Ltd., Cambridge Royalty Co., Cambridge Petroleum Royalties Ltd., North West Mining N.L.
EP 108	193	29/12/82	Houston Oil & Minerals Aust. Inc.
EP 110	200	3/8/83	Samantha Mines Pty Ltd., Otter Exploration N.L. Onslow Oil & Gas Exploration Pty Ltd.
EP 111	42	21/10/83	Jervois Sulphates (N.T.) Ltd.

PRODUCTION LICENCES

PL 1	5	24/10/92	West Australian Petroleum Pty Ltd.
PL 2	4	24/10/92	

* Surrender Pending

D. PETROLEUM TENEMENTS UNDER THE PETROLEUM PIPELINES ACT, 1969

PIPELINE LICENCES

Number	Date of Expiry of Current Term	Registered Holder or Applicant
1	1/12/91	California Asiatic Oil Co., Texaco Overseas Petroleum Co., Shell Development (Aust.) Pty Ltd., Ampol Exploration Ltd.
2	1/12/91	
3	1/12/91	
4	1/12/91	
5	1/12/91	

Tenement Activity Offshore (Figure 2, Table II and IV)

During the latter part of the year three areas totalling 36 340 square kilometres were advertised inviting applications for permits and one area of 1 110 square kilometres was made available without a closing date. Sixteen applications were received in respect of 10 areas or parts of areas. In each case the area applied for had been advertised prior to 1978. Eight permits totalling 90 460 square kilometres were granted and six were refused. One permit surrender was approved.

At the end of the year the total number of offshore permits held by exploration companies was 41 and these covered an area of 614 280 square kilometres. Two permit applications were pending. Figure 2 illustrates the tenement dealings during 1978 and Table II sets out the statistical details.

TABLE II

DEALINGS UNDER THE PETROLEUM (SUBMERGED LANDS) ACT, 1967 DURING 1978

(a) ADVERTISEMENTS (SECTION 20)

Area Number	Basin	Date Gazetted	Closing Date	No. of Blocks	Area (km²)
"Closing Date" Section 20(1)					
W78–42	Eucla	1/12/78	30/3/79	365	26 050
W78–43	Bonaparte	1/12/78	30/3/79	54	3 730
W78–44	Canning-Browse	1/12/78	30/3/79	80	6 560
				Sub Total	36 340
"No Closing Date" Section 20(3)					
W77–40	Perth	1/12/78	....	15	1 110
				Sub Total	1 110
				Grand Total	37 450

TABLE II—*continued*

DEALINGS UNDER THE PETROLEUM (SUBMERGED LANDS) ACT, 1967 DURING 1978—*continued*

(b) EXPLORATION PERMIT APPLICATIONS AND GRANTS (SECTIONS 21 AND 22)

Application or Permit Number	Area Number	Applicant	Date Received	Basin	No. of Blocks	Area (km²)	Status	Operative Date
WA–102–P	W76–31	CanadaNorth West *et al*	29/9/77	Carnarvon	234	18 410	Granted	16/3/78
WA–104–P	W77–41	Oberon	31/10/77	Browse	242	19 970	Granted	8/3/78
WA–105–P	W75–3	Agha-Jari *et al*	11/11/77	Perth	44	3 240	Refused	23/4/78
WA–106–P	W75–4	Agha-Jari *et al*	11/11/77	Perth	14	1 040	Refused	23/4/78
WA–107–P	W77–40	Agha–Jari *et al*	11/11/77	Perth	15	1 110	Refused	23/4/78
WA–108–P	W77–41	Metro *et al* [1]	11/11/77	Browse	242	19 970	Refused	27/2/78
WA–109–P	W76–17 (part)	Esso	13/1/78	Canning	75	6 150	Granted	5/7/78
WA–110–P	W76–6	CNW *et al*	24/2/78	Carnarvon	25	2 000	Granted	25/7/78
WA–111–P	W76–17 (part)	Pursuit[2]	13/3/78	Canning	222	18 215	Refused	28/6/78
	W76–15 (part)			Canning	178	14 530		
WA–112–P	W76–6	Oil and Mineral Quest[3]	19/4/78	Carnarvon	25	2 000	Refused	13/7/78
WA–113–P	W75–3	Haoma	2/5/78	Perth	44	3 240	Granted	23/9/78
WA–114–P	W76–10	Era *et al*	30/6/78	Canning	239	19 500	Pending	
WA–115–P	W75–4	Geometals N. L.	3/7/78	Perth	14	1 040	Granted	10/11/78
WA–116–P	W76–32	Geometals N. L.	3/7/78	Carnarvon	250	19 450	Granted	10/11/78
WA–117–P	W76–15	Pursuit	19/7/78	Canning	248	20 200	Granted	16/11/78
WA–118–P	W76–17 (part)	Conex *et al*	28/9/78	Browse	173	14 230	Pending	

1. Metro Industries Ltd., Pluranpe Pty Ltd., Westwools Holdings Limited, Westwools Exploration Limited, Lennard Oil No Liability, Malita Exploration Pty Ltd.
2. Pursuit Exploration Pty Ltd.
3. Oil and Minerals Quest N. L.

Note: For full title of all other Registered Holders and or Applicants, refer Table 1.

(c) SPECIAL AUTHORITIES AND CONSENTS (SECTIONS 112 AND 123)

(AA = Access Authority—Section 112)
(S = Scientific Investigation—Section 123)

Number	Applicant	Basin or Area of Survey	Permit or Area requiring Access Authority
AA48SL	Esso *et al*	Exmouth Plateau	WA–24–P, WA–25–P, WA–84–P and vacant area
AA49SL	Woodside *et al*	North West Shelf	WA–23–P, WA–25–P, WA–79–P, WA–80–P, WA–93–P and vacant area
AA50SL	Conoco *et al*	Carnarvon Basin	Vacant
AA51SL	Western Energy	Carnarvon Basin	WA–1–P, WA–28–P
AA52SL	Wapet	Carnarvon Basin	WA–1–P, WA–28–P
AA53SL	Wapet	Carnarvon Basin	WA–64–P and vacant area
AA54SL	Phillips *et al*	Exmouth Plateau	WA–25–P, WA–93–P, WA–96–P
AA55SL	Hudbay *et al*	Exmouth Plateau	WA–25–P, WA–28–P, WA–90–P
AA56SL	Western Energy	Carnarvon Basin	WA–1–P, WA–23–P, WA–28–P and vacant area
AA57SL	Otter *et al*	Carnarvon Basin	WA–28–P
AA58SL	Esso *et al*	Exmouth Plateau	WA–84–P
AA59SL	Getty *et al*	North West Shelf	WA–1P, WA–28–P, WA–29–P, WA–90–P and vacant area
AA60SL	Esso *et al*	Perth Basin	Vacant
AA61SL	Western Energy *et al*	Carnarvon Basin	WA–1–P
AA62SL	Canada North West *et al*	Carnarvon Basin	WA–24–P
AA63SL	CNW *et al*	Carnarvon Basin	WA–24–P, WA–25–P
AA64SL	Lennard *et al*	Bonaparte	WA–77–P
AA65SL	Oberon	Browse	WA–32–P, WA–33–P, WA–34–P

(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	17/11/78	49 (4060)	49 (4060)

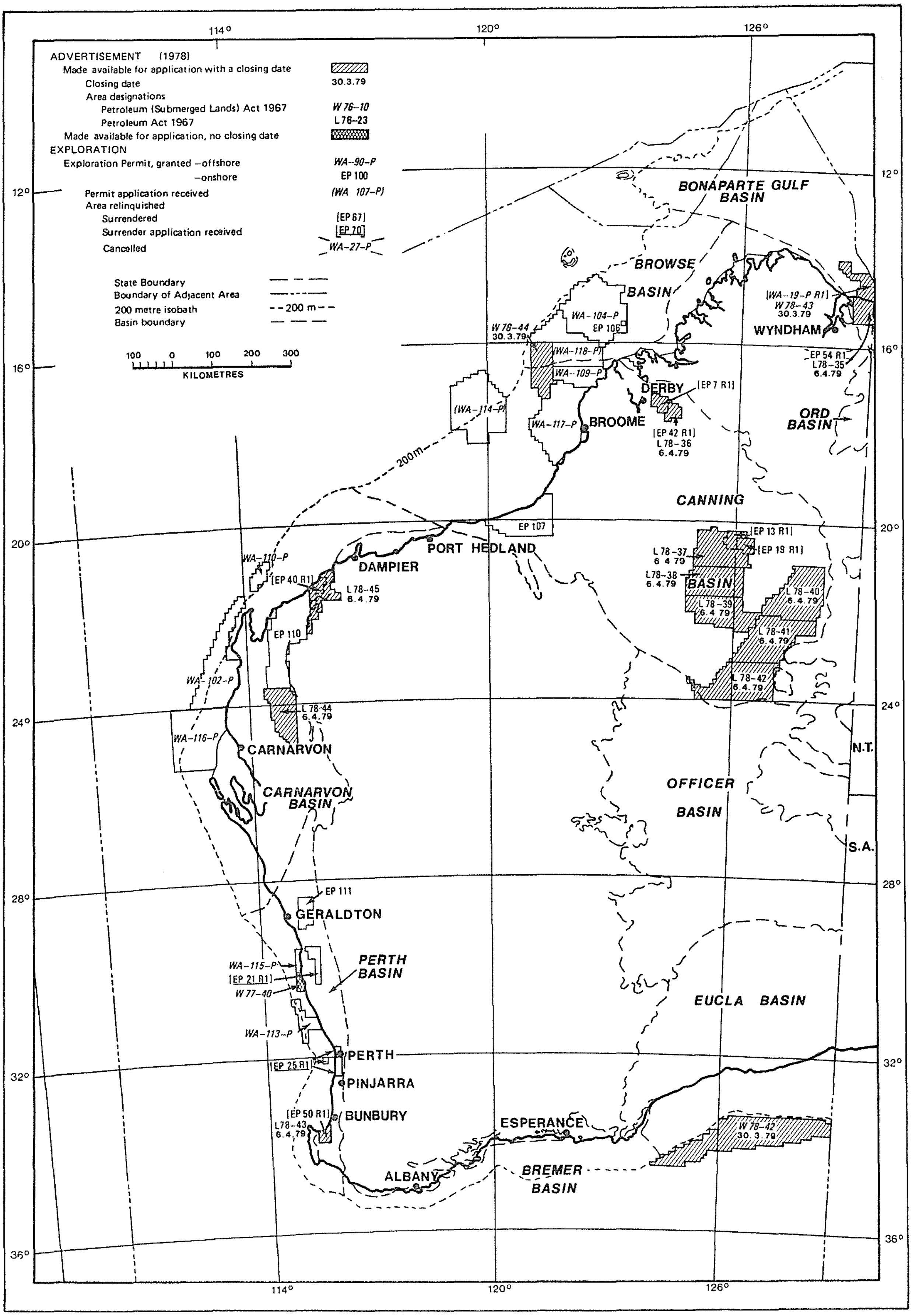

Figure 2 Petroleum Tenement dealings during 1978.

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TABLE IV

SUMMARY COMPARISON OF EXPLORATION PERMIT DEALINGS

(1977–1978)

	1977		1978	
	No.	Area (km²)	No.	Area (km²)
Areas Advertised—				
Onshore	12	130 900	11	106 120
Offshore	30	596 690	4	37 450
Totals	42	727 590	15	143 570
Permits Granted—				
Onshore	8	89 450	4	30 805
Offshore	16	345 830	8	90 460
Totals	24	435 280	12	121 265
Permit Applications (pending at year end)—				
Onshore	3	11 820	0	....
Offshore	7	63 050	2	33 730
Totals	10	74 870	2	33 730
Permits Held (at year end)				
Onshore	34	156 220	31	173 540
Offshore	35	548 490	41	614 280
Totals	69	704 710	72	787 820
Permits Surrendered—				
Onshore	2	380	6	9 600
Offshore	3	27 630	1	4 060
Totals	5	28 010	7	13 660

Tenement Activity Onshore (Figure 2, Table III and IV)

Five applications for permits to explore onshore areas were received in 1978. Four permits totalling an area of 30 805 square kilometres were granted. There was one cancellation, one refusal and six areas totalling 9 600 square kilometres were surrendered. In the latter part of the year eleven areas totalling 106 120 square kilometres were advertised inviting applications for exploration permits.

At the end of the year, exploration companies held a total of 31 onshore permits which cover an area of 113 540 square kilometres. Figure 2 illustrates the tenement dealings during 1978 and Table III sets out the statistical details. A summary comparison of dealings in relation to exploration permits for 1977 and 1978 is shown in Table IV.

TABLE III

DEALINGS UNDER THE PETROLEUM ACT, 1967, DURING 1978

(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))					
L78–35	Bonaparte	8/12/78	6/4/79	47	3 880
L78–36	Canning	8/12/78	6/4/79	43	3 510
L78–37	Canning	8/12/78	6/4/79	166	13 315
L78–38	Canning	8/12/78	6/4/79	132	10 535
L78–39	Canning	8/12/78	6/4/79	141	11 195
L78–40	Canning	8/12/78	6/4/79	200	15 935
L78–41	Canning	8/12/78	6/4/79	200	15 825
L78–42	Canning	8/12/78	6/4/79	200	15 710
L78–43	Perth	8/12/78	6/4/79	18	1 285
L78–44	Carnarvon	8/12/78	6/4/79	118	9 200
L78–45	Carnarvon	8/12/78	6/4/79	72	5 730
			Total		106 120

(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–106	L77–34	Oberon	31/10/77	Browse	1	80	Granted	8/3/78
EP–107	L75–11	Era *et al*	4/11/77	Canning	146	11 740	Granted	1/7/78
EP–109	L77–34	Metro *et al*	11/11/77	Browse	1	80	Refused	27/2/78
EP–110	L76–31	Samantha *et al*	22/5/78	Carnar-von	200	15 830	Granted	4/8/78
EP–111	Part L76–21	Jervois Sulphates	11/7/78	Perth	42	3 155	Granted	22/10/78

Note: For the full names of all registered holders or applicants refer Table I.

(c) EXPLORATION PERMIT SURRENDERS (SECTION 98)

Permit Number	Basin	Permittee	Date Surrender	No. of Blocks		Area (km²)
				Original	Surrendered	
EP– 7 R1	Canning	WAPET	30/6/78	24	24	1 960
EP–13 R1	Canning	WAPET	30/6/78	23	23	1 845
EP–19 R1	Canning	WAPET	30/6/78	18	18	1 445
EP–21 R1	Perth	WAPET	Pending	32	32	2 380
EP–25 R1	Perth	WAPET	Pending	36	36	2 620
EP–40 R1	Carnarvon	WAPET	8/12/78	19	19	1 515
EP–42 R1	Canning	WAPET	30/6/78	19	19	1 550
EP–50 R1	Perth	WAPET	30/6/78	18	18	1 285

(d) PERMIT CANCELLATIONS (SECTION 99)

Permit Number	Permittee	Basin	Cancellation Date	No. of Blocks	Area (km²)
EP–54 R1	AOD (Alliance)	Bonaparte	12/5/78	47	3 880

PETROLEUM APPRAISAL AND DEVELOPMENT

Barrow Island Field (Table V, Figure 3)

(Operator—West Australian Petroleum Pty Limited)

West Australian Petroleum Pty Limited undertook an eight well programme of drilling on Barrow Island in 1978. The programme was designed to investigate the possible existence of small new oil accumulations and to further expand the Windalia reservoir secondary recovery project. Six of the eight wells were regarded as development wells (three Windalia infill wells and three Gearle Siltstone evaluation wells). Two were classed as New Pool Wildcats.

A T–32 rig was landed on the island in July and the three Windalia infill wells were drilled by early September. The reservoir sandstone was continuously cored in each well and the cores have been sent for special analysis. The results of these analyses will be used in future studies of the main producing horizon. Each of the infill wells was completed as a producer. The cumulative production and average daily production for each well to 31st December is as follows:—B-17A 22802 bbls (238 BOPD); B-23A 10208 bbls (170 BOPD); B-31A 9014 bbls (123 BOPD).

The three shallow wells F-14G, L-82G and L-44G were drilled to evaluate and test selected zones within the Upper Cretaceous Gearle Siltstone. Two of these L-82G and L-44G were completed as producers but F-14G was not fully evaluated due to operational problems. An additional well to the programme, B-17T was drilled to 76 m in order to test oil shows which were encountered while drilling B-17A through the shallow Tertiary sequence. As at the 31st December, B-17T was waiting on pump equipment. The cumulative production and average daily production for the two Gearle Siltstone producers to 31st December are as follows:— L-44G 2668 bbls (70 BOPD); L-82G 1745 bbls (32 BOPD).

Two new pool wildcats S-53 and L-51J were drilled to investigate the Windalia sands and the Upper Jurassic 6 700 ft sands respectively. S-53 was plugged and abandoned after failing to encounter any significant hydrocarbon in the Windalia sand. In L-51J the 6 700 ft sand was dry and at the year's end preparations were being made to test the 1 830 m or 6 000 ft sand.

Both the Ideco H-35 and the Cooper rigs were employed throughout the year on routine well servicing, well repairs and stimulations. Packers were installed in four injection wells to isolate casing leaks and a four inch casing was cemented in one Muderong producer, F-62M. Remedial casing cementation was effected in well L-54J so that the adjacent Windalia producer L-54 could be converted to injection. Conversion of more producing wells to injection is in abeyance pending results of simulated reservoir studies which are currently in progress.

The status of wells within the Barrow Island field as at the end of 1978 is shown in Table V. At the end of the year 504 of the wells were operating with respect to the "Windalia Sand Member" which is the principal reservoir on the island. The status of all wells on Barrow Island is shown on Figure 3.

Dongara, Mondarra and Yardarino Fields (Figure 4)

Dongara Field

(Operator—West Australian Petroleum Pty Limited)

The Dongara No. 8 oil well has remained on part time production throughout 1978 and continues to produce at a low gas-oil ratio and low water cut. Dongara oil well No. 14 failed to sustain natural flow when a production test was attempted. Swabbing to induce flow resulted in the recovery of formation water with only traces of oil.

An attempt to shut off water produced with the gas from the Dongara No. 4 gas well was not successful. The well is currently producing 0·6 MMCFD gas and 70 barrels per day of water from the main Dongara reservoir.

Yardarino No. 1 well was placed on production in October 1978. Production from this well is 2·3 MMCFD gas, 10 barrels per day oil and 11 barrels per day water. The average daily production of oil from Dongara during 1978 was 28·27 m^3.

The status of the wells is shown on Figure 4.

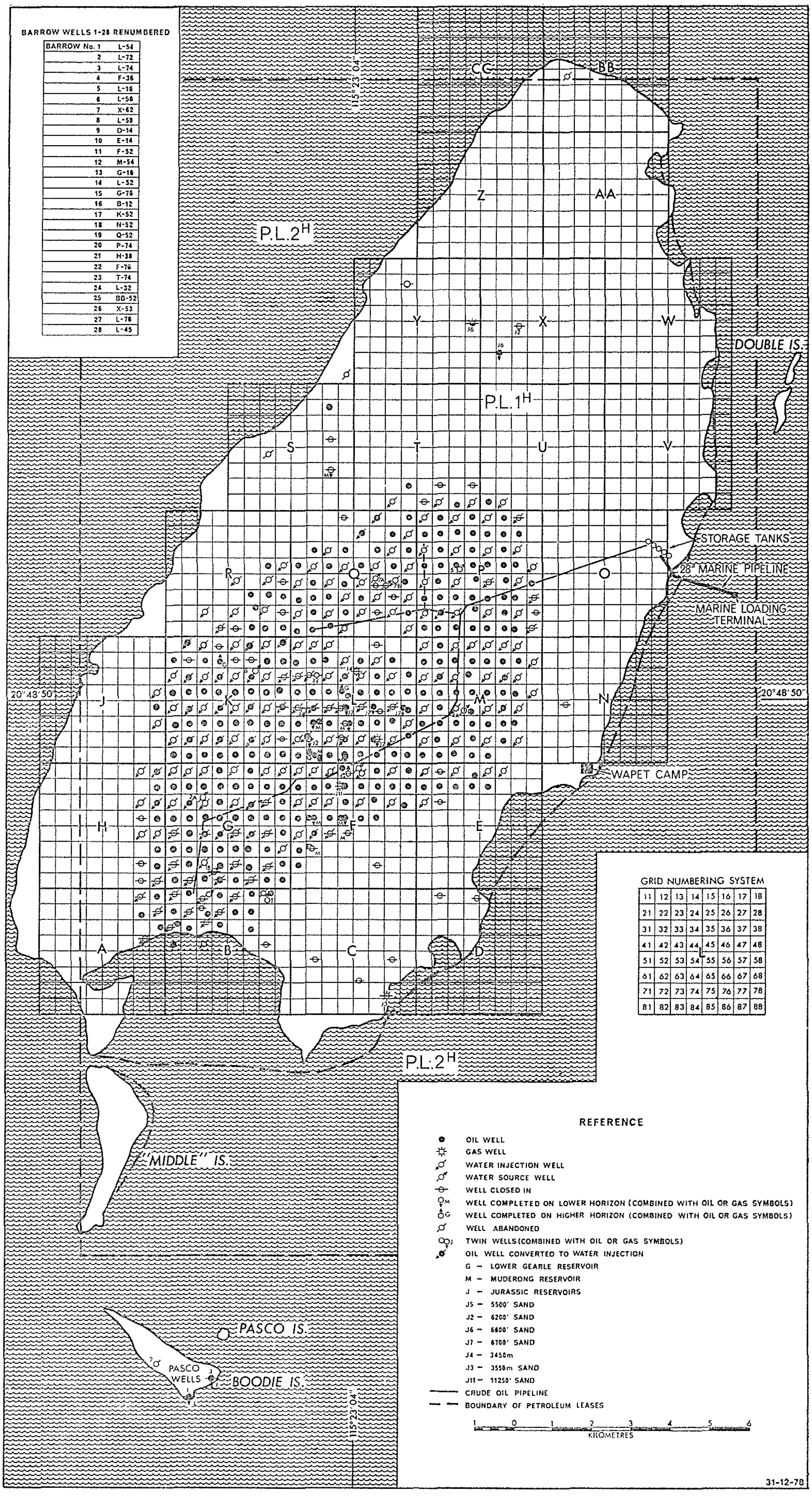


Figure 3 Barrow Island Field, northern Carnarvon Basin. Status of all wells on Barrow Island on 31st December, 1978.

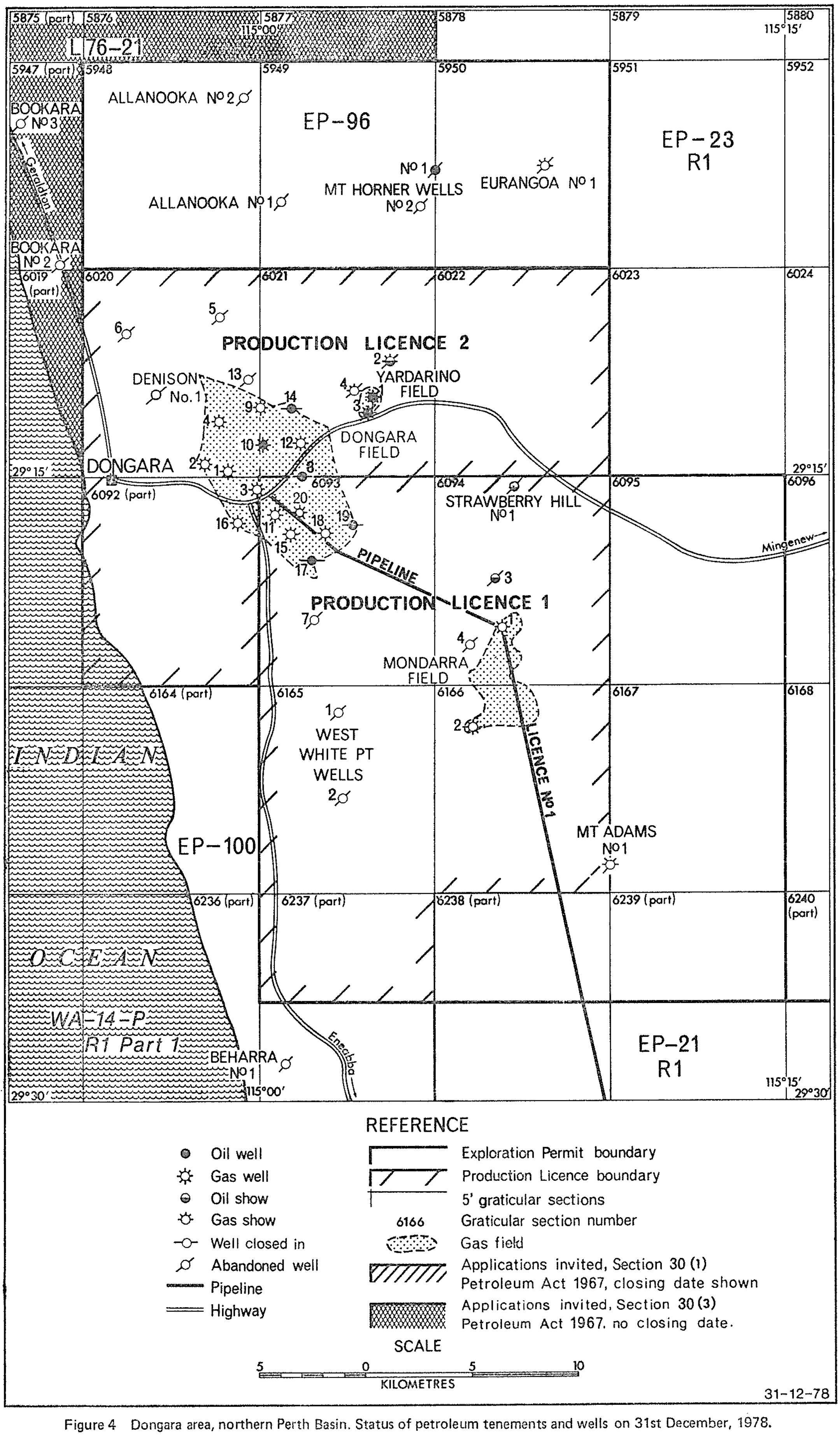


Figure 4 Dongara area, northern Perth Basin. Status of petroleum tenements and wells on 31st December, 1978.

TABLE V

BARROW ISLAND FIELD WELL STATUS BY RESERVOIRS AT 31st DECEMBER, 1978

Number of wells

Reservoir	Flowing	Pumping	Gas lift	Closed in	Water injection	Water source	Water disposal	Total
Lower Gearle	1	1	1	1	....	....	....	4
Windalia	1	179	78	*38	192	9	7	504
Muderong	....	3	2	3	....	....	....	8
Jurassic 5 500′	....	....	....	1	....	....	....	1
Jurassic 6 200′	....	....	....	†2	....	....	....	2
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	3	186	81	51	192	9	7	529

* Includes 1 radiolarite well; B-17, B-43, S-53 abandoned.
† L–32J abandoned.
‡ Whitlock No. 1.
§ Includes Biggada No. 1.

North Rankin Field (Figure 5)

(Operator—Woodside Petroleum Development Pty Ltd)

Reservoir evaluation continued throughout the year using all available data particularly the results of the North Rankin No. 5 core analyses and extensively reprocessed seismic data.

The platform areas from which such drilling would take place have been subjected to foundation and environmental investigations. Oceanographic and hydrographic studies were made along the proposed pipeline route from the platform areas into the Withnell Bay terminal area. (Figure 5) Withnell Bay has been selected as the preferred location for the onshore gas processing and liquefaction plants and for the LNG product loading terminal.

Goodwyn Field

(Operator—Woodside Petroleum Development Pty Ltd)

Further appraisal of the field was initiated by the spudding of Goodwyn No. 5 in the last quarter of 1978. At the end of the year the well was coring at 2 917 m as part of an extensive programme to evaluate the hydrocarbon potential of the Triassic sequences in this area.

PETROLEUM PRODUCTION

Barrow Island Field (Table VI and VII, Figure 6 and 7)

The total production and disposal of liquids and gas, produced from the various reservoirs during 1978 is shown in Table VI.

Of the associated gas produced with the crude oil, some 16 per cent was used as field fuel and the remainder flared after the 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. Production of oil from the Lower Gearle well K-24 continued throughout the year at an average rate of 49 barrels per day. Two additional Gearle wells were drilled and completed and brought onto production in the latter part of 1978.

A breakdown by reservoirs of the annual and cumulative production for the Barrow Island Field is given in Table VII and the average production of crude oil for each year from the start of production until the end of 1978 is shown in Figure 6. Figure 7 compares the cumulative water which has been injected into the Windalia sand against the cumulative oil and water produced from this reservoir. The volume of gas produced and the effect of pressuring the reservoir as a result of water injection have not been taken into account. The total royalty paid on Barrow Island sales during 1978 was $3 479 371 which is an increase of $1 441 528.54 over 1977.

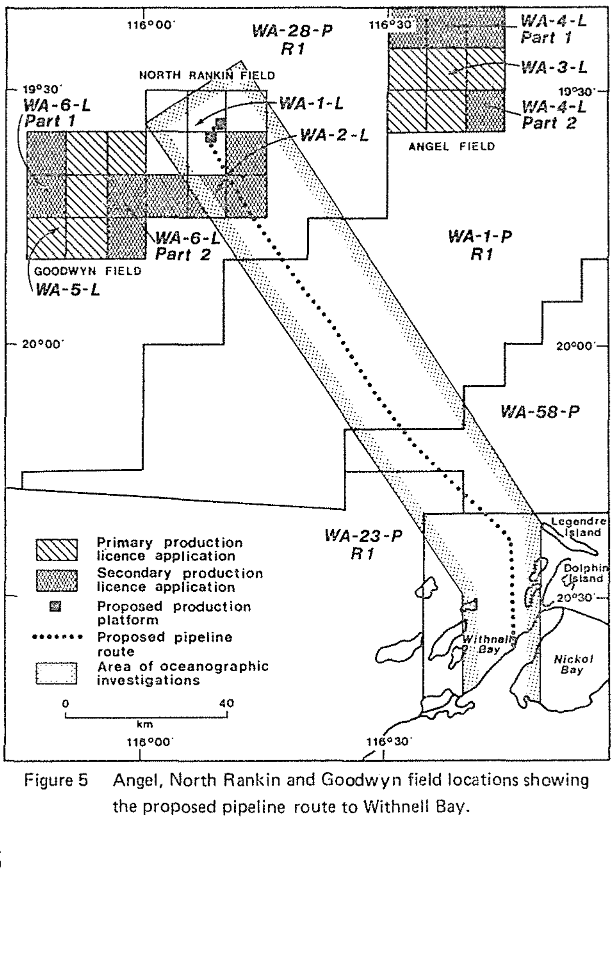


Figure 5 Angel, North Rankin and Goodwyn field locations showing the proposed pipeline route to Withnell Bay.

TABLE VI

BARROW ISLAND FIELD: PETROLEUM PRODUCTION DURING 1978

Reservoir	Production for year 1978					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	3 440 (21 637)			966	778 (4,891)	39 680 (249 577)			5 875	1 193 (7 501)
Windalia	1 740 436 (10 946 993)	5 186 (32 619)	4 657 (29 289)	93 517	884 979 (5 566 343)	23 683 943 (148 967 262)	(164 881)	(166 236)	2 053 578	6 803 618 (42 793 399)
Muderong	7 277 (45 771)			1 519	5 419 (34 087)	230 781 (1 451 566)			36 493	80 053 (503 515)
Jurassic 6 600′	1 734 (10 904)			252	5 419 (34 084)	76 963 (484 082)			23 965	153 474 (965 322)
Jurassic 6 700′	7 912 (49 765)			2 181	13 537 (85 143)	228 474 (1 437 055)			127 253	106 292 (668 555)
Jurassic 3 550 m						100* (629)			4 229	41 (255)
Jurassic 11 250′						731* (4 596)			26 662	282 (1 773)
Total	1 760 799 (11 075 070)	5 186 (32 619)	4 657 (29 289)	98 435	910 132 (5 724 548)	24 260 671 (152 594 767)	(164 881)	(166 236)	2 278 057	7 144 952 (44 940 320)
Cumulative totals for reservoirs which did not produce in 1978						12 009 *(75 534)			98 442	36 002 (226 447)
Cumulative grand totals						24 272 680 (152 670 301)	(164 881)	(166 236)	2 376 499	7 180 954 (45 166 767)

Water injected during 1978 = 4 860 679 m^3 (30 572 700 bbls). Cumulative water injected = 53 064 862 m^3 (333 767 370 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 liquefied petroleum gas are obtained by treatment of solution gas in the low temperature separation plant.

TABLE VII

BARROW ISLAND FIELD OIL AND GAS DISPOSAL DURING 1978

	Oil m^3 (bbls)	Natural gasoline m^3 (bbls)	Liquefied petroleum gas m^3 (bbls)	Gas 10^3m^3
Total Production	1 760 799 (11 075 070)	5 186 (32 619)	4 657 (29 289)	98 435
Field Fuel	....	....	†314 (1 977)	16 000
Sales	*1 809 848 (11 383 582)	....	3 793 (23 860)	....

Royalty paid on petroleum sales during 1978 = $A 3 479 370.54

* Oil sales include all natural gasoline produced and 4 752 bbls L.P.G.

† Vehicle fuel.

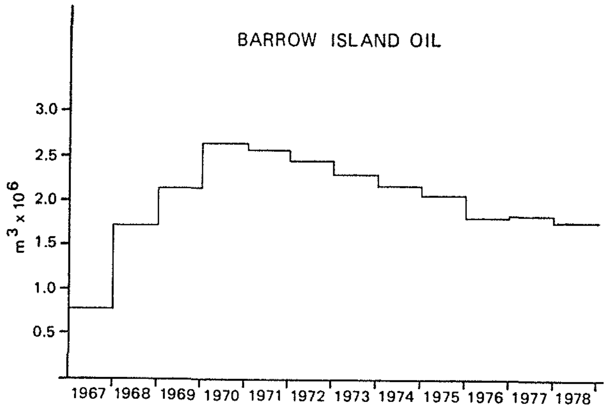


Figure 6 Barrow Island Field (Petroleum Lease 1H). Yearly production of crude oil from 1967 to 31st December, 1978.

Dongara, Mondarra and Yardarino Fields (Table VIII and Figure 8)

Table VIII shows the quantities of the various types of petroleum produced from the northern Perth Basin during 1978 together with the cumulative production since 1971. Yardarino No. 1 was brought into production in October, 1978.

Gas production from the three fields averaged 2 240 10^3m^3 per day. The yearly gas production from the northern Perth Basin between 25th October, 1971 and 31st December, 1978 is shown graphically on Figure 8. It is now estimated that approximately 40 per cent of the original in-place gas at Dongara and Mondarra has been produced.

The total royalty paid on petroleum production from the northern Perth Basin fields increased by $135 640.81 to $885 098.99.

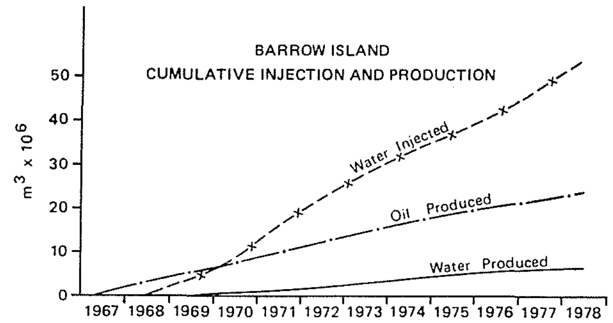


Figure 7 Barrow Island Field. Windalia Reservoir, cumulative production of oil and water and cumulative water injected from 1967 to 31st December, 1978.

TABLE VIII

DONGARA, MONDARRA AND YARDARINO FIELDS: PETROLEUM PRODUCTION DURING 1978

Field	Number of producing wells at 31/12/1978	Production for year 1978				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	16	760 062	2 633 (16 563)	10 182 (64 041)	5 571 (35 042)	(3) 5 155 841	24 211 (152 284)	38 084 (239 539)	27 809 (174 915)
Mondarra	1	52 777	342 (2 149)	0	750 (4 716)	402 675	5 764 (36 252)	0	2 996 (18 842)
Yardarino	1	4 587	0	135 (852)	115 (722)	4 587	0	135 (852)	115 (722)
Total	18	817 426	2 975 (18 712)	10 317 (64 893)	6 436 (40 480)	5 563 103	29 975 (188 366)	38 219 (240 391)	30 920 (194 479)

*Total royalties paid = $A885 098.99.
Total gas sold in 1978 = 806 865 m^3 x 10^3.
Total Condensate sold in 1978 = 3 070 m^3.
Total oil sold in 1978 = 10 208 m^3.

* Gas	861 611.28
Oil	18 455.36
Condensate	5 032.35
	$885 098.99

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.
3. Does not include 3 467 m^3 x 10^3 used in testing prior to production for commerce.
4. Volumetric figures rounded.

TABLE IX

IDENTIFIED PETROLEUM RESERVES (RECOVERABLE) 31st DECEMBER 1977

Field	OIL ($m^3 \times 10^6$)		GAS $C_1 + C_2$ ($m^3 \times 10^9$)		LPG $C_3 + C_4$ ($m^3 \times 10^6$)		CONDENSATE C_5 + in gas fields ($m^3 \times 10^6$)	
	P1	P2	P1	P2	P1	P2	P1	P2
PRODUCING FIELDS—								
Carnarvon Basin—								
Barrow Island	11·07	16·12	....	....	0·09	0·09	0·09	0·46
Perth Basin—								
Dongara	0·29	0·29	5·92	5·92	....	....	0·03	0·03
Mondarra	....	....	0·16	1·15	....	....	neg.	0·01
Yardarino	neg.	neg.	0·04	0·04	....	....	neg.	neg.
Totals	16·41		8·98		0·09		0·50	
UNDEVELOPED FIELDS—								
Carnarvon Basin—								
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
Totals	1·35		431·92		....		60·51	
Grand Totals	17·76		440·90		0·09		61·01	

P1 expectation >75%
P2 expectation >25%
* excludes 27% inerts

PETROLEUM RESERVES

The total recoverable petroleum reserves of the State are estimated to stand at $17 \cdot 76 \times 10^6$ m^3 crude oil, $61 \cdot 01 \times 10^6$ m^3 condensate and $440 \cdot 90 \times 10^9$ m^3 natural gas. There have been no significant additions to the estimated recoverable petroleum reserves during the year. Changes are due to actual production and minor revisions to previous estimates. Details of the reserves as at 31st December, 1978 are set out in Table IX.

PETROLEUM PIPELINES

Dongara to Pinjarra Natural Gas Pipeline

(Operator—West Australian Natural Gas Pty Ltd)

A total of 1 164 work proposals from Government Departments and Instrumentalities, and other parties, were processed during 1978. Four encroachments occurred on the West Australian Natural Gas Pty Ltd Dongara to Pinjarra high pressure natural gas pipeline, two of these being in the Kwinana area south of Fremantle, and two in open country north of Gingin. Damage to the pipeline resulted from two of these encroachments.

Minor damage to the pipeline in the Fremantle area was caused by unauthorised back-hoe excavations during the construction of concrete foundation supports of an above-ground fly-ash line from the Kwinana Power Station. The damage was repaired with a high pressure high tensile split sleeve. On 13th May the pipeline was pierced by the corner of the blade of a Caterpillar D9 bulldozer while stockpiling material in a gravel pit some 46 km north of the town of Gingin. The empiercement burst the pipeline violently and resulted in a split 8 metres in length. Gas supplies to Industrial Customers in Perth were shut down for over 17 hours awaiting installation of a replacement section of pipeline. The driver of the bulldozer was blown about 30 metres clear of the rupture and suffered abrasions, lacerations, and minor fractures in the right hand.

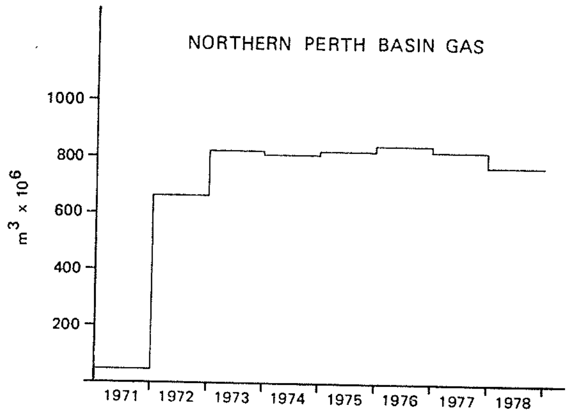


Figure 8 Northern Perth Basin. Yearly production of gas between 1971 and 31st December, 1978.

A comprehensive investigation into the problem of recurring encroachments was undertaken by the Petroleum Branch as a result of the Gingin pipeline accident.

TABLE X

ACCIDENT STATISTICS RELATING TO THE PETROLEUM EXPLORATION, PRODUCTION AND PIPELINE INDUSTRY DURING 1978

PETROLEUM INDUSTRY CATEGORIES

NATURE OF INJURY	Drilling Activities: Onshore	Drilling Activities: Offshore	Barrow Island Oil-field	Dongara Gas-field	Natural Gas Transmission Pipeline	Totals
	NUMBER OF INJURIES					
Head	....	12	5	....	....	17
Eye	....	10	16	....	....	26
Trunk	3	20	10	....	1	34
Arm	1	13	11	....	....	25
Hand	4	22	23	1	1	51
Leg	3	20	12	....	....	35
Foot	3	11	4	....	....	18
Occupational diseases	....	2	....	....	....	2
Other injuries and shock	....	....	1	....	....	1

TABLE X—*continued*

ACCIDENT STATISTICS RELATING TO THE PETROLEUM EXPLORATION, PRODUCTION AND PIEPLINE INDUSTRY DURING 1978—*continued*

PETROLEUM INDUSTRY CATEGORIES—*continued*

	Drilling Activities		Barrow Island Oil-field	Dongara Gas-field	Natural Gas Trans-mission Pipeline	Totals
	Onshore	Offshore				
AGENCY OF INJURY	**NUMBER OF INJURIES**					
Machinery in operation	2	5	1	....	....	8
Vehicles	....	....	2	....	....	2
Tools-hand	....	4	7	....	....	11
Tools-power	....	6	1	....	....	7
Manual handling	4	20	13	....	1	38
Harmful contacts	....	5	22	....	....	27
Persons falling or striking	5	36	20	....	....	61
Objects flying or falling	3	26	15	1	1	46
Other	....	8	1	....	....	9
MAGNITUDE OF INJURY	**NUMBER OF ACCIDENTS**					
Minor	6	64	68	....	1	139
Serious	8	46	14	1	1	70
Fatal	....	....	....	....	....	....
TIME FACTOR	**EXPOSURE TIME AND TIME LOST**					
Thousands of manhours exposure	112 846	808 975	288 911	17 840	16 850	1 245 422
Manhours lost*	341	1 117	312	....	....	1 770

* A nominal 8 hour day is assumed.

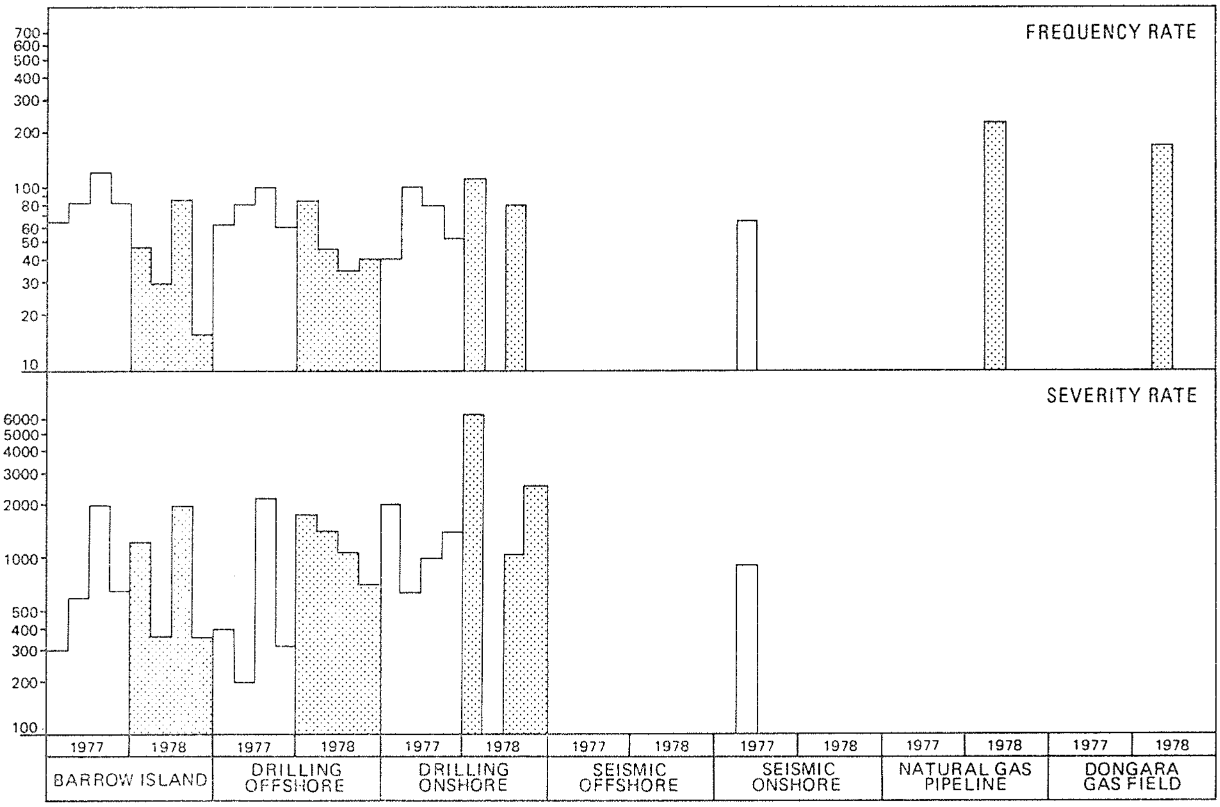


Figure 9 Serious injuries in the petroleum exploration and pipeline industry during 1977 and 1978. Frequency and severity rate.

STAFF

The staff of the Petroleum Branch during 1978 were as follows:—

A. J. Sharp—Director, Petroleum Branch (Level 6)

A. H. Pippet—Senior Petroleum Engineer (Level 5)

P. H. J. Hammett—Petroleum Engineer (Operations) (Level 4)

D. N. Smith—Production Geologist (Level 4)

S. P. Willmott—Reservoir Engineer (Level 4)

F. Kleinman—Typist/Receptionist (C–III–2)

DIVISION VI

Report of the Superintendent Surveys and Mapping for the Year 1978

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 December 31, 1978.

STAFF

The staff now totals 114 in addition to which there are 6 vacant items. Staff numbers comprise the following categories:

	Occupied	Attached	Vacant	Total
Professional	53	14	3	70
General	24	3	2	29
Technical	6	....	....	6
Clerical	11	....	1	12
Trainee	3	....	....	3
	97	17	6	120

The number of vacancies is causing concern. A full staff complement, especially of drafting officers, is essential in order to maintain a viable set of public plans and other associated documentation as well as to service the needs of other Divisions of the Department.

All of the Department's field survey needs were serviced by utilising private surveyors in accordance with long established procedures.

The decision, last year, by the Commonwealth Government to cease its long standing practice of assuming responsibility for the preparation and publishing of the 1:250 000 Geological Series necessitated a complete review of our capacity to accept the added work load of this activity both from the ability of the State to assume this expense and the Survey and Mapping Division's staff ceilings. The number of unpublished maps in the series stands at 8.

It was decided that several avenues be pursued during the year. In the first place one map would be prepared in this Branch for printing by the W.A. Government Printer—the drafting being done on an overtime basis—and four maps would be let on tender by the W.A. Government Printer. The four maps on tender were let in December to Mercury-Walch Pty. Ltd. of Hobart for a total price of $35 947. The other map was prepared by this Branch and is awaiting printing in the coming year.

State 150th Anniversary Celebrations.

In association with next year's celebrations, the Wiluna-Kimberley Stock Route Map was republished to be an historic contribution. The original map was published by the Mines Department in six sheets, black and white lithograph, to serve as a route guide to users of the Stock Route which has subsequently become known as the Canning Stock Route. In this edition the original repromat was used and was reduced in size to two sheets and embellished with photographs of the various parts of the expedition together with reproductions of some of the actual documentation as it appears on the Departmental files. Authenticity was retained on all occasions.

The map proved an instant success and the original printing run of 200 copies were sold out within a week. A new reprint was run. The public acceptance of this map proved a demand for unique historical type maps within the community generally.

SURVEY BRANCH

Field Surveys

Surveys of mining leases, claims and other tenements were carried out during 1978 by 27 licensed surveyors attached to 19 individual survey practices.

Survey work completed is summarised in the following table:—

Number of Surveyors	27
Number of tenements surveyed	1 259
Number of field books lodged	217
Total boundary line surveyed	2 891 km
Total area delineated by survey	122 153 ha
Distance travelled in positioning	62 540 km
Total value of cadastral survey	$570 897
Total value of connection (geodetic) survey	$52 466
Total value of project survey	$42 735
	$666 098

The work performed by individual Practitioners is itemised in the following table:—

Company	Surveyor(s)	No. of Surveys	Area surveyed (hectares)
Bernard McCarthy & Partners	J. Zuideveld	90	8 808
M. M. Fisher & Associates	E. J. Still .... M. M. Fisher	172	17 319
Markey, Campbell & Thomson Pty. Ltd.	T. L. Markey	22	1 879
D. F. V. Wilson	D. F. V. Wilson	112	12 556
McKimmie, Jamieson & Partners	G. S. Chignell	58	6 435
Ranieri, Bateman & Associates	J. S. Ranieri .... G. G. Bateman	113	10 878
K. R. Maguire	K. R. Maguire	65	5 624
D. J. McGay....	D. J. McGay	121	8 742
F. R. Rodda	F. R. Rodda .... E. Silby	63	7 174
A. K. King & Co.	K. M. Edwards .... C. Parker	65	4 529
R. G. Agnew	R. G. Agnew	73	8 650
Hille & Thompson	M. W. Hatch	79	8 965
K. F. Paterson	K. F. Paterson .... R. G. Agnew	71	7 841
Benetti, Croghan & Associates	A. Kane	....	....
A. R. Williams	A. R. Williams .... R. G. Beardman	50	5 003
K. M. Edwards	K. M. Edwards	30	3 245
Byrne & Associates	C. Gulaptis	41	3 308
Associated Surveys Pty. Ltd.	M. L. Hawker .... R. A. Holland J. McMullen	22	1 171
G. C. Callaghan	G. C. Callaghan	8	....
Aerial Surveys Pty. Ltd.		....	....
I. M. Gordon	I. M. Gordon	4	26
Totals: 19	27	1 259	122 153

The survey of a total of 1 259 tenements is 196 less in number than last year with a significant reduction in length of boundary run and with a large increase in the amount of travelling involved. This reflects the requirement for surveys in the more remote areas and that applicants are being more selective in marking-off smaller areas.

All surveys undertaken have been done after carefully vetting that the tenancy is on a likely long term basis and that there is productive potential. With the curtailment of expenditure it has been necessary to restrict the field activity to that extent and this has necessitated a cut-back in the issue of instructions to the private survey practitioners who have the capacity to accept more work if it were to be forthcoming.

Project and Photogrammetric surveys

Instructions were issued for completion of the survey, by photogrammetric means, of the sections of mineral lease 248SA situated in the West Angela and Pannawonica areas.

An extensive area of mineral claims at Ellendale in the West Kimberley Goldfield was surveyed by photogrammetric means. This area is being actively explored for diamonds.

A survey of approximately 39 kilometres of the common boundary between mineral lease 1SA (Alcoa) and temporary reserve 6304H (Alwest) was completed at Boddington.

Connection Projects (field)

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.

	New Stations Established
Mooloo Downs	6
Spinaway	2
Cooke Creek	2
Laverton	4
Teutonic Well	9
Cue-Nannine	12
Marvel Loch	11

Co-Ordinate Traversing (Office)

	Area Covered North/South (km)	Area Covered East/West (km)	Total length of Traverse (km)	Total points co-ordinated
(a) Projects proceeding from 1977.				
Ravensthorpe	20	33	183	262
Meekatharra-Nannine	85	35	864	1 945
Wiluna	105	60	2 259	2 931
(b) New Projects in 1978.				
Eneabba	37	25	260	304
Laverton	137	96	1 751	1 871
Teutonic Well	72	13	340	351
			5 657	7 664

Field Inspection

The following areas were visited to inspect surveys or proposed survey operations to assess field conditions and to evaluate the particular requirements.

Cogla Downs—mineral claim surveys.

Ripon Hills—in association with the Lands Department to investigate the possibility of establishing control for manganese claims.

Ellendale—inspection of marking of photogrammetric survey for a group of mineral claims.

Barker Gorge—inspection of claims in this vicinity.

Pillara Springs—inspection of ground marking at this lead-zinc prospect.

Alice Downs—inspection of marking.

Sallay-Mallay—inspection of marking.

Kununurra—disputed quarry areas inspected.

Sorby Hills—inspection of ground marking on blacksoil plains.

Yandicoogina—inspection of controversial overpegging situation determined by the Departmental authorised surveyors.

Nullagine—inspection of surveys involving delineation of authorised tenements, Lands Department titles and encroaching mineral claims for diamonds.

Cooke Creek—inspection of surveys of groups of mineral claims and reconnaissance for survey control.

Quartz Circle—inspection of new survey and connection to original surveys and control.

Marvel Loch-Cheritons—reconnaissance for extension of control and check of terrain and vegetation for fee loading purposes.

The offices of the Mining Registrars at Mt. Magnet, Cue, Meekatharra, and Northampton were inspected by the Assistant Superintendent, Mr. Moore, and the Principal Registrar Mr. Christie. At the same time, together with the appropriate Mining Registrar, representative samples of the field survey were inspected at each centre.

To assist the officers concerned in developing the "Mindust" computer programme, the Mining operations at Karratha, Telfer, Port Hedland and Newman were visited.

Field Heighting GSWA

Elevations on bore hole sites for the Hydrological Branch were established in the Bunbury-Capel areas.

Standard Plans

The activity relating to co-ordinate traversing has resulted in the following new computer generated plots for plan production.

Project	Number at 1:50 000	Number at 1:5 000
Halls Creek-Angelo	3	....
Pannawonica	3	....
Eneabba	2	....
Kanowna/Bulong (plots only)	5	....
Kalgoorlie (plots only)	....	6

Computer Section

The resources of the computer section have been mainly absorbed in setting up the "Mindust" (Dust Sampling) system.

Other work has been:—

(a) Assistance with geodetic control and traversing calculations and adjustments.

(b) Production of control project guidelines for use by other staff.

(c) Development of programmes for storing traverse data and calculations on the PDP 11/40 computer.

(d) Training of staff in the usage of the computer facility.

(e) Conversion and implementation of computer programmes for use by the Geological Survey Division.

(f) Updating of the "Wells drilled for Petroleum" data file.

The scope of the Computer Section has been expanded by:—

(1) connection of a remote terminal at Mineral House to the Main Roads Department Cyber 172 computer.

(2) Provision of an extra line to the PDP 11/40 computer.

(3) Connection of a second visual display unit.

Use of the new terminal will increase when the "Mindust" programming is concluded.

Petroleum Activity

With the current policy of gazetting all areas available for application immediately they become available there has been an upsurge in Permit applications and interest generally has been sparked by developments on the North West Shelf.

This has required:—

(1) Preparation of technical descriptions for permit documents.

(2) Plans for the promotion of areas available for application with press releases in appropriate journals in Australia and Overseas.

(3) Continuous updating of the State Petroleum Map.

With the prospect of 25 tenement renewals in the next 18 months together with the need to show smaller permit areas after relinquishment, the existing Petroleum tenements Map of W.A. (M175—scale 1:4 000 000) has become inadequate. A replacement map has been designed and will be produced at a scale of 1:2 500 000. It is envisaged this plan will be suitable for use over the next decade.

Considerable time is now required to be expended in listing land reserves affected by new onshore permits, applications to drill wells, requests for seismic surveys and other associated matters.

Office Activity

The emphasis on office activity has changed from the issue of survey instructions, the monitoring of survey activity and the examination procedures to a long overdue production and upgrading of the standard plan system to bring it into line with modern practices and concepts. The emphasis is now directed to control survey and the production of integrated co-ordinate systems particularly over the more active mining areas.

The area of greatest activity has moved from the Eastern Goldfields area to the Kimberley and West Kimberley areas where survey is more expensive.

The statewide activities covered by the Survey Branch are shown on the figure 1.

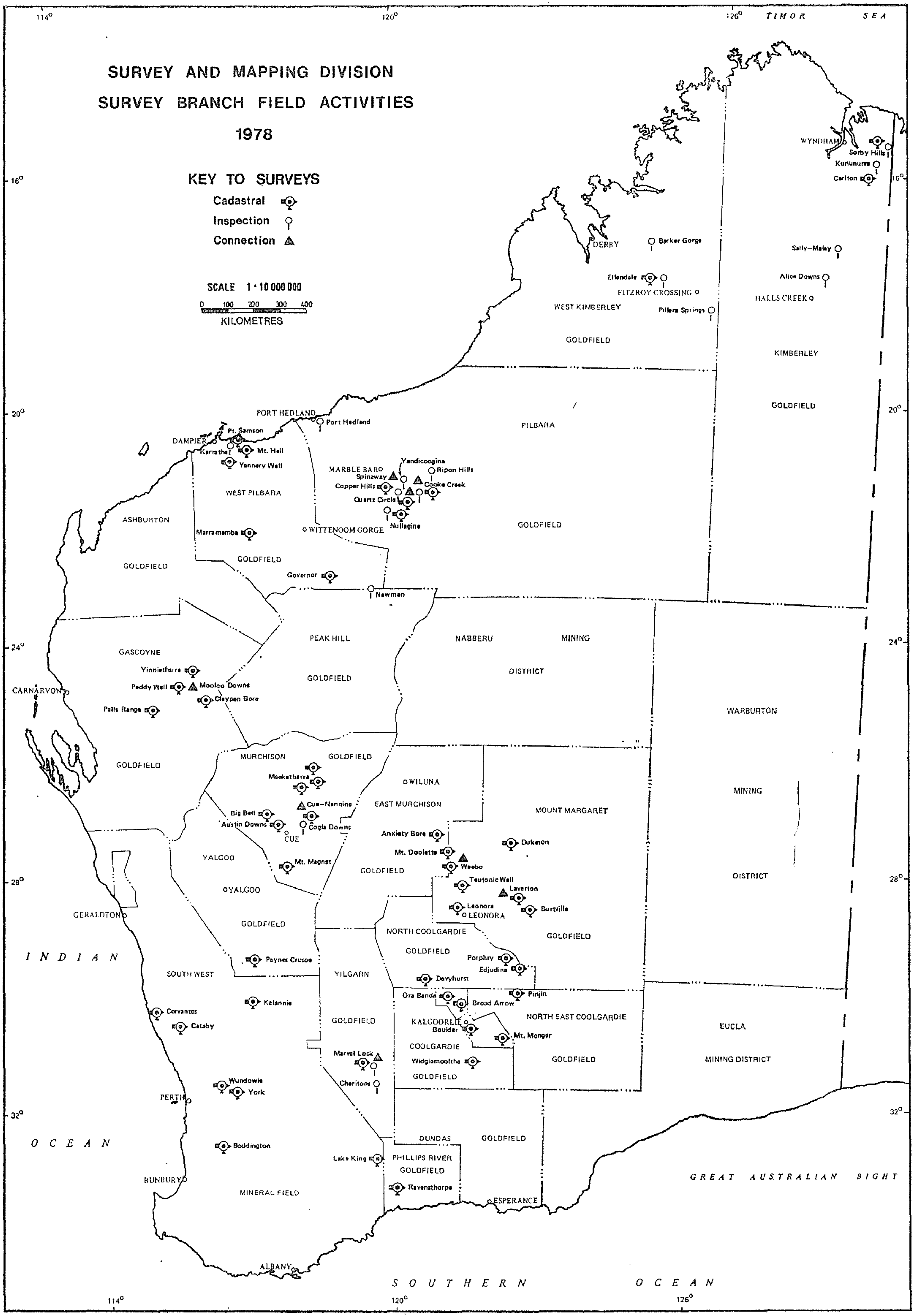

SURVEY AND MAPPING DIVISION
SURVEY BRANCH FIELD ACTIVITIES
1978
KEY TO SURVEYS
Cadastral
Inspection
Connection
SCALE 1 : 10 000 000
KILOMETRES
TIMOR SEA
INDIAN OCEAN
SOUTHERN OCEAN
GREAT AUSTRALIAN BIGHT
WEST KIMBERLEY GOLDFIELD
KIMBERLEY GOLDFIELD
PILBARA GOLDFIELD
WEST PILBARA GOLDFIELD
ASHBURTON GOLDFIELD
GASCOYNE GOLDFIELD
PEAK HILL GOLDFIELD
NABBERU MINING DISTRICT
WARBURTON MINING DISTRICT
MURCHISON GOLDFIELD
EAST MURCHISON GOLDFIELD
MOUNT MARGARET GOLDFIELD
YALGOO GOLDFIELD
NORTH COOLGARDIE GOLDFIELD
YILGARN GOLDFIELD
NORTH EAST COOLGARDIE GOLDFIELD
COOLGARDIE GOLDFIELD
EUCLA MINING DISTRICT
SOUTH WEST MINERAL FIELD
DUNDAS GOLDFIELD
PHILLIPS RIVER GOLDFIELD
WYNDHAM
Sorby Hills
Kununurra
Carlton
DERBY
Barker Gorge
Ellendale
FITZROY CROSSING
Pillara Springs
Sally-Malay
Alice Downs
HALLS CREEK
PORT HEDLAND
Port Hedland
DAMPIER
Pt. Samson
Karratha
Mt. Hall
Yannery Well
MARBLE BAR
Yandicoogina
Ripon Hills
Spinaway
Copper Hills
Cooke Creek
Quartz Circle
Nullagine
Marramamba
WITTENOOM GORGE
Governor
Newman
Yinnietharra
Paddy Well
Mooloo Downs
Claypan Bore
Pells Range
CARNARVON
Meekatharra
WILUNA
Cue-Nannine
Big Bell
Austin Downs
Cogla Downs
CUE
Anxiety Bore
Mt. Doolette
Duketon
Weebo
Mt. Magnet
YALGOO
Teutonic Well
Laverton
Leonora
LEONORA
Burtville
GERALDTON
Paynes Crusoe
Porphry
Edjudina
Davyhurst
Pinjin
Ora Banda
Broad Arrow
KALGOORLIE
Boulder
Mt. Monger
Kalannie
Cervantes
Cataby
Marvel Lock
Widgiemooltha
Cheritons
Wundowie
York
PERTH
Boddington
Lake King
Ravensthorpe
ESPERANCE
BUNBURY
ALBANY

FIGURE 1

PUBLIC PLANS BRANCH

Applications

New applications for tenements were received and processed:—

Mineral Claims	9 193
Mineral Leases	22
Gold Mining Leases	695
Prospecting Areas	383
Licenses to Treat Tailings	123
Coal Mining Leases	129
Other Tenements	419
	10 964

Temporary Reserves

Iron	25
Gold	37
Coal	10
Other Minerals	428
	475

Plans

A full set of public plans at Perth and an appropriate set in each District Office were maintained and these carried all title dealings during the year. New plans at a scale of 1:100 000 to cater for the large number of applications in the West Kimberley as a result of the interest in diamond prospecting were prepared.

A steady interest by way of public enquiry and plan search was maintained at the public enquiry counter.

Plan sales totalled $14 395. Numbers of copies sold was made up of:—

Dyelines	8 318
Photocopies	5 161
Transparencies	199
Gold bearing area maps	195
State maps	231
Gazetteer	213
Mineral occurrence maps	207
Petroleum maps	925
Canning Stock Route maps	431
Temporary Reserve lists—iron	30
Temporary Reserve lists other minerals	45

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.

Public Plans	Current	Obsolete
1:1 000 000 index sheets	14	73
1:1 000 000 temporary reserve	14	36
1:1 000 000 petroleum	33	29
1:250 000 public plans	110	302
1:100 000 public plans	58	34
1:50 000 public plans	1 147	2 005
1:10 000 public plans	4	9
Lands old series (imperial)	188	803
Mines old series (miscellaneous)	22	460
Lands old series (TM)	14	181
Old index sheets	....	137
Petroleum map (M175)	1	62
	1 605	4 131
Standard Plans—		
Old projection (20 chains)	600	67
Transverse mercator	212	8
Australian map grid—		
1:50 000	146	
1:25 000	31	
1:10 000	12	
Provisional (all scales)	370	2
	1 371	77
Field Books—		
Cadastral surveys	5 453	
Survey Plans (OP's)		
Imperial	285	
Metric	352	
	637	
Survey Diagrams—		
Imperial	49 000	
Metric	5 900	
	54 900	

MAPPING BRANCH

Cadastral Mapping Section

Ten new map sheets at a scale of 1:100 000 were drawn on A.M.G. covering the Drysdale and Medusa Banks areas and 24 new sheets at 1:50 000 scale covering the Menzies 1:250 000 sheets were drawn.

The revision programme continued with a total of 219 sheets at 1:50 000 scale being updated covering the areas of Balfour Downs, part of Robertson, Wiluna, Sandstone, Sir Samuel, Duketon, Kirkalocka, Ninghan, Jackson and parts of Throssell and Rason. Six sheets at 1:100 000 were updated covering Noonkanbah (See figure 2).

Geological Mapping

1:250 000 series

A total of 24 sheets were in progress during the year, almost twice the number of the previous year and three times that of 1975. The figures were made up of 16 first edition sheets of Marble Bar, Nullagine, Perth, Mt. Egerton, Sir Samuel, Duketon, Bullen, Trainor, Pinjarra, Ningaloo-Yanrey, Onslow, Robinson Range, Kingston, Gunanya, Collier, Rudall and 8 preliminary editions of Nabberu, Wiluna, Stanley, Moora, Southern Cross, Perenjori, Mt. Phillips, Glengarry.

Due to the withdrawal of finance by the Federal Government for map printing and with no funds available from the State budget, only 1 first edition map, that of Laverton, was printed.

Other Mapping

Coloured maps for the Copper Bulletin were prepared and completed and the maps for the Meckering Bulletin were continued.

1:50 000 *Urban Geology series*

The coloured edition of Mandurah was printed during the year and seven other sheets were in progress, they being Pinjarra, Nickol Bay, Pt. Samson, Karratha, Dampier, Baynton and Roebourne. Preliminary editions of Karratha, Dampier, Nickol Bay, Pt. Samson, Baynton and Roebourne were also completed.

State Map

The Departments main State map and gazetteer was revised and brought near to completion for publication in 1979.

The State Geological map was also revised and prepared for publication as a 150th edition.

Geological Publications

A high standard of drafting was maintained for the many drawings required for the publication of Bulletins, Report Series, Records and Explanatory notes. The Copper Bulletin and Meckering Bulletin were brought to conclusion and work was continued on black and white figures of the Pilbara Bulletin. Other publications were prepared for the Government Chemical Laboratories and many drawings were done for 35 mm and overhead slides for lectures interstate and overseas.

Microfilm

The programme of Microfilming continued of the G.S.W.A. "S" series reports and "M" series reports. A total of 44 rolls of 35 mm film was prepared and duplicated. Sales of film continued at a steady rate.

Photographic Section

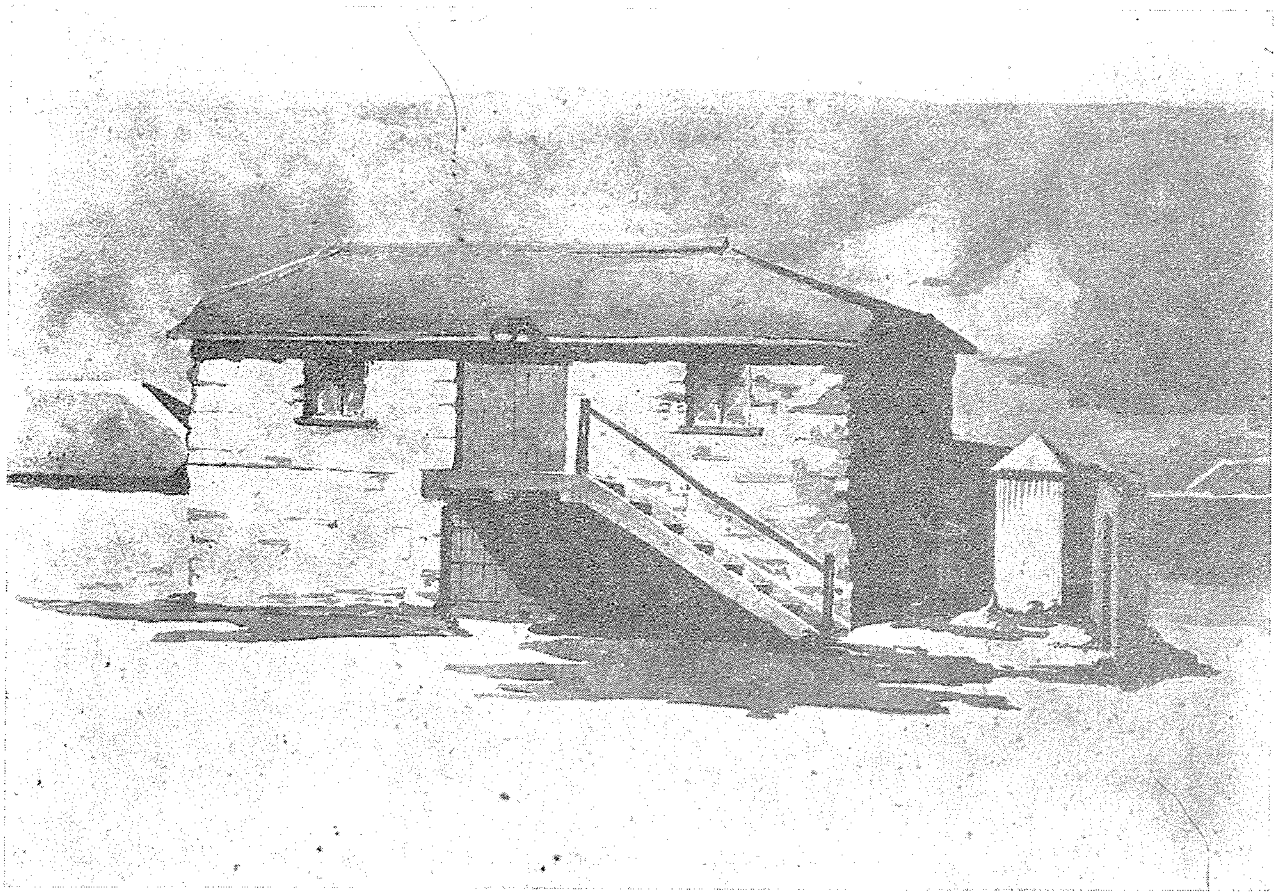
A very wide range of photographic processes and skills is employed in this section and overtime was often necessary to meet demands and to balance the staff situation. The process camera and printing down frames were in constant use producing over 4 000 separate items of work.

Colour printing was again a major item and a new colour print processor was purchased to assist with this work. Specialised prints including panoramas were produced for SME's Branch and Government Chemical Laboratories. Many coloured and black and white films were processed and printed and 35 mm coloured slides for lectures were again in demand.

Other specialised work included colour proofs of maps, colour masking, preparation of screen masters for map printing and printing from glass negatives.

The plan printing section also provided continued service to all Divisions and Branches and 32 000 prints were prepared, 900 plans were mounted with cloth, 900 plans were photocopied and over 600 booklets were bound,.

S. M. HOCKING,
Superintendent, Surveys and Mapping.



GOVERNMENT ANALYST'S LABORATORY
FREMANTLE 1896

GOVERNMENT ANALYSTS

1896-1921	E. A. MANN
1922-1939	E. S. SIMPSON
1939-1947	H. BOWLEY
1947-1955	H. P. ROWLEDGE
1955-1957	J. C. HOOD
1957-1973	L. W. SAMUEL
1973-	R. C. GORMAN

CONTENTS

DIVISION VII

Government Chemical Laboratories Annual Report—1978

UNDER SECRETARY FOR MINES

I present the 84th Annual Report on the operations and functions of the Government Chemical Laboratories for the calendar year 1978.

ADMINISTRATION

The Laboratories continued its functions with the Agricultural Chemistry, Food and Industrial Hygiene, Industrial Chemistry, Mineral, Forensic Chemistry and Water Divisions on the Plain Street site, the Engineering Chemistry Division at Bentley and the Kalgoorlie Metallurgical Laboratory at Kalgoorlie.

STAFF

Although additional staff including three temporary positions for the Australian Water Resources Council National Survey work were obtained this year, staff growth is sadly lacking behind the increasing requests on our services. Staff has increased by six in the five years since 1973 i.e. 4.4 per cent whereas samples received have increased by 75.0 percent in the same period.

The staff of the Laboratories including three temporary positions now consist of the following:

Professional Division	81
General Division	47
Clerical Division	12
Wages staff	2
Total	142

The contributions and support of all staff during 1978 are gratefully acknowledged.

ACCOMMODATION

The extensions for the Water Division were completed and occupied during the year. These as new buildings, are airconditioned and this only emphasises even more, the need for airconditioning of the remainder of the building.

Ministerial approval has been received for the re-building of the Kalgoorlie Metallurgical Laboratory in conjunction with the new metallurgical buildings of the School of Mines and the Technical Education Division of the Education Department. The old current weatherboard building is considerably sub-standard and is in the way of the proposed School of Mines extension. Re-building on the School of Mines campus will ensure continuing and close co-operation with the School of Mines, through certain shared facilities.

EQUIPMENT

The following items of major equipment were received during the year: Hewlett Packard mass-spectrograph gaschromatograph, Prototype and Technicon Autoanalysers, two Decwriter Visual Display Units, Shimadzu gaschromatograph, Varian 375 AB atomic absorption spectrophotometer, Taber abrader, MSE high speed centrifuge, Unicam auto-sample changer and auto cell, RK 611 Disk Drive and Controller, Varian atomic absorption indicating module, two Digital Decwriters, rhodium and iron X-ray target tubes and a Coleman mercury analyser.

HISTORICAL

On the occasion of the 150th Anniversary of the State it is appropriate that a review of the early history of the 84 years of the laboratory of the Government Analyst, should be included in my report of this year.

Although the first Annual Report of the Government Analyst was for the year 1896, there were analytical services within the colonial Government, primarily in assaying, prior to this. In 1891 Mr. B. H. Woodward was appointed as Curator of the Geological Museum and Government Assayer in the Mines Department. With the proclamation of the Explosives Act of 1895, Mr. E. A. Mann was brought from Melbourne in 1896 by Sir John Forrest to be Chief Inspector of Explosives and Government Analyst at the age of 22. Mr Mann was stationed in Fremantle and in the first few years was primarily concerned with administering the Explosives Act. The frontispiece of this report shows a painting of the first Government Analyst's laboratory in Fremantle.

For the years 1896-1901 Mr. Mann was responsible to the Colonial Secretary or Premier. During this time his laboratory was involved in work on criminal cases for the

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Police, customs work and general analytical work for Government Departments. The current concern over salinity in drinking water was foreshadowed by him in 1899, by his concern over the increasing salinity of Fremantle's water supply, which came from bores which he found were affected by the tide.

In 1902 the Explosives Act became the responsibility of the Minister for Mines, so Mr. Mann as Government Analyst and Chief Inspector of Explosives was transferred to the Mines Department. From then till 1922, there were two laboratories in the Mines Department, that of the Government Analyst and the much smaller one of the Government Mineralogist and Assayer. The staff of the Government Mineralogist in 1910 consisted of only one professional officer other than E. S. Simpson, the Government Mineralogist.

In 1904 because of increasing work on agricultural material, Mr. Mann became Government Analyst, Agricultural Chemist and Chief Inspector of Explosives and by 1905 his staff had grown to eight analysts.

The laboratory in Fremantle had become cramped and unsatisfactory and in 1906 was transferred to a building in Wellington Street, Perth, the site of the present Royal Perth Hospital boiler house.

In the annual report of that year, 1906, is the first mention of the laboratory of the Government Analyst being known as the Government Chemical Laboratory.

Work of the Laboratory increased and it is of interest to note that in 1907 they were working on the problem of acid rotting of superphosphate bags. Mr. Mann's suggestion of treating the hessian bags with red gum kino received world wide attention. History repeated itself in the late 1940s and early 1950s when the problem arose again, however the use of red gum kino was not then an economical proposition.

Another interesting comment is in the 1911 Annual Report when Mr. Mann opposed the opinion of visiting experts from London, on their suggestion of prevention of corrosion of the Goldfields Water Supply pipeline. The suggestion of de-aeration of the water which was implemented, was later abandoned as not suitable in practice.

The work on customs was eventually transferred to the Commonwealth Customs Department laboratory in 1915. In Queensland today customs work is still done in the State Government Chemical Laboratory for the Commonwealth, the only State where it still continues since Federation.

With the advent of the first world war, Mr. E. A. Mann became secretary of the State Munitions Committee and four of his staff were seconded to England for work on munitions production. These were Messrs Hill, Hoare, Hood and Malloch. The latter two distinguished themselves by showing great courage during a fire and explosion in a munitions factory and were awarded the O.B.E. because of their efforts.

After the war the laboratory continued to grow and in 1922 there was a major re-organisation. Mr. E. A. Mann who had played a leading role in the 1920 Civil Service strike was removed from his position as Government Analyst, after serving in that position for 27 years. He subsequently went into the Federal Parliament as the member for Perth, and later still, became widely known as the radio and newspaper commentator the Watchman. The laboratory of Government Analyst and Agricultural Chemist was amalgamated with the laboratory of the Government Mineralogist and Dr. E. S. Simpson who started in the Mines Department in 1897 became the Government Mineralogist, Analyst and Agricultural Chemist. The position of Inspector of Explosives was made a separate entity and was filled by the former Deputy Inspector of Explosives, Mr. Kirton. Three sections were formed in the combined laboratory, Toxicology, Foods and Drugs; Mineralogy, Mineral Technology and Geochemistry; and Agriculture, Water Supply and Sewerage.

At this time a committee was formed consisting of the Commissioner of Public Health, the Government Analyst and the Engineer Metropolitan Water Supply Department to investigate pollution of the Swan River. The laboratory's direct association with control of pollution of the river continued, through the Swan River Reference Committee and Swan River Conservation Board for 55 years, till 1977 when the Swan River Management Authority was formed relegating these Laboratories to a subsidiary role.

From 1922 to 1939 when Dr. Simpson died in office several weeks before retiring, the laboratory continued to grow in staff and status. Dr. Simpson himself became world renowned because of his work on the mineralogy of Western Australia. Dr. Simpson in 1925 was a foundation member of a committee of three, which became the Combined Water Purity Advisory Committee, which today still has the role of safeguarding the quality of water supply throughout the State. When the Australasian Association for Advancement of Science held its meeting in Perth for the first time in 1926, Dr. Simpson presented a paper on "The Problems of Water Supply in Western Australia", this has become a basic reference ever since.

It is again of interest to note during this period how history later repeats itself. In 1928 the laboratory was working on leaching of copper ore from Whim Creek, 50 years later in 1978 we were again working on leaching of copper ore from the same source.

Mr. Harry Bowley became the next Government Analyst in 1939 and he immediately started planning for a new building to be built on the present site, fronting Adelaide Terrace, Hay Street and Plain Street. The foundation stone of the new building was laid on 2 September, 1941 and in December, 1942 the new building was occupied as the Government Chemical Laboratories. Mr. Bowley was instrumental in forming a Soil Mineralogy Section for investigation of nutrient problems on certain soils. This section, however, was short lived as the principal officer involved Dr. Dorothy Carroll, left the State shortly after.

In 1947 with emphasis on post war industrial development, the Laboratories were reorganised with the foundation of two new Divisions, the Industrial Chemistry Division to assist industry and utilisation of local materials, and the Fuel Technology Division to investigate better utilisation of Collie coal and other fuels. With this reorganisation Mr. Bowley became Director in charge of five newly created Divisions, of which the Chiefs of only two, Messrs Hood and Rowledge, were appointed from within the Laboratories, to the Food and Drug and Toxicology Division and Mineral Division respectively. Dr. L. W. Samuel was appointed in charge of the Agriculture Water Supply and Forestry Division, Mr. A. Reid in charge of Industrial Chemistry Division and Mr. R. P. Donnelly in charge of the Fuel Technology Division. All these appointments were made in 1947, in which year Mr. Bowley himself retired and was replaced by Mr. H. P. Rowledge as Director.

Mr. H. P. Rowledge remained Director till 1955 when he retired. During this time further staff growth meant the establishment of an annex laboratory for sewage work at Smith Street, East Perth and a coal laboratory at Collie.

Mr. J. C. Hood was the next Director for the short period 1955 till May, 1957 when he died in office. Dr. L. W. Samuel became Director till he left to take accumulated leave in February, 1973 prior to retiring in November, 1973. During the 16 years that Dr. Samuel was Director there were several building extension programmes and increases in staff and functions. In 1960 the sewage work and staff were transferred to the Metropolitan Water Board in their new laboratory at Shenton Park. In the same year the Bureau of Research of the Department of Industrial Development at Bentley was transferred to the jurisdiction of the Laboratories and became the Engineering Chemistry Division under the control of Dr. Uusna.

With the retirement of Mr. R. P. Donnelly, Chief of the Fuel Technology Division in 1969, the Fuel Technology and Engineering Chemistry Divisions were amalgamated as the work on coal had diminished and their other functions overlapped to some extent. In the same year the Agriculture and Water Supply Division which had grown rapidly in numbers and work, was split into two separate Divisions, the Agricultural Chemistry Division and the Water Division. The Water Division occupied the remodeled old Fuel Technology Division building in 1971.

1971 also saw the incorporation of the Kalgoorlie Metallurgical Laboratory within the Government Chemical Laboratories. The Kalgoorlie Metallurgical Laboratory on the School of Mines campus was left as a separate entity of the Mines Department after the School of Mines became part of Western Australian Institute of Technology. The Kalgoorlie Metallurgical Laboratory which had become somewhat negelected in the meantime was built up again to its former staff numbers and the building and equipment were updated to service the goldmining industry.

During Dr. Samuel's period as Director there was an increased role played by the Laboratories in an advisory and consultative capacity in both statutory and ad hoc committee work. In his time as Director, the statutory role of the Laboratories was increased through the Poisons

TABLE 1

SOURCE AND ALLOCATION OF WORK—1978

Source	Agricultural Chemistry Division	Engineering Chemistry Division	Food and Industrial Hygiene Division	Forensic Chemistry Division	Industrial Chemistry Division	Kalgoorlie Metallurgical Laboratory	Mineral Division	Water Division	Total
STATE—									
Aboriginal Lands Trust	....	....	....	....	....	....	14	....	14
Agricultural Department	18 118	1	756	82	....	....	....	89	19 046
Albany Port Authority	....	....	1	....	....	....	....	28	29
Conservation & Environment	....	....	....	....	....	....	....	102	102
Consumer Affairs	1	1	11	....	13	....	2	....	28
Department of Corrections	....	....	....	56	....	....	....	....	56
Department of Industrial Development	....	....	8	2	....	....	....	199	209
Education Department	19	....	....	....	6	....	....	....	25
Fisheries & Wildlife Department	40	....	1 298	....	....	....	....	100	1 438
Geological Survey	4	3	....	....	....	....	1 143	440	1 590
Government Chemical Laboratories	24	55	25	55	25	....	241	60	485
Government Stores	....	....	59	....	1	....	....	....	60
Labour & Industry Department	....	....	172	....	....	....	5	....	177
Leschenault Inlet Management Authority	....	....	4	....	....	....	....	71	75
Main Roads Department	....	....	....	....	10	....	23	29	62
Metropolitan Water Board	....	2	35	2	2	....	24	1 471	1 536
Mines Department	....	....	122	....	....	6	543	7	678
Office of the North-West	1	22	....	....	5	....	....	....	28
Peel Inlet Management Authority	....	....	....	....	....	....	....	66	66
Police Department	....	....	27	2 189	....	26	57	....	2 299
Public Health Department	10	6	1 890	28	6	....	1 421	140	3 501
Public Works Department	10	2	234	....	39	....	25	3 857	4 167
Road Traffic Authority	....	....	....	1 297	....	....	10	....	1 307
State Energy Commission	....	....	20	....	5	....	12	....	37
State Housing Commission	....	....	....	....	2	....	6	4	12
Swan River Management Authority	....	....	....	....	....	....	....	288	288
Tender Board	....	1	....	....	201	....	....	....	202
Various Authorities	....	....	4	2	8	....	5	11	30
COMMONWEALTH—									
Various Departments	....	....	2	....	....	....	3	2	7
PUBLIC—									
Free	....	....	....	....	....	6	28	....	34
Pay	895	239	118	648	119	770	443	733	3 968
TOTAL	19 122	332	4 786	4 361	442	808	4 005	7 697	41 553

Advisory Committee, the Pesticide Advisory Committee, the Fluoridation of Water Advisory Committee and changes in the Road Traffic Act with respect to blood alcohol and Breathalyser sampling. With Dr. Samuel's retirement in 1973, Mr. R. C. Gorman became the current Director of the Laboratories.

Current: In the earlier years of the Government Analyst the only chemists in the State Government employed outside of these Laboratories were in the Railways Department. Currently there are chemists employed as such in nine other Government Departments or instrumentalities. However, these Laboratories still continue to provide the main bulk of analytical service and chemical advice to Government Departments. Having a body of chemists and ancillary staff together with a wide range of expertise provides economies in the ability to provide expensive equipment and use it to capacity. It also means that for problems requiring experience and expertise in a wide range of chemistry these are available to be brought directly to bear on current problems. This is illustrated within this report by work on Laporte effluent disposal, underground water, Cockburn Sound, Swan River, copper, vanadium and zirconium production, asbestos dust and other industrial hygiene and air pollution problems, advice on fertiliser usage, drug and other criminal work, together with other projects more fully detailed in the Divisional Reports which follow.

GENERAL

Our function in providing analytical, advisory and consultative services has continued unabated this year. There have been appreciable increases in the advisory and consultative work, particularly in relation to effluent disposal, ground water and river monitoring, hazardous chemicals and work for various committees.

Prime Minister Fraser's words 'that life was not meant to be easy' certainly applied to 1978. The continuing restrictions on staff growth, the very stringent financial restrictions for 1978/79 and the further increase of 12 percent in sample receivals makes a decrease in our efficiency almost inevitable. The time of turn around of work has increased and Departments are having to learn there is a long queuing time for results even in cases of some urgent work. Work for some Departments is having to be actively discouraged and in some cases refused for the first times ever.

In the last few years the limit on staff increases have been overcome to some extent by expenditure on automated equipment. As mentioned earlier, in the last five years there has been a 75 percent increase in work received but only a 4.4 percent increase in staff. This has been achieved only by increased efficiency through introduction of modern techniques and automation of equipment. Our current apparatus budget, however, has been severely cut and so affected by inflation in the cost of minor equipment that further significant improvement in instrumentation will cease without some financial relief.

The numbers of samples and source of work received in 1978 is given in Table 1. The summarised reports of Divisions which follow, again emphasise the variety, complexity and importance of the work done by the Laboratories.

R. C. GORMAN,
Director.

AGRICULTURAL CHEMISTRY DIVISION

GENERAL

The Division conducts chemical and physical examination of a variety of materials relating to applied agricultural research.

The year was notable for increased interest in work on soil properties related to Department of Agriculture investigations of fertility problems in the south west and Kimberley regions of the State and to soil tests for farmers to aid more economic use of fertilizers. There was a continued demand for chemical composition data of plants to assist in drawing conclusions from results of agronomic trials and effect on meat production, and involvement with revision of procedures for regulating quality of fertilizers and rapeseed. The Division also participated in a number of inter-laboratory collaborative studies of methods of analysis.

Changes in responsibilities of staff and upgrading of facilities introduced in 1977 were consolidated during 1978.

Accommodation

Interruptions to work patterns were experienced for the third year in succession because of renovations and maintenance of the building. It was frustrating that, because of lack of finance, these minor works were not co-ordinated with proposals, which reached sketch-plan stage, for major reconstruction of the older section of the Division including replacement of old fume cupboards no longer suitable for our work.

Air conditioning for rooms accommodating instrumental systems was not forthcoming and interfered with plans for automated analysis of soils.

Because of the dramatic increase in sample receivals in the last five years there is increasing pressure on the staff, accommodation, facilities and storage space of the section devoted to sample receival, identification, preparation and disposal.

Computer

The PDP 11/40 computer system is housed in the Division. It now consists of 96 K core memory, 26.4 M bytes disk storage, a nine-track magnetic tape and cassettes running under V3.1 of the RSX 11 M operating system. There are 13 terminals (including four in Mineral House) two plotters, a digitiser and an XRF spectrometer connected to the computer by DJ11 and DZ11 multiplexors. There are three auto analyser systems (eight channels), an amino acid analyser, a gas chromatograph and a spectrophotometer connected to a LPS11 multiplexed analogue to digital converter.

CONFERENCES, WORKSHOPS AND TALKS

The Division acted as joint host of a workshop on trace elements in marine tissues conducted in these Laboratories by arrangement with the then Department of Environment Housing and Community Development. The accent was on arsenic and selenium.

The regular programme of talks held in the Division continued.

Severe restrictions on funds and travel resulted in a complete lack of attendance at out of State conferences.

NATURE OF WORK

Table 2 shows the numbers, nature and sources of samples received. The total is 14 percent greater than the previous year, largely due to increased soil sampling of field trials studying leaching of fertilizers. There were increases in numbers of rice plants and pasture samples and decreases in wheat, lupin, clover, grapevine, citrus and apple leaf samples.

There was an improved output of work so that analysis of 22 275 samples was completed. This reduced the backlog from 8 158 at the beginning of the year to 5 005 at the end of 1978.

The contribution of the three Sections within the Division are reviewed briefly below.

PLANT SECTION

Automatic Analysis

Investigations were directed toward improvement of procedures for handling data produced by instrumental analysis.

Programming for on-line data collection from a four channel autoanalyser was completed and testing of the system against manual operation commenced. Except for the data logging programme which was written in MACRO assembly language, all programmes were written in FORTRAN. Correction for baseline drift is applied and a new calibration is calculated for each set of standard solutions. A quadratic function was found to give the best fit for standards.

A locally produced automatic sampler powered by compressed air was incorporated in the system to replace the original electrically driven unit. Problems of variable results appeared to be due to variation of the quantity of solution in the sampler tubes. Fitting constant hydraulic

TABLE 2

AGRICULTURAL CHEMISTRY DIVISION

	Agricultural Department	Departmental	Education Department	Fisheries & Wildlife	Pay	Public Health Department	Public Works Department	Other	Total
ANIMAL—									
Bones	151	....	....	5	....	....	....	....	156
Liver	90	1	....	....	....	....	....	....	91
Tissue	276	....	....	....	....	....	....	....	276
Various	25	....	....	....	....	....	....	....	25
CEREAL—									
Barley	291	....	....	....	3	....	....	....	294
Maize	80	....	....	....	1	....	....	....	81
Oats	323	....	....	....	9	....	....	....	332
Rice	702	....	....	....	....	....	....	....	702
Wheat	2 445	....	....	....	....	....	....	....	2 445
Various	40	....	....	....	....	....	....	....	40
FERTILIZER—									
Fertilizer	28	....	....	....	13	....	....	....	41
Fertilizer Act	94	....	....	....	....	....	....	....	94
Poultry manure	56	....	....	....	....	....	....	....	56
HORTICULTURE—									
Apple leaves	460	....	....	....	....	....	....	....	460
Cabbage leaves	17	....	....	....	....	....	....	....	17
Carrot	40	....	....	....	....	....	....	....	40
Citrus leaves	32	....	....	....	....	....	....	....	32
Grape leaves	23	....	....	....	....	....	....	....	23
Peach leaves	67	....	....	....	....	....	....	....	67
Plum leaves	10	....	....	....	....	....	....	....	10
Tomato leaves	152	....	....	....	....	....	....	....	152
Various	16	....	....	....	....	....	....	....	16
MISCELLANEOUS—									
Fish	....	....	....	35	....	....	....	....	35
Rapeseed	40	....	....	....	....	....	....	....	40
Sunflower seeds	44	....	....	....	....	....	....	....	44
Various	8	6	....	....	24	4	....	1	43
PASTURE & STOCKFOODS—									
Clover	143	....	....	....	....	....	....	....	143
Feedstuffs	171	....	13	....	31	....	....	....	215
Hay....	38	....	....	....	2	....	....	....	40
Lucerne	8	....	....	....	1	....	....	....	9
Legumes	117	....	....	....	....	....	....	....	117
Lupins	643	....	....	....	2	....	....	....	645
Mixed feed	24	....	....	....	....	....	....	....	24
Native vegetation	251	....	....	....	....	....	....	1	252
Pasture	989	....	....	....	1	....	....	....	990
Plant parts	58	....	....	....	....	....	....	....	58
Silage	32	....	....	....	1	....	....	....	33
Veterinary Preparations & Animal Feeding Stuffs Act	11	....	....	....	....	....	....	....	11
SOIL—									
Soil	10 123	17	6	....	807	6	10	4	10 973
TOTAL	18 118	24	19	40	895	10	10	6	19 122

head devices to reagent reservoirs and lowering the position of the sampler turntable in relation to the pump unit resolved the problem but further investigation of the effect is needed.

The sample digestion step and the operation times of the system were reviewed to ensure optimum throughput of samples when computer calculation of results replaces manual chart reading. Fine grinding of samples in a Tecator cyclone type mill solved the problem of sub-sampling for analysis reported last year.

Most of the plant samples (4 877 out of 6 864) dealt with by the Section were analysed for N and P (colorimetry) and K and Na flame photometry) on the above system. The use of a nitrous oxide-acetylene flame enabled Ca and Mg to be determined on the same sample digest solution (sulphuric acid) by atomic absorption. A separate digestion using nitric-perchloric acids was used for determination of Cu, Fe, Mn and Zn by atomic absorption.

Material analysed for all or selected elements using the above procedures included cereal grains and tops, pastures and fodder crops, and fruit and vegetable leaves. Much of the work was associated with continued investigations listed in the report on Soil Section.

Plant Material

Wheat grain and plant tops from nitrogen soil test trials provided a large part of the work. Some grain had unusually high levels of up to 25 percent crude protein (N x 6.25) a reflection of low yields caused by drought conditions.

Triacontanol treatment of wheat plants had no effect on nitrogen content or dry matter yield. This was contrary to overseas reports of outstanding responses to small quantities of the chemical.

Lupin plant parts were examined for the influence of manganese deficiency on split seededness and amino acids and nitrogen fractions in seeds and pods. Potassium uptake by lupins was monitored in several trials establishing optimum fertilizer rates and times of application. Plant uptake of rubidium applied as a tracer to follow potassium fertilizer behaviour was readily measured.

Rice plants and grain from trials at Kununurra were analysed for N, P and Zn to complement yield data. Zinc levels were unusually high in some cases.

Export shipments of barley and sorghum were checked for crude protein and tannin content respectively. Proximate analysis was carried out on a 1977/78 standard oat grain sample to assist the Grain Pool of W.A. in marketing.

Horticultural work included monitoring of nutrient levels in leaves of apple, citrus, stone fruits and vegetables. A trial with tomatoes tested the effect of various types of airborne dust on leaf levels of potassium and chloride and attempted to relate these to plant damage and yields. A series of tomato leaf samplings at progressive growth stages under glasshouse conditions established critical levels for 12 nutrients.

Feeding Stuffs

Pasture and stock foods were examined for feeding value mainly in terms of protein content and proximate analysis. Available lysine in experimental rations was checked against total lysine in a few samples but trouble with the method resulted in delays which have not been overcome.

Eleven samples were submitted under the Veterinary Preparations and Animal Feeding Stuffs Act. Six did not comply with the guaranteed composition. Three samples were deficient in crude protein and four were deficient in phosphorus.

Crayfish meal prepared by a process new to W.A. was analysed in detail. The main defect was an exceptionally high salt content.

Mincemeat

Three hundred samples of beef mincemeat were examined for moisture, fat and ash content in connection with carcase evaluation trials aimed at proving a rapid physical method for estimation of carcase fat.

Fertilizers and Manures

A total of 193 Certificates of Analysis were issued for samples received under the Fertilisers Act 1928, 99 of these being for samples outstanding from 1977. Deficiencies were found in 72 (37 percent) of the cases and were mainly due to shortages of N in mixed fertilizers.

Regulations to the new Fertilizer Act 1977 were introduced in November 1978 by the Department of Agriculture. Recommendations for suitable methods of analysis of fertilizers and suggestions for alterations to the allowed limits of deviation from guaranteed composition were made at the drafting stage of the Regulations. Analytical and preparative procedures used in the Division were critically reviewed. No samples were received under the new Act since it was not introduced until November 1978.

Examination of copper and zinc distribution in a superphosphate-trace element mix showed even distribution over three sizes of particles, less than 1 mm, 1 to 3 mm and greater than 3 mm. However, in the fraction greater than 3 mm individual granules contained between 0.2 and 1.7 percent Cu and 0.1 to 0.6 percent Zn.

Poultry manure checked for moisture confirmed that feeding lupins to broilers raises the moisture content of droppings. Other fertilizers were checked to verify whether composition was true to label.

SOIL SECTION

The group again had a busy year in which samples receival was 47 percent more than in 1977. Reports on 12 860 samples were completed.

Farmers submitted 807 samples for tests to help with estimating fertilizer requirements. The time between receipt of sample and issue of results was maintained between one or two weeks. Three thousand samples came from a series of new Department of Agriculture trials to study sulphur deficiency of W.A. soils. A trial comparing the effectiveness of sulphur coated urea as a slow release N source, involved weekly measurements of urea, ammonia and nitrate.

Other work dealt with continued investigations including:

(1) NH_4 and NO_3 for effects of reduced tillage on mineralisation of soil nitrogen.
(2) P extracted by 0.5M $NaHCO_3$ for short term and residual effects of different sources of phosphate fertilizer.
(3) K extracted by 0.1M HCl for leaching of potassium fertilizer.
(4) Total N, organic carbon and extractable P and K for losses of nutrients from poultry manure applied to sandy soil under irrigation.
(5) Total N, NH_4, NO_3, extractable P (0.5M $NaHCO_3$ or 0.005M H_2SO_4), organic carbon and Zn extracted by $(NH_4)_2CO_3$-EDTA for monitoring N, P and Zn status of Kununurra soils growing rice, sugar cane, fodder crops and peanuts.
(6) Cu extracted by 0.2M $(NH_4)_2C_2O_4$, 0.05M EDTA, 0.1M HCl for measuring "available" copper in soils from pot trials.
(7) Total N, NH_4, NO_3, incubatable N and cation exchange capacity for following changes in nitrogen status and overall fertility produced by legumes and pastures grown in rotation with cereals.
(8) Total N and P extracted by 0.5M $NaHCO_3$ in top-soil fractions removed by mechanical means to quantify fertility loss caused by wind erosion.

Diagnostic work included:

(1) P extracted by 0.5M $NaHCO_3$ for suspected P deficiency of citrus at Wiluna.
(2) NH_4 and NO_3 for suspected toxicity on lettuce in market gardens at Wanneroo.
(3) Cd, Cu, Hg, Pb, Zn for suspected hazards from soils near abandoned lead mines.
(4) P extracted by 0.5M $NaHCO_3$ and pH of basic slag used as earth fill.
(5) Soluble salts, sodium adsorption ratio and dispersiveness of soils for use in earth fill dams.
(6) Organic carbon, N and P for relating top soil fertility to distribution of different plant species in ecological studies.

Copper

Effects of incubation on availability of added Cu in a range of W.A. soils required the measurement of extremely small increments of copper of the order of 0.03 ppm in soil at which wheat plants in pots showed responses.

Soils were extracted with three extractants, 0.2M ammonium oxalate, 0.1M hydrochloric acid or 0.05M EDTA. The latter proved unsuitable because of colloid dispersion at the pH7 of the extractant. The HCl extractant removed variable proportions of copper and like ammonium oxalate was unsuitable for calcareous soils. Measurement of copper extracted by ammonium oxalate required a concentration step before using conventional atomic absorption spectrophotometry. Both plant and soil analysis showed evidence of reduced availability of copper following the incubation period of 60 days.

Soil Test for Nitrogen

Three hundred soils from the third and final year of trials in collaboration with Department of Agriculture aimed at finding a test to aid in determining N requirement of wheat were analysed for chemical and physical properties. Statistical evaluation of the combined results obtained over the three years of the programme for total N, organic carbon, Alkaline distillable N and incubatable N showed highly significant relationships between total N and the other parameters.

For top-soils 0-10 cm the regression equations obtained were:—

Y (organic carbon, percent) = 16.6X − 0.008
r = 0.89

Y (alkaline distillable N, ppm) = 456.5X + 7.1
r = 0.92

Y (incubatable N, ppm) = 164.2X + 4.6
r = 0.68 where X = total N, percent

For alkaline distillable N the regression obtained from the 1975 data was unaccountably and significantly different from the 1976 and 1977 regressions which were not significantly different. In deriving the equations, data for samples having greater than 0.2 percent total N were omitted because of poor reproducibility of alkali distillable N for a small proportion of samples in the range 0.2 to 0.3 percent total N.

While the correlation between alkaline distillable and total N values is excellent, the usefulness of the test as a rapid alternative to total N (Kjeldahl) is limited because (a) some soils gave poorly reproducible results especially those having about 0.3 percent N and (b) it is labour intensive and not adaptable to batch work. For these reasons attention was directed toward improving output of total N (Kjeldahl) determinations.

Total Nitrogen

Development of a semi-micro procedure was commenced employing electrically heated aluminium blocks of local manufacture for Kjeldahl digestion of 0.5 g samples and a colorimetric determination of ammonia. The current procedure uses digestion-distillation-titration of 10 g samples.

Organic Carbon

An inter-laboratory check with the Biological & Chemical Research Institute NSW showed good agreement between results for total carbon obtained using a Leco furnace and our procedure based on that of Mebius (1960) Anal. Chim. Acta 22, 120. Disadvantages of the Mebius procedure are that, because it involves a refluxing step, batch size is limited by equipment availabilty and laboratory space and in addition total carbon is not always the measurement preferred when dealing with soil organic matter. Because of this a modification of the Walkley & Black method is being investigated.

Sulphur

A three year programme was initiated to extend knowledge of requirements of pasture production of W.A. soils for P and S fertilizers as a result of increasing use of P fertilizers containing low levels of S. Rapid analysis was required for sulphate S extracted by 0.01M $Ca(H_2PO_4)_2$ on intensive samplings of trials designed to re-examine movement of fertilizer S in highly leaching situations.

An automated turbidimetric system based on that of Sinclair (1973) NZ J. Agric. Res. 16, 287 was shown to be an effective replacement for the labour intensive and temperamental colorimetric Johnson & Nishita procedure. Limit of detection was 2 ppm S with a precision of $\pm$ 1 ppm S up to 20 ppm S in soil. This was adequate for following leaching of sulphate applied as gypsum.

It was demonstrated that, for seven different soils examined, air drying and storage of samples before analysis had no measurable effect on results for sulphate S. A more sensitive procedure would be needed to follow changes in mineralisation of natural soil S at the low levels encountered in W.A. soils.

Autumn and spring samplings of the sulphur trials showed that sulphate S was leached from the root zone within 3 to 5 weeks after application of the fertilizer.

Further, it was shown that the use of granulated gypsum introduced sub-sampling difficulties for top-soils which gave poor reproducibility of results even if 30 g sub-samples were used for extraction. Grinding of the samples removed the problem but is undesirable for S mineralisation studies and impractical for samples requiring analysis immediately on receipt.

Sulphur Coated Urea

Similar difficulties were experienced in determining urea in top-soils where sulphur coated urea was applied broadcast. In trials at Lancelin testing the effectiveness of two grades of S coated urea as slow release N fertilizers, the levels of ammonia and nitrate in treated plots fell to those in the control (nil treatment) plots within 3 to 5 weeks after application of the fertilizers and remained at that level for the duration of sampling. At the end of the trial urea was detected in 4 out of 12 plots treated with S coated urea.

Kununurra Soils

High levels of zinc extracted from Kununurra soils indicated heavy dressings of zinc fertilizer. Levels in "nil treatment" plots were about 10 times higher than normal Kununurra clay soils and above the level likely to give responses of rice to zinc.

P status of some soils on the Ord region did not appear to be measured by extraction with 0.5M $NaHCO_3$. Extraction with 0.005M H_2SO_4 was introduced as an additional test.

Soils from the Weaber Plains were evaluated for irrigation potential.

Cobalt

Five soils from the Denmark district, all of which were supposed to be Co sufficient for animal health, had from 0.01 to 0.35 ppm Co extractable in 2.5 percent acetic acid. All except one was below 0.25 ppm regarded as deficient by Canadian standards.

Erosion

In addition to established trials of the Department of Agriculture studying wind erosion, several samples were examined to attempt to quantify fertility losses in terms of N and P due to removal of top-soil by cyclone Alby. At Katanning soil from "heaped up" areas near obstructions contained twice as much P and K as soil from areas depleted by the cyclone.

Ecological

Soils from the Ashburton catchment area were analysed for total soluble salts, N and P to define habitats of various plants found through the catchment and top-soils from Eneabba district were analysed for organic carbon in an attempt to relate soil fertility to the distribution of native plant species.

Reduced Tillage

A less intensive sampling programme than in previous years was due in part to abandonment of some trial sites because of effects of cyclone Alby.

At Mt. Barker no differences between tillage systems, in levels of ammonia and nitrate, were observed. At Avondale nitrate levels in "spray seed" treated plots were slightly higher than other reduced tillage treatments and were lowest for conventional cultivation. Changes in ammonia levels were less evident. Conversely, at Wongan Hills conventional cultivation (low ammonia, high nitrate) appeared to have stimulated mineralisation of N compared with minimum tillage (high ammonia, low nitrate) and similar effects were observed at Merredin. Esperance trials showed no discernible trends.

Take-all Disease

Ammonia and nitrate in top-soils were monitored to assist in interpretation of observed suppression of disease incidence by ammonium fertilizers.

TRACE AND ENVIRONMENT SECTION

The section was involved in several investigations, some of which related to work of other sections, for example development of methods for automatic analysis of soils, major modifications to the automated analysis of plants and amino acid composition of feedstuffs.

Other major activities embraced measurement of low levels of Cu in small samples of wheat plants, rapid analysis of erucic acid in rape seed oil, fluoride determinations in various materials and provision of a diagnostic service for trace elements in plant and animal tissue for Department of Agriculture. Results obtained using a method for low levels of extractable Co in soils are reported under Soil Section.

Fluoride

The Section has expertise in analysis and function of fluoride in matters of animal health and environmental problems.

Limesand used in scrubbing devices intended to trap fluoride emissions from brick making kilns had higher levels of fluoride in fine particles than in coarser fractions. A proposal to beneficiate the sand by elutriation of the fines to improve fluoride absorbing efficiency did not appear worthwhile because of the relatively small proportion of emissions trapped in the fine fraction.

Grapevine leaves sampled by Department of Agriculture from areas adjacent to brickworks showed gradual accumulation of fluoride, as in previous years. The use of 3.2M nitric acid as extractant for fluoride in vine leaf has been shown to be quantitative. This procedure gives considerable saving in time and effort.

Clays from Greenbushes area intended for brick making contained 100 to 420 ppm F.

Fluorosis

Fluorosis (Annual Report 1976) in laboratory animals has occurred once again. The animals affected were mice and the symptoms were ill thrift and mortality of weanling mice, with decreasing fertility of the breeding stock. The fluoride content of bones from very young mice in affected litters was three to four times that of healthy animals. The monitoring of fluoride levels in prepared feeds is required to protect these valuable animals.

Woilies

Woilies *(Bettongia Penicillata)* are native marsupial animals with the ability to detoxify fluoracetate (1080)—the toxin present in indigenous gastrolobium and oxylobium species. Analysis of bones from collected specimens of these animals showed low levels of fluoride indicating either lack of exposure to fluoracetate or a different mechanism of detoxification compared to other marsupial species. Further work in conjunction with the Department of Fisheries and Wildlife may help to elucidate the anomaly.

Feed Additives

Bones from a study of the effects on pigs of different sources of fluoride in the diet showed that sodium fluoride and rock phosphate additives gave levels of F in the skeleton which were about two or three times higher than in animals fed calcium fluoride and that Mg levels in the bones increased as F levels increased. Teeth, muscle, liver, kidney, spleen and testes from a previous trial were analysed. Tissues did not store fluoride.

Feed mixes containing Christmas Island rock phosphate were analysed for fluoride content. The results obtained revealed that the additive was not being evenly mixed throughout the ration. Sampling from various points within the mixer showed that it was concentrated in certain areas. Further work by the Department of Agriculture is needed to resolve this problem as it may well apply to the incorporation of other additives in low (ppm) concentrations.

Copper in Wheat

Pot trials, conducted by the Department of Agriculture and University of W.A. have indicated that the copper level in the youngest fully emerged leaf can be utilised as a diagnostic test. This establishes the copper status of the wheat plant early in the growth cycle allowing copper deficiency to be remedied. Analytical difficulties are encountered when very low copper levels are present or when small samples are available. It is necessary to concentrate the copper into a small volume to obtain satisfactory analysis.

A solvent extraction procedure based on ammonium pyrrolidine dithiocarbamate and n-butyl acetate was successfully applied. The use of micro techniques and atomic absorption spectroscopy (Annual Report 1977) allows sample (aqueous) solutions to be screened for copper content after digestion-solution. This is useful since it allows selection of those samples which require solvent extraction to concentrate the copper and indicates the volume of solvent necessary for optimum results. Precision of ± 8 percent was achieved at a concentration of 1 ppm Cu in leaf samples using this technique, which is of the same order as flameless atomic absorption using electrothermal atomisation.

Rape Seed Oil

The development by the Department of Agriculture of blackleg resistant, low erucic acid rapeseed *(Brassica napus* c.v. Wesreo) has reached the stage were seed is to be certified for sale to farmers. This necessitated the development of a rapid method for the analysis of erucic acid content. Considerable reduction of the analysis time has been achieved by expressing the seed oil using pressure, rather than the traditional solvent extraction process. Significant improvements have also been achieved in the gas chromatographic determination step. The method, including sample variation, has a precision of ± 6 percent at a level of 1 percent erucic acid in oil. The expression of oil from seed was applied to analysis of sunflower seed oil for linoleic acid.

Collaborative Interlaboratory Studies

The Section participated in analysis of bovine liver as part of a survey of trace element methods arranged by the Institute of Medical and Veterinary Science, Adelaide. Co, Cu, Fe, Mn, Mo, Se and Zn were determined.

As part of the workshop on trace elements in marine tissue mentioned above, determinations of Cu, Se and Zn were made on samples of fish, mussels and rock lobster. The workshop involved most members of the Section, who contributed to discussion groups and demonstrated selenium methodology to delegates from Eastern States Laboratories and other local organisations.

Results have been published (JAOAC (1977) 60, 1414) of an international study on selenium in which results of our spectrofluorimetric method, used as a reference, rated highly with other reference laboratories and were selected for inclusion in the final publication.

J. JAGO,
Chief Agricultural Chemistry Division.

ENGINEERING CHEMISTRY DIVISION

The present day Engineering Chemistry Division continues to carry out the functions of its predecessors—the former Bureau of Research and Development of the Department of Industrial Development and the lesser ancestor in the Fuel Technology Division of these Laboratories.

The main activities of the Division can be described under the generalised headings of mineral processing, extractive metallurgy, chemical engineering and fuel technology and these operational areas are consistent with those conceived for the parent groups.

The Division's activities are related to the recognition of the need for applied research and developmental testwork to encourage industrial expansion and efficient utilisation of natural resources and the main objectives of the Division can be summarised as follows:—

(1) To carry out testwork on request to assist companies and individuals to process and use the State's natural resources—especially minerals and fuels. Such work is carried out on a confidential basis and a fee is charged.

(2) To initiate research programmes and make appraisals on mineral processing themes to provide general information to benefit the subsequent development of WA's resources.

(3) To provide a technological advisory service to the Government and the Public on mineral processing and resource utilisation matters.

(4) To maintain a 'data bank' on the mineral processing industry and mineral commodity economics of the State.

(5) To appraise methods of encouraging utilisation and further processing of local minerals in wider applications in lieu of imported alternatives.

During 1978 a range of projects has been undertaken. Some have been allied to direct industrial application and others have contributed to flowsheet design, operational efficiency, quality control and general development aspects.

Some Departmentally backed studies have been carried out initially to assess process applicability and to provide background data. If subsequently commercial interest develops, the Division will be well placed to assist and involve in further and more specific testwork.

1978 INVESTIGATIONAL PROJECTS

The main effort was again directed to a limited number of projects each of which required extensive investigational work.

There was a continuing demand from industry for the undertaking of test programmes and generally these were afforded priority. However, progress was maintained on Departmental projects which were assessed to be pertinent to the processing of WA's natural resources and had potential for satisfying future needs.

CONTRACT INVESTIGATIONS

A range of sponsored test programmes was undertaken during the year but because of the need to preserve confidentiality only broad outlines can be given in this Report.

Copper Ores

A strengthening in demand for copper pushed world prices up during 1978 and generated renewed interest in the potential development of WA deposits. Two techniques for extraction of copper from low grade oxidised ores were examined on request during the year.

Vat Leaching

A pilot plant scale project which had begun in late 1977 was completed in the first half of 1978.

The objective of the investigation was to provide a simulated vat leaching system for sulphuric acid extraction of copper from low grade ore.

By arrangement, the Company erected on the Bentley site three 7 metre high PVC lined concrete leaching towers together with acid liquor storage, piping and control systems. Then the Engineering Chemistry Division assumed the responsibility for all operational aspects of the investigation.

The test programme enabled the confirmation of key economic factors such as copper extraction efficiency and acid consumption and provided data on operational variables such as preferred ore size, column flooding rate and off-liquor copper levels.

Thin Layer Leaching

This alternative method of extraction, which is being pioneered at commercial level in Chile, was investigated for its potential applicability to copper ores after receiving a request from a Company which held leases in the North West of Western Australia.

Thin layer leaching involves crushing the ore to approximately minus 10 mm and adding strong acid in a continuous mixing drum. The ore is then stacked and allowed to cure undisturbed for up to 24 hours. Once cured, the ore is spread evenly on a large concrete pad in a layer not exceeding one metre thick. Leach liquor is then sprayed uniformly over the bed for two or more days and the leachate recovered from the base of the bed. This pregnant liquor is then routed to a suitable copper recovery system such as solvent extraction, electrowinning or cementation.

The technique was simulated in the laboratory on 5 kilogram batches of ore and data obtained on extraction efficiency, acid consumption and other variables.

Vanadium Ores

A local Company having confirmed its intention to install an approximately one million kilogram per annum vanadium recovery processing operation at Wundowie again involved the Division in considerable testwork during the year. The main purpose of the trials was to confirm the best method and conditions for flux roasting the ore to enable maximum recovery of vanadium in later stages of the process.

Approximately 5 tonne ore parcels were processed in a range of feed forms through the 5.3 metre rotary kiln (0.35 m diameter) employing differing levels of temperature, residence time and flux incorporation.

Optimum roasting parameters for solubilising the vanadium were confirmed and it was demonstrated that some of the characteristics of the ore such as particle size and the presence of deleterious constitutents also influenced ultimate vanadium recovery.

On completion of a further two stages of rotary kiln trials, smaller scale testing aimed at proving alternative methods of roasting and flux incorporation was carried out wtith promising results. These results were sufficiently encouraging for the Company to proceed to the installation of a pilot scale roasting unit at Wundowie and this unit was operational by the end of the year.

Zircon Beneficiation

In recent years the Division has been called upon by several operating Companies to evaluate various processes aimed at removing deleterious surface coatings and minor contaminants from zircon grains. In times of tight marketing the higher grade zircon concentrates are more readily saleable and generally the Western Australian producers are hard pressed to compete because of the slightly inferior quality of the zircon recovered from this State's near-coastal heavy mineral sand deposits.

Again in 1978, the Division was requested to involve in proving trials of a new upgrading method and late in the year laboratory scale testing commenced. These initial trials gave encouraging results and were followed by larger scale treatment involving several tonnes of feed material. The work will be continued into 1979.

Beneficiation of Silica Sands

Assistance was given to an international consulting company which had been retained to design a flowsheet for processing local silica sands to meet the stringent quality requirements for use in glass manufacture.

The test programme was aimed at assessing the efficiency of wet trommel screening and obtaining data for extrapolation to probable commercial design and performance.

Diatomite Based Insecticide

In recent years a major Departmental study has been directed to examining methods of processing low grade diatomite material from local deposits to products that are acceptable for filter aid and other refined uses.

This background knowledge was used to advantage during 1978 to assist a local company which wished to evaluate the manufacture of a novel form of agricultural insecticide and to subsequently carry out field testing of its potential to eradicate insects from stored cereal crops. Diatomite was required for use as a carrier for the insecticide and the local material required beneficiation before use.

An upgrading circuit was perfected and a bulk quantity of beneficiated diatomite was made available for processing to the insecticide product. The Division offered further assistance by devising a pulverising circuit and dispersing the final product material into a form suitable for the field trials.

PROJECTS FOR OTHER DEPARTMENTS

The Division assists other Government Departments when required. Examples of studies undertaken during 1978 are—

Stabilised Soil Bricks

This project, which is aimed at using indigenous soils from the Northern areas of the State for the making of bricks and other structural components, has been referred to in previous Annual Reports. The work is being done in conjunction with the office of Regional Administration and the North West.

Previous trials had confirmed that satisfactory bricks and monolithic wall sections can be produced by stabilising selected soils with cement or lime and curing under ambient conditions. A prototype house that has been built in Broome from bricks and wall sections manufactured from the local Pindan soil stabilised with approximately 10 percent of lime or cement has been well received.

In 1978, the project was expanded to include a wide range of soils of different types from several areas of the North. Samples from Kununurra, Port Hedland, Derby, Wyndham, Fitzroy Crossing, Halls Creek and Pandanus Park were examined and a preliminary physical and chemical characterisation of the soils has been made.

A batch of 150 cement stabilised Pindan bricks was produced for exhibition purposes.

Late in the year approval was received for funding to the value of $30 000 to support a continuation of the research programme during 1979. This will enable an expansion of the testwork and direction of additional staff to service the project. In addition to characterisation of a wide range of soils the 1979 programme will include assessment of the mechanical properties of compacted soils, an examination of the influence of process variables and exploratory tests to widen the application of stabilisation methods in housing construction.

Agglomeration of Phosphatic Fertilizer

The Department of Agriculture requested trials to check the feasibility of agglomerating a phosphatic fertilizer and the subsequent production of approximately 150 kg of agglomerated product for field trials. The fertilizer, Aerophos -x (mono calcium phosphate) was in fine powdered form and the preferred particle size range for agglomerated product was set at 1.5-5 mm. The product was required to withstand handling without disintegration and yet be readily broken down after application.

Drum and disc type pelletising was tried and the drum unit found to be better suited to small batch production. The fertilizer was readily agglomerated without a binder and the strength of the agglomerates was a function of balling time and curing conditions.

INTRA-DIVISION PROJECTS

Examples of projects in hand during 1978 that had been Departmentally innovated are the following—

Form-coke and Carbonaceous Compacts

Western Australia has only one producing coal field which is located at Collie, approximately 160 kilometres south-south-east of Perth. The coals at Collie are of Permian age and are hard and black although of high (20-30 percent) moisture content. Ash contents range from 2 to 12 percent for most seams and the volatile matter which is high in carbon dioxide and low in tar comprises 22-28 percent of the coal. Hence the fixed carbon content is low at 42-50 percent and Collie coal is completely non-caking.

The lack of indigenous coking coal has hindered the development of metallurgical processing in Western Australia and earlier testwork carried out by the Division had been directed towards producing a substitute coke from Collie coal. A process involving carbonisation, grinding and briquetting with a carbonaceous binder was proven at the pilot plant scale.

In 1978 changed circumstances, relating particularly to sources of binder and briquetting stock (char and charcoal), prompted a review of the earlier work. The later testwork in general validated the earlier findings and confirmed that the briquetting technique still stands as the best available technology for producing a formcoke from Collie coal or for briquetting charcoal for metallurgical use. The following points were substantiated in the re-appraisal.

(1) The briquetting technique is generally applicable to coals of the type occurring at Collie and to charcoal.

(2) The porous and reactive nature of the briquetting stock causes the briquettes to be more reactive than coke.

(3) Rotary kiln char was briquetted satisfactorily but the product was weaker than briquettes made from vertical rinsing gas retort char

(4) For bitumen binders it may be economic and satisfactory to add heated binder to the hot dry solid phase particularly if the briquette strength requirement was not critical.

(5) The optimum briquetting technique must be chosen from a number of possible variations including choice of binder, and type of maturing stage.

Report of Investigations: A Report titled "A Re-Appraisal of Briquetting Collie Coal Char and Wood Charcoal" by L. J. Brennan was published during the year.

Banded Iron Formation

As part of its programme to evaluate the future long term needs, the Division continued its studies into the potential for beneficiation of the primary "banded iron formation" (BIF) deposits of the State to upgrade concentrates suitable for pelletising as feed for iron production or steel via the direct reduction route.

Testwork during 1978 was concentrated on diamond drill core samples originating from near the Colonial Mine at Wittenoom.

The head sample contained iron of the following approximate mineral composition:—

30 percent magnetite contained in fine grained quartz—stilpnomelane

15 percent hematite

5 percent siderite

By using fine grinding and wet magnetic separation, magnetic concentrates containing 69 percent iron were produced at a recovery rate of 76 percent of the contained iron. Indurated pellets were made from the magnetic concentrates and these showed breaking strengths between 300 and 500 kilograms and a silica content between 3.7 and 4.4 percent. It was demonstrated that the silica level could be lowered to the order of 2 percent by employing cationic flotation. The final iron content of this "superconcentrate" was 69.8 percent.

In some areas of the Hamersley Basin, the magnetic content of BIF is low, making magnetic separation an unsuitable means of concentration. These ores will be considered in further work.

The recent programme has also confirmed that the grain size of the constituent minerals in the BIF ores varies according to location and depth, thus indicating the need to study liberation characteristics for each particular sample.

Treatment of Copper Oxide Ores

Copper is present in the earth's crust mainly in the form of sulphide minerals such as chalcopyrite ($CuFeS_2$), bornite (Cu_5FeS_4) and chalcocite (Cu_2S) and from these minerals approximately 90 percent of the world's primary copper production is derived.

The majority of these sulphide deposits are overlain by a zone of oxidised material in which the copper exists in the form of carbonates, oxides, silicates or sulphates (collectively referred to as oxidised copper minerals). These minerals when present in sufficient quantity can be reduced pyrometallurgically to metal. However, the majority of presently mined oxide minerals are too lean in copper for economic smelting and most cannot be efficiently processed to produce a high grade concentrate. For these reasons oxidised copper ores are normally more effectively treated by leaching followed by precipitation or electrowinning to recover the copper from solution.

The majority of Western Australia's oxide copper deposits are of only modest size, occur in isolated areas and have often been intermittently and selectively mined thus depleting the deposit of higher grade ore.

A Departmental investigation has been aimed at defining the extraction methods most applicable to processing the State's oxidised copper ores. During 1978, ores from the Peak Hill area (Thaduna), Yalgoo area (Warriedar and Golden Grove), West Pilbara area (Whim Creek and Mons Cupri) and Broad Arrow area (Mount Pleasant) were examined and a range of techniques including heap, vat and agitation leaching and a range of leaching agents were evaluated. The results of this testwork are currently being compiled and will be published in 1979.

CONSULTATIVE AND COMMITTEE WORK

The Division continued to provide advice and information on all matters pertinent to its sphere of activities.

Senior Officers of the Division continued to serve on various Government and other advisory committees.

GENERAL

The Chief of Division (Mr B. A. Goodheart) visited an operating taconite iron ore mine and mill and the U.S. Bureau of Mines Research Centre in Minnesota, the Mineral Science Laboratories of the Canadian Mineral and Energy Department in Ottawa and the Warren Spring Research Laboratory in England while overseas in October.

Chemist and Research Officer (Mr R. V. Field) attended the Australian Mineral Foundation Workshop Course on "Mineralogy for Metallurgists" in Adelaide during July.

B. GOODHEART,
Chief Engineering Chemistry Division.

FOOD AND INDUSTRIAL HYGIENE DIVISION

GENERAL

This year has seen an increase in samples of 23 percent on the previous year. The increase in foods was 44 percent while there were decreases of 2 percent in industrial hygiene samples and 17 percent in miscellaneous samples compared with last year. The current restrictions on additional staff and the unsuitable conditions under which some of the Division's operations are carried out make such increases in work load a strain on our resources.

The Division in conjunction with the Agricultural Chemistry Division hosted a workshop on arsenic and selenium for the then Department of Environment, Housing and Community Development, Marine Branch (now part of the Department of Science and the Environment). The interchange of ideas from the various participants from Commonwealth and State Laboratories was beneficial to all who took part.

The Division has handled numerous enquiries for technical information and advice from Government Departments, Instrumentalities and the public during the year.

The source and type of samples received are given in Table 3.

CONFERENCES AND COURSES

Mr. G. F. Ebell attended the Residue Conference in Canberra in May. Mr. F. E. Uren attended the Fourth International Pesticide Chemistry Conference in Zurich, Switzerland in July. Mr. G. A. Taylor attend a 90 day course on Occupational Hygiene held at Sydney University, School of Public Health and Tropical Medicine from August to November. Mr. Uren attended the Food Analysts' Meeting in Adelaide in October.

PUBLICATIONS

Messrs. D. E. Fleming and G. A. Taylor published a short paper on "Improvement in the Determination of Arsenic by Arsine Generation and Silica Furnace A.A. Spectrophotometry", in the January issue of Analyst. Messrs. D. L. N. Collett D. E. Fleming and G. A. Taylor published a short paper on "The Determination of Antimony by Stibine Generation and Silica Furnace A.A. Spectrophotometry", in the October issue of Analyst.

FOODS

Of the 42 samples of tripe received this year one failed to comply with the Food and Drug Regulations with respect to pH.

TABLE 3

FOOD AND INDUSTRIAL HYGIENE DIVISION

	Agricultural Department	Consumer Affairs Bureau	Departmental	Fisheries & Wildlife Department	Government Stores	Hospitals	Department of Labour and Industry	Metropolitan Water Board	Mines Department	Pay	Police Department	Public Health Department	Public Works Department	State Energy Commission	Other	Total
FOODS—																
Apples	40	....	....	....	....	....	....	....	....	....	....	1	....	....	....	41
Bananas	18	....	....	....	....	....	....	....	....	....	....	....	....	....	....	18
Beer	....	....	....	....	....	....	....	....	....	....	....	10	....	....	....	10
Bread	....	....	....	....	....	....	....	....	....	....	....	21	....	....	....	21
Coconut	....	....	....	....	....	....	....	....	....	....	....	67	....	....	....	67
Crabmeat	....	....	....	....	....	....	....	....	....	....	....	18	....	....	....	18
Eggs	3	....	....	....	....	....	....	....	....	....	....	45	....	....	....	48
Fish	....	....	....	1 117	....	....	....	....	....	....	....	633	....	....	....	1 750
Fruit juice	....	....	....	....	....	1	....	....	....	....	....	22	....	....	....	23
Grapes	32	....	....	....	....	....	....	....	....	....	....	1	....	....	....	33
Home Brew	....	....	....	....	....	....	....	....	....	....	17	....	....	....	....	17
Human milk	....	....	....	....	....	....	....	....	....	....	....	11	....	....	....	11
Lima beans	....	....	....	....	....	....	....	....	....	....	....	48	....	....	....	48
Liquor	....	....	....	....	....	....	....	....	....	....	4	31	....	....	....	35
Meat	....	....	....	....	....	....	....	....	....	1	....	12	....	....	....	13
Milk	96	....	1	....	....	....	....	....	....	....	....	1	....	....	....	98
Mussels	....	....	....	....	....	....	....	....	....	....	....	18	....	....	....	18
Oysters	....	....	....	....	....	....	....	....	....	....	....	17	....	....	....	17
Rice	12	....	....	....	....	....	....	....	....	....	....	....	....	....	....	12
Shark	....	....	3	....	....	....	....	....	....	....	....	27	....	....	....	30
Soft drink	....	....	....	....	....	....	....	....	....	....	....	21	....	....	....	21
Squid	....	....	....	....	....	....	....	....	....	....	....	11	....	....	....	11
Tripe	....	....	....	....	....	....	....	....	....	....	....	42	....	....	....	42
Vegetables	....	....	....	....	....	....	....	....	....	....	....	27	....	....	....	27
Yoghurt	8	....	....	....	....	....	....	....	....	....	....	6	....	....	....	14
Various	161	2	....	....	....	4	....	....	....	....	....	123	....	....	....	290
INDUSTRAIL HYGIENE—																
Air	....	....	....	....	....	....	....	....	1	....	....	85	....	9	....	95
Anaesthetic Air	....	....	....	....	....	....	....	....	....	....	....	168	....	....	....	168
Blood	....	....	....	....	....	....	....	....	16	....	....	29	....	....	....	45
Urine	....	....	....	....	....	....	172	....	95	22	....	31	....	....	....	320
Various	....	....	....	....	....	3	....	....	3	....	....	17	....	....	....	23
MISCELLANEOUS—																
Air	....	....	....	....	....	....	....	....	4	....	....	43	....	....	....	47
Animal tissue	24	....	....	....	....	....	....	....	....	....	....	....	....	....	....	24
Animal tox.	10	....	....	2	....	....	....	....	....	1	....	1	....	....	....	14
Blood-ovine	10	....	....	....	....	....	....	....	....	....	....	....	....	....	....	10
Fat	59	....	....	....	....	....	....	....	....	....	....	....	....	....	....	59
Fat-ovine	16	....	....	....	....	....	....	....	....	....	....	....	....	....	....	16
Fish tissue	....	....	....	179	....	....	....	....	....	....	....	....	....	....	....	179
Flue gas	....	....	....	....	....	....	....	....	....	....	....	....	....	10	....	10
Grass	18	....	....	....	....	....	....	....	....	....	....	....	....	....	....	18
Guinea pig tissue	18	....	....	....	....	....	....	....	....	....	....	....	....	....	....	18
Pasture	14	....	....	....	....	....	....	....	....	....	....	....	....	....	....	14
Pesticides	12	....	7	....	....	....	....	....	....	2	....	20	1	....	....	42
Senna plants	12	....	....	....	....	....	....	....	....	....	....	....	....	....	....	12
Sheep dip	34	....	....	....	....	....	....	....	....	2	....	....	....	....	....	36
Soil	46	....	....	....	....	....	....	....	....	....	....	41	....	....	....	87
Specimen from patients	....	....	....	....	....	44	....	....	....	18	....	86	....	....	2	150
Surgical dressings	....	....	....	....	59	....	....	....	....	....	....	....	....	....	....	59
Surgical equipment	....	....	....	....	....	....	....	....	....	....	....	30	....	....	....	30
Water	....	....	8	....	....	2	....	35	....	4	....	20	229	....	12	310
Wool	49	....	....	....	....	....	....	....	....	....	1	....	....	....	....	50
Various	64	9	6	....	....	4	....	....	3	10	5	106	4	1	5	217
Total	756	11	25	1 298	59	58	172	35	122	60	27	1 890	234	20	19	4 786

To assess the nutritional aspects of food served to patients in hospitals 22 different main meals from the Sir Charles Gairdner Hospital were analysed for their nutritive constituents.

The sodium and potassium content of some foods were determined for the dietitian of Royal Perth Hospital. This hospital also submitted a sample described as vegetable salt. The bulk of this sample was sodium chloride instead of potassium chloride.

Two highly coloured buns described as pumpkin buns were in fact yeast buns with an excess of yellow dyestuff. No pumpkin was detected in the samples.

The Public Health Department submitted four samples of skim milk yoghurt for analysis. Each of the yoghurts had a slightly higher fat content than that allowed by the Food and Drug Regulations but there was insufficient fat to identify the nature of the fat.

Two vinegar samples packed in plastic bottles were examined for vinyl chloride monomer. No monomer was detected in the samples.

A sample of flavoured milk with reduced fat was analysed. The fat content of the sample was indeed reduced but the Food and Drug Regulations do not have a fat reduced milk whereas the Dairy Industry Regulations allow such a milk.

A brand of packet soup made the claim that the fat in the soup is polyunsaturated and that the cholesterol content is less than 5 mg/100 g. The soups submitted were analysed and the fat was polyunsaturated but one of the samples had an amount of cholesterol well in excess of the 5 mg/100 g claimed.

A number of samples of bread were examined for fibre content. These samples complied with the fibre content but the packages all stated that the fibre was due to bran which is not an additive permitted by the Food and Drug Regulations.

A fire in the upper floor of the freezer block at the W.A. Meat Export Commission resulted in several samples of sheep carcass and water samples being examined. Water used to extinguish the fire poured through the cracks in the floor to the lower floors. Where the water came into contact with the carcasses it contaminated the carcasses with products of combustion but those that were not in contact with the water were not affected.

A sample of ham was said to be contaminated with powdered glass. The so called "glass" consisted of small crystals of disodium hydrogen phosphate, a chemical sometimes used in the preparation of hams.

The Department of Agriculture submitted 40 samples of apples. These apples were in connection with two problems which the Department has viz: bitter pit and cold storage scald. The Division has assisted the Department to develop a system of spraying the apples with a mixutre of calcium chloride and diphenylamine, a combination of chemicals which controls both problems.

The majority of the liquor samples received failed to comply with respect to the required alcoholic strength. This is not surprising as most of the samples were taken because of suspected low alcohol content when examined by a Public Health Surveyor using a Sikes hydrometer.

Twenty one samples of illicit beer were received from the Police Department in connection with the prosecution of a person making and selling a "home brew".

Three samples of whisky were examined in connection with a suspected adulteration case. An opened expensive whisky displayed for counter sale was found to be a mixture of the expensive whisky and a much inferior whisky.

The Public Health Department submitted 18 samples of mussels obtained from Cockburn Sound in relation to the disposal of gypsum in the Sound from a fertiliser factory. These samples have been submitted on a regular basis and in all cases the level of cadmium found was below the level of 2 parts per million recommended by the National Health and Medical Research Council and well below the 5.5 parts per million of the Food and Drug Regulations.

The Fisheries and Wildlife Department submitted over 1 100 fish samples for mercury. These fish were species caught in the Great Australian Bight which had not been previously commercially marketed. The computer was used to print the reports from the crude data it received.

A school Christmas party resulted in a large number of children being taken to hospital after reported vomiting. The only food common to all the children was soft drink so 29 samples of soft drink, opened cans of soft drink and ingredients from the manufacturer were examined. No heavy metals or deterioration of the cans were detected in any of the samples. It was later learnt that the children who were sick were very few in number and that none were actually admitted to hospital.

A survey of vegetables grown in the Kwinana area resulted in 18 various vegetables being examined for cadmium and lead. The amounts found were well below that allowed by the Food and Drug Regulations. There is no reason to suspect vegetables grown in this area to be any higher in cadmium and lead than those in other areas of the State.

The Public Health Department submitted only 27 samples of shark this year. Only four samples were below the allowed limit of 0.5 mg/kg. The samples submitted were all from large sharks so the results are not surprising.

INDUSTRIAL HYGIENE

This year 365 biological specimens were examined from workers to measure their exposure to industrial chemical hazards. Of these samples 229 were urine samples from workers to monitor their uptake of lead. Workers with a normal level of lead of 80 μg/l or less lead content accounted for 68.1 percent of these samples, those with an acceptable level of 90-150 μg/l for 22.6 percent and those with greater than 150 μg/l, an excessive level, for 9.3 percent. Blood and urine samples for mercury accounted for a further 109 analyses. It was noted that several workers in a mine gold room had high levels of mercury. Modifications to their method of handling mercury amalgam have resulted in a reduction in the mercury level of the worker's blood and urine specimens.

Table 4 gives a summary of the analysis performed on biological samples in connection with industrial hygiene.

TABLE 4

SPECIMENS FROM WORKER—ANALYSES

Analysis	Number
Antimony	4
Arsenic	4
Fluorine	25
Lead	230
Mercury	109
Thallium	17
Organochlorine pesticides	1
Zinc	1

It was noted that three of the samples supplied as urine samples were in fact water. It is deplorable that workers jeopardise the efforts of those who are monitoring their health risks by such foolish action.

During the year several on the spot inspections and samples were taken from various laboratories and industrial situations.

An electrical engineering workshop was visited to measure toluene di-isocyanate (TDI) and 4,4'-methylene-bis-2-chloroaniline (MOCA) concentrations during the coating of trommel wheels. Recommendations were also made regarding the housekeeping within this factory.

A mineral research laboratory where large quantities of tetrabromoethane (TBE) and acetone are used was again visited this year. Our previous reports on these premises reported several unsatisfactory aspects of their operation. There has been little improvement in this laboratory since our last visit and a strong recommendation was made that it be revisited when the alterations suggested had been carried out.

Two visits were made to a hospital sterilising room where ethylene oxide is used to sterilise surgical dressings and equipment packaged in plastic bags. Several packages were examined to determine the half life of the ethylene oxide remaining in the equipment. This appears to be about three hours. Residual ethylene oxide over a certain concentration in the equipment acts as a serious irritant.

Several establishments have been visited to determine mercury in air. These have included a private dental surgery, a technical school, a hospital intensive care laboratory, a chemical repackers where a worker had mercury poisoning and a dental hospital. All the mercury levels were satisfactory. At the chemical repackers the workman was repacking mercuric chloride and although the mercury level in the air was satisfactory there was a strong possibility that the mercury was absorbed via the skin.

A bitumen paving operation was checked for the carcinogen β-naphthylamine, but none was detected.

Princess Margaret, Repatriation General and Bethesda Hospitals were all checked during the year for anaesthetic gas levels in operating theatres and recovery rooms. Recommendations were made concerning the air flow in a recovery room to control a high level of anaesthetic gases.

Two series of tests of air in a N-class diesel locomotive while operating between Kwinana and Jarrahdale were taken and analysed for oil mist, carbon monoxide, aldehydes and ketones. All the tests were well below the appropriate threshold limit value.

Following the death of two workmen at Kwinana analyses of compressed breathing air and the atmosphere in the vessel where they died were made. The breathing air was found to be normal but the air in the vessel was low in oxygen.

At the request of the Ventilation Board Mr. Uren took part in a "Walk Through Survey" of Mining treatment plants in the Kalgoorlie and Norseman areas.

Several visits to vessels in the port of Fremantle were made during the year. One case involved the use of a LPG fork lift in a freezer hold where adequate ventilation was not provided. This type of fork lift should not be used in these confined spaces.

SPECIMENS FROM PATIENTS

There has been a decrease in the number of samples received from doctors' and hospital patients. These samples are taken to assist in the patients' diagnosis.

Table 5 lists the analyses which were carried out on these samples.

TABLE 5
SPECIMENS FROM PATIENTS—ANALYSES

Analysis	Number
Arsenic	85
Lead	49
Mercury	45
Thallium	23
*Miscellaneous	43

* Includes 2,4–D, aldrin, antimony, barium, bismuth, chromium, cobalt, copper, fluorine, gold, iron, manganese, uranium, pentachlorophenol, polychlorinated biphenyls.

A method for uranium in biological fluids was developed as a result of samples of blood and urine being received from a patient with a record of past industrial exposure to that element.

PESTICIDES

This year has seen much interest in the compound dioxin (2,3,7,8-tetrachlorodibenzo-p-dioxin). This compound can be present in 2,4,5-T formulations as an impurity. Australian Standard 1175-1976 states that "the dioxin content of 2,4,5-T ester shall not exceed 0.1 mg/1 of the total acid content". This limit was not exceeded by any of the 13 commercially available samples that were submitted for analysis.

Two legal samples of a sheep dip taken under the Veterinary Medicines and Feeding Stuffs Act were stated to contain rotenone. This material was not detected in the samples. The manufacturer has been prosecuted for this offence and his products were deregistered.

In connection with a sheep dipping trial at Badgingarra Research Station 30 samples of the diazinon dip and 45 samples of fleece were examined.

Pesticide Residues

Table 6 gives a summary of the major types of samples received this year for pesticide residue analyses.

The Department of Agriculture submitted 144 oranges in connection with fumigation and storage trials using ethylene dibromide as the fumigant.

A restaurant which was sprayed with a pesticide to control a cockroach infestation, had on display live crayfish in a glass tank. The tank was uncovered during the spraying. Next day the crayfish were dead. There is no published data on this particular pesticide's toxicity to crayfish but the amount found in the water indicated that it could have been the cause of death. Dieldrin was found in an outside pond in which goldfish had died. The dieldrin was traced to treatment of a nearby fence for termite proofing.

TABLE 6
PESTICIDE RESIDUE ANALYSES

Sample	Number
Animal—	
Blood	14
Fat	43
Kidney	28
Bananas	20
Breast milk	11
Coconut	67
Foods	84
Lima Beans	48
Dairy Products	144
Pasture and Stock Feed	58
Rice	12
Soils	78
Waters	300
Wool	50

Rice which was grown in the Ord River area, while being stored in the Perth area, is refumigated with methyl bromide. Samples of rice taken after fumigation had residues well within the limit set by the Food and Drug Regulations.

A number of samples of lima beans were received this year. In the past years lima bean samples had been treated with lindane which was only present on the surface of the beans. Rumbling of these beans removed most of the lindane to give a level below that permitted by the Food and Drug Regulations. This year lima beans imported from one area had the lindane also present in the body of the bean so that rumbling did not materially reduce the level of lindane.

There have been several cases of pesticide spray drift that have come to our attention. These have resulted from fences being treated with pesticide and the spray drift then falling on home vegetable gardens. In all cases the amount of pesticide found on the vegetables and foliage was not above that level permitted by the Food and Drug Regulations.

In a feeding trial at Badgingarra Research Station a flock of sheep were fed on pasture which had been treated with DDT. DDT and metabolites were monitored in sacrificed sheep. When a predetermined level of DDT and metabolites was reached the sheep were transferred to DDT free pasture. The DDT and metabolites remained fairly constant for a period before decreasing.

ANIMAL TOXICOLOGY

Further samples of cat organs were received again this year. All these samples had elevated levels of pentachlorophenol. The pentachlorophenol came from the sawdust used in their cages. Deaths of laboratory animals which were kept on sawdust litter were traced to the wood from which the sawdust was made. The wood had been treated with pentachlorophenol.

A domestic fowl was examined for organochlorine pesticides and a high concentration of dieldrin was found. The source of the dieldrin was traced to treatment of the soil with aldrin (dieldrin is a metabolite of aldrin). Dieldrin was also found in eggs from other birds in the fowl yard. This case is similar to one which we have been monitoring for some time. A commercial pest operator sprayed a fowl yard with aldrin to control ticks. Eggs produced by the birds showed high concentrations of aldrin and dieldrin. Birds sacrificed also showed high levels of aldrin and dieldrin. The top layer of soil was removed from the fowl yard and replaced with other soil and the fowl yard restocked with new birds. After a short lapse of time dieldrin and lesser amounts of aldrin were found in the eggs. The levels were still well over the amount allowed by the Food and Drug Regulations. New soil and birds were placed in the yard but the soil and eggs were still unsatisfactory. This case demonstrates the difficulty that exists in removing persistent pesticides from soil once they have been applied. The question this raises is: How many fowl yards have been similarly treated where the authorities are not aware of the situation?

MISCELLANEOUS

Two samples of sperm whale oil were submitted by the Consumer Affairs Bureau. A local bottler of whale oil had complained that another bottler's product was not sperm whale oil and had supplied an analysis to support his case. Both samples were analysed and both found to be sperm whale oil. Our analysis of the complaint sample in no way resembled the bottler's purported analysis of the sample.

Four unlabelled bags were found at Fremantle Wharf and the contents were submitted for identification. Two of the bags contained kaolin and the other two sodum fluorosilicate.

It was reported in "Choice" that certain gas mantles gave off beryllium when ignited for the first time. Two of the more popular brands of mantles were examined but no beryllium was detected.

Government Stores submitted 59 samples of surgical dressing, bandages, adhesive bandages and absorbent cotton wool to assist them in selecting which tenders to accept.

Another 12 samples of senna plants from a pilot trial were received this year as part of a project commenced the previous year. Analysis of the active principle, the sennoside, was undertaken. Although the levels of sennosides were higher than in the previous samples they were not high enough to make the proposition a commercial venture.

Seven chemical toilet preparations were examined for their compliance with British Standard 2893:1957. Four of the samples passed but three failed by having a flash point below 150°F.

Samples of sea water taken from the Abrolhos Islands by the Public Health Department were examined to ascertain if chemical toilet discharges were affecting the area. No formaldehyde, the active constituent of the chemical toilets, was detected.

F. E. UREN,
Chief, Food and Industrial Hygiene Division.

FORENSIC CHEMISTRY DIVISION

The Division, formerly known as the Toxicology and Drug Division was renamed during the year to reflect in the name a more accurate picture of the Division's activities.

the staff of the Division continue to absorb the continued increases in work load is a tribute to the conscientious approach which they show to their work. There is, however, a limit to the staff's capacity to absorb additional work before a decline in the quality will become evident. The addition of one staff member for 1979 is appreciated but simply allows the Division to keep up with the inflow. It does not allow the staff the time to provide the wide range of service which could be offered to the Police by incorporating the latest developments in instrument technology.

The quality, the depth and scope of service which can be provided for police investigation is dependent on the staff and instrumentation which is available and the question is posed as to just how much society is prepared to pay to provide the expert scientific service which will assist the Police in their criminal investigations and in the successful prosecuton of criminals.

The lack of space exacerbated by the increased and more varied work load has resulted in the Physical Evidence Section of the Division expanding into a laboratory away from the main body of the Division. The inconvenience caused by such a move was considered less undesirable than the badly overcrowded situation within the laboratory. It is unfortunate that the alterations to the Division planned for 1979 were curtailed leaving the staff with a laboratory with many inconvenient features and the Chief of the Division with sub-standard office accommodation.

A highlight of the year's activities was the acquisition of the Hewlett-Packard Model 5592 Gas Chromatograph-Mass Spectrometer. This has enabled the identification of drugs to be performed with greater assurance and it has been useful in the detection and assay of some drugs present in such low concentrations as to make them difficult to detect and quantify by other means. The range of work in the Physical Evidence Section has shown an interesting variety and it is reassuring to note that the Police are making greater use of our scientific service for a wide range of investigations.

The source and type of samples received are shown in Table 7.

TABLE 7

FORENSIC CHEMISTRY DIVISION

	Agriculture Department	Department of Corrections	Departmental	Greyhound Racing Control Board	Pay	Police Department	Public Health Department	Road Traffic Authority	Western Australian Trotting Association	Other	Total
BAITS	4	....	....	....	1	6	1	....	....	....	12
BLOOD & URINE ALCOHOL—											
Sobriety	....	....	....	....	....	....	....	831	....	....	831
Traffic Deaths	....	....	....	....	....	34	....	458	....	....	492
CRIMINAL INVESTIGATION	....	....	....	....	....	397	1	2	....	....	400
DOPING CONTROL IN SPORT—											
Greyhounds	....	....	....	160	....	....	....	....	....	....	160
Horses	....	....	12	....	1	....	....	....	460	....	473
DRUGS	2	....	8	....	2	793	1	3	....	....	809
MISCELLANEOUS—											
Blood	....	....	18	....	....	....	4	....	....	....	22
Maritime pollution	....	....	....	....	....	33	....	....	....	2	35
Pesticide	....	....	....	....	....	....	13	....	....	....	13
Specimen from prisoners	....	56	....	....	....	....	....	....	....	....	56
Various	31	....	17	7	2	1	6	....	3	5	72
TOXICOLOGY—											
Animal	45	....	....	....	11	7	....	....	....	....	63
Human	....	....	....	....	....	918	2	3	....	....	923
TOTAL	82	56	55	167	17	2 189	28	1 297	463	7	4 361

It has been a particularly busy but interesting year with an overall increase of 10 percent in the number of samples received. The major contributing factors to this increased work load were the increased activity within the drug scene particularly, the overall increase in the crime rate and the undertaking of analysis of samples for the Department of Corrections in relation to drug and alcohol offences within the corrective establishments. The increased illicit drug work and the physical evidence work resulted in greater demands by the Courts on chemists' time.

Despite the increased demands made on the Division the work was carried out without additional staff. That

TOXICOLOGY

Exhibits were received from 314 cases of sudden death which were the subject of Police investigation. Of this number 211 cases were submitted for examination of poisons and/or drugs.

In 60 of these cases no evidence of any poison or drug was established, and in the remaining cases the presence of at least one drug or poisonous substance was detected. The concentrations of drugs detected in some cases made their toxicological significances uncertain.

Details of drugs and poisons identified are listed in Table 8.

TABLE 8
DRUG AND POISON CASES

Drug or Poison	No. of Positive Identifications
Carbon Monoxide	33
Amitriptyline	10
Propoxyphene	10
Pentobarbitone	8
Morphine	6
Amylobarbitone	6
Imipramine	6
Trichloroethanol	5
Nortriptyline	5
Phenytoin	5
Diazepam	5
Salicylic acid	4
Oxazepam	4
Phenobarbitone	4
Paracetamol	4
Desipramine	4
Glutethimide	3
Methadone	3
Various*	38

* Thioridazine, lignocaine, quinalbarbitone, quinine, arsenic, benzodiazepine metabolites, dextromoramide, propranolol (2 each,) acetone, orphenadrine, prochlorperazine, chlordane, clindamycin, carbromal, chloroquine, chlordiazepoxide, natrazepam, doxepin, colchicine, cyanide, trimethoprim, theophylline, primidone, hydroxychloroquine, codeine, meprobamate, chlorpromazine, methanol, dieldrin, toluene (1 each).

In 34 percent of cases received alcohol was detected and in 54 cases the concentration of alcohol was such that it caused or contributed to the cause of death. For instance in 15 cases of drowing out of 25 cases examined, alcohol was present in the blood.

In one case, involving a person who drowned whilst spearfishing (a sport not without some risk itself) the deceased was found to have a blood alcohol level of 0.189 percent which is roughly equivalent to the person having consumed 5 bottles of beer. It would seem that the danger inherent in combining alcohol with boating, fishing and swimming should be continually stressed to the public.

The pattern of drugs and poisons detected in 1978 was similar to that found in 1977. Of note was an increase from 3 to 6 in the number of deaths associated with heroin abuse. The increase, which fortunately has not paralleled the 500 percent increase in heroin identifications in exhibits examined in connection with drug trafficking charges, is nevertheless very disturbing.

ANIMAL TOXICOLOGY

The Division continued its animal toxicology service with samples being received mainly from the Police Department, Agriculture Department and from private veterinarians. As in previous years strychnine was the most commonly encountered poison and was involved in nine fatal cases of dog and one fatal cat poisoning.

An outbreak of pig deaths was eventually traced back to a feed which included blue lupin seeds. High levels of lupanine (16-31 mg/kg) were detected in the livers from the affected animals and also in the consumed feeds.

ALCOHOL AND DRUG CONTROL IN PENAL INSTITUTIONS

Since May the Division has undertaken the analysis of blood and urine samples from the Fremantle Gaol and other corrective institutions run by the Department of Corrections, in connection with alcohol or drug offences. Of 56 samples received, there were eleven cases involving alcohol and eight cases which involved drugs including dextropropoxyphene, pethidine and the benzodiazepine class of drugs e.g. Valium.

DOPING CONTROL

The monitoring of horse and greyhound urines for the Western Australian Trotting Association and the Greyhound Racing Control Board continued during the year in programmes designed to keep the sports free from the indiscriminate use of drugs. From over six hundred samples submitted five positives were reported, three in horses and two in greyhounds. Two cases of caffeine and one of phenylbutazone were reported to the Western Australian Trotting Association whilst one caffeine case and one alcohol case were returned to the greyhound authorities. In the latter case the dog was withdrawn before the race and subsequent blood and urine samples revealed high levels of alcohol.

GAS CHROMATOGRAPH—MASS SPECTROMETER (GC-MS)

In April the Division took delivery of a Hewlett-Packard 5992A GC-MS system. The instrument has been in continual use since its installation and has proved to be an invaluable addition to the equipment available to the Division. The GC-MS has enabled a number of analyses to be carried out routinely which the laboratory was previously incapable of performing and has meant that other examinations which were extremely difficult can now be accomplished with relative ease.

Included in the former category is the analysis of blood samples for drugs of abuse, such as cannabis, heroin and methadone. The small volumes of blood available for such analyses, when taken in conjunction with the Traffic Act, for instance, combined with the extremely low concentration of these drugs which exist in the blood, even in cases of acute intoxication, make the analyses for these drugs difficult. The legal implications of these analyses also means that absolute proof of identity of the drugs must be included in the analysis and it is this dual requirement which is impossible to accomplish without the sensitivity and specificity offered by the GC-MS.

Similarly to the above, the detection and identification of trace quantities of drugs in syringes, spoons, pipes and other paraphenalia associated with drug abuse is now a comparatively straight forward procedure.

Some other problems which the GC-MS has proved valuable in solving have been the identification of drug metabolites, pesticides and industrial chemicals, the confirmation of the identity of derivatives of compounds during the investigation of new methods and procedures for the analysis of those compounds and in the sensitive and specific detection of trace quantities of by-products in herbicide formulations.

BLOOD ALCOHOLS (Traffic Act)

Under the Road Traffic Act blood samples are taken from persons who choose to provide a blood sample rather than or in addition to a Breathalyzer test. The frequency of the levels of alcohol in the blood samples received (calculated to the time of the offence) are shown in Fig. 1. The histogram shows that 90 percent of the bloods had an alcohol level in excess of 0.08 percent while 63 percent were greater than 0.15 percent. The histogram shows a similar trend to that of previous years with no diminution of the proportion of drivers' bloods received with high alcohol levels. Despite attempts to remove them, the 'problem drinkers' still remain as a hazard on the roads.

During the year, a number of blood samples were received, in which drugs were found. The drugs detected were diazepam, amylobarbitone, quinalbarbitone and methaqualone. One of the problems confronting the Police is that if a person has a preliminary breath test or subsequent Breathalyzer test which produces a nil or a low alcohol result then there is no means of obtaining a blood or urine sample from the person for the purpose of detecting drugs. Feed-back from Traffic Police indicates that there is an increase in the incidence of cases where nil or low breath alcohol figures are obtained but where the driver is obviously not in a fit condition to drive a motor vehicle. It is reasonable to suggest that in most cases these drivers were probably under the influence of drugs.

The extent to which drug affected drivers are the cause of accidents is unknown. Because of this, there is a need for the power to enable blood and urine samples to be taken for the detection of drug-affected drivers.

Reports of occasional acquittals due to the last drink containing alcohol being taken after the offence continue to be made. When a drink is taken after the offence it has been claimed with success in some cases, that the amount consumed would have been sufficient to lift the blood alcohol level above 0.08 or 0.15 percent.

The effects of the last drink calculation over a three year period show consistently that the calculation is far more favourable to the accused driver by bringing his blood alcohol concentration at the time of offence to below 0.08 or 0.15 percent than by increasing the concentration to above those levels. See Table 9. In 1978 the overall effect of the calculation resulted in a lowering of the figure at the time of offence in 70 percent of the cases, no change in 5 percent and an increase figure in 25 percent of the cases.

FIG. 1

SPREAD OF BLOOD ALCOHOL LEVELS

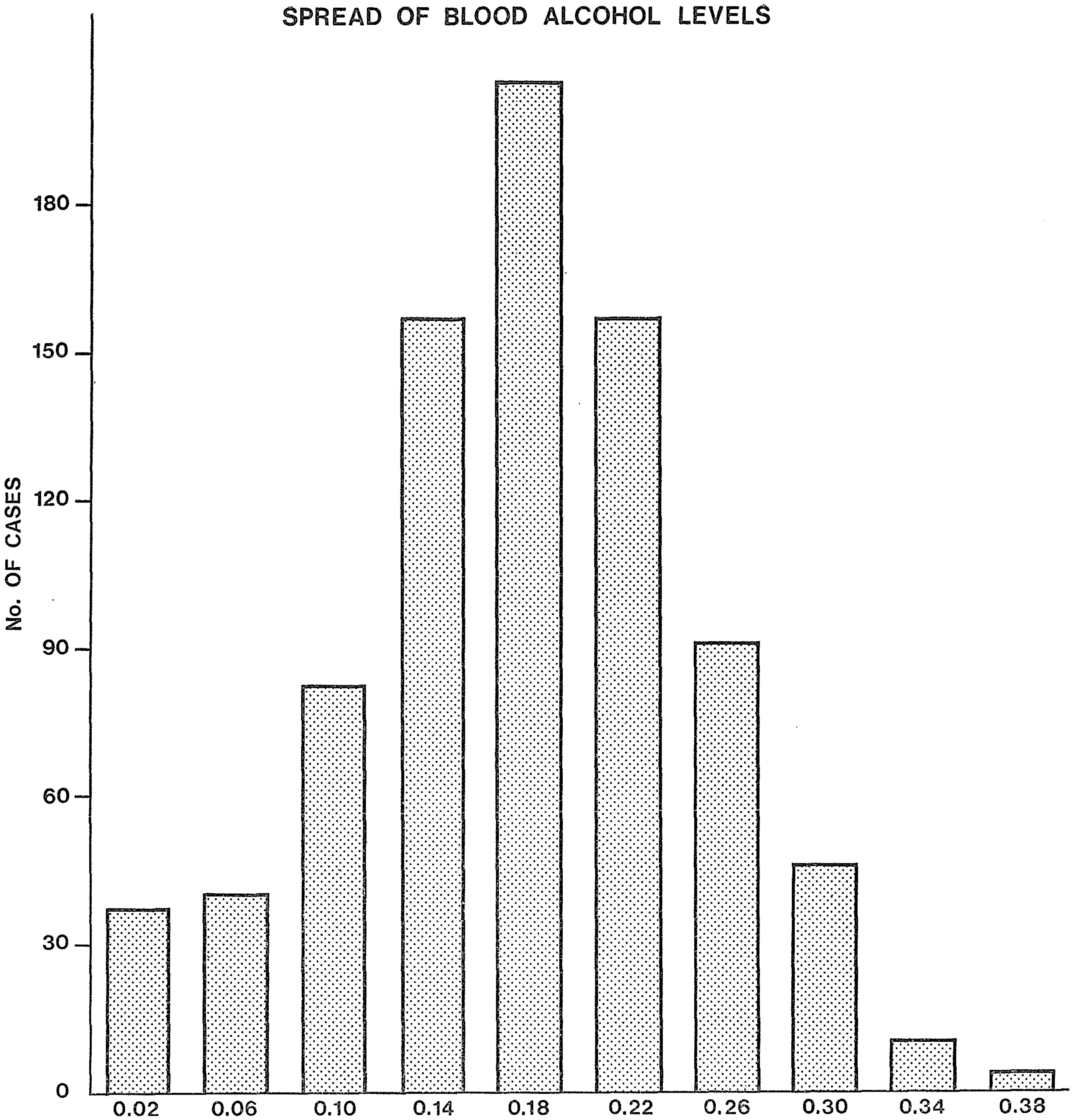

TABLE 9

EFFECT OF LAST DRINK CALCULATION

	1976	1977	1978
Blood alcohol level—	%	%	%
reduced to less than 0·08	2·6	2·5	2·6
reduced to less than 0·15....	4·2	7·6	4·2
increased to more than 0·08	0·1	0·5	0·7
increased to more than 0·15	2·1	2·0	2·1

In Western Australia under the Road Traffic Act a blood sample taken in connection with a driving offence must be taken within four hours of the occurrence of the event leading to the sample being taken. In some other States this time limit is set at two hours and at least one State is having difficulties in taking samples within that time limit. In this State in 1978, only 69 percent of the blood samples were taken within two hours, 91 percent within three hours but 99.6 percent were collected within the specified four hour period.

Table 10 shows a break down of the times between occurrence of the event and the testing of the blood sample, for 1978.

TABLE 10

TIME BETWEEN EVENT AND TAKING OF BLOOD SAMPLE

Time Minutes	No. of cases
0– 29	49
30– 59	165
60– 89	197
90–119	161
120–149	117
150–179	62
180–209	37
210–239	34
240	2
more than 240	3

TABLE 11

TRAFFIC DEATHS—BLOOD ALCOHOL LEVELS

Alcohol percent.	Motor Vehicle Drivers	Passengers	Pedestrians	Motor Cycle Riders	Push Cycle Riders
not detected	41	38	10	9	5
less than 0·05	3	4	3	2	....
0·050–0·079	3	1	1	....	....
0·080–0·099	1	3	1	1	....
0·100–0·149	11	5	3	2	....
0·150–0·199	6	3	1	1	....
0·200–0·249	9	8	9	....	....
0·250–0·299	6	3	3	2	....
more than 0·299	5	2	4	1	....
	85	67	35	18	5

TABLE 12

TRAFFIC DEATHS—BLOOD ALCOHOL LEVELS

	greater than 0·15%			greater than 0·08%		
	1976	1977 percent	1978	1976	1977 percent	1978
Motor vehicle drivers	37	33	31	44	47	45
Passengers	38	21	24	46	36	36
Pedestrians	47	49	49	58	54	60
Motor cycle riders	32	29	60	50	41	**39**

BLOOD ALCOHOL (Traffic Deaths)

In cases of fatal traffic accidents, blood, urine and sometimes other exhibits taken from the victims are submitted to the Division for alcohol determinations. In 1978, 492 such exhibits were received mainly from the Road Traffic Authority.

Table 11 shows the distribution of alcohol in the bloods of drivers, passengers, pedestrians, motor cycle riders and push cyclists. These figures apply only to samples received at the laboratory.

The figures show that 45 percent of drivers of motor vehicles had blood alcohol levels in excess of 0.08 percent while the corresponding figures for passengers, pedestrians and motor cycle drivers were 36, 60 and 39 percent respectively.

Blood alcohol levels of 0.15 percent or more were found in 31 percent of motor vehicle drivers, 24 percent of passengers, 40 percent of pedestrians and 22 percent of motor cycle drivers.

Table 12 shows the consistently high blood alcohol levels of fatal traffic accident victims as a percentage of the total fatal traffic accidents for the three year period 1976-78.

DRUGS

One hundred and forty eight cases comprising 801 exhibits were received for the identification of drugs and suspected drugs. The exhibits were in the majority of cases submitted by the C.I.B. Drug Squad.

Details of drug cases are listed in Table 13.

TABLE 13

DRUGS—POLICE DRUG SQUAD

Type of Drug	No. of positive identifications
Heroin	58
Cannabis	54
Morphine	4
Methylamphetamine	3
Bromodimethoxyamphetamine	2
L.S.D.	2
Cocaine	2
Dextromoramide	2
Mandrax	2
Various*	7

* diazepam, doloxene, ephedrine, methadone, oxazepam, procaine, pentobarbitone.

The above figures represent an increase of 40 percent in case numbers and a 66 percent increase in the number of exhibits examined compared to 1977.

The increase is due entirely to the number of heroin cases received throughout the year, there being 58 cases comprising 478 exhibits. The significance of the increase can be better realized when the number of heroin cases from the previous four years are compared (Table 14).

TABLE 14

HEROIN CASES 1974-78

1974	4
1975	5
1976	15
1977	11
1978	58

The increase in heroin identifications is an indication of both the increased proliferation of the drug in Western Australia and the increased activity of the C.I.B. Drug Squad in its efforts to combat the problem. The main thrust of the Drug Squad's operations is aimed at apprehending and eliminating dealers and traffickers of drugs and this is reflected in the fact that greater than 90 percent of analyses are carried out in connection with charges of selling and supplying.

More than 90 percent of the heroin exhibits received were in "deal" quantities i.e. in quantities from 0.1 to 1.0 gram of material generally "cut" with glucose and contained in capsules or small paper or metal foil packets. It would appear that the frequency of this type of seizure is an indication of the increasing degree of organisation and sophitication of drug traffickers in this State.

Other cases of note received during the year were five involving a total of 940 capsules of purified cannabis resin (470g). The resin was unusual in that it contained an unusually high proportion of the n-propyl cannabinoids which are homologues of the normally present pentyl cannabinoids. These compounds were easily identified and characterized by gas chromatography—mass spectrometry.

Bromodimethoxyamphetamine which was first encountered in 1976 reappeared this year in several new dosage forms. This material which was generally purported to be L.S.D. occurred in quantities of 1.3 to 0.8 milligrams.

CRIMINAL INVESTIGATION

Chemical and physical examination of exhibits collected from scenes of crime and accidents is undertaken in this Division to assist police enquiries and to provide expert evidence for the courts. The number of cases examined during 1978 continued the upward trend noted in 1977. The 28 percent increase reflected both the general rise in criminal activity and also a greater awareness by the Police in the value of science in the investigation of crime. Accompanying this rise in casework was an increased attendance at court proceedings by officers of this section.

TABLE 15
CRIMINAL CASES 1978

Type of Exhibit:	No. of Cases
Flammable liquids (including fire debris)	44
Paint and paint flakes	26
Blood and urine	26
Explosive and incendiary residues	10
Clothing	6
Fibres	5
Food and Drink	4
Glass	4
Gunshot residues	4
Miscellaneous	21

Table 15 summarises the range of exhibits received and Table 16 summarises the matters which gave rise to their submission for examination.

TABLE 16
CATEGORY OF OFFENCE OR INCIDENT

Arson and fires	44
Hit run traffic	13
Stealing	13
Sex offences	12
Murder	11
Explosives	10
Wilful damage	7
Assaults and wounding	3
Unclassified	7

As in previous years, suspicious fires accounted for a considerable number of cases. In 39 per cent of all fires investigated some fire accellerant was detected, with petrol residues being detected in nine cases, kerosene residues in four cases and diesoline in three cases. In addition to the investigation of suspected arsons, this Division is often asked to comment on the likelihood of spontaneous combustion causing certain fires. In the vast majority of cases no such cause is found to be at all likely. There were, however, three cases worth mentioning. One involved the transportation of a large quantity of calcium hypochlorite (swimming pool chlorine) by truck when the vehicle suddenly caught fire and was destroyed. It was concluded that the unstable nature of certain calcium hypochlorite with the conditions and possible contamination was the most likely cause of the fire.

A second fire occurred in a container terminal at Fremantle. In this case the substance involved was 'Butanox', a mixture of methyl ethyl ketone peroxide and dimethyl phthalate which is used in the plastics industry. Methyl ethyl ketone peroxide is a powerful oxidising agent and will decompose spontaneously above 50°C or when in contact with certain compounds. In this case the cargo was loaded in the same container as buckwheat and stannous octoate. It was established that high temperatures and the possible mixing with adjacent cargo was the most probable cause of the fire.

The third fire which occurred in a car involved a disposible cigarette lighter which was said to have spontaneously ignited. Examination revealed that the lighter had been heated externally causing it to rupture. The fuel gases, mainly butane, require a high temperature for ignition and it was concluded that a flame pre-existed in the car. The escaping butane was found to have exacerbated the fire but not to have caused it.

Paint specimens continue to be major evidential items and the examinations are mainly comparisons of paint detached during criminal activity or accident with a suspect or control paint. Other cases involve relating an unknown paint to a possible motor vehicle type.

A greater number of explosions were investigated during 1978. The majority of these were found to be improvised mixtures and were usually associated with acts of vandalism. Two explosions were found to have involved gelignite and two others were found to have involved stolen army ordnance.

A number of articles were examined for gunshot residues. In one case it was required to determine whether a home made device had been used as a firearm. Analysis of swabbings from the barrel showed that it contained black powder decomposition products, enabling a prosecution to be made. Other cases involved determination of firing range and detection of residues on the clothing of the weapon firer.

A considerable number of miscellaneous exhibits were examined and included such items as sheepskins, coins, vomit, tyres, rubber, car polish, glues and adhesives. Such variety requires the use of many different examination procedures and considerable experience in assessing their evidential value.

The size and range of exhibits which are being submitted for examination is tending to indicate the use of more sophisticated techniques than we now have available. Such a technique is scanning electron microscopy and the facilities of the C.S.I.R.O. and W.A.I.T. have been borrowed on an *ad hoc* basis. It is anticipated that formalised access to an S.E.M. will allow development work in addition to casework.

An important event which occurred during the year was the inauguration of Government forensic chemist conferences, the first meeting being held in Sydney and at which all States were represented. A wide range of topics of forensic interest were discussed including methodology, instrumentation, case studies and general topics. Also held in Sydney immediately prior to the forensic chemists conference was an expert witness seminar organised by the Australian Forensic Science Society from which useful ideas were acquired.

MARITIME POLLUTION

Thirty five samples of oil were received in connection with ten incidents of maritime pollution. These samples include oils both from the pollution episode and from possible offenders and were analysed to identify the sources of the oil spills. In five cases the spill was confirmed as having come from a particular vessel.

CONFERENCES—PAPERS

N. T. Campbell attended the Annual Conference of Forensic Toxicologists and the Annual Conference on Illicit Drugs both of which were held in Adelaide.

B. F. Lynch attended the inaugural meeting of Government forensic chemists in Sydney. He also lectured to a number of the Detective Training School courses.

V. J. McLinden attended the Meeting of Racing Analysts held in Brisbane in conjunction with the Association of Official Racing Veterinarians.

A paper entitled "Analysis of Horse Urine for Evidence of the Administration of Diazepam (Valium)" by V. J. McLinden and C. M. Polanski was submitted to the Proceedings of the 32nd Meeting of the Association of Official Racing Chemists (1978).

A paper entitled "A Chromatography System for Drug Identification" by V. J. McLinden and A. M. Stenhouse has been accepted for publication in Forensic Chemistry International.

V. J. McLINDEN,
Chief Forensic Chemistry Division.

INDUSTRIAL CHEMISTRY DIVISION

The Division continues to receive enquiries covering a wide range of subjects from Government, private industry and the general public. This consultative work involves much effort in searching the literature to assist in answering these enquiries. As before, a large proportion dealt with plastics.

Dr Smith again delivered the final lecture to the Know Your Plastics series organised by the Plastics Institute of Australia and also a talk on plastics to WAIT architctural students. He also acted as chairman of a seminar, 'The Cost of Burning', organised by the Australian Fire Protection Association through the University Extension Service.

As chairman of the WA Branch of the Oil and Colour Chemists Association, Dr Smith acted as host to the Annual Convention of the Association held this year in Perth.

Dr Smith was also a member of several judging panels of the Industrial Design Council.

MATERIALS TESTING

Paint

1. As in previous years the major activity has been the Government paint tender and 38 samples of paint were supplied ex Government stock. These were tested for compliance with the appropriate GPC specifications and comparison with the reference samples. The paint tender itself was called very late this year because of the need to add several new items and work is still in progress.

2. A complaint of poor hiding power from Northam Hospital was found to be caused by low viscosity. In the laboratory test for wet hiding power, satisfactory results were obtained, but in practical application a low viscosity usually means that too thin a coating is applied.

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3. An examination of samples of paint flakes taken from three areas of a new school turned out to be more difficult than expected. The specification required four coats to be applied and in two cases only three coats were found. The difficulty arose in determining whether two top coats had been applied. Normal methods of examination did not show two coats, but film thickness indicated that there should be. It was not until scanning electron microscopy was used that two layers were found. The missing layers were undercoats.

4. A synthetic rubber coating from Germany was examined for Public Health Department. The coating had been proposed as a lining for grain bins. The base material was found to be chloroprene rubber as claimed, in the form of a room temperature curing latex. Information obtained and work done on the sample indicated it was likely to comply with German Health Regulations for use in contact with foodstuffs and should be acceptable.

5. The paintwork of a car was claimed to have been badly spotted by a termite control spray and Consumer Affairs Bureau requested an investigation. Painted test panels from the paint manufacturer were obtained and spots of diluted insecticide, bore, tap and distilled water were applied to them. The panels were dried in the hot sun and all samples except distilled water produced spots which could not be completely removed by detergent washing, but could be polished off. The insecticide spray gave the worst results.

6. A number of other more minor investigations were carried out during the year. These included: lifting of paint from wooden laboratory bench tops around sinks and caused by water penetration; cracking and breaking up of white lines on bitumen paving caused by applying too thick a coating on a hot day; determination of viscosity of several samples of bituminous paint; examination of the rheological properties of two duplicator inks, one of which soaked through the inking pads too quickly; staining of paint on newly plastered and painted walls caused by high alkalinity in the plaster (pH above 13).

Building Materials

1. Thirteen samples of various carpets were examined during the year. Ten were submitted to the range of tests normally applied. As a Taber Abraser was purchased during the year all abrasion tests are now done on this machine. One sample of locally made carpet faded very badly on exposure to UV light in the weatherometer. The other three samples were complaints raised with the Consumer Affairs Bureau and submitted for investigation.

2. Thirteen samples of vinyl flooring were submitted One sample was tested for durability, etc., as for carpets. The other twelve samples were abraded under standard conditions on the Taber Abraser. They formed part of an investigation of flooring materials for use in hospital radiological laboratories and intended to determine ease of decontamination of any spillage of radioactive materials.

3. Because of some worker complaints during the installation of air conditioning ducting, a number of samples of various components were submitted for identification of materials used. The components included a heat-shrink sealing band with adhesive, fibrous insulation and a laminated aluminium foil. Identifications were made and composition of possible fumes discussed.

4. A batch of lightweight building bricks was tested. These had been made by firing a mixture of sawdust and clay, following research done by the CSIRO. Various standard tests were carried out such as dimensional measurements, water absorption, suction, tendency to spalling and shrinkage.

5. Six samples of concrete underlay were submitted by PWD Architectural Division. Some were new materials not previously tested, but all were of similar construction, being woven from polyethylene ribbon and laminated on one side to polyethylene film. Tests applied were those reported previously. Only two materials adequately passed the test programme and these have now been approved.

6. As an indication of the importance of concrete underlays, adhesion failure of carpet tiles in two houses at Kununurra was investigated for Main Roads Department. The houses had concrete floors with no underlay. Moisture was present under the tiles and this was no doubt the cause of the failure. Treatment required removal of adhesive and the sealing of the concrete surface with a suitable waterproofing treatment such as a water-based epoxy coating.

7. A complaint concerning the poor performance of a floor polish was submitted by Education Department. A reference sample was supplied with the faulty material. The latter was found to contain a small quantity of dibutyl phthalate. Addition of this amount to the reference sample, which had performed satisfactorily, caused it to give unsatisfactory results similar to the faulty sample.

8. Other matters dealt with during the year included: an examination of damaged galvanised shelving; problems with ammoniated strippers for floor polishes at two country hospitals; effect of cement-based tile grouting on unprotected skin; a synthetic rubber flashing and sealant identified as EPDM rubber and silicone building sealant respectively.

9. Tenders received for the Floor and Wall Maintenance Products Tender were examined and recommendations made. Some testing will be carried out on the selected products.

Plastics

1. A sample of clear, reinforced plastics hose for conveyance of beer was submitted for identification. It was found to be plasticised PVC with 57 percent of plasticiser, which was found to be largely decyl 2-ethylhexyl phthalate. A hot extraction with a 4 percent solution of alcohol extracted only 0.06 percent of phthalate ester. The hose was considered to be satisfactory for use with beer.

2. A plastic putty for use in car body repairs was identified as a standard polyester resin containing styrene. The hardener was benzoyl peroxide in a phthalate ester. Advice was given on handling precautions.

3. Five samples of PVC work gloves were submitted for testing by State Energy Commission. PVC coating thickness was determined and resistance of the gloves to petrol, fuel oil and a jointing compound used by the Commission. The two gloves with the thickest PVC layer were resistant, but the others showed some penetration of the liquids. All samples passed an impact test without damage.

4. As the result of a claim that a 2,4,5-T weedkiller spray had damaged a soft contact lens and caused temporary blindness in a spray operator, Public Health Department requested test to be carried out. Soaking of lenses for 24 hours in use dilutions of both ester and amine forms of 2,4,5-T had no effect.

5. A fibreglass reinforced PVC fabric with antibacterial properties for use as a mattress ticking was submitted by Mental Health Services. When tested for flammability by BS2963:1958, "Vertical Strip Test", the result was 'flame not propagated'. Contact for 24 hours with urine, blood and faeces did not cause staining.

6. Other investigations dealt with included: identification of organic fibres in a building dust as PVC/PVA copolymer; identification of type of rubber in washers for Metropolitan Water Board; determination for Main Roads Department of fibre content in reclaimed rubber crumb locally produced from scrap tyres; and for the same Department confirmation that a sample of polystyrene granules was in fact pure polystyrene.

Miscellaneous

1. Six samples of synthetic turf were tested on behalf of the Community Recreation Council for the surfacing of an international standard hockey field. The tests applied were similar to those used for the Perry Lakes synthetic running surface tested last year and included frictional properties, resilience, resistance to UV light, etc.

2. Tenders submitted for the Detergent Tender were assessed and a recommendation made.

3. Two lots of termite bait based on the insecticide Mirex were prepared for the Office of Regional Administration and the North West for experiments on the control of Mastotermes.

4. A sample of engine oil from a car with a seized engine was submitted by Consumer Affairs Bureau. It was extermely viscous and it was thought that this may have been the cause of the engine failure. The sample was found to contain a very high proportion of water plus some unburnt fuel. The oil content was only 27 percent and the sample was in fact a water-in-oil emulsion. As supplied its viscosity was 5000 cs at 37.8°C and after drying it was 200 cs at 37.8°C and 19.7 cs at 98.9°C. The viscosity of the dried oil was quite normal for a used 20W-50 multigrade oil. The sample would have been too viscous for circulation in the engine and may have caused the failure.

5. Other investigations for Consumer Affairs Bureau included: a cardigan with one colour not fast to washing and which marked off on testing; a carpet sold as 80 per-

cent wool, 20 percent nylon which was found to be at least 96 percent nylon; a jumper with a torn collar probably caused by excessive force during removal; a polyester/cotton sheet claimed to have shrunk during normal washing—a sample of similar material shrank significantly only at the boil; a stainless steel saucepan with a copper base pad cracked in the stainless steel around the circumference of the pad; a light cotton skirt claimed to have caught fire when about two feet away from a kerosene heater.

6. Other investigations included: a sample of transformer sealing jelly for evidence of carbonisation and test for its temperature resistance; a sample of flameproof mattress ticking for flammability testing—found to be non-burning under the conditions of the test; analysis of oil sludge from a waste oil treatment plant for water and acidity—acidity was similar to many vegetable oils; analysis of laundry detergent for comparison with the reference sample and the manufacturer's claimed composition.

ASSISTANCE TO INDUSTRY

1. Samples of white PVC cattle tail tags, some with black and others with red lettering, were tested for resistance to UV light in the weatherometer, resistance to scrubbing and urea solution. All samples behaved satisfactorily for their end use.

2. Samples of double tongue and grooved pine panels were tested in accordance with AS1530 Part 3, "Early Fire Hazard Test of Materials", for a timber company.

3. Further work was done on the treatment of synthetic pig swill to remove water and fat.

4. Several car window stickers supplied by a major vehicle distributor were exposed in the UV weatherometer for 500 hours. There was some fading and yellowing in all samples with little difference between them.

5. A total of 71 painted steel panels were exposed in the salt spray cabinet. The objective was to assess the performance of local micaceous iron oxide in comparison with imported material and in a variety of paint resin systems. The initial exposure was for 500 hours. The best 20 panels were selected and exposed for a further 500 hours. The local micaceous iron oxide generally performed satisfactorily.

7. The bonding of bronze plaques to brickwork was investigated for the Karrakatta Cemetery Board.

8. A sample of wet karri bark was submitted by a timber company for drying at a low temperature. Freeze drying was used.

9. At the request of a firm of solicitors a report was prepared on the flammability of plastic rope after a sample had been identified as polyethylene.

10. Sixteen samples of small cement blocks pigmented with several different black pigments, such as carbon black and black iron oxide, with different additives were submitted to a water spray in the spray cabinet for 500 hours. The blocks were unaffected by the exposure and in particular no leaching of carbon black was evident.

INVESTIGATIONAL

The test panels on outdoor exposure for the clear finishes for timber project have now been exposed for a year and a report is being prepared on results obtained.

CONSULTATIVE

As usual a wide range of enquiries was received from all sections of the community and a selection is given below:

- Materials of construction for a gold recovery plant.
- Painting of swimming pools and control of water quality.
- Detergent formulations for carbonised fat removal.
- Advice on leather manufacture.
- Use of urea—formaldehyde foam for insulation.
- Casting of plastic models of body parts.
- Disposal of starch wastes.
- Growth of algae in fibreglass reinforced plastics water tanks and repair of damaged tanks.
- Plastic strip for gym. floor markings.
- Formulation of a fly lure.
- Fungicidal treatment of painted panels and chipboard cupboards.
- Use of plastics in building for a Technical Education textbook.
- Waste treatment for recycling.
- Use of plastic materials at CSIRO Laboratories to eliminate trace metal contamination of water for feeding trials.
- Plastic coated metal pipe for handling sewage.
- Formulation of deodorant for portable toilets.
- Use of plastics in sculpture.
- Storage of hazardous chemicals.
- Cracking of PVC irrigation pipe at joints.
- Plastic tarpaulins for fumigation.
- Properties of Boronia essential oil.
- Biodegradability of detergents.
- Materials of construction for plant to treat apples with calcium chloride.
- Plastic film for air inflated hospital bed covers.
- Production of solid tyres from scrap rubber crumb.
- Formulation of type correction fluids.
- Adhesives for brake pads.
- Sealing of terrazo floor panels at entrance to Parliament House.
- Supply of design data for fibreglass reinforced plastics.
- Packaging of briquettes of nickel metal in plastic film.
- Use of PVC flooring in MTT buses.
- Formulation of zinc rich paints.
- Welding of PVC swimming pool liners.

E. B. J. SMITH,
Chief, Industrial Chemistry Division.

KALGOORLIE METALLURGICAL LABORATORY

GENERAL

The Kalgoorlie Metallurgical Laboratory carries out research in mineral beneficiation and ore dressing for mining companies, consultants and individual prospectors. Both its metallurgical and assay resources are available to the public and Government Departments.

The rising price of gold was the major factor responsible for an increase in workload during 1978. Certificates for metallurgical investigations increased to 37 from 21 in the previous year. Over two thirds of the metallurgical investigations undertaken related to gold beneficiation.

Towards the end of 1978 an arrangement was reached with North Kalgurli Mines Ltd for this laboratory to carry out all metallurgical test work associated with the evaluation of gold ores offered by prospective clients for the proposed custom milling plant. This arrangement will continue until a permanent laboratory is established by the company and is expected to contribute significantly to additional workload in 1979.

METALLURGICAL INVESTIGATIONS

The number of investigations reported to sponsor clients increased to 37 (21 in 1977). Gold was the dominant metal investigated and cyanidation was the metallurgical process most frequently used. The frequency of mineral beneficiation investigations is presented in Table 17.

TABLE 17.

MINERAL BENEFICIATION

Mineral	No. of Investigations
Gold	26
Copper ore	3
Graphite	2
Talc	1
Attapulgite	1
Iron ore	1
Miscellaneous	3
Total	37

In carrying out the above investigations the following metallurgical processes were encountered: cyanidation (19), sizing (5), flotation (4), leaching (3), gravity separation (2) and miscellaneous (4).

Gold

Gold Tailing Retreatment: During 1978 twelve investigations were carried out into the retreatment of old residues by cyanidation. The most frequent method requested was column leaching, this method being used to simulate re-cyanidation of tailings in plastic-lined earth wall vats.

A number of clients proceeded with tailing retreatment. These investigations highlighted a number of treatment problems that would be encountered in field practice. They include:—

(a) the serious effect of cyanide soluble copper, resulting in very high cyanide consumptions;

(b) the poor percolating properties of a number of tailing residues;

(c) the frequent high lime consumptions encountered due to high bi-carbonate mine waters or tailing residues with high lime consuming properties.

Internally innovated programs will be designed in 1979 to further investigate the above problem areas.

During the year the carbon-in-pulp method of cyanidation has achieved greater acceptance. This method is particularly suitable for tailings with poor percolation properties. Wider acceptance of this method should continue if treatment of loaded charcoal can be carried out within Western Australia. Currently one loaded charcoal stripping and gold electrolysis plant is operating at Bullfinch.

Gold Ore from Bamboo Creek: A high grade ore from this area was investigated by battery grinding and cyanidation. Most of the gold present was found to be refractory. Using flotation a high gold recovery into a sulphide concentrate was achieved. Due to the fine disseminated nature of the gold bearing sulphides present, concentration by tabling was not successful. Further work on this ore will be undertaken next year.

Gold Ore from Mt Ida: In contrast to the ore from Bamboo Creek, the Mt Ida ore proved to be free milling with a high proporition of the gold being recovered in the amalgamation circuit. The balance of the gold is easily cyanided to a low residue.

Copper

A number of investigations were continued during the year for Whim Creek Consolidated N L on a predominantly sulphide copper ore from the Wyundo ore body. The main sulphide mineral is pyrite while chalcocite is the main copper mineral. Approximately 30 percent of the copper is present in an oxidized form. A coarse fraction of the ore was successfully leached using a combination of sulphuric acid and bacterial leaching. A further programme on discarded fines is now in progress. Leaching in remote areas has to be carried out with low operating costs. Bacterial leaching of sulphide ores is a hydrometallurgical process that is well suited for such a task.

Graphite

A successful pilot plant scale investigation on the Munglinup graphite deposit was concluded for Norseman Mining N L early in 1978. Further upgrading investigations on a laboratory scale produced a very high grade graphite concentrate, indicating the potential of a higher purity product in an efficient metallurgical plant. The pilot plant concentrate product, after undergoing an aciding stage to remove acid soluble impurities, is now being used by the Company for market development.

Miscellaneous

Two novel investigations of a preliminary nature were the benefication of the fines from a talc deposit by flotation and the removal of quartz from a high grade attapulgite deposit.

ANALYTICAL SERVICES

Supported by good fire assaying and atomic absorption spectrophotometric facilities, experienced assaying staff undertook a large range of analyses of varying complexities. Two important services to clients in 1978 worthy of mention are the umpire assaying of nickel concentrates for Metals Exploration Ltd and gold bullion assaying at public request. Both services require a high degree of accuracy and reproducibility.

STAFF

This year saw the retirement of the Senior Research Metallurgist, Mr H. Dunstan and the Officer in Charge, Mr G. Muskett. Both officers contributed greatly to the services and reputation of this laboratory and their experience will be missed.

ADVISORY AND CONSULTATIVE

Advisory services to the mining public on treatment problems and operating techniques continued throughout the year. More emphasis will be placed on inspections of both large and small metallurgical operations to obtain on-site familiarization of new processing techniques.

A number of small cyanidation operators use the laboratory for continual consultative services on operating problems. The unique problems of small scale remote treatment plants will be examined in greater depth in the future.

BUILDING

The laboratory drew up draft specifications on room sizes and fittings for the proposed new laboratory. It is hoped that construction of the new laboratory in conjunction with the School of Mines and Technical Education Division metallurgical buildings will proceed in the next financial year.

A. MYKYTIUK,
Officer in Charge,
Kalgoorlie Metallurgical Laboratory.

MINERAL DIVISION

GENERAL

A survey of the general statistics covering sample receivals indicate a year very similar to 1977. The submissions direct from the public were again approximately 12 percent of the total but the proportion of these done at public expense was less.

The 372 examinations done for the public on a fully commercial basis again consisted largely of products from investigations conducted at the Laboratories, and mineral identifications for which the client did not wish to disclose the locality of occurrence.

The major sources of samples were again the Geological Survey Branch, 29 percent, other Branches of the Mines Department, 14 per cent, and the Public Health Department 35 percent. This latter figure is an increase from 26 per cent in 1977, and represents additional monitoring of dust hazards and nuisances.

The volume of work associated with the sample numbers is largely in the analyses of silicate rocks which rose from 85 last year to 764 in 1978. Production of data on these rocks by x-ray fluorescence spectroscopy was greatly hampered by breakdowns of the equipment for which technical service was delayed to an unsatisfactory degree with the resultant loss of several months of machine time. The expected increase in capacity associated with the installation of a logic controller to the spectrometer was not fully realised because of extended delays in installation which was still not complete at the end of the year. Additional difficulties in management of the laboratory derived from an extended period of repair and renovation of the Division's building which necessitated movement of equipment and personnel.

Other areas of activity have included participation in the production of Australian and International Standards, the supply of information from systematised records re mineral occurrences, and interpretation of reports obtained by Government Departments from other laboratories.

The sources and nature of the samples received are shown in Table 18 on Page 25.

ROCK EXAMINATIONS

A number of geochemical studies requiring complete silicate rock analyses with trace element determinations and quantitative mineralogical analyses were concerned with elucidating the environment of deposition of sediments. These included bore samplings through the Mt. McRae shales to the iron ore formation of the Rhodes Ridge central deposit. Particularly useful element concentrations are boron, gallium, potassium and rubidium.

For interpretation of the geology of dam foundations, complete chemical and mineralogical analyses of rock types were necessary to classify a structure which was possibly a fault in strongly sheared granite, or a dolerite dyke. Materials occurring in joint planes which in a number of incidences were shown to be laumontite-leonhardite, were examined to predict engineering properties and problems which might occur in the construction of a dam tunnel.

TABLE 18

MINERAL DIVISION

	Geological Survey	Government Chemical Laboratories	Main Roads Department	Metropolitan Water Board	Mines Department	Police Department	Public Health Department	Public Works Department	Road Traffic Authority	Other	Public			Total
											Pay	Concession	Free	
Building Materials	....	....	8	....	....	....	....	4	....	9	7	....	....	28
Dusts	....	8	....	....	471	....	1 353	....	....	14	7	....	....	1 853
Forensic Examinations	....	....	....	....	....	57	....	....	....	....	....	....	....	57
Geochemistry	148	3	....	....	....	....	....	....	....	....	3	1	....	155
Mineral Identifications	26	103	2	....	2	....	32	2	....	16	51	36	7	277
Miscellaneous	4	10	6	24	5	....	8	....	....	3	5	....	....	65
Ores and Minerals—														
Clay	5	....	....	....	....	....	....	17	....	....	8	2	....	32
Copper	....	4	....	....	....	....	....	....	....	....	47	....	....	51
Gold	33	....	....	....	12	....	....	....	....	....	22	35	21	123
Iron	29	57	....	....	....	....	8	....	....	....	3	....	....	97
Lead	....	....	....	....	43	....	12	....	....	....	....	....	....	55
Limestone	102	....	....	....	....	....	....	....	....	....	....	....	....	102
Vanadium	....	....	....	....	....	....	....	....	....	....	136	....	....	136
Zircon	....	34	....	....	....	....	....	....	....	....	48	....	....	82
Various	32	22	7	....	10	....	8	2	....	5	18	....	....	104
Silicate Rocks	764	....	....	....	....	....	....	....	....	....	....	....	....	764
Pyrometry	....	....	....	....	....	....	....	....	10	....	14	....	....	24
Total	1 143	241	23	24	543	57	1 421	25	10	47	369	74	28	4 005

Throughout the year series of samples were examined to determine the properties of materials used in construction of the Wungong and other dams. This was necessary, since various soil types were disclosed in obtaining filling material and blending of some soils was necessary to control engineering characteristics. In most cases a quantitative assessment of mineral species, particularly clays was needed.

Other rock examinations were to define the mineralogy of the cherts in the Bangemall Basin on the Edmund, Mt. Egerton and Collier 1 : 250 000 sheets, and to deduce the environment of deposition of the older limestones on the Winning Pool sheet of the Carnarvon Basin, and the iron ore formations of the Nabberu Basin.

A major group of samples was part of a study of the potential for mineralisation of the Saddleback greenstones and the heavy metal content of various fractions was examined.

A group of samples requiring examination to provide explanatory notes for the Regional Mapping 1 : 250 000 geological sheets was concerned largely with anomalous mineral occurrences. The sheets concerned were Ajana, Bremer Bay-Newdegate, Byro, Glengarry, Glenburg, Kirkalocka, Ninghan and Wiluna.

Work is currently in hand on a project for complete geochemical characterisation and assessment of potential for mineralisation of various rock types from individual batholiths in the Pilbara region. X-ray fluorescence determinations made have numbered 4 057 and sample preparation is well advanced for the outstanding samples.

MINERAL IDENTIFICATIONS

These identifications have been made largely for the public and in the course of maintaining a record of occurrences. Others have been made for the Geological Survey on material not recognised in routine petrology. A group of growing size consists of dusts other than those from routine dust surveys which have to be related to sources of occurrence.

As in the past, in addition to those samples treated in the laboratory numerous identifications were made by visual inspection, free of charge.

Other mineral occurrences, recorded largely from material acquired by the Division by approaches to companies and individuals were:

Andalusite crystals from fuchsite schist in the Paynes Find area.

Dump material from the Hainault Mine, Kalgoorlie containing anhydrite, tetrahedrite, chalcopyrite, sphalerite and celestite with common gangue minerals.

Palygorskite from Lake Nerramyne, a possible economic source of the mineral.

Wolframite, chalcopyrite, covellite and powellite from Brookton.

Glaukosphaerite from Farrell Well. Clinobisvanite from Hillside. Both the above specimens are of material first described in Western Australia.

Bindheimite, newberyite, mimetite, plattnerite and hollandite in secondary lead ore from the Silent Sisters Lead Mine, Wyloo. Variscite and leucophosphite from a number of sites covering the veins at Ninghaboun Hills.

Aphthitalite, sylvite, whitlockite and hannayite from Winbirra Cave, Nullarbor Plain.

Franklinite in drill core from a zinc deposit near Mukinbudin.

Wolframite concentrate associated with pharmacosiderite, and scorodite from altered arsenopyrite at Dalgaranga.

Kimberlite containing pyrope and ilmenite, from Geebung and Barnes Well areas.

Lithographic stone from Morwa Island, off Onslow.

Spessartine crystal and celadonite of lapidary interest from Marble Bar area.

Marcasite and pyrite partially altered to crusts of thenardite, aluminite, jarosite and melanterite from a mine dump 5 km south of the old Burbidge townsite.

New Mineral Occurences

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.

All of these species had been previously identified in Western Australia.

The Divisions used, are those of Simpson's "Minerals of Western Australia".

Kimberley	
Dolomite	Nabberu
Ilmenite	Geebung
Pyrope	Geebung
North West	
Axinite	Tom Price
Baryte	Giralia Range
Celadonite	Marble Bar area
Epidote	Tom Price
Gypsum	Giralia Range
Hollandite	Wyloo Station
Lepidolite	Paynes Find
Newberyite	Wyloo Station
Powellite	Hillside Station
Canning	
Goethite	Wolf Creek Meteorite Crater
Maghemite	Wolf Creek Meteorite Crater

Murchison	
Andalusite	Mt. Magnet
Beryl	Five Mile Hill
Beryl	Kirkalocka
Brochantite	Glenburgh
Chloritoid	Mt. Magnet
Feldspar	Five Mile Hill
Feldspar	Kirkalocka
Fibroferrite	Glenburgh
Goethite	Glenburgh
Hematite	Glenburgh
Muscovite	Glenburgh
Palygorskite	Lake Nerramyne
Pyrophyllite	Mt. Magnet
Quartz	Glenburgh
Quartz	Kirkalocka
Central	
Aluminite	Burbidge
Aphthitalite	Nullarbor
Hannayite	Nullarbor
Jarosite	Burbidge
Marcasite	Burbidge
Melanterite	Burbidge
Melonite	Kambalda
Pyrite	Kambalda
Pyrite	Burbidge
Septechlorite, Nickel	S. Windarra
Sylvite	Nullarbor
Thenardite	Burbidge
Uvarovite	Menzies
Whitlockite	Nullarbor
Warburton	
Hollandite	Wanarn
Pyrolusite	Wanarn
South-West	
Cryptomelane	Smithfield
Molybdenite	Needilup
Quartz	Kundip
Sulphur	Kundip

MINERAL COLLECTIONS

The collections maintained by the Division are the Simpson Collection of 4 989 entries and the Mineral Division Collection now numbering 6 206 specimens. In 1978 one hundred and nineteen specimens were added representing localities in Western Australia. A further 17 specimens from overseas and 4 from Eastern State localities were added in donated suites.

An appeal is made to companies and individuals having access to unusual mineral species to donate specimens to the Laboratories collection.

Specimens of interest received from overseas localities and included in the Mineral Division Collection during 1978 were:

A suite of telluride-bearing gold ore specimens from the Emperor Mine, Fiji, which contained the species krennerite, tellurium, sylvanite, petzite and coloradoite associated with hexahydrite and common gangue minerals.

Several specimens of holtite from the Kola Peninsula U.S.S.R., the second recorded world occurrence of this mineral described for the first time in Western Australia.

ORES AND MINERALS

Clay

Apart from clay species examined as part of the mineralogy of sedimentary deposits being mapped, the largest group was concerned with engineering properties in relation to the construction of dams at Wungong Brook, Logue Brook and in the Pilbara. Also of engineering interest were clays for Main Roads Department in relation to track stabilisation. In some instances clays failed to respond to lime stabilisation. Clays relative to foundations at a building site were examined for Public Works Department.

Clay species were identified in a number of prospecting samples including those taken in search of potters clay and for replacement of raw materials for a brickworks. The suspended matter in water supplies was examined to decide whether the material was clay natural to the area, or drilling mud.

Copper

Work on copper products largely was derived from sponsored and Departmental experimental programs on copper hydrometallurgy.

Prospectors samples included oxidised ore assaying 33 and 21 percent copper.

Gold

Check assays for gold were made on State Battery tailing samples, and 2 umpire assays were made.

Gold was included in numerous scans of trace elements for Geological Survey projects, and assays were made of experimental products from the Engineering Chemistry Division.

Values of note from prospectors samples included (grams per tonne); Calyerup Creek (22), Comet Vale (17), Fields Find (34), Jerramungup East (49), Kundip (15), Marble Bar (18), Paynes Find (101), Southern Cross—roasted slimes (2 480), Yillaring (10) and Yundamindra Station (129).

Gold nuggets discovered with metal detectors were examined from several localities. Some containing more than 300 g of gold were reported from Laverton, Murrin and Sandstone.

Iron

Iron ores examined derived mainly from a survey of the quality of various iron ore Temporary Reserves. Several ores were comprehensively analysed as head samples for an Engineering Chemistry Division investigation of upgrading procedures for banded iron formations. Investigation of analytical methods for establishing Australian and International Standards continued.

Lead

Assessment of the deposit, by the State Mining Engineer, was the reason for the analysis of a group of samples from the Mary Springs Lead Mine.

A calculation was made of the probable analysis of a commercial parcel to be made up of proportions of separated fractions, the property of the Northampton State Battery.

A private sales parcel of lead ore was analysed comprehensively.

Limestone and Limesand

Limesands examined were entirely from an assessment of resources in the Dampier Archipelago. Limestones in the Carnarvon Basin were examined for Geological Survey Mapping.

Sands

Cretaceous sands from north east of Wanneroo were examined as part of a study of Northern Corridor resources.

An examination of metropolitan sand supplies included chemical and sizing evaluation of sands including potential glass sands, from Banjup, Beechboro, Canning Vale, Gnangara and Jandakot.

Vanadium

Samples of natural and beneficiated cap-rock ore were analysed as head samples of an investigation of extraction processes. Experimental products were analysed for total and water soluble vanadium and sodium.

The crystal form of saltcake from precipitators at a vanadium plant was established.

Zircon

All zircon samples were either head samples or experimental products derived from upgrading investigations at Engineering Chemistry Division or in this Division.

BUILDING MATERIALS

Examinations of building materials have again been associated largely with failure of mortar either in masonry construction or in plastering of internal walls. The investigations generally arose from complaints to the Consumer Affairs Bureau and include not only examination of submitted samples but also interpretation of reports made to clients by private laboratories.

The point which is required to be established is generally the proportions of the original mix, on the assumption that a weak mix may be the cause of failure.

It is important to note that while a weak mix may be a contributory cause there are many facets of technique in mixing and applying the mortar which may have overriding effects. One of the most important of these, in the Western Australian climate, is to ensure that moisture required for setting of cement type mortars is not drawn out by insufficient wetting of the supporting surface.

An examination of the chemical basis for establishing the proportions of constituents in an original mix should be made. Such an assessment is generally by a method analogous to Australian Standard AS A110 for determining the cement content of hardened Portland cement concrete, although this is restricted for greatest accuracy to situations where samples of original materials are available.

The Australian Standard A123-1963 dealing with mortar for masonry construction does not recommend a method of estimating the original mix, and in fact specifies the mortar types by mix proportions only when the constituents are confined to Portland cement, hydrated lime and fine aggregate (sand).

Current building practice includes the use of "masonry" cement of which two distinct types are marketed in W.A. Without knowledge of the original components it is only possible to make very guarded statements regarding the original mix of a set mortar and these must be based on assumptions regarding the composition of the original constituents.

Another area in which opinion was sought by the Bureau of Consumer Affairs, on a report from a private laboratory, related to rejection of a sand as a fine aggregate. The sand did not fully conform to the requirements of Australian Standard AS 1465-1974 but fell within the limits at which it would not be rejected outright. An oral opinion apparently given by the private laboratory was not supported in the report issued.

A series of brick, mortar, and water samples from the Shire of Boulder was analysed to assist a visiting expert in assessing the value of a patented but dubious method of preventing rising damp in walls.

A sample of Twertup stone (spongolite) was submitted by a financing institution for an opinion regarding its suitability for use in construction of a private home. As in many instances of this type, the sample submitted was small and could not be related to the mass of stone which would be used in construction. The appropriate action when use of a natural stone is contemplated is to have the potential supplier submit a sample of quality to which he can supply. Comparison of actual deliveries and this sample can then be made. A major factor in the use of such a porous material as spongolite is the thickness and siting of the walls in the design, relative to roof protection.

FORENSIC EXAMINATIONS

Mineralogical examinations were made of 57 samples from the Police Scientific Bureau to assist in investigations and to provide court evidence.

A high proportion of these examinations consisted of the comparison of soils from the scene of a crime, often rape but including murder and robbery, with mineral matter associated with the victim or a suspect. Generally the mineral matter was adhering to items of clothing, but included also were vehicle mudguards and interiors. In several cases distinctive mineral assemblages, including artificial minerals, were correlated.

Exhibits from Reabold Hill and from a car suspected to have been used in a robbery, were compared mineralogically. Gouge marks on the underside of the car were also compared with marks on the rocks. Microscopical, chemical, x-ray examination and photography were used to show that the material and gouge marks on the car were consistent with having originated from the Reabold Hill site.

A metal particle found in a stolen safe was compared with a suspect's chisel, and soil from inside the safe was compared with sand from the point where the safe was buried. The steels of the particle and the chisel were found to be different.

A cut-down rifle and a hacksaw with blades thought to have been used in the modification of the said weapon were submitted for comparison. Optical examination showed a close correlation between the distinctive wood of the stock with wood particles on the blades. Conversely, thin smears of aluminium on the sawn wood surface correlated by X.R.D. with aluminium surface films coated on several of the suspect hacksaw blades during manufacture, as anti-corrosion agent.

Two officers made Court appearances in connection with these cases.

HEALTH HAZARDS

Asbestos Hazard

Asbestos in air: Because of increased public awareness, asbestos related materials represented a high proportion of the dusts examined.

The presence of crocidolite asbestos in the soil at several sites in Wittenoom was established and a mass concentration estimated on some samples. These varied over a large range up to 0.02 percent. The fibres observed were relatively coarse compared with airborne particles but indicated the possibility of continued slow delivery as breakdown of particles continues. A survey of the air breathed in the town was commenced with volunteer residents operating personal samplers.

A trial run established the reliability of using inexperienced personnel to carry out sampling and packaging of the samples for air freight to Perth. The early results have shown a wide variation in individual exposure apparently related to differences of location and/or occupation. The survey is continuing.

The method used to estimate the concentration of fibres in the air is that published by the National Health and Medical Research Council (N.H.M.R.C.). Employing light microscopy the method is similar to that which has been used overseas to monitor the exposure of workers handling chrysotile asbestos in manufacturing industries, and thereby to correlate the incidence of lung disease with the level of exposure. In 1968 the British Occupational Hygiene Society published a hygiene standard of 4 fibres/ml, a level of exposure which was estimated to produce a 1 percent expectation of contracting asbestosis for workers handling chrysotile asbestos over a 25 year working span. The N.H.M.R.C. have adopted a hygiene standard of 4 fibres/ml for both chrysotile and amosite asbestos although there is no published data to show whether exposure to the different forms of asbestos, or to more than one type of asbestos, involves a similar risk of contracting asbestosis.

The fibres examined by this method are those between 5 and 100 micrometres in length and with a length to breadth ratio of at least 3:1. Fibres outside this range have been considered to be of no consequence. Later evidence has indicated that particles finer than these are of importance relative to mesothelioma.

Published epidemological evidence suggests that crocidolite asbestos is particularly potent in causing mesothelioma and that the level of exposure required is much lower than would be necessary to induce asbestosis. For this reason a threshold limiting value of 0.2 fibres/ml for crocidolite has been adopted or proposed in several countries. The Asbestos Regulations under the W.A. Factories and Shops Act, 1963-1978 requires a Threshold Limiting Value (TLV), on long term average, of 2 fibres/ml. In these Regulations, asbestos is defined as the minerals crocidolite, amosite, chrysotile, fibrous anthophyllite, tremolite, actinolite and any mixture of them.

Dusts examined from private homes, offices and other work places generally indicated concentrations of less than 0.01 fibres/ml and up to 1 fibre/ml but in one instance when asbestos insulation was being stripped a level of 3.7 fibres/ml was recorded.

The initial check used in these instances was to establish the nature of the fibrous material which was suspect, and many insulating materials were examined. A feature of these insulation materials is their diversity. In one large institution samples of ceiling insulation were taken from six sites in different buildings. It was different at each of the six sites. Of all samples examined 70 percent consisted of a binder with one or a combination of the asbestos species amosite, chrysotile, and crocidolite. An additional 17 percent consisted of an asbestos species with another fibre, 13 percent contained no asbestos. The additional fibre in 50 percent of the cases was slag wool but included diatomite, cellulose fibre and saw dust. Those insulating materials which did not contain asbestos consisted of slag wool, slag wool plus cellulose fibre, wood and paper fibre, saw dust, cellulose and protein fibres and finely shredded plastic. In one, the insulator was vermiculite, and another consisted only of montmorillonite clay and gypsum-plaster. The cellulose fibre of one sample was impregnated with boric acid as a fire retardant. This itself was probably the cause of the respiratory irritation reported to have been observed.

The bonding material present in the insulation was finely divided calcite in 70 percent of the cases, and cement in most of the others. The amount present varied from 10 to 90 percent of the total sample. In a number of cases the insulation consisted of two layers, generally a thick (8 mm) base coat of crocidolite, overlain by a thin (2 mm) coat of chrysotile. In one instance the layers were amosite and chrysotile.

Of all samples containing asbestos 52 percent contained amosite, 36 percent contained chrysotile and 12 percent contained crocidolite.

Some specialised insulation materials examined were: a webbing consisting of woven chrysotile; two asbestos ropes consisting of 10 percent amosite, 60 percent chrysotile with 30 percent cellulose fibre, and 70 percent chrysotile with 30 percent cellulose fibre; and a cable coating which contained 5-10 percent chrysotile with calcite and talc in a matrix of polychlorinated resin. Another woven material consisted of composite fibres of slag wool sheathed in cellulose fibre. Fibres from an air conditioner filter consisted of cotton plus fibres of polyvinyl acetate-chloride copolymer.

Settled dust from a works dealing with brake linings contained 10-15 percent chrysotile, and an associated air sample contained 0.1 fibres/ml.

Asbestos in Water. Because of current uncertainty as regards the hazard associated with orally ingested asbestos fibres an assessment of all possible environmental sources of exposure is necessary. A potential source which has not received attention in the past is the domestic use of rainwater collected as run-off from asbestos roofs. This practice is not uncommon for householders living in rural areas of Western Australia.

An investigation has been conducted to measure, under controlled conditions, the number of asbestos fibres released from a new roofing sheet. It was of particular interest to see if a relative decline in fibre concentrations would occur with repeated showering of the sheet, and if so how long it would be before the concentration stabilised at a minimum level. Also it was intended to measure mean fibre size and mineral composition, to obtain equivalent mass concentrations which could be compared with similar determinations reported for water supplies in other parts of the world.

The results of this investigation indicate that water run-off from a newly erected asbestos-cement roof will initially have a high asbestos concentration which will reduce to a sustained level approximately two orders of magnitude lower. The sustained level in the current experiment was approximately 100 x 10^3 fibres or 10 μg of asbestos per litre. The size distribution of fibres present is almost entirely in the range up to 1 μm diameter and length from 5-100 μm.

Other fibrous materials: Talc dusts were examined to determine whether fibres were present because in overseas deposits, asbestos minerals have been associated with talc. No fibres were present in the Three Springs talc samples but some fractions of Mt. Seabrook talc contained talc in fibrous form, possibly pseudomorphous after an asbestos mineral.

Dusts from a talc handling firm were also examined in relation to the National Health and Medical Research Council limit of 2.5 mg/ml.

Fibrous iron ore from Marramamba was shown to consist of goethite of ultimate fibre diameter of 0.1-0.2 micrometers (μm) and length from less than 10 to several hundred micrometers. The morphology is asbestiform and suggests replacement by iron oxides of pre-existing crocidolite. Air samples by personal sampler had a fibre concentration of 0.1 to 0.6 fibres/ml.

Other Dusts

(1) Quartz. Ninety two percent of dusts examined for free silica (quartz) were from mines or quarries with the remainder being from other work places mainly where sand blasting was in progress. Brick making and potters clays were also examined.

An investigation was made to determine the factors other than mineral dust which would contribute to the load of exposed sample filters. The relative contributions of minerals, carbon smuts and soluble salts in water were assessed.

A group of locally available potential substitutes for quartz grit for sand blasting operations was examined to establish their quartz content which was as follows—

	Quartz percent
Zircon concentrate	4
Zircon-kyanite concentrate	25
Ilmenite concentrate	0.1
Nickel slag	less than 0.1
River sand	98
Steel works slag	les than 1

The cost of some of these materials makes substitution an economically unattractive proposition but the efficiency associated with greater density is an advantage.

(2) Lead. Approximately fifty samples of lead in air were from the mining industry, particularly from the fluxing rooms of gold assay offices, but also from a survey of the Northampton district. Lead in factory air showed 0.1 mg Pb/m^3 at a battery works and 0.006 mg Pb/m^3 at a copper workshop. In a plastics factory where powdered materials consisting of lead stearate, dibasic lead phthalate, and basic lead carbonate are used, the air contained 0.19 to 2.21 mg Pb/m^3. Samples of settled dust from a foundry yard contained 5 and 29 percent lead, and from a wire works 2.5 percent lead.

Air Pollution

Samples examined in relation to air pollution have largely been from surveys undertaken by the Public Health Department.

Alumina: Samples from Naval Base area were checked for alumina but included also graphite and coal in some.

Cement works dust: A regular survey was made in the Rivervale and in the Munster areas. The latter included 196 samples. Each sample contained an array of up to 10 types of particles, and in the case of the Munster samples, 5 varieties of cement works products. To support this work a survey was made of materials used in industries located in the Cockburn-Munster area.

Iron ore dust: Sites at Cape Lambert and Port Hedland were each sampled in four directions at the rate of approximately 15 samples per month.

Lead in Perth Outer-city air: These samples were taken daily throughout the year and repeated the pattern of previous years.

Mine dust: A survey was commenced of sites at a range of 400 metres from the Mt. Charlotte gold mine. This was preceded by a study of the local soils and mine dust from the point of view of mineralogy, chemistry and physical characteristics. The identification of fresh mine dust is possible.

Phosphate dust: Several sites in the Fremantle-Kwinana area were sampled for estimation of phosphorus, sulphur and calcium.

Miscellaneous: Samples taken following nuisance complaints were examined from:

(1) Point Peron. The dust was natural to the area with domestic ash and char not of an industrial source.

(2) North Fremantle. Samples contained from 5-60 percent talc, with quartz, calcite and wheat dust.

(3) Bunbury. The dust was essentially quartz with fibres, charred wood and carbon cenospheres and traces of zircon and calcite.

(4) Osborne Park. The dust was consistent with having been derived from a granite crushing plant.

METALS AND ALLOYS

Most examinations of metals were to determine the cause of failure of various items either by excessive corrosion or mechanically.

Exceptions were an artificial mineral from north of Paynes Find which was an alloy of gold, copper, silver, tin, nickel and iron, and a child's silver ring submitted by the Bureau of Consumer Affairs. Its analysis approached the limiting figures of silver 92.5 percent, copper 7.5 percent, for Sterling silver as closely as could be expected with a minimal sample.

Mechanical failure was the reason for examination of one and a batch of six broken camshafts from the State Batteries Branch. Hardness and manganese content were both outside the specifications for the alloy. Also from the State Batteries Branch was a shoe from a stamp battery. Normal life for the type of shoe is approximately 1 000 hours. The shoe under test had shown excessive wear after 60 hours. Chemical analysis showed that the composition of the metal used was substantially consistent with the recommended specification. The observed wear was due to metallurgical treatment. Samples from Telecom Australia included a steel conduit the galvanising of which showed considerable deterioration. It was examined and compared with an unused length of conduit. The conduit which had been in service was partially covered by a heavily pitted discontinuous layer of zinc of thicknesses ranging from 3.6 to 4.6 μm. The exposed iron oxide surface consisted of corrosion products of the underlying iron. The thickness of the zinc layer on the unused sample ranged from 12-17 μm. The used conduit, when in service, had lain exposed to bore water on a large expanse of concrete. Zinc is susceptible to attack in solutions with a pH greater than 11. The pH of a solution in equilibrium with wet concrete is between 12 and 13. The corrosive action of such a solution is more severe if calcium chloride has been used in the concrete mix.

A sample of lead sheathing encasing a portion of the old multicore telephone cable to the Eastern States was examined to find the cause of failure. The sheathing was designed to carry a small positive air pressure as a moisture preventative device, but pressure was lost despite repeated repairs. When yellow and white corrosion products consisting of massicot (PbO) and basic lead carbonate $Pb_3CO_3)_2.(OH)_2$ were removed from the internal surface, a pattern of deep intergranular cracking around crystals 1 to 2 mm, was observed. The inter-granular cracks carried lead oxide, in part hydrated, indicating corrosion subsequent to cracking. The corrosion products are indicative of an alkaline environment.

Portion of a steel hot-water cylinder was examined. The steel was coated with a thick ceramic layer over-lain by a thin surface layer. Corrosion had occurred where transverse cracks in the thin surface layer penetrated to a large bubble in the thick base layer, allowing penetration of water to the underlying metal.

An inter-laboratory test with eleven participating laboratories was undertaken for the analysis of 5 elements in a silver brazing alloy. The elements were silver, nickel, copper, zinc and cadmium. In the case of each element the figure from these Laboratories fell within the 95 percent confidence limits.

PYROMETRY

Facilities for the calibration of thermometers, to the standards of the National Association of Testing Authorities (N.A.T.A.), have been maintained since no other laboratory in Western Australia undertakes this work commercially.

Responsibility for the work has been taken over by Mr. R. W. Lindsey who attended a course on temperature measurement at the National Measurement Laboratories (N.M.L.) at Lindfield, N.S.W. in July.

During the year eleven N.A.T.A. certificates of thermometer calibration were issued. Ten other thermometers were calibrated for the Road Traffic Authority.

MISCELLANEOUS EXAMINATIONS

A sample of acid from an accumulator battery which had failed at a hospital while under warranty, was examined to identify a deposit lying in the bottom of the battery case. It had been suggested that the deposit was a contaminant. It proved to be composed of lead sulphate and lead oxide. The latter indicates the mechanical breakdown of the anode plate.

A deposit in the spear of an underground water system was found to consist of fine shell fragments and some quartz grains bonded together with the fine grained calcium carbonate and iron oxide. The spear had blocked and ceased to function after two years service. Regular treatment at approximately monthly intervals with hydrochloric acid was recommended in the case of a stainless steel or plastic spear. An inhibited acid is recommended when more corrodible material is used for the spear.

Two fragments of marine shell excavated from one of the lower layers of the floor deposit at Devil's Lair, a small limestone cave at Augusta, were examined for the W.A. Museum. The form of crystallisation of the calcium carbonate was critical since the form of calcite would indicate recrystallisation arising from its being embedded in the limestone formation of the cave. In fact the shell was in the original orthorhombic form of aragonite, indicating that the shell was unaltered and had possibly been brought into the cave by human beings. The deposit has been dated at over 30 000 years old.

Iron oxides which had been used in plants operating the Sirofloc water treatment process were examined to relate their characteristics to performance. Experience had been gained on their use by the Metropolitan Water Board. The magnetic susceptibility of materials from several sources was correlated with their mineral composition, the ferrous and ferric iron content, and the specific surface as an indicator of particle size.

COMPUTING ACTIVITIES

With the installation of the logic controller into the X-ray fluorescence system, divisional computing has centred mainly around the commissioning of this unit.

Initial installation problems were experienced with incompatible computer connections and a separate line driver module was required to connect the logic controller to the computer.

Several times during the year, the lines connecting the controller and associated terminals to the computer failed due to unidentified power surges. Line filters were installed on all lines between the XRS room and the computer.

Existing programs for manual operation of the spectrometer were modified for use with the logic controller. As experience was gained in use of the system, the control programs have evolved to the point where the computer directs the analytical process according to operational parameters supplied by the operator.

The proposed final phase of development will be to store all operational parameters on the computer to further decrease the amount of manual operator involvement in the analytical process.

Associated file management, calculation and reporting programs have been upgraded to reflect the increasing automation of the system.

Due to a lack of computer staff *per se,* Mineral Division staff have been required to assist other Divisions to the Laboratories in computing matters. Assistance has also been provided for other Branches of the Mines Department including Geological Survey, Surveys and Mapping and the State Mining Engineer's Branch.

Assistance has been in the form of programming and transfer of program and data from external sources to the GCL system.

Mineral Division staff also shared responsibility for general management of the computer system. This work involved advice to users on application programs and also the maintenance and upgrading of operating system programs. Weekly copying of programs and data onto "backup" magnetic storage was carried out.

A Computer Users Group was set up by Divisional staff to disseminate information and to co-ordinate computer usage throughout the Branches concerned. Staff also served on the Computer Advisory Committee within the Department.

Work continued on the validation and correction of the index to the combined Mineral Division—Simpson Collection.

A validated version of this comprehensive index (approximately 25 000 entries) will be produced in 1979.

EQUIPMENT

Severe delays were experienced with the major analytical equipment of the Division (a Siemens x-ray spectrometer) when a major component had to be replaced at a time when no serviceman was available in the State. The equipment was out of action for 2 months. Other down time has averaged one week per quarter resulting from difficulties of inter linkage with the computer, and general wear.

During the year a logic controller for the spectrometer was received and its installation completed sufficiently for its use late in the year. This acquisition has allowed:

(1) an increase in reproducibility due to reduction of operator manual setting of instrument parameters.

(2) an increase in the total number of measurements recorded in a working day, due to increased hours of operation in automatic mode.

(3) a decrease in operator attention necessary in automatic mode.
This is significant in the present climate of no staff growth since it allows additional support to be given in the area of sample preparation.

To satisfy the increased demand for assessment of environmental and occupational health problems most of the limited funds available for equipment purchase have been used for instruments essential to these areas.

METHOD APPRAISAL AND DEVELOPMENT

This Division has continued to work with the Standards Association of Australia sub-committee MT11 in examining and standardising methods for chemical analysis of iron ores. The ultimate objective of this work is the agreement of International Standards. Progress has been slow as regards production of ISO standards but the benefit of the technical discussions are available to all participating organisations, which consists of the Standards Organisation of each country, and through them to practically all iron ore producing and using groups in the world.

In November, Mr. D. Burns attended a meeting of the International Standards Organisation Committee on Iron Ores. At this meeting in Sydney 13 countries were represented by 90 delegates. All aspects of ore handling including sampling, chemical analysis, physical testing and sieving, were discussed. Several standards were agreed and test programs decided.

At the request of the W.A. Chamber of Mines a representative (Mr. J. Gamble) has been named for the newly formed S.A.A. committee for the chemical analysis of heavy mineral sands.

The industry has expressed a concern that an Australian Standard for zircon in particular, should be rapidly produced. Test work to support standard methods of analysis will be undertaken in the Division.

The Division has also participated in an inter-laboratory test program arranged by the Natonal Association of Testing Authorities.

Methods for presentation of samples for X-ray fluorescence examination have been developed in the case of waters and urine following pre-concentration. As little as 0.5 microgram of uranium can be detected.

A thin film technique of presentation of air borne dust samples to the X-ray spectrometer has been developed for estimation of phosphorus and sulphur in samples of a few milligrams. The technique will allow estimation of heavy metal elements on the same samples, which, when prepared, can be readily stored pending further analytical requirements.

Beneficiation trials designed to improve the colour of some W.A. zircon has produced a series of experimental products for which quantified assessment of colour improvement was required. The ultimate market test is simply appearance, since the levels of iron present are acceptable. Therefore the test required close correlation with visual assessment.

A series of sands of natural grain size were ranked according to quality by 10 observers acting independently and their assessments were averaged. It was found that this ranking was closely followed by measurements of percent reflectance of light of wavelength 457 mm as compared with reflectance from a magnesium oxide standard.

PUBLICATIONS

Papers published during the year were:

"Copper Minerals from Bali Lo Copper Mine Ashburton Downs, Western Australia"—P. J. Bridge & M. W. Pryce. Australian Mineralogist No. 14, 69-70.

"Minerals of the Greenbushes Tinfield." M. Pryce & J. Chester. Mineralogical Record *9* No. 2 81-4.

"Sampleite from Jingemia Cave, Western Australia". P. J. Bridge, M. W. Pryce, R. M. Clarke & M. B. Costello. Mineral Mag. 42, 369-71.

D. BURNS,
Chief Mineral Division.

WATER DIVISION

GENERAL

Structural changes to both staff and buildings have made a significant impact on the Water Division performance during the year. With a doubling of floor space and a 20 percent increase in staff numbers, brought about by the current and pending commitment to Australian Water Resource Council Network Survey analyses, the working area per staff member is now less cramped and in keeping with the rest of the Laboratories.

Subdivision of divisional activity into three sections, namely (i) water and treatment, (ii) environmental and (iii) network/automated, under three section leaders was effected during the year. Although no immediately measurable improvements in efficiency have resulted at this early stage, improvements in analytical and investigational output are expected to improve. Liaison between section leaders and staff of other departments has noticeably increased.

The transition from manual to fully automated analytical techniques is occurring at an acceptable rate if due allowances are made for the increasing service facility requirements without proportionate staff growth or equipment purchases. Computer control of automated equipment and printout of results is an aim for 1979/80.

TABLE 19—WATER DIVISION

Source	Agriculture Department	Albany Port Authority	Conservation and Environment	Departmental	Department of Industrial Development	Fisheries and Wildlife Department	Leschenault Inlet Management Authority	Main Roads Department	Metropolitan Water Board	Mines Department	Peel Inlet Management Authority	Public Health Department	Public Works Department	Swan River Management Authority	Public—Pay	Other	Total
Corrosion plus Deposits	1	....	....	6	....	....	....	4	....	....	....	2	8	....	2	....	23
Effluent	1	6	65	....	53	....	....	....	1	4	....	8	93	55	13	....	299
Environmental Monitoring—																	
Albany Harbour	....	22	....	....	....	....	....	....	....	....	....	....	....	....	....	....	22
Cockburn Sound	....	....	....	....	64	....	....	....	....	....	....	....	....	....	....	....	64
Leschenault Inlet	....	....	....	....	....	....	71	....	....	....	....	....	....	....	....	....	71
Peel Inlet	....	....	....	....	....	....	....	....	....	....	66	....	....	....	....	....	66
Swan River	....	....	....	....	....	....	....	....	....	....	....	....	....	193	....	....	193
Investigations	....	....	....	....	....	....	....	....	2	....	....	....	4	....	....	....	6
Soil	....	....	....	34	....	....	....	....	....	....	....	6	18	....	3	....	61
Waters—																	
Fluoridated	....	....	....	....	....	....	....	....	678	....	....	....	1 243	....	....	....	1 921
General	87	....	37	13	82	100	....	25	790	443	....	124	2 490	40	711	17	4 959
Various	....	....	....	7	....	....	....	....	....	....	....	....	1	....	2	2	12
Total	89	28	102	60	199	100	71	29	1 471	447	66	140	3 857	288	731	19	7 697

The analytical output, based on sample numbers alone, has increased again for the ninth consecutive year, the increase being approximately 500 samples or 7 percent. This increase is approximately equivalent to the receivals of the A.W.R.C. Network Section which commenced output almost immediately after occupying the new building in September. The demands on this Network Section could alter due to new Commonwealth guidelines for funding of the scheme, but there is to date no reason to suppose that it will not increase to that number predicted in the previous Annual Report of 4 000 samples for more than 20 components. Even with fully developed automation it appears impossible to carry out such a programme without further staff increases.

Mr. J. C. Weir, who had officially remained a member of our staff until 1978, despite complete transfer of his activities to the Metropolitan Water Board in 1973, has now officially become a staff member of the Board.

Only one publication resulted during the year, that being Report of Investigation No. 19 "Water Quality Monitoring Survey of Princess Royal Harbour Albany". Membership of technical and other advisory committees remains unaltered from 1977. Several talks were given by staff to various professional and subprofessional organisations during the year.

Reference to Table 19 on Page 30 shows that samples from P.W.D. total 3 875 and this total has almost doubled over the three years from 1975. These sample number increases are largely of an environmental nature and include effluents and samples associated with the "Rights in Water and Irrigation Act" as well as with Laporte effluent disposal in the sand dunes.

PUBLIC WATER SUPPLIES

Salinity of Hills Catchment Dams

Table 20 lists the annual average chloride levels for surface samples from the major Hills catchment dams which are used for drinking supplies and it can be seen, that despite a year wtih slightly higher than normal annual rainfall (based on Perth 1978 reading of 923 mm versus the average of 881 mm), some of the dams have shown an increase in average salinity over that of 1977. The most significant increase is that at Wellington Dam, which with its commensurate increases in other ions means that the average level for total dissolved salts for 1978 was 840 mg/l. This is significantly higher than any previously recorded average level.

The trends in these salinities are of increasing importance because of current and proposed expansion of bauxite mining and other Hills catchment activities.

Wellington Dam has exceeded the desirable maximum for total dissolved salts in a drinking supply (namely 500 mg/l) for six of the past ten years, while Mundaring has slightly exceeded this maximum on only two occasions over the same period. The currently high salinity of Wellington Dam is still significantly below the maximum level recommended by W.H.O. for total dissolved salts in a drinking supply (1500 mg/l) but such water is anticipated to reduce slightly the yields of certain pastures irrigated by it.

It will also be noted that the chloride level of Wellington and Mundaring frequently exceeds the W.H.O. desirable maximum in a drinking supply (namely 200 mg/l) but never exceeds the permitted maximum of 600 mg/l.

Sodium Hazards

Although mainly regarded previously as only an incidental component of total dissolved salts, sodium levels in drinking supplies aroused considerable interest in 1978. This resulted in the determination of this component in many more drinking supplies, although the order of the level was known because of the relationship of sodium to other components.

While there are no standards set by the W.H.O. for sodium levels in a drinking supply, it might be inferred on the basis that sodium is the major cation of the total dissolved salts, that levels of less than 200 mg/l are desirable and that levels of up to about 500 mg/l could be permitted.

A report in Archives of Environmental Health in Sept/Oct 1977 "Elevated Blood Pressure and High Sodium Levels in the Public Drinking Water" indicated that sodium levels of 107 mg/l in the drinking water supply produced blood pressure distribution characteristics, in a group of students, of persons several years older, when compared to a similar group of High School students on a drinking water supply containing 8 mg/l of sodium. There is some debate on the appropriateness of the methodology used in this report.

Prior to this report the only clearly documented hazard caused by sodium was considered to be to those people already suffering heart complaints, who required reduced dietary intake of sodium. The American Heart Association had listed the following maximum sodium intakes, together with the associated recommended maximum level in the drinking water, for three classes of diet.

Class of diet	Total daily sodium intake mg	Maximum sodium in drinking water mg/l
Strict	500	20
Moderate	1000	270
Mild	2400–4500	270

The levels in the drinking water for strict and moderate diets were based on full food restriction but that in the mild diet was based on liberalisation of the food diet.

The American Heart Association recommendation places most of the restriction of sodium in the diet on food intake, as food supplies of the order of 90 percent of sodium in the total diet. It can be seen from Table 21, which lists the current sodium values in W.A. drinking supplies, that only minor country town supplies with surface catchment dams would qualify for the 20 mg/l criterion and that all major town supplies would qualify for the 270 mg/l criterion. The source of most concern with respect to people with sodium restricted diets, would be the Wellington Comprehensive Scheme because of the greater total population served.

Table 21 was prepared utilising the most recent analytical information available for each of the towns listed. Due to seasonal variations and to being supplied from a number of sources several of the towns listed have supplies of

TABLE 20

SALINITY OF HILLS CATCHMENT DAMS 1960–1978

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
1978	923	130	65	220	110	110	85	110	455	95

* Conversion factor for Cl to total dissolved solids (by evaporation at 180°C)

1·85 for Wellington Dam

2·0 for all others

TABLE 21
SODIUM LEVELS IN RETICULATED DRINKING SUPPLIES
mg/l

0–20	20–100		100–200		200–270
			Major Supplies		
	Metropolitan		Metropolitan (*a*), Mundaring/Comprehensive		Wellington/Comprehensive
			Other Supplies (*b*)		
Borden	Albany	Kirup	Arrino (1)	Greenhead	Balingup
Boyup Brook	Boddington	Kununurra	Augusta	Guilderton	Mullewa
Buntine	Bolgart	Lancelin	Bunbury	Jurien Bay	Nabawa
Caron	Boyanup	Latham	Calingiri	Karratha (3)	Northampton
Cranbrook	Bridgetown	Ledge Point	Carnamah (2)	Leeman	Sandstone
Hyden	Broome	Manjimup	Cervantes	Mandurah (5)	
Onslow	Brunswick	Margaret R.	Coomberdale	Marble Bar	
Pingaring	Busselton	Mt. Barker	Coorow (2)	Meekatharra	
Wandering	Camballin	Nannup	Dampier (3)	Miling	
Wyndham	Capel	Newdegate	Denmark	Moora	
	Carnarvon	Northcliffe	Derby	Mt. Magnet	
	Collie	Nullagine	Dongarra (4)	Morowa	
	Cowaramup	Ongerup	Donnybrook	Newman	
	Dandaragan	Panawonica	Dunsborough	Perenjori (1)	
	Dardanup	Pemberton	Eneabba	Roebourne	
	Denham (desal.)	Pinjarra	Esperance	Walpole	
	Dwellingup	Quinns Rock	Exmouth	Watheroo	
	Eaton	Ravensthorpe	Gascoyne	Wickham (3)	
	Gingin	Rocky Gully	Junction	Yunderup (5)	
	Greenbushes	Two Rocks	Geraldton (4)		
	Halls Creek	Waroona			
	Harvey	Wittenoom			
	Jarrahdale	Yarloop			
	Jerramungup	Yerecoin			
	Kalbarri	Yuna			
	Karlgarin				

(*a*) Only in the 100–200 range when artesian water is blended.
(*b*) Other than those supplied by the Mundaring or Wellington comprehensive.
(1) Arrowsmith headworks.
(2) Dathagnoorara headworks.
(3) Millstream complex.
(4) Allanooka headworks.
(5) Yunderup source supply.

varying salinity and hence sodium. This should not have much effect on the four ranges into which the towns have been placed in Table 21. However people concerned about sodium restricted diets can obtain the most recent information on sodium in their supply from the relevant water authority or ourselves.

Fluoridated Water Supplies

It can be seen from Table 22, which lists the average fluoride level in the various fluoridated town supplies, that with the exception of Perth Metropolitan, Esperance and Geraldton, all other towns have maintained their intended levels during 1978. The mean levels in Perth, Esperance and Geraldton were 0.01, 0.05 and 0.03 mg/l respectively below the minimum of the range intended. These slightly reduced levels were caused by malfunction of feeding equipment but nevertheless would not be expected to contribute significantly to any lowering of the prevention of dental caries.

Due to electrical problems, fluoridation at Broome and Derby town supplies did not proceed beyond the "commissioning of plant" stage. Fluoridation of these two town supplies and that at Exmouth should be implemented during 1979.

TABLE 22
FLUORIDATED WATERS

Supply	No. of samples	Fluoride, F mg/l mean	Fluoride, F mg/l intended
Perth Metropolitan	672	0·69	0·8±0·1
Mundaring/Goldfields	143	0·71	0·8±0·1
Wellington/Comprehensive	133	0·76	0·8±0·1
Albany	99	0·83	0·9±0·1
Collie	551	0·72	0·8±0·1
Esperance	104	0·75	0·9±0·1
Geraldton	96	0·67	0·8±0·1
Manjimup	86	0·87	0·9±0·1

Copper in Drinking Supplies

Due mainly to recent disclosures of elevated copper levels in high rise buildings in Newcastle, levels were investigated in ten high rise buildings in Perth and included water from both hot and cold services. The levels in Newcastle were sometimes more than tenfold the W.H.O. International Drinking Water Standards permitted maximum in a drinking supply (1.5 mg/l). It is of interest to note that the W.H.O. European Drinking Water Standards allows copper levels to increase to 3.0 mg/l after 16 hours contact with copper pipe.

Most of the Perth samples analysed had levels below 1.5 mg/l and all had values less than 3 mg/l after "over week-end" standing. The results obtained were not at variance with previously obtained values taken after "overnight" standing and indicated in Table 23. Because copper levels of less than 10 to 20 mg/l are not considered health hazards, the problems associated with the higher levels indicated in the Table are only ones of taste, possibie excessive corrosion and staining.

TABLE 23
LEVELS OF COPPER IN PERTH RETICULATED SUPPLY
Copper, Cu

	Range mg/l	Average mg/l
Cold Water Situation—		
1. New Copper Pipe		
(a) first draw	0·2—4·0	2·0
(b) after flushing	0·1—1·0	0·5
2. Old Copper Pipe		
(a) first draw	0·2—1·0	0·5
(b) after flushing	0·1—0·5	0·2
Hot Water Situation (Copper Storage Vessel or Ring Mains)—		
(a) first draw	0·3—4·0	2·0
(b) after flushing	0·3—3·0	1·0

Cadmium in Drinking Water

Following recently published work by de Laeter, which showed the level of cadmium, a toxic substance, in the water from an urn at the W.A. Institute of Technology approached that of the maximum permitted in a drinking water (namely 0.01 mg/l) a number of water samples taken from high rise buildings and covering a wide range of contact times with urns and copper pipes were tested. The highest level found was 0.001 mg/l and most levels were less than 0.0001 mg/l.

Polycyclic Aromatic Hydrocarbons

The W.H.O. has suggested that the maximum level for a total of six of these polycyclic aromatic hydrocarbons in a drinking supply should be 0.0002 mg/l. This level is significantly lower than all other listed organics allowed in a drinking supply. Because they are sparingly soluble in water and are derived mainly from coal tar and mineral oil sources, it is difficult to experimentally assess the health hazard (if any) of using organic coatings derived from such sources in water supply practices. Advice is frequently sought about such coatings and materials and the recommendation is usually a compromise between past practices, published standards and alternative materials. Recommendations that involved such considerations during 1978 include the use of petrolatum tapes and coal tar epoxies as corrosion preventatives and the use of hydrogen peroxide as a water treatment chemical.

Lead in Underground Water

Waters derived from disused mineshafts (mainly lead mines) in the Northampton area have shown seasonal fluctuation in water quality, particularly in relation to copper and lead. The exposure of sulphide ores to the atmosphere during late summer and the associated oxidation allows release of metals from these ores into the water when the water table rises again in spring. Water from such a disused mineshaft near Northampton had a lead level which was harmless at 0.01 mg/l in late summer, but which by spring had increased to 1.2 mg/l. The people concerned wishing to use this supply were advised not to use the water and to have it checked again next summer before using it then.

Country Water Treatment Plants

Activity associated with established and experimental developments at the Perth metropolitan treatment plants has been reduced since the official transfer of Mr. Weir this year from these Laboratories. There has nevertheless been considerable activity associated with water treatment plants in country centres.

Apart from the regular testing of all treated supplies and offering advice on ways to alleviate apparently recurring problems, there were a number of new areas of activity during the year. Visits were made to both Nannup and Mt. Barker to satisfactorily commission and carry out plant trials on two clarifiers of a new design. The Nannup visit revealed a shortcoming in the new design which was subsequently corrected for Mt. Barker.

A visit to Miling, where the supply is derived from two separate sources with complex interconnection to the reticulation and where the iron is not completely removed by aeration and sand filtration, did not satisfactorily resolve the issue and further work is pending.

Bacterial slimes of manganese at the Denham reverse osmosis plant and of iron in supply lines from new sources at Albany were identified and recommendations for their removal and control were made.

ENVIRONMENTAL

Laporte Effluent Disposal

Activity in this area was not reduced in 1978. The involvement in the sand dune disposal was effluent, aquifer and soil analysis and their interpretation, while that for the experimental pipeline to sea involved additional technical information and advice to the consultants and committees.

Despite problems in gaps in the knowledge about each of the disposal systems, up to date reports are expected to be completed by the two separate committees during 1979.

1. Sand Dune Disposal:—Aquifer samples have been analysed mainly to assess the degree of neutralisation of the effluent and of iron immobilisation, within the two main aquifers (shallow and deep) and the extent of the area affected. Recommendations for relocation of the disposal lagoon can be made on the basis of the results obtained, the main criteria being when excessive levels of iron are moving through the aquifer beneath the ocean shoreline.

Soil samples taken from vibro cores have been analysed at two separate locations in order to assess the extent of iron immobilisation within the aquifers. Neither of these exercises was considered to be as useful as the earlier exercise in 1976 when it was predicted that 95 percent of the iron in the effluent could be immobilised in the soil. There is currently no satisfactory core sampling technique to enable soil samples to be taken at precise depth intervals.

If the deep limestone aquifer could be effectively utilised it could extend the life of the sand dune disposal area by a factor of approximately four. Although evidence during 1977 indicated that this deep limestone could be made available for effluent neutralisation, subsequent evidence based on soil samples in the immediate vicinity of the injection trial are not so positive and there is now doubt as to the extent to which it is available. Aquifer samples suggest that at least a significant portion of it is available but there is now also some doubt as to whether the aquifer samples truly represent the depth purported.

2. Pipeline to Ocean Disposal:—While environmental aspects and studies have been the responsibility of other organisations, the chemistry of effluent neutralisation and oxidation by sea water has been our responsibility. The only, apparently unanswered, question to date on this aspect is the ultimate fate of the insolublised iron. It appears to have a final diminution in its level in the sea water which is well in excess of that caused by either dilution or fixation onto bottom materials. Settling does not appear to be significant and one current theory is that the insolublised iron, while originally in obviously particulate form, is broken down into a colloidal form.

Cockburn Sound Study

The monitoring programme on effluents as described in the 1977 Annual Report was continued and completed towards the end of 1978. Apart from the already established undesirable levels of nutrients being discharged to the Sound, a survey of approximately sixty bores in the industrial area showed that most contained high levels of nutrients. Levels of nitrogen in some cases were up to 500 times the level considered to be indicative of contamination, while phosphorus levels in some cases were up to 100 times higher than the levels normally found in uncontaminated ground water. In the vicinity of a chemical works, high levels of phenols, and herbicides were found in bores beyond the boundary of the factory site.

Princess Royal Harbour Albany

Work on this 12 month monitoring programme was completed early in 1978, and the summary of the report on this programme stated "A twelve month monitoring survey, carried out at three monthly intervals at Princess Royal Harbour between April 1977 and January 1978 was undertaken to assess the degree of contamination of the main body of the Harbour water by certain drains and trade wastes". Some contamination of the Harbour water is indicated by both monitoring and calculation techniques, but the results do not indicate either that the effect on the main body of water is completely innocuous or that there is any significant deterioration in quality. Definite visual pollution is occurring at the outlets to the Harbour of certain trade wastes, but this is having no significant effect on the main body of water in the Harbour.

Because of staff commitments to other spheres of activity, considered to have higher priority, it was not possible to carry out a proposed monthly monitoring of the Harbour water and any subsequent work in this area will be restricted to sample collection and analysis of trade wastes and other inputs to the Harbour.

Estuarine Monitoring

Three monthly monitoring, involving sample collection, analysis and interpretation, continued during 1978 for the three Management Authorities, namely Swan River, Peel Inlet and Leschenault Inlet. While all three bodies of water are generally considered to be in acceptable condition and unlikely to become eutrophic under present equilibrium conditions, the section of the Swan River upstream of the Causeway and the main water body of the Peel Inlet and Harvey Estuary are likely to be the worst affected by increases in inorganic nitrogen input.

Apart from normal quarterly monitoring, the Swan River received additional attention during the year and this was mainly because of existing ana proposed rubbish disposal sites on the shores of the river and the possible effects of the Westfield sewage plant.

Levels of inorganic nitrogen in aquifers immediately beneath rubbish tips generally are of the order of 100 mg/l in the Perth metropolitan area and movement of such water into the Swan River would require an approximate 300 fold dilution with inorganic nitrogen free water to keep the inorganic nitrogen level below that considered limiting for eutrophication (0.3 mg/l). The water aquifer beneath "completed" rubbish disposal sites, such as the Burswood Island site on the Swan River also contain approximately 100 mg/l of inorganic nitrogen. A detailed study involving water levels and soil permeability has not been undertaken to assess the effect of such a water on the Swan River. From results of quantities and concentrations found at the experimental site at Hertha Road and nett flow characteristics of the Swan River in spring, an equilibrium situation could be calculated to increase the inorganic nitrogen level of the river water by 0.07 mg/l. The S.R.M.A. has been advised to oppose future siting of rubbish disposal sites on the river shorelines.

At Keane Street, a surface drain contaminated with surplus run-off or sub-surface seepage from irrigation of pasture with treated sewage effluent, had levels of phosphorus and inorganic nitrogen of several mg/l, on reaching the Southern River, a tributary of the Canning River. The phosphorus contribution by the drain to the Southern River increased the phosphorus level many fold but had little effect on the already relatively high inorganic nitrogen level, which is apparently due to natural drainage of pastoral areas. The resultant nutrient levels moved the status of the Southern River water from one of meso-eutrophic to one of polytrophic. Such inputs as from this treated sewage effluent could increase the potential for eutrophication in the Southern River and perhaps the Canning River if they persisted during the non-winter months. Pasture areas being irrigated at the time of the exercise have subsequently been increased and with other treatments this should reduce impacts on the river. Further testing during 1979 is planned.

Two new monitoring programmes planned in 1978 for the Swan River are to commence in 1979. The first is to assess the heavy metal input to the system over a one year period. The second involves a replacement of the previous monitoring programme by one of 5 year duration with a significant increase in the overall number of monitoring sites. Sites have been selected to enable—

(a) better assessment of the status of the main water body;
(b) an assessment of nutrients and organics input from various sites;
(c) a study of long term stratification effects;
(d) a correlation of algal activity with the above.

Waste Disposal Sites

Monitoring of the aquifers beneath and adjacent to the present rubbish disposal sites at Hertha Road, Wanneroo and Brockway at Mt. Claremont, the proposed site at Jones Street Wanneroo, the present liquid disposal site at Gnangara and from an experimental site at Hertha Road continued during the year. The results were similar to those obtained in previous years.

Mainly because of the inorganic nitrogen (as ammonia) content of leachates, the locating of rubbish disposal sites adjacent to surface lakes or rivers can lead to eutrophication (most natural surface waters in W.A. have limiting nitrogen levels but the phosphorus levels are above that required to produce eutrophication). The ammonia and other undesirable components can lead to additional problems if sites are located near shallow aquifer drinking water supplies, now a large component of Perth's drinking water. There has therefore been a considerable reduction of what was previously considered to be suitable rubbish disposal sites and such sites are now at a premium in the metropolitan area.

Rights in Water and Irrigation Act

Activity in this area has increased considerably. Generally the activity has concentrated in the non-metropolitan south west region of the state where interest is in wastes from factories based on primary industry (abattoirs and dairies), mineral sources, mine dewatering and coal ash disposal. Industries in the metropolitan area, not specifically controlled by the Metropolitan Water Board or other authorities, also received attention, such as some located in the Kwinana/Cockburn industrial area. Apart from final effluent analysis, impacts of such discharges on underground aquifer and surface waters are predicted and measured where possible.

1. Wundowie Charcoal Iron Effluent:— A detailed study of the storage of effluent in ponds and their access to the nearby Werribee Creek was undertaken. While the evaporative lagoons are functioning as intended the only significant contamination to the nearby creek is to increase the phenol level by approximately 0.01 mg/l. This indicated relatively impervious evaporative lagoons, where phenol levels in the contained effluent were of the order of several hundred mg/l.

2. Collie Coal Mine Dewatering:— Such dewatering appears generally to lower the overall salinity of the adjacent river drainage system without significant alteration to the final pH or iron and manganese levels.

3. Mineral Sands at Capel:— The combined effect of process water and neutralised effluent overflowing to surface drainage is not clear cut. With poor control of neutralisation, which has obviously occurred in the past, vegetation along the banks of the immediately adjacent surface streams has been affected. With good effluent control the overall effect is one of increased salinity and manganese levels. The river water quality is normally suitable for stock, but not domestic use. The disposal could be advantageous because it provides a flow during late summer which might otherwise not exist.

Cyanide Spillage at Wanneroo

Samples of soil and water from various downstream sections of a nearby creek were collected within twelve hours of a cyanide spillage from a transport vehicle on the Great Eastern Highway at Wooroloo. It was raining at the time. Levels of cyanide in the soil were compatible with the small quantity of unrecovered cyanide and the area of ground affected. Samples from intermediate pools between the spillage site and the creek, and from the creek itself, all had levels below the maximum permitted in a drinking supply, namely 0.05 mg/l. Subsequent samples taken later confirmed this insignificant effect.

Brewery Wastes at Wanneroo

Disposal at Wanneroo of brewery waste from a yeast extraction plant over a period of two years at 20 cubic metres weekly had affected the aquifer at a site several hundred metres away. At this site water was being pumped for irrigation at approximately 2 000 cubic metres weekly. Based on BOD values of the effluent and of the water of 70 000 and 300 mg/l respectively, it would appear that a major component of the discharged effluent was gaining access to and being removed by the bore pump. This indicates little breakdown of the effluent within the soil. The irrigated water was not considered suitable for irrigation of fruit or vegetables for human consumption.

This was an unexepected event because previous sites in the metropolitan area accepting many times this quantity of brewery waste had not indicated any aquifer contamination. Because, at a nearby site brewery waste was also being disposed of at a rate ten to twenty fold that of the yeast extraction plant, recommendations were made for the siting of observation bores on the downstream side of the anticipated aquifer movement from the disposal site.

MISCELLANEOUS

Iron Stain Prevention—Iron Silica Complex.

Subsequent to publishing two pamphlets during the year advising the "home handy man" how to construct a sodium silicate dosage facility for iron stain prevention, it has become obvious that probably 100 or more people have availed themselves of this process.

Additionally one contractor has made approximately 40 installations. The feed back on the success or otherwise is spasmodic. While some systems are giving apparent 100 percent stain prevention, others are not, due to a variety of causes. These causes are generally due to malfunctioning of the dosage equipment, which in turn appears to be mostly due to the formation of a sludge hydrolysis product in aged diluted solutions of sodium silicate. The current recommendation is to prepare only enough diluted solution to last for several weeks.

It was previously thought that iron levels below 0.5 mg/l did not produce significant staining to buildings, but there have since been instances where iron levels of 0.4 mg/l have produced noticeable staining on asbestos cement fencing or other alkaline white materials within several weeks.

The treatment has been applied successfully to trickle irrigation systems where problems of blocked orifices had been encountered previously.

In only one instance where correct dosage had been consistently applied, has the system been shown to be only partially successful. This was with a water where calcium carbonate deposition from overhead sprinkle irrigation would have been expected. Because of this, it is not recommended for those waters with a hardness in excess of 250 mg/l (as Ca CO_3). It is hoped to carry out some detailed inspections and testing of bore waters at a number of installations during 1979, to gain a better overall estimate of performance where dosage has been consistent.

Nitrite and Pink Meat

A leakage into a hot water supply from a primary hot water circuit, dosed with sodium nitrite to prevent corrosion, had caused a noticeable discoloration of minced meat cooked in such water. Instead of turning the normal grey brown colour after cooking, the meat retained its pink colour. Experiments showed that cooking water containing as little as 1 mg/l of nitrite was capable of imparting a pink tinge to the meat.

Arsenic in Irrigation Water

The salinity of two underground sources at Meekatharra, Butlers and Ingleston Albert shafts, is below the maximum recommended for the irrigation of ovals. The arsenic levels in both these supplies has consistently averaged 0.8 mg/l which is well in excess of the maximum permitted in a drinking supply (0.05 mg/l), but is not considered to have any short term adverse effects on the health of lawns. The potential hazards to someone unknowingly drinking this water, meant for an oval reticulation, needs careful consideration and control before the water is used for this purpose.

Abattoir Effluent for Irrigation

A sample of abattoir effluent for irrigation indicated that the application of 1 metre of water (a normal annual requirement) would supply the following nutrient levels, (kg per hectare): 2 200 Nitrogen N, 220 Phosphorus P, 430 Potassium K, 0.3 Copper Cu, 12 Iron Fe, 1.4 Manganese Mn and 1.1 Zinc Zn. The macro nutrients would be more than adequate for most irrigational practices and additional fertilizer application would not be necessary. The trace metals were considered to be not necessarily adequate for the plants needs and certainly sub-toxic.

Hot Water System Corrosion

Considerable activity during the year has been devoted to preparing drafts for Australian Standards for water used in domestic hot water systems as well as for materials and methods of construction of storage vessels. One of the limiting components to be included in the Standard for water is carbon dioxide and a recommended maximum of 50 mg/l is likely.

A bore water at Kelmscott with a pH of 5.5 and salinity and carbon dioxide levels of 1 560 and 480 mg/l respectively, had caused repeated failures due to corrosion, each within three months, of a variety of storage vessels including stainless steel and glass lined steel. The manufacturers, who were replacing the units under warranty, were obviously unaware of the effects of the excessive levels of carbon dioxide and the moderate salinity level. Efficient aeration to reduce carbon dioxide, with perhaps subsequent lime addition to eliminate it were the recommendations.

Deposits in Urinals

At various roadhouses across the Nullarbor, and previously recorded at Rottnest, where high salinity waters with associated high calcium and magnesium levels are used for urinal flushing, there have been found deposits in outlet pipes which are difficult to remove. Such a deposit from Balladonia was found to be mainly phosphate of calcium and magnesium brought about by the high level of phosphate in urine (700 mg/l as P).

As a means of reducing the quantity of deposit, increasing the proportion of flushing water and avoiding use of alkaline cleaning agents was recommended. The material could be removed from plastic pipes with 10 percent hydrochloric acid but inhibited acids would be required for metal pipes.

N. PLATELL,
Chief Water Division.

DIVISION VIII

Annual Report of the Chief Inspector of Explosives, for the Year 1978

In accordance with Section 10 of the Explosives and Dangerous Goods Act, 1961–1974, I submit for the information of the Honourable Minister for Mines, the following report on the administration of the Act for the year ended December 31, 1978.

LEGISLATION

Comprehensive amendments were made to the Second Schedule of the Act and both the Flammable Liquids and Explosives Regulations. By virtue of the amended Second Schedule, explosives are now classified in Western Australia according to the United Nations system. This is consistent with current Australian and world-wide trends and should greatly simplify the interstate and international movement of explosives.

Amendments were made to the Explosives Regulations in accordance with the new explosives classification.

The publication in 1977 by the Standards Association of Australia of two Standards on the construction and operation of road tank vehicles for flammable liquids resulted in a request from industry to incorporate the Standards into the Flammable Liquids Regulations. These amendments, together with complementary actions in all other States have resulted in a uniform standard of requirements for flammable liquid vehicles across Australia.

Late in the year, the Explosives and Dangerous Goods Act Amendment Bill was assented to. This Bill will be proclaimed upon the gazettal of amendments to the Flammable Liquids Regulations which will incorporate the United Nations classification of dangerous goods. In addition to enabling the adoption of the U.N. system of dangerous goods classification in Western Australia, the Bill will make provision for the possible future regulation of:

1. the carriage of all dangerous goods by road; and
2. the storage, conveyance and supply of liquefied petroleum gas.

The Bill has also enabled materials to be gazetted as Dangerous Goods without requiring that they be regulated to the same extent as currently applies to flammable liquids. Thus, regulations may specify packaging and transport standards but storage facilities need not be licensed.

AUTHORISATION OF EXPLOSIVES

Six additions were made to the List of Authorised Explosives for Western Australia. These were:

Class 1.1B (0029) Capped Delay Assembly (z)
(0029) Fuse Delay Assembly (z)
(0029) Nonel GT Detonators (z)
(0029) Nonel GT1 Detonators (z)
(0029) Nonel GT2 Detonators (z)
Class 1.1D (0065) Redcord (zz)

The explosives "Tovex DX", "Tovex 650" and "Tovex 700" were approved for use under the authorised name "Tovex". "Molanite PH" was approved for use under the authorised name "Molanite".

The product "Stopecord" was approved for experimental use under the authorisation for "Plastic Igniter Cord" subject to it being authorised in its own right should it be found suitable for commercial use.

Approval was given for minor changes in the authorised composition of the explosives Anzite Blue; Anzomex Booster; Quarigel; Aquaflex; Geoflex, Cordtex; Amex; Molanite; Ribcord; Shearcord; Tuffcord, and Flexicord.

The following explosives were deleted from the list of authorised explosives.

Class 3—Nitro Compound
Division 1
DuPont Gelatine (zz)
DuPont Gelatine Primer 80% (zz)
Nitramon WW (zz)
Polar Ajax (zz)
Polar AN Gelatine Dynamite (zz)
Polar AN Gelignite (zz)
Polar A3 Monobel (zz)
Polar Blasting Gelatine (zz)
Polar Geophex (zz)
Polar Hydrogel (zz)
Polar Monograin (zz)
Polar Plastergel (zz)
Polar Quarigel (zz)
Polar Quarry Monobel (zz)
Polar Roxite (zz)
Polar Semigel (zz)
Polar SN Gelignite (zz)
Polar SN Gelatine Dynamite* (zz)
Tovex Regular (zz)
Tovex A6 (zz)

*Formerly incorrectly referred to as Polar Gelignite Dynamite.

The word "Polar" was deleted from the authorised name Polar Rollex 60.

Class 6—Ammunition
Division 3
Nonel System (z)

The titles of the following explosives were corrected.

Hi-Velocity Gelatin (zz) (formerly Hi-Velocity Gelatine (zz))
Seismograph Hi-Velocity Gelatin (zz) (formerly Seismograph Hi-Velocity (z)
Special Gelatin (zz) (formerly Special Gelatine (zz))

MANUFACTURE OF EXPLOSIVES

The manufacture of nitrate based explosives at licensed plants throughout the State showed a marginal drop which corresponded closely to a decrease in iron ore production. (Approximately 90 per cent of the ANFO manufactured in Western Australia is used in the winning of iron ore.) A breakdown of these explosives and a comparison with the previous year is as follows:

	1977 (tonnes)	1978 (tonnes)
ANFO	62 945	66 392
A1/ANFO	5 059	775
Water Gel	1 626	1 759
	69 630	68 926

The year 1978 saw significant changes in several operations involving ammonium nitrate. The closure of the rail line to Meekatharra resulted in the transfer of the facilities for handling bulk nitrate to Dalwallinu and the operation of road trains from that point. This operation seems to be working satisfactorily. Several of the larger iron mines completed bulk

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storage facilities for ammonium nitrate and, in conjuction with this, a gantry similar to that at Dalwallinu was constructed at Narngulu. As a result of these moves, the transport of bagged ammonium nitrate to the North West should almost cease in favour of the much more convenient—and safer—bulk transport.

Approval was continued for the manufacture and cartridging of a detonator sensitive nitrate explosive for continuing experimental blasting at Collie. This involved five tonnes of explosive.

IMPORT AND USAGE OF EXPLOSIVES

Though the importation and use of small diameter cartridged watergel explosives continued to increase (by 36 per cent), nitroglycerine based explosives continue to dominate this area of usage. However, the quantity of nitroglycerine explosives imported and used remained the same as it was in 1977.

A total of 9·1 tonnes of cartridged watergel explosive was repacked at Woodman Point following damage in transit.

TOTAL CONSUMPTION OF EXPLOSIVES

	1977	1978
Propelling powders (including gunpowder, fireworks, etc.)	3·2	4
Bulk Nitrate Explosives	69 630·0	68 926
Cartridged Nitrate Explosives	307·1	418
Nitroglycerine Based Explosives	1 100·5	1 100
Primers and Boosters	61·0	58
Detonating Cords ($5 \cdot 23 \times 10^6$ m)	101·3	117
Primary Initiators ($2 \cdot 28 \times 10^6$ units)	116·0	98
	71 319·1	70 721

A series of improperly controlled quarry blasts by the holder of a Shotfirer's Permit resulted in the incorporation of some changes to the method of assessing applicants. Since the introduction of the permit system, almost 1 200 persons have been issued with Shotfirer's Permits. Most of these people had been using explosives for several years before the need for a permit was introduced, however, it became evident that many of the newer applicants had little or no practical experience with explosives even though their knowledge of blasting theory was sound. Consequently, evidence of practical experience is now required of all applicants before a Shotfirer's Permit is issued.

Among the 40 permits issued for the public display of fireworks were several for the use of black powder in theatres to create a special effect. This use of powder has flourished recently and is strictly controlled by the Branch because of the potential dangers it entails.

EXPLOSIVES RESERVES

Woodman Point

No theft of explosives or malicious damage to magazines occurred but several instances of mischievous behaviour took place at the Reserve. These included one persistent trespasser who had to be removed by the Police, two small fires of undetermined cause and the removal of the locks from an unused gate. In the last incident, no evidence of subsequent entry into the Reserve was seen. As a result of the above incidents, the unused gates were replaced with fencing and additional signs were placed at the south side of the Reserve.

The most notorious visitor to the Reserve was Cyclone Alby which, in less than 12 hours, extensively damaged the explosives jetty, demolished some 200 metres of fencing and damaged two magazines. Repairs to the damaged areas were soon effected.

The jetty was used several times for small shipments of explosives and once as a base for an ocean survey of an area of Cockburn Sound by a section of the Metropolitan Water Board.

Once again the distribution of explosives by road and rail proved to be the main function of the Reserve with some 4 200 tonnes of explosives and 675 tonnes of prilled ammonium nitrate dispatched to various locations in the south western part of the State. As in previous years, all vehicles leaving the Reserve with explosives (more than 3 900) were checked by the Reserve staff.

A suitable site has been chosen for the relocation of the Woodman Point Reserve and firm planning will proceed upon receipt of approval in principle from the Metropolitan Region Planning Authority. The Woodman Point area—including the Explosives Reserve—was inspected by the Commonwealth Minister for Administrative Services, Senator Withers and the Honourable Minister for Urban Development and Town Planning, Mr. C. Rushton.

Kalgoorlie

Despite the reduced output or closure of many mines in this area, operations on the Explosives Reserve at Kalgoorlie have shown no sign of slowing down. Changes were made to the manufacturing plant on the Reserve to enable the use of bulk supplies of ammonium nitrate in the manufacture of nitrate explosives. The new section of the plant was inspected and found to be satisfactory before approval was given for its use.

The increase in manufacturing operations prompted preliminary enquiries towards the provision of a supply of water for fire protection. The current water supply to the Reserve is a domestic service which is completely inadequate for fire protection. These enquiries are continuing.

Extensions were also made to the internal road/firebreak system.

ANALYSIS AND TESTING

Eight samples of explosives were submitted to the Department's laboratories for analysis and all but one were found to comply with the manufacturer's specifications. Enquiries are being made to determine the reason for the discrepancy between the stated composition and the analytical result of the non-complying sample.

The chemical analysis of locally produced explosives grade ammonium nitrate was continued on a quarterly basis. All samples were found to be suitable for the manufacture of blasting agents.

Three samples of watergel explosives were tested to determine their sensitivity. All were assessed as satisfactory when fired according to the manufacturer's recommendations.

At the request of the manufacturer, a sample of fertiliser was tested to determine the likelihood of it exploding under adverse circumstances. Initiation of a substantial primary charge in a sample did not result in explosion of the fertiliser which was consequently declared non-explosive.

Tests were conducted on a device used to seal polyethylene bags containing ANFO. The safety devices built into the sealer were sufficient to ensure that the possibility of accidental explosion was minimal.

A disposable, butane fired, cigarette lighter was involved in a motor vehicle fire in which a child perished. Subsequently, tests were conducted to determine the behaviour of similar lighters when subjected to concentrated solar heat. Although no definite conclusions could be drawn from the tests, the lighter could not be eliminated as a possible cause of the blaze.

One hundred photo electric powered circuit testers were examined by the Branch scientific officers and all were approved for use on mine-sites. A locally manufactured blasting machine was examined and approved for use.

A meter, used to check the electrical continuity of earthing wires in fuel delivery hoses, was examined and found to deliver a satisfactorily low level of current, which ensured that it would not ignite an atmosphere of flammable vapours.

Preliminary tests were conducted on a battery powered circuit tester. These tests could not be completed as the meter was not supplied in the form in which it was intended to be sold to the public.

The routine testing of imported nitroglycerine explosives continued throughout the year together with the random sampling and testing of all safety fuse passing through the Woodman Point Reserve. The Abel Heat Test was conducted on 477 samples of nitroglycerine explosives and 77 samples of safety fuse were tested for burning rates and cross ignition. All samples were found to be satisfactory.

EXPLOSIVES LICENCES AND PERMITS

There was an increase in the number of licences issued for explosives of the order of 12 per cent over the previous year. The most significant increases occurred in the numbers of Licences to Manufacture a Blasting Agent and of Shotfirer's Permits. The increase in Licences to Manufacture can be seen as a direct flow on from increased advisory activity by the inspectorate in this area during 1977. This activity continued at a high level into 1978.

A total of twelve training courses for Shotfirers were conducted by the explosives inspectorate for 286 trainees. One hundred and seven of these attended the four evening courses and the remainder were government or local authority employees who attended one of the eight in-service courses. At the conclusion of each course the trainees were examined and 38 failed to obtain a Permit.

A further 86 candidates were examined and 77 were given Permits without the need for a comprehensive training course.

Twelve candidates attended a training course conducted by the lecturing staff at the Kalgoorlie School of Mines. All achieved a satisfactory standard and were given Permits. Educational institutions are being encouraged to conduct more of these courses in an attempt to reduce the amount of time spent in this area by the Branch inspectorate.

A comparison of the number of licences and permits issued for explosives during the past two years is shown below.

Licence	1977	1978
Import	8	8
Explosives Manufacture	28	11
Blasting Agent Manufacture	281	354
Storage—Mode A	35	33
Storage—Mode B	16	12
Magazine Type One (1 000 kg)	113	96
Magazine Type Two (5 000 kg)	45	46
Magazine Type Three (greater than 5 000 kg)	73	72
Sell	41	39
Convey	45	39
Total licences	685	710
Permit—		
Shotfirer's	963	1 146
Fireworks Display	38	41
Entry Permit for Explosives	37	39
Total Licences and Permits	1 723	1 936

EXPLOSIVES SECURITY

Once again the inspectorate continued their efforts to ensure that explosives security was maintained at a high level. Fewer premises were inspected but most of those found to be unsatisfactory were reinspected soon after to ensure the appropriate action had been taken.

An unusually high number of thefts were reported to the Branch. This is believed to be the result of amendments to the Police Standing Orders on this subject.

Fifteen instances of theft were reported and once again the Branch was faced with the problem of deciding what constitutes an adequate degree of security for explosives magazines. In three notable instances some six hundred kilograms of explosives were stolen from magazines considered to be of an acceptable standard of security. In all cases, the isolated positions of the magazines allowed the thieves to work undisturbed for several hours. It is almost impossible to construct a security building to withstand this amount of mistreatment.

Small, isolated mining leases were the subjects of five of the thefts involving approximately 113 kilograms of explosives. Typically in these cases, some weeks elapse before the theft is discovered and it may be weeks more before it is reported. Little action can be taken by the inspectorate or the Police to rectify these situations.

In five other instances where explosives were stolen, action has been taken to upgrade security to a higher standard. Inquiries are continuing into another theft where explosives were kept in a shed at a historical museum site on the Eastern Goldfields.

The final incident involved the theft of a carton of explosives from a rail wagon at Coonana on the Nullarbor Plain. The theft was reported by the Commonwealth Police officers after they had arrested the offender—some five months after the event. It had not been noted by the Company which had suffered the loss. The Company concerned has since been requested to improve its stock control procedures and Australian National Railways have been advised of the necessity that rail vans be locked when carrying explosives.

A total of approximately 700 kilograms of explosives and 9 500 detonators were collected by the inspectorate from 37 different locations throughout the State. As in previous years, the majority of the explosives were destroyed by the magazine staff at Woodman Point though in several instances items were destroyed at a nearby safe place.

One hundred and fifty deteriorated or outdated marine distress signals were also disposed of at Woodman Point.

DANGEROUS GOODS

Once again, flammable liquids inspections dominated the activities of the Branch with some 6 300 inspections of premises and vehicles. Licences were issued for 5 259 premises to store flammable liquids.

The enforcement of the amendments to the regulations controlling transport of flammable liquids was not without its initial problems—the most common being the basic antagonism of the public to any change. As these amendments had been specifically requested by the fuel industry, most opposition to the changes was readily overcome and enforcement of the regulations is now proceeding quite smoothly—aided in no small measure by the attendance of the Senior Inspector of Explosives at two meetings of fuel agents.

Comprehensive fire drills were supervised at several major metropolitan fuel terminals. The results, while generally satisfactory revealed major shortcomings in the protection systems at some of the premises. In all cases, action has been taken or is in progress to bring the fire protection facilities up to a satisfactory standard.

Tests conducted on a well in the Guildford area confirmed the presence of significant quantities of petrol which was believed to have leaked from the underground tanks of a nearby service station. Tests on the tanks could not confirm the presence of any leaks and subsequent tests on the well over a period of months have shown the petrol in the well has dissipated. The atmosphere in the well will be monitored further but is not expected to again reach a dangerous level.

The number of self serve petrol stations has increased phenomenally since they first commenced operations in this State. The number has grown from five at the end of 1976 to more than 80 and the growth rate shows no sign of slowing. Despite this rapid growth no accidents involving self serve operations were reported. This is due in no small measure to the regular activities of the inspectorate in this area, ensuring that all the requirements of the regulations continue to be adhered to.

Swimming pool chemicals—in particular the chlorinating agents—when retailed through service stations have been controlled by this Branch for several years. Storages were inspected annually when the flammable liquid storage was checked, but following reports of unsafe storage, they were subjected to special scrutiny at the beginning of summer. It was found that the vast majority of service station proprietors were complying with the Branch requirements and public safety was being maintained. With one exception, the few who did not comply at the time of inspection rapidly changed their storage to a safe level. The excess storage was confiscated from the one persistent offender who refused to comply and his case has also been referred to Crown Law for recommendation on whether or not he should be prosecuted.

For some years the inter-departmental Transport of Dangerous Goods Advisory Committee has been investigating the possible need for regulations to control the transport of hazardous materials other than those currently gazetted as Dangerous Goods. Following a recommendation to the Honourable Minister for Transport by the Advisory Committee, Cabinet, through the Honourable Minister for Mines, instructed the Chief Inspector of Explosives to draw up regulations based on the Model Code for the Transport of Dangerous Goods. These regulations will be gazetted as prescribed in the amended Explosives and Dangerous Goods Act.

With the assistance of interested parties in the industry, draft regulations were written to control the storage, handling and transport of liquefied petroleum gas. It is anticipated that the proposals will be suitable for presentation to the Honourable Minister during 1979. This is the culmination of several years work by the Branch which has been subjected to innumerable requests for advice in that period.

ACCIDENTS AND OUTRAGES

(a) *Explosives*

No fatalities from explosives misuse were reported though there were several accidents which resulted in severe injuries. Incidents reported during the year were:

(i) Petrol was found in several of a series of drill holes while they were being prepared for charging. The holes were for a trench for sewerage mains and it is believed that shots, fired the previous day further along the trench, had fractured a nearby underground tank. This caused fuel to leak out and flow along the top of a small underground stream. After the tank was emptied and the holes cleared of fuel and vapour, blasting proceeded with no further incident.

(ii) Vandals broke into a shed on a small unattended mine on the Eastern Goldfields and stole 25 kilograms of explosives and detonators. They then used the explosives to extensively damage the outbuildings and three shafts on the lease.

(iii) Sticks of gelignite were thrown into the backyards of three Kalgoorlie homes during one weekend. No obvious motive could be determined for this stupid and potentially disastrous action.

(iv) A man lost the top of his thumb and forefinger when a detonator exploded in his hand. The man, who knew nothing about explosives, noticed the fuse attached to the detonator was burning and ran some 10 metres to pick up the assembly and throw it away, but it exploded before he could throw it.

(v) Two boys received severe eye injuries and a third had a hand amputated following the premature explosion of detonators they had stolen. Several thousand detonators and some safety fuse were involved.

(vi) A man suffered severe injuries to his head, chest and both hands when a stick of explosives detonated while he was holding it. The man had been throwing primed charges into a pool in a river bed. He was using fuses much shorter than the minimum legal length and holding the charges until the fuse had burned almost to the detonator.

(vii) A young boy suffered injuries to both eyes when a detonator exploded while he was trying to open it. The publicity from the accident resulted in the handing over to the Police of another detonator found in the same area.

(viii) The Police took action against a man who used explosives in a country town contrary to Section 121 of the Police Act. The offender was found guilty and fined $20.00.

(ix) A charge of gelignite caused extensive damage to the rear of a city shop and a second, unexploded charge was also found on the scene. The incident was investigated by the Police as it was obviously a criminal act.

(x) Following several threats against a Police officer, charges were laid by the C.I.B. against a man who was in possession of explosives contrary to the requirements of the Explosives Regulations. The case has not yet been heard.

(xi) A summons was taken out against a shotfirer who used explosives without the permission of the local municipal authority. The case has been adjourned indefinitely because of difficulties in locating the offender.

(b) *Flammable Liquids*

One person was killed and there were several major accidents involving flammable liquids. None of the incidents were caused by breaches of the regulations.

(i) A young woman was burned in a vehicle which caught fire when a "home made" electric window winder was operated soon after the vehicle had been refuelled from a jerry can.

(ii) A factory was gutted following a fire in an electric arc drilling machine which used a tank of flammable liquid as a dielectric. Although the use of the flammable liquid did not contravene the regulations, the use of liquid of a higher flash point was recommended, to safeguard against fire when the factory was rebuilt.

(iii) A fire of undetermined cause was investigated at a fibre glass boat factory. All flammable liquids on the premises had been stored in accordance with the regulations.

(iv) In two separate incidents, service station buildings were damaged in fires attributed to vandals. In both cases, all flammable liquids were stored in accordance with the regulations and they did not contribute to the fires. One site—a self serve station—suffered severe damage to only one room before the fire was extinguished by the local brigade. Buildings at the other site were almost destroyed.

(v) A man was killed following the explosion of a vehicle fuel tank which he was welding. Examination of the scene after the event indicated that the welder had used compressed air in a futile attempt to gas free the tank which had contained distillate.

(vi) Investigation of a fire in a warehouse used to store scientific supplies revealed that no licensable quantities of flammable liquids were stored on the premises and all reasonable precautions had been taken to prevent accident by fire. The warehouse was almost totally destroyed and the cause of the fire could not be determined.

(vii) A fuel leak from the base of a pump installation in a service station entered a telephone cable junction box and permeated along the conduit. Prompt action by the proprietor of the service station and the fire brigade cut off the supply of fuel and the spillage was washed away without further complications.

(viii) A drum of paint thinners was ignited during welding operations in a factory. The resultant fire spread to a small paint store and the intensified blaze caused part of the walls and roof of the premises to collapse. The paint store had not contravened the requirements of the regulations and the fire was attributed to poor working practice.

(ix) Extensive damage was caused to a building when a leak from a 20-litre drum of photocopying fluid was ignited by a nearby electric radiator. The leak occurred when the valve came out of a plastic tap screwed into a fitting at the base of the drum and the leaking solvent fed the fire making it impossible to extinguish with the available portable extinguishers. The institution using the solvent was subsequently advised on safety precautions which should be taken to prevent a similar incident.

(x) A fire scene was inspected following a report that the blaze had originated in an underground tank. Investigations revealed that the tank was in fact an open topped concrete pit which contained quenching oil (flash point 216°C.). A pile of hot manufactured articles had accumulated in the tank following a malfunction in the conveyor intended to remove them. When the pile reached the surface of the liquid, conditions existed which permitted ignition of the liquid. The fire was extinguished by the local fire brigade and there was no breach of the Flammable Liquids Regulations.

(xi) A 14 year old girl was burned when a bottle of burning fuel was thrown into a room where she was sitting. Two youths were subsequently prosecuted by the Police for this act.

(xii) A woman suffered burns to 30 per cent of her body and the vehicle in which she was sitting was extensively damaged in a fire at a country service station. A driveway attendant had placed the automatic nozzle of a dispenser into the vehicle's tank and then left to attend to another customer. The owner of the vehicle completed filling the main tank and then proceeded to fill an auxilliary tank inside the vehicle. Fumes from this operation were ignited; most probably by a refrigerator installed in the vehicle. The flames were extinguished using the hand held extinguishers available on site.

(xiii) A small fire occurred in a fuel terminal laboratory when vapours from a sample of petrol being used for density determination were ignited by the flame from a flash point apparatus. The volume of fuel involved was quite small and the flames were extinguished before they could spread beyond the laboratory. The company concerned has since taken action to avoid a recurrence of the event.

(xiv) A tanker vehicle carrying some three kilolitres of petrol rolled onto its side following a traffic accident. Although several hundred litres of fuel were lost, prompt action by the fire brigade, Police and oil company personnel prevented ignition and the vehicle was subsequently righted and towed to the company terminal for repair.

(xv) The driver of a tanker vehicle was injured when his vehicle overturned on an isolated section of country road. Although no fire or explosion resulted several tanks and the prime mover were extensively damaged and the trailer was considered irrepairable.

(xvi) An empty tanker vehicle was damaged beyond repair in a fire which started when the brakes on the trailer jammed and overheated. The brakes were hydraulically operated; a type which is being phased out of use. The tanker was returning to a fuel depot following the delivery of a load of diesel fuel and although the aluminium tank melted there was no vapour explosion.

(xvii) A fully loaded articulated tanker carrying fuel oil overturned at an intersection on a major suburban highway. Because of the high flash point of the load there was little danger of fire though the Police and fire brigade attended the scene to minimise the danger to the public. The tanker was subsequently righted and towed back to the depot for repair.

(c) *Dangerous Goods*

(i) Only one accident involving the deliberate misuse of swimming pool chemicals was reported. As in previous years, the Police took legal action for breach of Section 19 of the Explosives and Dangerous

Goods Act. The ready availability of this chemical ensures that it will continue to be one one of the most frequently abused, and it is unfortunate that the people usually hurt in any mishap are youths or children. However, there is little that can be done to prevent some youngsters from experimenting in this way.

(ii) A complete disregard for the manufacturers recommended safety precautions for the storage and packing of swimming pool chemicals resulted in a fire which partially destroyed a private motor car. Large drums of chemicals were stored adjacent to containers of linseed oil, bird seed and other combustibles and a common scoop was used to dispense small quantities of solid items. In the incident investigated, the chemical had been dispensed into a paper bag and the bag and contents burst into flames soon after being put into the car.

(iii) Advice and assistance was given to the Emergency Services following the spillage of approximately 400 kilograms of sodium cyanide from a vehicle on a major highway at the edge of the Perth metropolitan region.

(iv) Advice was given to the Police attending an accident in which a vehicle overturned while conveying 19 tonnes of hydrofluoric acid. The driver of the tanker was subsequently charged by the Police for drunken and careless driving.

MISCELLANEOUS ACTIVITIES

(i) *Committee Attendance*

The Chief Inspector participated in the activities of several committees throughout the year. These were: Melbourne, July 17–19 Committee on packaging requirements for dangerous goods.

Sydney, August 2–3, SAA Committee AU/17—Road Tank Vehicles for Hazardous Liquids and Gases (liquid petroleum gas).

Brisbane, September 11–13, SAA Committee AU/17 Road Tank Vehicles for Hazardous Liquids and Gases (liquid petroleum gas).

Melbourne, October 31–November 1, Advisory Committee on the Transport of Dangerous Goods.

Sydney, November 23–24, Association of Australian Port and Marine Authorities Dangerous Goods Committee.

Additionally, the 14th Annual Conference of Chief Inspectors of Explosives, was attended in Brisbane, October 9–11.

(ii) *Lectures*

The Chief Inspector addressed the Oil and Colour Chemists Association on the hazards of flammable liquids. The text of this talk has been submitted to the journal "Chemistry in Australia" for publication. A talk on the Transportation of Dangerous Liquids and Gases was delivered by the Chief Inspector at a "mini-symposium" organised by the W.A. Division of the Chemical Engineering Branch of the Institution of Engineers.

A lecture on the Explosives and Dangerous Goods Act was delivered by the Deputy Chief Inspector of Explosives to officers of the Police Department.

The Senior Inspector of Explosives addressed a safety seminar for fuel agents and also a State Branch meeting of the Australian Petroleum Agents and Distributors Association on various aspects of the Flammable Liquids Regulations. Both talks were requested because of the changes in the regulations controlling the transport of flammable liquids.

(iii) Liaison with the Police in matters concerning explosives and flammable liquids continued to be close and cordial. The increased number of accidents reported to the Branch is one result of this.

CONCLUSION

Although enforcement of the Flammable Liquids and Explosives Regulations continued to dominate the activities of the Branch Inspectorate, increasing demands were made for advice on various aspects concerning other dangerous goods. These demands could only be met by sacrificing some of the time which could have been spent on improving the hard won safety standards for explosives and flammable liquids.

The Branch continues to receive excellent co-operation from all other Departments and Authorities with which it has a working association and it is recorded once again that all Inspectors and other staff members have given their utmost in serving the public with every personal consideration while at the same time maintaining due observance of the regulations which are directed toward the safety of life and property.

H. DOUGLAS,
Chief Inspector of Explosives.

28th February, 1979.

DIVISION IX

Report of Superintendent, Mine Workers' Relief Act, and Chairman, Miners' Phthisis Board 1978

Under Secretary for Mines

Annual Report—Mine Workers' Relief Act 1932 and Miners Phthisis Act 1922

1. This report is submitted for the information of the Honourable Minister for Mines, on the above Acts for the Year ended 31st December 1978.

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:—

Armadale, Bullfinch, Cardup, Coolgardie Fimiston, Kalgoorlie, Kambalda, Leinster, Leonora, Marvel Loch, Menzies, Nepean, Norseman, Red Ross, Selcast, Waterloo, Windarra.

3. *Mine Workers' Relief Act*

3.1 TOTAL EXAMINATIONS

The examinations made under the Mine Workers' Relief Act during the year totalled 6 923 and compared with 7 414 for the previous year; a decrease of 491. The results of examinations are as follows:—

Normal	6 719
Silicosis early, previously normal	17
Silicosis early, previously silicosis early	174
Silocisis advanced, previously normal	....
Silicosis advanced, previously silicosis early	....
Silicosis advanced, previously silicosis advanced	5
Silico-tuberculosis, previously normal	....
Silico-tuberculosis, previously silicosis early	....
Silico-tuberculosis, previously silicosis advanced	....
Silico-tuberculosis, previously tuberculosis	....
Tuberculosis, previously normal	....
Asbestosis early, previously normal	1
Asbestosis early, previously Asbestosis early	1
Asbestosis advanced, previously normal	....
Asbestosis advanced, previously asbestosis early	....
Silico-asbestosis early, perviously normal	1
Silico-asbestosis early, previously asbestosis early	4
Silico-asbestosis early, previously asbestosis early	1
Silico-asbestosis early, previously silico-asbestosis early	....
Silico-asbestosis advanced, previously silicosis early	....
Silico-asbestosis plus tuberculosis, previously normal	....
Silico-asbestosis advanced plus tuberculosis, previously silico-asbestosis early	....
Total	6 923

The 1978 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 6 719 or 97.05 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 7 414 or 96.74 per cent of the men examined.

3.2.2 EARLY SILICOSIS

These numbered 191 of which 17 were new cases and 174 had previously been reported; the figures for 1977 being 18 and 212 respectively. Early silicotics represent 2.75 per cent of the men examined, the percentage for the previous year was 3.10 per cent.

3.2.3 ADVANCED SILICOSIS

There were five cases of Advanced silicotics reported representing 0.07 per cent of the men examined, the percentage for the previous year being 0.11 per cent.

3.2.4 ASBESTOSIS

There was one case of early asbestosis reported during the year and one previously reported.

3.2.5 SILICOSIS-ASBESTOSIS

Cases of early silicosis-asbestosis were reported during the year, and this represents 0.08 per cent of the men examined.

4. *Mines Regulation Act*

4.1 TOTAL EXAMINATIONS

Examinations under the Mines Regulation Act totalled 6 923. There was a decrease of 491 under this Act in 1978 as compared with 1977.

Of the total of 6 923 examined, 3 134 were new applicants and 3 789 were re-examinees.

4.2 ANALYSIS OF EXAMINATIONS

Particulars of examinations are as follows:—

4.2.1 NEW APPLICANTS

Normal	3 134
Silicosis early	....
Silicosis early with tuberculosis	....
Tuberculosis	....
Other conditions	....
Total	3 134

4.2.2 RE-EXAMINEES

Normal	3 585
Silicosis early	191
Silicosis Advanced	5
Asbestosis early	2
Asbestosis Silicosis early	6
Total	3 789

These men had previously been examined and some were in the industry prior to this examination.

4.3 HEALTH CERTIFICATES ISSUED TO NEW APPLICANTS AND RE-EXAMINEES

The following health certificates were issued under the Mines Regulation Act:—

Initial Certificates (Form 2)	6 923
Temporary Rejection Certificates (Form 3)	....
Rejection Certificates (Form 4)	....
Re-admission Certificates (Form 5)	....
Special Certificates (Form 9)	....
Total	6 923

5. *Miners' Phthisis Act*

The amount of compensation paid during the year was $4 782.40 compared with $4 950.40 for the previous year.

The number of beneficiaries under the Act as on 31/12/1978 was 19 being 2 ex-miners and 17 widows.

R. S. THOMPSON,
Superintendent Mine Workers Relief Act
and
Chairman, Miners' Phthisis Board.

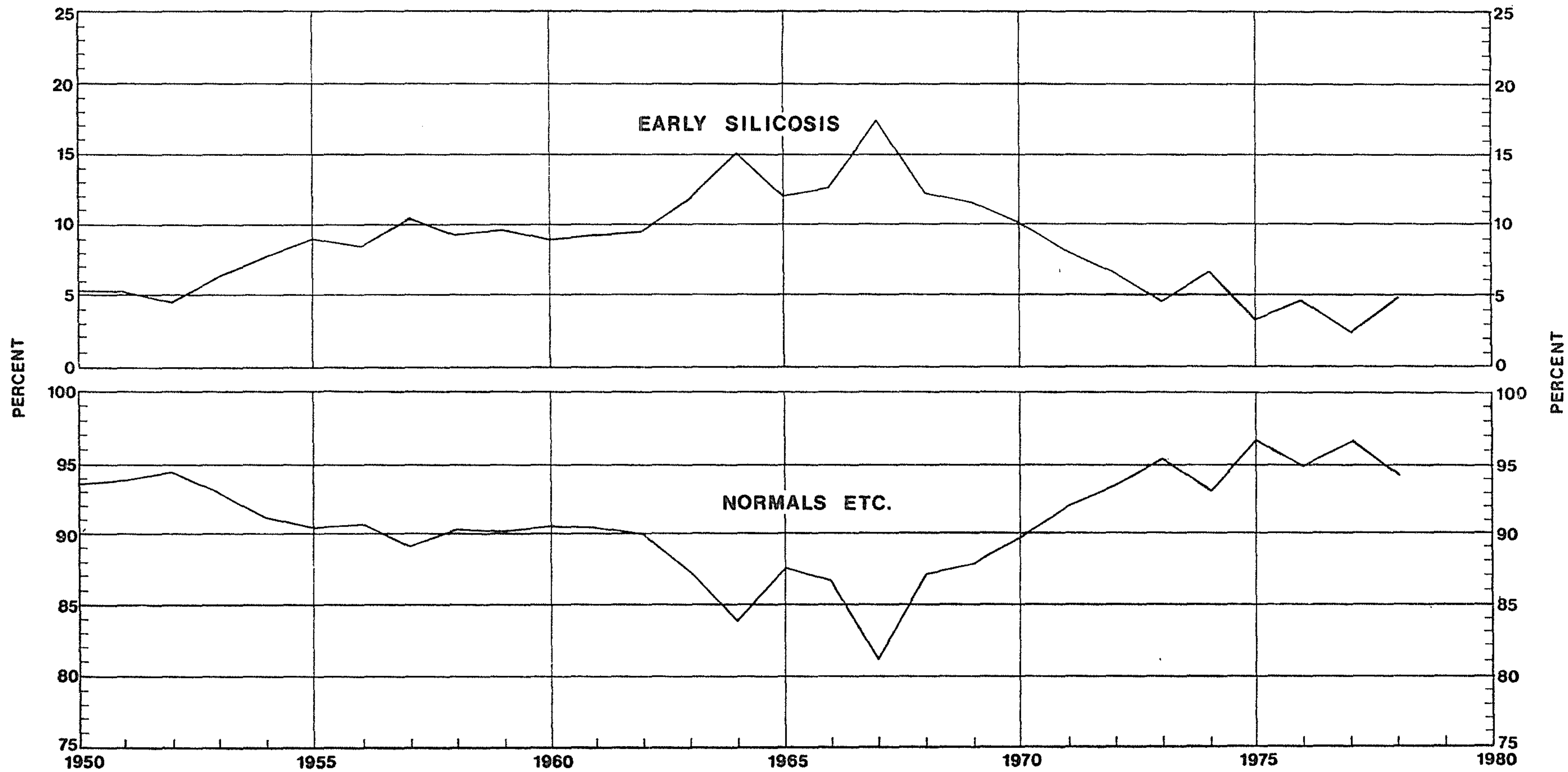
TABLE SHOWING RESULTS OF PERIODICAL EXAMINATION OF MINE WORKERS FROM INCEPTION OF EXAMINATIONS (1925)

Year	Normal		Silicosis Early				Silicosis Advanced					Silicosis plus Tuberculosis					Tuberculosis Only		Asbestosis									Total
	Total	Per Cent.	Previously reported as normal etc.	Previously reported as Silicosis early	Total	Per Cent.	Previously reported as normal etc.	Previously reported as Silicosis early	Previously reported as Silicosis advanced	Total	Per Cent.	Previously reported as normal etc.	Previously reported as Silicosis early	Previously reported as Silicosis advanced	Total	Per Cent.	Total	Per Cent.	Asbestosis early previously normal	Asbestosis early previously asbestosis early	Asbestosis advanced previously normal	Asbestosis advanced previously asbestosis early	Asbestosis advanced previously asbestosis advanced	Asbestosis plus tuberculosis previously normal	Asbestosis plus tuberculosis previously asbestosis	Total	Per Cent.	
1925 } 1926	3 239	80·5	....	....	459	11·4	....	....	....	183	4·5	....	....	....	131	3·3	11	0·3	....	....	....	....	....	....	....	....	....	4 023
1927	3 116	83·6	33	348	381	10·2	8	....	85	93	2·5	39	27	62	128	3·4	10	0·3	....	....	....	....	....	....	....	....	....	3 728
1928	2 977	85·5	59	303	362	10·4	3	16	79	98	2·8	18	14	10	42	1·2	4	0·1	....	....	....	....	....	....	....	....	....	3 483
1929	2 120	81·9	102	224	326	12·6	....	34	60	94	3·6	8	14	19	41	1·6	7	0·3	....	....	....	....	....	....	....	....	....	2 588
1930	2 785	81·9	136	247	383	11·3	2	22	43	67	2·0	8	60	46	114	3·3	50	1·5	....	....	....	....	....	....	....	....	....	3 399
1931	2 530	84·0	94	252	346	11·5	....	18	35	53	1·8	4	35	19	58	1·9	25	·8	....	....	....	....	....	....	....	....	....	3 012
1932	3 835	89·5	35	338	373	8·7	....	6	47	53	1·2	3	9	4	16	·4	8	·2	....	....	....	....	....	....	....	....	....	4 285
1933	2 920	86·5	57	322	379	11·2	1	15	44	60	1·8	2	9	4	15	·4	3	·1	....	....	....	....	....	....	....	....	....	3 377
1934	5 140	92·4	54	315	369	6·6	1	24	12	37	·7	6	6	....	12	·2	5	·1	....	....	....	....	....	....	....	....	....	5 563
1935	4 437	92·3	35	303	338	7·0	....	24	2	26	·6	....	5	....	5	·1	2	·0	....	....	....	....	....	....	....	....	....	4 808
1936	6 972	94·7	29	323	352	4·8	1	15	4	20	·3	3	8	....	11	·1	8	·1	....	....	....	....	....	....	....	....	....	7 363
1937	7 487	95·4	15	319	334	4·3	....	14	4	18	·2	1	10	....	11	·1	2	·0	....	....	....	....	....	....	....	....	....	7 852
1938	6 833	95·7	13	266	279	3·9	....	15	2	17	·2	1	8	....	9	·1	3	·0	....	....	....	....	....	....	....	....	....	7 141
1939	6 670	95·6	18	264	282	4·0	....	7	3	10	·1	1	9	1	11	·2	2	·0	....	....	....	....	....	....	....	....	....	6 975
1940	7 023	96·2	12	245	257	3·5	....	10	1	11	·2	....	4	....	4	·0	4	·0	....	....	....	....	....	....	....	....	....	7 299
1941	6 840	95·8	32	248	280	3·9	....	11	3	14	·2	....	....	....	....	....	7	·1	....	....	....	....	....	....	....	....	....	7 141
1942	5 469	93·9	61	264	325	5·6	....	20	5	25	·4	....	2	....	2	·0	3	·1	....	....	....	....	....	....	....	....	....	5 824
1943	3 932	91·5	63	262	325	7·6	....	25	7	32	·7	....	5	....	5	·1	4	·1	....	....	....	....	....	....	....	....	....	4 298
1944	4 079	91·5	70	270	340	7·5	....	21	14	35	·8	1	7	....	8	·2	6	·1	....	....	....	....	....	....	....	....	....	4 468
1945	3 071	92·1	54	166	220	6·6	....	26	10	36	1·1	3	2	....	5	·2	2	·1	....	....	....	....	....	....	....	....	....	3 334
1946	5 294	94·4	89	172	261	4·7	1	36	2	39	·7	3	1	2	6	·1	6	·1	....	....	....	....	....	....	....	....	....	5 606
1947	6 021	93·3	101	237	338	5·2	....	49	9	58	1·0	13	11	1	25	·3	8	·1	....	....	....	....	....	....	....	....	....	6 450
1948	4 827	94·0	24	239	263	5·1	....	18	17	35	·7	1	3	....	4	·1	5	·1	....	....	....	....	....	....	....	....	....	5 134
1949	5 162	94·0	24	239	263	4·8	....	20	31	51	1·0	3	2	1	6	·1	7	·1	....	....	....	....	....	....	....	....	....	5 489
1950	5 077	93·6	14	269	283	5·2	....	14	41	55	1·0	....	1	2	3	·1	8	·2	....	....	....	....	....	....	....	....	....	5 426
1951	4 642	93·9	13	248	261	5·3	....	9	20	29	·6	....	4	2	6	·1	4	·1	....	....	....	....	....	....	....	....	....	4 942
1952	5 073	94·6	8	234	242	4·5	....	4	31	35	·6	....	2	....	2	·1	7	·1	....	....	....	....	....	....	....	....	....	5 359
1953	4 474	93·03	74	225	299	6·22	....	8	24	32	·6	....	2	....	2	·1	2	·1	....	....	....	....	....	....	....	....	....	4 809
1954	5 142	91·33	154	275	429	7·62	....	22	21	43	·76	1	6	2	9	·1	7	·1	....	....	....	....	....	....	....	....	....	5 630
1955	4 559	90·40	63	286	449	8·90	....	9	22	31	·62	1	1	1	3	·06	1	·02	Segregation of asbestosis diagnoses commenced in 1959									5 043
1956	4 600	90·78	25	401	426	8·41	....	8	25	33	·65	1	3	....	4	·08	4	·08	....	....	....	....	....	....	....	....	....	5 067
1957	3 925	89·08	30	424	454	10·30	....	8	10	18	·41	1	4	....	5	·12	4	·09	....	....	....	....	....	....	....	....	....	4 406
1958	5 154	90·20	46	483	529	9·26	....	15	9	24	·42	....	6	....	6	·10	1	·02	....	....	....	....	....	....	....	....	....	5 714
1959	5 242	90·10	66	485	551	9·47	....	9	....	....	·15	1	5	1	7	·12	3	·05	6	....	....	....	....	....	....	6	....	5 818
1960	5 214	90·54	50	473	523	9·08	....	5	....	5	·09	2	9	....	11	·19	3	·05	2	....	....	....	....	1	....	3	....	5 759
1961	5 188	90·18	54	479	533	9·26	....	13	....	13	·23	2	3	....	5	·09	3	·05	5	5	....	1	....	....	....	11	·19	5 753
1962	5 183	89·98	50	499	549	9·53	1	10	....	11	·19	1	5	....	6	·10	1	·02	2	7	....	1	....	....	....	10	·18	5 760
1963	4 795	87·21	188	451	639	11·62	....	22	....	22	·40	7	6	....	13	·24	3	·05	10	11	....	4	....	1	....	26	·47	5 498
1964	3 484	83·85	64	561	625	15·04	....	9	1	10	·24	....	1	....	1	·02	2	·05	13	17	....	2	....	....	1	33	·80	4 155
1965	3 770	87·39	53	459	512	11·87	....	6	....	6	·14	....	1	....	1	·02	5	·12	5	15	....	....	....	....	....	20	·46	4 314
1966	3 411	86·56	26	469	495	12·56	....	14	....	14	·36	3	1	....	4	·10	1	·02	4	12	....	....	....	....	....	16	·40	3 941
1967	1 644	81·03	19	332	351	17·30	....	7	1	8	·39	....	2	....	2	·10	5	·24	8	6	....	5	....	....	....	19	·94	2 029
1968	3 364	86·93	39	431	470	12·14	....	18	3	21	·54	....	1	1	2	·05	1	·03	5	4	....	3	....	....	....	12	·31	3 870
1969	3 406	87·77	36	412	448	11·55	....	13	1	14	·36	....	1	....	1	·03	1	·01	2	7	....	2	....	....	....	11	·28	3 881
1970	3 841	89·73	30	400	430	10·04	....	6	....	6	·14	....	1	....	1	·02	3	·07	....	....	....	....	....	....	....	....	....	4 281
1971	3 915	91·80	15	327	342	8·02	....	5	2	7	·16	....	....	....	....	....	1	·02	....	....	....	....	....	....	....	....	....	4 265
1972	4 647	93·30	20	308	328	6·55	....	5	2	7	·15	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	4 982
1973	5 078	95·27	27	215	242	4·54	....	4	3	7	·13	....	....	....	....	....	2	·04	....	1	....	....	....	....	....	1	·02	5 330
1974	4 803	93·02	31	310	341	6·60	....	4	4	8	·15	....	2	....	2	·04	....	....	3	7	....	....	....	....	....	10	·19	5 164
1975	8 394	96·53	33	242	275	3·16	....	11	3	14	·16	....	....	....	....	....	1	·01	4	7	1	....	....	....	....	12	·14	8 696
1976	5 495	94·94	20	250	270	4·67	....	7	5	12	·21	....	....	....	....	....	....	....	1	9	....	....	....	....	....	10	·18	5 788
1977	7 172	96·74	18	212	230	3·10	....	1	7	8	·11	....	....	....	....	....	....	....	....	3	....	1	....	....	....	4	·05	7 414
1978	6 719	97·05	17	174	191	2·75	....	....	5	5	·07	....	....	....	....	....	....	....	2	6	....	....	....	....	....	8	·08	6 923

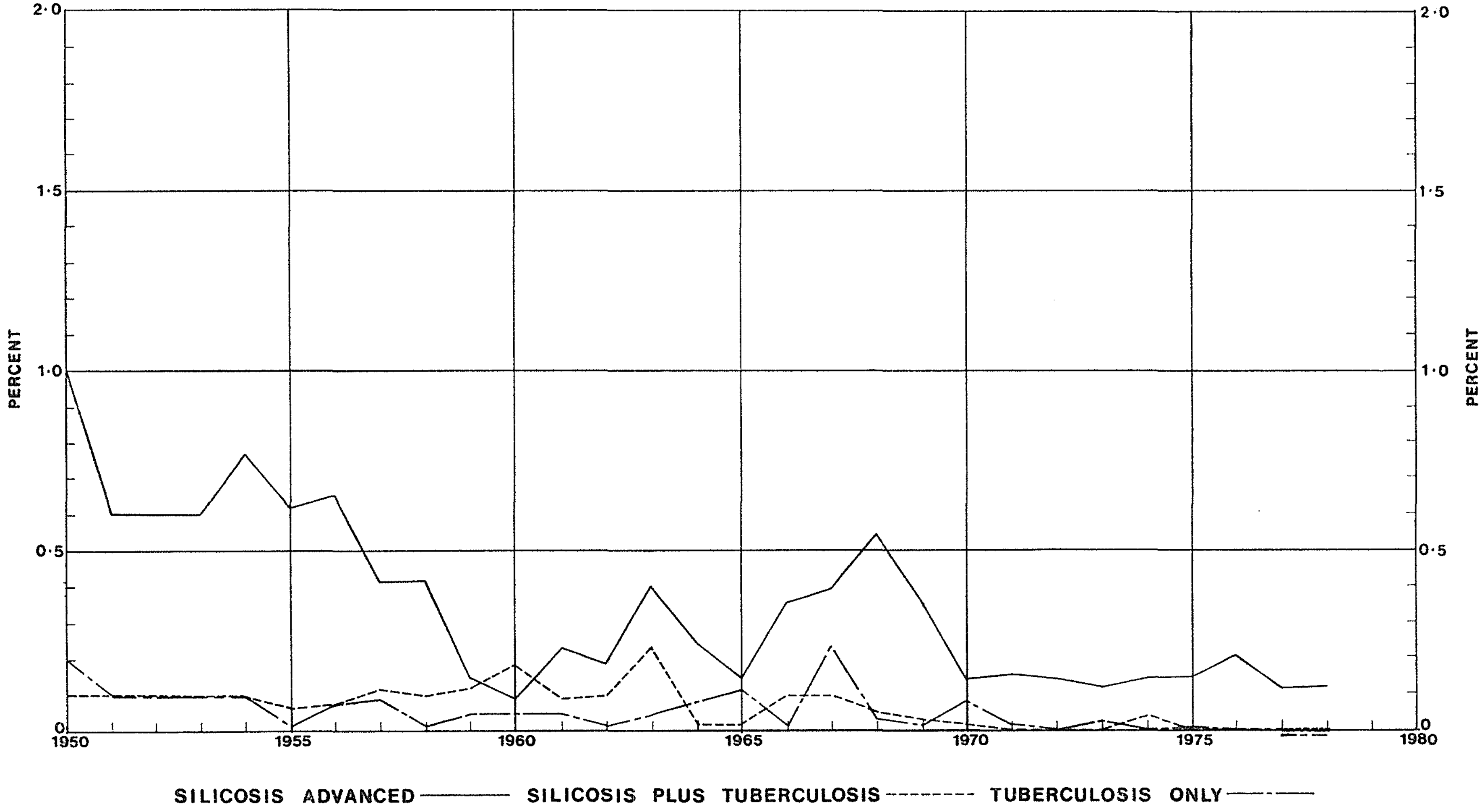
PERIODICAL EXAMINATION OF MINE WORKERS

GRAPH №1

SHOWING PERCENTAGES OF NORMALS AND EARLY SILICOTICS FROM 1950 ONWARDS



PERIODICAL EXAMINATION OF MINE WORKERS
GRAPH Nº 2
SHOWING PERCENTAGES OF SILICOSIS ADVANCED, SILICOSIS PLUS TUBERCULOSIS AND TUBERCULOSIS ONLY, FROM 1950 ONWARDS



MINING STATISTICS
to 31st December, 1978

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TABLE I

PRODUCTION OF GOLD AND SILVER AS REPORTED TO THE MINES DEPARTMENT DURING 1978

(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 1978					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												
Marble Bar	G.M.L. 45/1450	Betty Boo	....	....	111·00	·323	....	·027	....	1 439·00	3·091	....
	1487	Charger	....	....	152·00	·323	....	·292	....	1 552·00	3·392	....
	1529	Halleys Comet	....	....	....	23·147	1·674	....	....	6 462·06	304·099	33·304
	1309	Homeward Bound	....	....	14·00	·063	....	....	....	102·00	·135	....
	1209	Ironclad	....	....	22·00	·076	....	....	....	2 131·23	4·143	·006
	1458	Kangaroo	....	....	5·00	·148	....	....	....	373·49	5·648	....
	1534	Miracle	....	....	85·00	·422	....	....	....	85·00	·422	....
	1247	Stray Shot	....	....	97·00	·338	....	....	....	117·00	·441	....
		Sundry Claims	....	....	86·00	·783	....	2·086	8·552	22 937·39	407·881	·341
Telfer	1421 etc.	Newmont Pty. Ltd.	....	....	435 612·00	7 000·167	62·515	....	....	728 699·00	11 433·351	138·753
NULLAGINE DISTRICT												
Middle Creek	G.M.L. 46/339 etc.	Mulga Mines Pty. Ltd.	....	....	1 589·00	44·903	....	....	....	47 422·00	723·973	....
Nullagine	401	Lucky Star	....	....	6·00	·180	....	....	....	6·00	·180	....
Peak Hill Goldfield												
Peak Hill	G.M.L. 52/610	North Star	....	·377	2 072·00	1·745	....	·260	·377	2 072·00	1·745	....
East Murchison Goldfield												
LAWLERS DISTRICT												
Agnew	G.M.L. 36/1462	Cottee	....	....	70·00	·073	....	....	....	70·00	·073	....
WILUNA DISTRICT												
Corboys	G.M.L. (53/701)	Rumble Rest	....	....	17·00	·290	....	....	....	17·00	·290	....
Murchison Goldfield												
CUE DISTRICT												
Reedys	G.M.L. (20/2381)	Bronzewing	....	....	55·00	·421	....	....	....	119·00	1·389	....
Tuckabianna		Sundry Claims	....	·731	93·00	·575	....	5·045	15·953	5 963·06	88·002	·041

Murchison Goldfield—cont.

MEEKATHARRA DISTRICT

Meekatharra	G.M.L. 51/2244	Gloria Jean	....	....	240·00	1·177	....	....	....	240·00	1·177	....
	2068	Halcyon	....	....	546·00	·913	....	....	·051	4 481·20	8·849	....
	2015	Haveluck	....	....	1 181·00	2·016	....	....	....	18 151·51	34·801	....
	2139	Ingliston Gold Mine	....	....	1 001·00	27·334	....	....	....	2 064·00	66·376	....
		Sundry Claims	....	....	137·00	1·836	....	8·704	43·777	33 388·41	368·850	·407
Yaloginda....	2050	Bluebird	....	....	301·00	·153	....	....	....	363·49	·190	....

MOUNT MAGNET DISTRICT

Lennonville	G.M.L. 58/1792	Empress	....	....	72·00	·330	....	....	....	72·00	·330	....
	1773	Hard Up	....	....	118·00	·114	....	....	....	118·00	·114	....
Mt. Magnet	1701	Alison	....	....	1 270·00	4·360	....	....	....	1 270·00	4·360	....
	1708	Gay Parisian	....	....	120·00	·196	....	....	....	120·00	·196	....
	1356 etc.	Hill 50 Gold Mine N.L.	....	....	....	4·006	....	....	....	3 219 720·49	42 211·735	2 147·058
	(1782)	Joanne	....	·023	50·00	·025	....	....	·367	280·00	·364	....
	1444	Late Comer	....	....	56·00	·396	....	....	·079	631·20	12·783	....
		State Battery—Boogardie	....	....	....	·100	....	....	....	353·85	1 091·908	·486

Yalgoo Goldfield

Goodingnow	G.M.L. 59/1357	Ark Gold Mines	....	....	26·00	·018	....	....	·388	4 117·41	116·942	....
	1242	Carnation	....	....	249·00	1·256	....	....	....	969·78	7·841	....
	1380	Little Pot	....	....	36·00	·032	....	....	....	36·00	·032	....
		Sundry Claims	....	....	25·00	·344	....	4·757	6·220	11 103·97	163·250	·004
Gullewa	1377	Gullewa Gold	....	....	20·00	·039	....	....	....	20·00	·039	....
Noongal	1376	Black Rabbit	....	....	15·00	·505	....	....	....	15·00	·505	....

Mt. Margaret Goldfield

MOUNT MORGANS DISTRICT

Redcastle	G.M.L. 39/689	Lady Susan	....	....	1 313·00	3·393	....	....	....	1 398·00	3·604	....
		Sundry Claims	....	....	100·00	·214	....	....	3·541	1 435·54	21·015	....

MOUNT MALCOLM DISTRICT

Leonora	G.M.L. 37/2065	British King	....	....	606·00	9·513	....	....	....	806·00	13·664	....
	1888	Healeys Hope	....	....	208·00	2·225	....	....	....	323·83	3·648	....
	2015	Island	....	....	761·00	4·016	....	....	....	1 547·72	14·123	....
	2050	Jasper Mine	....	....	40·00	·128	....	....	....	75·00	·310	....
	1948	Jessie Alma	....	....	150·00	·204	....	....	....	564·01	·475	....
	1907	Longs Lucky Lode	....	....	390·00	·408	....	....	....	522·00	·918	....
	2041	Narroona	....	....	50·00	·232	....	....	....	50·00	·232	....
	2058	Picnic	....	....	500·00	·912	....	....	....	770·00	1·410	....
	1762	Sons of Gwalia	....	....	2 470·00	6·265	....	....	·676	9 519·07	24·639	....
	1860	Tower Hill	....	....	470·00	1·264	....	....	....	6 689·61	15·563	....
		Sundry Claims	....	....	170·00	·583	....	1·207	12·211	26 367·52	421·614	·833
Wilsons Patch		Sundry Claims	....	....	40·00	·226	....	·145	1·694	1 972·03	46·306	·035
		State Battery—Leonora	....	....	....	*10·068	1·116	....	....	92·46	*107·290	3·417
		L.T.T. 37/31 (2626H) Smith, G. J.	....	....	....	*·084	....	....	....	....	*·150	....

MOUNT MARGARET DISTRICT

Burtville	G.M.L.(38/2770)	Aybe	....	....	52·00	·048	....	....	....	183·00	·198	....
Laverton	2818	Craiggiemore South	....	....	450·00	·464	....	....	....	450·00	·464	....
	2747	Mary Mack	....	....	421·00	·763	....	....	....	481·00	·804	....

Table I.—*Production of Gold and Silver from all sources, etc.*—continued.

North Coolgardie Goldfield

MENZIES DISTRICT

Mining Centre	Number of Lease	Registered Name of Company or Lease	Total for 1978: Alluvial kg	Total for 1978: Dollied and Specimens kg	Total for 1978: Ore treated Tonnes	Total for 1978: Gold therefrom kg	Total for 1978: Silver kg	Total Production: Alluvial kg	Total Production: Dollied and Specimens kg	Total Production: Ore treated Tonnes	Total Production: Gold therefrom kg	Total Production: Silver kg
Goongarrie	M.L. 29/24	Goongarrie	....	....	77·00	·243	....	....	....	87·00	·262	....
Menzies	G.M.L. 29/5971	Alfia	....	....	19·00	·639	....	....	....	83·00	3·702	....
	5815	Espacia	....	....	1 620·00	5·331	....	....	....	4 060·60	19·234	....
		State Battery—Menzies	....	....	....	*2·365	·395	....	·237	20·32	*137·143	35·467
		L.T.T. 29/49 (2684H) Craig, K. C.	....	....	....	*1·171	....	....	....	....	*1·171	....

ULARRING DISTRICT

Mining Centre	Number of Lease	Registered Name of Company or Lease	Total for 1978: Alluvial kg	Total for 1978: Dollied and Specimens kg	Total for 1978: Ore treated Tonnes	Total for 1978: Gold therefrom kg	Total for 1978: Silver kg	Total Production: Alluvial kg	Total Production: Dollied and Specimens kg	Total Production: Ore treated Tonnes	Total Production: Gold therefrom kg	Total Production: Silver kg
Davyhurst	G.M.L. 30/1333	Makai	....	....	18·00	·085	....	....	....	31·00	·153	....
	1346	Piano Rag	....	....	66·00	·117	....	....	....	66·00	·117	....
		Sundry Claims	....	....	81·00	·283	....	....	6·484	14 694·75	181·256	....
Morleys	1221	Emerald	....	....	95·00	·476	....	....	....	509·60	3·683	....
Mulline	1107	Ajax West	....	....	36·00	·134	....	....	·043	8 868·58	210·513	....
	1340	Little Willee	....	....	207·00	·796	....	....	....	661·00	2·367	....
Mulwarrie	1153	Four Mile....	....	....	16·00	·265	....	....	....	138·43	25·420	·352
	1113	Oakley	....	....	540·00	1·109	....	....	....	6 552·05	285·624	10·387
	(1350)	Ruby	....	....	10·00	·062	....	....	....	10·00	·062	....

NIAGARA DISTRICT

Mining Centre	Number of Lease	Registered Name of Company or Lease	Total for 1978: Alluvial kg	Total for 1978: Dollied and Specimens kg	Total for 1978: Ore treated Tonnes	Total for 1978: Gold therefrom kg	Total for 1978: Silver kg	Total Production: Alluvial kg	Total Production: Dollied and Specimens kg	Total Production: Ore treated Tonnes	Total Production: Gold therefrom kg	Total Production: Silver kg
Niagara		Sundry Claims	....	....	38·00	·189	....	·874	3·024	14 967·80	257·286	....
		L.T.T. 40/16 (2512H) Bright, J.	....	....	....	*·524	....	....	....	....	*·524	....

YERILLA DISTRICT

Mining Centre	Number of Lease	Registered Name of Company or Lease	Total for 1978: Alluvial kg	Total for 1978: Dollied and Specimens kg	Total for 1978: Ore treated Tonnes	Total for 1978: Gold therefrom kg	Total for 1978: Silver kg	Total Production: Alluvial kg	Total Production: Dollied and Specimens kg	Total Production: Ore treated Tonnes	Total Production: Gold therefrom kg	Total Production: Silver kg
Yarri	G.M.L. 31/1448	Porphyry	....	....	148·00	·422	....	....	....	72 943·91	324·650	8·147
	(1456)	Rat Sack	....	....	7·00	·079	....	....	....	7·00	·079	....
		Sundry Claims	....	·056	58·00	·056	....	·027	·240	19 308·94	201·323	·043
		State Battery—Yarri....	....	....	....	*4·283	·360	....	....	280·94	*293·512	1·033

Broad Arrow Goldfield

Mining Centre	Number of Lease	Registered Name of Company or Lease	Total for 1978: Alluvial kg	Total for 1978: Dollied and Specimens kg	Total for 1978: Ore treated Tonnes	Total for 1978: Gold therefrom kg	Total for 1978: Silver kg	Total Production: Alluvial kg	Total Production: Dollied and Specimens kg	Total Production: Ore treated Tonnes	Total Production: Gold therefrom kg	Total Production: Silver kg
Broad Arrow	G.M.L. 24/2348	Wentworth	....	....	190·00	1·427	....	....	....	482·62	4·363	....
Ora Banda	2270, 2290	Gimlet South Leases	....	....	4 597·00	9·660	....	....	....	76 792·56	219·715	5·120
	2446	Herbies	....	....	162·00	·082	....	....	....	162·00	·082	....
	2300	Sleeping Beauty	....	....	....	1·240	....	....	....	6 198·96	38·756	·035
		Sundry Claims	....	....	69·00	·563	....	....	15·034	18 941·93	165·577	....
		State Battery—Ora Banda	....	....	247·00	*·022	....	....	....	130·10	*890·993	3·367
		L.T.T. 24/50 (1872H) Harford, P.	....	*36·731	....	....	....	....	*57·948	....	....	....

North-East Coolgardie Goldfield

KANOWNA DISTRICT

Mining Centre	Number of Lease	Registered Name of Company or Lease	Total for 1978: Alluvial kg	Total for 1978: Dollied and Specimens kg	Total for 1978: Ore treated Tonnes	Total for 1978: Gold therefrom kg	Total for 1978: Silver kg	Total Production: Alluvial kg	Total Production: Dollied and Specimens kg	Total Production: Ore treated Tonnes	Total Production: Gold therefrom kg	Total Production: Silver kg
Kalpini		Sundry Claims	....	....	11·00	·164	....	·768	8·389	1 826·42	33·307	·005
Six Mile	G.M.L.(27/1720)	Zephyr	....	....	103·00	·073	....	....	....	103·00	·073	....

KURNALPI DISTRICT

Kurnalpi		Sundry Claims	....	....	23·00	·199	....	10·081	22·884	4 879·36	74·655	....
Mulgabbie		Sundry Claims	....	....	50·00	·111	....	·251	86·241	1 418·06	70·836	....

East Coolgardie Goldfield.

EAST COOLGARDIE DISTRICT

Binduli	G.M.L. 26/6881	Golden Aces	....	....	103·00	6·932	....	....	1·435	130·00	9·711	....
Boorara	6658	Waterfall	....	....	105·00	·848	....	....	·088	538·34	6·314	....
	6671	Waterall North	....	....	197·00	·701	....	....	·361	1 172·75	8·724	....
Boulder	(5815)	Great Boulder No. 1 South	....	·050	....	·416	·045	....	·050	6·00	·446	·045
	5345 etc.	Kalgoorlie Lake View Pty. Ltd.	....	....	....	71·258	13·702	....	....	1 108 024·40	6 435·049	2 357·793
		Prior to transfer to present holders	....	....	....	....	....	....	26·700	62 162 730·32	732 838·733	106 492·417
	6663	Kalgoorlie Lake View Pty. Ltd.	....	....	1 833·00	9·652	....	....	....	2 227·00	12·671	....
	(5816)	Do.	....	....	1 092·00	2·550	....	....	....	1 092·00	2·550	....
	6896	Do.	....	....	881·00	2·365	....	....	....	881·00	2·365	....
	6897	Do.	....	....	2 196·00	11·715	....	....	....	6 647·00	24·609	....
	6905	Do.	....	....	1 703·00	4·169	....	....	....	3 408·00	7·241	....
	6593	Do.	....	....	2 164·00	14·102	....	....	....	2 898·00	15·559	....
	6869	North Kalgurli Mines Ltd.	....	....	309·00	·895	....	....	....	396·00	·926	....
Feysville	7016	Bellview West	....	....	318·00	1·132	....	....	....	318·00	1·132	....
		Sundry Claims	....	....	110·00	·400	....	....	6·189	1 827·00	23·035	....
Hampton Plains	P.P.L. 222 Loc. 48	Phillips, J. W.	....	....	200·00	·285	....	....	....	200·00	·285	....
	S.L. 28 Loc 48	Simmonds, P.	....	·042	....	....	....	....	·042	....	....	....
	S.L. 24 Loc. 48	Trinidad, B.	....	....	225·00	·424	....	....	....	572·00	1·008	....
Kalgoorlie	G.M.L. 26/6630	Golden Star	....	....	147·00	·238	....	....	....	2 165·37	4·151	....
	6563 etc.	Kalgoorlie Lake View Pty. Ltd. (Mt. Charlotte)	....	....	636 153·00	3 089·260	597·496	....	....	3 483 892·38	14 540·432	....
		Prior to transfer to present holders	....	....	....	....	....	....	·178	4 947 601·36	21 751·229	5·336
	6485	Maritana Hill	....	....	1 150·00	2·413	....	....	....	8 493·95	24·462	....
	(5852)	Pedestal	....	....	32·00	·068	....	....	....	1 860·88	15·350	....
	6991	Taroya	....	....	1 438·00	1·547	....	....	....	1 490·00	1·619	....
Wombola	6844	Daisy	....	....	518·00	7·089	....	....	1·756	30 309·50	868·464	27·519
	6912	Dry Mount North	....	....	15·00	·054	....	....	....	15·00	·054	....
	G.M.L. 26/7013	Gimberella	....	....	230·00	·303	....	....	....	230·00	·303	....
	6487	Leslie	....	....	290·00	·639	....	....	....	1 182·60	15·919	·036
	6614	Logans Gold Mine	....	....	81·00	·180	....	....	5·227	8 240·20	47·275	·039
	6877	Lurgan	....	....	168·00	1·193	....	....	·310	705·00	5·573	....
	6676	Rosemary	....	....	59·00	·493	....	....	....	983·00	11·757	....
		Sundry Claims	....	....	240·00	1·890	....	....	22·459	30 359·31	490·361	·006
		State Battery—Kalgoorlie	....	....	....	*9·043	·835	....	....	396·97	*1 327·104	25·773
		L.T.T. 26/143 (2741H) Moser, G. & Simon, J.	....	....	....	*·167	....	....	....	....	*·167	....
		L.T.T. 26/142 (2740H) Moser, G. & Simon, J.	....	....	....	*·410	....	....	....	....	*·410	....

BULONG DISTRICT

Bulong	G.M.L. 25/1379	Long Shot	....	....	60·00	·230	....	....	....	60·00	·230	....
		Sundry Claims	....	....	80·00	·151	....	51·503	50·126	18 842·41	564·102	·010
Trans Find		Sundry Claims	....	....	35·00	·092	·014	....	·184	774·94	9·891	·014

Coolgardie Goldfield.

COOLGARDIE DISTRICT

Bonnievale	G.M.L. 15/6151	Melva Maie	....	....	183·00	5·688	....	....	·084	1 365·38	9·440	....
	6380	Oshkosh	....	....	19·00	·023	....	....	....	19·00	·023	....
	5890	Rayjax	....	....	39·00	1·257	....	....	1·416	2 052·09	60·967	·159
Bulla Bulling	6278	Pool Mans Wealth	....	....	95·00	·301	....	....	....	214·00	·943	....
Burbanks	6381	Belgium Queen	....	....	87·00	·622	....	....	....	87·00	·622	....
	6225	Glenloth	....	....	12·00	·050	....	....	....	41·00	·237	....
Coolgardie	(6333)	Bicentenary	....	....	27·00	·050	....	....	....	72·00	·233	....
	6282	Doreen Rose	....	....	476·00	·595	....	....	....	981·26	2·060	....
	6178	Eagle Rock	....	....	48·00	·187	....	....	....	48·00	·187	....
	6059	Empress	....	....	106·00	·162	....	....	....	456·00	·931	....
	6337	Golden Hope	....	....	22·00	·136	....	....	....	105·00	·276	....
	6350	Hennessy	....	....	131·00	·101	....	....	....	131·00	·101	....
	6314	McPhersons Reward	....	....	105·00	·162	....	....	....	275·00	·597	....
	6154	Monkani	....	....	2 187·00	2·182	....	....	....	15 599·92	21·237	....
	6371	Peerless	....	....	50·00	·023	....	....	....	50·00	·023	....
	6176	Three Mile	·140	2·221	287·00	·394	....	·140	2·259	1 378·15	1·888	....
	6144	Tindals South	....	....	1 078·00	1·697	....	....	....	1 078·00	1·697	....
	G.M.L. 15/6346	Worked Out	....	....	89·00	·527	....	....	....	89·00	·527	....
		Sundry Claims	....	·218	845·00	1·714	....	7·375	95·778	94 503·12	945·830	·059

Table I.—*Production of Gold and Silver from all sources, etc.*—continued.

Coolgardie Goldfield—cont.

COOLGARDIE DISTRICT—cont.

Mining Centre	Number of Lease	Registered Name of Company or Lease	Total for 1978: Alluvial (kg)	Total for 1978: Dollied and Specimens (kg)	Total for 1978: Ore treated (Tonnes)	Total for 1978: Gold therefrom (kg)	Total for 1978: Silver (kg)	Total Production: Alluvial (kg)	Total Production: Dollied and Specimens (kg)	Total Production: Ore treated (Tonnes)	Total Production: Gold therefrom (kg)	Total Production: Silver (kg)
Gibraltar	6341	Reform	....	....	373·00	·646	....	....	....	373·00	·646	....
Hampton Plains	H.P.I.	Hampton Areas Aust. Pty. Ltd.	....	....	176·00	·108	....	....	....	176·00	·108	....
	P.P.L. 486 Loc. 59	Peterkin, N.	....	....	272·00	1·070	....	....	....	272·00	1·070	....
	P.P.L. 330 Loc. 59	Sack, R.	....	·022	....	....	....	....	·022	....	....	....
	P.P.L. 371 Loc. 59	Trinidad, B.	....	....	67·00	·211	....	....	....	67·00	·211	....
	S.L. 29	Waters, L. K.	....	....	41·00	·186	....	....	....	41·00	·186	....
	S.L. 24	Wright, G.	....	....	85·00	·373	....	....	....	85·00	·373	....
	S.L. 17	Celestina, M.	....	....	21·00	·029	....	....	....	21·00	·029	....
Higginsville	G.M.L. 15/5647	Fair Play Gold Mine	....	....	1 666·00	2·910	....	·137	1·950	41 244·04	117·257	·001
		Sundry Claims	....	....	116·00	·495	....	....	5·824	4 124·34	62·894	....
Kambalda	M.C.s 15/152 etc.	Western Mining Corpn	....	....	....	63·665	191·424	....	22·003	32·00	345·406	1 271·127
		Sundry Claims	....	....	29·00	·135	....	....	....	204·50	·972	....
Larkinville		Sundry Claims	....	....	11·00	·031	....	....	4·578	556·90	35·002	....
Ryans Find	G.M.L. 15/5999	Consolidated Gold Mining Areas N.L.	....	....	10·00	·218	....	....	....	1 319·56	31·860	....
		Prior to transfer to present holders	....	....	....	....	....	....	97·256	245·63	76·812	....
Widgiemooltha	6434	Host Group	....	·500	192·00	·282	....	....	·896	1 830·89	17·884	....
		Sundry Claims	....	....	71·00	·127	....	1·446	14·620	16 766·21	215·450	·002
		State Battery—Coolgardie	....	....	....	*2·309	·061	....	....	*783·38	1 352·423	1·090

KUNANALLING DISTRICT

Mining Centre	Number of Lease	Registered Name of Company or Lease	Total for 1978: Alluvial (kg)	Total for 1978: Dollied and Specimens (kg)	Total for 1978: Ore treated (Tonnes)	Total for 1978: Gold therefrom (kg)	Total for 1978: Silver (kg)	Total Production: Alluvial (kg)	Total Production: Dollied and Specimens (kg)	Total Production: Ore treated (Tonnes)	Total Production: Gold therefrom (kg)	Total Production: Silver (kg)
Carbine	G.M.L. 16/1082	Hawkins Find	....	....	1 267·00	2·011	....	....	·270	3 989·00	8·542	·065
		Sundry Claims	....	....	40·00	·195	....	4·238	3·487	7 167·04	76·086	....
Dunnsville	1128	Min Min Revisited	....	1·177	....	....	....	....	1·268	4·00	·234	....
Kintore	1059	New Haven	....	·130	1 220·00	6·534	....	....	·367	4 416·57	17·797	·011
	1140	Newminster	....	....	667·00	1·671	....	....	....	667·00	1·671	....
Kunanalling	1135	Kiora	....	....	73·00	·244	....	....	....	73·00	·244	....
	1134	Last Chance	....	·254	106·00	·416	....	....	·254	106·00	·416	....

Yilgarn Goldfield.

Mining Centre	Number of Lease	Registered Name of Company or Lease	Total for 1978: Alluvial (kg)	Total for 1978: Dollied and Specimens (kg)	Total for 1978: Ore treated (Tonnes)	Total for 1978: Gold therefrom (kg)	Total for 1978: Silver (kg)	Total Production: Alluvial (kg)	Total Production: Dollied and Specimens (kg)	Total Production: Ore treated (Tonnes)	Total Production: Gold therefrom (kg)	Total Production: Silver (kg)
Bullfinch	G.M.L. 77/4607	Open Cut	....	·085	....	....	....	....	4·00	664·49	2·197	....
Corinthian	4826	Corinthian South	....	....	303·00	1·003	....	....	....	303·00	1·003	....
Golden Valley	4427	W.A. Gold Development N.L.	....	....	104·00	·135	....	....	·173	9 987·15	128·228	1·400
		Prior to transfer to present holders	....	....	....	....	....	....	·084	47 347·58	2 081·249	62·354
Greenmount	4829	Electrum	....	....	187·00	·660	....	....	....	187·00	·660	....
Hopes Hill	4810	Hopes Hill North	....	....	56·00	·115	....	....	....	56·00	·115	....
Kennyville	(3875)	Victoria	....	·258	....	....	....	....	·258	5 545·58	37·521	·066
	(4802)	Dorothy Leslie	....	....	74·00	·112	....	....	....	382·00	·418	....
Marvel Loch	4434	Cornwall	....	....	9·00	·026	....	....	....	18 231·23	77·282	16·426
	4039	Cromwell	....	·038	....	....	....	....	·038	1 086·66	5·117	·002
	4490	Frances Firness Links	....	....	104·00	·312	....	....	....	104·00	·312	....
	4646	Jacoletti South	....	....	135·00	·231	....	....	....	589·00	·871	....
	4816	New Nevoria	....	....	106·00	·376	....	....	....	106·00	·376	....
	4807	Robyn Louise	....	....	89·00	·393	....	....	....	205·00	·683	....
Mt. Palmer	4250	Palmerston	....	....	677·00	1·602	....	·063	·052	1 669·26	7·400	·059
Parkers Range	4512	Constance Una	....	....	403·00	7·976	....	....	....	9 295·81	195·153	2·628
	4621	Dollar	....	·114	....	....	....	....	·114	293·18	1·992	....
	4626	The Australia	....	....	60·00	·230	....	....	·660	242·00	1·159	·035
	4821	White Horseshoe	....	....	130·00	·086	....	....	....	130·00	·086	....
		Sundry Claims	....	....	84·00	·103	....	·205	9·453	15 033·83	179·269	·101
Southern Cross	4634	Frasers	....	....	288·00	1·330	....	....	195·626	9 014·58	170·525	....
	4639	Golden Pig	....	....	54·00	·015	....	....	....	54·00	·015	....
		Sundry Claims	....	....	113·00	1·957	....	2·983	20·218	9 360·74	89·151	·298
		State Battery—Marvel Loch	....	....	....	*6·343	1·350	....	....	149·36	*193·253	93·175
		L.T.T. 77/122 (2620H)—Beavis, Jordan & Gould	....	·049	....	*13·353	....	....	·049	....	*49·077	....
		L.T.T. 77/140 (2676H)—Chown, J. A.	....	4·803	....	....	....	....	4·803	....	....	....
		L.T.T. (77/133 (2668H))—Steineck, H.	....	....	....	·276	....	....	....	....	·276	....
		L.T.T. 77/116-8 (2615H–7H)—Washer, R.	....	....	....	·844	....	....	....	....	·844	....
		L.T.T. (77/56–(2396H))—Smith, A.E.	....	·282	....	....	....	....	·282	....	3·042	....

Dundas Goldfield.

Dundas	G.M.L. 63/2286	South Ridge	....	....	17·00	·045	....	....	....	17·00	·045	....
Norseman....	1936 etc.	Central Norseman Gold Corpn N.L.	....	....	149 813·00	2 710·104	807·340	....	....	6 041 402·18	84 884·517	54 794·836
		Prior to transfer to present holders	....	....	....	....	....	....	51·735	70 940·22	1 489·610	513·482
	2318	Iron Duke	....	....	125·00	·321	....	....	....	125·00	·321	....
	2331	Rosehole	....	....	45·00	·122	....	....	....	45·00	·122	....
		Sundry Claims	....	....	99·00	·197	....	32·729	112·653	50 987·01	705·303	7·623
Peninsula	2319	Peninsula	....	....	348·00	·502	....	....	....	348·00	·502	....

TABLE II

Production of Gold and Silver from all Sources, showing in kilograms the output as reported to the Mines Department during the year 1978.

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
Kimberley	....	....	....	....	....	....	....	....	....	....	....	....	....
West Kimberley	....	....	....	....	....	....	....	....	....	....	....	....	....
Pilbara	Marble Bar	....	....	436 184·00	7 025·790	7 025·790	64·189	....	....	437 779·00	7 070·873	7 070·873	64·189
	Nullagine	....	....	1 595·00	45·083	45·083	....						
West Pilbara	....	....	....	....	....	....	....	....	....	....	....	....	....
Ashburton	....	....	....	....	....	....	....	....	....	....	....	....	....
Gascoyne	....	....	....	....	....	....	....	....	....	....	....	....	....
Peak Hill	....	....	....	....	....	....	....	....	·377	2 072·00	1·745	2·122	....
East Murchison	Lawlers	....	....	70·00	·073	·073	....	....	....	87·00	·363	·363	....
	Wiluna	....	....	17·00	·290	·290	....						
	Black Range	....	....	....	....	....	....						
Murchison	Cue	....	·731	148·00	·996	1·727	....	....	·754	5 240·00	43·952	44·706	....
	Meekatharra	....	....	3 406·00	33·429	33·429	....						
	Day Dawn	....	....	....	....	....	....						
	Mt. Magnet	....	·023	1 686·00	9·527	9·550	....						
Yalgoo	....	....	....	....	....	....	....	....	....	371·00	2·194	2·194	....
Mt. Margaret	Mt. Morgans	....	....	1 413·00	3·607	3·607	....	....	....	8 191·00	41·010	41·010	1·116
	Mt. Malcolm	....	....	5 855·00	36·128	36·128	1·116						
	Mt. Margaret	....	....	923·00	1·275	1·275	....						
North Coolgardie	Menzies	....	....	1 716·00	9·749	9·749	·395	....	·056	3 036·00	18·629	18·685	·755
	Ularring	....	....	1 069·00	3·327	3·327	....						
	Niagara	....	....	38·00	·713	·713	....						
	Yerilla	....	·056	213·00	4·840	4·896	·360						
Broad Arrow	....	....	....	....	....	....	....	....	36·731	5 265·00	12·994	49·725	....
North East Coolgardie	Kanowna	....	....	114·00	·237	·237	....	....	....	187·00	·547	·547	....
	Kurnalpi	....	....	73·00	·310	·310	....						
East Coolgardie	East Coolgardie	....	·092	651 957·00	3 242·831	3 242·923	612·078	....	·092	652 132·00	3 243·304	3 243·396	612·092
	Bulong	....	....	175·00	·473	·473	·014						
Coolgardie	Coolgardie	·140	2·961	9 016·00	88·666	91·767	191·485	·140	4·522	12 389·00	99·737	104·399	191 485
	Kunanalling	....	1·561	3 373·00	11·071	12·632	....						
Yilgarn	....	....	....	....	....	....	....	....	5·629	2 976·00	37·478	43·107	1·350
Dundas	....	....	....	....	....	....	....	....	....	150 447·00	2 711·291	2 711·291	807·340
Phillips River	....	....	....	....	....	....	....	....	....	....	....	....	....
South West Mineral Field	....	....	....	....	....	....	....	....	....	....	....	....	....
Northampton Mineral Field	....	....	....	....	....	....	....	....	....	....	....	....	....
State Generally	....	....	....	....	....	....	....	....	....	....	....	....	....
Outside Proclaimed Goldfield	....	....	....	....	....	....	....	....	....	....	....	....	....
Total	....	....	....	....	....	....	....	·140	48·161	1 280 172·00	13 284·117	13 332·418	1 678·327

TABLE III

Return showing total production reported to the Mines Department to 31st December, 1978.

Goldfield	District	District: Alluvial (kg)	District: Dollied and Specimens (kg)	District: Ore Treated (Tonnes)	District: Gold Therefrom (kg)	District: Total Gold (kg)	District: Silver (kg)	Goldfield: Alluvial (kg)	Goldfield: Dollied and Specimens (kg)	Goldfield: Ore Treated (Tonnes)	Goldfield: Gold Therefrom (kg)	Goldfield: Total Gold (kg)	Goldfield: Silver (kg)
West Kimberley	....	....	....	....	....	....	....	282·614	94·412	23 299·89	537·841	914·867	4·005
Kimberley	....	....	....	....	....	....	....	·040	·768	1·02	·077	·885	1 160·705
Pilbara	Marble Bar	487·965	143·119	1 098 446·97	22 137·597	22 768·681	1 195·247	815·036	233·817	1 298 590·92	27 077 240	28 126·093	1 228·867
	Nullagine	327·071	90·698	200 143·95	4 939·643	5 357·412	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	173·206	798 969·12	10 044·683	10 233·771	118·009
East Murchison	Lawlers	221·544	73·823	2 055 242·12	25 750·138	26 045·505	848·153	280·939	691·665	12 833 675·81	113 736·648	114 709·252	1 876·336
	Wiluna	7·355	39·007	9 016 082·65	58 236·403	58 282·765	321·060						
	Black Range	52·040	578·835	1 762 351·04	29 750·107	30 380·982	707·123						
Murchison	Cue	160·036	285·097	6 926 374·34	43 661·951	44 107·084	8 548·605	802·353	1 862·511	15 795 978·67	188 946·879	191 611·743	16 343·740
	Meekatharra	457·427	584·045	2 392 779·85	40 925·204	41 966·676	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	639·483	4 406 114·75	61 567·234	62 289·226	2 360·540						
Yalgoo	....	....	....	....	....	....	....	56·477	102·155	455 718·04	8 287·004	8 445·636	47·372
Mt. Margaret	Mt. Morgans	111·191	292·443	1 240 857·67	22 339·546	22 743·180	181·374	366·763	1 104·393	11 736 872·70	154 765·166	156 236·322	8 177·785
	Mt. Malcolm	126·552	520·996	7 923 343·88	95 902·160	96 549·708	5 937·650						
	Mt. Margaret	129·020	290·954	2 572 671·15	36 523·460	36 943·434	2 058·761						
North Coolgardie	Menzies	52·773	219·239	1 993 161·83	44 671·660	44 943·672	1 221·971	151·123	622·079	3 814 807·17	80 656·074	81 429·276	2 259·877
	Ularring	4·033	227·341	551 489·43	13 948·339	14 179·713	693·202						
	Niagara	53·451	56·717	961 070·06	16 446·144	16 556·312	177·793						
	Yerilla	40·866	118·782	309 085·85	5 589·931	5 749·579	166·911						
Broad Arrow	....	....	....	....	....	....	....	684·367	944·066	1 485 499·55	23 643·452	25 271·885	185·796
North East Coolgardie	Kanowna	3 314·052	424·792	1 058 406·73	19 655·913	23 394·757	94·903	3 713·342	683·713	1 074 188·10	20 256·553	24 653·608	95·298
	Kurnalpi	399·290	258·921	15 781·37	600·640	1 258·851	·395						
East Coolgardie	East Coolgardie	1 049·527	1 303·607	107 559 998·18	1 236 745·084	1 239 098·218	209 083·557	1 901·934	1 803·439	107 755 702·69	1 240 915·128	1 244 620·501	209 086·674
	Bulong	852·407	499·832	195 704·51	4 170·044	5 522·283	3·117						
Coolgardie	Coolgardie	546·114	723·085	3 127 185·37	48 722·337	49 991·536	2 965·792	593·450	915·540	3 515 012·35	56 670·305	58 179·295	2 989·913
	Kunanalling	47·336	192·455	387 826·98	7 947·968	8 187·759	24·121						
Yilgarn	....	....	....	....	....	....	....	69·348	404·567	8 474 189·37	76 663·249	77 137·164	6 748·343
Dundas	....	....	....	....	....	....	....	70·176	519·883	8 122 730·26	115 161·930	115 751·989	67 798·086
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	....	....	....	....	....	....	....	10 471·695	10 255·399	177 360 416·23	2 122 733·005	2 143 460·099	323 229·696

TABLE IV

Total output of Gold Bullion, Concentrates, etc., entered for export and received at the Perth Mint from 1st January, 1886.

Year	Export	Mint	Total	Estimated Value
	kg	kg	kg	$A
From 1886 to 1960 (inclusive)	360 147·861	1 556 923·314	1 917 071·175	887 344 248
1961	91·524	27 025·885	27 117·409	27 413 780
1962	141·179	26 588·160	26 729·339	26 871 460
1963	145·109	24 744·257	24 889·366	25 035 372
1964	95·516	22 076·504	22 172·020	22 299 886
1965	93·204	20 417·579	20 510·783	20 722 164
1966	45·475	19 511·667	19 557·142	19 765 287
1967	85·325	17 830·932	17 916·257	18 071 924
1968	28·580	15 887·164	15 915·744	16 785 723
1969	43·951	14 431·968	14 475·919	17 707 219
1970	49·089	10 576·110	10 625·199	11 069 049
1971	29·183	10 795·117	10 824·300	11 921 570
1972	....	10 850·502	10 850·502	16 042 688
1973	6·098	7 934·406	7 940·504	18 326 747
1974	60·504	6 570·454	6 630·958	22 324 330
1975	39·341	6 950·413	6 989·754	28 887 180
1976	71·589	7 194·549	7 266·138	25 570 928
1977	105·448	9 721·736	9 827·184	42 572 837
1978	63·665	13 380·475	13 440·140	73 719 472
	361 342·641	1 829 411·192	2 190 753·833	1 332 451 864

	1977	1978
	$A	$A
Estimated Mint value of above production	1 142 357 726	1 157 736 289
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	111 195 462	169 536 371
Estimated Total	$A1 258 732 392	$A1 332 451 864
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 288 255 899	$A1 361 975 371

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 1978

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.	2 174 387	....	173 950 960
M.L. 70/1SA	.... South West	Alcoa of Australia (W.A.) Ltd.	1 295 993	....	103 679 440
			3 470 380	....	(*l*) 277 630 400
		BUILDING STONE			
		Quartz			
M.C. 70/1921	.... South West	Cutts, J. E.	1 253	....	1 253
M.C. 70/2110	.... South West	Snowstone Pty. Ltd.	2 263	....	101 835
			3 516	....	(*a*) (*c*) 103 088
		Quartzite			
M.C's 70/1158–9	.... South West	House, R. P.	615	....	(*a*) (*c*) 7 466
		Spongolite			
M.C. 70/1062	.... South West	Worth, H.	30	....	420
M.C. 70/726	.... South West	Universal Milling Co. Pty. Ltd.	195	....	2 930
			225	....	(*a*) (*c*) 3 350
		CLAYS			
		Cement Clay			
M.C. 70/788	.... South West	Bell Bros. Pty. Ltd.	22 927	....	(*a*) (*c*) 57 317
		Fire Clay			
M.C. 70/436–7	.... South West	Midland Brick Co. Pty. Ltd.	162 436	....	24 856
M.C. 70/304 etc.	.... South West	Clackline Refractories Ltd.	6 420	....	12 748
M.C's 70/522–3	.... South West	Bridge, J. S.	97 847	....	97 847
			266 703	....	(*a*) (*c*) 135 451
		White Clay-Ball Clay			
M.C. 70/109	.... South West	Bristile Ltd.	519	....	(*a*) (*c*) 6 228
		Kaolin			
M.C's 70/247, 605	.... South West	Universal Milling Pty. Ltd.	353	....	2 104
M.C. 70/2110	.... South West	Snowstone Pty. Ltd.	55	....	1 210
			408	....	(*a*) (*c*) 3 314
		COAL			
C.M.L. 12/448 etc.	.... Collie	.... Griffin Coal Mining Co. Ltd.	1 091 188	....	11 116 159
C.M.L. 12/437 etc.	.... Collie	.... Western Collieries Ltd.	1 312 315	....	17 526 086
			2 403 503	....	(*e*) 28 642 245
		COBALT			
		(Metallic by-product of nickel mining)		Cobalt Tonne	
M.L. 15/152 etc.	.... Coolgardie	Western Mining Corporation	....	172·293	854 689
		COPPER			
		(Metallic by-product of nickel mining)		Copper Tonne	
M.L. 15/152 etc.	.... Coolgardie	Western Mining Corporation	....	1 376·859	1 178 637
M.L. 15/246	.... Coolgardie	Anaconda Aust. Inc.	....	124·560	152 075
			....	1 501·419	1 330 712
		EMERALDS	Carats	Grams	
M.C. 30/1243, 1245	.... North Coolgardie	McKay, N. J.	....	17	136
M.L. 20/116, 2131	.... Murchison	Bellairs, R. D.	....	651	5 210
M.L. 20/116, 2131	.... Murchison	Bellairs, R. D.	7	....	875
			....	....	6 221
		FELSPAR			
M.C. 70/2110	.... South West	Snowstone Pty. Ltd.	457	....	22 850
M.C. 59/5801	.... Yalgoo	Chandilla Exploration & Investments Pty. Ltd.	432	....	6 428
			889	....	(*a*) 29 278

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
		GLASS SAND			
M.C. 70/1191	South West	Silicon Quarries Pty. Ltd.	12 460	....	6 131
M.C. 70/1074	South West	Ready Mix Group W.A.	68 759	....	N.A.
M.C. 70/417 etc.	South West	Australian Glass Manufacturers Co.	22 478	....	29 874
M.C. 70/6056	South West	Zaninovich, L. V.	1 000	....	500
			104 697	.... (*c*)	36 505
		GYPSUM			
M.C's 77/50 etc.	Yilgarn	H. B. Brady Pty. Ltd.	19 246	....	47 353
M.C's 77/9 etc.	Yilgarn	W.A. Plaster Mills	26 173	....	88 347
M.C's 70/612 etc.	South West	Gypsum Industries of Australia Pty. Ltd.	18 046	....	49 105
M.C. 70/15467	South West	Nixon, P. F. & R. S.	3 952	....	15 494
M.C's 70/15466 etc.	South West	Swan Portland Cement Ltd.	6 043	....	91 828
M.C's 9/43, 49, 50	Gascoyne	Agnew Clough Ltd.	86 077	....	296 533
			159 537	.... (*a*)	588 660
			Plaster of Paris reported as manufactured during the year 33 461 tonnes from 47 251 tonnes of Gypsum by 2 companies.		
		GARNET SANDS			
M.C. 70/11563	South West	Target Minerals N.L.	479	.... (*b*)	33 474
		IRON ORE			
		Pig Iron	Ore Treated Tonne	Pig Iron Recovered Tonne	
M.L. 77/2SA	Yilgarn	Wundowie Iron & Steel Industry	65 700	42 691 (*c*) (*d*)	3 760 667
		Ore Railed to Kwinana		Av. Assay Fe %	
M.L. 77/2SA	Yilgarn	Dampier Mining Co. Ltd.	*1 091 008	63·00 (*n*)	7 986 586
		Ore Shipped Interstate			
M.L. 52/244SA	Peak Hill	Mt. Newman Mining Co. Ltd.	7 210 430	64·00 (*b*)	68 238 644
		Ore Exported Overseas			
M.L. 4/10 etc.	West Kimberley	Dampier Mining Co. Ltd.	745 992	68·80 (*b*)	9 284 588
M.L. 4/50 etc.	West Kimberley	Dampier Mining Co. Ltd.	1 742 124	67·40 (*b*)	21 217 978
M.L. 52/244 SA	Peak Hill	Mt. Newman Mining Co. Ltd.	24 055 334	63·00 (*b*)	277 650 558
M.L. 47/4SA	West Pilbara	Hamersley Iron Pty. Ltd.	27 765 275	63·88 (*b*)	316 936 845
T.R. 2401H	West Pilbara	Cliffs W.A. Mining Co. Pty. Ltd.	7 629 633	59·29 (*b*)	60 365 263
M.L. 45/235SA	Pilbara	Goldsworthy Mining Ltd.	5 879 249	63·35 (*b*)	68 835 573
			76 119 045	....	830 516 035
		PELLETS (Exported Overseas)			
M.L. 47/4SA	West Pilbara	Hamersley Iron Pty. Ltd.	2 006 220	63·43 (*b*)	38 657 094
T.R. 2401H	West Pilbara	Cliffs W.A. Mining Co. Pty. Ltd.	4 373 324	62·62 (*b*)	87 791 910
			6 379 544	....	126 449 004
		***LIMESTONE** (For Building, Burning & Agricultural Purposes etc.)			
M.C. 70/692	South West	Bell Bros, Pty. Ltd.	65 018	....	57 215
M.C. 70/1290	South West	Bellombra, V.	9 218	....	26 305
M.C. 70/1298	South West	Maffescioni, M. C.	710	....	710
M.C. 70/1093	South West	Piper Walker Pty. Ltd.	228	....	228
M.C. 70/709	South West	Snader, R.	37 807	....	18 604
M.C. 70/1660	South West	Swan Portland Cement Ltd.	317 577	....	890 911
M.C. 70/2734–5	South West	Swan Portland Cement Ltd.	16 172	....	47 341
M.C. 70/989	South West	W.A. Limestone Co. Pty. Ltd.	46 400	....	116 000
M.L's 47/266–277 etc.	West Pilbara	Hamersley Iron Pty. Ltd.	24 847	....	18 560
M.L. 47/513	West Pilbara	Specified Services	1 513	....	1 513
	South West	†Unspecified Producers	196 000	....	196 000
			715 490	.... (*c*)	1 373 387

* Includes 42 792 wet tonnes shipped from Kwinana overseas.

* Incomplete. † From Private Property not held under the Mining Act.

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
		MANGANESE (Metallurgical Grade)			
				Av. Assay Mn %	
T.L. 52/14	.... Peak Hill	.... Universal Milling Co. Pty. Ltd.	922	47·5	16 140
		MINERAL BEACH SANDS			
		Ilmenite (*g*)			
				Av. Assay TiO2 %	
M.C's 70/619 etc.	.... South West	.... Westralian Sands Ltd.	130 571	55·26	
M.C's 70/746 etc.	.... South West	.... Cable Sands Pty. Ltd.	79 455	54·48	
Sussex Loc. 7	.... South West	.... Cable Sands Pty. Ltd.	67 556	54·46	
M.C's 70/389 etc.	.... South West	.... Western Mineral Sands Pty. Ltd.	155 107	54·00	
M.C. 70/516	.... South West	.... Western Titanium Ltd.	266 622	54·68	
M.C. 70/7556	.... South West	.... Jennings Mining Ltd.	33 138	60·92	
M.C. 70/7062	.... South West	.... Allied Eneabba Pty. Ltd.	253 646	61·12	
			986 095	....	(*b*)23 687 589
		Upgraded Ilmenite (*g*)			
M.C. 70/516	.... South West	.... Western Titanium Ltd.	53 236	92·92	
		Rutile (*g*) (*h*)			
				TiO2 Tonnes	
M.C. 70/7556	.... South West	.... Jennings Mining Pty. Ltd.	27 588	26 458	5 282 352
M.C. 70/7062	.... South West	.... Allied Eneabba Pty. Ltd.	49 703	47 787	8 734 372
M.C. 70/7002	.... South West	.... Western Titanium Ltd.	36 822	35 312	8 274 812
M.C. 70/15565–9	.... South West	.... W.M.C. Mineral Sands Ltd.	530	510	130 600
			114 643	110 067	(*b*) 22 422 136
		Leucoxene (*g*) (*h*)			
				TiO2 Tonnes	
M.C's 70/619 etc.	.... South West	.... Westralian Sands Ltd.	8 053	7 275	1 048 205
Sussex Loc. 7	.... South West	.... Cable Sands Pty. Ltd.	1 542	1 353	215 117
M.C's 70/746 etc.	.... South West	.... Cable Sands Pty. Ltd.	3 678	3 245	510 380
			13 273	11 873	(*b*) 1 773 702
		Monazite (*g*) (*h*)			
				ThO2 Units	
M.C. 70/516	.... South West	.... Western Titanium Ltd.	1 762	11 098	289 467
M.C. 70/7062	.... South West	.... Allied Eneabba Pty. Ltd.	4 697	29 843	883 369
M.C's 70/619 etc.	.... South West	.... Westralian Sands Ltd.	3 487	21 428	579 873
M.C's 70/746 etc.	.... South West	.... Cable Sands Pty. Ltd.	365	2 356	68 869
Sussex Loc. 7	.... South West	.... Cable Sands Pty. Ltd.	146	941	27 189
			10 457	65 666	(*b*) 1 848 767
		Zircon (*g*) (*h*)			
				ZrO2 Tonnes	
M.C's 70/619 etc	.... South West	.... Westralian Sands Ltd.	29 470	18 886	1 875 573
M.C's 70/746 etc.	.... South West	.... Cable Sands Pty. Ltd.	6 485	4 277	322 708
Sussex Loc. 7	.... South West	.... Cable Sands Pty. Ltd.	2 573	1 692	136 684
M.C. 70/7556	.... South West	.... Jennings Mining Ltd.	12 169	8 055	844 921
M.C. 70/7062	.... South West	.... Allied Eneabba Pty. Ltd.	41 885	27 710	2 635 453
M.C. 70/516	.... South West	.... Western Titanium Ltd.	24 903	15 899	1 291 050
M.C. 70/7002	.... South West	.... Western Titanium Ltd.	33 812	22 518	1 508 046
			151 297	99 037	(*b*) 8 614 435
		Xenotime (*g*) (*h*)			
				Y2O3 kg	
M.C. 70/516	.... South West	.... Western Titanium Ltd.	13	3 900	(*b*) 12 138
		NICKEL CONCENTRATES			
				Av. Assay Ni %	
M.L's 15/152 etc.	.... Coolgardie	.... Western Mining Corporation	307 896	13·07	146 046 772
M.L's 38/32, 35	.... Mt. Margaret....	Windarra Nickel Mines Pty. Ltd.	76 677	10·60	22 154 466
M.L. 15/336	.... Coolgardie	.... Selcast Exploration Ltd.	10 809	16·67	7 232 306
M.L. 15/246	.... Coolgardie	.... Anaconda Australia Inc.	9 146	13·09	4 196 699
			404 528	....	(*o*) 179 630 243

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
		NICKEL ORE			
				Av. Assay Ni %	
M.C. 15/1288 .... M.L. 15/248	.... Coolgardie	.... Metals Exploration N.L.	64 413	3·79	6 458 162
		PALLADIUM (*h*) (Metallic by-product Nickel Mining)			
M.L's 15/152 etc.	.... Coolgardie	.... Western Mining Corporation	....	kg 229·717	418 136
		PLATINUM (*h*) (Metallic by-product Nickel Mining)			
M.L's 15/152 etc.	.... Coolgardie	.... Western Mining Corporation	....	kg 92·096	557 698
		OCHRE			
M.C's 20/26, 29	.... Murchison	.... Universal Milling Co. Pty. Ltd.	281	....	4 776
		PETROLEUM Crude Oil			
			Barrels		
1H	Ashburton	.... West Australian Petroleum Pty. Ltd.	11 383 582	....	(*m*) 77 529 092
Lic. 1	South West	.... West Australian Petroleum Pty. Ltd.	64 773	....	(*q*) 378 278
			11 448 355	....	77 907 370
		Natural Gas			
Lic. 1	South West	.... West Australian Petroleum Pty. Ltd.	$m^3 10^3$ 806 865	....	(*p*) 17 232 225
		Condensate			
Lic. 1	South West	.... West Australian Petroleum Pty. Ltd.	Tonne 2 368	....	N.A.
		SALT			
		State Total Reported to Mines Dept.	3 888 065	....	(*b*) 27 410 412
		SEMI PRECIOUS STONES Amethyst			
			kg		
M.C. 8/1919	.... Ashburton	.... Soklich, D. & E,. Burkitt, R. C. and Hazlett, J. E.	12	....	84
M.C. 9/44	.... Gascoyne	.... Soklich, F.	300	....	200
		Chrysoprase			
M.C. 69/965	.... Outside Proclaimed	.... Irrunijtju Community Inc.	350	....	2 500
		Moss Opal			
M.C. 63/60	.... Dundas	.... Soklich, F.	4 767	....	2 375
		Chalcedony			
M.C. 9/498	.... Gascoyne	.... Soklich, F.	2 154	....	1 788
9/1921	.... Gascoyne	.... Butler, R. G. & A. W.	3 588	....	2 220
		Serpentinite			
M.C. 45/1094	.... Pilbara	.... Stubbs, S. H.	352	....	1 408
			....	....	10 575
		TALC			
M.L. 70/433	.... South West	.... Three Springs Talc Pty. Ltd.	80 756	....	N.A.
M.C. 52/190	.... Peak Hill	.... Westside Mines N.L.	39 596	....	N.A.
			120 352	....	....
		SILVER			
			kg		
		By-product of Gold Mining	1 986·683	....	178 236
		By-product of Nickel Mining	191·424	....	25 017
			2 178·107	....	203 253

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
		TANTO-COLUMBITE ORES AND CONCENTRATES (*g*) (*h*)			
				TA205 Units	
M.L's 1/660 etc.	Greenbushes	Greenbushes Tin N.L.	126·860	5 071	2 382 089
M.C. 59/5052	Yalgoo	Warda Warra Mining Co. Pty. Ltd.	·287	14	6 531
M.C's 59/5799 etc.	Yalgoo	Chandilla Exploration & Investments Pty. Ltd.	·105	6	3 369
D.C's 45/553 etc. M.C's 45/107 etc.	Pilbara	Goldrim Mining Australia Ltd.	11·271	573	359 275
			138·523	5 664	(*b*) 2 751 264
		TIN CONCENTRATES			
				Sn Tonnes	
M.L's 1/660 etc.	Greenbushes	Greenbushes Tin N.L.	565·330	408·56	4 209 986
D.C's 45/672, 700	Pilbara	Hart, D. N. & L. E.	2·973	2·108	18 134
M.C's 45/668 etc.	Pilbara	Endeavour Resources Ltd.	118·080	82·270	1 074 653
D.C's 45/553 etc. M.C's 45/107 etc.	Pilbara	Goldrim Mining Australia Ltd.	5·954	4·258	38 952
			692·337	497·196	(*b*) 5 341 725
		TUNGSTEN ORES AND CONCENTRATES—SCHEELITE			
				W03 Units	
M.C. 16/6339	Coolgardie	Cable, D.	·140	10·08	1 108
		VERMICULITE			
M.C. 74/1567	Phillips River	Vermiculite Industries Pty. Ltd.	244	....	2 440

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 Commonwealth Government for Barrow Island Crude Oil at Kwinana.
(n) Nominal Value.
(o) Estimated F.O.B. Value based on the current price for Nickel Cathodes.
(p) Nominal Value at Well Head.
(q) Net Well Head Value.

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TABLE VI

Total Mineral Output of Western Australia

Recorded mineral production of the State to 31st December, 1978, showing for each mineral the progressive quantity produced and value thereof, as reported to the Department of Mines; including Gold (Mint and Export) as from 1886, and Other Minerals as from commencement of such records in 1899.

Mineral		Quantity	Value $A
Abrasive Silica Stone	tonne	2	18
Alumina (from Bauxite)	,,	21 853 426	1 564 784 740
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	,,	42 851	796 099
Quartzite	,,	13 011	77 505
Sandstone	,,	681	4 020
Sandstone (Donnybrook)	,,	84	3 486
Slate	,,	239	2 115
Spongolite	,,	4 193	46 947
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	,,	679 354	1 362 356
Fireclay	,,	2 538 118	2 079 277
Fullers Earth	,,	467	3 821
White Clay—Ball Clay	,,	32 686	234 249
Kaolin	,,	9 705	47 749
Coal	,,	55 110 630	247 203 102
Cobalt (Metallic By-Product Nickel Mining)	,,	1 809	6 284 377
Copper (Metallic By-Product Nickel Mining)	,,	11 542	10 356 359
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	33 960	24 349
Emeralds	grams	1 407	11 149
Emery	tonne	21	750
Felspar	,,	77 032	644 361
Fergusonite	kg	300	783
Gadolinite	tonne	1	224
Garnet Sands	,,	643	45 774
Glass Sand	,,	1 670 040	1 243 505
Glauconite	,, (h)	6 571	300 769
Gold (Mint and Export)	kg	2 190 753	1 332 451 864
Graphite	tonne	156	2 608
Gypsum	,,	2 381 304	6 109 844
Iron Ore—			
Pig Iron Recovered	tonne	1 180 755	67 990 480
Ore Exported	,,	655 740 261	5 304 764 735
Pellets Exported	,,	44 573 860	623 912 843
Locally Used Ore	,,	19 317 600	124 942 553
For Flux	,,	58 996	74 096
Jarosite	,,	10	75
Kyanite	,,	4 283	43 562
Lead Ores and Concentrates	,,	489 720	10 636 394
Limestone	,,	13 866 081	15 920 429
Lithium Ores—			
Petalite	,,	8 042	124 123
Spodumene	,,	108	3 627
Magnesite	,,	60 376	1 075 116
Manganese—			
Metallurgical Grade	,,	1 930 271	41 453 348

TABLE VI.—Total Mineral Output of Western Australia—*continued*

Mineral		Quantity	Value $A
Manganese—*continued*			
Battery Grade	tonne	2 254	90 860
Low Grade	,,	5 135	81 538
Mica	,,	1 986	17 005
Mineral Beach Sands—			
Ilmenite Concentrates	,,	10 879 835	152 415 232
Monazite Concentrates	,,	50 404	7 104 804
Rutile	,,	351 051	65 571 237
Leucoxene	,,	122 588	11 255 971
Zircon	,,	1 076 288	61 208 986
Xenotime	,,	263	257 749
Crude Concentrates (Mixed)	,,	158	1 553
Molybdenite	,,	79	1 730
Nickel Concentrates	,,	3 300 332	1 316 821 221
Nickel Ore	,,	630 115	43 122 425
Ochre—			
Red	,,	13 655	269 676
Yellow	,,	455	5 956
Peat	,,	4 052	62 633
Petroleum (Crude Oil)	bbls.	152 514 133	469 387 796
(Natural Gas)	$m^3 10^3$	5 628 779	58 721 705
(Condensate)	tonne	25 327	N.A.
Palladium (By-Product Nickel Mining)	kg	1 080	1 966 261
Platinum (By-Product Nickel Mining)	kg	476	2 101 638
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	29 074 355	140 339 261
Semi Precious Stones—			
Amethyst	kg	27 478	24 083
Beryl (Coloured)	,,	91	100
Chalcedony	,,	88 835	39 221
Chrysoprase	,,	122 552	123 642
Dravite	,,	8 640	15 594
Green Beryl	,,	50	629
Magnesite	,,	5 073	2 780
Moss Opal	,,	114 559	48 879
Moss Agate	,,	16 257	4 800
Opal	,,	4	16 994
Opaline	,,	11	8
Opalite	,,	1 020	400
Prase	,,	3 955	730
Quartz	,,	33 484	13 545
Serpentinite	,,	807	3 228
Tiger Eye Opal	,,	20 447	14 412
Topaz (Blue)	,,	3	4
Tourmaline	,,	1 035	2 124
Sillimanite	tonne	2	26
Silver (*c*)	kg	429 458	9 572 185
Soapstone	tonne	574	3 856
Talc	,,	645 556	4 719 452
Tanto/Columbite Ores and Concentrates	,,	2 676	12 267 571
Tin	tonne	35 311	46 354 792
Tungsten Ore and Concentrates—			
Scheelite	,,	172	144 532
Wolfram	,,	310	125 810
Vermiculite	,,	4 481	47 331
Zinc (Metallic By-Product) (*d*)	,,	2 934	(j)
Zinc Ore (Fertiliser)	,,	20	200
Total Value to 31st December, 1978	....		$11 844 646 899

(a) By-Product from Gold Mining.
(b) Part By-Product from Gold Mining.
(c) By-Product from Gold, Copper and Lead Mining.
(d) By-Product from Lead Mining.
(e) Quantity not recorded.
(f) Value of mineral or concentrate recovered.
(g) Incomplete.
(h) Mineral Recovered.
(i) Assayed Metallic Content.
(j) Value included in Lead value.
(k) Based on the price assessed by the Commonwealth Government for Barrow Island Crude Oil at Kwinana.
(l) Nominal well-head value.

Footnote.—Comprehensive Mineral production records maintained in the Statistical Branch of the Department of Mines show locality, producers, period, quantity, assayed or metallic content, and value of the various minerals listed above.

TABLE VII

Showing average number of men employed above and below ground in the larger mining companies operating in Western Australia during 1977 and 1978.†

Company	1977			1978		
	Above	Under	Total	Above	Under	Total
*Gold—						
Central Norseman Gold Corporation N.L.	149	72	221	146	66	212
Kalgoorlie Lake View Pty. Ltd. (Mt. Charlotte)	19	131	150	31	144	175
Mulga Mines Pty. Ltd.	69	25	94	66	24	90
Newmont Pty. Ltd. (Telfer Project)	90	....	90	93	....	93
All Other Operators	204	112	316	255	135	390
State Average	531	340	871	591	369	960
Alumina (from Bauxite)—						
Alcoa of Australia (W.A.) N.L.	2 594	....	2 594	2 804	....	2 804
Coal—						
Griffin Coal Mining Co. Ltd.	272	....	272	269	....	269
Western Colleries Ltd.	267	323	590	282	319	601
Iron Ore—						
Cliffs Western Australian Mining Co. Pty. Ltd.	366	....	366	364	....	364
Dampier Mining Co. Ltd.	555	....	555	583	....	583
Goldsworthy Mining Ltd.	879	....	879	812	....	812
Hamersley Iron Pty. Ltd.	2 034	....	2 034	2 073	....	2 073
Mt. Newman Mining Co. Pty. Ltd.	1 367	....	1 367	1 309	....	1 309
Wundowie Iron & Steel	8	....	8	10	....	10
Mineral Beach Sands—						
Allied Eneabba Pty. Ltd.	203	....	203	200	....	200
Cable Sands Pty. Ltd.	65	....	65	62	....	62
Jennings Mining Limited	175	....	175	107	....	107
Western Mining Corporation	53	....	53	....	....	....
Western Mineral Sands Pty. Ltd.	45	....	45	30	....	30
Western Titanium Ltd.	226	....	226	237	....	237
Westralian Sands Ltd.	105	....	105	100	....	100
Nickel—						
Anaconda Australia Inc.	22	99	121	14	59	73
Western Mining Corporation-Great Boulder Operations	25	62	87	....	....	....
Metals Exploration N.L.	92	131	223	88	86	174
Selcast Exploration Ltd.	35	77	112	36	69	105
Western Mining Corporation	624	802	1 426	552	643	1 195
Windarra Nickel Mines Pty. Ltd.	239	125	364	135	66	201
Petroleum—Crude Oil—						
West Australian Petroleum Pty. Ltd.	101	....	101	102	....	102
Salt—						
Dampier Salt Limited	164	....	164	179	....	179
Lefroy Salt Co.	14	....	14	12	....	12
Leslie Salt Co.	39	....	39	39	....	39
Texada Mines Pty. Limited	166	....	166	170	....	170
All Other Minerals	346	25	371	295	....	295
State Total—Other than Gold	11 081	1 644	12 725	10 864	1 242	12 106

* 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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