Department of Mines ANNUAL REPORT 1975

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Department of Mines

ANNUAL REPORT 1975

REPORT OF THE

DEPARTMENT *of* MINES

WESTERN AUSTRALIA

FOR THE YEAR 1975

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

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To the Honourable the Minister for Mines.

Sir,

I have the honour to submit the Annual Report of the Department of Mines of the State of Western Australia for the year 1975, *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, 1976.

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DIVISION I

PART 1—GENERAL REMARKS

The Honourable the Minister for Mines:

I have the honour to submit for your information a report on the Mining Industry for the year 1975.

The estimated value of the mineral output of Western Australia (including gold, coal and petroleum) for the year was $1 240.6 million, a 30 per cent increase over that for the previous year and an all-time record, due in the main to higher prices for iron ore and nickel, and increased production of alumina.

To the end of 1975 the progressive value of the mineral production of the State from 1886 amounted to $6 933 million. The value of exports of iron ore which began in 1966 already amounts to $3 212 million, close to half the progressive total. When iron ore exports commenced in 1966, gold represented 80 per cent of the total, but today it has dwindled to 17 per cent.

ROYALTIES

Royalty revenue during the year amounted to $42.8 million, an increase of 6.5 million above the figure for 1974. Iron ore royalties accounted for $38.8 million, 90.6 per cent of the total. Full details are contained in table 2 of Part 2.

IRON ORE

Iron ore production for local use and export fell from 87 million tonnes in 1974 to 85 million tonnes in 1975, due to cut-backs in overseas imports. However, the value of the iron ore rose from $589.1 million in 1974 to $750.5 million, an increase of 27 per cent due to higher prices obtained and a more favourable exchange rate than existed for most of the previous year.

NICKEL

The total value of nickel in concentrates, briquettes and powder amounted to an estimated $183.8 million compared with $126.3 in 1974. Nickel concentrates and nickel ore produced during the year increased by 50 000 and 3 500 tonnes respectively above the figures for 1974.

The price per lb quoted by Inco, Ltd. for four inch square electrolytic nickel cathodes F.O.B. Fort Colborne, Canada, (the price upon which nickel royalties are calculated) which had stood at US $2.01 since 20th December, 1974, rose to US$2.20 as from 29th August, 1975.

ALUMINA

Alcoa of Australia (W.A.) Limited continued to increase production of alumina from bauxite from its mines at Jarrahdale and Del Park fed to refineries at Kwinana and Pinjarra respectively. Production increased from 1.98 million tonnes in 1974 to 2.23 million tonnes in 1975 with an estimated value of $161 million.

PETROLEUM
(Crude Oil and Natural Gas)

Sales of oil from Barrow Island during 1974 were down from 13.8 million barrels valued at $31.2 million in 1974 to 12.8 million barrels valued at $28.7 million in 1975, as from 18th September, 1975, the Federal Government granted a price increase of 50 cents per barrel for Barrow Island crude to $2.73/barrel f.o.b. Kwinana.

About 45% of the original estimated recoverable Barrow Island oil reserves have now been produced.

The Dongara and Mondarra gas fields supplied a total of 832.1 million cubic metres of natural gas valued at $5.3 million to sales outlets at Perth-Fremantle-Kwinana-Pinjarra area. There was a 1.2% increase in gas production from the Dongara field compared with 1974 and a 16% decrease from the Mondarra field. Overall, 0.7% more gas was produced from the northern Perth Basin in 1975 than in 1974.

Petroleum exploration operations during 1975 were again at a greatly reduced level compared with the previous year. Expressed in rig months, overall operations declined by 52.5 per cent from 33.6 rig months in 1974 to 16 rig months in 1975. The fall was greater in the offshore drilling activity which declined by 61 per cent while onshore drilling fell by 21 per cent.

GOLD

The estimated value of gold received at the Perth Mint during 1975 was $28 887 180, an increase of $6 562 850 compared with the figure for 1974. The quantity of gold received was $6 989.754 kg an increase of 358.796 kg over the 1974 figure.

Details of gold production reported to the Department as distinct from that received at the Mint are set out in table 1 of Part 2 of this report. The quantity of auriferous ore treated during the year was 1 270 000 tonnes compared with 1 379 000 in 1974, a drop of 109 000 tonnes. The average number of workers engaged in the gold-mining industry dropped from 2 027 in 1974 to 1 808 in 1975.

The weighted average price obtained for Western Australian gold (including premiums on gold sold by the Gold Producers' Association Limited) as recorded by the Mines Department for 1974 and 1975 computes to $104.70 and $128.54 per fine ounce (troy) respectively.

Western Australian gold included in sales on overseas premium markets by the Gold Producers' Association Limited for the period November, 1974 to November, 1975, amounted to 7 336.380 kg. The premium received in excess of the Mint value amounted to $21 516 208, an overall average of $2 932.8 per kg ($91.25 per fine ounce, troy) compared with $16 010 063, an average of $2 426.153 per kg ($75.52 per fine ounce, troy) for the period November, 1973, to October, 1974.

No subsidy was paid during 1975 by the Commonwealth Government under the Gold-Mining Industry Assistance Act, 1954. It is apparent that no Western Australian producer qualified for the subsidy due to the high prices for gold obtained on the free market. The Act was allowed to lapse on 30th June, 1975.

COAL

Coal production from Collie during the year showed an increase of 667 931 tonnes (46 per cent) over that for 1974, and was an all-time record for the field. This increase was due almost entirely to greater consumption of coal by the State Energy Commission.

Figures for the last three years were:—

	1973	1974	1975
Tonnes	1 171 069	1 446 048	2 113 979
Total Value	$7 048 726	$9 144 982	$15 073 668
Average Value per Tonne	$6·019 0	$6·324 1	$7.130 5
Average Effective Workers	619	685	836
Proportion of Deep Mined Coal	36·08%	33·95%	26.08%

OTHER MINERALS

Other minerals to yield over a million dollars for the year were: Salt $17.1 million, Ilmenite $14.9 million, Zircon $14 million, Rutile $5.5 million, Tin (Conc) $3.6 million, Leucoxene $1.4 million and Limestone $1.3 million, while Pig Iron valued at $5.1 million was produced by the Wundowie Iron and Steel Industry.

OUTLOOK

The mining industry of Western Australia passed through a difficult year in 1975, having experienced serious marketing problems in a period of worldwide recession and rising costs of mining, ore treatment and transport.

While there are signs of economic improvement and of a lessening inflation rate, the industry however is still faced with serious problems of industrial unrest, in some cases apparently motivated politically rather than industrially. This type of obstruction discourages investment in mining projects which by their nature and generally isolated locations are already high risk ventures without the addition of man-made hazards.

The extensive and varied mineral resources of the State afford the opportunities for expansion, and given industrial and political co-operation, I am confident the mining industry will continue to grow and contribute to the welfare of Western Australia and indeed of Australia.

PART 2—COMPARATIVE STATISTICS

TABLE 1

SUMMARY

Mineral Production : Quantity, Value, Persons Engaged

	1974	1975	Variation
IRON ORE—			
Tonnes	87 054 190	**85 253 013**	— 1 801 177
Value ($A)	$593 051 596	**$755 720 026**	+ $162 668 430
Persons Engaged	4 050	**4 525**	+ 475
ALUMINA—			
Tonnes	1 981 205	**2 230 255**	+ 249 050
*Value ($A)	$124 800 000	**$161 479 900**	+ $36 679 900
Persons Engaged	1 965	**2 072**	+ 107
NICKEL—			
Tonnes (ore and concentrates)	437 049	**490 385**	+ 53 336
Value ($A)	$126 292 134	**$183 788 642**	+ $57 496 508
Persons Engaged	2 090	**2 767**	+ 677
PETROLEUM—CRUDE OIL			
Barrels	13 801 191	**12 867 769**	— 933 422
†Value ($A)	$31 257 312	**$28 695 124**	— $2 562 188
Persons Engaged	146	**110**	— 36
GOLD—			
Reported to Department (Mine Production)—			
Ore treated (tonnes)	1 378 991	**1 270 168**	— 108 823
Gold (Kilograms)	6 583	**7 105**	+ 522
Average Grade (grams per tonne)	4.8	**5.6**	+ 0.8
Persons Engaged	2 027	**1 808**	— 219
Mint and Export (Realised Production)—			
Gold (Kilograms)	6 631	**6 990**	+ 359
Estimated Value ($A) (including Overseas Gold Sales Premium)	$22 324 330	**$28 887 180**	+ $6 562 850
COAL—			
Tonnes	1 446 048	**2 113 979**	+ 667 931
Value ($A)	$9 144 982	**$15 073 668**	+ $5 928 686
Persons Engaged	685	**836**	+ 151
MINERAL BEACH SANDS—			
Tonnes	972 009	**806 517**	— 165 492
Value ($A)	$19 818 642	**$36 326 714**	+ 16 508 072
Persons Engaged	550	**878**	+ 328
OTHER MINERALS—			
Value ($A)	$28 219 049	**$30 668 593**	+ $2 449 544
Persons Engaged	755	**690**	— 65
TOTAL ALL MINERALS—			
Value ($A)	$954 908 045	**$1 240 639 847**	+ $285 731 802
Persons Engaged	12 268	**13 686**	+ 1 418

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

† Based on the price assessed from time to time by The Industries Assistance Commission for Barrow Island crude oil at Kwinana.

TABLE 1 (a)

Quantity and Value of Minerals, other than Gold and Silver, produced during Years 1974 and 1975
Western Australia

Mineral	1974		1975		Increase or Decrease for Year Compared with 1974	
	Quantity	Value	Quantity	Value	Quantity	Value
	Tonnes	$	Tonnes	$	Tonnes	$
Alumina (from Bauxite)	1 981 205	124 800 000	2 230 255	161 479 900	+ 249 050	+ 36 679 900
Barytes	....	....	778	14 688	+ 778	+ 14 688
Beryl	79	14 124	....	....	— 79	— 14 124
Building Stone (Quartzite)	608	5 850	509	5 320	— 99	— 530
(Quartz)	4 206	110 765	5 076	116 360	+ 870	+ 5 595
(Quartz Crystal)	70	3 467	....	....	— 70	— 3 467
(Lepidolite)	76	567	....	....	— 76	— 567
(Spongolite)	79	1 092	....	....	— 79	— 1 092
Clays (Bentonite)	569	7 869	938	11 613	+ 369	+ 3 744
(Cement Clay)	34 975	95 670	59 825	148 325	+ 24 850	+ 52 655
(Fire Clay)	220 943	88 576	204 094	92 161	— 16 849	+ 3 585
(White Clay—Ball Clay)	719	6 881	575	6 792	— 144	— 89
(Brick, Pipe and Tile Clay)	310 893	309 863	22 410	22 056	— 288 483	— 287 807
(Kaolin)	....	....	1 779	10 751	+ 1 779	+ 10 751
Coal	1 446 048	9 144 982	2 113 979	15 073 668	+ 667 931	+ 5 928 686
Cobalt (By-product of Nickel Mining)	135	608 308	57	153 406	— 78	— 454 902
Copper (By-product of Nickel Mining)	267	341 520	678	515 721	+ 411	+ 174 201
	Carats		Carats		Carats	
Emeralds (cut)	19	1 400	1 304	5 250	+ 1 285	+ 3 850
	Tonnes		Tonnes		Tonnes	
Felspar	880	17 487	701	17 621	— 179	+ 134
Glass Sand	280 670	306 075	107 306	105 408	— 173 364	— 200 667
Gypsum	162 136	460 667	109 229	322 184	— 52 907	— 138 483
Iron Ore (Pig Iron Recovered)	53 378	3 906 401	62 978	5 136 216	+ 9 600	+ 1 229 815
(Exported and locally used)	81 442 070	534 996 420	79 637 369	665 880 227	— 1 804 701	+ 130 883 807
(Pellets)	5 558 742	54 148 775	5 552 666	84 703 583	— 6 076	+ 30 554 808
Limestone	1 157 315	1 275 064	1 081 654	1 256 455	— 75 661	— 18 609
Lithium Ores (Petalite)	1	16	....	....	— 1	— 16
Magnesite	....	....	5 119	102 244	+ 5 119	+ 102 244
Manganese (Metallurgical Grade)	18 107	336 655	11 140	195 938	— 6 967	— 140 717
Mica	34	418	87	1 218	+ 53	+ 800
Mineral Beach Sands (Ilmenite)	868 697	11 237 932	666 721	14 960 955	— 201 976	+ 3 723 023
(Monazite)	2 662	386 461	2 851	469 349	+ 189	+ 82 888
(Rutile)	11 275	1 515 196	36 298	5 476 700	+ 25 023	+ 3 961 504
(Leucoxene)	15 878	1 660 705	10 296	1 417 436	— 5 582	— 243 269
(Zircon)	73 468	4 997 311	90 351	14 002 274	+ 16 883	+ 9 004 963
(Xenotime)	26	21 037	....	....	— 26	— 21 037
Nickel Concentrates	368 258	121 458 359	418 025	177 828 528	+ 49 767	+ 56 370 169
Nickel Ore	68 791	4 833 775	72 360	5 960 114	+ 3 569	+ 1 126 339
	kg		kg		kg	
Palladium (By-product of Nickel Mining)	164	428 700	108	267 240	— 56	— 161 460
Platinum (By-product of Nickel Mining)	60	227 200	45	178 236	— 15	— 48 964
Ruthenium (By-product of Nickel Mining)	5	7 300	6	8 221	+ 1	+ 921
	bbls		bbls		bbls	
Petroleum—Crude Oil (barrels)	13 801 191	31 257 312	12 867 769	28 695 124	— 933 422	— 2 562 138
	$m^3 10^3$		$m^3 10^3$		$m^3 10^3$	
Natural Gas ($m^3 10^3$)	831 604	5 285 738	832 171	5 337 272	— 567	+ 51 534
	Tonnes		Tonnes		Tonnes	
Condensate	4 284	N.A.	3 745	N.A.	— 539	N.A.
Salt	3 906 492	14 466 338	3 629 328	17 138 054	— 277 164	+ 2 671 716
	kg		kg		kg	
Semi-precious Stones	27 746	30 875	7 425	3 814	— 20 321	— 27 061
	Tonnes		Tonnes		Tonnes	
Talc	61 653	N.A.	48 336	N.A.	— 13 317	N.A.
Tanto/Columbite Ores and Concentrates	138	729 163	150	850 214	+ 12	+ 121 051
Tin Concentrates	880	2 918 919	967	3 607 289	+ 87	+ 688 370
Vermiculite	225	2 768	268	3 350	+ 43	+ 582
Total		932 454 001		1 211 581 275		+ 279 127 274

TABLE 1 (b)

Quantity and Value of Gold and Silver received at the Perth Mint during the Years 1974 and 1975

Mineral	1974		1975		Increase or Decrease for Year Compared with 1974	
	Quantity	Value	Quantity	Value	Quantity	Value
	kg	$	kg	$	kg	$
Gold	*6 630.958	†22 324 330	*6 989.754	28 887 180	+ 358.796	+ 6 562 850
Silver	*1 718.213	129 714	*2 020.662	171 392	+ 302.449	+ 41 678
Total		22 454 044		29 058 572		+ 6 604 528
Grand Total		954 908 045		1 240 639 847		+ 285 731 802

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

TABLE 2
ROYALTIES

Mineral	Royalty Collected		Increase or Decrease Compared with 1974
	1974	1975	
Alumina	410 737.19	596 484.81	+ 185 747.62
Amethyst	11.43	2.49	— 8.94
Barytes	....	38.63	+ 38.63
Bentonite	40.55	51.19	+ 10.64
Beryl	17.86	1.20	— 16.66
Beryl (Green)	7.52	....	— 7.52
Building Stone	398.91	520.95	+ 122.04
Chalcedony	7.13	1.42	— 5.71
Clay	15 541.36	15 380.63	— 160.73
Coal	32 765.18	53 670.19	+ 20 905.01
Cobalt	924.67	1 309.26	+ 384.59
Emeralds	....	16.50	+ 16.50
Felspar	43.11	37.46	— 5.65
Glass Sand	14 350.17	6 306.49	— 8 043.68
Gypsum	7 815.91	5 302.45	— 2 513.46
Ilmenite	59 051.64	79 315.97	+ 20 264.33
Iron Ore	33 111 946.15	38 807 645.52	+5 695 699.37
Lepidolite	1.23	2.50	+ 1.27
Leucoxene	533.13	1 719.51	+ 1 186.38
Limestone	38 402.20	39 708.98	+ 1 306.78
Magnesite	....	755.76	+ 755.76
Manganese	3 387.72	2 582.51	— 805.21
Mica	1.68	6.80	+ 5.12
Monazite	1 831.19	2 193.55	+ 362.36
Moss Opal	20.97	21.05	+ .08
Natural Gas	270 980.83	271 206.85	+ 226.02
Natural Gas Condensate	3 864.29	6 496.81	+ 2 632.52
Nickel	841 403.27	1 513 336.95	+ 671 933.68
Ochre	....	40.50	+ 40.50
Oil (Crude)	1 254 762.53	1 216 838.90	— 37 923.63
Opal (Tiger Eye)	24.87	....	— 24.87
Opal	78.97	....	— 78.97
Opalite	2.00	....	— 2.00
Palladium	583.78	804.81	+ 221.03
Petalite	0.05	....	— 0.05
Platinum	305.69	569.20	+ 263.51
Quartz Crystal	17.33	....	— 17.33
Quartz (Semi-precious)	8.91	0.07	— 8.84
Ruthenium	14.03	29.47	+ 15.44
Rutile	493.68	5 520.20	+ 5 026.52
Salt	221 004.21	187 852.89	— 33 151.32
Talc	5 239.72	5 057.57	— 182.15
Tanto-Columbite	3 455.58	4 000.98	+ 545.40
Tin	1 237.94	206.04	— 1 031.90
Tourmaline	13.15	....	— 13.15
Vermiculite	11.07	13.19	+ 2.12
Xenotime	52.13	37.58	— 14.55
Zircon	8 103.85	6 592.95	— 1 510.90
Total	36 309 494.78	42 831 680.78	+ 6 522 186.00

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	
	1974	1975	1974	1975	1974	1975
	kg	kg	Per cent.	Per cent.	grams	grams
Kimberley	....	....	....	....	....	....
West Kimberley	....	....	....	....	....	....
Pilbara	39.720	36.113	.61	.53	11.0	8.1
West Pilbara	....	....	....	....	....	....
Ashburton	....	....	....	....	....	....
Gascoyne	....	4.465	....	.06	....	....
Peak Hill	.232	.107	....	....	6.6	3.5
East Murchison	2.887	1.599	.04	.02	2.3	29.1
Murchison	192.429	8.027	2.93	.12	8.0	2.4
Yalgoo	21.287	16.668	.33	.24	17.0	27.1
Mt. Margaret	29.891	36.806	.46	.54	4.2	4.8
North Coolgardie	8.655	12.714	.13	.18	3.8	6.6
Broad Arrow	7.252	44.709	.11	.65	2.2	4.1
North-East Coolgardie	4.201	.506	.06	.01	4.0	2.9
East Coolgardie	5 206.263	5 124.093	79.38	74.64	4.3	4.7
Coolgardie	81.030	85.034	1.24	1.24	7.8	6.1
Yilgarn	56.833	55.692	.87	.81	8.8	12.2
Dundas	904.741	1 438.150	13.79	20.95	7.9	11.1
Phillips River	.275	....	....	....	11.9	....
South-West Mineral Field	.043	....	....	....	.8	....
State Generally	3.069	.287	.05	.01	....	....
	6558.808	6 864.970	100.00	100.00	4.8	5.4

* Averages exclude alluvial and dollied gold.

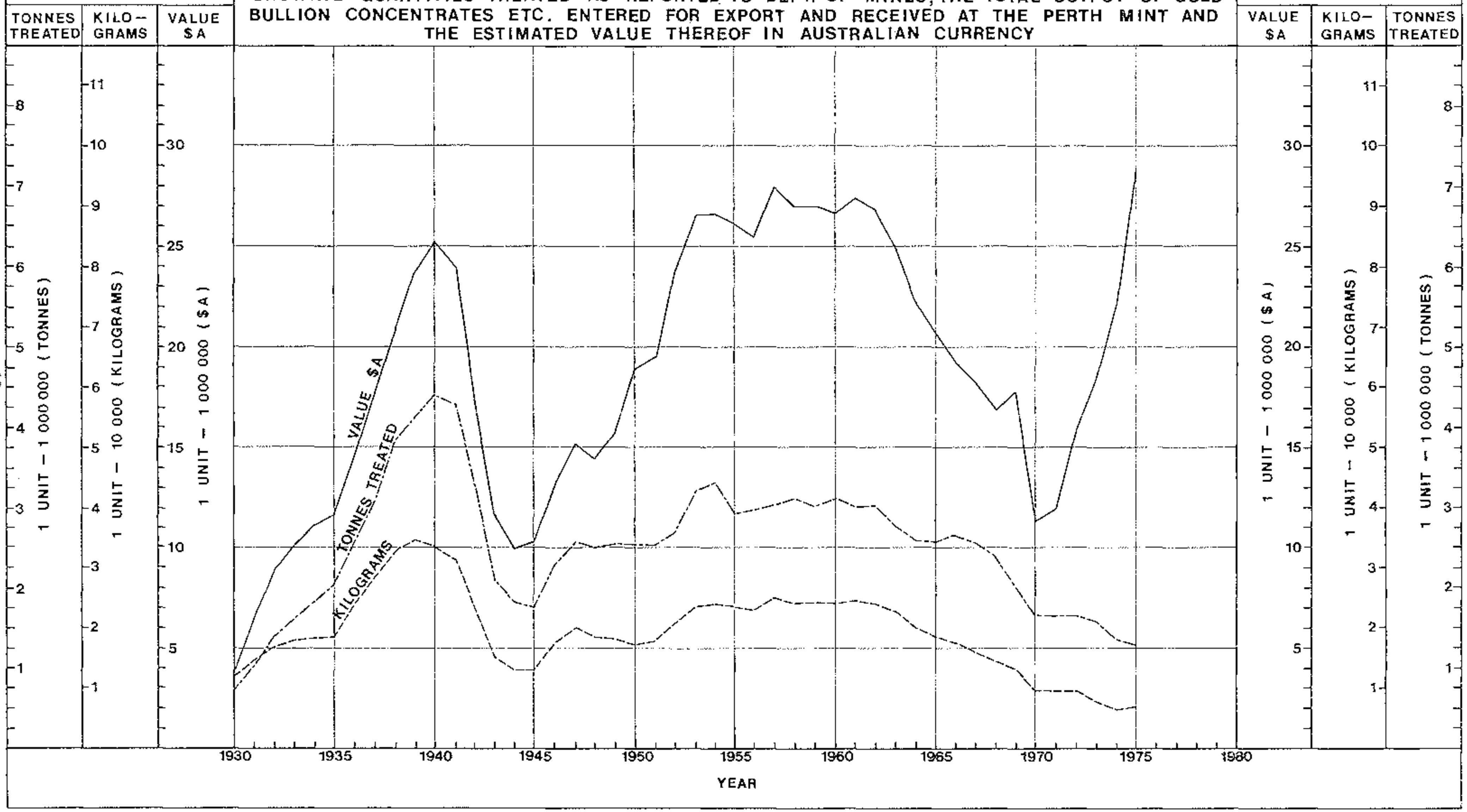
TABLE 4

Total Coal Output from Collie River Mineral Field, 1974 and 1975, 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
1974	490 891	4 440 893	100	323	....	....	1 520	1 160
1975	551 305	5 625 307	114	332	....	....	1 661	1 236
Open Cut Mining—								
1974	955 157	4 704 089	....	....	262	3 646	....	....
1975	1 562 673	9 448 360	....	....	390	4 007	....	....
								In All Mines
Totals—								
1974	1 446 048	9 144 982	100	323	262	....	....	2 111
1975	2 113 979	15 073 668	114	332	390	....	....	2 529

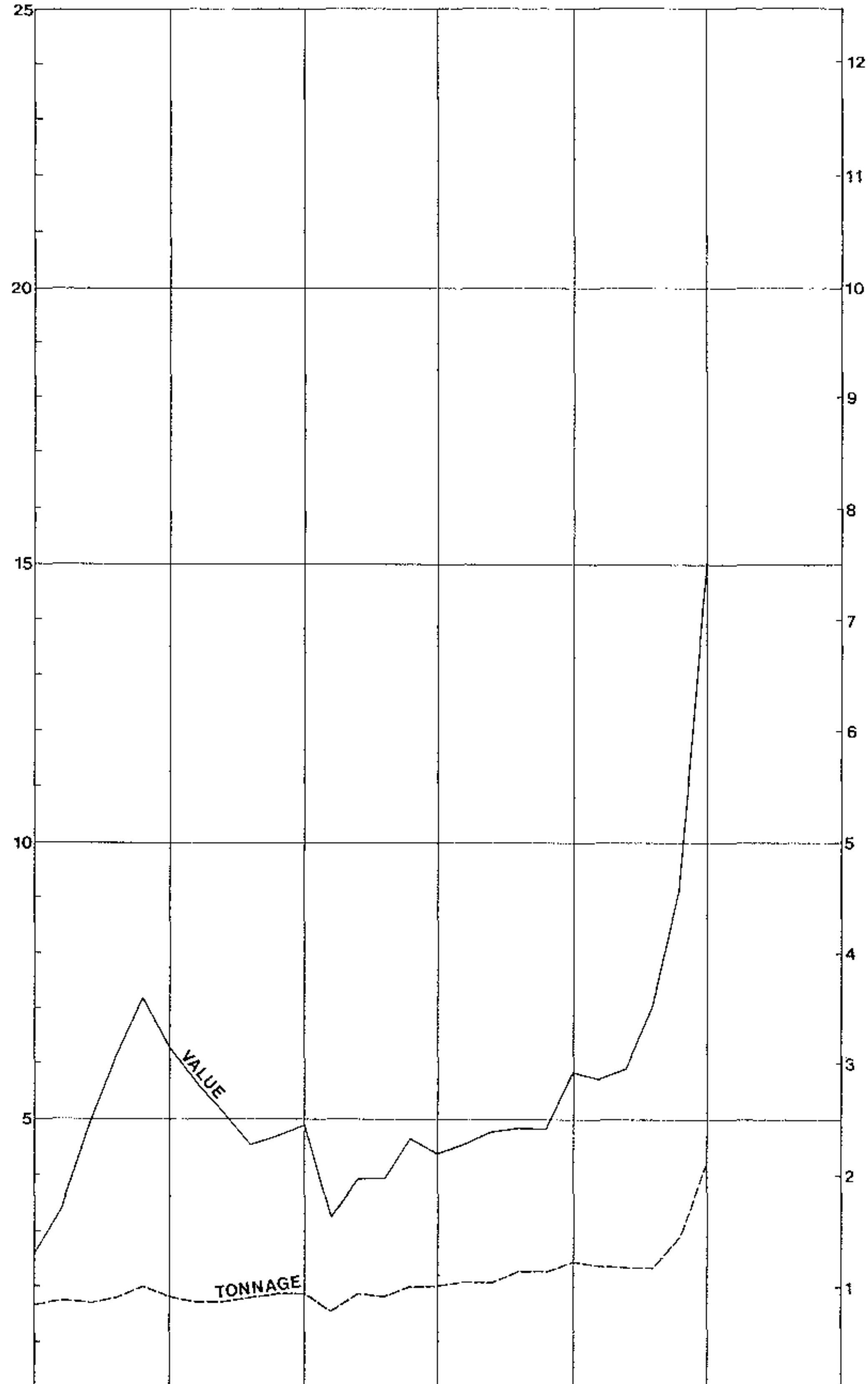
DIAGRAM OF GOLD OUTPUT

SHOWING QUANTITIES TREATED AS REPORTED TO DEPT. OF MINES, THE TOTAL OUTPUT OF GOLD BULLION CONCENTRATES ETC. ENTERED FOR EXPORT AND RECEIVED AT THE PERTH MINT AND THE ESTIMATED VALUE THEREOF IN AUSTRALIAN CURRENCY

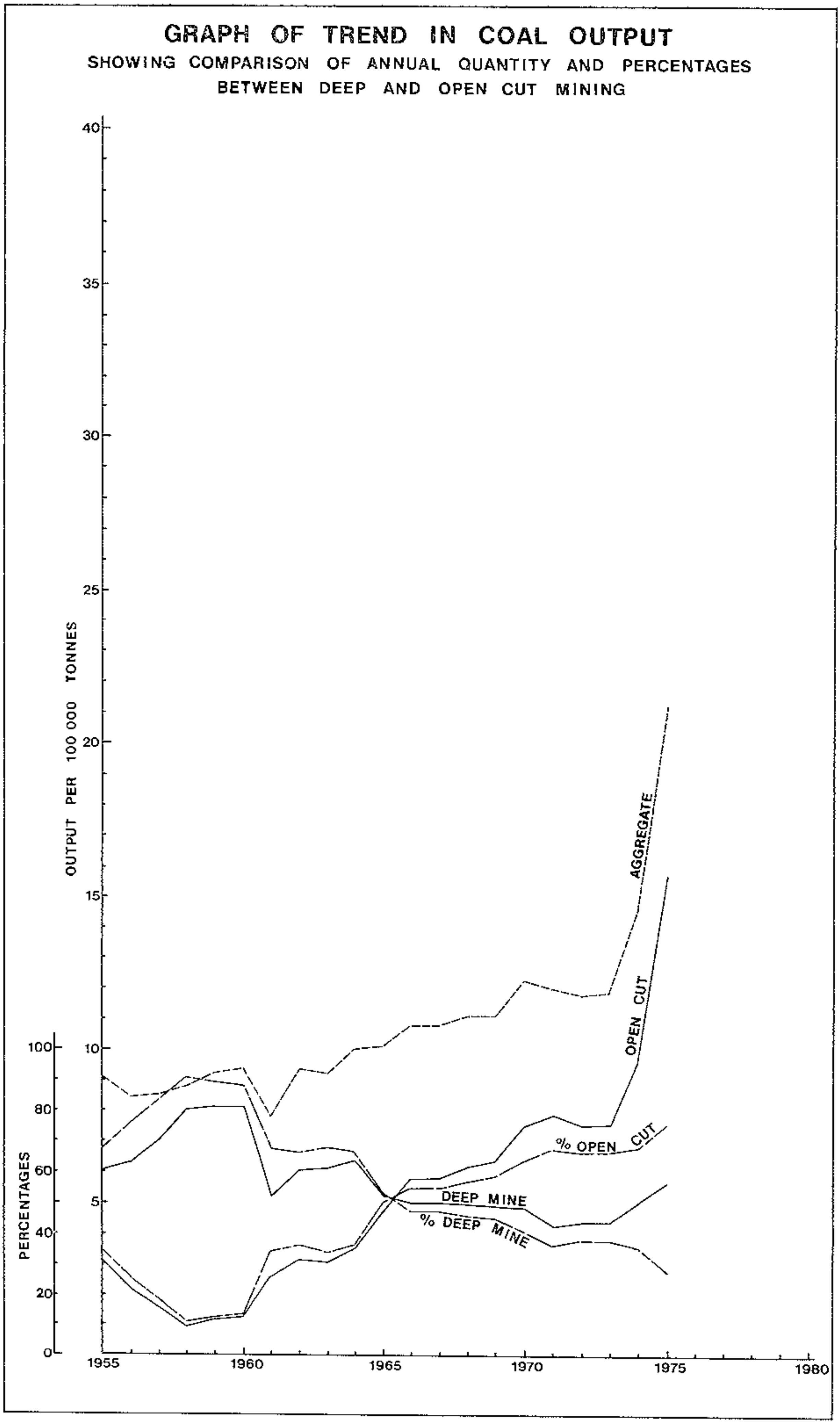


GRAPH OF COAL OUTPUT

SHOWING QUANTITIES AND VALUES AS REPORTED TO DEPT. OF MINES



YEAR	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	4,804,083	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		
1977		
1978		
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

LEASES AND OTHER HOLDINGS UNDER VARIOUS ACTS RELATING TO MINING.

TABLE 5

MINING ACT, 1904.

Total Number and Area of Mining Tenements applied for during 1975 *and in force as at* 31st *December*, 1975 (*compared with* 1974)

—	Applied for				In Force			
	1974		1975		1974		1975	
	No.	Hectares	No.	Hectares	No.	Hectares	No.	Hectares
Gold—								
Gold Mining Leases	575	4 807	336	2 710	2 275	18 310	2 403	19 276
Dredging Claims	14	1 471	26	2 982	2	243	6	561
Prospecting Areas	398	3 307	304	2 587	282	2 364	289	2 430
Temporary Reserves	6	685	5	603	14	1 602	6	679
Totals	993	10 270	671	8 882	2 573	22 519	2 704	22 946
Coal—								
Coal Mining Leases	110	13 089	98	7 421	113	13 177	128	14 864
Prospecting Areas	1	120	36	41 472	1	1 214	4	3 576
Temporary Reserves	4	63 200	8	131 670	5	65 200	12	156 391
Totals	115	76 409	142	180 563	119	79 591	144	174 831
Other Minerals—								
Mineral Leases	257	27 177	94	10 803	544	47 691	637	58 880
Dredging Claims	38	3 174	32	2 891	253	8 805	209	8 211
Mineral Claims	5 422	600 159	3 251	344 071	14 833	1 543 918	11 581	1 173 304
Prospecting Areas	24	203	18	154	23	199	14	116
Temporary Reserves	41	516 428	18	184 380	275	4 433 277	272	4 416 528
Totals	5 782	1 417 141	3 413	542 299	15 928	6 033 890	12 713	5 657 039
Other Holdings—								
Miner's Homestead Leases	2	16	....	....	324	13 349	322	13 428
Miscellaneous Leases	7	41	5	96	121	832	110	776
Residence Areas	1	1	....	....	49	17	48	17
Business Areas	....	....	....	....	17	7	16	6
Machinery Areas	5	10	1	2	25	33	24	34
Tailings Areas	14	96	....	....	32	123	27	42
Garden Areas	8	17	12	23	74	125	84	140
Quarrying Areas	57	495	23	185	160	1 361	158	1 312
Water Rights	5	1 264	7	5 504	112	854	102	844
Licenses to Treat Tailings	200	....	71	....	132	....	132	....
Totals	209	1 940	119	5 810	1 046	16 701	1 024	16 599
Grand Totals	7 189	1 235 760	4 345	737 554	19 666	6 152 601	16 585	5 871 415

TABLE 5 (a)

SPECIAL ACTS

Leases applied for during 1975 *and in force at* 31st *December*, 1975 (*Compared with* 1974)

Mineral	Applied for				In Force			
	1974		1975		1974		1975	
	No.	Hectares	No.	Hectares	No.	Hectares	No.	Hectares
Bauxite	....	....	....	....	7	1 269 612.17	7	1 269 612.17
Iron	1	54 625.00	....	....	8	255 457.85	8	255 457.85
Salt	1	14 710.00	....	....	4	256 242.58	4	256 242.58
Totals	2	69 335.00	....	....	19	1 781 312.60	19	1 781 312.60

TABLE 5 (b)
PETROLEUM ACTS

Permits, Licences and Leases applied for during 1975 and in force as at 31st December, 1975 (Compared with 1974)

Holding	Applied for 1974 No.	Applied for 1974 Blocks	Applied for 1975 No.	Applied for 1975 Blocks	In Force 1974 No.	In Force 1974 Blocks	In Force 1975 No.	In Force 1975 Blocks
Onshore—								
Petroleum Act, 1967—								
Exploration Permits	2	204	**1**	**3**	49	5 408	**28**	**1 679**
Production Licences	....	....	....	....	3	14	**2**	**9**
Petroleum Lease (Barrow Island)	....	....	....	....	1	8	**1**	**8**
Totals	2	204	**1**	**3**	53	5 430	**31**	**1 696**
Petroleum Pipelines Act, 1969—						km		km
Pipeline Licences	....	....	....	....	5	444.9	**5**	**444.9**
Totals	....	....	....	....	5	444.9	**5**	**444.9**
Offshore—						Blocks		Blocks
Petroleum (Submerged Lands) Act, 1967:								
Exploration Permits	....	....	**2**	**385**	30	7 138	**19**	**2 231**
Production Licences	....	....	**1**	**5**	....	....	....	....
Petroleum Lease (Barrow Marine)	....	....	....	....	1	12	**1**	**12**
Totals	....	....	**3**	**390**	31	7 150	**20**	**2 243**
Grand Totals	2	204	**4**	**393**	84	12 580	**51**	**3 939**

(A part block contains approximately 77·7 sq. km and the numbers given above include part blocks.)

TABLE 5 (c)
MINING ACT, 1904

Leases in Force at 31st December, 1974 in each Goldfield, Mineral Field or District

Goldfield, Mineral Field, or District	Gold Mining Leases No.	Gold Mining Leases Hectares	Mineral Leases No.	Mineral Leases Hectares	Miner's Homestead Leases No.	Miner's Homestead Leases Hectares	Miscellaneous Leases No.	Miscellaneous Leases Hectares
Ashburton	5	48.40	10	985.75	....	....	....	....
Black Range	14	105.00	10	1 197.65	....	....	....	....
Broad Arrow	48	321.69	2	227.43	....	....	....	....
Bulong	27	233.05	....	....	....	....	....	....
Collie	....	....	58	6 834.90	....	....	....	....
(Private Property)	....	....	2	210.43	....	....	....	....
Coolgardie	131	966.07	210	23 319.14	22	752.26	3	11.74
Cue	32	291.04	1	40.46	5	490.79	....	....
Day Dawn	48	412.74	....	....	1	8.09	....	....
Dundas	482	4 314.97	....	....	17	365.33	....	....
East Coolgardie	398	2 901.89	3	230.45	61	1 319.35	74	543.49
Gascoyne	8	67.15	5	70.40	....	....	....	....
Greenbushes	....	....	73	3 954.30	7	217.63	....	....
Kanowna	65	552.99	5	221.34	12	284.03	....	....
Kimberley	2	18.71	1	121.40	....	....	....	....
Kunanalling	14	98.69	....	....	2	210.43	....	....
Kurnalpi	13	120.94	....	....	....	....	....	....
Lawlers	37	292.07	8	967.16	4	441.07	....	....
Marble Bar	228	1 837.83	110	13 300.72	....	....	14	86.13
Meekatharra	102	834.75	....	....	11	754.68	1	.40
Menzies	70	570.78	1	28.73	7	299.43	1	4.04
Mount Magnet	104	733.13	....	....	1	4.00	....	....
Mount Malcolm	54	403.93	....	....	9	513.90	....	....
Mount Margaret	60	555.94	59	6 018.15	7	23.43	....	....
Monnt Morgans	73	670.58	1	12.14	....	....	....	....
Niagara	13	86.91	....	....	1	8.09	....	....
Northampton	....	....	3	34.29	....	....	....	....
(Private Property)	....	....	3	16.49	....	....	....	....
Nullagine	23	160.50	....	....	2	8.89	2	19.42
Peak Hill	22	163.30	8	351.03	4	99.92	....	....
Phillips River	3	12.13	15	703.11	106	5 882.90	....	....
(Private Property)	....	....	9	1 085.84	....	....	....	....
South-West	2	19.42	22	2 171.42	....	....	....	....
(Private Property)	....	....	25	2 193.57	....	....	....	....
Ularring	25	196.07	1	121.40	....	....	....	....
West Kimberley	....	....	63	5 372.11	....	....	....	....
West Pilbara	11	98.71	22	502.56	3	14.15	10	91.00
Wiluna	4	34.00	24	2 757.87	16	1 367.80	....	....
Yalgoo	40	282.41	3	78.70	....	....	....	....
Yerilla	71	546.66	....	....	1	4.04	....	....
Yilgarn	157	1 175.26	8	615.01	23	357.62	5	20.08
(Private Property)	17	148.06	....	....	....	....	....	....
Outside Proclaimed	....	....	....	....	....	....	....	....
Totals	2 403	19 275.77	765	73 743.95	322	13 427.83	110	776.30

	No.	Hectares
Gold Mining Leases on Crown Land	2 386	19 127·71
Gold Mining Leases on Private Property	17	148·06
Mineral Leases on Crown Land	735	71 323·46
Mineral Leases on Private Property	30	2 420·49
Miner's Homestead Leases on Crown Land	322	13 427·83
Other Leases on Crown Land	110	776·30
Other Leases on Private Property	—	—

58638—2

TABLE 5 (d)

MINING ACT, 1904

Claims and Authorised Holdings in Force at 31st December, 1975 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	
	Number	Hectares	Number	Hectares	Number	Hectares	Number	Hectares	Number	Hectares	Number	Hectares	Number	Hectares	Number	Hectares	Number	Hectares	Number	Hectares
Ashburton	1	9.71	....	....	328	35 029.59	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Black Range	3	29.10	....	....	226	24 093.18	3	1.20	....	....	....	....	....	....	....	....	....	....	....	....
Broad Arrow	28	221.82	....	....	97	10 605.71	1	.40	....	....	....	....	....	....	....	....	....	....	4	3.62
Bulong	7	58.25	....	....	106	12 524.47	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Collie	....	....	....	....	....	....	....	....	....	....	1	2.00	....	....	....	....	1	4.00	....	....
(Private Property)	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Coolgardie	40	337.29	....	....	462	45 850.68	3	.30	....	....	1	.40	....	....	8	12.51	26	204.37	5	18.06
Cue	8	48.34	....	....	365	39 506.20	1	.10	....	....	1	2.02	....	....	....	....	1	9.71	....	....
Day Dawn	1	9.71	....	....	33	3 431.81	....	....	....	....	....	....	....	....	4	8.08	....	....	....	....
Dundas	6	51.79	....	....	270	22 408.85	....	....	....	....	....	....	1	2.02	....	....	2	19.42	2	4.85
East Coolgardie	22	188.46	....	....	197	20 996.12	30	12.00	....	....	1	.80	10	18.57	12	21.80	7	46.10	12	12.57
Gascoyne	1	9.70	2	165.91	245	23 923.75	....	....	....	....	....	....	....	....	....	....	5	45.33	....	....
Greenbushes	....	....	....	....	1	8.00	1	1.00	....	....	....	....	....	....	9	21.00	....	....	2	15.00
Kanowna	10	82.50	....	....	171	19 629.40	....	....	....	....	....	....	....	....	....	....	....	....	1	.40
Kimberley	....	....	....	....	597	66 785.26	....	....	....	....	....	....	....	....	4	8.00	12	101.00	....	....
Kunanalling	11	93.80	....	....	6	716.10	....	....	....	....	....	....	....	....	....	....	....	....	2	9.71
Kurnalpi	7	65.32	....	....	108	12 048.37	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Lawlers	1	9.71	....	....	1 000	109 926.91	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Marble Bar	12	3 533.62	191	6 971.59	824	75 970.44	....	....	3	1.20	7	10.21	2	2.02	17	27.45	33	282.75	24	169.79
Meekatharra	10	76.23	4	394.90	255	27 803.72	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Menzies	8	59.25	....	....	297	29 841.67	....	....	....	....	....	....	....	....	1	.40	....	....	4	4.02
Mount Magnet	21	184.24	....	....	103	12 098.87	....	....	....	....	....	....	....	....	6	6.00	....	....	3	2.00
Mount Malcolm	19	160.30	....	....	339	37 355.23	....	....	....	....	....	....	....	....	9	14.52	....	....	2	1.20
Mount Margaret	8	72.80	....	....	240	27 338.04	....	....	....	....	2	3.96	5	9.90	2	2.82	....	....	2	3.96
Mount Morgans	2	14.56	....	....	148	16 054.24	....	....	....	....	....	....	....	....	....	....	....	....	1	0.40
Niagara	5	41.15	....	....	28	3 307.27	....	....	....	....	....	....	....	....	....	....	2	11.74	3	2.40
Northampton	....	....	....	....	56	3 334.17	....	....	....	....	....	....	....	....	....	....	....	....	....	....
(Private Property)	....	....	....	....	16	844.13	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Nullagine	1	9.70	6	408.90	263	16 704.35	....	....	....	....	1	0.40	3	1.60	1	1.21	....	....	11	11.27
Peak Hill	5	40.83	....	....	159	13 460.02	....	....	1	0.40	4	6.80	2	4.00	3	5.98	7	67.90	2	8.80
Phillips River	....	....	....	....	310	29 567.88	....	....	....	....	1	.80	1	.80	....	....	1	2.02	....	....
(Private Property)	....	....	....	....	150	16 506.23	....	....	....	....	....	....	....	....	....	....	....	....	....	....
South West	2	129.41	9	693.71	358	26 013.23	....	....	....	....	....	....	....	....	....	....	....	....	1	2.83
(Private Property)	1	9.69	....	....	669	57 658.57	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Ularring	6	47.33	....	....	24	2 547.17	....	....	....	....	1	.40	2	1.61	....	....	....	....	3	1.60
West Kimberley	....	....	1	121.40	154	14 887.51	....	....	....	....	2	4.04	....	....	....	....	18	128.27	2	19.42
West Pilbara	....	....	2	15.37	667	62 016.75	4	1.60	6	2.40	....	....	....	....	4	7.67	40	367.75	10	16.54
Wiluna	2	14.50	....	....	573	65 479.31	....	....	....	....	....	....	1	1.21	....	....	....	....	2	534.60
Yalgoo	21	183.76	....	....	1 036	116 393.22	....	....	6	2.40	....	....	....	....	....	....	2	11.70	1	.40
Yerilla	6	48.52	....	....	47	4 616.53	....	....	....	....	....	....	....	....	....	....	....	....	5	4.82
Yilgarn	32	280.20	....	....	646	65 363.61	5	.55	....	....	2	2.01	....	....	4	3.00	1	9.71	....	....
(Private Property)	....	....	....	....	5	487.70	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Outside Proclaimed	....	....	....	....	2	169.96	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Totals	307	6 121.59	215	8 771.78	11 581	1 173 304.22	48	17.15	16	6.40	24	33.84	27	41.73	84	140.44	158	1 311.77	104	848.26

TABLE 6

MEN EMPLOYED

Average number of Men employed in Mining during 1974 *and* 1975

Goldfield	District	Gold 1974	Gold 1975	Other Minerals 1974	Other Minerals 1975	Total 1974	Total 1975
Kimberley	....	....	....	....	....	....	....
West Kimberley	....	....	....	349	**373**	349	**373**
Pilbara	Marble Bar	47	**35**	782	**908**	829	**943**
	Nullagine	1	....	....	....	1	....
West Pilbara	....	....	**3**	2 059	**2 300**	2 059	**2 303**
Ashburton	....	....	....	146	**112**	146	**112**
Gascoyne	....	....	**3**	317	**233**	317	**236**
Peak Hill	....	7	**5**	913	**1 036**	920	**1 041**
East Murchison	Lawlers	1	....	....	....	1	....
	Wiluna	....	....	....	....	....	....
	Black Range	5	**2**	....	....	5	**2**
Murchison	Cue	4	**1**	5	**3**	9	**4**
	Meekatbarra	13	**10**	....	....	13	**10**
	Day Dawn	3	**2**	....	....	3	**2**
	Mt. Magnet	101	**4**	....	....	101	**4**
Yalgoo	....	10	**10**	4	**4**	14	**14**
Mt. Margaret	Mt. Morgans	8	**4**	1	....	9	**4**
	Mt. Malcolm	40	**27**	....	....	40	**27**
	Mt. Margaret	4	**11**	....	**406**	4	**417**
North Coolgardie	Menzies	9	**15**	75	**70**	84	**85**
	Ularring	10	**24**	....	....	10	**24**
	Niagara	7	**8**	....	....	7	**8**
	Yerilla	14	**5**	....	....	14	**5**
Broad Arrow	....	38	**27**	317	**405**	355	**432**
North-East Coolgardie	Kanowna	11	**2**	....	....	11	**2**
	Kurnalpi	7	**2**	3	....	10	**2**
East Coolgardie	East Coolgardie	1 343	**1 211**	....	....	1 343	**1 211**
	Bulong	6	**9**	....	....	6	**9**
Coolgardie	Coolgardie	42	**70**	1 718	**1 905**	1 760	**1 975**
	Kunanalling	14	**15**	....	....	14	**15**
Yilgarn	....	57	**63**	134	**149**	191	**212**
Dundas	....	221	**240**	3	**2**	224	**242**
Phillips River	....	2	....	....	....	2	....
South-West Mineral Field	....	2	....	2 642	**3 048**	2 644	**3 048**
Northampton Mineral Field	....	....	....	....	....	....	....
Greenbushes Mineral Field	....	....	....	88	**88**	88	**88**
Outside Proclaimed Goldfield	....	....	....	....	....	....	....
Collie Coalfield	....	....	....	619	**836**	619	**836**
Total—All Minerals	....	2 027	**1 808**	10 241	**11 878**	12 268	**13 686**

	1974	1975
Minerals Other than Gold—		
Alumina (from Bauxite)	1 965	**2 072**
Barytes	....	**4**
Beryl	5	....
Building Stone	7	**5**
Clays	18	**20**
Coal	685	**836**
Emeralds	3	**3**
Felspar	5	**8**
Glass Sand	13	**14**
Gypsum	9	**9**
Iron Ore	4 050	**4 525**
Limestone	33	**37**
Mica	2	**2**
Mineral Beach Sands	550	**878**
Nickel	2 090	**2 767**
Petroleum (Crude Oil)	146	**110**
(Natural Gas)	7	**7**
Salt	497	**425**
Semi-precious Stones	7	**6**
Talc	17	**15**
Tanto Columbite	....	**2**
Tin	130	**131**
Vermiculite	2	**2**
Total, Other Minerals	10 241	**11 878**

PART 3—STATE AID TO MINING

(a) State Batteries

At the end of the year there were 16 State Batteries including the Northampton Base Metal Plant.

From inception to the end of 1975, gold, silver, tin, tungsten, lead, copper and tantalite ores to the value of $45 401 503 have been treated at the State Batteries. $43 227 964 came from 3 909 807 tonnes of gold ore, $430 934 from 85 366 tonnes of tin ore, $41 595 from 4 338.6 tonnes of tungsten ore, $1 560 634 from 71 198.2 tonnes of lead ore, $11 932 from 224.0 tonnes of copper ore, $73 459 from 2 192.8 tonnes of tantalite ore, and silver valued at $4 985 recovered as a by-product from the cyaniding of gold tailings.

During the year 54 003.6 tonnes of gold ores were crushed for 364.193 kilograms bullion, estimated to contain 308.647 kilograms fine gold equal to 5.71 grams per tonne. The average value of sands after amalgamation was 2.20 grams per tonne, making the average head value 7.91 grams per tonne. Cyanide plants produced 29.775 kilograms of fine gold, giving a total estimated production for the year of 338.422 kilograms of fine gold valued at $1 316 255.

The working expenditure for the year for all plants was $1 275 401 and the revenue was $175 557 giving a working loss of $1 099 844 which does not include depreciation, interest or Superannuation. Since the inception of State Batteries, the Capital expenditure has been $2 027 329 made up of $1 506 140 from General Loan Funds; $436 373 from Consolidated Revenue; $57 244 from Assistance to Gold Mining Industry; and $27 572 from Assistance to Metalliferous Mining.

Head Office expenditure including Worker's Compensation Insurance and Pay Roll Tax was $192 835 compared with $142 160 for 1974.

The actual expenditure from inception to the end of 1975 exceeds revenue by $10 297 589.

(b) Prospecting Scheme

At the end of the year three men were in receipt of prospecting assistance as compared with five at the end of 1974.

Total expenditure for 1975 was $2 111.68 and refunds amounted to $930.90.

Assisted prospectors crushed 869.58 tonnes of ore during the year for 1.954 kilograms of gold.

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

Expenditure—$1 052 718.

Refunds—$204 763.

Ore Crushed—131 170 tonnes.

Gold Won—1 812.880 kilograms.

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

(c) Geological Survey of Western Australia

The scope of the advice and information available from the Branch is well known and its officers provide advice not only to the mining and allied industries but also those engaged in exploration and development of water supplies.

During the year great demands were made on the services of the Geological Survey in providing regional geology, specialists' services and information from its library and other records.

PART 4—GOVERNMENT CHEMICAL LABORATORIES

The wide range of functions of this Branch is indicated by the titles of its seven Divisions:—

(1) Agricultural Chemistry.

(2) Food, Drug, Toxicology and Industrial Hygiene.

(3) Industrial Chemistry.

(4) Mineral.

(5) Water.

(6) Engineering Chemistry (Bentley).

(7) Metallurgical Laboratory (Kalgoorlie).

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

There was a decrease of 8 per cent in the number of samples received for examination and determination during 1975, when 27 740 were received as against 30 158 in 1974.

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

PART 5—EXPLOSIVES BRANCH

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

477 licences of various types for explosives, and 285 permits dealing with shotfiring, entry of explosives and fireworks were issued during 1975 under the Explosive and Dangerous Goods Act, 1961-1974.

Under the Flammable Liquids Regulations 4 802 licences were issued for the storage of flammable liquids throughout the year for which some 3 820 inspections were made which included the examination of 228 vehicles conveying bulk petroleum fuels.

The consumption of explosives throughout Western Australia during 1975 was 80 300 tonnes, the greater part of which was used in iron ore mining.

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

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

A total of 17 886 examinations were made of which 8 696 were made under the Mine Workers' Relief Act and 9 190 under the Mines Regulation Act. Of the latter 8 248 were new applicants and 942 were re-examinees. In addition, Provisional Certificates were issued to 832 persons in isolated areas.. Compensation payments under the Miners' Phthisis Act amounted to $5 273 compared with $6 202 for the previous year. The number of beneficiaries under the Act as on 31/12/75 was 23 being two ex-miners and 21 widows.

PART 7—SURVEYS AND MAPPING BRANCH

Cadastral surveys carried out increased in number to 2 219 in 1975 compared with 1 764 in 1974, and 5 357 applications for mining tenements and 353 applications for Temporary Reserves were received for processing.

In the Photographic Section the process camera was in constant operation with 2 286 items being handled. There was a 175% increase in general photographic work with over 7 200 items being produced during the year.

A great deal of microfilming was carried out, 154 rolls of film having been prepared. Also, assistance was given to Westrail with their microfilming programme in the preparation of 12 rolls of film.

PART 8—STAFF

Members of the Staff both in Perth and the outstations are to be congratulated on the manner in which they carried out their duties during the year under review and I am very appreciative of their efforts. It is also noteworthy that the introduction of flexi-hours has been achieved smoothly and without loss of efficiency.

In this summary I have referred only to specific items of the Department's many 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 1975

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. The activities in each inspectorate—Perth, Kalgoorlie, Port Hedland, Collie—are the subjects of separate reports by the Mining Engineer-Senior Inspector of Mines responsible for his particular inspectorate. Also included are reports by the Principal Senior Inspector, the Drilling Engineer and the Board of Examiners.

It is anticipated that the recently re-written Mines Regulation Act Regulations will come into force early in the new year. These regulations cover inspection, management, electricity, machinery, explosives, ventilation, occupational diseases, hygiene, underground diesel equipment, shaft sinking, winding equipment and signals, quarrying, dredging, railway operations and general safety in and about mines.

As part of the State-wide ground water investigation the Drilling Section completed 11 279 metres of exploratory drilling at sites in the Canning Basin, the Fortescue Valley and at Moora, Joondalup, Bunbury, Mill Stream, De Grey river and Weelamurra creek. In addition, 2 088 metres of drilling was completed in the Manjimup area to provide long term recording sites for water sampling and water level measurement points in the study of the effects of logging in the area.

The value of mineral production (excluding petroleum) at $1 206 105 447 was an increase of 32 per cent as compared with the value of production for the previous year. Product price increases accounted for part of the overall increases as iron ore production was down 2 million tonnes on the previous year's output of 87 million tonnes and ilmenite sales were down by about 249 000 tonnes.

Alumina output from Pinjarra and Kwinana increased by just under 250 000 tonnes to 2 230 255 tonnes. Nickel ore and concentrate production reached 490 385 tonnes an increase of 53 336 tonnes on the 1974 production. The most significant increase was in coal production from the Collie field where a record output of 2 113 979 tonnes was produced from one underground and two open cut collieries. This output represented a 46 per cent increase on the previous year's output of 1 446 048 tonnes.

Although there was some development work in progress at the end of the year gold production from underground at Fimiston has virtually ceased. Central Norseman Gold Corporation at Norseman and Kalgoorlie Lake View Pty. Ltd operating the Mt. Charlotte mine at Kalgoorlie continue to be the State's leading gold producers. Two new enterprises namely Mulga Mines Pty. Ltd. at Blue Spec and Newmont Pty. Ltd. at Telfer in the Paterson Range should commence gold mining in the coming year.

STAFF

Appointments—

Leggerini, R. J., Workmen's Inspector of Mines	10/2/75
Fraser, R. D., Ventilation Officer	10/11/75
Sheppard, A., Ventilation Officer	18/11/75

Promotions—

Johnson, D. C., Mining Engineer-District Inspector of Mines	21/5/75
Faichney, J. M., Mining Engineer-Principal Senior Inspector of Mines	19/11/75

Retirements—

Boyland, J., Mining Engineer-Principal—Senior Inspector of Mines	30/9/75
Haddow, J. F., Mining Engineer-District—Inspector of Mines	31/12/75

Resignation—

Berryman, L. P., Ventilation Officer	21/3/75

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.

and are based on information obtained from various sources including the Statistical and Mines Inspection Sections of the Department.

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

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

Accident Statistics

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

There were 18 (12) fatal and 826 (699) serions accidents. (The figures for the previous year are shown in brackets.)

The diagram showing the fatal accidents segregated according to the class of mining operation and extending over the past twenty years appears below.

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

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

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

—FATAL ACCIDENTS

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

Name and Occupation	Date	Mine	Details and Remarks
Wilde, C. (Leading Hand Electrician)	22/1/75	Mt. Newman Mining Co. Pty. Ltd.—Newman	Contacted active circuit whilst working on phase rotation in a cubicle in the quarry and was electrocuted.
McPherson, S. (General Hand)	6/2/75	Texada Mines Ltd.—Lake McLeod	Caught in tension pulley for conveyor belt whilst endeavouring to remove build up of salt.
Ristoski, S. (Conveyor Belt Attendant)	27/2/75	Hamersley Iron Pty. Ltd.—Leighton Contractors, Tom Price	Died from injuries received when caught in a conveyor structure whilst replacing skirting.
Potisk, W. (Maintenance Fitter)	6/3/75	Alcoa of Aust (W.A.) Ltd.—Pinjarra	The rim of a wheel split whilst it was being removed from a water truck thrusting the deceased backwards against another truck.
Brown, K. (Loader Operator)	7/3/75	Metro Sands Pty. Ltd.—Perth	The loader fell over the face of a sand pit and pinned him to the floor of the pit.
Clark, D. H. (Plant Operator)	15/3/75	Jennings Mining Ltd.—Narngulu	His arm was caught and pulled in between the belt and tail pulley forcing his chest against the conveyor frame.
Graffin, A. (Timberman)	15/4/75	Kalgoorlie Lake View Ltd.—Perseverance Mine	He fell onto a piece of steel used as a stanchion on a trolley and it penetrated his body.
Martin, B. S. (Miner) and Bryan, P. P. (Miner)	28/5/75	Windarra Nickel Mines Pty. Ltd.—Windarra Mine	The two men were caught by the fall of a large quantity of rock from the back of the stope whilst they were clearing off a bench.
Burrows, C. F. (Miner)	4/6/75	Western Mining Corporation Ltd. (Kambalda Nickel Operations)—Otter Juan Mine	Died from injuries received when crushed between the bucket of a diesel engined loader and the wall of the decline.
Buncic, B. (Trainee Miner)	12/6/75	Western Mining Corporation Ltd. (Kambalda Nickel Operations)—Silver Lake Mine	The deceased was discovered amongst broken dirt in a mill hole. It is not known how he came to fall into the ore pass in the stope.
Moore, J. H. (Platman)	10/7/75	Selcast Exploration Ltd.—Spargoville Mine	Whilst attaching a rope to a shackle under the skip at the No. 11 level plat he slipped and fell to the bottom of the shaft.
Bort, T. D. (Jumbo Drill Operator)	10/7/75	Windarra Nickel Mines Pty. Ltd.—Windarra Mine	A large rock fell from the back of the drive whilst he was barring down and crushed him.
Watson, A. (Truck Driver)	16/8/75	Goldsworthy Mining Ltd.—Shay Gap	His truck slipped over the edge of the dump whilst tipping waste and he received multiple injuries.
Dowsing, C. P. (Leading Hand Plant Operator)	16/8/75	Mt. Newman Mining Co. Pty. Ltd.—Port Hedland	He was asphyxiated when buried by iron ore after he entered a chute in a bin to release jammed steel
Kerstma, W. H. (Bulldozer Operator)	21/8/75	Mt. Newman Mining Co. Pty. Ltd.—Newman	He received chest injuries when struck by a Haulpak truck whilst afoot in the quarry.
Deakin, E. (Trucker)	25/9/75	Western Mining Corporation Ltd.—(Kambalda Nickel Operations)—Silver Lake Mine	Found in Granby truck placed under manway after a sand blast on a large slab of rock over the manway was fired electrically.
Roberts, K. J. (Electrician)	15/11/75	Cliffs Robe River Iron Associates —Pannawonica	He reversed a four wheel drive vehicle into the path of a forward moving haulpak truck and was crushed in the cab.

WINDING MACHINERY ACCIDENTS

A number of accidents involving winding machinery and associated shaft equipment were reported and investigated. The necessary action to repair any damage caused and eliminate hazards to safety were taken. They are described briefly as follows:—

Overwinds (6). At the Associated shaft of K.L.V. Ltd the east skip was wound too high through the tipping position and when the driver attempted to ease it back insufficient power was applied and the full skip in the other compartment caused the east skip to rise further.

Overwind limits were activated and brakes applied when the control gates at an underground loading station at the Redross mine of Anaconda Aust. Inc. malfunctioned. This created an overload in the skip causing it to run down the shaft, thus raising the opposite skip in the skyshaft which activated the O/W Limit Switch. No damage resulted.

A partial shear in the copper pin in the detaching hook occurred at the Jan haulage shaft of W.M.C. Ltd (K.N.O.), when the driver applied full power in the wrong direction. The overwind limits applied the brakes.

Two incidents occurred in the shaft sinking of the Long shaft of W.M.C. Ltd. (K.N.O.). The winder driver was unable to stop when hoisting in single gear as the linkage of the brake mechanism jammed in the "brake off" position. The linkage mechanism of the brakes were modified to prevent a recurrence. The other incident was due to an electrical fault in the dynamic brake circuit and caused the kibble crosshead to come off the end of the skids in the skyshaft. No damage occurred in either incident.

A hood for shaft inspection purposes fitted above the skip in the North compartment at the Silver Lake haulage shaft of W.M.C. Ltd (K.N.O.) struck the bell when the skip was raised too high in the skyshaft. The rope was kinked and it was necessary to cut off the damaged section.

Cage/Skip Hang Up (15). In the Redross shaft of Anaconda Aust. Inc. there were four hang ups. The first occurred when the north skip was taken out of the scrolls too quickly causing the locking arms to bounce and fail to engage the bridle, and as a result the skip sat on a shaft set. No damage resulted. In the second instance the grippers on the north skip engaged on the skids between the Nos. 6 and 7 Levels. It was attributed to excessive braking. No damage was apparent although about 40 metres of rope was unwound. With the third incident a similar slack rope condition occurred due to the actuation of the grippers by the application of the brakes in an emergency condition. A kinked rope occurred and it was necessary to cut off 8.5 metres. On the other occasion the skip jammed in the skyshaft after tipping into a launder which was completely filled with a build up of wet and sticky ore. Slack rope resulted but there was no damage to rope or attachments. To prevent a similar occurrence a closed circuit T.V. has been installed whereby the winder driver can observe on a monitor screen when a build up of dirt occurs on the launder.

There were cage/skip hang ups in various shafts of Kalgoorlie Lake View Pty. Ltd. as follows:

Associated Shaft. A gate on the cage was left open when at the No. 5 level and slack rope resulted when the driver lowered the cage on receiving a "phantom" signal. No damage occurred.

When lagging protuded into the shaft after the collapse of timber at the No. 19 level plat the cage, full of men descending to that level, came to an abrupt stop. Fortunately no persons were injured and no damage to cage or rope resulted.

Hannan Star Shaft. Due to a tight spot in the shaft timber the double cage hung up just above the No. 6 level.

Oroya Shaft. The skip jammed in the shaft and the rope pulled out of the detaching hook which opened up at the jaws. It is believed that a large stone which projected from the skip caught the underside of a shaft timber set.

Chaffers Service Shaft. The counterweight hung up on a damaged skid joint whilst the cage was between the Nos. 35 and 34 levels.

Horseshoe No. 2 Shaft. The cage grippers actuated at about the No. 15 level when the cage was run through the shaft at the start of the shift. The grippers had been repaired on the previous day. It was necessary to cut off 3 metres of rope.

Mt. Charlotte Reward Shaft. The overspeed device on the winding engine was activated causing an emergency stop during the tracing of an electrical fault. The grippers engaged on the ascending cage when the momentum allowed a slack rope condition. Nine metres of rope were cut off.

At the Nepean shaft of Metals Exploration N.L. a bottom dump skip sat on a shaft set when the skip door was not fully closed. The locking arm had not engaged. The rope kinked.

The south skip of the Kalgurli shaft of North Kalgurli Mines Ltd., which is used as a counterweight, hung up between the Nos. 3 and 4 levels due to tightness in the shaft timber. No other damage occurred.

Excessive amounts of slack rope occurred on two consecutive days due to inattentive driving by the winding engine driver at the Durkin Haulage shaft of W.M.C. Ltd. (K.N.O.). On the first day sixty metres of rope wound off the drum when the skip jammed in the skyshaft due to the bin being full and the skip unable to empty. The next day a skip jammed in the shaft between Nos. 5 and 6 levels and approximately 213 metres of rope wound out leaving only a few turns on the winder drum. Normally, 14 to 15 turns remain on the drum when the skip is at the lowest level.

MISCELLANEOUS (9)

Selcast Exploration Ltd. The failure of cast bearing housings allowed the shaft and wheel assembly which supports and guides the skip door of a bottom dump skip to drop down the shaft from the skyshaft damaging the cage in the next compartment.

W.M.C. Ltd. (K.N.O.)—Durkin Haulage shaft: The locking arms failed to engage correctly on a skip and when ascending the skip struck some slightly protruding rails at the No. 6 level plat causing the skip door, shaft and wheel assembly to break away at the cast bearing housing.

Silver Lake Haulage shaft: The wheel assembly shaft supporting the underside of the skip door broke in two parts allowing one part to drop down the shaft. Dirt which had compacted between the underside of the skip and its door caused the shaft to bend and continuous flexing resulted in the break. Modifications were made to the skips to eliminate this build up of dirt.

Due to the failure of a shackle pin the body of a Granby truck slung beneath the cage fell to the bottom of the Silver Lake Haulage shaft from about the No. 4 level loading pocket. An unsuitable pin had been used.

Long shaft (Sinking): An empty kibble was lowered past a predetermined point in the shaft without receiving a signal and struck and broke a compressed air line on the stage. The shaft sinking crew were jointly to blame as they had established a practice of signalling to lower past the point in the shaft whilst the kibble was still in motion. The mine manager was directed to ensure that correct signalling procedures were adopted.

Kalgoorlie Lake View Pty. Ltd. Kinks were observed in the winding ropes on the Lake View shaft and Mt. Charlotte Reward shafts by a winding engine driver and a skipman respectively, at the commencement of their shifts and the ropes were cut and the necessary sections of rope removed.

Mt. Charlotte Reward shaft: The failure of a weld allowed the door of the skip to fall down the shaft from the tip position in the skyshaft. The door jammed in the shaft about 300 feet below the surface but caused considerable damage to the shaft timbers over this distance.

Central Norseman Gold Corporation N.L.:—Regent shaft: The winding engine was out of service for a week when a shaft in the gearbox fractured. A new shaft was manufactured.

DECLINE ACCIDENTS

W.M.C. Ltd (K.N.O.)—A collision occurred in the Fisher Decline between a personnel carrier and a Kiruna truck when the brakes of the former vehicle failed. It was later found that the brake fluid reservoir for the front brakes was empty. Two of the seven occupants of the carrier received minor injuries.

Kalgoorlie Lake View Pty. Ltd.—Mt. Charlotte mine: The driver of a front end loader deliberately drove this vehicle into the wall of the 1 in 7 decline when he discovered that his braking system was insufficient to stop the vehicle. He sustained only minor injuries to his face and forehead.

PROSECUTIONS

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

The driver of a front end loader was successfully prosecuted for breaches of section 49 and section 54 for working from an elevated loader bucket without wearing a safety belt attached to the bucket, and for leaving the loader unattended whilst the engine was running.

A miner was found guilty of breaching Regulation 58 (4) by drilling two holes and collaring another before washing and cleaning the butts in a drive face. Another miner breached Regulation 58 (4) by drilling a hole before washing and cleaning the butts in a drive face, and also failed to report the position of a misfired hole in contravention of Regulation 58 (1). These prosecutions resulted from an explosives accident in which one of the men was slightly injured.

A miner was observed drilling in a development face which was 43 metres from the through airway without the necessary ventilation and he was successfully prosecuted under Regulation 152 (1).

Complaints were made against a miner for failing to securely protect and make safe for persons employed in the mine a mill hole rise situated in a stope, contrary to Regulation 70, and, being a person employed in or about a mine commenced working in a place while that place was unsafe or apparently unsafe, contrary to section 49. The charges were defended and the Magistrate found that the prosecution had not proved its case beyond reasonable doubt and acquitted the defendant and dismissed the complaints. Two other complaints against the mine foreman and the mine manager were then withdrawn.

INQUIRY BY BOARD OF EXAMINERS

(Under Regulation 36 of the Mines Regulation Act)

The inquiry was instituted following representation to the Minister by a Mining Engineer-District Inspector of Mines that a certified Underground Supervisor was incompetent to discharge his duties by permitting an unsafe procedure to be carried out by a workman, viz. to permit the driver of a front end loader, which was parked with the engine running on a 1 in 9 gradient in a Decline, to leave the vehicle to assist him while working from the elevated bucket of the loader. Witnesses were called and evidence was taken by the Board, which found that the Supervisor was negligent in his responsibility as a certificated Underground Supervisor in that he did not admonish or prevent the driver of the front end loader from leaving the controls while he was working in the elevated bucket of the loader. The Board recommended that the Supervisor be officially admonished by the Governor, and the decision of the Governor be made known to The W.A. Chamber of Mines and The Western Australian Gold and Nickel Mines Supervisors' Association. The admonishment of the Supervisor and notification to the two bodies were duly made.

CERTIFICATES AND PERMITS

Certificate of Exemption: Two certificates of exemption were granted under section 46 of the Mines Regulation Act.

Sunday Labour Permits: Nineteen permits were issued for the installation, and reconnection of ventilation equipment; the repair and making safe of mine openings after pillar blasts; stripping declines to allow safe clearances for new trucks; installing power cables in shaft and substations; transferring pumping equipment; removing shaft penthouse; stripping a plat; repairing a damaged conveyor belt; and diamond drilling off a Main Decline. Approval was obtained from the Minister for Mines for permission to hoist ore on the 23rd November in order that the winding engine at the Mt. Charlotte mine could be tested. All permits were issued in order to avoid loss of time in the subsequent working of the mines. Three applications for permission to work were refused.

Permits to Fire Outside Prescribed Times. Six permits were issued for this purpose. All were subject to special conditions such as the posting of warning notices notifying all mine personnel to ensure general safety, the prevention of persons entering the area prior to firing, and the exhausting of all fumes, dust etc., direct to the surface. Firing within ¾ of a hour of the recognised firing times was prohibited.

Permits to Rise: Seventy-nine permits for rises totalling 2 163 metres in length were issued. Thirty-seven of these were risen in the conventional manner and the other forty two were made on boreholes. Ventilation and access were the main reasons given for the rises but ore, and mullock, passes and a stope preparation were other uses for the rises.

Permission was given for Decline development at Cockatoo Island to be placed under the management of the contractor, Roberts Union Construction, at the request of the Dampier Mining Co. Ltd.

AUTHORISED MINE SURVEYOR'S CERTIFICATES

The Survey Board issued one certificate. The successful applicant was:—

J. E. Maisey—Certificate No. 194.

VENTILATION

All mines, crushing and treatment plants within the State were inspected by staff of the ventilation section and dust concentrations or dust counts, temperature and humidity conditions, and ambient gas levels, checked in all working areas.

In all underground mines where diesel engined equipment was in use the primary and secondary airflows were measured regularly and the concentrations of carbon monoxide and nitrous fumes in the atmosphere determined.

As usual the ventilation staff provided assistance, when requested, to mining companies on ways to improve ventilation and minimise dust, and several investigations were undertaken.

Gravimetric sampling for determining dust concentrations has been introduced and new mining regulations to become effective in 1976 will impose standards for these concentrations. However the konimeter was still in use in 1975 and the results of this sampling are tabulated as follows:—

Dust Samples from	No. of Samples	Samples Giving Over 1 000 p.p.c.c.	Average Count p.p.c.c.
Surface Plants	48 (122)	– (32)	185 (451)
Stoping	312 (773)	1 (1)	181 (141)
Levels	209 (347)	1 (6)	187 (246)
Development	205 (261)	– (2)	181 (196)
Totals	774 (1503)	2 (41)	183 (200)

Counts of 1 000+ p.p.c.c. are included in the average count.
1974 figures are shown in brackets.

Konimeters take an instant sample of the air and the result is not representative of the conditions and dust in the air whereas gravimetric sampling can be extended over a much longer period, even the whole working shift, and therefore must be considered as more representative of the "dustiness" in that working area. Dust is collected on filters which must be weighed before and after sampling and the number of samples obtained by a person is necessarily reduced, but it is an advantage to collect the dust on a filter as the free silica content in the sample can be determined by x-ray diffraction analysis.

The principal cause for dust problems underground was created by miners not ensuring that their secondary ventilation equipment was kept in good condition and up to their working place whilst lack of maintenance of dust suppression and collection systems resulted in dusty conditions in most crushing plants.

Lead in the air in Assay Offices continued to be a concern but redesign of work locations and exhaust fan installations is doing much to eliminate the problems. Mercury in the atmosphere in gold rooms was also shown to be a hazard and investigations involving air measurements disclosed that retorting of gold was the major cause. Stricter controls for handling of mercury have been imposed. Urine samples were collected from all those involved in the handling of lead and mercury.

Forty-six new permits to use diesel engined equipment underground were issued for mines operating in the Kalgoorlie inspectorate and eleven permits for two underground operations in the Port Hedland inspectorate. Undiluted diesel exhaust gas determinations for carbon monoxide and nitrous fume were taken at 178 units in operation. Five per cent of the determinations exceeded the standards and the necessary action was enforced.

There were twenty three fuming reports affecting twenty nine men but fortunately none were fatal. All were investigated and disclosed that nine men were affected by blasting fumes which had not cleared, three were the result of handling explosives, seven were affected by sulphur dioxide, two from diesel exhaust emissions, four from a lack of ventilation, and four from other causes.

Self rescue breathing equipment is available to all workmen employed on mines where diesel engined equipment is in use, and underground fire fighting and rescue teams equipped with self contained breathing apparatus are being formed by the major companies. Safety chambers are also being prepared in underground workings.

Methane gas emissions were reported from a diamond drill hole at North Kalgurli Mines Ltd. and a diamond drill hole in the St. Ives Area operations of Western Mining Corporation Ltd (Kambalda Nickel Operations). Emissions from these two holes "blew out" in two days. SO_2 emissions were investigated at the Oroya and Chaffers treatment plants of Kalgoorlie Lake View Ltd and at the Nickel Smelter of Western Mining Corporation Ltd. The conditions at the Smelter were very satisfactory at the end of the year.

GENERAL

Inspections of working places on all mines were undertaken in accordance with the Mines Regulation Act. The frequency of inspections was generally in accord with the past years but there were periods when staff shortages, due to illness and other causes, limited the visits to the mines.

The Sprengnether seismograph was used a number of times to determine ground vibrations from blasting mainly to assist other Departments such as the Metropolitan Water Supply Board, and local Town Councils. A number of complaints arising from blasting in quarries were investigated and measures recommended to eliminate the causes.

Mining Engineers in the Branch were called upon to study and comment on proposals submitted by the Department of Industrial Development on projects such as the feasibility study on Coates Siding ferro vanadium, Telfer gold, Mt. Mulgine tungsten, W.M.C. Ltd Mineral Sands agreement, and financial assistance for North Kalgurli Mines Ltd.

Other assignments such as potential danger to the public due to unprotected shafts and workings, and surface subsidence from the collapse of abandoned workings were attended to.

Rehabilitation at Greenbushes received considerable attention after the imposition of more stringent conditions in reaching agreement for the relocation of the South West Highway to give access to additional tin ore reserves. An environmental assessment of the Collie field has also been examined and rehabilitation in some areas is now in progress. A proposal to mine diatomite by dredging in Lake Gnangara was examined in order to prepare conditions suitable to all departments and the local governing body.

TABLE 1

Mineral and Metal Output (excluding Petroleum)

Mineral Product	1974		1975	
	Production	Value	Production	Value
	Tonne	$A	Tonne (t)	$A
Alumina	1 981 205·00	124 800 000	2 230 255	161 479 900
Barytes	....	....	778	14 688
Bentonite	568·99	7 869	938	11 613
Beryl	79·00	14 124	....	....
Building Stone	5 039·46	121 741	5 585	121 680
Clays	567 529·82	500 990	288 683	280 085
Coal	1 446 047·93	9 144 982	2 113 979	15 073 668
Cobalt	135·00	608 308	57.28	153 406
Copper—Metal	267·00	341 520	678	515 721
Emeralds Carats (Cut)	19·00	1 400	1 304	5 250
Felspar	880·43	17 487	701	17 621
Glass Sand	280 669·87	306 075	107 306	160 562
Gold (kg)	6 583·43	22 258 720	7 104.98	28 330 022
Gypsum	162 135·99	460 667	109 229	322 184
Ilmenite	868 696·65	11 237 842	619 964	14 960 955
Ilmenite (upgraded)	....	....	46 757	Not available
Iron Ore	87 000 812·00	589 145 195	85 190 035	750 583 810
Iron Ore—Pig Iron	86 936·00	3 906 401	99 225	5 136 216
Leucoxene	15 667·80	1 635 905	10 296	1 417 436
Limestone	1 157 315·73	1 275 064	1 081 654	1 256 455
Lithium Ore—Petalite	1·00	16	....	....
Magnesite	....	....	5 119	102 244
Manganese	18 107·04	336 655	11 140	195 938
Mica	34·00	418	87	1 218
Monazite	2 661·66	386 461	2 851	469 349
Nickel Ore and Concentrates	437 048·61	126 292 134	490 385	183 788 642
Palladium (kg)	163·72	428 700	108.17	267 240
Platinum (kg)	59·54	227 200	44.99	178 236
Ruthenium (kg)	5·28	7 300	5.63	8 221
Rutile	11 275·02	1 515 196	36 298	5 476 700
Salt	3 906 492·38	11 576 831	3 629 328	17 138 054
Semi-Precious Stones	27·75	30 875	7.42	3 814
Silver (kg)	1 718·21	129 714	2 020.66	171 392
Talc	61 653·00	Not available	48 336	Not available
Tantalo-Columbite	138·01	729 163	150.10	850 214
Tin Concentrate	880·45	2 918 919	967.25	3 607 289
Vermiculite	225·00	2 768	268	3 350
Xenotime	26·00	21 037	....	....
Zircon	73 681·27	5 022 111	90 351	14 002 274
Totals	....	915 409 788	....	1 206 105 447

1 Kilogram (kg) = 32·150 75 troy ounces = 35·273 96 ounces.
1 Tonne (t) = 0·984 206 5 ton.

TABLE 2

Reported Mine Development

Gold or Mineral Field	Mine	Shaft Sinking Metres	Decline and Incline Metres	Driving and Cross Cutting Metres	Rising and Winzing Metres	Explora-tory Drilling Metres	Total Metres
Gold—							
East Coolgardie	North Kalgurli Mines Ltd.	....	....	6	46	1 835	1 887
	Kalgoorlie Lake View Pty. Ltd.						
	Fimiston	....	....	4 951	1 107	8 300	14 358
	Mt. Charlotte	....	476	2 058	521	6 796	9 851
	Great Boulder Mines Ltd.	....	....	....	....	357	357
	Daisy Mine	....	....	6	....	....	6
Dundas	Central Norseman Gold Corporation N.L.	....	....	979	472	13 061	14 512
East Murchison	Scheelite Gold Mine	....	....	14	....	....	14
Yilgarn	Marvel Loch Gold Mine	....	....	358	59	759	1 176
	W.A. Gold Development	....	....	160	10	....	170
	Frasers Gold Mine	....	....	40	30	....	70
Murchison	Hill 50 Gold Mine N.L.	15	....	217	91	881	1 204
Pilbara	Mulga Mines Ltd.	27	200	129	38	....	394
	Totals in Gold Mines	42	676	8 918	2 374	31 989	43 999
Nickel—							
Coolgardie	Western Mining Corporation Ltd. (Kambalda Nickel Operations)	319	3 393	10 919	3 150	109 868	127 649
	Anaconda (Aust.) Inc.	....	....	946	319	3 590	4 855
	Metals Exploration N.L.	10	62	983	479	3 136	4 670
	Selcast Exploration Ltd.	....	....	938	510	1 279	2 727
Broad Arrow	Great Boulder Mines Ltd.	....	....	559	160	605	1 324
North Coolgardie	Great Boulder Mines Ltd.	....	....	16	45	123	184
Mt. Margaret	Western Mining Corporation Ltd. (Windarra)	....	417	2 689	1 134	16 432	20 672
	Totals in Nickel Mines	329	3 872	17 050	5 797	135 033	162 081
Iron—							
West Kimberley	Dampier Mining Co. Ltd. (Cockatoo Isl.)	....	104	....	....	....	104
Peak Hill	Mt. Newman Mining Co. Pty. Ltd.	....	....	....	219	....	219
West Pilbara	Cliffs Robe River Iron Associates	....	....	100	160	....	260
	Totals in Iron Mines	....	104	100	379	....	583

TABLE 3

Principal Gold Producers

Mine	1974			1975		
	Tonnes Treated	Yield Kilograms	Grams Per Tonne	Tonnes Treated	Yield Kilograms	Grams Per Tonne
Kalgoorlie Lake View Pty. Ltd.	470 932	2 400.62	5.1	433 899	2 272.86	5.2
Kalgoorlie Lake View Pty. Ltd. (Mt. Charlotte)	690 537	2 605.01	3.8	610 849	2 657.42	4.4
Central Norseman Gold Corporation	114 199	900.31	7.9	129 479	1 436.80	11.1
North Kalgurli Mines Ltd.	32 265	161.10	4.6	28 617	116.81	4.1
Hill 50 Gold Mine N.L.	21 493	187.07	8.7	....	....	....
Minor Producers	46 565	329.33	7.1	67 324	621.08	9.2
Total State Production	1 378 991	6 583.43	4.8	1 270 168	7 104.97	5.6

Note: The calculated value of the gold produced in 1975 was $28 330 022 which includes $21 516 208 distributed by the Gold Producers Association from the sale of 7 336.38 kilograms of gold at an average premium of $2 932.81 per kilogram.

TABLE 4

Overseas Iron Ore Exports

Company	Sales Tonnes	Grade % Fe
Hamersley Iron Pty. Ltd.	31 504 678	63.72
Mt. Newman Mining Co. Pty. Ltd.	23 894 369	63.00
Cliffs W.A. Mining Co. Pty. Ltd.	10 897 717	59.47
Goldsworthy Mining Ltd.	7 260 239	63.19
Dampier Mining Co. Ltd.	3 252 373	67.66
Totals	76 809 376	63.01

TABLE 5

Nickel Producers

Product and Producer	Centre	Quantity Tonnes	Grade % Ni	Value $
NICKEL CONCENTRATES				
Western Mining Corporation Ltd.	Kambalda	306 379	12.03	129 965 608
Western Mining Corporation Ltd. (Windarra)	Windarra	68 850	11.48	25 725 337
Great Boulder Mines Ltd.	Scotia	10 968	14.82	5 814 255
Great Boulder Mines Ltd. and North Kalgurli Mines Ltd.	Carr-Boyd Rocks	4 941	9.70	1 573 900
Selcast Exploration Ltd.	Emu Rock	8 539	14.00	4 256 772
Anaconda Australia Inc.	Redross	18 348	15.75	10 492 656
Total Concentrates		418 025	12.19	177 828 528
NICKEL ORE				
Metals Exploration N.L.		72 360	3.42	5 960 114

DIAGRAM OF FATAL ACCIDENTS

SEGREGATED ACCORDING TO CLASS OF MINING

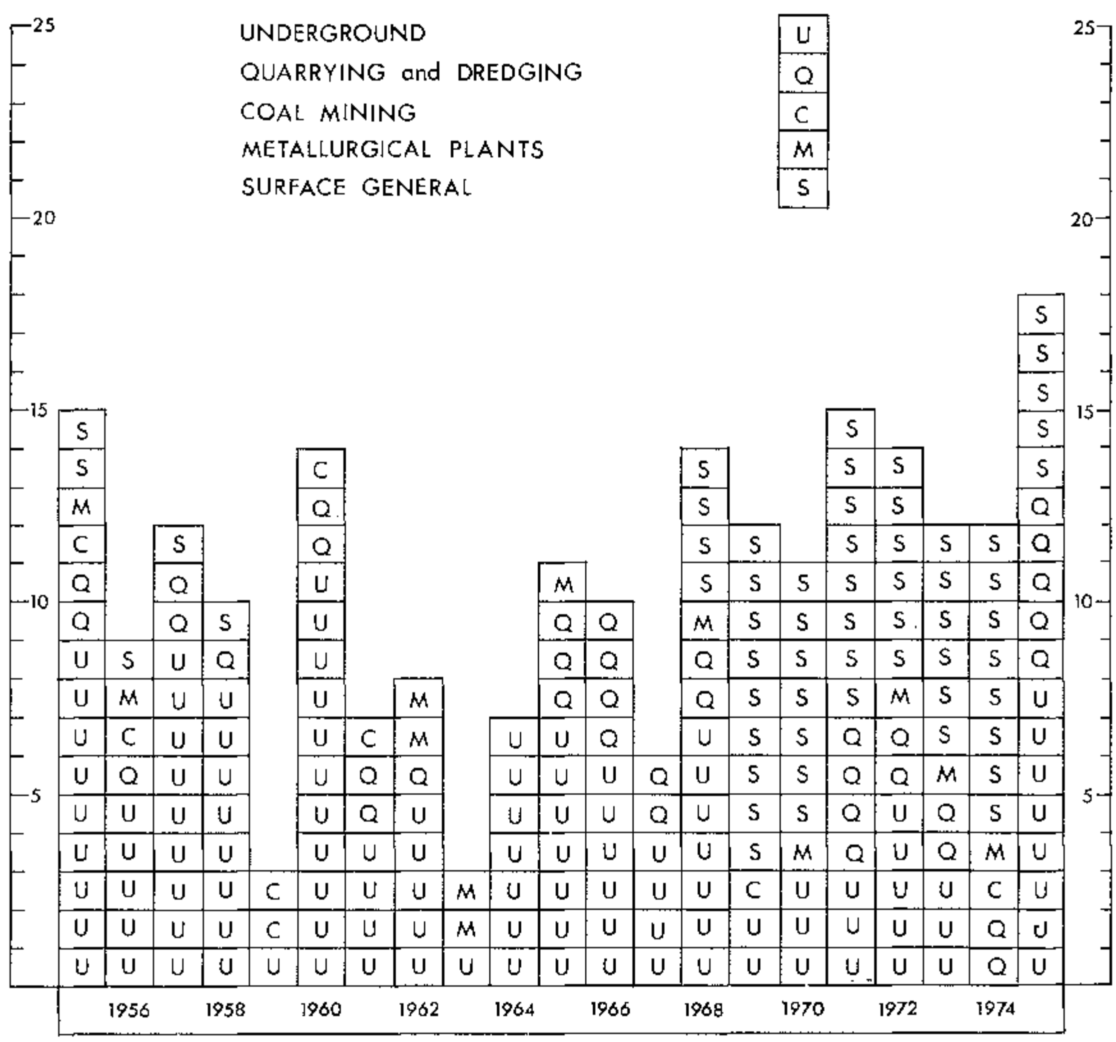


TABLE "A"

SERIOUS ACCIDENTS FOR 1975

Class of Accident	West Kim-berley	Pil-bara	West Pil-bara	Peak Hill	Gas-coyne	Murchi-son	North Cool-gardie	Mount Mar-garet	Broad Arrow	East Cool-gardie	Cool-gardie	Dun-das	Yil-garn	South West	Green-bushes	Collie	Total
Major Injuries (exclusive of fatal)—																	
Fractures—																	
Head	....	....	1	1	....	....	....	2	....	....	....	....	....	....	....	....	4
Shoulder	....	....	....	....	....	....	....	....	....	1	1	....	....	....	....	....	2
Arm	....	1	4	1	....	1	....	1	1	1	2	....	1	4	1	1	19
Hand	....	....	2	....	....	....	....	....	1	2	3	....	....	1	....	1	10
Spine	....	....	....	1	....	....	....	....	....	....	....	....	....	....	....	....	1
Rib	....	1	3	....	....	....	....	....	1	1	2	....	....	1	....	....	9
Pelvis	....	....	....	1	....	....	....	....	....	1	1	....	....	....	....	....	3
Thigh	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Leg	....	2	....	....	....	....	....	....	....	2	2	....	1	3	....	....	10
Ankle	....	1	....	2	....	....	....	2	....	1	2	....	....	2	....	....	10
Foot	....	1	1	....	....	....	....	1	....	1	7	....	....	1	....	....	12
Amputations—																	
Arm	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	1	1
Hand	....	....	....	....	....	....	....	....	....	....	1	....	....	....	....	....	1
Finger	....	....	2	1	....	....	....	....	....	1	5	....	....	....	....	1	10
Leg	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Foot	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Toe	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Loss of Eye	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Serious Internal	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Hernia	....	....	3	....	....	....	....	....	....	3	3	1	....	4	....	1	15
Dislocations	....	....	1	....	....	....	....	1	....	1	1	....	....	....	....	....	4
Other Major	....	....	....	....	....	....	....	1	....	....	1	....	....	2	....	1	5
Total Major	....	6	17	7	....	1	....	8	3	15	31	1	2	18	1	6	116
Minor Injuries—																	
Fractures—																	
Finger	....	1	4	....	....	1	....	....	....	4	9	....	....	6	....	3	28
Toe	....	1	1	1	1	....	....	1	....	2	1	....	....	....	....	6	14
Head	....	....	2	....	....	....	....	....	....	1	3	....	....	1	....	2	9
Eye	....	1	3	....	1	....	....	....	1	1	3	....	....	5	....	....	15
Shoulder	....	1	4	....	....	....	....	....	1	3	7	....	....	4	....	2	22
Arm	....	1	6	1	2	....	....	1	....	6	6	5	....	5	1	2	36
Hand	1	6	7	2	2	1	4	3	4	23	39	5	....	10	1	13	121
Back	1	11	17	2	10	3	1	1	4	33	41	2	....	20	....	30	176
Rib	....	2	1	....	....	....	....	....	....	2	2	....	....	....	....	1	8
Leg	....	9	24	2	4	1	....	6	1	19	29	2	2	13	1	10	123
Foot	....	1	1	1	1	1	....	1	....	24	18	....	2	21	....	6	77
Other Minor	....	3	4	1	....	....	....	....	....	11	18	....	....	22	....	22	81
Total Minor	2	37	74	10	21	7	5	13	11	129	176	14	4	107	3	97	710
Grand Total	2	43	91	17	21	8	5	21	14	144	207	15	6	125	4	103	826

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

TABLE "B"

ACCIDENTS SEGREGATED ACCORDING TO MINERAL MINED AND PROCESSED

Mineral	Men Employed	Accidents		
		Fatal	Serious	Minor
Bauxite (Alumina)	2 172	1	43	44
Coal	854	....	103	382
Gold	1 760	1	129	317
Ilmenite	992	1	47	111
Iron	10 336	6	171	772
Nickel	3 800	7	292	795
Salt	429	1	21	62
Tin	150	....	4	4
Other Minerals	157	1	3	4
Rock Quarries	294	....	13	31
Totals	20 944	18	826	2 522

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	....	....	....	....	....	....	....	....	....	....	....	2	....	2
Pilbara	....	....	....	....	....	....	....	....	....	....	2	43	2	43
West Pilbara	....	....	....	....	....	....	....	....	....	....	2	91	2	91
Ashburton	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Peak Hill	....	....	....	....	....	....	....	....	....	....	2	17	2	17
Gascoyne	....	....	....	....	....	....	....	....	....	....	1	21	1	21
Murchison	....	....	....	....	....	....	....	....	....	3	....	5	....	8
East Murchison	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Yalgoo	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Northampton	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Mount Margaret	....	....	3	1	....	....	....	....	....	9	....	11	3	21
North Coolgardie	....	....	....	....	....	1	....	....	....	4	....	....	....	5
Broad Arrow	....	....	....	....	....	....	....	....	....	13	....	1	....	14
North East Coolgardie	....	....	....	....	....	....	....	....	....	....	....	....	....	....
East Coolgardie	....	1	....	7	....	1	....	....	1	52	....	83	1	144
Coolgardie	1	2	....	16	1	....	....	1	2	134	....	54	4	207
Yilgarn	....	....	....	....	....	....	....	....	....	1	....	5	....	6
Dundas	....	....	....	3	....	....	....	....	....	8	....	4	....	15
Phillips River	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Greenbushes	....	....	....	....	....	....	....	....	....	....	....	4	....	4
South West	....	1	....	....	....	....	....	....	....	....	3	124	3	125
Collie	....	....	....	4	....	....	....	....	....	73	....	26	....	103
Nabberu	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Warburton	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Eucla	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Total for 1975	1	4	3	31	1	2	....	1	3	297	10	491	18	826
Total for 1974	....	2	....	22	....	7	....	3	....	264	12	401	12	699

METALLIFEROUS MINING OPERATIONS—KALGOORLIE INSPECTORATE

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

MOUNT MARGARET GOLDFIELD

Nickel mining at Windarra is the major mining operation in this Goldfield. On July 16th, 1975 Windarra Nickel Mines Pty. Ltd., relinquished control as managers of the Windarra Mining Operation in favour of Western Mining Corporation Ltd.

This mining operation involves both underground and open pit mining and during 1975 some 302 686 tonnes of nickel ore was mined from the underground operations and 700 602 tonnes of ore from the open pit at South Windarra. Total concentrates produced amounted to 109 724 tonnes, which were transported by road train to the Malcolm siding where they were then loaded on rail and transported to the nickel smelter at Kalgoorlie.

Due to bad ground conditions encountered in the main production areas underground, the company relied heavily on the open pit operation for the supply of ore for the concentrator early in the year. However, towards the latter part of the year the main underground mining problems had been overcome and the company is at present enjoying regular production from this source.

Prospectors have been active throughout the year in this Goldfield and some very good returns have been obtained from crushings of gold ore put through the State Batteries located at Leonora and Laverton.

Exploration companies have been reasonably active but no significant finds were reported.

EAST MURCHISON GOLDFIELD

Apart from limited exploration work carried on by various companies, mining activity in this Goldfield was very quiet.

The Yeelirrie Uranium Project (W.M.C. Ltd.) and the nickel projects at Mount Keith (Metals Exploration Ltd.) and Perseverance (Agnew Mining Co. Pty. Ltd.) have remained on a care and maintenance basis throughout the year but it is expected that at least two of these projects could commence mining operations during 1976.

The Scheelite Gold Mine at Barrambie continues to operate on a very small scale.

NORTH COOLGARDIE GOLDFIELD

The Carr Boyd Rocks Nickel Mine operated by Great Boulder Mines Ltd., ceased operations in June, 1975 and is now on a care and maintenance schedule.

During the six months of operation the company treated 40 442 tonnes of nickel ore from the mine which yielded 4 930 tonnes of concentrates.

Development on a limited scale continued at the Aspacia Gold Mine. The mine which is situated just west of the Menzies Townsite had planned to increase production significantly during 1975 but this did not eventuate due to the lack of facilities to treat the sulphide ore.

NORTH EAST COOLGARDIE GOLDFIELD

Mining activity in this Goldfield consisted of quarry operations at Karonie where approximately 250 000 tonnes of rock for railway line ballast were produced.

Precious opal was mined spasmodically on Mineral Claim 392K located approximately 110 Kilometres East of Kalgoorlie.

BROAD ARROW GOLDFIELD

Nickel mining by Great Boulder Mines Ltd., continued on a reduced scale at the Scotia mine where 126 328 tonnes of ore were broken. Concentrates produced amounted to 10 905 tonnes.

Aurex Minerals, a small privately owned company treated some 16 000 cubic metres of tailings from in situ vats excavated in the dump at Grants Patch. The cyaniding process resulted in over 31 kilograms of gold being won.

The Gimlet South Open Cut Operation was the main contributor to the State Battery at Ora Banda where 10 000 tonnes of ore were crushed for a return of 8.308 kilograms of gold.

EAST COOLGARDIE GOLDFIELD

A fall in the price of gold coupled with spiralling costs and poor treatment facilities saw a major decline in the Kalgoorlie Gold Mines.

North Kalgurli Mines Limited discontinued underground mining operations on December 9, 1975 and Kalgoorlie Lake View Pty. Ltd., began to curtail operations on their Fimiston leases towards the latter part of the year and in doing so dismissal notices were served on several hundred employees.

The Mount Charlotte operation was the biggest producer on the Golden Mile and from the 610 849 tonnes of ore treated 2 657.452 kg of gold were recovered.

Several open cut operations were worked throughout the year on the Ivanhoe, Hannan Star, Oroya and Paringa leases and of the 93 812 tonnes treated 325.958 kg of gold were recovered.

The Croesus treatment plant of North Kalgurli Mines Limited continued to treat nickel ore from Anaconda's Redross Mine and on February 28, 1975 the No. 2 circuit was commissioned to treat nickel ore from the Spargoville project of Selcast Exploration Limited.

The Fimiston operation of Great Boulder Mines Ltd., was confined to treating nickel ore from Scotia and Carr Boyd Rocks and gold ore from shallow open pits on the Fimiston leases. To treat the gold bearing ore it was necessary for the company to re-establish a free milling gold plant. This plant treated 14 399 tonnes of ore for a recovery of 41.60 kg of gold.

During the year Western Mining Corporation Ltd., Nickel Smelter treated 280 000 tonnes of concentrate yielding 63 000 tonnes of contained nickel.

The commissioning of a third Pierce Smith Converter, a 9 M.V.A. Electric Slag Cleaning Furnace and a 4 M.V.A. Electrode installation in the flash furnace was completed.

COOLGARDIE GOLDFIELD

Within this Goldfield are situated the major nickel producing mines in the State.

During the year Selcast Exploration Ltd., began serious production and at the end of 1975 production was mining at about 100 000 tonnes per year and this was expected to increase to approximately 160 000 tonnes per year by the end of 1976.

Anaconda Australia Incorporated increased production during the year to a rate of 130 000 tonnes of ore mined. Ore treated during the year amounted to 100 173 tonnes giving 18 349 tonnes of nickel concentrate.

Both Anaconda and Selcast have all their broken ore transported by road train to the Croesus treatment plant at Kalgoorlie where a nickel concentrate is produced.

The Nepean mine, operated by Metals Exploration Ltd., produced 2 352.4 tonnes of recovered nickel from the 72 860.6 tonnes of ore treated.

A change in management half way through the year saw yet another change in fill placement methods—from dry gravel filled flat back stopes to hydraulic sand filled stopes. It is anticipated that shaft sinking will recommence at this mine sometime in 1976.

Prior to going into liquidation in October 1975, a company named Roebourne Exploration treated several thousand tonnes of alluvial material for a return of 15.199 kg of gold, from areas adjacent to the Coolgardie Townsite.

Western Mining Corporation Ltd. pursued a vigorous exploration and development programme in the Kambalda area during the year and after treating 1.37 million tonnes of nickel ore were able to maintain ore reserves.

The Jan shaft and Edwin decline are nearing the production stage and sinking of a new shaft on the Long Shoot has commenced.

All existing shafts and declines continued to operate as in the previous year.

Construction of an underground crushing station at the 10 level horizon of the Otter-Juan decline is nearing completion and it will be linked directly to a 2.44 metre diameter raise bore shaft from the surface.

Lefroy Salt Pty. Ltd., produced 154 212 tonnes of washed salt of which 94 792 tonnes were shipped out from Esperance. Nine crystalizing ponds and one storage pond have been constructed having total areas of 432 and 23 hectares respectively.

DUNDAS GOLDFIELD

Central Norseman Gold Corporation continued operations during 1975 and ore treated amounted to 125 219 tonnes from which was recovered 1 432.14 kg of gold.

Between February and September, 1975 the Company established the North Royal Open Cut. During that time 1 684 000 cubic metres of material consisting of 1 597 000 m^3 of mullock and 87 000 m^3 of ore was removed.

Towards the latter end of the year the Readymix Group reopened their quarry East of Esperance to crush and supply road metal to various contractors in the Esperance district.

A quarry operated by R & N Palmer Pty. Ltd., broke 152 000 tonnes of granite rock during the first half of the year. This rock was used on the extension of the Esperance break water.

PHILLIPS RIVER GOLDFIELD

During the year Norseman Gold Mines N.L. mined some 137 000 tonnes of magnesite and shipped a 23 900 tonne bulk sample to Austria for metallurgical tests.

Various companies were active in the exploration field the most prominent being Western Mining Corporation Ltd., (nickel) and Amoco and Union Miniere (gold and copper).

YILGARN GOLDFIELD

Mining activity in the Yilgarn Goldfield changed little from the previous year. The iron ore mines at Koolyanobbing continued to produce at normal rates. One of the iron ore companies Charcoal Iron and Steel was taken over by a division of Agnew-Clough early in the year and renamed Wundowie Iron and Steel.

The principal development in the gold mining was the further proving of reserves at the Marvel Loch Gold Mine to a stage where a 60 000 tonne per year treatment plant will be erected early in 1976.

Level development West of the known lodes on the four level led to the discovery of the "QUAY" Lode and some hundred metres of driving on this lode has been on good grade ore.

Another small mine to be reopened during the year was the Francis Furness Gold Mine but small gold mines that closed included the Frasers and Radio mines.

A small private company has erected a plant at Diemal's and will commence to treat tailings early in the new year.

Mineral exploration was at a low ebb throughout the Goldfield except for the Forrestania area where several nickeliferous ore bodies have been delineated by drilling and further exploration work is proceeding. Amax Mining (Aust) Ltd., is the main company in the area.

GENERAL

During 1975 two new mobile compressors were commissioned at Kalgoorlie and Southern Cross. These units may be hired out for a small hire charge by any bona fide prosecutor. Also, the compressors located at Norseman and Leonora were given major overalls during the year.

Early in December, the Registration and Inspectorial staff transferred to the new Department of Mines building erected in Brookman Street.

PT. HEDLAND INSPECTORATE

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

Overall, a reported total of 190.128 million tonnes of ore and waste was broken, for which 65 357 tonnes of explosives were used; and 4.061 million tonnes of salt and allied products were harvested, resulting in the shipment of 89.216 million tonnes of minerals, despite the loss of an unusually high number of man-days through various causes.

The above figures do not include the production of tin, tantalite, gold, semi-precious stones, building stone, sand, or "blue metal" for roads and railway ballast.

An estimated total of 10 500 men are employed in the mining industry.

IRON

Five companies produce and ship iron ore, and with other companies are also very active in the exploration field.

9 828 men are reported to be employed by these five companies, and exploration in the Hamersley Range and Opthalmia Range areas by other interests would increase the employment figure to more than 10 000 men.

The 1 200 kilometres of railroads receive constant attention and the company townsites and accommodation are of a high standard.

Production and Shipping (Million Tonne Units)

Company	Men Employed	Ore Broken	Ore Shipped			
			Lump	Fines	Pellets	Total
Hamersley Iron Pty. Ltd.	4 192	65.663	15.237	15.573	1.651	32.461
Mt. Newman Mining Co. Pty. Ltd.	2 953	44.425	16.598	14.139	....	30.737
Cliffs Robe River Iron Associates	1 232	10.883	....	7.557	3.980	11.537
Goldsworthy Mining Ltd.	1 144	7.069	3.719	3.542	....	7.261
Dampier Mining Ltd.	307	3.271	3.314	....	....	3·314
Totals	9 828	131.311	38.868	40.811	5.631	85.310

Hamersley Iron Pty. Limited. At the two centres, Tom Price and Paraburdoo, the quarry faces are maintained at 15 metres in height. The designed pattern of drilling varies slightly with the known difference in ores

Anfo and Al-Anfo are the blasting agents used.

At both sites, primary and secondary crushing is carried out and the resultant product railed to the Port at Dampier where further treatment provides lump ore, fines and pellets for shipment.

At Tom Price, mining took place over 13 operating benches and the workings now cover an area 6 000 metres long and 2 000 metres wide.

Equipment used includes thirty-four 120 tonne trucks and eight 9 cubic metre electric and diesel-electric shovels. The crushing plant capacity is 25 million tonnes per annum.

At Paraburdoo, mining took place over 7 operating benches and covered an area of 2 000 metres by 2 700 metres. The fleet of 36 trucks includes

58636—3

thirty-one 100 tonne Darts and five 120 tonne Haulpaks which cart ore from five 9 cubic metre electric shovels.

The crushing plant capacity is 17 million tonnes per annum.

At Dampier, the pellet plant at Parker Point incorporates an ore dryer, followed by dry grinding, balling with discs and a straight grate indurating machine.

The newer facilities at East Intercourse Island can accommodate ships up to 160 000 d.w.t. and has stockpile capacity of 2 million tonnes.

Mt. Newman Mining Co. Pty. Limited. Ore from Mt. Whaleback is crushed through primary and secondary stages to minus 100 mm then railed to the Nelson Point plant at Port Hedland where tertiary crushing and screening produces —30 mm + 6 mm lumps and —6 mm fines for shipment.

At Mt. Whaleback quarrying continued with several new benches formed.

New equipment included one P & H 2800 shovel of 22 yards capacity, seven Wabco 120 tonne trucks and six Wabco 200 tonne trucks. Also added were five crawler dozers, two graders and two front end loaders.

A test winze programme was completed on the Marra Mamba ore body, and the crew shifted to a site East of Newman to sink further winzes.

At Nelson Point, a new plant parallel to the present operating plant is under construction. When completed, treatment capacity will be 40 million tonnes per annum.

The railway yard was extended and the port dredged to allow a wider turning circle.

Cliffs Robe River Iron Associates. At Pannawonica, mining is confined to the breaking of a limonitic capping on flat topped mesas. The deposits control the face heights and lend themselves to easy mining. New train load out facilities were completed to decrease haulage distance from Area 2402C which is being opened up East of the other deposits.

Five new 120 tonne Haulpaks, a P & H 2100 B.L. shovel and other equipment were added to the fleet.

The ore is railed to Cape Lambert where it is crushed and formed into pellets. Only fines and pellets are shipped. The dust conditions were improved during the year with a start on the cleaning up of the area and the addition of fogging sprays.

At West Angelas a winze programme for exploration purposes was in progress.

Goldsworthy Mining Limited.

The ore from the deposits at Goldsworthy and Shay Gap passes through primary crushing before being railed to Finucane Island for further treatment.

At Goldsworthy mining reached the —160 metre level where width was restricted.

A programme to remove waste on the hangingwall side from the surface to the —160 bench is well in progress. This will allow restricted mining and further depth in the quarry will depend on waste to ore ratio.

At Shay Gap and nearby Sunrise Hill, the deposits are mainly above plain level, but the ore requires blending with the Goldsworthy ore to attain an average grade. Five separate deposits are mined in this area.

At Finucane Island, dust conditions were greatly improved through general clean up and the greater use of sprays.

Dampier Mining Limited.

Koolan Island:

The ore body is 1 670 metres in length and 40 metres wide. Mining is continuing on the 98 metre level.

The ore is a high grade and averages 67.21%.

2.431 million tonnes of ore and 3.892 million tonnes of waste were broken during the year.

58 134 metres of rotary blasthole drilling was necessary and 1 281.5 tonnes of explosives were used in primary blasting plus 9.5 tonnes in secondary blasting.

Cockatoo Island:

This ore body is down to the 12 metre level and as the ore is situated on the sea wall further quarrying is restricted. To test the ore at depth and to determine if underground mining is feasible, a decline was commenced from the 15.2 metre floor. It was advanced 104 metres, using diesel equipment. Some difficult ground was met and roof and wall support was necessary.

In the quarry, 839 790 tonnes of high grade ore (68.01%) was broken.

SALT

Total salt harvested was reported as 4 055 155 tonnes of which 3 838 773 tonnes was shipped.

Texada Mines Pty. Ltd.—Lake McLeod. 1 540 300 tonnes of salt was harvested, of which 1 118 800 tonnes was shipped.

A further 27 188 tonnes of mixed salt and 9 165 tonnes of Langbienite was produced and stockpiled.

The Langbienite plant was closed down and a reorganization of the company in August reduced the men employed from 230 down to 157.

Salt ponds totalled 668 hectares. Concentration ponds of 339 hectares and mixed salt ponds of 67 hectares were in use to August, and bittern ponds of 395 hectares were used from September onwards.

Dampier Salt Limited—Dampier. 1 315 665 tonnes of salt was harvested and 1 474 097 tonnes shipped from Mistaken Island. 145 men were employed. Ponds covered an area of 10 180 hectares.

Leslie Salt Co.—Port Hedland. 939 641 tonnes of salt was harvested and 974 343 tonnes shipped.

24 ponds covered an area of 7 233 hectares.

52 men were employed.

A radial stacker with a capacity of 850 tonnes per hour became operational early in the year.

Shark Bay Salt. About 60 men at Useless Loop were employed on salt havesting mainly for local markets. Production figures were not available for publication.

GOLD

Mulga Mines Pty. Limited at Blue Spec carried out considerable underground development and surface construction work preparatory to commencing operations in 1976.

The workforce built up to 48 men.

The shaft was completely equipped and level development commenced on the No. 4 level.

Workshop areas were formed and a 1 in 7 decline commenced and advanced a distance of 200 metres.

Diesel equipment was used for decline development.

At the Comet Mine near Marble Bar 4 men were employed and 16.5 km of fine gold from the retreatment of 3 030 tonnes of residues was reported.

The plant was almost fully reconditioned and underground sampling carried out.

At Telfer, Newmont Pty. Ltd. commenced construction and preparatory work for mining which is expected to commence about the middle of 1976.

A number of prospectors were at various centres.

TIN

Western Queen at Collegong employed 36 men and Pilbara Concentrates employed 12 men, but no production figures were available.

A number of small operators were in the field.

BARITE

Dresser Industries employed 8 men at the North Pole mine. Two men in the quarry broke and selected the ore which was then dry crushed and screened.

The company hope for improved sales opportunities with the brighter outlook for oil drilling on the North West Shelf.

MARBLE

Kinetic Mining transferred men from Wyloo and concentrated on the white marble at Nanutarra. Work ceased in October when the company encountered financial difficulties.

MANGANESE

Bell Brothers reported the shipment of manganese of 45% grade from their stockpile.

PERTH INSPECTORATE

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

SOUTH WEST MINERAL FIELD

ALUMINA:

Alcoa of Australia (W.A.) Ltd. Alcoa remains the sole producer of alumina in the State with a production of 2 230 255 tonnes. Production from the Pinjarra refinery continues to increase and for the first time exceeded that of the Kwinana refinery.

In conjunction with the expansion of the Pinjarra refinery, the Del Park minesite increased production of bauxite by 749 000 tonnes to 3 816 000 tonnes. As the refinery continues to expand the increased bauxite requirements will come from the minesite known as "Huntley". Huntley is located some 6.5 km east of the original Del Park minesite and will come on stream during the first half of 1976.

A second WESERHUTTE walking crusher has been constructed along with workshops, offices and other facilities to make the Huntley area an independent operation. A second overland conveyor is under construction between the minesite and the refinery where storage facilities have been expanded. By mid 1976 alumina from the Pinjarra refinery will be shipped through Bunbury. Storage and shiploading facilities have been under construction throughout the year.

The rehabilitation programme was stepped up during the year. Mining pits totalling 130 ha were contoured, covered with topsoil, deeply ripped, fertilised and planted with trees. The company's average work force increased by 206 persons to 2 172 which total is made up of 365 personnel on bauxite mining and 1 807 on alumina extraction.

BUILDING STONE:

Granite-Diorite. The production of crushed granite and diorite is a steadily growing division of the mining industry, and directly employed 195 personnel on quarry sites throughout the year. By far the largest user of crushed granite is the concrete industry, while the bulk of the diorite is used for road construction.

Avon Quarries—Northam. Because of the deteriorating quality of the rock and the proximity to the Northam-Spencers Brook Road, the owners decided to close down the quarry and commence mining on a granite outcrop some 300 km to the east.

The rock in the new quarry is of good quality and the fly rock problem has been eliminated.

Bell Bros Quarries Pty Ltd—Maddington. Dust emission has been dramatically reduced throughout the company's crushing and screening plant since the introduction of washing screens and heavy water sprays.

Reconstruction of the storage bins continued throughout the year and modifications were made to the main crusher, including the replacement of the vibrating feeder with a pan feeder.

Pioneer Concrete (W.A.) Pty Ltd—Quarry Division. Operations at Herne Hill continued throughout the year, whereas the Walkaway and Carnamah quarries operated for a few months only.

Quarry Industries Ltd—Walkaway. This quarry operated throughout the year producing ballast for the new Dongara-Eneabba railway.

The Readymix Group (W.A.). Readymix operated quarries at Gosnells and Bunbury on a full time basis throughout the year while the Merredin quarry operated for six months during which time large stock piles were accumulated.

At Gosnells, Readymix increased capacity by replacing some of the secondary crushing and screening equipment with larger units. Five new, off highway, quarry trucks were also put into service during the year.

DECORATIVE BUILDING STONE

Building stone of the decorative variety such as crushed quartz and Toodyay stone continued to be mined in small quantities only.

CLAYS

The Midland Brick Co. Pty. Ltd. remains the largest single producer of clay with a production of 150 000 tonnes from the Bullsbrook District. Other producers accounted for a further 139 621 tonnes.

DIATOMITE

B.H.P. Mallina Mining. Broken Hill Pty Ltd continued production tests at its Diatomite Pilot Plant, situated on the outskirts of Dongara, until the end of October.

Feed for the plant was obtained from leases approximately 20 km to the south east of Dongara.

After assessment of the results and completion of feasibility studied, B.H.P. decided that an economic operation was not possible and withdrew from the venture. The pilot plant then became the property of Mallina under the terms of the agreement.

FELSPAR

Only minor tonneages of felspar were produced in the South West Mineral Field. Parcels of 172 tonnes and 186 tonnes were recovered from small operations at Mukinbudin and Balingup respectively.

GYPSUM

Gypsum Industries of Australia Pty Ltd. This company produced 20 492 tonnes of gypsum from around the perimeter of Lake Cowcowing.

ILMENITE, LEUCOXENE, MONAZITE, RUTILE, XENOTIME AND ZIRCON

Producers in the Capel Field experienced a state of recession during the second half of the year. Sections of some operations were shut down completely, while the remainder were all operating on restricted production schedules. These cuts resulted in three companies reducing their work force by a combined total of 127 personnel.

Cable Sands Pty. Ltd. During the year the company mined and treated 1 728 000 tonnes of sand for the production of 186 686 tonnes of minerals. Only 102 741 tonnes of minerals were shipped, the surplus being stockpiled.

Western Mineral Sands Pty. Ltd. During the year the company switched from dry mining to dredging. A floating wet plant was also put into operation. Sands mined and treated, totalled 1 397 000 tonnes. From the concentrates treated, 219 700 tonnes of ilmenite and 58 957 tonnes of mineral bearing residues were produced. The latter being sold to Westralian Sands for further processing. Ilmenite shipments were down by 43 000 tonnes to 151 929 tonnes.

Western Titanium Ltd. Western Titanium produced 261 802 tonnes of minerals from the treatment of 1 559 000 tonnes of sands.

The production of upgraded ilmenite (90%+, TiO_2) increased from 12 068 tonnes in 1974 to 41 164 tonnes in 1975 as a result of the first full year of operation of the new 30 000 t.p.y. plant.

Westralian Sands Ltd. This company mined and treated 1 733 000 tonnes of sands for the production of 199 894 tones of minerals.

A multi-million dollar expansion programme was completed during the year. This included new screening facilities at Yoganup Extended, a new mining operation at Busselton and major extensions and alterations to the Capel dry plant. By the end of the year the Yoganup and Yoganup Extended mine sites had been closed down. The Busselton operation, which is on leases owned by Mid East Minerals, continued mining, but all concentrates were being stockpiled on site. The dry plant was kept operating on a reduced scale treating the residues from Western Mineral Sands, together with old concentrate and residue stockpiles which have accumulated over the years.

The Eneabba-Jurien Field is expanding rapidly with three mines now in production and a fourth under construction.

Allied Eneabba Pty. Ltd. The mine and wet plant at Eneabba were commissioned during August with the dry plant at Narngulu following a few weeks later.

During the remaining months, the company treated 720 000 tonnes of sands for the production of 31 400 tonnes of minerals. Allied have established a central wet plant to which the sands are delivered by self loading scrapers at an average rate of 800 tonnes per hour.

The treatment plant, which utilizes Reichert Cones for heavy mineral concentration, incorporates a 100 metre diameter thickener to ensure maximum water recovery. Even so, 5 bores produce 23 000 000 litres of water per day for use in the plant.

The dry separation plant at Narngulu is designed to produce ilmenite, rutile, zircon and monazite at a combined rate of 420 000 tonnes/annum.

Jennings Mining Ltd. The end of 1975 saw the first full year of production by Jennings Mining in which they mined and treated 4 160 000 tonnes of ore for a production of 229 000 tonnes of heavy mineral concentrates. The proposed change over in the water circuit from open settling dams to thickeners was accomplished, but not without major mechanical difficulties which resulted in considerable loss of production.

At Narngulu, determined efforts by staff resulted in production exceeding design capacity in the later months of the year. In all, 251 000 tonnes of minerals were produced, of which 117 646 tonnes were shipped.

W.M.C. Mineral Sands Operation. Commissioning of the mine and primary wet plant was commenced in early March with the dry plant following about a month later.

Mining is achieved by tracked dozers pushing the sands within easy reach of a bucket wheel excavator which feeds them into an in pit screening and pumping plant.

This ore body is overlain by barren sands and limestone varying in thickness from 4-30 metres. The overburden is pre-stripped by either scrapers or a quarry shovel and trucks. The transportable primary wet plant, which utilizes trays for the rougher stage and Reichert Cones thereafter, produces a 60% concentrate which is transported by road to a second stage wet plant for further concentration.

The bulk of the ilmenite is removed from the concentrate by wet magnetic separators and sent to storage dams. The high cost of transportation prohibits the sale of ilmenite at current prices.

Ore mined amounted to 1 536 000 tonnes, while 2 353 000 tonnes of overburden was stripped and dumped in nearby valleys. Of the ore mined, 1 424 000 tonnes was processed for a recovery of 4 620 tonnes of rutile and 965 tonnes of zircon.

Western Titanium Ltd. Western Titanium plan to commence mining and extraction of mineral sands from their Eneabba leases during 1976. By the end of the year construction was well in hand. The dry plant is being built on site. Housing is being built at the coastal township of Leeman.

IRON

Australian Iron and Steel Limited. Pig iron production increased by 11.1% to 717 819 tonnes. This tonneage was achieved in ten months as the blast furnace was shut down during October and November for a complete reline; its first since being commissioned in 1968.

Wundowie Iron and Steel. Pig iron production increased by 18% to 62 978 tonnes and was obtained from the treatment of 99 225 tonnes of ore railed from Koolyanobbing.

A series of experiments were conducted throughout the year with the aim of increasing production from the existing furnaces.

LIMESTONE

A large number of limestone quarries exist in and around the Metropolitan area, but most work on an intermittent basis only. Because of the lack of funds available for construction and road building purposes most producers were operating well below capacity.

NICKEL

Western Mining Corporation Limited. Western Mining Corporation continued operations at the Kwinana refinery throughout the year where production of metallic nickel was increased by 10.6% to 22 607 tonnes. By-products produced were:—copper sulphide, 2 901 tonnes; mixed sulphides, 554 tonnes; ammonium sulphate, 137 941 tonnes.

A complete ammonia plant, purchased in Queensland, was reconstructed on the refinery site during 1975.

SAND

Sand for use in the manufacture of glass, concrete products, bricks, bitumen products and for general filling, continues to be mined in large quantities in the South West Mineral Field and particularly the Metropolitan and surrounding areas.

TALC

Three Springs Talc Pty Ltd. Unfortunately the major increase in sales of the previous year was not fully sustained during 1975 when only 39 604 tonnes of a production of 52 490 tonnes were railed, representing a 30% decrease on the 1974 figures.

To permit safe mining of high grade talc below the bottom bench, the company commenced the development of a series of new benches along the high eastern wall of the pit. This resulted in 103 000 tonnes of waste being mined in addition to a production of 54 000 tonnes of ore.

GREENBUSHES MINERAL FIELD

TIN-TANTALITE CONCENTRATES

Major decisions and agreements at both company and Government level were made during 1975 which will dramatically effect the viability of Tin-Tantalite mining in the Greenbushes Mineral Field.

On August 22nd, 1975 Vultan Minerals Limited ceased operations as the result of an agreement with Greenbushes Tin N.L. whereby Greenbushes Tin would carry out mining operations on Vultan leases for a period of three years.

An agreement was made between the Western Australian Government and Greenbushes Tin N.L. to divert the South West Highway to the east of the townsite and to allow mining of that portion of the road reserve which would become redundant.

The negotiations involved several Government Departments and resulted in a set of rehabilitation conditions being established for all Greenbushes Tin and Vultan Minerals leases, along with a firm rehabilitation programme involving a minimum expenditure of $50 000 per annum.

The highway deviation is expected to be completed during the first quarter of 1976, following which mining pits will expand in size and depth in an orderly and systematic manner.

Greenbushes Tin N.L. Mine production totalled 1 097 000 cubic metres of which 1 094 000 cubic metres were treated for a recovery of 558 tonnes of tin concentrate and 97 tonnes of tantalite concentrate.

In the later part of the year the company commenced a major rehabilitation programme, and by the end of the year considerable improvements were already noticeable in some areas.

Vultan Minerals Limited. During their eight months of operation, Vultan mined and treated 135 350 tonnes of ore and 90 000 tonnes of tailings for a recovery of 57 tonnes of tin concentrates and 10 tonnes of tantalite concentrates.

On cessation of operation the plant was shut down. All ore now mined on Vultan leases by Greenbushes Tin is being treated in the Greenbushes plant.

Mineral Lease 717 (E. Jones). The only other miner in the Greenbushes Mineral Field is Mr. E. Jones who operates a small tin-tantalite pit on this lease. A small plant has been constructed on the site and two tonnes of concentrates were recovered.

NORTHAMPTON MINERAL FIELD

LEAD

As in the previous year, no sales of lead concentrates have been reported to this Department. Prospectors have continued to hold their concentrates because of the low prices offered.

Crushings from McGuires Lead Mine yielded 24 tonnes of concentrates from 211 tonnes of ore; 10 tonnes were recovered from 98 tonnes of ore from the Protheroe, while a 26 tonne parcel from the Lucky Lou yielded 10 tonnes of concentrates.

The Mendip Mine at Mt. Erin operated for a few months, but no ore was taken to the battery. A north drive was advanced approximately eight metres from the shaft at the thirty-five metre horizon and then leading stoped.

YALGOO GOLDFIELD

The Yalgoo Goldfield received considerable attention from major exploration groups during 1975 and considerable areas of land were pegged.

The Electrolytic Zinc Company of Australasia Ltd continued their diamond drilling exploration programme at Golden Grove. At Mt. Mulgine, Minefields Exploration N.L. commenced an exploration shaft to obtain bulk samples and check drilling results on a Wolfram deposit.

GOLD

The Ark Gold Mine at Paynes Find continued to be a rich producer with the recovery of 19.607 kg of gold from a parcel of 410 tonnes. The shaft was sunk a further 16.6 metres and the ore shoot benched to that depth.

MURCHISON GOLDFIELD

1975 saw a further deterioration in the ability of the Murchison Goldfield to retain its recognition as a Gold producing district.

GOLD

Hill 50 Gold Mine N.L. An average of 93 personnel remained on the payroll throughout the year, however, no gold was produced from this once rich mine.

Underground mine development was continued on a restricted basis with 5 metres of driving, 50 metres of crosscut and 51 metres of rising being achieved in the Main shaft workings, and on the Morning Star mine there were 15 metres of shaft sinking, 158 metres of driving, 4 metres of crosscut and 40 metres of rising. 881 metres of diamond drilling was undertaken at the Morning Star mine mainly to delineate the ore body on the new No. 10 level. Overhaul and modification to the surface plant was continued.

Sundry Producers. A number of small producers operated throughout the field. The largest being the Haveluck Gold Mine at Meekatharra which crushed 2 829 tonnes of ore for a return of 5.303 kg of fine gold.

LOWER PEAK HILL GOLDFIELD

The only continuous mining operation in this field below the 24° S latitude is the talc mine operated by Westside Mines N.L. A total of 0.888 kg of fine gold was recovered from three small prospects.

TALC

Westside Mines N.L. Mining at Mt. Seabrook produced 47 600 tonnes of talc from the open cut of which 19 866 tonnes were selected for treatment. This resulted in the recovery of 9 752 tonnes of saleable talc.

COAL MINING

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

There was a very significant increase in output from the Collie Coalfield during 1975. For the first time in the history of the field over two million tonnes of coal were produced in one year. The new record output of 2 113 982 tonnes produced from the one underground and two open cut collieries, and the unprecedented increase in production of 667 934 tonnes compared with last year's output of 1 446 048 tonnes, reflect the resurgence of activity and rapid development which is taking place in the industry.

Practically three quarters (73.92 per cent) of the coal was produced from open cuts and slightly more than one quarter (26.08 per cent) from the underground mine.

The total value of the coal produced during 1975 was $15 073 671, an increase of $5 928 689 compared with the 1974 value of $9 144 182.

Western Collieries Ltd. Western No. 2 Mine.

This colliery produced an output of 551 307 tonnes of coal, an increase of 60 416 tonnes over the previous year's output of 490 891 tonnes.

The extended use of diesel engined equipment for materials distribution, man riding and coal loading improved the flexibility and efficiency of operations.

Units in use at the end of the year were thirteen Melroe Bobcat Loaders, four BHB Dirt Devil Loaders, one Eimco 911 LHD Unit, five Holder Tractors and two Wagner PT 14 Supplies and Personnel Carriers.

The main ventilation air flows were adequate and satisfactory throughout the mine. The increased use of diesel equipment on the coal faces was accompanied by the extended application of brattice ventilation to replace the previous widespread use of auxiliary fans.

Methane was not detected in any of the numerous tests made for this gas throughout the mine.

Mining continued under normally satisfactory conditions in the widespread areas of the mine. Work was recommenced in No. 2 B West District where workings to be opened out will provide replacements for No. 1 West District where only a limited amount of first working extraction remained to be completed.

Very good conditions prevailed in the predrained areas in Nos. 4 West, 6 West and 6 East Districts, but some difficulties were experienced in the 6 West "D" Panels Dips Area. Conditions were generally normal in the Nos. 3 B West, 4 B East and Cullen Headings areas.

The depths of cover in relation to the surface route of the South Branch of the Collie River is a limiting factor in the amount of pillar splitting which may be undertaken in some areas.

Western Collieries Ltd. Western No. 5 Open Cut Mine.

The extent of the increased activity at this colliery is evident from the fact that the year's coal output of 589 465 tonnes was an increase of 376 946 tonnes over the previous year's output of 212 519 tonnes. The output achieved during 1975 amounted to 44 per cent of the total production of 1 342 180 tonnes since the mine commenced in March, 1970.

At the Wyvern Seam Excavations where coal production commenced on the 15th October, 1974, on No. 1 Bay, mining continued satisfactorily with the coal from No. 1 Bay being completely mined out and overburden from the North end of No. 2 Bay backfilled into the void. Following winning of the coal from the Northern portion of No. 2 Bay, overburden from the South of the area was being backfilled and good progress was being made towards exposure of the remaining coal.

By the end of April, bush clearing was completed in the No. 3 Bay area. Thereafter significant progress was made on overburden removal and on coal winning which was nearing completion.

Very good progress was made on the removal of overburden and mining of coal from the Central-Northern Areas of the Cardiff Seam Excavation and towards the end of the year, coal was being exposed and won over an adjacent area on the Neath Seam.

The high wall over the Cardiff Seam was advanced over a portion of the original position of the river bed to the East of the temporary diversion channel.

Towards the end of the year, a portion of the South Branch of the river was being permanently diverted to the East in relation to new excavations planned over relatively shallow coal in the Cardiff and Neath Seams on the West bank of the river.

Ancillary works were carried out on a large scale and there were extensions to the Bath House and Workshops.

The Griffin Coal Mining Company Limited—Muja Open Cut

This colliery was, again, by far the largest single coal producer. The output of 973 210 tonnes was 230 572 tonnes more than the previous year's output of 742 638 tonnes.

The workings are extensive and widespread at this mine where the Hebe Seam is exposed on a coal face line approximately 1.8 km in length. The entire current workings, including the backfill area at the South West of the mine and the overburden excavations at the North Extension, extend over a distance of approximately 2.6 km.

There is a major curve along the general line of the excavations where the East Extension area workings along the long axis of the basin adjoin the excavations which are being advanced across the short axis.

Beyond the sub crop line of the Hebe Seam, surface overburden dumps extend intermittently over a distance of approx 3.6 km from the South West to the North East extremities while, along the surface on the West side of the basin, there are another 1.3 km of overburden dumps.

Overburden removal and coal winning related to extremely widespread areas and different levels of excavation on Blocks Nos. 5, 6 and 7, East Section Panel No. 6, Connection Panel and the East Section North Extension and North Extension Areas.

For the first time, a portion of the Ate or top seam in the series of mine coal seams at the mine was exposed and won. Coal was won from the Ate, Diana, Eos, Flora, Galatea and Hebe Seams. Some Bellona and Iona Seam coal was being exposed and work was proceeding towards exposure of some Ceres Seam coal.

The Bucyrus Eric 200 W Walking Dragline was used to safely remove overburden from a disturbed and highly inclined area to expose Hebe Seam Coal over old underground mine workings.

General.

There was 485 reported accidents of which 382 were minor and 103 were classified as serious where an employee was absent from work for fifteen days or more. These figures must be viewed against the fact that there was an increase of 146 from 708 to 854 persons employed in the industry during the year.

The Rehabilitation of open cut coal mines and amendments to the Coal Mines Regulation Act and Regulations were matters discussed and conferred upon frequently during the year. Some progress was made in these areas.

Since coal mining commenced at Collie in 1898, 48 080 524 tonnes of coal have been produced for a total value of $174 922 525. Rapid expansion is now anticipated to provide for the industry to make an increasingly important contribution to the State's energy requirements and economy.

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, 1975.

Mining Law Examinations

Two examinations were held in 1975. The normally scheduled examination was held on April 7, 1975 and a special examination (on demand) was held in conjunction with the Underground Supervisor's examination on September 8, 1975. Details of each examination are as follows:—

April 7, 1975—

Entries	13
Admitted	11 (Subsequently 13)
Pass	11

Entries lodged by R. A. Dennis and A. D. Owens were initially rejected on the grounds of their academic standard. These were subsequently admitted in view of further investigations made regarding their Diploma in Mining from the S.A.I.T.

The names of the successful candidates were:—

Blackburn, J. L.
Davis, C. W.
Dennis, R. A.
Devereux, R. B.
Pooley, R. H.
Grun, W.
Ireland, S. D.
Micke, B. P.
Owens, A. D.
Choy Show, W. F.
Wilson, D. W.

September 8, 1975—

Entries	6
Admitted	6
Pass	3

The names of the successful candidates were:—

Boving, N. O.
Johnson, R. J.
Sauer, G. J.

Underground Supervisor's Examinations

In addition to the general examination held on September 8, 1975, a "Special Supplementary" examination was held on May 13, 1975. This examination was restricted to those persons who had gained a partial pass (either in Mining only or Mining Law only) at the 1974 September general examination. This examination was scheduled at the request of the Chamber of Mines representative, Mr R. Hooker, in view of the difficulty being experienced by the industry in obtaining the services of reliable supervisors.

There were nine (9) applications received and accepted and all candidates were successful. They were:—

Bowe, G. H.
Christian, G. A.
Emmerson, P. J.
Kroczek, N. K. P.
Spoljarich, A.
Casey, I. R.
Darlington, K.
Irvine, J. J.
Perry, W. A.

The general examination was held on September 8, 1975 and attracted entries from the following centres:—

Kalgoorlie	39
Laverton	4
Mt. Magnet	1
Norseman	5

The following number of applications were subsequently accepted:—

Kalgoorlie	35
Laverton	4
Mt. Magnet	1
Norseman	1

Results were as follows:—

Passed	26
Failed	15

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

Kalgoorlie:

Belkner, G.
Christinger, R. A.
Cullen, C. C.
Hall, T. D.
Hall, W. J.
Hardingham, E. C.
Hudson, A.
Johansen, J.
Lethlean, K. L.
Marrinan, T. P.
Martin, D. L.
Marzola, S.
Mileham, E.
Moore, E. A.
Pullin, B. J.
Rixson, E. C.
Rodgers, F. M.
Taaffe, R. S.
Watts, J. W. T.
Williams, K. A.

Mt. Magnet:

East, R. F. G. (Restricted to Hill 50 G.M. operations at Mt. Magnet)

Norseman:

Malcolm, C. A.

Laverton:

Grice, A. W.
Stretton, B.
Watts, T. C.
Logue, W. J.

Mine Manager's Certificates

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

Jannson, B. R. M.
Wregg, C. B.
Palmer, A. J.
Durrant, P. S.
Wilson, W. D.
Grun, W.
Johnson, D. C.
Johnson, R. J.

General

There were several changes of note in the membership of the Board during 1975. The first occurred on April 8, 1975 when the Chamber of Mines advised that they were replacing their representative, Mr. H. B. Newman with a younger man Mr. N. R. Hooker. This advice was tabled at a special meeting of the Board held on above date. Mr. Newman had served the Board extremely well in his twenty odd years as a member. Both the Chairman, Mr. Wilson and the School representative, Dr. Pegler expressed the wish that their own appreciation and that of the Board should be placed on record of the sterling service given by Mr. Newman.

In July, 1975, the Principal of the School of Mines, Dr. Pegler was transferred to W.A.I.T. Bentley, and Mr. A. Evans (Lecturer in Mining) was asked to represent the School pending the arrival of the new Principal and Dean of the School of Mining and Mineral Technology, Dr. I. O. Jones.

Five meetings (including the special meeting on April 8, 1975) were held during the year and the Board visited Kalgoorlie and Windarra to examine candidates orally for the Underground Supervisor's examinations.

DRILLING OPERATIONS

D. A. MacPherson—Drilling Engineer

During 1975, the Drilling Section was responsible for the drilling of 13 367 metres in 685 bores and the development and testing of 20 bores. The drilling of 12 983 metres and the testing of all 20 bores was carried out by Departmental employees and equipment. The remaining 384 metres in 8 bores was carried out by contract. This year the total metreage controlled by the Drilling Section is the second highest on record. In 1974, 13 933 metres were controlled by the Section. The metreage drilled by Departmental employees and equipment in 1975 is the highest on record.

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

Comments on Staff and Plant matters are also given.

MOORA LINE

This job forms part of the state-wide ground water investigation conducted by the Geological Survey of Western Australia, and is financed by the Department of Mines. The Moora Line commences at Moora and runs west to within three miles of the coast. The job is required to provide information on stratigraphy and ground water conditions to a projected depth of 762 metres at selected sites on the line. This is generally effected by drilling one bore to target depth to provide strata samples, geophysical bore logs and side wall cores. This bore is then screened at a selected depth and air lifted to provide accurate water samples and water level measurements for the aquifer at the selected depth. Subsequent bores are drilled at the same site to provide water quality and water level measurements for aquifers at different depths. The bores are left in suitable condition for continuous water level measurements.

At the start of the year all drilling at site one had been completed, during the year construction work was completed at site 2. At site 3 the deep bore had been drilled to 592 metres where the drill string became stuck in the hole. Two shallower bores were completed at this site and work on the job was then suspended until the following year.

CANNING BASIN

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

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

The work was re-commenced in 1975 at the cessation of the wet season. The work proceeded smoothly except for transport difficulties caused by the sandy terrain and drilling difficulties on some sites, due to the presence of pressure water in the aquifers. The current drilling programme was completed during 1975 and development and testing of the bores will be carried out in 1976.

JOONDALUP

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

This is being done by drilling one bore to target depth to provide strata samples, geophysical bore logs and bottom hole core. This bore is then screened at a selected depth, developed and tested. Prior to testing, observation bores to observe movement in water levels are drilled near some of the pumping bores. One bore at each site is left in suitable condition for continuous water level measurement.

It was re-commenced in 1975 and carried on by contract. All of the drilling work was completed except for two special requirement bores which will be done in 1976. Bores constructed during 1975 were developed and tested.

PORT HEDLAND WATER SUPPLY—DEGREY RIVER

This is an investigation into obtaining water for Port Hedland from ground water sources additional to those already being utilised. The work is carried out for and financed by the Public Works Department.

The job is located on the alluvium of the DeGrey River and is a continuation of work done there previously.

During 1975, four bores drilled during 1974 were developed and tested and an additional eight bores were drilled and screened at selected sites and two of these were developed and tested. Development and testing of the remaining six bores was prevented by cyclone and these bores will be completed during 1976 by the Public Works Department.

No further involvement in this job is envisaged at present.

MANJIMUP WOOD CHIP INDUSTRY

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

The work consists of drilling a bore by continuous coring hollow auger methods, at each of a number of selected sites and completing the bores as water sampling and water level measurement points for long term recording of ground water variations in the area.

The work which was commenced in 1974 continued smoothly to completion in 1975.

It is expected that further work will be carried out on a new programme on this job in 1976.

MILL STREAM

This is a ground water investigation carried out for and financed by the Department of Public Works, to obtain further information on the ground water supplies in the Mill Stream area. The work was done up stream of Mill Stream Station on the Fortescue River flats.

The drilling was required to provide information on stratigraphy and ground water conditions at a number of sites.

The work consisted of drilling at each site, one bore to target depth to provide strata samples and geophysical bore logs. The bore was then cased and screened and tested by air lifting. The bore was left in suitable condition for continuous water level measurement.

The 1975 programme of work on this job was carried through to completion without undue difficulties. It is anticipated that investigation of the Fortescue River flats will be continued in 1976 under the job name Fortescue River Valley Investigations.

WEELAMURRA CREEK

This is a ground water investigation carried out for and financed by the Department of Public Works, to obtain information on the ground water supplies at the junction of Weelamurra Creek and Fortescue River.

The drilling was required to provide information on stratigraphy, groundwater conditions and yield of bores at a number of sites.

The work consisted of drilling at each site a bore to target depth to provide strata samples and geophysical bore logs. The bore was then cased and screened and where there was a reasonable supply, tested by pumping. The bore was left in suitable condition for continuous water level measurement.

The job was commenced and completed in 1975. Some difficulty was experienced initially with loose gravel in the upper portion of the bores. Suitable bores were developed and tested.

It is expected that further investigation will be conducted in this area in 1976 as part of the Fortescue Valley investigation.

FORTESCUE VALLEY

This job forms part of the state-wide ground water investigation conducted by the Geological Survey of Western Australia and is financed by the Department of Mines. The job is required to provide information on stratigraphy and ground water conditions over a considerable portion of the Fortescue Valley.

During 1975, 460 shot holes were drilled for use in seismic surveys being carried out by the Geological Survey of Western Australia.

It is expected that further work will be carried out on this job in 1976 involving drilling of bores for stratigraphic and ground water information.

BUNBURY JOB

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

The work was commenced late in 1975 and proceeded smoothly to the end of the year. It is expected that work will continue during 1976.

STAFF

On 14th April, 1975 Mr. M. Owens replaced Mr. I. Cochran as a temporary General Assistant G.V11.1.

On 14th August, 1975 Mr. D. Thomas joined the staff as a temporary General Assistant G.V11.1. in the position of Storeman-Field Units.

PLANT

During 1975, the new rotary drilling rig and mud pump were received and placed in service. These replace the Mayhew Drilling rig which has been derated and placed on light work because of deterioration due to a long period of hard use.

The Ruston Bucyrus Cable Tool Drilling rig was sold during the year and an E500 Mindrill Diamond Drilling rig was also sold. These items had reached the end of their economic life.

Various other items of plant which had reached the end of their economic life were replaced.

TABLE SHOWING WORK CARRIED OUT DURING YEAR ENDED 31/12/75

Place	Purpose	Type of Work	Done By	No. of Bores	Metreage
Moora Line	Groundwater Investigation	Rotary Drilling	Dept. of Mines	8	2 817
	" "	Bore Testing		1	....
Canning Basin	Groundwater Investigation	Rotary Drilling	Dept. of Mines	22	3 739
Joondalup	Groundwater Investigation	Cable Tool Drilling	Contractors	8	384
		Bore Testing	Dept. of Mines	9	....
Port Hedland Water Supply	Groundwater Investigation	Rotary Drilling	Dept. of Mines	8	657
		Bore Testing	Dept. of Mines	6	....
Manjimup Wood Chip	Investigation of Effects of Logging on Groundwater	Rotary (Auger) Drilling	Dept. of Mines	138	2 088
Mill Stream	Groundwater Investigation	Rotary Drilling	Dept. of Mines	11	498
Weelamurra	Groundwater Investigation	Rotary Drilling	Dept. of Mines	8	558
		Bore Testing	Dept. of Mines	4	....
Fortescue Valley	Groundwater Investigation	Seismic Shot-hole Drilling	Dept. of Mines	461	1 420
Bunbury	Groundwater Investigation	Rotary Drilling	Dept. of Mines	21	1 206
			Totals—		
			Drilling	685	13 367
			Testing	20	

DIVISION III

Report of the Superintendent of State Batteries—1975

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, 1975.

Crushing Gold Ores

One 20 head, six 10 head, and eight 5 head mills crushed 54 003.6 tonnes of ore made up of 370 separate parcels, an average of 145.9 tonnes per parcel. The bullion recovered amounted to 364.193 kilograms, estimated to contain 308.647 kilograms of fine gold, equal to 5.71 grams per tonne of ore.

The average value after amalgamation but before cyaniding was 2.20 grams per tonne, giving an average value of ore received of 7.91 grams per tonne, compared with 7.46 grams per tonne for 1974.

Forty five tonnes of scheelite ore were also crushed at plants that crush mainly gold ore. The cost of crushing the 54 048.6 tonnes was $20.19 per tonne. In 1974 46 317.8 tonnes were crushed at the gold plants, for a cost of $16.95 per tonne.

Cyaniding

Eight plants treated 11 163 tonnes of tailings from amalgamation for a production of 29.775 kilograms of fine gold. The average content was 4.38 grams per tonne before cyanidation, while the residue after treatment was 1.50 grams per tonne giving a theoretical recovery of 65.8%. The actual extraction was 60.8%. The low actual recovery was caused by loss of gold solution due to leaking vats at Kalgoorlie, and initial difficulties with operations at Menzies and Sandstone. The cost of cyaniding was $13.70 per tonne, lower than the previous year when 8 319 tonnes were treated at a cost of $14.12 per tonne.

Silver recovered by the cyaniding of gold tailings was valued at $495.62.

TREATMENT OF ORES OTHER THAN GOLD

Lead Ores

During the year the Northampton State Battery crushed 335 tonnes of lead ore with an average content of 10.99% lead and 4.96% zinc. There were 4 separate parcels giving an average of 83.8 tonnes per parcel.

A total of 44.1 tonnes of concentrates were recovered. These averaged 71.1% lead and 6.7% zinc, giving an estimated content of 31.4 tonnes of lead and 3.0 tonnes of zinc. Tailings discarded amounted to 290.9 tonnes, having an average content of 1.87% lead and 4.69% zinc. The recovery in the concentrates was 85.2% of the lead and 17.8% of the zinc in the ore delivered to the plant.

The cost of operating the Northampton State Battery, including administration was $31 107.65 being $92.86 per tonne of ore treated. The corresponding figures for 1974 when 2 056.9 tonnes were treated were, operating cost $42 285.00 being $20.60 per tonne.

Tungsten Ores

The Norseman Battery crushed 45 tonnes of scheelite ore for a recovery of 508 kilograms of low grade concentrates.

Tin Ore

The Marble Bar Magnetic Plant treated 1.52 tonnes of alluvial tin concentrates for a recovery of 1 358 kilograms of high grade tin concentrates and 35 kilograms of high grade tantalite 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

	1975 $	Since Inception $
Gold	1 316 255	43 227 964

OTHER METALS

	1975 $	Since Inception $
Silver	496	4 985
Tin (Concentrates)	4 750	480 934
Tungsten (Concentrates)	508	41 595
Copper (ores for agricultural use)	....	11 932
Lead and Zinc (Concentrates)	6 594	1 560 634
Tantalite-Columbite (Concentrates)	198	73 459
Total other metals	$12 546	$2 173 539
Grand total	$1 328 801	$45 401 503

FINANCIAL

	Tonnes	Expenditure	Receipts	Loss
Crushing—Gold Mills	54 048.6	1 091 328	138 255	953 073
Crushing—Northampton Lead plant	335.0	31 108	1 087	30 021
Magnetic Separator Plant—Marble Bar	1.52	62	40	22
Cyaniding	11 163	152 903	36 175	116 728
Total	6 548.12	$1 275 401	$175 557	$1 099 844

The loss of $1 099 844 is an increase of $255 341 on the previous year. It does not include depreciation and interest on capital.

Capital Expenditure, $35 010.41 from General Loan Fund and the remainder from Consolidated Revenue Fund, was incurred as follows:

	$
Coolgardie (Conversion to A/C power)	7 591.67
Kalgoorlie (Purchase of Plant)	8 766.00
Leonora (installing another 5 head of stamps)	35 010.41
Meekatharra (Bin and conveyor)	13 323.96
Sandstone (Erection of camps)	204.88
	$64 896.92

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
1973	52 135·97	12 998·85	24·93
1974	48 374·70	18 954·25	39·18
1975	54 383.6	12 555.0	23.09

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

Administrative

Expenditure was $192 835, equal to $2.94 per tonne crushed and cyanided, compared with an expenditure of $142 159.91, $2.51 per tonne for 1974.

	1974	1975
	$	$
Salaries	73 546	82 549
Payroll Tax	30 878	43 026
Workers' Compensation	27 348	55 797
Travelling and Inspection	3 775	4 903
Sundries	6 613	6 560
	$142 160	$192 835

General

The 54 003.6 tonnes of gold ore crushed was the highest annual total since 1941. This increased activity was caused by the high price of gold at the beginning of the year. There was a considerable reduction in the gold price during 1975, and with rapidly rising costs, the outlook for gold production for 1976 is not bright.

The cyanide leaching of tailings in plastic lined vats at Yarri has shown that this is an economical method of treating small amounts of tailings. By employing contractors with suitable trucks and front end loaders, the initial cost for the State Batteries is very low, and the equipment can be readily moved when required. This method was continued at Yarri, and started at Marble Bar, Menzies and Sandstone during the year. Some troubles were experienced at Sandstone and Menzies, but these should be overcome with more experience by the Contractors and Battery Staff.

The Northampton Battery treated only 335 tonnes of lead ore for the year. Low lead prices, high mining costs, and high freight and smelting charges made it uneconomical to work the lead mines. Until there is a considerable increase in lead prices there is unlikely to be much lead mining activity at Northampton.

The Marble Bar magnetic plant treated 1.52 tonnes of tin concentrates.

K. M. PATERSON,
Superintendent State Batteries.

Schedule No. 1

NUMBER OF PARCELS TREATED, TONNES CRUSHED, GOLD YIELD BY AMALGAMATION AND HEAD VALUE FOR THE YEAR ENDED 31st DECEMBER, 1975

Battery	Number of Parcels Treated	Tonnes Crushed	Yield by Amalgamation		Amalgamation Tailings Content Fine Gold	Contents of Ore—Fine Gold	
			Bullion	Fine Gold		Total	Per Tonne
			kilograms	kilograms	kilograms	kilograms	grams
Boogardie	15	419.0	3.881	3.289	0.371	3.660	8.73
Coolgardie	67	7 047.7	42.673	36.165	17.290	53.455	7.58
Kalgoorlie	69	11 501.7	98.059	83.105	26.920	110.025	9.56
Lake Darlot	3	545.0	1.950	1.652	.538	2.190	4.01
Laverton	11	1 016.0	4.418	3.744	2.087	5.831	5.73
Leonora	26	5 597.0	27.848	23.601	16.195	39.796	7.11
Marble Bar	31	4 474.5	18.364	15.563	3.771	19.334	4.32
Marvel Loch	45	4 107.0	70.987	60.161	16.194	76.355	18.59
Meekatharra	19	3 122.5	21.621	18.323	6.534	24.857	7.96
Menzies	23	1 658.4	12.181	10.323	5.379	15.702	9.46
Norseman	11	2 660.3	14.153	11.994	6.518	18.512	6.95
Ora Banda	30	10 562.5	22.104	18.733	12.504	31.237	2.95
Paynes Find	12	612.0	21.079	17.864	1.987	19.851	32.43
Sandstone	2	55.0	0.932	.789	0.337	1.126	20.47
Yarri	6	625.0	3.943	3.341	1.952	5.293	8.46
	370	54 003.6	364.193	308.647	118.577	427.224	7.91

Average per Parcel .... 145·9 Tonnes
Average Yield by Amalgamation (Fine Gold) .... 5·71 Grams per Tonne
Average Value of Tailings (Fine Gold) .... 2·20 Grams per Tonne

Schedule No. 2

DETAILS OF EXTRACTION TAILINGS TREATMENT 1975

Battery	Tonnes Treated	Head Value		Tail Value		Calculated Recovery		Actual Recovery	
		Per Tonne	Total Content	Per Tonne	Total Contents				
		grams	kilograms	grams	kilograms	kilograms	%	kilograms	%
Kalgoorlie	450.0	3.0	1.350	.7	.315	1.035	76.6	.757	56.1
Leonora	4 800.0	3.8	18.180	1.4	6.597	11.582	63.7	11.398	62.7
Marble Bar	1 348.0	5.4	7.267	1.3	1.813	5.520	76.1	5.326	73.3
Marvel Loch	1 650.0	5.0	8.281	2.3	3.804	4.475	54.0	4.619	55.8
Menzies	450.0	4.6	2.079	1.6	.702	1.377	66.2	.870	41.8
Norseman	335.0	5.9	1.976	1.4	.469	1.507	76.3	1.304	66.0
Sandstone	780.0	5.4	4.236	2.1	1.673	2.563	60.5	1.431	33.8
Yarri	1 350.0	4.1	5.605	1.0	1.426	4.179	74.5	4.070	72.6
	11 163.0	4.38	48.974	1.50	16.799	32.247	65.8	29.775	60.8

Schedule No. 3

DIRECT PURCHASE OF TAILINGS YEAR ENDED 31st DECEMBER, 1975

Battery	Tonnes of Tailings Purchased	Initial Payment to $28.00 per ·0311 kg
		$
Coolgardie	272.1	648.84
Kalgoorlie	584.8	274.46
Laverton	64.8	123.33
Leonora	1 854.0	1 354.90
Marble Bar	79.2	406.96
Marvel Loch	1 143.1	2 439.81
Meekatharra	27.9	19.79
Menzies	420.3	791.32
Norseman	760.5	995.82
Ora Banda	11.2	57.57
Paynes Find	311.7	339.41
Sandstone	67.5	175.32
Yarri	81.0	373.00
	5 678.1	8 000.53

Schedule No. 4

STATEMENT OF RECEIPTS AND EXPENDITURE FOR THE YEAR ENDED 31st DECEMBER, 1975

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	419.0	9 069.29	9 243.42	2 463.26	20 775.97	49.58	1 829.29	6 993.96	29 599.22	70.64	1 249.78	2.98	....	28 349.44
Coolgardie	7 047.7	16 716.60	39 159.19	11 723.07	67 598.86	9.59	5 932.38	27 015.46	100 546.70	14.26	18 496.41	2.62	....	82 050.29
Cue	....	....	....	....	....	....	....	....	....	....	1 490.00	....	1 490.00	....
Kalgoorlie	11 501.7	24 614.60	139 002.15	23 756.05	187 372.80	16.29	14 090.30	54 629.28	256 092.38	22.26	30 528.28	2.65	....	225 564.10
Lake Darlot	545.0	3 245.58	11 916.75	2 053.43	17 215.76	31.58	2 374.80	2 044.81	21 635.37	30.70	1 397.50	2.56	....	20 237.87
Laverton	1 016.0	8 447.51	10 873.83	3 064.43	22 385.77	22.03	818.79	5 665.08	28 889.64	28.43	2 870.50	2.82	....	26 019.14
Leonora	5 597.0	22 059.13	62 865.27	10 831.00	95 755.40	17.10	6 991.98	22 580.27	125 27.65	22.39	15 554.50	2.77	....	109 773.15
Marble Bar	4 474.5	15 348.89	25 943.42	8 629.26	49 921.57	11.15	5 553.64	16 068.31	71 63.52	12.79	11 317.28	2.52	....	60 246.24
Marvel Loch	4 107.0	13 295.75	41 621.38	7 553.66	62 470.79	15.21	4 443.19	14 592.73	81 6 71	18.22	11 661.62	2.83	....	69 845.09
Meekatharra	3 122.5	12 517.51	45 343.61	6 811.46	64 672.58	20.71	3 820.63	13 241.26	81 7 4.47	26.17	6 390.67	2.04	....	75 343.80
Menzies	1 658.4	18 674.39	29 123.90	4 362.28	52 160.57	31.45	6 818.28	9 780.86	68 7 9.71	41.46	4 847.95	2.92	....	63 911.76
Norseman	2 705.3	9 746.48	30 635.47	4 736.59	45 118.54	16.67	2 342.81	9 375.43	56 8 6.78	21.01	7 202.25	2.66	....	49 634.53
Nullagine	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Ora Banda	10 562.5	16 932.34	44 771.42	12 269.10	73 972.86	7.00	2 260.73	33 134.53	109 368.12	10.35	21 134.00	2.00	....	88 234.12
Paynes Find	612.0	8 198.13	11 179.26	1 205.43	20 582.82	33.63	1 207.29	1 986.27	23 776.38	38.85	1 851.75	3.02	....	21 924.63
Peak Hill	....	....	....	....	....	....	....	....	....	....	220.00	....	220.00	....
Sandstone	55.0	1 396.95	4 035.00	645.95	6 077.90	110.50	258.33	679.15	7 015.38	127.55	170.00	3.09	....	6 845.38
Yarri	625.0	5 268.36	6 486.43	3 403.20	15 157.99	24.25	9 830.94	3 687.16	28 676.09	45.88	1 722.00	2.75	....	26 954.09
Head Office	....	....	....	....	....	....	....	....	....	....	150.54	....	150.54	....
Sub total	54 048.6	185 531.51	512 200.50	103 508.17	801 240.18	14.82	68 573.38	221 514.56	1 091 328.12	20.19	138 255.03	2.55	1 860.54	954 933.63
Marble Bar (Mag. Plant)	1.52	....	24.64	....	24.64	16.21	....	37.69	62.33	41.01	40.00	26.31	....	22.33
Northampton	335.00	17 237.16	4 965.90	2 447.11	24 650.17	73.58	4 983.20	1 474.28	31 107.65	92.86	1 087.00	3.24	....	30 020.65
Total	54 385.12	202 768.67	517 191.04	105 955.28	825 914.99	15.18	73 556.58	223 026.53	1 122 498.10	20.64	139 382.03	2.56	1 860.54	984 976.61

Operating Loss $983 116·07

Schedule No. 5

STATEMENT OF RECEIPTS AND EXPENDITURE FOR THE YEAR ENDED 31st DECEMBER, 1975

Cyaniding

Battery	Tonnes	Management and Supervision	Wages	Stores	Expenditure Total Working	Cost per Tonne	Repairs and Renewals	Sundries	Gross Expenditure	Cost per Tonne	Receipts	Receipts per Tonne	Profit	Loss
		$	$	$	$	$	$	$	$	$	$	$	$	$
Coolgardie	....	....	....	....	....	....	....	49.28	49.28	....	....	....	....	49.28
Kalgoorlie	450.0	2 402.67	5 848.36	1 384.79	9 635.82	21.41	1 024.79	1 697.20	12 357.81	27.46	3 182.83	7.07	....	9 174.98
Leonora	4 800.0	....	28 962.85	6 831.24	35 794.09	7.46	1 204.29	18 518.52	55 516.90	11.57	16 989.65	3.53	....	38 527.25
Marble Bar	1 348.0	3 439.12	4 748.02	2 321.81	10 508.95	7.79	898.40	5 321.44	16 728.79	12.41	6 407.27	4.75	....	10 321.52
Sandstone	1 650.0	651.32	9 841.19	2 421.20	12 913.71	7.82	98.21	7 094.56	20 106.48	12.18	5 699.49	3.45	....	14 406.99
Norseman	450.0	....	2 571.83	1 127.83	3 699.66	8.22	1 125.30	2 300.09	7 125.05	15.83	583.97	1.29	....	6 541.08
Menzies	335.0	....	4 007.85	1 269.85	5 277.70	15.75	375.38	2 640.44	8 293.52	24.76	395.65	1.18	....	7 897.87
Marvel Loch	780.0	433.83	6 777.54	3 109.33	10 320.70	13.23	73.57	2 315.37	12 709.64	16.29	826.46	1.05	....	11 883.18
Yarri	1 350.0	....	11 776.45	2 950.65	14 727.10	10.91	711.17	4 576.80	20 015.07	14.83	2 089.87	1.54	....	17 925.20
Total	11 163.0	6 926.94	74 534.09	21 416.70	102 877.73	9.22	5 511.11	44 513.70	152 902.54	13.70	36 175.19	3.24	....	116 727.35
								Interest Paid to Treasury			4 320·00			4 320·00
									152 902·54		31 855·19			121 047·35

STATE BATTERIES

TRADING AND PROFIT AND LOSS ACCOUNT FOR THE YEAR ENDED 31st DECEMBER, 1975

1974 $		$	1975 $
	Trading Costs—		
594 985	Wages	786 601	
91 813	Stores	127 372	
67 314	Repairs Renewals and Battery Spares	79 067	
195 336	General Expenses and Administration	286 680	
949 448			1 279 720
	Earnings—		
104 944	Milling and Cyaniding Charges		175 557
844 504	Operating Loss for the Year		1 104 163
	Other Charges—		
61 881	Interest on Capital	63 457	
32 902	Depreciation	31 884	
17 027	Superannuation—Employers' Share	20 918	
111 810			116 259
956 314	Total Loss for the Year		1 220 422

BALANCE SHEET AS AT 31st DECEMBER, 1975

Funds Employed

31st December, 1974			31st December, 1975
	Capital—		
1 471 130	Provided from General Loan Fund	1 506 140	
406 746	Provided from Consolidated Revenue Fund	436 373	
1 877 876			1 942 513
	Reserves—		
57 244	Commonwealth Grant—Assistance to Gold Mining Industry	57 244	
27 572	Commonwealth Grant—Assistance to Metalliferous Mining	27 572	
84 816			84 816
	Liability to Treasurer—		
2 760 986	Interest on Capital		2 824 442
	Other Funds—		
9 195 532	Provided from Consolidated Revenue Fund (Excess of payments over collections)		10 297 589
13 919 210			15 149 360
	Deduct—		
	Profit and Loss :		
12 713 196	Loss at Commencement of year	13 671 622	
956 314	Loss for Year	1 220 422	
13 669 510	Total Loss from Inception		14 892 044
249 700			257 316

Employment of Funds

31st December, 1974			31st December, 1975
	Fixed Assets—		
1 866 693	Plant Buildings and Equipment	1 931 430	
1 626 393	Less Depreciation	1 658 277	
240 300			273 153
	Current Assets—		
36 273	Debtors	43 379	
118 156	Stores	118 205	
25 856	Battery Spares	37 891	
	Purchase of Tailings :		
31 375	Treasury Trust Account	32 739	
64 874	Tailings not Treated	63 879	
11 390	Estimated Gold Premium	11 609	
287 924			307 702
528 224	Total Assets		580 855
	Deduct—		
75 125	Current Liabilities : Creditors	98 634	
191 760	Liability to Treasurer (Superannuation—Employer's Share)	212 678	
	Purchase of Tailings :		
249	Creditors	618	
11 390	Estimated Premium Due	11 609	
278 524			323 539
249 700			257 316

DIVISION IV

Annual Report of the Geological Survey Branch of the Mines Department for the Year 1975

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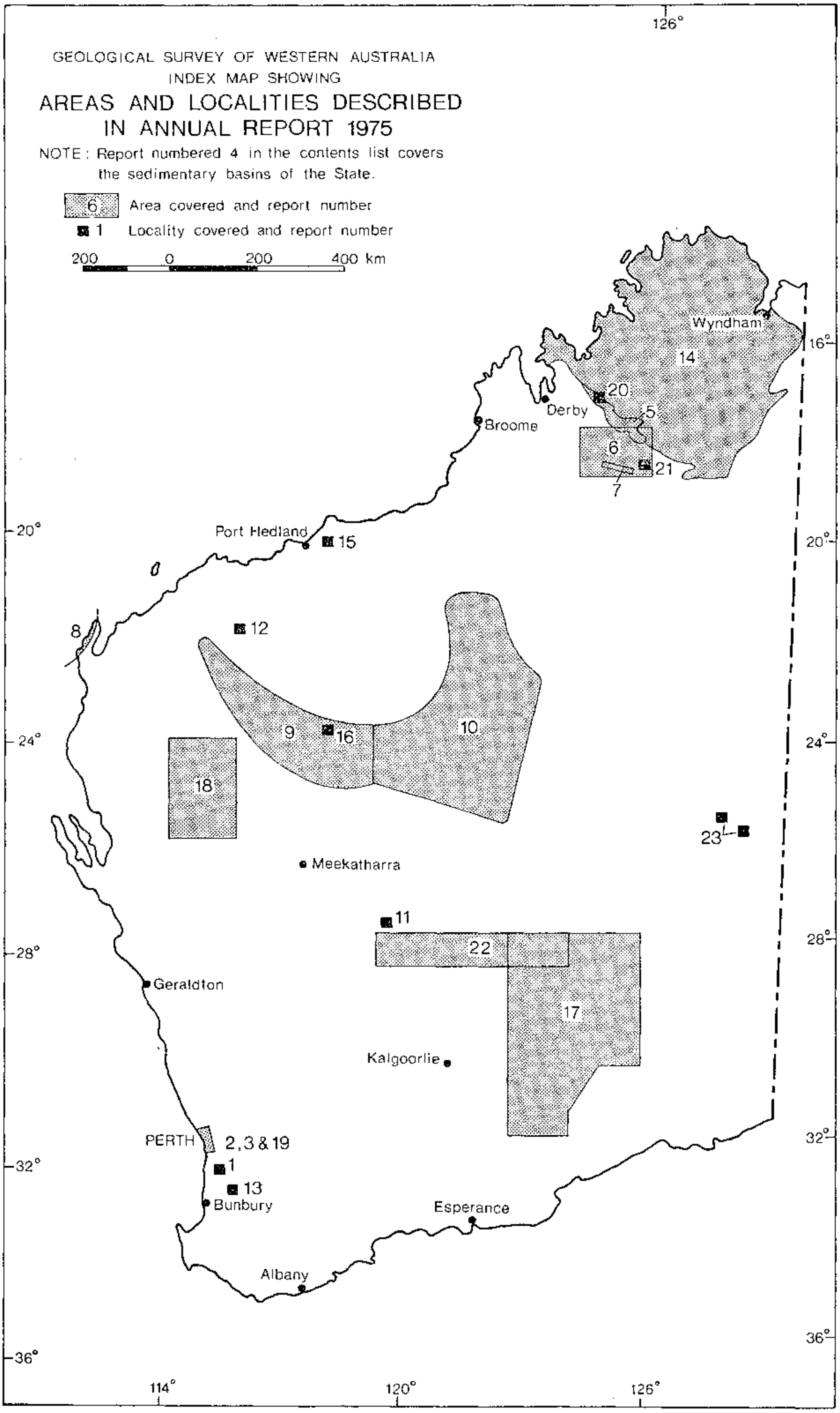

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DIVISION IV

Annual Report of the Geological Survey Branch of the Mines Department for the Year 1975

Under Secretary for Mines:

My report for 1975 on the activities of the Geological Survey of Western Australia, together with selected reports on investigations and studies made for departmental purposes, are submitted for the information of the Honourable Minister for Mines.

INTRODUCTION

The downward trend in exploration which was so evident during the two previous years, continued in 1975 due to the lack of an encouraging minerals policy from the Commonwealth Government. The amount of general exploratory work done by companies still interested has been on a greatly reduced scale, while the rate of work on promising prospects has been on a restricted scale.

Financial statistics do not show the full extent of this decline in expenditure on exploration as they are not adjusted for the high inflation rate which in itself has seriously affected exploration. A better assessment of the marked decrease in activity can be obtained from the amount of land taken up for exploration and the amount of work reported.

In exploration for minerals, other than iron ore and gold, the granting of new temporary reserves in the last three years shows the run down of activity.

1973	182 granted
1974	47 granted
1975	20 granted

Reports on the results of exploration, submitted to the Department under requirements of the Mining Act, decreased from 1 188 in 1974 to 685 in 1975.

A similar situation prevails for oil exploration both on and offshore, where the number and total depth of wells drilled and the length of seismic work continued to decline substantially.

	Total wells drilled	Total metreage	Seismic km	
			Land	Marine
1971	29	70 620	2 744	19 983
1972	29	102 876	3 266	43 218
1973	22	63 612	1 776	14 904
1974	21	48 172	550	11 815
1975	6	17 115	484	2 737

While exploration has been greatly reduced there have been several new interesting finds of mineralization but these require more investigation before any announcement regarding their potential can be made.

Iron ore exploration has continued without any new major finds being reported. Test parcels of Marra Mamba-type iron ore have been shipped to Japan from Mining Area C and Marandoo, but neither company concerned has yet received a contract. The Broken Hill Pty. Co. Ltd. announced that it would proceed to develop the Deepdale deposits.

Bauxite exploration remains dormant. Alwest has satisfactorily concluded an agreement with the Commonwealth Government on environmental problems. Pacminex, the operator, has withdrawn from a consortium which had planned to develop bauxite deposits in the Chittering area north of Perth. No activity has been reported on the Mitchell Plateau deposit.

Nickel exploration has continued throughout the State in a dilatory manner. The companies concerned with the Forrestania area continue to report promising drill intersections. The mine at Carr Boyd closed as the deposit proved to be uneconomic.

At Eneabba, Jennings Mining Ltd. and Allied Minerals are producing heavy minerals, and Western Titanium is establishing a plant. A plant is also being constructed by W.M.C. Mineral Sands Pty. Ltd. at Jurien Bay. Very little exploration for new deposits is being undertaken.

Some exploration for uranium has continued, despite the fact that the Yeelirrie deposit remains undeveloped while waiting for Commonwealth Government approval to develop the prospect.

Drilling at Golden Grove continues and 13.5 million tonnes of ore averaging 3.95 per cent copper and some zinc have been delineated. Some interesting copper/gold mineralization has been reported from drilling near Kundip.

Exploration is continuing on the lead occurrences located in Devonian limestone in the Kimberley.

While the established gold mines are experiencing operational difficulties under the present economic conditions, several smaller mines are operating in the Yilgarn.

The rapid decline in exploration for oil and gas is shown in the table above. The total length of holes drilled decreased by 65 per cent and there was a 74 per cent decrease in total length of land and marine seismic surveys.

There were two discoveries of significance. The first was the follow-up hole to Barrow Deep No. 1 drilled by Wapet on Barrow Island. This hole, Biggada No. 1, located several gas sands similar to those in the original hole, which await production testing.

The second was at Tidepole No. 1 well, drilled on an untested structure close to the Goodwyn field. In Triassic sands a net pay zone of 102 m, indicating 17 m of oil, was discovered and the well was completed as a gas/condensate/oil discovery.

There is an urgent need, as stated last year, for a change to a policy which will encourage further oil exploration.

A lecture evening was given at Laverton followed by a three-day excursion onto the Duketon and Sir Samuel 1 : 250 000 Sheet areas. Despite the general run down in exploration, approximately 63 persons attended.

A helicopter was used for regional mapping by the Survey for the first time. As a result of good planning and dedicated work by the field geologists, a large area of desert country was mapped, which included the Precambrian rocks on the Tabletop, Runton, Gunanya, Trainor, and portion of the Buller Sheet areas.

This Branch has pioneered microfilming of geological information in Australia. Priority has been given to microfilming of data on surrendered oil exploration permits to facilitate release of this information to interested parties, who are able to purchase relinquishment information packages on 35 mm positive film. Technical difficulties, firstly with the process camera operation and secondly with production of subsequent copies, as well as the inconvenience of camera location remote from Mineral House, have delayed release in some cases. A further large body of information contained in company reports on mineral exploration will also be microfilmed to reduce storage problems.

STAFF

It is with regret that the death of two senior officers is recorded.

Mr. George H. Low, who had devoted the whole of his working geological life to this Survey, collapsed and died suddenly on 1st April, 1975. During his 25 years service he had worked in many parts of the State and his major works on coal, gypsum, iron ore, and copper are recorded in the Survey's publications. Latterly he was involved in oil geology and is co-author of a bulletin on the Perth Basin at present in press. The Survey lost a loyal and sincere officer.

Mr. Alan A. Gibson joined the Survey at the beginning of 1972 as a senior geologist. Unfortunately he suffered ill health soon afterwards and retired because of this in June 1975 and passed away on 3rd October, 1975. During his relatively short time with the Branch he demonstrated his sincerity and dedication by his continual perseverance in his position. It was a pity that he was not with us longer in order to pass on to younger geologists more of his wealth of experience.

While vacancies have occurred in the professional positions, they have been filled satisfactorily. There is still considerable movement amongst sub-professional officers of the General Division.

Lionel Finmell, who joined the Survey in 1946 as a laboratory assistant, retired in September 1975. For the whole of his service he has been in charge of the Laboratory which has expanded to include many new techniques. He made a major contribution to the Survey during his 29 years of service with his ability and willingness to assist with all problems.

PROFESSIONAL

Appointments

Name	Position	Effective Date
Butcher, B. P., B.Sc (Hons.) Dip.Ed.	Geologist L1	18/2/75
Hirschberg, K. J. B., Ph.D. (Germany)	Geologist L1	21/2/75
Lewis, I. H., B.Sc. (Hons.)	Geologist L1	7/4/75
Denman, P. D., B.A. (Hons.) M.A.Geol.	Geologist L2	21/4/75
Crank, K. A., B.Sc.	Geologist L3	15/7/75

Promotions

Backhouse, J.	Geologist L2	6/1/75
Barnett, J. C.	Geologist L2	6/1/75
Hill, W. B.	Geologist L2	6/1/75
Williams, S. J.	Geologist L1	25/4/75
Hirschberg, K. J. B.	Geologist L2	17/9/75
Harley, A. S.	Geologist L2	26/9/75

Retirement (ill health)

Gibson, A. A.	Geologist L3	4/6/75

Transfer Out

Sanders, C. C.	Geologist L2	2/7/75

Deceased

Low, G. H.	Geologist L3	1/4/75

CLERICAL AND GENERAL

Appointments

Pettigrew, D. C.	Geological Assistant	16/5/75
Walker, I. W., B.Sc. (Hons.)	Geological Assistant	16/5/75
Maczurad, M. N.	Technical Assistant	22/5/75
Wells, R. W.	Core Librarian	18/8/75
Graham-Sutton, P. B.	Geological Assistant	20/8/75
Hind, P.	Assistant Librarian	1/9/75
McManus, C. H.	Clerk	24/10/75
Emery, L. S.	Technical Assistant	1/12/75
Whiskin, M. K.	Laboratory Assistant	1/12/75

Promotions

Williams, G. T.	Technical Officer	22/8/75
Williams, G. T.	Laboratory Technician	10/10/75

Resignations

Dawson, H. G.	Technical Assistant	21/2/75
Bontemps, T. H.	Geological Assistant	14/3/75
Rankin, P. J.	Geological Assistant	1/5/75
Rettig, H. F.	Core Librarian	6/6/75
Wakeham, J. I.	Assistant Librarian	22/8/75
Dowling, N. R.	Technical Assistant	22/8/75
Blundell, C. D.	Geological Assistant	10/10/75

Transfers Out

Veitch, R. J.	Clerk	24/10/75

Retirement

Finmell, L. H.	Laboratory Technician	2/9/75

ACCOMMODATION

Although the Branch has had very good accommodation in Mineral House since 1971, the area allocated has gradually become inadequate. This is due to additional staff, growth in library, additional storage required for company exploration reports, and the establishment of a microfilm library with the necessary readers and printers.

There being no area available within Mineral House, it has been necessary to obtain additional office accommodation some 800 m west of Mineral House in Adelaide Terrace. Some 20 geologists are to be housed in this new office but it will be inconvenient as they will have to commute to Mineral House for administrative, library, and laboratory services.

OPERATIONS

HYDROGEOLOGY AND ENGINEERING GEOLOGY DIVISION

E. P. O'Driscoll (Chief Hydrogeologist), T. T. Bestow, R. P. Mather (Supervising Geologists), K. Berliat, A. D. Allen (Senior Geologists), G. W. A. Marcos, W. A. Davidson, J. C. Barnett, A. S. Harley, R. E. J. Leech, D. P. Commander, J. M. Campbell, G. Klenowski, E. H. Briese, I. H. Lewis.

Hydrogeology

The aggregate depth drilled throughout the State for groundwater resource exploration during the year was just over 18 000 m. This is in excess of any previous annual figure since the inception of Commonwealth financial assistance for the purpose.

Twenty bores were drilled in the Canning Basin to a maximum depth of 965 m. The bores were designed to study separately both the confined and unconfined aquifers, and complete the present programme of exploration. Although the final evaluation of groundwater resources awaits the collection of hydrographic and further hydraulic data from test pumping, there is no doubt that a large water resource has been proved to exist in this area.

Studies have continued in the Millstream area of the Fortescue River to define the extent and storage characteristics of the calcrete used for the West Pilbara water supply. There have been five special core holes and 18 exploration bores drilled as far east as Weelumurra. The continued expansion of Port Hedland water supply has necessitated further drilling along the De Grey River. The eight bores drilled will aid the layout design of a production field to be drilled in 1976.

Deep drilling in the Perth Basin has continued on the new Moora-Grey cross section where the total depth drilled was 2 367 m.

A major part of the exploratory drilling programme of the Metropolitan Water Board has again been directed to the evaluation of the shallow unconfined aquifers both to the north of Perth at Pinjar and Mirrabooka, and also to the south at Lake Thompson and Jandakot. In all, 116 bores have been drilled to an aggregate depth of over 5 329 m. Two sites at Woodmans Point have also been drilled to explore the deep pressure water aquifers and a further two bores at Whitfords were drilled into the shallow pressure water aquifers to provide stratigraphic and hydrological information. A network of bores has been left available for long-term operation.

Investigation of the Perth Basin shallow aquifers has continued at Joondalup, where eight bores complete that programme.

A new project has been started near Bunbury. Twenty-two bores have been drilled to a maximum depth of 120 m to test the aquifers from which the town water supply is drawn.

A major regional hydrogeological survey of the Albany area has been completed as an aid to future water supply planning both for Albany and other townships in the region. Reports are being prepared.

Further drilling has been completed for interdepartmental studies of the hydrological effects of bauxite mining and the woodchip industry, by Alcoa and the Mines Department respectively. A substantial body of hydrographic, water salinity, and salt storage data has been collected as a result of this work.

Members of the public and other government departments continue to make substantial use of the advisory facilities available to satisfy the increasing demands of small townships, stations, farms, and small holdings. Considerable progress has been made with the preliminary studies required for setting up a state-wide network of monitoring bores required for the Commonwealth-sponsored water quality monitoring programme.

Engineering Geology

The work of the section was confined mainly to investigation for other government departments, including

Department of Public Works:

(a) Yule River proposed dam site—geological mapping, geophysics, and drilling as a preliminary investigation.

(b) Dogger and Gregory Gorges, Fortescue River—continued comparative study of these sites—preliminary reports being prepared.

(c) Port Denison breakwater—geological mapping and drilling of proposed quarry sites.

Metropolitan Water Board:

(a) Wungong Dam—this is now under construction, and geological mapping in the foundation area is continuing.

(b) North Dandalup River proposed dam site —geological mapping, geophysics, and exploratory drilling and report written.

(c) South Canning proposed dam site, Canning River—additional geological mapping, geophysics, and exploratory drilling.

(d) Beenyup Tunnel—geological mapping, experimental refraction seismic work and drilling along the tunnel line, and preparation of a report.

(e) Wungong proposed tunnel—preliminary geological mapping as an aid to selection of the most satisfactory route for the tunnel. Report prepared.

W.A. Government Railways: Geological advice given to aid the selection and development of quarry sites in the Walkaway and the Worsley areas.

SEDIMENTARY (OIL) DIVISION

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

The evaluation and collation of data submitted by petroleum companies continued. Although exploration reached its lowest level for some 12 years during 1975, the amount of petroleum administrative work by the Division increased considerably because of the large volume of information to be processed in data packages submitted by companies on the expiry or surrender of permits. A majority of permits held in the State reached the end of their initial terms during the year and many were renewed over reduced areas.

Mapping of the Carnarvon Basin began during the year, and the Onslow, Yanrey, and Ningaloo 1:250 000 Sheets were completed. Compilation of seismic maps covering the land area of the basin and the continental shelf between 23° and 29°S is in progress.

The Canning Basin mapping project was continued in conjunction with the Bureau of Mineral Resources. The Sahara, Percival, Rudall, Tabletop, Ural, Wilson, Runton, Morris, and Ryan 1:250 000 Sheets were mapped during the year.

REGIONAL GEOLOGY DIVISION

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

Regional mapping of the Precambrian portion of the State for publication on a scale of 1:250 000 continued. Progress is shown on Figure 2.

Field mapping of the Gunanya, Trainor, Buller, Robinson Range, and the Precambrian of Tabletop and Runton Sheets was completed.

Mapping on the following sheets is progressing towards completion in 1976: Rudall (80 per cent), Stanley (10 per cent), Kingston (90 per cent), and Southern Cross (60 per cent).

Work continues on the bulletin on the area covered by the Kalgoorlie and Esperance 1:1 000 000 Sheets.

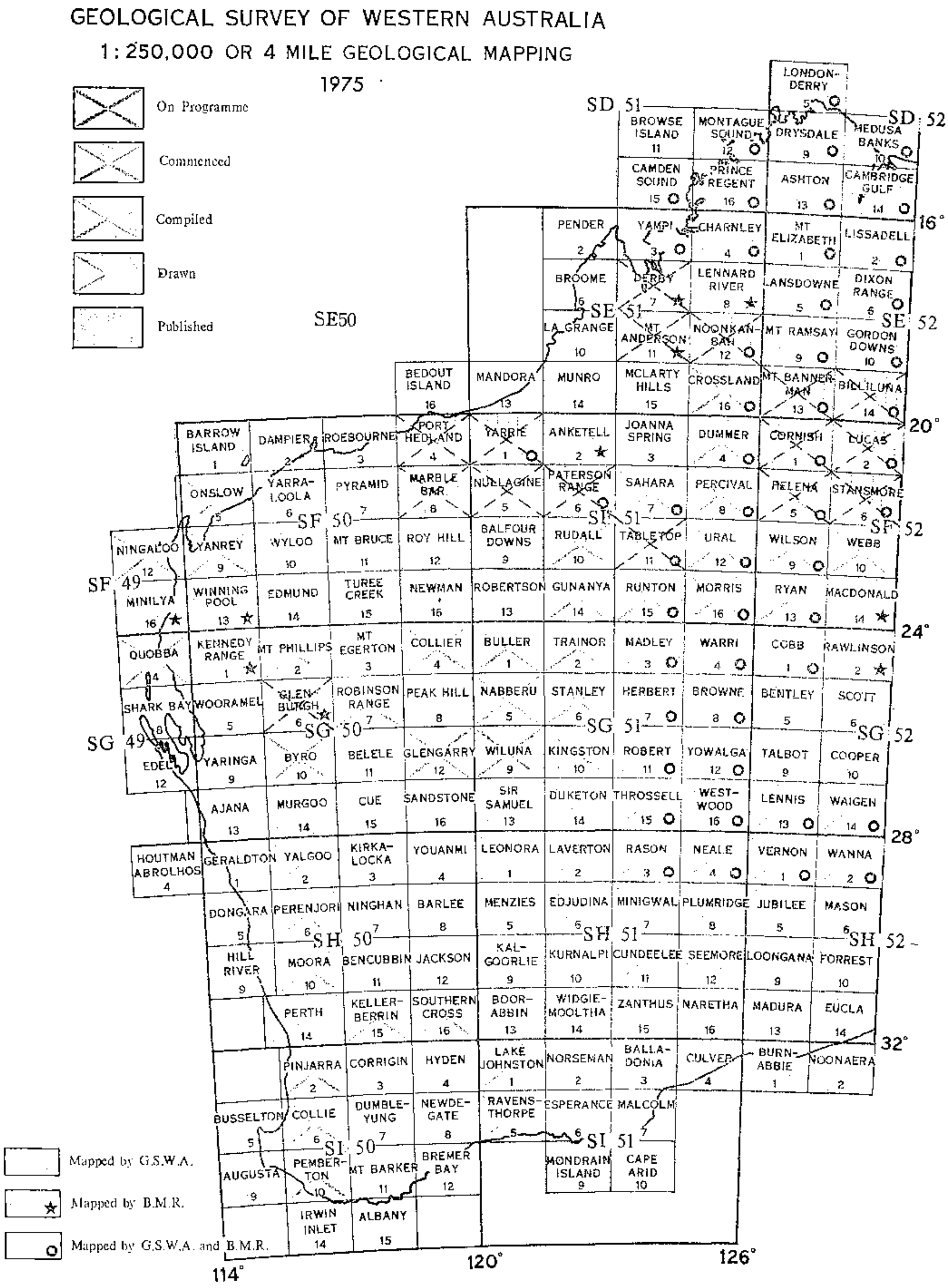

Figure 2. Progress of 1 : 250 000 or 4-mile geological mapping at end of 1975.

MINERAL RESOURCES DIVISION

J. G. Blockley (Supervising Geologist), J. D. Carter (Senior Geologist), J. L. Baxter, A. H. Hickman, S. L. Lipple, S. A. Wilde, and W. B. Hill.

The Precambrian portion of the Port Hedland Sheet was remapped and some time was spent examining the geology of the West Pilbara for a bulletin on the Pilbara Block. The Precambrian portions of the Paterson Range and Yarri Sheets were compiled.

A Ministerial Reserve was created over a new discovery of barite in the Pilbara and some preliminary sampling carried out.

Manuscripts for Mineral Resources Bulletins on chromium, vanadium, tungsten, and molybdenum have been completed. The writing of a bulletin on the State's tin deposits continues while the proposed copper bulletin has been temporarily suspended.

Sundry work included inspections of deposits of limestone, moulding sand, kaolin, copper, tiger-eye, and fluorite.

Some 140 general inquiries from the public were answered and 115 requests for company data handled. An additional 685 assessions were added to the collection of mineral exploration data, a decrease of 503 as compared with 1974.

COMMON SERVICES DIVISION

Petrology (W. G. Libby, J. D. Lewis, J. R. Drake)

The demand for petrological services stabilized during 1975. Eighty-eight reports were written on 1 333 samples, including 1 330 thin sections. About 2 000 further thin sections were examined in order to classify samples already in the collections for incorporation into the computerized rock and mineral data system.

Special studies included syenitic rock at the Fitzgerald Peaks, small ultramafic bodies from the Canning Tunnel, garnet from Heaney's Find, and felsic volcanic rocks from the Bangemall Basin. A study of the granitic and felsic volcanic rocks of the Eastern Goldfields was completed.

Twelve projects in the co-operative geochronological programme with the Western Australian Institute of Technology were active during 1975 and three were added for 1976. The results of three projects were published in 1975 and several others should be ready for publication in 1976.

The laboratory prepared 2 065 thin sections of which 1 474 were petrological; 235 polished slabs were cut, 38 heavy mineral samples were separated, 22 sieve analyses performed, 54 samples crushed for analysis, and 11 mounts polished.

The Government Chemical Laboratories continued to provide valuable chemical analyses and mineral determinations.

Palaeontology (A. E. Cockbain, J. Backhouse, K. Grey)

The 155 file reports written this year reflect the increasing demand for palaeontological information by the Hydrogeology and Engineering Geology Division. A new feature this year was the preparation of an illustrated guide to Mesozoic and Tertiary fossils for use by the Carnarvon Basin mapping party. The main fields covered by the reports are shown in the table below.

Report requested by	Field of palaeontology		
	Palynology	Micropalaeontology	Macropalaeontology
Hydrogeology and Engineering Geology Division	132	1	3
Sedimentary Division	2	....	
Regional Mapping and Mineral Resources Divisions	2	....	2
Other Survey requests	....	4	1
Other organisations	1	1	....

The major effort in palynology has been devoted to further detailed studies on the biostratigraphy of Cretaceous rocks in the Perth Basin. Work continued on the Devonian fauna from the Canning Basin and included studies of stromatoporoids, ostracods, tentaculitids, brachiopods, bivalves, and gastropods. New projects include a study of aspects of the Tertiary fauna of the Carnarvon Basin, and a study of the Proterozoic stromatolites of the Bangemall Basin.

Geophysics (D. L. Rowston, I. R. Nowak)

Geophysical water-bore logging reached a new, and probably all-time, peak during 1975; 258 bores were logged with an aggregate depth of some 29 900 m. Total chart recordings for all parameters measured were equivalent to about 58 000 m of hole. The unprecedented increase from 133 bores in 1974 was due mainly to exploratory drilling of the unconfined aquifer systems in the northern and southern Perth areas by the Metropolitan Water Board. Operations also included logging as far afield as the Fortescue Valley and West Canning Basin.

Several seismic refraction surveys were undertaken on groundwater and engineering projects. At Weelumurra Creek in the Fortescue Valley about 40 km of section were shot and at Albany in the extreme south another 10 km of profiling and several depth probes were carried out. Dam and reservoir sites investigated included North Dandalup, Forrestfield, and Kangan on the Yule. Seismic sections were also obtained in paired catchments for the woodchip industry monitoring near Manjimup.

Normal laboratory servicing and calibration of geophysical, hydrological, and communications equipment were maintained. Conductivity measurements were made on some 800 bore water samples.

Geochemistry (R. Davy)

Analyses of samples submitted to the Government Chemical Laboratories in connection with the regional rock geochemistry survey of the Laverton, Leonora, and Rason 1:250 000 Sheets were finally completed in August. A report on the Laverton Sheet is on file, and reports on the Rason and Leonora Sheets are in preparation. A paper on regional changes in the granitoids of the three sheets is included later in this report.

Samples from *in situ* laterite and bauxite profiles have been submitted to the Government Chemical Laboratories for chemical and X-ray diffraction analysis. Investigations of this material by the Geological Survey have been completed.

Samples of groundwater from observation bores at and adjacent to the Del Park Mine Site have been monitored periodically to determine the labile elements and their concentrations at different seasons of the year. The results are being related to the weathering pattern, and the nature of the bauxite profiles.

Environmental Geology (E. R. Biggs, R. H. Archer)

The first two preliminary sheets of a series of 1:50 000 Urban Geology maps were issued during the year, entailing detailed geological mapping and correlation with the hydrology, engineering geology, and mineral resources of the area. Field mapping has been completed on a third sheet and initial photogeological interpretation done for a fourth. Other appropriate Divisions contributed to these sheets.

The study into supply and demand of clays near Metropolitan Perth was completed and the results issued as a Record. A similar study on dimension stone and aggregates is substantially complete.

The appraisal of mineral tenements applications continues with a view to protecting the environment while encouraging mining.

The geology was recorded from several score temporary excavations in and around Perth, expanding the knowledge of geological strata within the urban area.

Liaison with and supplying geological information to other departments, instrumentalities, and companies continues to occupy a large part of the section's activities and has included the compilation of appraisals of the geology of the proposed Perth Urban Corridors, heavy mineral examination of samples from Hardy Inlet and compilation of palaeogeological environment of Port Gregory area.

Technical Information (K. H. Green, M. M. Harley, M. E. Wenham, and S. M. Fawcett).

The number of enquiries from the general public including requests for rock identification directed to the section has been smaller during the year than in past years, reflecting the lapse in exploration activity and consequent lack of mining publicity. Two Bulletins were edited and sent to the press, sixteen Records were edited and eight Explanatory Notes published. The collection of Survey photograph negatives and prints has been up-dated

Requisitions raised on the Surveys and Mapping Branch for drafting services and photography for the Survey totalled 1 043. Photocopying for the public of out-of-print publications numbered 800 requisitions, many of these contained several items.

During the year 1 657 members of the public visited the library for research purposes. Book loans to the staff totalled 4 649, and loans to other libraries 547.

ACTIVITIES OF THE COMMONWEALTH BUREAU OF MINERAL RESOURCES

Geological and geophysical projects carried out by the Bureau of Mineral Resources in Western Australia included the following:—

(i) Compilation of two bulletins on the Kimberley Division as a joint project with the Survey, whose portion was completed some years ago. (As it is some 10 years since the field work was completed, it appears as if this project will never be completed, so it will be omitted from the programme in future unless the B.M.R. becomes active again.)

(ii) Preparation of a bulletin on the Officer Basin joint project. The Survey has completed its contribution and is keen to see this work finalized and not have the sad history of (i) above.

(iii) Continuation of mapping in the Canning Basin as a joint venture with the Survey.

(iv) Joint collection of rock specimens from the Pilbara area to test for trace element characteristics in selected type sections.

(v) Aeromagnetic survey of the Officer Basin commenced.

PROGRAMME FOR 1976

HYDROGEOLOGY AND ENGINEERING DIVISION

A. Hydrogeology

1. Continuation of the hydrogeological survey of the Perth Basin, including deep drilling on the Moora and Quindalup lines, and pump testing on the Eneabba line.

2. Hydrogeological investigation and/or exploratory drilling for groundwater in the following areas:—
   (a) West Canning Basin
   (b) Fortescue River including coastal district, East Millstream and Weelumurra
   (c) Re-assessment of De Grey, Yule, and Gascoyne River areas
   (d) Stirling Range area for farm water supply.

3. Town water supply investigations and/or drilling for the following:—
   Albany district, Bunbury district, Hopetoun, Horrocks Beach, Halls Creek, Geraldton.

4. Hydrogeological investigations for Metropolitan Water Supply Board:—
   (a) Regional studies
   (b) Shallow drilling at Lake Thompson, Mirrabooka extension area, Salvado
   (c) Studies of certain areas for pollution control
   (d) Study of water balance in coastal lakes.

5. Inter-departmental studies concerning groundwater salinity problems in the Darling Range area.

6. Continuation of bore census of selected areas.

7. Kimberley Division—hydrogeological assistance to pastoralists as required.

8. Miscellaneous investigations and inspections as requested by Government Departments and the public.

B. Engineering

1. Pilbara area—further investigation of proposed dam sites on the Forescue River, at Cooya Pooya and Kangan on Yule.

2. Darling Range area—continuation of investigations at South Canning and North Dandalup dam sites, Wungong Dam, Wungong tunnel, and a safety review of existing dams.

3. Investigation, including drilling of proposed Bibra Lake sewerage tunnel.

4. Miscellaneous investigations by Government Departments as requested.

SEDIMENTARY (OIL) DIVISION

1. Maintain an active interest in the progress and assessment of oil exploration in Western Australia.

2. Continuation of the surface and subsurface study of the Carnarvon Basin including Quobba, and the Phanerozoic portions of the Mount Phillips, Glenburgh, and Byro 1.250 000 Sheets.

3. Continuation of the geological mapping of the Canning Basin in conjunction with the Bureau of Mineral Resources on the Mount Anderson and Derby 1:250 000 Sheets.

4. The commencement of a Bulletin on further studies of the Devonian reef complexes of the Lennard Shelf, Canning Basin.

REGIONAL GEOLOGY DIVISION

1. Completion of mapping of the Bangemall Basin mainly on the Stanley and Nabberu 1:250 000 Sheets and commencement of Bulletin.

2. Completion of mapping of the Nabberu Basin on the Stanley and Nabberu 1:250 000 Sheets.

3. Mapping of the Archaean on the Kingston 1:250 000 Sheet and continuing onto Wiluna and Glengarry Sheets.

4. Commencement of the Gascoyne Province mapping on the Mount Phillips, Glenburgh, and Byro 1:250 000 Sheets.

5. Completion of mapping on the Rudall and Southern Cross 1:250 000 Sheets.

MINERAL RESOURCES DIVISION

1. Maintain records and assess mineral exploration in Western Australia.

2. Completion of Mineral Resources Bulletins on tin, copper, vanadium, and chromium.

3. Reassessment of the regional and economic geology and commencement of Bulletin on the Pilbara Block.

4. Continuation of regional mapping of the Darling Range on the Collie, Pemberton, Moora, and Perenjori 1:250 000 Sheets and a study of the bauxite occurrence.

5. Geological investigation of Cooke Bluff barite prospect.

COMMON SERVICES DIVISION

Petrology

1. Carry out petrological investigations as required by other Divisions.
2. Completion of the petrological project on Eastern Goldfields granites and acid rocks.
3. A study of the regional petrology of the Pilbara granites.
4. A study of the low-grade metamorphism of the Talbot and Yowalga 1:250 000 Sheets.

Palaeontology

1. Carry out palaeontological investigations as required by other Divisions.
2. Continuing a study of the Devonian stromatoporoids, Lennard Shelf, Canning Basin.
3. A study of ostracod fauna from the same region.
4. A study of the stratigraphic palynology of the Cretaceous Yarragadee Formation.
5. Completion of study of Devonian Atrypids.
6. A study of stromatolites from the Bangemall Basin.

Geophysics

1. Well logging as required on groundwater drilling projects.
2. Seismic surveys for groundwater on the Fortescue River and near Albany.
3. Seismic surveys for dam sites in West Pilbara, South Canning, and of existing dam sites and foundations in the Metropolitan area.
4. Seismic survey for portals and sections of proposed Wungong Tunnel.

Geochemistry

1. Completion of regional geochemistry project on Leonora-Laverton-Rason and a study on laterite profiles in the Darling Range.
2. Examine the nature of the anomalous lead/zinc in the parts of the Bangemall Basin.
3. An assessment of the SO_2 prospecting technique in Western Australia.
4. A geochemical examination of laterites, Mount Saddleback area.

Environmental Geology

1. Continuation of urban geology studies on the Mandurah, Pinjarra, Dampier, and Port Hedland 1:50 000 Sheets.
2. A study of the sand resources in the urban area of Perth.
3. Attend to environmental geological problems as required.

PUBLICATIONS AND RECORDS

Issued during 1975

Annual Report, 1974.

Memoir No. 2: The Geology of Western Australia.

Report 3: An annotated bibliography of the palaeontology of Western Australia 1814-1974.

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

Geological map of Dongara-Hill River 1:250 000 Sheet (SH/50-5 and 9 International Grid) with explanatory notes.

Geological map of Herbert 1:250 000 Sheet (SG/51-7 International Grid) with explanatory notes.

Geological map of Malcolm-Cape Arid 1:250 000 Sheet (SH/51-7 and 10 International Grid) with explanatory notes.

Geological map of Mason 1:250 000 Sheet (SH/52-6 International Grid) with explanatory notes.

Geological map of Murgoo 1:250 000 Sheet (SG/50-14 International Grid) with explanatory notes.

Geological map of Seemore 1:250 000 Sheet (SH/51-12 International Grid) with explanatory notes.

Geological map of Warri 1:250 000 Sheet (SG/51-4 International Grid) with explanatory notes.

Reprints

Geological map of Mount Bruce 1:250 000 Sheet (SF/50-11 International Grid).

Geological map of Yarraloola 1:250 000 Sheet (SF/50-6 International Grid).

In press

Bulletin 124: The geology of the Perth Basin.

Mineral Resources Bulletin 11: Heavy mineral sands of Western Australia.

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

Geological map of Browne 1:250 000 Sheet (SG/51-8 International Grid) with explanatory notes.

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

Geological map of Madley 1:250 000 Sheet (SG/51-3 International Grid) with explanatory notes.

Geological map of Neale 1:250 000 Sheet (SH/51-4 International Grid) with explanatory notes.

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

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

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

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

Geological map of Yalgoo 1:250 000 Sheet (SH/50-2 International Grid) with explanatory notes.

In preparation

Bulletin 125: The geology of the Eastern Goldfields.

Mineral Resources Bulletins: Tin, Copper, Vanadium, Chromium, Molybdenum, and Tungsten.

Geological maps 1:250 000 with explanatory notes, the field work having been completed: Billiluna, Crossland, Cundeelee, Duketon, Dummer, Helena, Laverton, Lennis, Leonora, Marble Bar, Minigwal, Mount Bannerman, Mount Egerton, Nullagine, Paterson Range, Perth, Robert, Sir Samuel Stansmore, Throssell, Waigen, Wanna, Webb, Westwood, Yarrie, Yowalga.

Geological maps 1:1 000 000 Kalgoorlie, Esperance.

Records produced

1975/1 Wells drilled for petroleum exploration in W.A. to the end of 1974, by G. H. Low.

1975/2 A system for storage and retrieval of rock and mineral data, by W. G. Libby.

1975/3 Hydrogeology of the Mandurah-Pinjarra area, by D. P. Commander.

1975/4 Clay resources of the Perth region, by R. H. Archer.

1975/5 Explanatory notes on the Nullagine 1:250 000 geological sheet, W.A., by A. H. Hickman.

1975/6 Explanatory notes on the Perth 1:250 000 geological sheet, W.A., by S. A. Wilde and G. H. Low.

1975/7 Explanatory notes on the Duketon 1:250 000 geological sheet, W.A., by J. A. Bunting and R. J. Chin.

1975/8 North Dandalup proposed dam site: seismic refraction survey, by I. R. Nowak.

1975/9 Explanatory notes on the Throssell 1:250 000 geological sheet, W.A., by J. A. Bunting, M. J. Jackson, and R. J. Chin.

1975/10 Beenyup outfall tunnel and outlet: geological report, by G. Klenowski.

1975/11 Moochalabra Creek dam, Stage II: geological investigation, by G. W. A. Marcos.

1975/12 Hydrogeological reconnaissance of the northwest Pilbara region, by W. A. Davidson.

1975/13 Bullinarwa Pool dam site: geological report, by J. M. Campbell.

1975/14 Wungong proposed tunnel: preliminary geological report, by R. P. Mather.

1975/15 North Dandalup proposed dam site, North Dandalup River: geological investigation progress report, by G. Klenowski.

1975/16 South Dandalup dam: final geological report, by G. W. A. Marcos.

Reports in other publications

Lord, J. H., 1975, Coal deposits of Western Australia *in* Economic Geology of Australia and Papua New Guinea: Australasia Inst. Mining and Metall. Monograph 6, Coal. p. 269-279, 339, 372.

Playford, P. E., 1975, Petroleum in Western Australia—a review of exploration, production and future prospects: Australia Petrol. Expl. Assoc. Jour. v. 15, pt. 2, p. 72-79.

Trendall, A. F., 1975, Iron Formations of the Hamersley Basin: International Geological Correlation Programme, Moscow, 1975 *in* Correlation of the Precambrian, Abstracts, p. 147-148.

Van de Graaff, W. J. E., 1975, Carboniferous deltas in the Pisuerga area, Cantabrian Mountains, Spain *in* Deltas, models for exploration, M. L. Broussard (ed.), Houston Geological Society, p. 451-456.

Yeates, A. N., Crowe, R. W. A., Towner, R. R., Lyborn, L. A. I., and Passmore, V. L., 1975, Notes on the geology of the Gregory Sub-basin and adjacent areas of the Canning Basin, Western Australia: Australia Bur. Mineral Resources Rec. 1975/77 (unpublished).

J. H. Lord,
Director.

2nd February, 1976.

THE EFFECTS OF BAUXITE MINING AT DEL PARK ON GROUNDWATER HYDROLOGY

by T. T. Bestow

ABSTRACT

A study of hydrographic and salinity data collected from a grid of bores drilled through lateritic profiles, both in a rehabilitated mine pit and the adjoining Darling Range forest, indicates that the combined effects of selective felling, Phytopthora cinnamomi and bauxite mining are resulting in an annual discharge of salt of about 1.2 times the accession from rainfall. However, the greater infiltration and the absence of a transpirative draw from the water table below the mine pit, as compared with the forest, has resulted in the creation of a groundwater mound below and downslope of the mine pit. This has a substantially lower salinity than that of groundwater below the adjoining forest. Comparative water balances in the mine pit and forest indicate that the groundwater discharge from the pit area is about twice that from the forest.

The study indicates that bauxite mining in the Del Park area has benefitted the groundwater regime by increasing the volume being discharged and by reducing salinities. It is estimated that the present salt imbalance within the mine pit is expected to return to balance in between 24 and 48 years.

INTRODUCTION

The increase in stream salinity which results from forest clearing in the South West Division, has been recognized for a considerable number of years (Wood, 1924). Research into the underlying physical causes of such increases was slow to start and it was not until salination became a serious problem in the agricultural areas east and northeast of the Darling Range that the first serious studies were commenced (Burvill, 1947). Indeed it was not until about 1964 that detailed studies can be said to have started (Bettenay and others, 1964). Since then the pace of research has quickened, and concern at the environmental risks of land use changes has become more widespread in the community. The West Australian Government has recognized the need for research specific to the hydrologic effects of land use changes related to major developments such as the Manjimup Wood Chip Industry and bauxite mining, and in 1973 set up committees to supervise and carry out research. Several projects were started under the guidance of inter-departmental panels and with the full co-operation of the mining companies concerned. One of them was conducted at Del Park, 13 km almost due east of Pinjarra (Fig. 3).

HISTORY AND OBJECTIVES

The particular objectives of the investigation at Del Park (which forms part of what is known as Project 3) are to assess the changes in the groundwater hydrology which have resulted from mining, by drilling a series of boreholes in the mined and the adjoining unmined area and then observing the salinity and water-table levels.

The Del Park area falls within the Alcoa mining lease (1SA) and at the time when its bauxite potential was initially explored by grid drilling, was entirely covered by jarrah forest. This had been cut over early this century and was already infected with the root fungus Phytopthora cinnamomi which was destroying the jarrah and other susceptible species.

Most of the Del Park mine area was cleared between August and October 1970, but the part presently described was not cleared until the corresponding months of 1971. This clearing included not only the mine pit area but also a surrounding narrow strip of ground. After the felling and burning, the top soil was removed and stockpiled. Then between November and December 1972 bauxite was mined by open-cut methods, and early in 1973 the area was rehabilitated. This involved firstly deep-ripping the pit floor to 1.5 m and replacing the top soil which was contour ploughed. Finally exotic eucalypts were planted to re-establish a forest cover and by February 1974, when the present series of investigation bores were drilled, these trees had grown to between 1 and 2 m in height.

TOPOGRAPHY

The Del Park mine site lies on the north flank of the Boomer Brook, a westward-draining tributary of the South Dandalup River, and is at an elevation of between 300 and 330 m above sea level. The valley form is essentially juvenile although the higher ground tends to have a pateau-like form. Valley slopes in the forest and at the mine site have gradients between 1 in 6.5 and 1 in 13. The removal of bauxite has had the effect of lowering the surface in the rehabilitated mine pit by an average of 3.83 m, to produce a southward-sloping depression. At its southern margin there is an up-slope batter which tends to impound run-off within the mine pit.

RAINFALL

Rainfall records for Del Park are available only from July 1972 (Table 1).

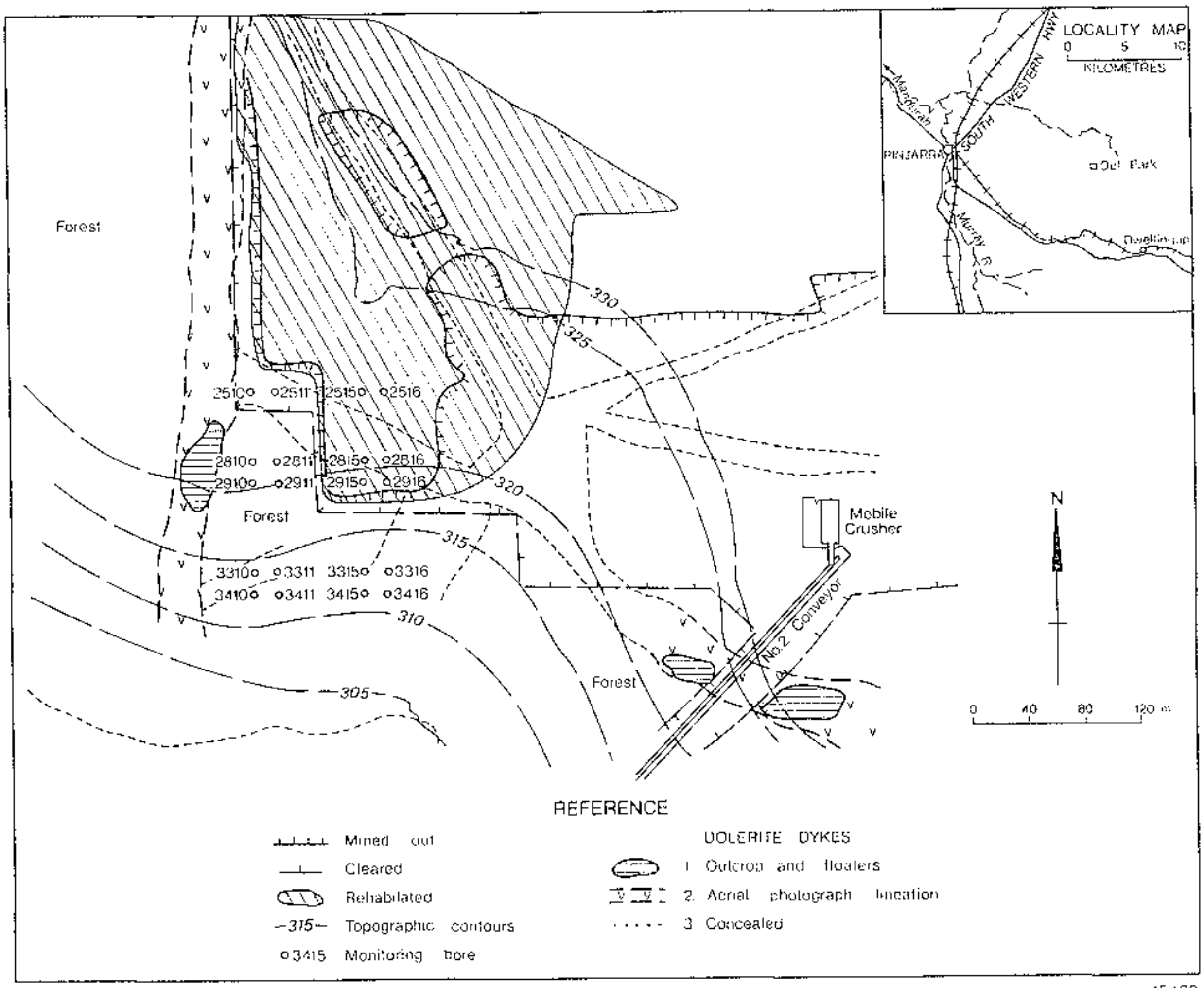

Figure 3. Locations of monitoring bores at Del Park.

TABLE 1. MONTHLY RAINFALLS AT DEL PARK

		mm			mm
1972	July	342·9	1974	January	0
	August	376·9		February	0
	September	81·3		March	0
	October	98·3		April	105·40
	November	10·2		May	343·20
	December	0		June	256·30
				July	532·90
		(909·6)		August	201·90
				September	52·07
1973	January	18·0		October	150·02
	February	0		November	23·37
	March	0		December	0
	April	187·7			
	May	251·0			1 665·16
	June	364·0			
	July	399·0			
	August	173·0	1975	January	0
	September	234·2		February	0
	October	88·4		March	0
	November	16·5		April	16·30
	December	0		May	364·70
		1 731·8			(380·10)

The nearest rainfall station with a long record is at Dwellingup. The season pattern of rainfall is mediterranean, with rain confined to a winter period and dryness between November and March. The long-term mean annual rainfall at Del Park is probably about 1 500 mm but the total rainfalls for the years 1973 and 1974 were above average, being 1 732 and 1 665 mm respectively.

MONITORING BOREHOLES AND DATA COLLECTION

Twenty boreholes were drilled with an auger-type rig without the use of drilling fluids, on a grid consisting of five sites on each of four lines. Six of the bores are in the mined area and the remainder in the relatively undisturbed forest. Four of the bores were cored and a full suite of drill cuttings collected from the remainder. Only three bores reached reasonably unweathered bed-rock.

Each bore was cased with 38 mm I.D. P.V.C. pipe slotted to allow the ingress of groundwater from 2 m below the surface to the full depth of the bore (6.9-44.10 m) (Table 2). The position and elevation of each bore was surveyed and related to the grid of exploration bores drilled by the mining company through part of the profile, and numbered accordingly. The cores were analysed to determine the pH of pellicular moisture, the total soluble salts and the sodium chloride content (Table 3).

The water levels in each bore were measured as soon as possible after drilling was completed, and subsequently each month. As all boreheads have been accurately levelled, it is possible to reduce all standing water level measurements to height above mean sea level (Table 4).

TABLE 2. SUMMARY OF BOREHOLE DATA

Bore No.	Elevation of borehead	Total depth m	Depth cased m	Date completed in 1974	Water cut m	Standing water level on completion	Salinities recorded during drilling (TDS mg/l)	Sample log	Comments
2510	325·27	15·52	15·52	9·2	Dry	....	....	0–12 laterite, 12–14 weathered dolerite, 14–15 dolerite	Auger samples damp from 2m
2511	325·45	21·50	21·50	12·2	16	17·34	200	0–15 laterite, 15–18 clay, 18–21 weathered dolerite, 21–21·5 dolerite	
2515	320·75	23·64	23·64	30·3	15	11·91	....	0–18 clay	No sample recovery below 18 m
2516	320·24	17·18	17·18	4·4	15·13	11·36	....	0–17 clay, 17–17·5 slightly weathered granite	No recovery 15–17 as clay became a slurry
2810	322·13	20·61	20·61	26·2	....	....	....	0–6·5 laterite, 6·5–17·5 kaolin, 17·5–20·6 weathered granite	Cored but no recovery between 8·1–10·2, 19·7–20·6
2811	321·88	19·58	19·58	18·2	....	....	140		
2815	317·63	9·62	9·62	29·3	9·5	9·5	....	0–3 kaolin, 3–9 silt	
2816	317·55	6·90	6·00	5·4	Dry	....	....	0–3 laterite, 3–6·9 weathered dolerite	Cored from 1 to 4·95 m with 80 per cent recovery
2910	320·84	34·00	30·00	28·2	21·0	19·25	120, 130	0–12 laterite, 12–27 kaolin, 27–33 silty clay, 33–34 clay	
2911	320·50	23·50	23·50	19·2	....	....	....	0–6 laterite, 6–22 kaolin	No recovery 22–23·5
2915	315·53	15·13	15·13	28·3	8·0	7·8	115	0–6 laterite, 6–15·1 kaolin, 15·1 weathered granite	
2916	315·04	12·27	12·27	28·3	7·0	7·0	....	0–3 laterite, 3–6 silt, 6–10 silty clay	Cored to 4·95, no sample recovery 10–12·27
3310	314·44	36·28	36·28	18·3	18·0	16·35	....	0–4 laterite, 4–16·8 kaolin, 16·8–20 weathered granite, 20–21·3 kaolin, 21·6–22·3 weathered dolerite	Cored but no recovery 17·5–18·9, 22·3–36·28
3311	314·29	42·12	41·29	14·3	19·0	....	160–220	0–12 laterite, 12–18 kaolin, 18–42 sandy and silty clay	Partially cored, bore completed in puggy clay
3315	312·60	31·29	31·29	25·3	7·0	7·0	....	0–2·8 laterite, 2·8–6·2 kaolin, 6·2–12 deeply weathered dolerite	Cored to 7·8 m
3316	312·13	30·34	30·34	28·3	10·6	10·6	....	0–3 silty clay, 3–6 kaolin, 6–11 silty clay, 11–30·3 clay	
3410	312·83	35·65	35·65	11·3	18·0	14·0	....	0–12 laterite, 12–24 kaolin, 24 clay	No recovery 24–35·6
3411	312·60	34·20	31·37	6·3	16·0	13·6	185–210	0–3 laterite, 3–6 clay, 6–12 sandy clay, 12–15 kaolin, 15–21 weathered granite, 21–24 sand, 24–27 clay	No recovery 27–34
3415	311·08	44·10	38·51	21·3	9·03	7·4	....	0– laterite, 33–42 clay	Partially cored, 0–33 not recorded
3416	311·00	24·00	24·00	26·3	....	6·6	....	0–3 gravel, 3–6 kaolin, 6–9 silty clay, 9–15 clay	No recovery 15-24

All bores were drilled 152 mm diameter and cased with 2 m of 76 mm PVC stand pipe from 180 mm above ground to 1·82 m below. Each bore is also cased with 38 mm ID PVC pipe slotted with hacksaw cuts(20 per metre) from 2 m below ground level to the appropriate depth given above.

TABLE 3. ANALYTICAL DATA FROM CORE SAMPLES

Bore	Depth m	Density kg/m³	H_2O %	pH	E.C. μS	TSS %	NaCl %	Remarks
2810	0	....	4·2	6·2	28	·005	·004	Surface sample
	1	....	4·5	6·1	7	·001	< ·001	DTH-Hammer sample
	2	....	3·2	5·95	9	·001	·003	DTH-Hammer sample
	3	....	16·7	5·35	21	·003	·005	DTH-Hammer sample
	3·487	820	25·5	5·4	31	·005	·008	Complete core ?
	4	....	16·5	5·4	10	·003	·006	DTH-Hammer sample
	5	....	20·2	5·25	22	·003	·006	DTH-Hammer sample
	5·842	....	16·8	5·25	37	·006	·010	Incomplete core
	6·582	....	18·8	4·95	42	·007	·010	Incomplete core
	7·292	....	27·2	4·85	57	·011	·015	Incomplete core
	8·143	....	25·2	4·95	56	·011	·013	Most of sample lost
	10·176	1 530	26·2	5·25	32	·005	....	Complete core ?
	16·724	....	35·2	5·25	47	·009	·005	Incomplete core
	18·252	1 590	20·5	5·1	20	·003	·005	Complete core ?
	18·987	1 650	24·8	5·0	24	·004	·006	Complete core ?
	19·707	....	26·2	5·0	27	·004	·006	Incomplete core
2816	Surface	....	....	5·25	19	·003	·004	
	1·590	....	....	5·15	18	·003	·004	
	2·236	....	....	5·15	19	·003	·004	
	3·010	....	....	4·70	22	·003	·003	
	3·715	....	....	4·70	25	·004	·004	
	4·260	....	....	4·95	24	·004	·004	
	4·950	....	....	5·20	23	·004	·005	
3310	0	....	6·2	6·0	31	·005	·004	Surface
	3	2 520	8·4	5·8	8	·001	·001	Complete core ?
	4·767	....	17·0	5·55	15	·002	·004	Incomplete sample
	5·537	....	....	....	....	....	....	Complete core lost
	6·322	....	15·3	5·45	14	·002	·004	Incomplete core
	7·057	....	15·1	5·35	17	·002	·005	Sample from auger flight
	7·821	....	14·0	5·20	18	·003	·005	Sample from auger flight
	8·572	....	15·8	5·05	24	·004	·006	Sample from auger flight
	9·262	....	17·9	5·05	26	·004	·006	Sample from auger flight
	10·062	....	18·8	5·05	27	·004	·006	Sample from auger flight
	10·817	....	20·0	4·95	31	·005	·006	Sample from auger flight
	11·607	....	18·2	4·95	32	·005	·006	Sample from auger flight
	12·347	....	17·8	4·85	34	·006	·006	Sample from auger flight
	13·132	....	18·7	4·85	34	·006	·005	Sample from auger flight
	13·847	1 270	29·5	4·65	29	·005	·005	Core length 122 mm, ID 48 mm
	14·557	....	19·2	4·6	38	·007	·006	Incomplete core
	15·232	....	....	4·6	75	·015	·016	Complete core lost
	15·552	1 300	36·4	....	....	....	....	Full shoe length 122 mm, ID 48 mm
	15·982	1 310	39·1	4·9	73	·015	·016	Full core
	16·822	....	23·0	4·95	38	·007	·009	Incomplete core
	17·532	....	30·6	4·8	48	·010	·011	Incomplete core
	18·182	....	....	....	....	....	....	Complete core lost
	18·892	....	....	....	....	....	....	Complete core lost
	19·287	1 470	35·2	4·85	55	·011	·013	Complete core ?
	20·082	1 410	36·8	4·0	56	·012	·013	Complete core ?
	20·757	1 400	36·5	4·8	53	·011	·012	Complete core ?
	21·317	1 860	19·9	5·0	31	·005	·006	Complete core ?
	21·550	....	....	....	....	....	....	Blind bit
	22·550	....	17·3	5·3	96	·020	·011	Incomplete core
	23·027	....	....	....	....	....	....	No core
3311	15·982	....	....	4·9	70	·014	·010	
	16·822	....	....	5·0	37	·006	·009	
	17·532	....	....	4·8	46	·009	·011	
3315	....	....	....	5·85	13	·002	< ·001	No cores
	....	....	....	5·8	7	·001	< ·001	
	....	....	....	5·7	11	·001	·003	
	....	....	....	5·15	10	·001	< ·001	
	....	....	....	4·45	21	·003	·003	
	....	....	....	4·3	33	·006	·004	
	....	....	....	4·05	53	·011	·008	
	....	....	....	4·05	66	·013	·011	
	....	....	....	4·35	54	·011	·011	
	....	....	....	4·75	73	·015	·016	
3415	3·657	1 650	19·8	4·95	14	·002	·003	Complete sample
	6·482	1 720	29·8	4·4	48	·010	·010	Complete sample
	9·522	....	34·1	4·75	52	·010	·012	Incomplete sample
	10·607	....	32·5	5·3	53	·011	·012	Incomplete sample
	15·732	....	26·0	5·15	31	·005	·007	Incomplete sample

1. NOTE—TSS % calculated using the new relationship of

$$Y = \cdot 0000000483\, x^2 + \cdot 0002175\, x - \cdot 0014$$

where Y = TSS % and x = E.C.
TSS % at 25°C.

2. NOTE—NaCl % may be slightly higher than the TSS % in the low range because of the equation used for TSS %.

TABLE 4. MONTHLY REDUCED LEVELS OF THE WATER TABLE (METRES ABOVE MSL)

MONTH	4	5	6	7	8	9	10	11	12	1	2	3	4
						FOREST							
2510	309·62	309·81	310·34	310·94	312·59	310·47	310·64	309·94	....	....	....	....	....
2511	308·11	308·80	310·30	310·91	312·47	311·43	310·49	309·90	309·00	308·93	308·49	....	308·03
2810	....	302·42	304·09	305·74	309·83	307·93	306·26	304·95	302·52	303·30	302·83	....	....
2811*	304·67	305·09	307·45	308·70	311·62	309·51	308·92	307·80	305·72	306·00	305·31	....	304·77
2910*	301·14	301·45	303·44	304·41	308·20	303·37	304·82	303·73	302·21	302·19	301·70	....	301·32
2911*	305·17	304·62	307·48	308·79	311·70	310·00	309·04	307·57	304·79	305·60	304·46	....	304·27
3310*	298·67	298·80	299·34	299·85	301·30	300·43	299·93	299·52	298·39	299·10	298·88	....	298·77
3311*	299·34	299·59	300·35	300·93	303·05	302·09	301·37	300·76	299·32	300·05	299·69	....	299·47
3410*	298·53	298·78	299·25	299·88	301·31	300·50	299·83	299·55	297·89	299·09	298·51	....	298·73
3411*	298·72	299·06	299·23	299·88	301·30	300·59	300·05	299·78	298·67	299·26	298·97	....	298·90
Average (of 7)	300·89	301·06	302·36	303·21	305·51	303·78	303·42	302·67	301·00	301·61	301·07	....	300·89
						PIT							
2515*	308·84	309·75	310·78	311·71	313·41	312·50	311·09	310·53	309·90	309·72	309·27	....	308·88
2516	308·88	310·16	311·14	311·92	313·94	312·89	311·37	310·56	....	309·74	309·23	....	308·74
2815	307·96	308·73	310·51	311·50	313·18	312·23	310·77	309·97	308·88	308·82	308·32	....	....
2816	....	....	310·58	311·59	313·19	312·20	310·77	310·43	....	....	....	....	....
2915*	307·72	308·80	310·42	311·41	313·03	312·14	310·70	310·00	309·01	308·65	308·17	....	307·61
2916*	307·75	308·88	310·44	311·62	313·09	312·24	310·71	310·40	308·97	308·74	308·21	....	307·61
Average (of 3)	308·10	309·14	310·55	311·58	313·18	312·29	310·83	310·31	309·29	309·04	308·55	....	308·03
						FOREST DOWNSLOPE OF MINE PIT							
3315*	305·66	306·00	307·87	309·08	310·29	308·93	308·19	307·53	306·20	306·43	306·03	....	305·70
3316*	306·31	306·93	308·55	309·97	310·55	309·50	308·62	305·48	306·11	306·95	306·57	....	306·28
3415*	304·72	305·49	306·50	310·28	308·98	307·21	306·59	305·38	305·10	304·10	304·92	....	304·25
3416	305·44	305·39	307·10	308·75	309·40	308·56	....	....	305·70	306·13	....	....	....
Average (of 3)	305·56	306·34	307·64	309·78	309·94	308·55	307·80	306·13	305·83	305·83	305·84	....	305·41

* Included in the monthly averages.

Water samples were collected in the course of drilling where this was possible, and after completion at monthly intervals (Table 5). At the same time any variations of salinity with depth were measured *in situ* by means of a down-hole conductivity meter (Table 6).

TABLE 5. MONTHLY WATER SAMPLE ANALYSES—TOTAL DISSOLVED SOLIDS EXPRESSED AS MG/LITRE

Month	4	5	6	7	8	9	10	11	12	1	2	3	4	Average
							FOREST							
2510	280	130	210	221	140	127	145	190	....	....	....	....	....	180
2511*	170	90	150	139	130	98	120	125	135	150	138	150	120	132
2810	....	98	150	141	110	110	140	96	133	115	133	....	....	123
2811*	144	95	150	137	120	71	85	90	148	227	135	130	125	127
2910*	130	90	140	84	80	60	120	110	135	140	120	115	115	111
2911*	125	80	120	103	80	76	115	90	126	131	100	100	104	104
3310*	170	105	170	78	110	140	165	140	170	168	160	170	164	142
3311*	180	130	210	90	130	125	185	165	203	195	205	180	155	166
3410*	205	130	200	76	80	165	120	105	220	280	180	205	245	174
3411*	175	130	210	166	80	104	125	82	155	161	166	158	187	146
Average (of 8)	162	106	169	109	101	105	129	121	161	181	150	151	153	140
											Mean of monthly averages			138
							PIT							
2515*	145	75	190	128	120	143	125	125	152	152	133	115	124	126
2516*	148	98	104	100	80	75	75	90	121	100	128	115	90	106
2815	280	135	136	120	110	98	105	96	132	242	200	....	....	150
2816	....	....	....	90	110	78	100	....	....	....	....	....	....	....
2915*	115	73	115	78	70	73	95	82	121	105	118	98	104	95
2916*	148	75	95	85	70	68	75	76	121	124	133	120	104	104
Average (of 4)	139	80	103	96	85	100	92	93	120	135	128	112	105	115
											Mean of monthly averages			108
							FOREST DOWNSLOPE OF THE MINE PIT							
3315*	245	110	100	50	40	72	95	110	208	260	250	260	245	157
3316*	245	100	120	50	320	255	140	60	100	167	208	152	187	162
3415*	100	100	100	50	50	120	95	140	105	90	205	160	170	114
3416*	238	170	300	166	270	235	195	220	275	270	265	240	228	236
Average (of 4)	207	120	155	77	170	170	131	132	172	197	232	203	207	167
											Mean of monthly averages			168

* Includedi n the monthly averages.

TABLE 6. VERTICAL VARIATIONS IN SALINITY BASED ON DOWNHOLE CONDUCTIVITY

Bore-hole No.	19–4–75		16–5–74		17–6–74		17–7–74		20–8–74		16–9–74		17–10–74	
	Depth (m)	mg/l	Depth (m)	mg/l	Depth (m)	mg/l	Depth (m)	mg/l	Depth (m)	mg/l	Depth (m)	mg/l	Depth (m)	mg/l
2510	15·65–15·67	280	15·46–15·67	130	14·93–15·67	210	14·33–15·67	221	12·68–15·67	140	13·80–15·67	127	14·63–15·67	145
2511	17·34–21·76	170	16·65–20·00 20·00–21·76	90 95	15·15–20·80 20·80–21·76	150 190	14·54–21·76	139	12·98–21·20 21·20–21·76 21·76	130 120 180	14·02–21·76	98	14·96–20·77 20·77–21·76	120 140
2515	11·91–24·16	145	11·00–24·16	75	9·97–11·00 11·00–24·16	100 150	9·04–24·16	123	7·34– 8·57 8·57–10·60 10·60–24·16	120 140 160	8·25–24·16	143	9·66–14·50 14·50–24·16	125 160
2516	11·36–17·54	148	10·08–17·54	98	9·10–17·54	104	8·32–17·54	100	6·30–17·54	80	7·35–17·54	75	8·87–17·54	75
2810	....	....	19·71–21·00	98	17·44–21·09	150	16·39–21·09	141	12·30–13·40 13·40–21·09	110 100	14·20–21·09	110	15·87–21·09	140
2811	17·21–20·23	144	16·79–20·23	95	14·43–19·00 19·00–20·23	150 95	13·18–20·23	137	10·26–16·60 16·60–20·23	120 100	12·37–20·23	71	12·96–17·12 17·12–20·23	85 135
2815	9·67– 9·85	280	8·90– 9·85 9·85	135 160	7·07– 9·85	135	6·13– 9·85	120	4·45– 4·50 4·50– 9·85	110 120	5·40– 9·85	98	6·86– 9·85	105
2816	....	....	....	....	....	....	5·96– 7·35	90	4·36– 7·35	110	5·35– 7·35	78	6·78– 7·35	100
2910	19·70–34·31	130	19·39–34·31	90	17·40–29·00 29·00–34·31	140 90	16·43–34·31	84	12·64–23·40 23·40–34·31	80 140	17·47–34·31	60	16·02–34·31	120
2911	15·33–23·80	125	15·88–23·80	80	13·02–21·00 21·00–23·80	120 90	11·71–23·80	103	8·80–13·90 13·90–23·80	80 110	10·50–23·80	76	11·46–23·80	115
2915	7·81–15·31	115	6·73–15·31	73	5·11–15·31	115	4·12–15·31	78	2·50–15·31	70	3·39–15·31	73	4·83–15·31	95
2916	7·29–12·48	148	6·16–10·00 10·00–12·48	75 130	4·60–12·48	95	3·42–12·48	85	1·95–12·48	70	2·8–12·48	68	4·33–12·48	75
3310	15·77–36·58	170	15·66–30·00 30·00–36·58	105 115	15·10–16·20 16·20–36·58	170 180	14·59–36·58	78	13·08–20·00	110	14·01–36·58	140	14·51–24·50 24·50–36·58	165 150
3310	....	....	....	....	....	....	....	....	20·00–36·58	165	....	....	....	....
3311	14·95–41·30	180	14·70–41·30	130	13·94–41·30	210	13·36–41·30	90	11·24–41·30	130	12·20–41·30	125	12·92–11·30	165
3315	6·94–31·61	245	6·00–10·00 10·00–31·61	110 180	4·73–26·00 26·00–31·61	100 180	3·52–31·61	50	2·31–31·61	40	3·67–31·61	72	4·41– 7·25 7·25–31·61	95 140
3316	5·82–30·77	245	5·20–30·77	100	3·58–30·77	120	2·16–30·77	50	1·58–30·77	320	2·63–30·77	255	3·51– 6·76 6·76–30·77	140 180
3410	14·30–35·65	205	14·05–25·00 25·00–35·65	130 190	13·58–22·00 22·00–35·65	200 220	12·95–35·65	76	11·52–35·65	80	12·33–35·65	165	13·00–35·65	120
3411	13·88–34·37	175	13·54–34·37	130	13·37–34·37	210	12·72–34·37	166	17·17–34·37	80	12·01–34·37	104	12·55–34·37	125
3415	6·36–44·48	100	5·58–44·48	100	4·58–44·48	100	0·80–44·48	50	2·10–44·48	50	3·87–44·48	120	4·49–44·48	95
3416	5·56–24·19	238	5·61–10·00 10·00–20·00 20·00–24·19	170 180 175	3·90–24·19	300	2·25–24·19	166	1·60–24·19	270	2·44–24·19	235	?	195

Depth measured below top of casing.

20-11-74		23-12-75		23-1-75		24-2-75		15-4-75		19-5-75		Weighted mean
Depth (m)	mg/l	Depth (m)	mg/l	Depth (m)	mg/l	Depth (m)	mg/l	Depth (m)	mg/l	Depth (m)	mg/l	
15·33–15·67	190	dry	....	dry	....	dry	....	dry	....	dry	....	142
15·55–21·76	125	16·45–21·76	135	16·52–20·49 20·49–21·76	150 185	10·96–21·76	138	17·42–20·85 20·85–21·76	126 220	17·69–20·65 20·65–21·76	140 156	133
10·22–24·16	125	10·85–24·16	152	11·03–24·16	152	11·48–24·16	133	11·87–24·16	124	17·24–24·16	118	126
9·68–17·54	90	?	121	10·50–17·54	160	11·01–17·54	128	11·50–17·54	90	11·69–17·54	105	101
17·18–21·09	96	19·61–21·09	133	18·83–21·09	115	19·50–21·09	133	dry	....	dry	....	120
14·08–20·23	90	16·16–20·23	148	15·88–20·23	227	16·57–20·23	135	17·11–20·23	125	17·49–20·23	125	122
7·66– 9·85	96	8·75– 9·85	132	8·81– 9·85	242	9·31– 9·85	200	dry	....	dry	....	123
	....	dry	....	dry	....	dry	....	dry	....	dry	....	96
17·11–34·31	110	18·63–34·31	135	18·05–34·31	140	19·14–34·31	120	19·52–19·78 19·78–34·31	117 120	19·82–19·90	115	110
12·93–23·80	90	15·71–23·80	126	14·90–23·80	131	16·04–23·80	100	16·23–23·80	104	16·50–16·75	100	102
5·53–15·31	82	6·52–15·31	121	6·86–15·31	105	7·36–15·31	118	7·92–15·31	104	8·25–15·31	102	94
4·64–12·48	76	6·07–12·48	121	6·30–12·48	124	6·83–12·48	133	7·43–12·48	104	7·72–12·48	105	95
14·92–36·58	140	16·05–36·58	170	15·34–23·60	168	15·56–36·58	160	15·67–25·00 25·00–29·80	164 190	15·72–18·90 18·90–20·90	160 151	156
....	....	....	....	23·60–30·70 30·70–36·58	215 300	....	....	29·80–36·58	201	20·90–36·58	253	
13·53–41·30	165	14·97–41·30	203	14·24–18·00 28·00–41·30	195 250	14·60–41·30	205	14·82–41·30	155	14·88–41·30	185	169
5·07–31·61	110	6·31–31·61	208	6·17–31·61	260	6·57–31·61	250	6·90–31·61	245	7·02–31·61	230	160
6·65–30·77	60	6·02–30·77	100	5·18–30·77	167	5·50–30·77	208	5·85–30·77	187	6·01–30·77	250	173
13·28–35·65	165	14·94–35·65	220	13·74–35·65	280	14·32–35·65	180	14·10–35·65	245	14·12–17·15 17·15–19·00 19·00–35·65	160 185 170	174
12·82–34·37	82	13·93–34·37	155	13·34–17·00 17·00–34·37	161 210	13·63–34·37	106	13·70–17·50 17·50–34·37	187 200	13·79–34·37	174	152
5·70–44·48	140	5·98–44·48	105	6·98–10·40 10·40–44·48	90 160	6·16–44·48	205	6·83–44·48	170	6·54–44·48	230	123
?	220	5·30–24·19	275	4·87–24·19	270	?	265	?	228		234	241

GEOLOGY

The Darling Range forms the western, uplifted rim of the Yilgarn Archaean shield, locally comprising gneissose or granitic rock types intruded by dolerite. These have been deeply weathered and lateritized to provide a mantle over the bed-rock which reaches a thickness of up to 50 m. Bauxite occurs close to the surface in the upper parts of the laterite profile, particularly at high topographic levels. The laterite occurs in massive, gravelly, pisolitic or gibbsitic form and immediately overlies kaolinite which may be subdivisible into a number of zones depending on its physical and mineralogical characteristics. The kaolinite may contain residual quartz from original veining as well as floaters of relatively unweathered rock. These veins, together with old root tubes, may provide favourable infiltration paths through an otherwise poorly permeable sequence.

GROUNDWATER REGIME FOLLOWING MINING

Although relatively few bores have fully penetrated the weathered section, it is evident from the bore records that this section becomes thicker from the north (where it is between 13 and 24 m) to the south (24 and 44 m).

The first set of water-level measurements to be taken at the observation bores after their completion have been reduced to elevation above mean sea level and used to construct a plan of the water table (Fig. 4A). The number of bores is insufficient to accurately place the potentiometric contours on the east side of the mine pit and it has been necessary to assume that they approximate to a mirror image of the pattern on the west. As the measurements were taken on the 19th April 1974 they precede the start of the winter rains and hence represent the lowest position of the water table. It is obvious that the water levels below and downslope of the mine pit are higher than those below the forest to the west.

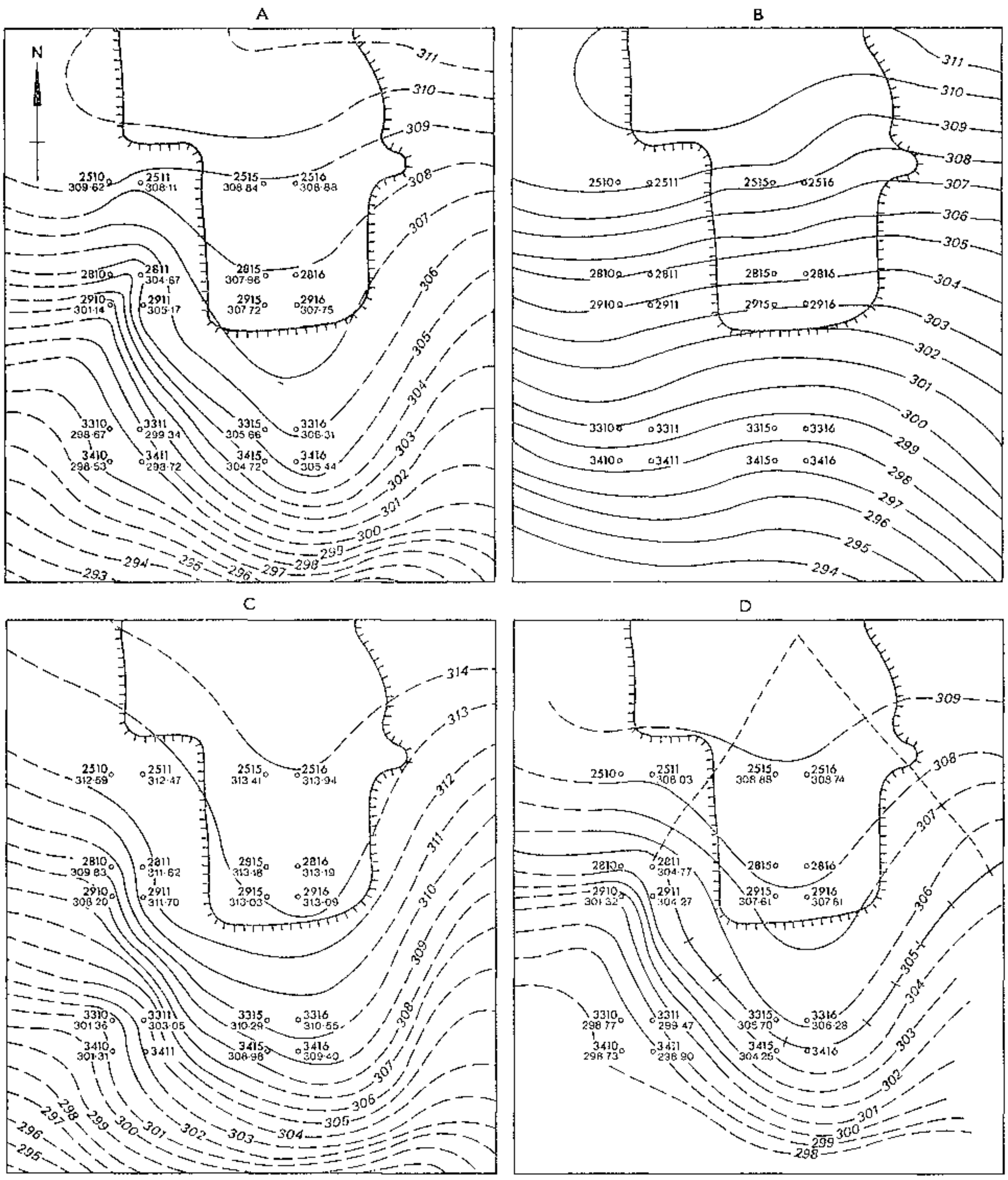

Figure 4. Water-table contours for:—A. April, 1974 ; B. April, pre-clearing ; C. August, 1974 ; D. April, 1975.

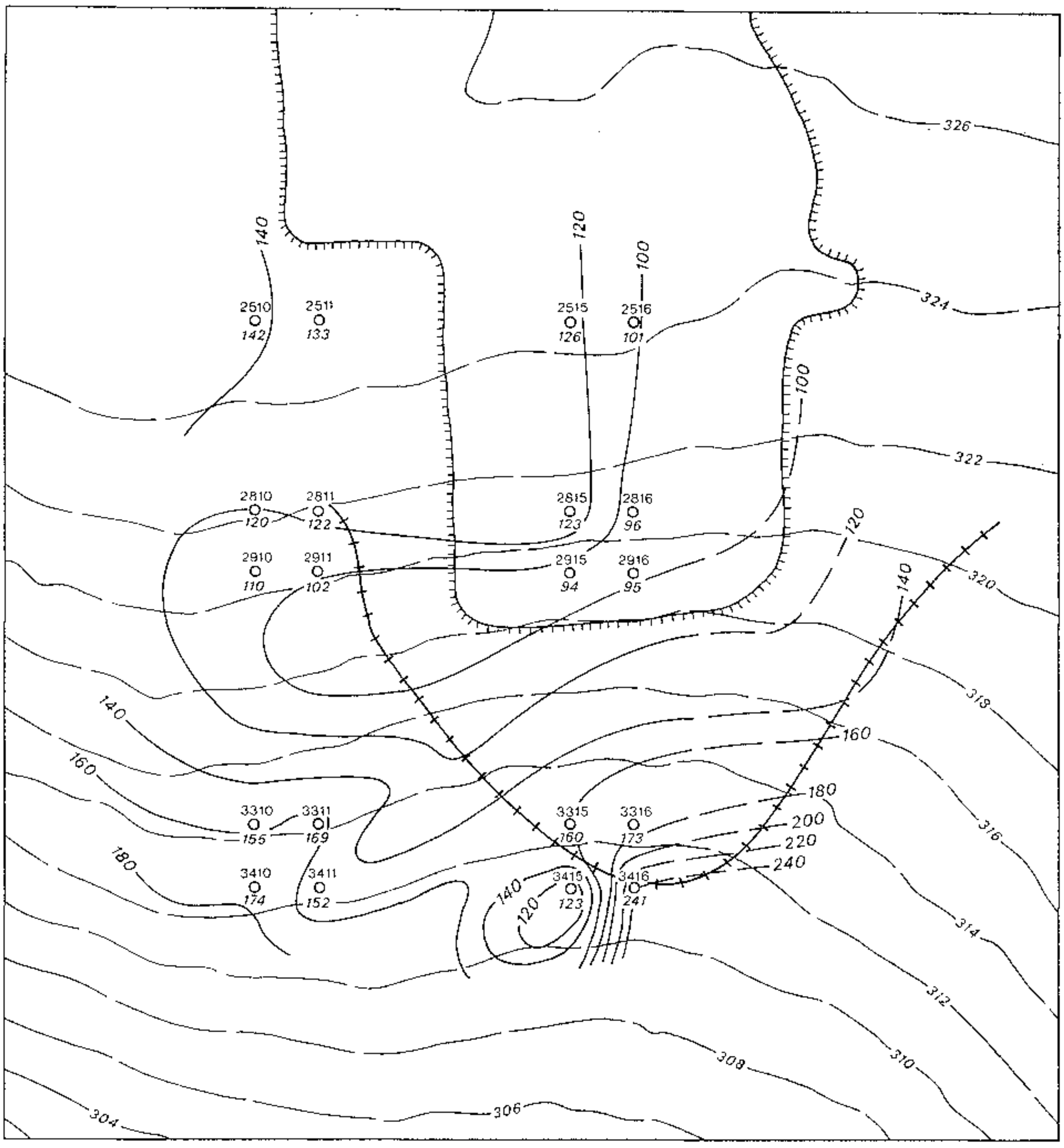

Figure 5. Contours of weighted average salinity (TDS mg/l).

If it is assumed that the April water-table position, prior to mining, was at a depth approximating to the depth indicated by the forest bores in April 1974, and that the water surface was a subdued reflection of the topographic contours, it is possible to very roughly depict the pre-mining water table (Fig. 4B). Comparison between the two plans clearly demonstrates that a groundwater mound has built up below the downslope section of the mine pit and southward below the forest. This has had the effect of steepening the hydraulic gradients to the west and south, possibly also to the east, whereas contours on the east side are subjective.

The pattern of salinity variations indicated by the analyses of water samples collected from the water table in April 1974 indicates that the freshest water occurs in bore 2915 at the southern end of the pit, where a TDS of 115 mg/l was recorded. From this point there is a general increase to the south and west to a maximum of 280 mg/l. There are some variations to this, notably at bore 3415 where relatively low salinities may be due to some annular leakage effects. Perhaps the clearest picture of areal variations in salinity is provided by the contour plan based on the weighted average of 13 monthly analyses between April 1974 and April 1975 (Fig. 5).

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SEASONAL CHANGES IN WATER LEVELS

During the months April to August 1974 inclusive, 1 440 mm of rain fell at Del Park. This resulted in a marked rise in the water table in all boreholes. Graphical plots of the reduced level of the water in each bore (Fig. 6) indicate the magnitude and variability of this rise. In the group of bores drilled west and southwest of the pit the average rise was 4.62 m and the range was between 2.58 and 7.06 m. In the mine pit group the variability was less and the range was between 4.57 and 5.34 m with an average of 5.08 m. Similarly, downslope of the pit in the other forest group of bores the rise was between 3.96 and 4.63 m with an average of 4.38 m. The greatest rise amongst all the bores was expressed in bore 2810 in the forest west of the pit. Bore 3411 in this group also exhibited the smallest rise. The maximum levels were experienced in August 1974 with the exception of bore 3415 in which it was July.

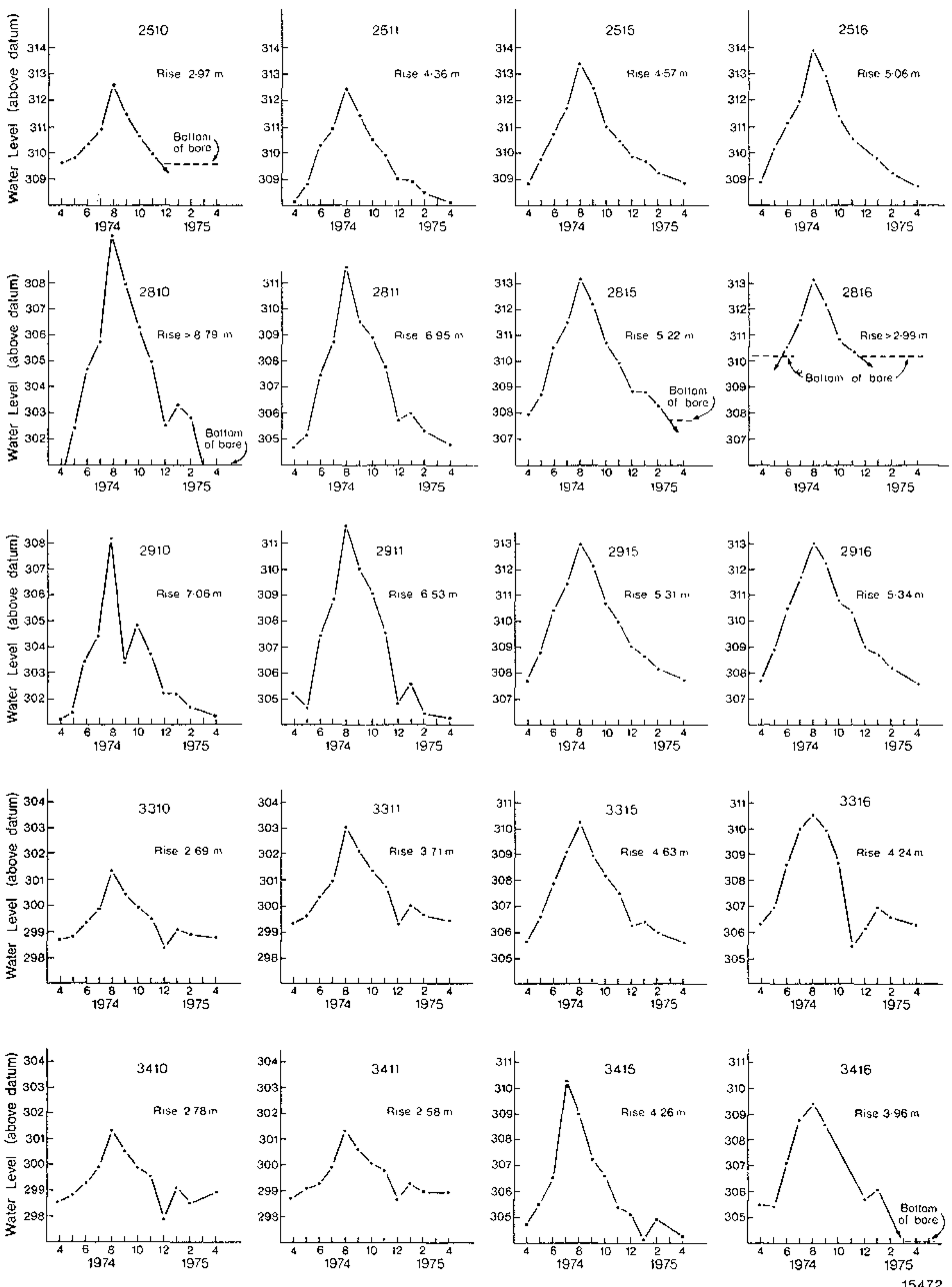

Figure 6. Hydrographs at observation bores (April, 1974 to April, 1975).

The August levels have also been used to construct a contour plan of the water table (Fig. 4C). Comparison with the preceding one for April indicates substantially the same pattern of groundwater flow with some differential rises producing minor changes in hydraulic gradient.

Most water levels exhibit a uniform recession from August onward (Fig. 6), whereas some of the hydrographs record an erratic drop in December or January and a subsequent slight recovery to the former line. The drop may be due to some instrumental error but it does coincide with some disturbance of the salinity trends and hence may be due to transpiration. Deep-rooting trees may be expected to increase their water usage with increases in summer temperatures.

The monthly water levels in each of the three bore groups have been averaged to produce mean hydrographs for each area (Fig. 7A). The April 1975 water-level data have been used to draw a further potentiometric contour plan of the water table (Fig. 4D) from which it is evident that the water table has fallen to the same position that it held during the previous April (Fig. 4A).

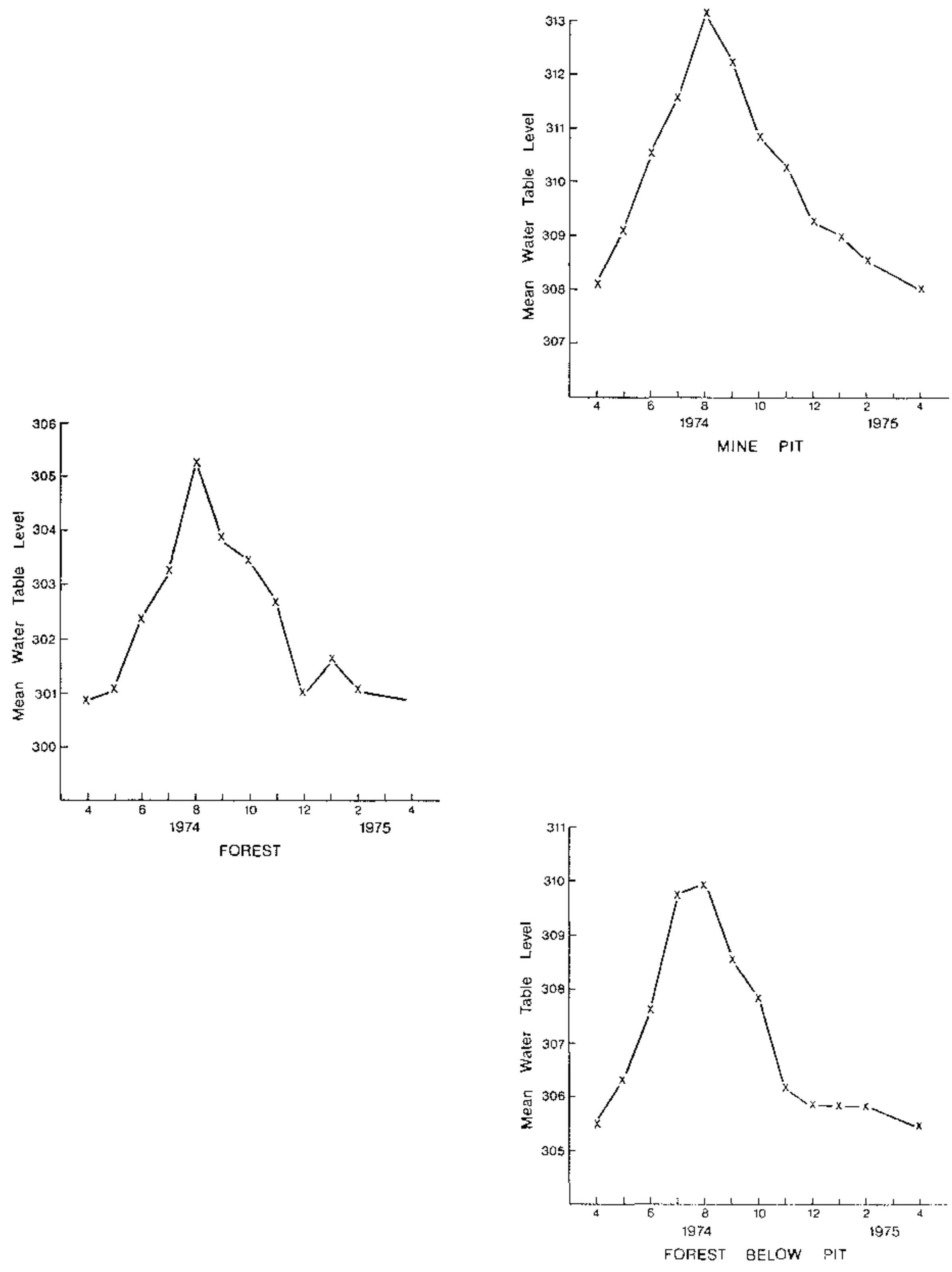

Figure 7A. Hydrographs based on mean water-table levels at each bore group.

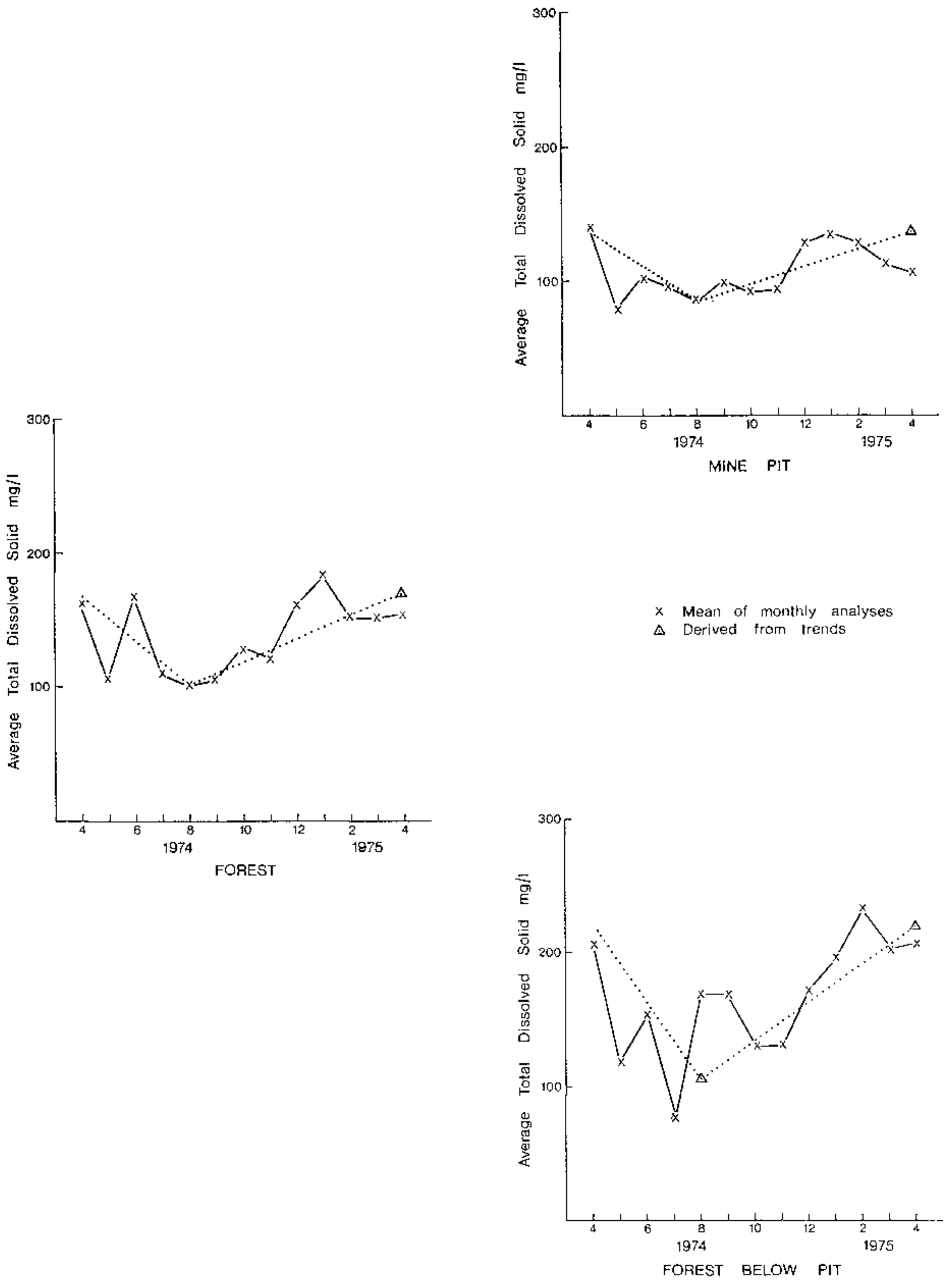

Figure 7B. Variations in mean salinity (TDS mg/l) at each bore group.

SEASONAL CHANGES IN SALINITY

Analyses of water samples collected each month from the water table (Table 5) have been used to produce graphs of salinity (TDS) against time (Fig. 8). These exhibit a relatively wide range of values for each bore group. The forest bores west and southwest of the mine pit have a range of 60 to 280 mg/l with an average of 140 mg/l. Maximum values tend to occur at any time between January and April and minimum values in July to September. However, there are many somewhat erratic variations that are difficult to account for. They may be due to sampling errors. A sudden drop in salinity during the winter period could be caused by annular leakage in the observation bore or the bore may have intersected a relict joint or root system which could provide a rapid infiltration path for rainwater. Alternatively an excessive disturbance of the natural disposition of water in bores may cause deeper and more saline water to rise and hence provide an indication of salinity above the seasonal trend. Blocking of the upper casing slots may have a similar effect. In order to minimize the effects of these factors, monthly averages of the analyses for bores providing complete records have been used to provide a mean plot of salinity against time for each bore group (Fig. 7B). These clearly indicate the time dependence of salinity, with minima occurring in July-August and maxima in January-April.

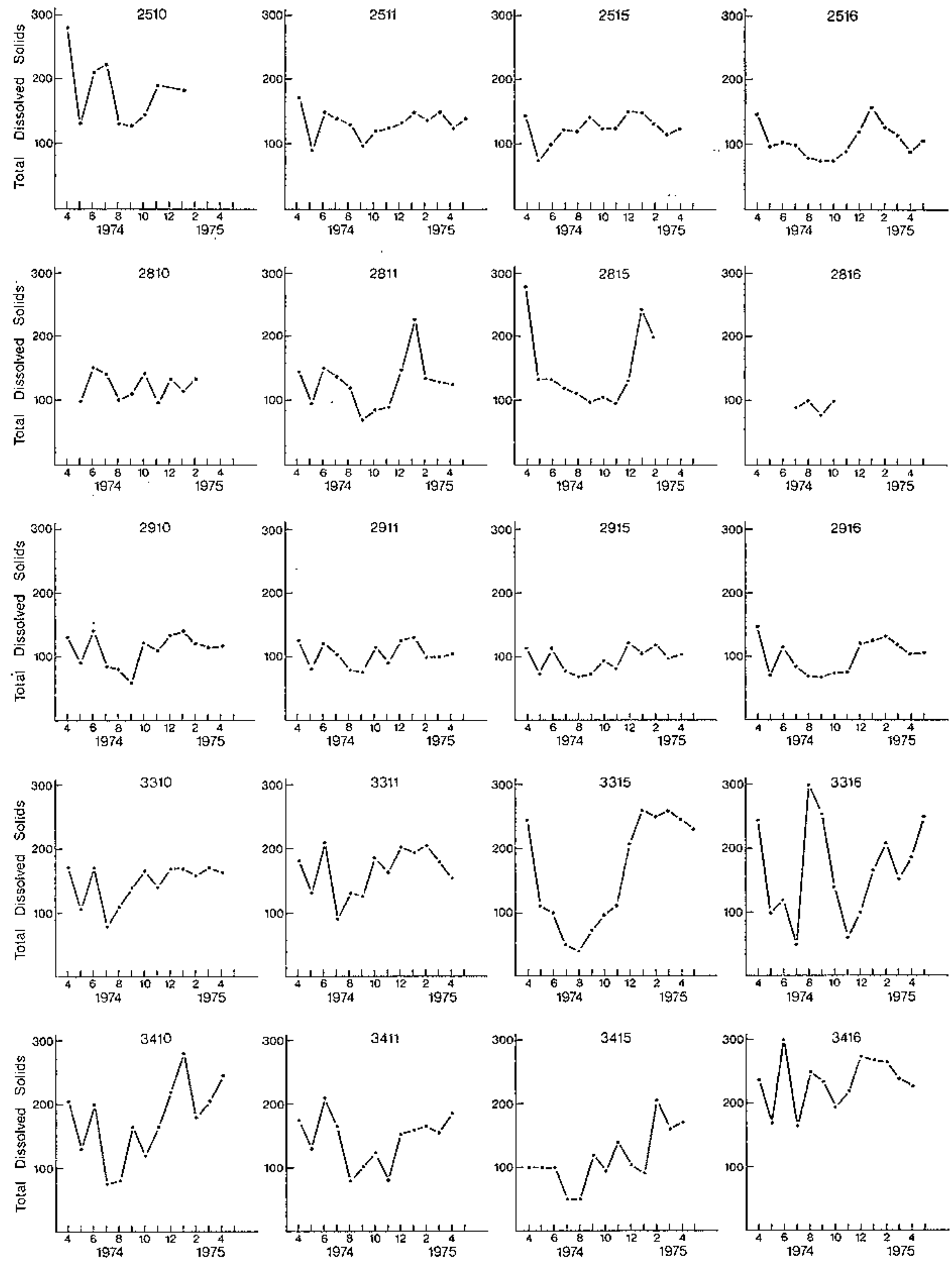

Figure 8. Variations in salinity at observation bores.

The water-table salinities for all bores in the mine pit group range from 70 to 280 mg/l and average 108 mg/l. Monthly averages of analyses of the four bores for which complete records are available (Fig. 7B) show a minimum of 85 in August and a maximum of 139 in April 1974. The graph shows a salinity rise in January to 135 mg/l and a fall to 105 in April 1975.

In the forest bores downslope of the mine pit the salinity range is from 40 to 320 mg/l and averages 168 mg/l. In general the graphs show sharper salinity variations than those for the other two bore groups, and this is reflected in the graph of averages (Fig. 7B). This shows a mean minimum of 77 in July and a maximum of 232 in February.

The forest group west of the mine pit has a minimum average salinity of 101 mg/l in August and a maximum of 181 mg/l in January 1975. The mean is 138 mg/l.

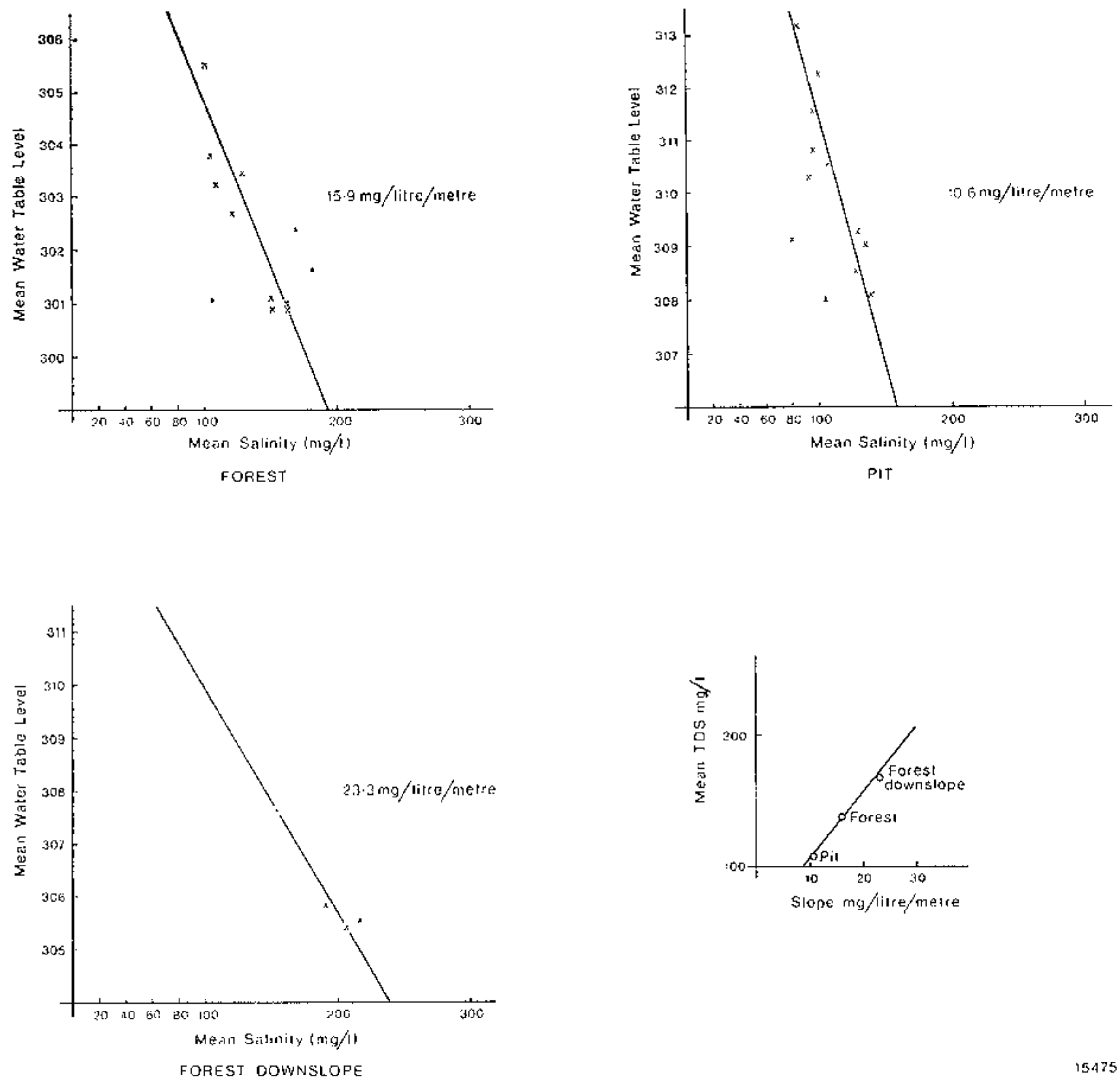

Figure 9. Relationships between mean salinity and mean water-table levels in three bore groups.

When the average salinity for each month in each bore group is plotted against the average water-table level there tends to be a linear correlation (Fig. 9). This is particularly strong in the mine pit group which exhibits an average salinity increase of 10.6 mg/l for every metre fall in water-table level. The increase is at a higher rate in the forest group at 15.9 mg/l/m and higher still in the group downslope of the mine pit. However the scatter of points for this group is wide and it is possible to draw alternative lines of equal validity. If the slope of the drawn line is correct there would appear to be a roughly proportional relationship between the slope and the mean TDS in each area.

RECHARGE TO THE WATER TABLE

The recharge (Q) to a groundwater system that is in balance both with respect to water and salt may be calculated from the relationship:—

$$Q = \frac{Cp}{Cg} \times (P-F) \qquad (1)$$

where Cg is the concentration of chloride in the recharge accession to groundwater (mg/l)

Cp is the concentration of chloride in precipitation (mg/l)

F is the overland flow (mm)

P is the precipitation in a given period (mm)

Q is the amount of recharge reaching the water table.

This presumes that the overland flow has the same chloride content as rainfall.

In order to apply this to the Del Park situation it is necessary to assess both aspects of the hydrologic balance. The hydrographic data reviewed to date have broadly indicated that over a complete climatic cycle the water table returns to the same position and maintains the same form. This was demonstrated by comparison between Figures 4A and 4D which are contoured plans for corresponding months. Detailed comparison between the level in each bore in April 1974 and 1975 indicates that the greatest difference is 470 mm (in one bore) but that the average is about 20 mm. It is therefore possible to say that there has been virtually no change in the saturated groundwater storage and that the output of water from the system is in balance with input.

The present salt balance in the unsaturated zone and at the water table is less easy to assess owing to the variability of the data. However the bores have been placed in three groups for study, each having characteristics which differentiate one from the others. Thus the forest west of the pit may be expected to have a substantial transpirative water loss and be subject to some run-off or overland flow.

Within the mine pit the transpiration loss from the water table would be negligible owing to its limited plant cover, and run-off would be contained within the pit; also a rise has taken place in the water table. The forest downslope of the pit would exhibit a transpiration loss, would have some overland flow and, like the mine pit, has experienced a large rise in the water table. This would partly be due to the influence of the rise below the mine pit immediately up-gradient and partly to extra infiltration allowed by die-back and selective felling. If the rainfall added less salt than was released to saturated groundwater storage from the unsaturated zone, the amount of such salt release would differ from area to area depending on localized conditions.

With the given data such variability may be assessed from the rise in the water table (R) in response to infiltration by assuming that the specific yield at each bore group is approximately the same. The relationship is:—

$$Q = RS \qquad (2)$$

so that combining with (1)

$$RS = \frac{Cp}{Cg} \times (P-F)$$

where R is the water table rise in mm

$$\text{or} \quad \frac{R\,Cg}{P-F} = \frac{Cp}{S}$$

S is the specific yield

Then for the forest group the value of $\frac{R\,Cg}{P-F}$ is:—

$$\frac{8\,200\dagger \times (101 \times 0.416)}{1\,440 - 120^*} = 261$$

similarly for the mine pit:—

$$\frac{9\,400\dagger \times (85 \times 0.416)}{1\,440} = 231$$

and the forest downslope of the pit:—

$$\frac{7\,200\dagger \times (108 \times 0.416)}{1\,440 - 120^*} = 245$$

Values for the two forest areas are fairly close but that for the mine pit differs by being 13 per cent lower which, having regard to the reliability of the salinity data, is a relatively small discrepancy. The results may be interpreted in three ways:

(a) The overland flow estimate is too high;

(b) The response to infiltration in the mine pit is lower than it should be because the specific yield is actually higher than that below the forest;

(c) The salinities in both of the forest bore groups are too high due to the accession of salt from the unsaturated zone.

If overland flow was actually absent in the forest areas the difference between the mine pit and other values would be reduced to about 4 per cent. The last point leads to the conclusion that if infiltration through the unsaturated zone is removing more salt than it adds to that zone, the relatively low salinity below the mine pit would indicate that its effect there must be much lower than below the forest and it could now be negligible. Thus comparison between the effects of bauxite mining and those of Phytopthora cinnamomi and selective felling in the forest areas would indicate that the latter result in higher groundwater salinities.

If it be accepted that the removal of salt from the unsaturated zone below the pit is now negligible, then the amount of the recharge resulting from 1 440 mm of rain in the mine pit may be calculated from equation (1). The chlorinity of the rainfall at Del Park is 9.0 (from Hingston, 1958) and the minimum salinity (TDS) is 85 mg/l. This may be converted to chlorinity by the factor 0.416 which is the ratio of Cl to TDS established from the chemical analysis of 9 samples drawn from various bores in the area (Table 7).

$$\text{Hence the recharge is } \frac{9}{85 \times 0.416} \times 1\,440 = 366 \text{ mm}$$

*Estimated from data from the Little Dandalup River.

†From recessions plotted in Figure 10.

Similar calculations for the forest area west of the pit and downslope to the south indicate infiltration of 283 and 264 mm respectively but these would be higher if the minimum seasonal salinities in these areas were influenced by salt release. Direct comparison of the figures as they stand indicates that the water table below the mine pit receives about 34 per cent more infiltration than the forest areas.

TABLE 7. CHEMICAL ANALYSES OF WATER SAMPLES

Partial analyses of water samples

Borehole	Depth (m)	Date	pH	TDS (mg/l)	NaCl (mg/l)
2511	20	6/3/74	6·3	200	112
2511	21	6/3/74	5·9	200	109
2811	18–19	6/3/74	5·2	140	94
2910	21	17/4/74	5·5	130	101
2910	34	17/4/74	5·1	120	91
3311	19	11/4/74	4·3	320	237
3311	42·12	11/4/74	5·2	170	124
3411	16	11/4/74	4·5	210	152
3411	34	11/4/74	5·5	200	140
Average				188	129

Ratio 1 : 0·686 4 NaCl
1 : 0·416 Cl

Standard analysis of water sample from Bore 2910

Bailed sample collected on 17th April, 1974

pH	5·7
TDS by Evaporation	110 mg/l
Conductivity x 0·7	130
NaCl	86
Total hardness	23
Total alkalinity	10
Calcium	3
Magnesium	4
Sodium	30
Potassium	1
Iron (Fe in solution)	<0·05
Boron	0·3
Fluoride	<0·1
Bicarbonate	12
Carbonate	Nil
Sulphate	7
Chloride	52
Nitrate	<1
Silica	7

AQUIFER CHARACTERISTICS

SPECIFIC YIELD

As has already been noted, infiltration reaching the water table causes it to rise by an amount depending on the specific yield. Where both the infiltration and the rise are known, the specific yield can be calculated from equation (2). However, only part of the potential water-table response to infiltration is recorded because recharge takes place over a period during which some losses by groundwater flow and transpiration take place. Account may be taken of this by extrapolating the water-table recessions into the recharge period, and measuring the "instantaneous" rise at a median time (Fig. 10). The indicated rise at the mine pit is 9.400 m, and as this was in response to the infiltration of 366 mm of rain, the specific yield S is

$$\frac{366}{9400} = 0.039\,0.$$

The specific yields for the forest bore groups may be similarly derived using the recharge figures previously quoted, these being 0.034 5 and 0.036 6 for the groups west and south of the pit respectively.

TRANSMISSIVITY

The quantity of water (Q_1) being discharged through a given cross section is given by the Darcy equation:

$$Q_1 = T\,a\,L \qquad (3)$$

where T is the transmissivity
a is the hydraulic gradient
L is the section length.

If the discharge is independently assessed it is then possible to derive the transmissivity at a particular flow section where the hydraulic gradient is known. In Figure 4D the catchment commanded by the section AA is indicated by two converging flow lines which contain an area of 18 590 m^2. The mine pit occupies 8 870 m^2 so that rainfall between April and August, 1974, could be expected to recharge the groundwater by 0.366 x 8 870 = 3 246 m^3 over this area.

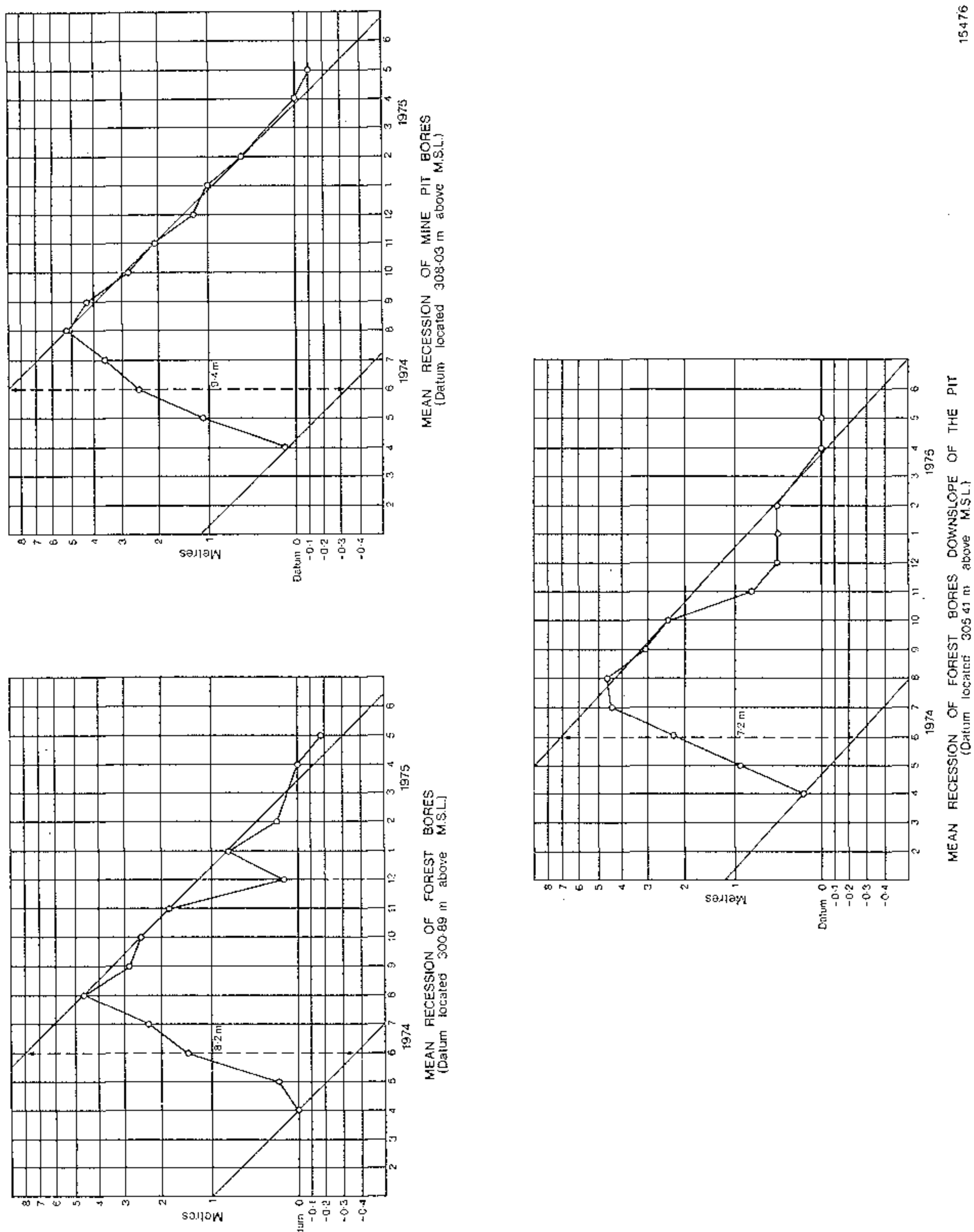

Figure 10. Seasonal rise and water-table recession between April, 1974 and April, 1975.

The recharge figure of 264 mm which has already been quoted for the forest area must be reduced for transpirative losses from the water table. As the water-table salinity in this bore group increases from 108 to roughly 230 mg/l during the recession it could be argued that the losses reduce the discharge to

$$\frac{108}{230} \times 264 = 129 \text{ mm}.$$

However, as will be seen later, some of the increase is due to leaching and indeed 1.22 times more salt is discharged from the area than is received from rainfall. If this factor is applied to the estimate of 129 mm, the estimated discharge becomes 158 mm. The area of the forest between the pit and the discharge section is 9 720 m² so that the groundwater discharge from this part of the catchment is 0.158 x 9 720 = 1 536 m³. The sum of the contributions from each part of the catchment is 4 782 m³ and the average hydraulic gradient through the section is 1.96 m in 24.38 m (80 feet) or 0.080 39 to 1. The transmissivity (T) through a section 255 m long is

$$T = \frac{Q}{aL} = \frac{4\ 782}{365 \times 255 \times 0.08039} = 0.636 \text{ m}^3/\text{day/m}.$$

HYDRAULIC CONDUCTIVITY

The average hydraulic conductivity may be derived by dividing the transmissivity by the average saturated aquifer thickness. Unfortunately many of the observation bores did not fully penetrate the water-bearing section and so it is only possible to state that the thickness is not less than 16.4 m and to estimate the value may be about 18 m. The hydraulic conductivity would therefore be approximately equal to

$$\frac{0.63}{18} = 0.0354 \text{ m}^3/\text{day}/\text{m}^2$$

$$\text{or } 68 \times 10^{-8} \text{ cm/sec}$$

These figures are quite high when account is taken of the lithology of the material through which water is passing, and may be indicative of some discharge taking place through fractures in the bedrock. The figures must in any case be regarded as approximate mean values as large variations are to be expected in relation to depth and possibly area. In the course of drilling several of the observation bores a slurry zone was encountered which defied recovery of samples by augering or coring, and apparently had a lower density than other material.

The hydraulic conductivity (K) may be used in conjunction with porosity and the hydraulic gradient to derive the velocity of water movement (V) from

$$V = \frac{Ka}{\phi} \qquad (4)$$

where ϕ is the porosity

If the porosity is 40 per cent, the velocity becomes

$$\frac{0.035 \times 0.08039}{0.4} = 0.0070 \text{ m/day in the direction of}$$

the hydraulic gradient. However as there is a water-table recession of about 8.2 m in 365 days there is a downward velocity component which averages $\frac{8.2}{365} = 0.022$ m/day. The vectorial addition of the two components yields a velocity of 0.027 m/day in a direction about 22° from vertical. This applies at the water table but deeper in the saturated profile the flow directions progressively veer towards the hydraulic gradient and the velocities approach 0.0070 m/day.

HYDROLOGIC BALANCE

The amount of infiltration which reaches the water table at each of the three groups of bores has been separately estimated. However the subsequent removal of water by transpiration and evaporation in the forested areas may be expected to cause the salinity of water at the water table to increase through the summer; the water loss also contibutes to the rate of recession. Salinities tend to reach a maximum in April, coinciding in time with minimum water-table levels. The relationship between these levels and salinity during the recession appears to be a linear one (Fig. 9) in at least two of the bore groups. However, the absence of deep-rooting trees in the mine pit area would obviously preclude transpirative losses and an alternative mechanism for salinity increase must be sought.

This may be illustrated by a simple model (Fig. 11) in which the water table is represented as moving through a series of 1-m cubes of water-bearing material. As the level falls, water drains successively from one cube to the next in the direction of groundwater movement. Each cube is assumed to have a porosity of 40 per cent of which 36.1 per cent is taken up by moisture of retention and the remaining 3.9 per cent (which is the specific yield) is occupied by water which is essentially mobile and takes part in the dynamic system. The salt stored in each cube is in balance so that when the water of saturation is displaced by an equal volume (Vd) of water having a salt concentration of C_i this is added to the salt stored in the moisture of retention (Vr) which has a concentration C_r. If the two concentrations then come into equilibrium by molecular and dynamic diffusion the water which drains from the first cube to the second will have a concentration C_e. This may be derived from $V_d C_i = V_r C_r = (Vd + Vr) C_e$

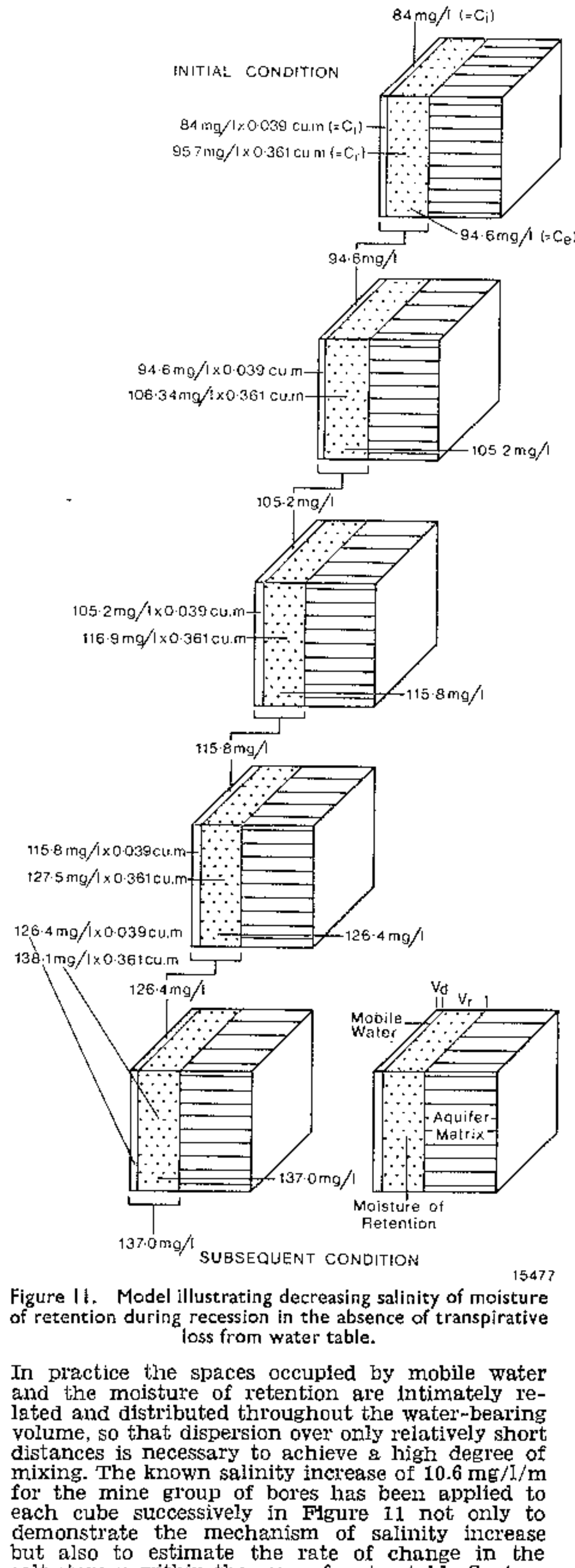

Figure 11. Model illustrating decreasing salinity of moisture of retention during recession in the absence of transpirative loss from water table.

In practice the spaces occupied by mobile water and the moisture of retention are intimately related and distributed throughout the water-bearing volume, so that dispersion over only relatively short distances is necessary to achieve a high degree of mixing. The known salinity increase of 10.6 mg/l/m for the mine group of bores has been applied to each cube successively in Figure 11 not only to demonstrate the mechanism of salinity increase but also to estimate the rate of change in the salt storage within the zone of water-table fluctuation. The model indicates a fall of 1.1 mg/l in the concentration of salt in the moisture of retention during each recession. The model has the disadvantage of taking no account of the passage of more than one volume (0.039 m³) through each cube, in the course of any one recession. However the measured water-table salinities are true ones and, provided the estimates of porosity and specific yield are reasonably correct, it is believed that the model indicates rates of leaching that are of the right order. At 1.1 mg/l per recession it will take

$$\frac{137-84}{1.1} = 48 \text{ recessions to reduce the salt stored}$$

in the zone of fluctuation to a storage level in balance with the influent water. The wetting or saturating cycle which takes place during the winter would probably have a similar leaching effect on the profile so that about 24 years is the time required for leaching to be completed. It is to be expected that during this period the salinities at all levels in the profile will decline unless water usage by plants increases, in which instance the reverse will occur until balance is again achieved.

In the forest west of the mine pit, the wide variations in the seasonal water-table rise and of the subsequent seasonal increases in salinity during the recession indicate wide variations in infiltration and of transpirative losses from the water table. The average infiltration is about 283 mm but could be a little higher. If the salt stored in water of retention within the zone of water-table fluctuation is in balance, then the average seasonal increase in salinity from 101 to about 170 mg/l would indicate a transpirative loss from the water table of about $283 - \frac{101}{170} \times 283 = 115$ mm. However this may be too high because the leaching of salt from the zone of fluctuation is quite possibly taking place as the forest association has been subject to disturbance due to Phytopthora, selective felling, and the use of forest tracks. The normal salt balance was disturbed before the commencement of mining.

The transpirative loss from the forest area downslope from the mine pit may be similarly calculated. It is not more than 135 mm and could be as low as 106 mm as previously derived.

If the quantity of infiltration reaching the water table is deducted from the incident rainfall (i.e. rainfall less overland flow), then the amount of water either directly evaporated or added to the soil and used by plants can be derived for each bore group. The greatest loss appears to occur in the mine pit where it is 1 074 mm and the smallest, 1 037 mm, in the forest to the west (Table 8). The difference is only about 3.5 per cent which is within the limits of error possible in the measurement of salinity or the estimation of run-off.

TABLE 8. WATER BALANCE (IN MM).

	Forest	Mine pit	Forest below pit
Rainfall (in period April-August)....	1 440	1 440	1 440
Run-off	120	0	120
Evaporation and moisture addition to unsaturated zone	1 037	1 074	1 056
Transpirative loss from the water table	115–78	0	135–106
Groundwater discharge	168–205	366	129–158
Infiltration reaching water table from rainfall	283	366	264

As rainfall in the period September to November, 1974, amounting to 225 mm, makes no contribution to the water-table rise, this quantity is almost certainly lost by evaporation and transpiration from the unsaturated zone and may be added to the corresponding figures in the table.

SALT BALANCE

The average annual input of chloride to a particular area may be derived from the rainfall chlorinity and the mean annual rainfall. The latter has been estimated to be 1 500 mm and the chlorinity 9 mg/l.

The input to the area defined by the flow lines and section on Figure 4D is therefore $9 \times 1\,500 \times 18\,590 \times 10^{-3} = 251$ kg. The flow of groundwater through the discharge section has been estimated to be 4 762 m^3/year. The mean salinity (TDS) derived from contours of the weighted means (Fig.5) for each borehole (Table 6) is 149 mg/l which includes a chloride content of $149 \times 0.416 = 62$ mg/l. The chloride discharge by groundwater movement is $62 \times 4\,762 \times 10^{-3} = 295.2$ kg. To this must be added the chloride discharged with the overland flow. This is estimated to be $9 \times 120 \times 9\,720 \times 10^{-3} \times 10^{-3}$ kg $= 10.5$ kg. The ratio of salt output to input is $\frac{295.2 + 10.5}{251} = 1.22{:}1$. An error of even 50 per cent in the estimation of overland flow would result only in a change of the calculated salt ratio of about 2 per cent. A more potent source of error would be any discharge of salt which takes place with flow through fractures in the bed-rock. This is quite possible and would result in the ratio, as calculated, being too low.

Although the preceding discussion of groundwater movement has mainly been in terms of flow through a relatively uniform medium of low hydraulic conductivity, the existence of open old root system tubes and remnant quartz-filled joints could provide a rapid and fairly direct means of recharging any groundwater contained in bed-rock fractures. Indeed such a condition could possibly constitute a distinct flow system which may have been the dominant means of groundwater movement in some forest areas prior to disturbance by felling or Phytopthora. At this time the salt outflow was in balance with inflow and the efficiency of water usage by the forest association was such that it consumed virtually the whole of the rainfall which entered the normal soil profile. The groundwater contribution to stream-flow would then have been almost entirely from the bed-rock joint system.

CONCLUSIONS

1. The infiltration of rainfall to the water table below the mine pit has been estimated by salt balance to average 34 per cent higher than below the forest area. This would be reduced by between 4 and 13 per cent if leaching of salt from the unsaturated zone were still occurring in the forest.

2. Infiltration in the forest area is very variable, and water-table rises are sometimes higher than below the mine pit.

3. Groundwater discharge from below the mine pit is more than twice that of the groundwater discharge from below the forest. This is due to a lack of transpirative loss once water has reached the water table.

4. The development of a large groundwater mound is mainly due to the absence of transpirative loss from the water table and only in minor degree is it due to a greater infiltration.

5. The groundwater mound represents an increase in the groundwater storage. It may be expected to recede when transpirative use both reduces the accession of water to the water table and increases withdrawal of water from it.

6. The average specific yield is approximately 0.039 and the hydraulic conductivity is 0.035 $m^3/day/m^2$.

7. The release of salt from the unsaturated zone in the mine pit is now very small but leaching is taking place in the zone of water-table fluctuation. The same may be occurring below the forest.

8. Although there is salt leaching taking place below the mine pit the lack of transpirative loss from the water table means that the additional salt is discharged in a larger quantity of water and hence is diluted to a salinity that is now lower than that of the main body of groundwater.

The pattern of salinity indicates increasing salinity in the direction of groundwater movement. This is due to the transpirative loss of water from the water table or reduced infiltration for the same reason. If this loss increased because of the water table being shallower, it could nullify the freshening effect of the additional groundwater discharge resulting from clearing upslope.

9. The present salt imbalance is such that approximately 1.2 times as much salt is being discharged as is received in rainfall. It is not possible to separately estimate the contributions of salt made by the disturbed forest and the mine pit.

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OUTLINE OF THE HYDROGEOLOGY OF THE SUPERFICIAL FORMATIONS OF THE SWAN COASTAL PLAIN

by A. D. Allen

ABSTRACT

The Swan Coastal Plain forms part of the eastern onshore edge of the Perth Basin. In downward order it is underlain by a highly variable sequence of "Superficial Formations" up to 90 m thick of Quaternary age which rest with marked erosional break on about 8 000 m of Phanerozic sedimentary rocks.

Unconfined groundwater occurs in the "Superficial Formations", and is locally in hydraulic continuity with the confined groundwater in the underlying formations. The areas to the north and south of Perth are hydrogeologically distinct. In the northern area the water table forms a pronounced north-south-trending ridge (Gnangara Mound) rising to 70 m above sea level, whereas to the south the groundwater generally slopes downward to the west apart from an area south of the Swan River (Jandakot Mound) where the water table reaches 25 m above sea level.

The Gnangara Mound contains substantially larger resources than those of the area south of the Swan River. The groundwater is replenished annually by rainfall, and north of the river has a salinity generally ranging beween 250 and 500 mg/l TDS. However the presence of iron, turbidity, and colour necessitates treatment before it can be used for public water supply purposes.

INTRODUCTION

LOCATION

The part of the Swan Coastal Plain where groundwater resources are being investigated for the Perth metropolitan region covers the area from Gingin Brook in the north to Peel Inlet in the south, and is shown in Figure 12. It extends for about 70 km north and 65 km south of Perth, and has an area of about 3 600 km^2 of which about 2 200 km^2 are north of the Swan River and 1 400 km^2 are to the south.

The area north of the Swan River has an average elevation of 30 to 60 m above sea level whereas to the south the average elevation is only 15 to 30 m. There is also a marked variation from west to east across the coastal plain. The area adjacent to the coast has an irregular topography typified by linear ridges, while the central part of the coastal plain is relatively flat, gradually increasing in elevation as the Darling Range is approached and increasing very steeply along the foot of the range. Modifying this general pattern are lower areas associated with the major rivers where they cross the plain.

The coastal plain to the north and south of Perth is topographically, hydrodynamically and to a certain extent geologically divisible into two distinct areas. They are described separately and for convenience of description they are hereafter referred to as the northern and southern areas.

PURPOSE AND SCOPE

The increasing demand for water in the Perth region has necessitated the assessment of the groundwater resources in the vicinity of Perth. At present, groundwater provides about 10 per cent of the requirements for Perth's water supply but by the year 2000 may provide 25 per cent.

Beneath the coastal plain there are two major, related groundwater resources: unconfined groundwater in the superficial formations, and confined groundwater (artesian and sub-artesian) in the considerably older, underlying sedimentary rocks.

This account deals with the unconfined groundwater resources. It is not a detailed or complete account because acquisition and assessment of data is still continuing. Nevertheless the broad outline of the hydrogeological regime is now becoming clear, and is described.

DRILLING PROGRAMMES

Exploratory drilling of the unconfined groundwater resources commenced in the northern area in 1962 and in the southern area in 1972. A total of 249 exploratory and production sites have so far been drilled of which 213 have been drilled in the last 3 years. The location of the exploratory and production sites is shown in Figure 13 and the different drilling programmes are summarized in Table 9.

TABLE 9. SUMMARY OF DRILLING PROGRAMMES

Project/ Scheme	Commenced	Completed	No. Sites	Authority
Northern Area				
Gnangara	1962	1969	35*	GSWA & MWB
Mirrabooka	1969	1975	19‡	MWB
Gwelup	1971	1974	15‡	MWD
Whitfords	1972	1972	6†	MWB
Wanneroo	1972	1974	24‡	MWB
Joondalup	1972	1975	23	GSWA
Gingin	1973	1973	11	MWB
Yanchep	1973	1973	10	MWB
Pinjar	1975	1975	30‡	MWB
Southern Area				
Lake Thompson 1	1972	1973	11	MWB
Lake Thompson 2	1974	1975	11	MWB
Lake Thompson 3	1975	1975	54	MWB
Jandakot	1975	Continuing	30	MWB
Total	....	....	279	

* Exploratory and production bores.
† Abandoned production bores.
‡ Production bores.

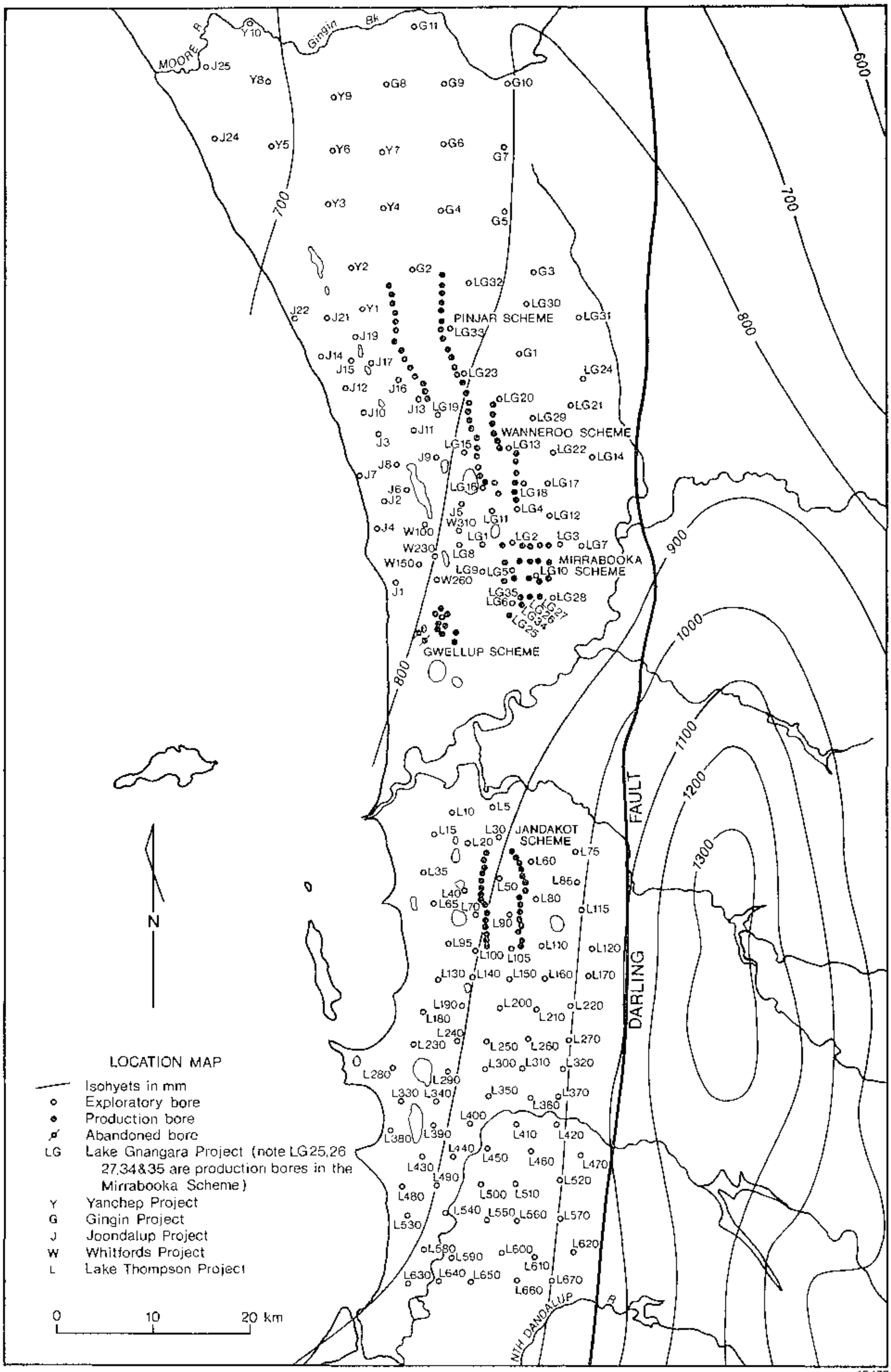

Figure 12. Location Map.

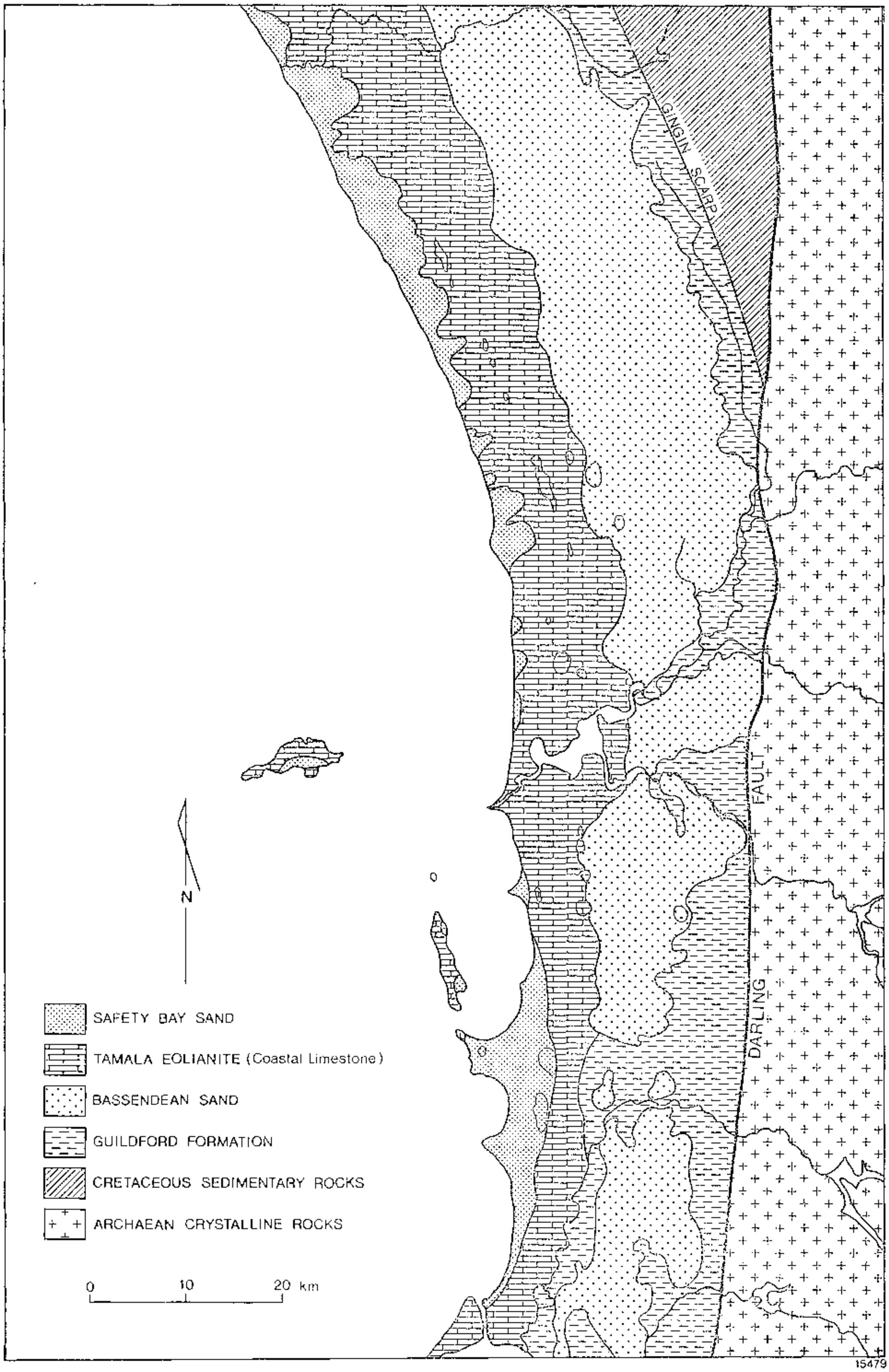

Figure 13. Simplified geology.

PROCEDURES

Drilling, sampling, construction and testing procedures have varied quite considerably in the different drilling programmes. At exploratory sites a single test-production bore alone, or with one, three or six observation bores was constructed. At production sites an observation bore was first constructed and then later a production bore.

The drilling has mainly been done using cable-tool rigs because of the better samples which can be obtained. However some exploratory bores and many production bores have been drilled using rotary rigs.

Sludge samples were taken at 1.5 m (5 feet) or 3 m (10 feet) intervals, geologically logged and if necessary sieved. The bores were usually sunk a minimum of 3 m into the underlying formations so that fresh samples could be obtained for palynological examination. Gamma-ray logs were run on all bores to assist in defining bed and formation contacts.

Test-production and production bores were usually constructed using 6-inch, 8-inch or 10-inch casing with screens set at the bottom of the bore and extending over about one third of the saturated aquifer thickness.

Observation bores were constructed using 2-inch galvanized iron pipe with short lengths of screen at the base, or more usually with 3-inch P.V.C. tubing slotted over the saturated aquifer thickness and gravel packed to provide stability.

Pumping tests were carried out on exploratory sites which warranted testing to determine the aquifer characteristics, and on all production bores to test their acceptability. Usually the testing was preceded by three to five-stage step up pumping tests, in which the pumping rate was increased in each test and held constant for one hour. The following day a continuous rate test, usually of 24 hours' duration was carried out, while measuring drawdown response in the pumping bore and observation bore(s).

At completion of the pumping test (and during the pumping test in some cases) water samples were taken to determine physical characteristics, principal ions, important trace elements, dissolved gases and bacteriological purity of the water.

When testing was completed the bores were left for observation purposes.

DATA

A very large volume of data has now been obtained. Apart from that given in various reports, detailed information on geology, pumping test results, and water quality are held on file at the Geological Survey and the Metropolitan Water Board.

Strata samples have been stored at the Geological Survey core library.

Monthly water-level measurements from the exploratory bores and pre-existing Metropolitan Water Board monitoring bores, are available from the Water Board computerized groundwater levels storage and retrieval system.

In addition, records of about 2 000 private bores obtained in the bore census work carried out by the Geological Survey are available in the Hydrology Division bore record system.

GEOLOGY

GEOLOGICAL SETTING

The Swan Coastal Plain is situated on the eastern onshore edge of the Perth Basin. It is underlain by about 8 000 m of Phanerozoic sedimentary rocks, separated from Archaean crystalline rocks of the Darling Range by the Darling Fault.

STRATIGRAPHY

The stratigraphic sequence of formations for the Perth Basin has been established from boreholes and regional geological mapping. The Mesozoic and Tertiary formations are reasonably well known, but the lithological complexity resulting from Quaternary formations is less so due to palaeogeographic variations.

The stratigraphic sequence referred to in this account is given in Table 10 (Playford and others, in press).

TABLE 10: STRATIGRAPHIC SEQUENCE

Formal Age		Group	Formation	Maximum Thickness (m)	Summary of Lithology
CAINOZOIC	Quaternary	....	Superficial Formations	90	Sand, limestone, clay
	UNCONFORMITY				
	Late Tertiary	....	Rockingham Sand	100+	Sand, minor siltstone
	UNCONFORMITY				
	Early Tertiary	....	Kings Park Formation	520	Calcareous siltstone, shale, minor sand and limestone
	UNCONFORMITY				
MESOZOIC	Late Cretaceous	Coolyena Group	Gingin Chalk	c. 25	Fossiliferous and glauconitic chalk
		Coolyena Group	Molecap Greensand	c. 15	Glauconitic sand
		Coolyena Group	Osborne Formation	150	Glauconitic shale, siltstone, minor sandstone
	Early Cretaceous	Warnbro Group	Leederville Formation	450	Siltstone, sandstone, shale
	Early Cretaceous	Warnbro Group	South Perth Shale	120	Siltstone, shale, minor sandstone
	UNCONFORMITY				
	Late Jurassic	....	Yarragadee Formation	3 000	Siltstone, shale, sandstone
	Middle Jurassic	....	Cadda Formation	....	Shale, siltstone
	Early Jurassic	....	Cockleshell Gully Formation	2 000	Massive siltstone, sandstone, shale

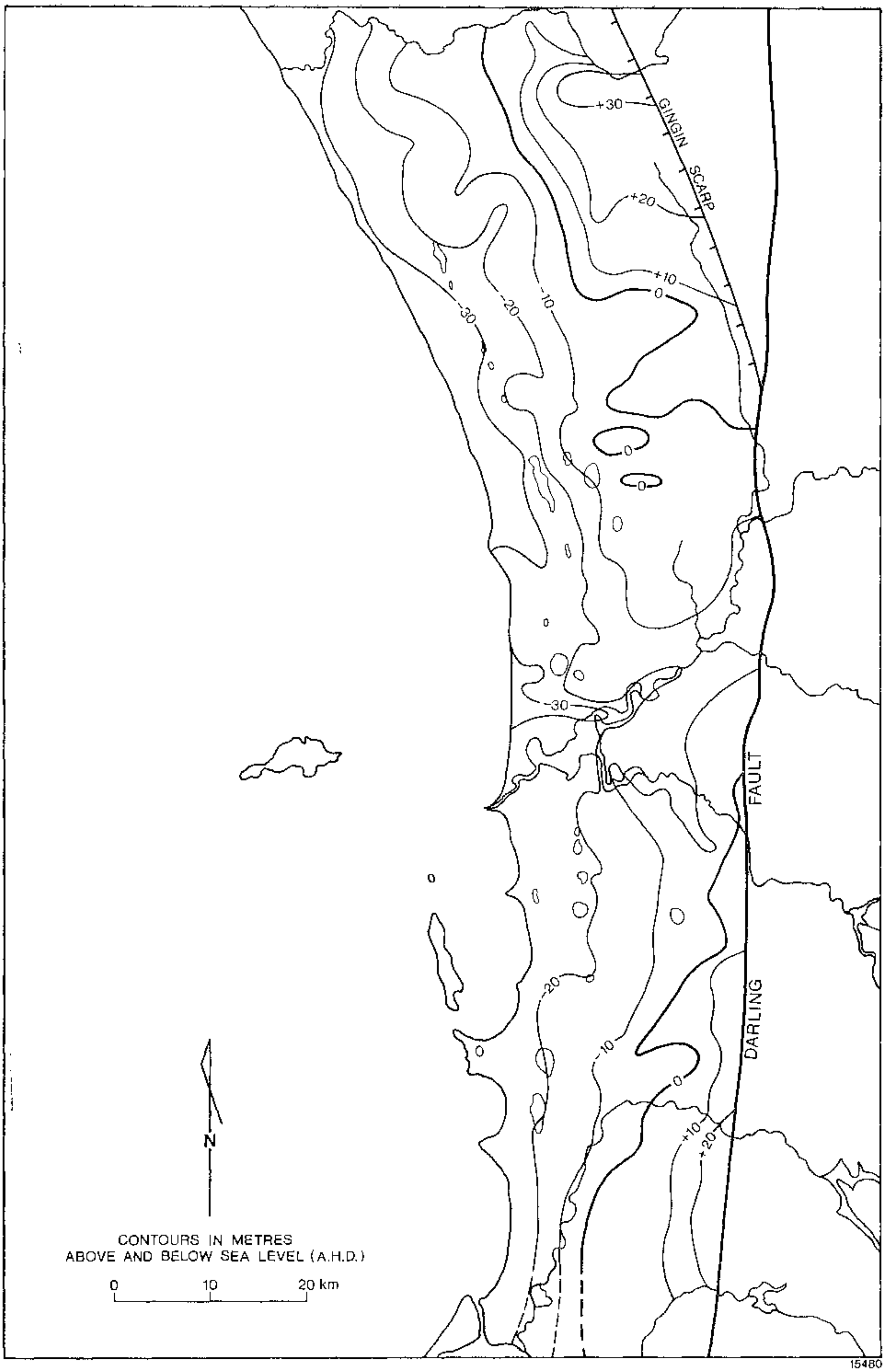

Figure 14. Map of pre-Quarternary erosion surface.

The Quaternary sediments vary in thickness from about 15 to 90 m. They rest with a pronounced unconformity on the much older Mesozoic and Cainozoic formations. The unconformity surface shown contoured in Figure 14 ranges from 35 m below sea level near the coast to about 35 m above sea level near Gingin. The surface is very irregular and is possibly a composite of two periods of erosion. It is below sea level over about three-quarters of the coastal plain, and is traversed by relatively deeper channels apparently associated with former courses of the major rivers.

The Quaternary has been mainly subdivided on the basis of geological mapping of the uppermost units. However, drilling has shown that there are also recognizable subsurface units and that the relationship between units is more complex than suggested by the surface mapping. The complexity results from the palaeogeographic conditions at the time of deposition and the variations in sea level since the Late Pliocene.

The Quaternary formations, despite their variability, form a single aquifer system, and to avoid complications with nomenclature are here referred to collectively as the Superficial Formations.

These formations consist of a laterally and vertically variable sequence of sand, limestone, silt and clay. In broad terms they consist of a sequence of calcareous marine sands and eolianites (Coastal Limestone) near the coast, passing inland to a variable sequence of fine and medium sand with minor silt and limestone (Bassendean Sand), which in turn grade into, and interfinger with, a sequence of clay, clayey sand and minor gravel (Guildford Formation) adjacent to the Darling Range. This general pattern is modified by younger deposits of silt, clay and gravel along the major rivers, and by recent dune sands or marine strand-line deposits along the coast. Remnants of older littoral and eolian deposits are preserved along the foot of the Darling Range. The generalized geology is given in Figure 13.

STRUCTURE

Structurally the Mesozoic formations form a broad, faulted, slightly asymmetric syncline with the steepest limb in the east. The Tertiary formations are preserved in channels, possibly related to the Rottnest Trench, which were eroded into the pre-existing formations. Together, they form a basement to the Superficial Formations which rest on an irregular surface which slopes downward to the west. The Superficial Formations are flat-lying, stratigraphically complex, and are not known to be faulted.

HYDROLOGY

RAINFALL

The average annual rainfall on the coastal plain decreases in a northwesterly direction from about 1 100 mm at Serpentine to less than 700 mm at Guilderton (Fig. 12). About 90 per cent of the average rainfall is received between April and October, but the annual amount may vary quite widely between different years.

DRAINAGE

The coastal plain is traversed by four major drainage systems: the Gingin Brook-Moore River System which forms the northern boundary to the area, the Swan-Canning River System which bisects the coastal plain into the northern and southern areas, the Serpentine River, and the South Dandalup-Murray River System which forms the southern boundary. All are major through-going rivers (some of which are dammed) carrying run-off from the Darling Ranges as well as a proportion of groundwater outflow from aquifers on the plain.

In the northern area the eastern edge of the coastal plain is bounded by Ellen Brook which carries run-off from a number of small tributaries rising in the Darling Range and from a number of small groundwater-fed drainages at the eastern edge of the Gnangara Mound. By contrast, in the southern area, south of Wungong Brook about a dozen small drainages (brooks) flow onto the coastal plain from the Darling Range where they dissipate or are canalized and linked with the Serpentine River.

The minor drainages are usually associated with the more silty or clayey Superficial Formations towards the eastern edge of the coastal plain. On the central and coastal parts of the plain there are no drainages developed because of the permeable nature of the sediments.

LAKES AND SWAMPS

Three main types of lakes can be recognized: circular lakes, linear lakes, and coastal lakes.

The circular lakes, such as Lake Gnangara or Lake Thompson, are usualy located close to the surface boundary between the Coastal Limestone and the Bassendean Sand. A few such as Lake Thompson and Lake Bambun occur toward the eastern edge of the coastal plain. They are not known to exceed about 3 m in depth.

The linear lakes are formed in interdunal areas on the coastal strip, and locally may be quite deep. To some extent their hydrology may be influenced by the presence of limestone caves, as appears to be the case at Lake Joondalup and Loch McNess.

The coastal lakes are restricted to the Rockingham district and appear to result from isolation and partial infilling of part of Cockburn Sound. They range in depth from 3 to 30 m.

All the lakes contain lacustrine sediments up to 10 m in thickness, consisting of clay, peat, diatomite, bog limestone, and peaty sand.

The lakes are outcrops of the water table, and their levels vary seasonally in sympathy with the water-table fluctuations. They are of variable salinity depending on the salt balance of each lake. While the lakes in each group have certain similarities, each is controlled by its own flow system.

Swamps are found mainly in the eastern and central parts of the coastal plain. They are rare on the coastal strip where the elevation of the dune system and depth to water generally precludes their formation. Most of the swamps occur in interdunal depressions but some may be on the sites of former lakes.

The swamps usually contain dense vegetation. They are formed where the water table is at or near the surface and may have areas of open water in the winter months. Peat and peaty sands occur in many swamps and most are underlain by a ferruginous hardpan (coffee rock).

The open water surfaces of the lakes, the dense vegetation which grows around their margins and the vegetation of the swamps directly deplete the groundwater by evaporation and transpiration. Swamps occupy about 9 per cent of the Swan plain and are responsible for very substantial quantities of groundwater being lost. They are also ecologically very important.

GROUNDWATER

GENERAL

The Superficial Formations on the coastal plain are saturated with water to a level controlled by the annual rainfall, the relief, the hydraulic characteristics of the aquifers and by the natural vegetation. The water which the sediments contain is unconfined and the top of the zone of saturation forms a water table which extends beneath all of the coastal plain.

The groundwater originates from rainfall which percolates into, and moves slowly under gravity through, the Superficial Formations, to be discharged at hydraulic boundaries formed by the sea and the major rivers. During movement through the Superficial Formations it is substantially depleted by evapotranspiration from lakes, swamps, and where the roots of vegetation can reach the water table; by infiltration into underlying formations; and by pumping from boreholes. In the vicinity of the coast line and the major estuaries the fresh groundwater is in direct contact with seawater in the Superficial Formations.

The present configuration of the water table is in a general way a reduced facsimile of the major topographic features. It has developed since the stabilization of sea level and under the prevailing climatic conditions. The configuration has been to some extent affected by man's activities, in particular clearing of bushland, drainage, and groundwater use.

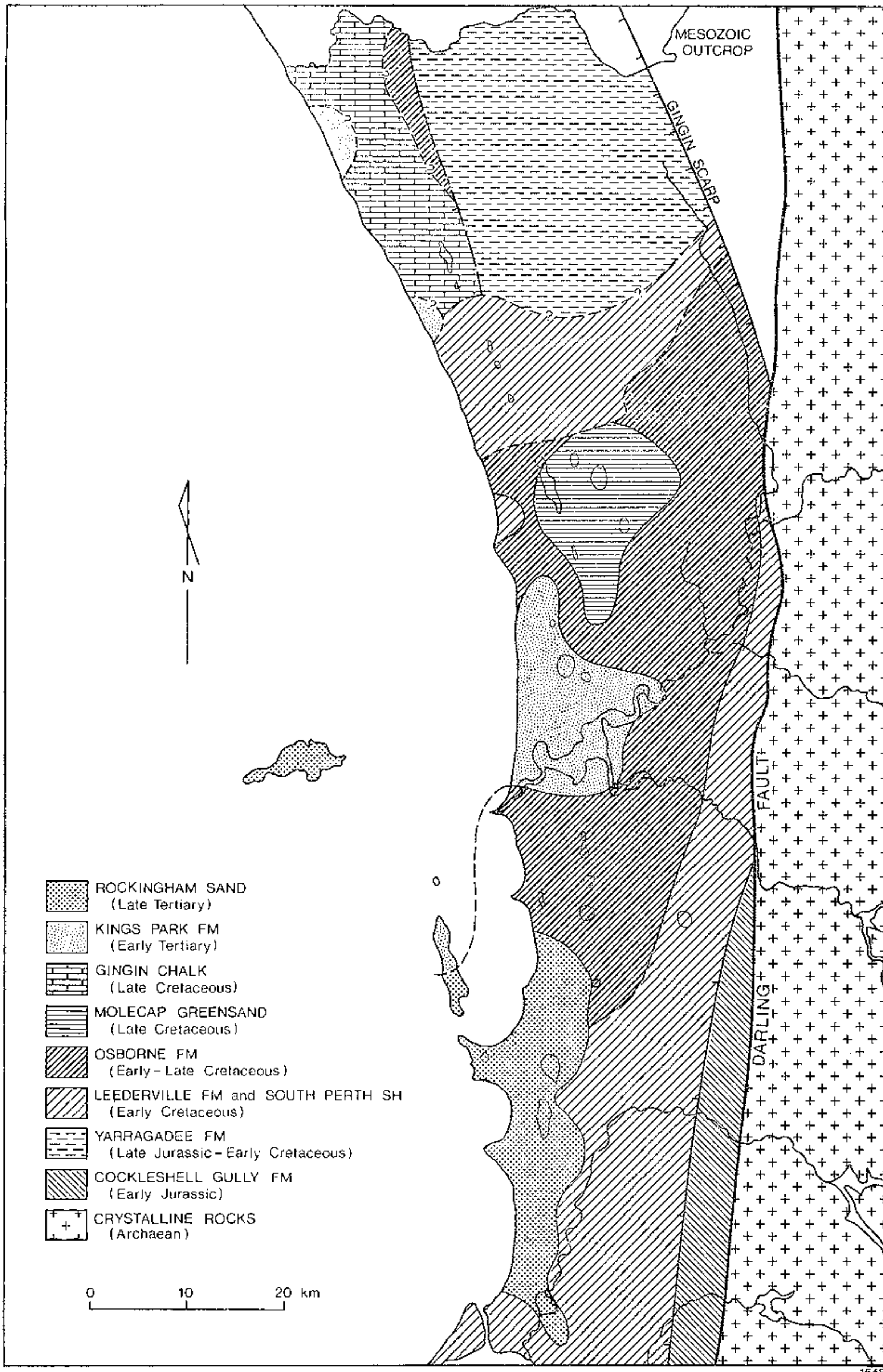

Figure 15. Subcrop map.

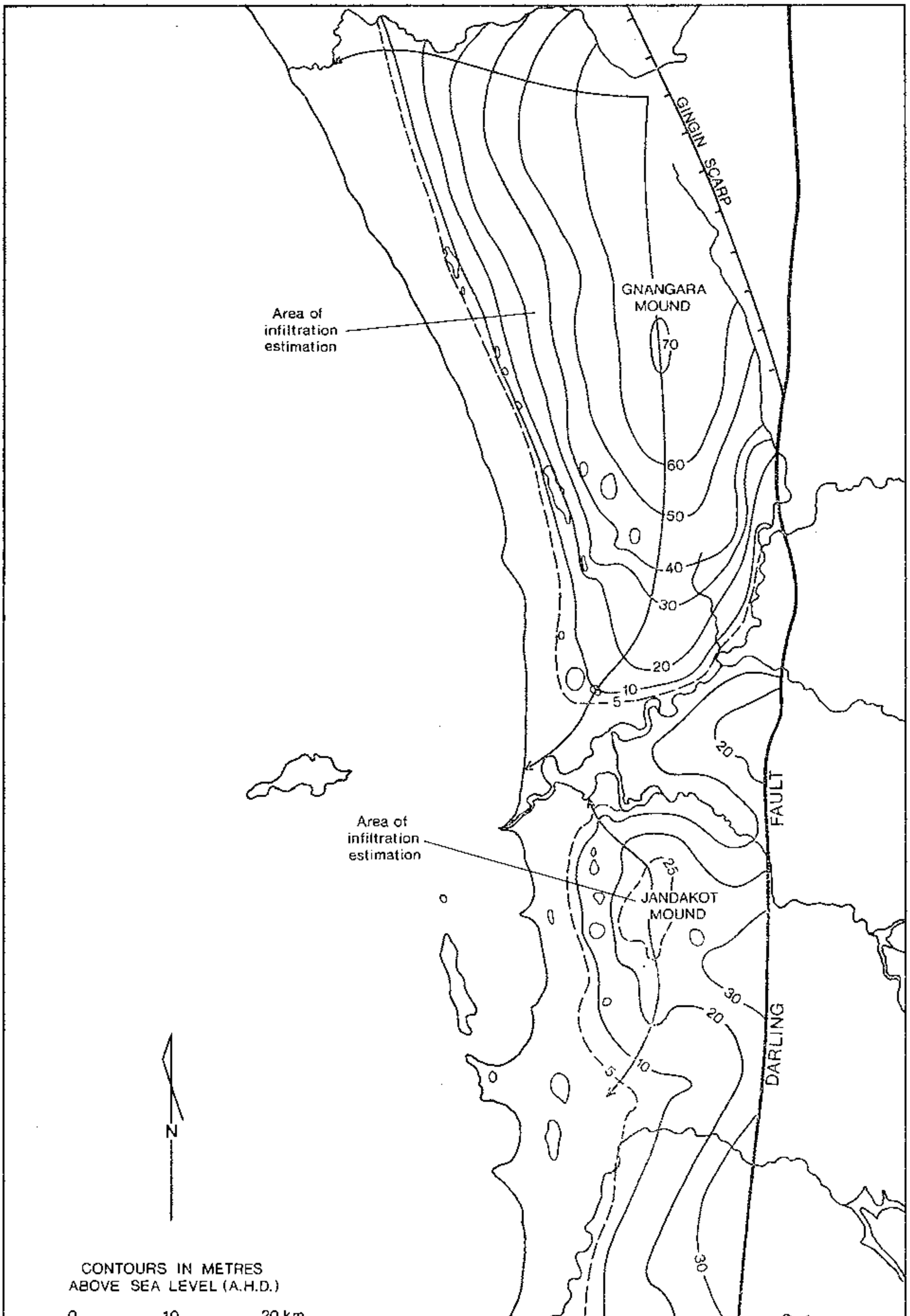

Figure 16. Water-table map.

The water table undergoes seasonal variations in level and configuration. Its general form, based on levels for summer 1974 in the northern area, and summer 1975 in the southern area, is given in Fignre 16.

The northern and southern areas are hydrodynamically distinct, and to a certain extent geologically different; they are therefore considered separately.

NORTHERN AREA

Water-table configuration

In the northern area the water table forms a pronounced north-south-trending ridge colloquially referred to as the Gnangara Mound. It has two crests rising to 70 m above sea level coinciding with the areas that are highest.

The water-table contours show that groundwater flow is radial and takes place towards hydraulic boundaries formed by the major rivers and the sea. A steepening of the groundwater gradiant in the vicinity of the linear lakes on the coastal strip possibly results from a reduction in transmissivity caused by the presence of lacustrine sediments or by cementation. The very low gradiants across the coastal strip result from the high transmissivity of the Coastal Limestone whereas the steep gradients around the eastern edge of the mound reflect the lower transmissivity of the Guildford Formation. The uniform low gradient extending south from the mound indicates that the Bassendean Sand, despite wide variation in lithology, has relatively uniform hydraulic characteristics.

Recharge

The water table undergoes seasonal water-level fluctuations. The levels are high in September-October after the winter rainfall, and lowest in March-April at the end of summer. They have a seasonal range between about 0.2 and 1.5 m depending on the location of the bore and depth to water. The smallest water-level variations are observed on the coastal strip and the highest are in the southern crestal area of the Gnangara Mound. Hydrographs show that water levels respond quickly to winter rainfall and that the peaking of water-level maxima and minima between bores may not be in phase because of local effects.

Recharge is not uniform over the coastal plain because of variations in the distribution of rainfall, the depth of the water table, the lithology of the Superficial Formations, and of the cover of vegetation. The frequent presence of a ferruginous hardpan (coffee rock) and limestone capstone may also reduce infiltration over wide areas.

The recharge to the Coastal Limestone along the coastal strip, and the Bassendean Sand forming the central part of the coastal plain are believed to be widely different. Along the coastal strip the water table is relatively deep and most recharge which reaches the water table is unaffected by evapotranspirative losses whereas on the central part of the coastal plain the shallow depth to water and the presence of numerous swamps and lakes allow large evapotranspiration losses.

The areally-averaged recharge to the central coastal plain can be estimated from available data because the throughflow past the 10 m water-table contour can be computed from hydraulie data derived from test pumping, and the area contributing to the throughflow (Fig. 16) can be measured. The recharge can then be estimated from the relationship

$$\frac{\text{Throughflow}}{\text{Contributing area}} = \text{Recharge.}$$

Substituting derived values and solving

$$\frac{71 \times 10^6 \text{ m}^3/\text{year}}{1\,026 \times 10^6 \text{ m}^2} = 0.069 \text{ m/year.}$$

This value is equivalent to 8.5 per cent of the adopted average annual rainfall of 813 mm. It is directly applicable to 47 per cent of the northern area and probably approximates the infiltration to the rest of the area. It represents a more conservative figure than one previously published of 0.085 m/year (Allen, 1975) which was derived by the same means from a 1 183 x 10^6 m^2 area and a throughflow of 101 x 10^6 m^3. This larger area incorporated a sub-area discharging to the Swan River which was estimated to have an exceptionally high groundwater recharge fignre of

$$0.191 \text{ m } \left(= \frac{30 \times 10^6 \text{ m}^3}{157 \times 10^6 \text{ m}^2}\right).$$

The difference between the two is probably a result of the large evapotranspirative losses from the lakes and swamps which occur in the area discharging to the sea.

Storage

The volume of groundwater in storage can be estimated by superimposing the water-table contour map for 1974 on the map of the pre-Quaternary erosion surface. From this a map of the saturated aquifer thickness can be constructed and the volume of saturated aquifer determined. The saturated aquifer thickness exceeds 40 m over 70 per cent of the northern area and the total volume is estimated to be 65 000 x 10^6 m^3. The volume of groundwater in storage based on a specific yield of 0.20 is estimated to be in the order of 13 000 x 10^6 m^3.

Outflow

The amount of outflow which takes place from the northern area can not yet be reliably estimated from hydraulic data. This is because of regional variations in transmissivity*, in particular across the coastal strip where estimates of transmissivity based on pumping test data and considerations of continuity of flow from the east differ by a factor of five. Estimates are further complicated by infiltration to and ontflow from the underlying formations.

The total outflow can best be approximated by applying the infiltration value of 0.069 m/year to the separate areas contributing to groundwater outflow at the major hydraulic boundaries (Fig. 16). The figures are given in Table 11.

TABLE 11: ESTIMATED OUTFLOW FROM THE NORTHERN AREA

Discharge area	Area km^2	Per cent total area	Est. outflow m^3/year x 10^6
Sea	1 481	69	102·2
Gingin Brook	155	7	10·7
Ellen Brook	310	14	21·4
Swan River	219	10	15·1
Totals	2 165	100	149·4

The figures for discharge to the sea are probably conservative because no account is taken of the higher recharge which is believed to take place on the coastal strip. The figure for the Swan area is also conservative when compared with the one derived by groundwater hydraulics for flow through the 10-m contour of 30 x 10^6 m^3/year. Despite these defects the figures probably indicate the order of magnitude of outflow for the northern area. In other terms the outflow is equal to about 1 per cent of the groundwater in storage.

Infiltration to underlying formations

Mesozoic and Tertiary formations subcrop beneath the Superficial Formations and their upturned edges are in direct hydraulic continuity with groundwater in the Superficial Formations. The erosion surfaee which truncates the Yarragadee and Leederville Formations (Fig. 15) and forms the floor on which the Superficial Formations rest, has an elevation of 0 to 35 m above sea level over about one third of the area (Fig. 14) and over the same area the water table is 50 to 70 m above sea level (Fig. 16).

A large head difference has been observed between the water table and the potentiometrie surface of the underlying Leederville Formation. In Wanneroo 305 for example, the water table has a head 17 m higher than the potentiometric surfaee. This shows that there is a large potential difference to facilitate downward infiltration. It is not yet possible to accurately define the actual area of recharge or the amount of infiltration but as the indicated area is large it must be very substantial.

*Hydraulic conductivity of the "Bassendean Sand" 15 m^3/day/m^2 and "Coastal Limestone" estimated to be 100 m^3/day/m^2.

Quality

In the northern area the groundwater salinity is 250 milligrams per litre, or less, of total dissolved solids over 50 per cent of its area, 250 to 500 mg/l TDS over 40 per cent of the area; and the remaining 10 per cent around the periphery contains water of variable but higher salinity. The salinity pattern is shown in Figure 17.

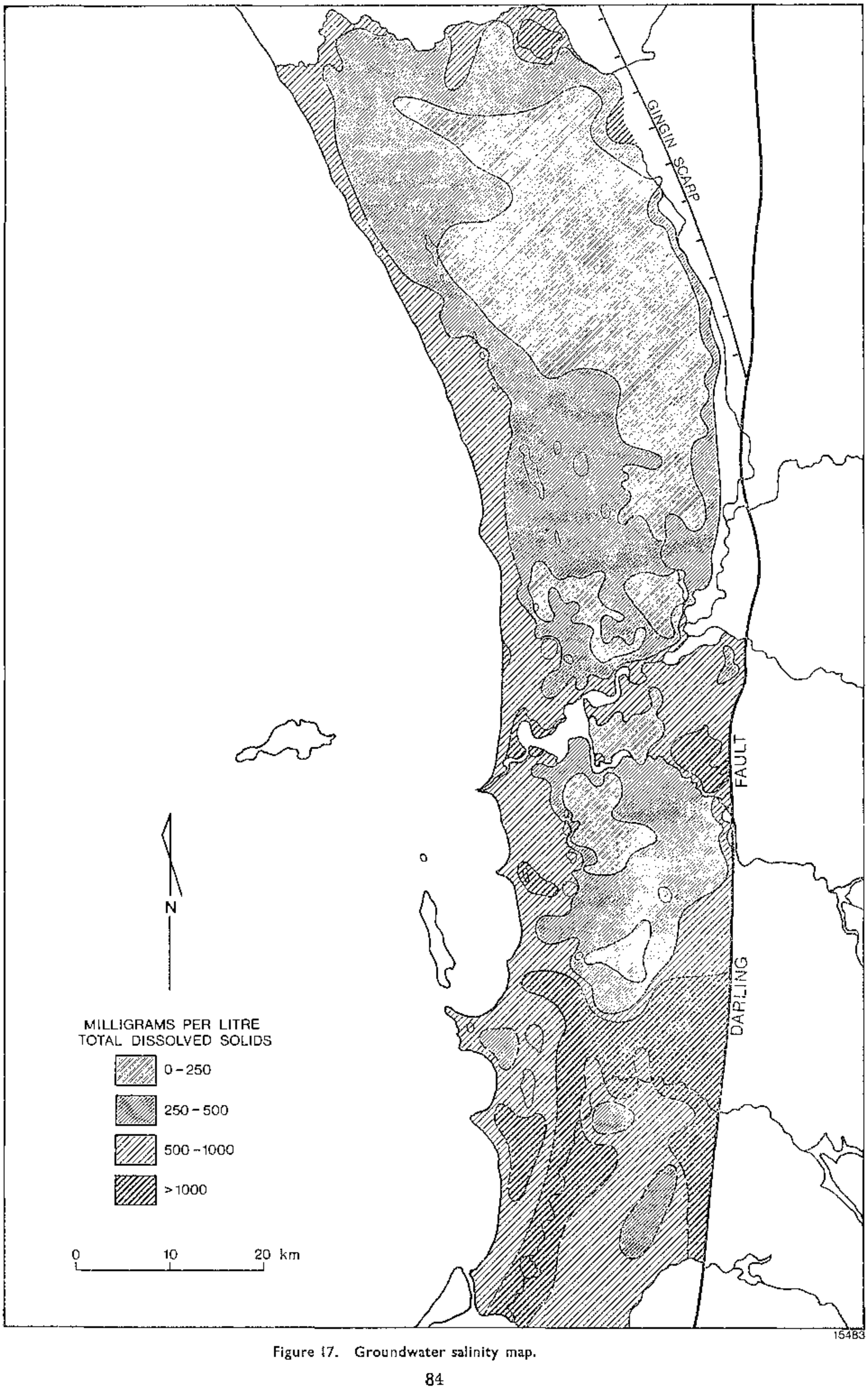

Figure 17. Groundwater salinity map.

The general increase in salinity towards the discharge boundaries results mainly from concentration of the rainfall recharge by evapotranspiration. There is evidence (not shown) to indicate that plumes of more saline water extend downstream from Lakes Pinjar and Joondalup and possibly other lakes. The decrease of cyclic salt inland from the coast may also affect the salinity pattern.

The relatively rapid increase in groundwater salinity along the eastern side of the mound reflects the effect of increased evapotranspiration from numerous springs and soaks.

Near the crest of the mound most bores encounter groundwater with a light brown colouration resulting from organic acids produced in the many swampy depressions. Colouration tends to decrease with depth and is not a problem in the calcareous sediments along the coastal strip.

Turbidity is also high in many bores, but not on the coastal strip. It results from the presence of suspended kaolin clay derived from kaolinized feldspar grains which occur in large quantities in some beds.

Ferrous iron occurs in most bore waters in various concentrations but usually at levels necessitating treatment for public water supply use.

Water with low pH and dissolved carbon dioxide and hydrogen sulphide occurs frequently on the central part of the mound but only rarely on the coastal strip.

Hardness ranges from moderately soft to slightly hard for groundwater near the crest of the Gnangara Mound and moderately hard to very hard for water obtained from the calcareous sediments of the coastal strip.

Wide differences in physical and chemical properties may commonly be found in nearby bores.

SOUTHERN AREA

Water-table configuration

Immediately to the south of the Swan River and covering about half the southern area, the water table forms a groundwater prominence referred to as the Jandakot Mound. Over the rest of the area the water table slopes gently downward to the west from the foot of the Darling Range.

The water table has an elevation of about 25 m on the Jandakot Mound and 30 m adjacent to the Darling Range in the Serpentine-Keysbrook area. The high parts of the water table coincide with areas that are topographically high and reach an elevation of only half that of the Gnangara Mound.

Groundwater flow is mainly westward to the sea with some flow taking place northward and north-eastward into the Swan and Canning Rivers. Notable features of the water-table map are the presence of a water-table divide which extends along the length of the Jandakot Mound; a water-table col in the vicinity of Lake Forrestdale indicating an area of large groundwater loss, and a large re-entrant in the water-table contours indicating significant groundwater outflow contributing to base flow of the Serpentine River. As in the northern area, there is a very low hydraulic gradient across the coastal strip.

Recharge

The water table undergoes seasonal fluctuations in level which are of essentially similar timing and amplitude as those of the northern area. During the winter large areas near the top of the Jandakot Mound and in the vicinity of the Serpentine River are flooded despite the sandy nature of the sediments. This suggests that although a large proportion of rainfall is available for infiltration, the hydraulic conditions or the widespread occurrence of a ferruginous hardpan (coffee rock) inhibit recharge.

An estimate of recharge to the Jandakot Mound can be made in a similar way as for the northern area. The area taken for the calculation is shown in Figure 16 and the throughflow calculation is based on an hydraulic conductivity of 10 $m^3/day/m^2$ (15 $m^3/day/m^2$ Gnangara Mound). The recharge is computed from the relationship

$$\frac{\text{Throughflow}}{\text{Contributing area}} = \text{Recharge}$$

Substituting

$$\frac{7.8 \times 10^6 \text{ m}^3\text{/year}}{166 \times 10^6 \text{ m}^2} = 0.047 \text{ m/year.}$$

The average recharge of 0.047 m/year is only about 70 per cent of that for a comparable area on the Gnangara Mound. Presumably the lower transmissivity of the sediments and their more uniform relief are the main reasons for the lower recharge.

The recharge to the coastal strip is presumably considerably higher and in the same order as for the northern area. Elsewhere in the southern area, considering the geology and topography, it is expected that infiltration is probably of the same order for the sandy sediments but possibly somewhat less in the clayey sediments along the eastern edge of the coastal plain and associated with the Serpentine River.

Storage

The volume of saturated aquifer (including some interbedded clay) has been estimated from cross-sectional areas, using Simpson's prismoidal rule, as 25 000 x 10^6 m^3. The volume of groundwater in storage, applying a specific yield of 0.20 is estimated to be 5 000 x 10^6 m^3. Hence the figures for saturated aquifer volume and the volume of groundwater in storage are considerably smaller in the southern area than in the northern area.

Outflow

The groundwater outflow from the southern area cannot yet be reliably estimated because of the wide variability of the hydraulic properties of the Superficial Formations, the effect of surface drainages, and the role played by surface water imported from the Darling Range.

The order of magnitude of the outflow based on the groundwater recharge rate of 0.047 m/year and the area of 1 400 km^2 is very approximately 65 x 10^6 m^3/year.

Infiltration to underlying formations

Areas where the water table has a higher head than the underlying Leederville Formation appear to exist all across the coastal plain, but the generally silty or shaley nature of the Mesozoic formations subcropping in this area probably considerably reduces the amount of infiltration which would otherwise take place. Some direct infiltration to the Rockingham Sand, possibly around its eastern subcrop also takes place.

Quality

The variation in groundwater salinity in the southern area is shown in Figure 17. The map is based on data of variable reliability and only shows the salinity pattern in a very general way. The variation in salinity is known in reasonable detail only on the Jandakot Mound, elsewhere considerable variation results from local effects of geology and sampling.

As in the case of the Gnangara Mound, colour, turbidity, iron, and hydrogen sulphide are present and the water requires treatment before it can be used for public water supply purposes.

CONCLUSIONS

Perth is extremely fortunate in having large supplies of low salinity water adjacent to developing urban areas, both to the north and south. The northern area is considerably better known than the southern area, and is hydrogeologically distinct. In terms of estimated recharge and groundwater in storage it is far more prosepective for large-scale groundwater abstraction.

The presence of iron, turbidity, and organic colouration will necessitate treatment before most of the unconfined groundwater can be used for public water supply purposes.

A constraint on the use of the unconfined groundwater will be the effect caused by pumping on wetlands. However, these effects will be offset to some extent by increased recharge due to clearing and lowering of the water table. In addition the network of monitoring bores around the borefields and the supplemental use of confined water should allow management of the resource so that deleterious effects on the wetlands are minimal.

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GEOTECHNICAL PROPERTIES OF THE COASTAL LIMESTONE IN THE PERTH METROPOLITAN AREA

by G. Klenowski

ABSTRACT

The Coastal Limestone is variable in composition and includes cemented rocks (calcareous quartz sandstone, limestone), calcretized rocks (caprock, pinnacles, solution pipes), rocks crystalized in cavities (dripstones), sand, and thin lenses of calcareous silt, clay, and marl. Geological structures that affect rock conditions include bedding, disconformities, slump planes, and solution structures.

Ranges in mechanical properties were determined using the uniaxial compressive strength test, Los Angeles test, Schmidt Hammer test and Brazilian test. A relationship has been established between the degree of rock cementation identified in the field and the range of uniaxial compressive strength.

Rock strength varies with the degree of cementation and type of carbonate cement. Tests show that rocks of uniform grain size are stronger than rocks with variable grain sizes. All rocks show a considerable increase in strength on drying, thought to be caused mainly by increasing molecular cohesive strength, but also by the evaporation of pore water containing $Ca(HCO_3)_2$ in solution and $CaCO_3$ in suspension, to form a carbonate cement.

The results of field investigation and mechanical testing have been applied to tunnelling and open-excavation problems, and the selection of suitable material for road bases and breakwaters. Mixed-face tunnelling in the Coastal Limestone requires special techniques such as shield protection and hydraulic spilers to prevent sand runs. Jacks would need to thrust against the tunnel lining or some other preconstructed support. Solution cavities can be detected by probe drilling. Drilling and blasting rather than ripping is generally necessary for massive zones of caprock or well-cemented rock.

Limestone base-course material for roads becomes recemented in time by the precipitation of dissolved carbonate to form a firmer layer. Calcretized and well-cemented rocks are undesirable materials. Careful selection of quarries will facilitate quality control.

In breakwater construction, caprock limestone may be used for armour blocks when dense material is required. Evaporation of pore water from limestone blocks prior to transport will increase rock strength and help prevent breakage during handling. Once placed the rock gradually undergoes case hardening if exposed to alternate wetting and drying.

INTRODUCTION

According to Fairbridge (1953) the term "Coastal Limestone Series" was first used in 1872 by the Government Geologist, H.Y.L. Brown, in a report to Parliament (Brown, 1872). Since then the term Coastal Limestone has been used in a general way to refer to a Quaternary deposit of mainly eolian origin, formed in a narrow belt along the west coast of Western Australia. In this paper, discussion is restricted to rocks from the Perth metropolitan area.

Investigation has been primarily oriented towards evaluating the geological problems expected in civil engineering works. Studies were made in the Shire of Wanneroo, where base-course material for roads is excavated. Correlations were also made with rock from the W.A. Limestone Co. quarry, Wattleup. Material from this quarry was used as breakwater aggregate for the Garden Island Causeway. Fletcher (1933) has discussed the use of Coastal Limestone as a building stone.

LITHOLOGY

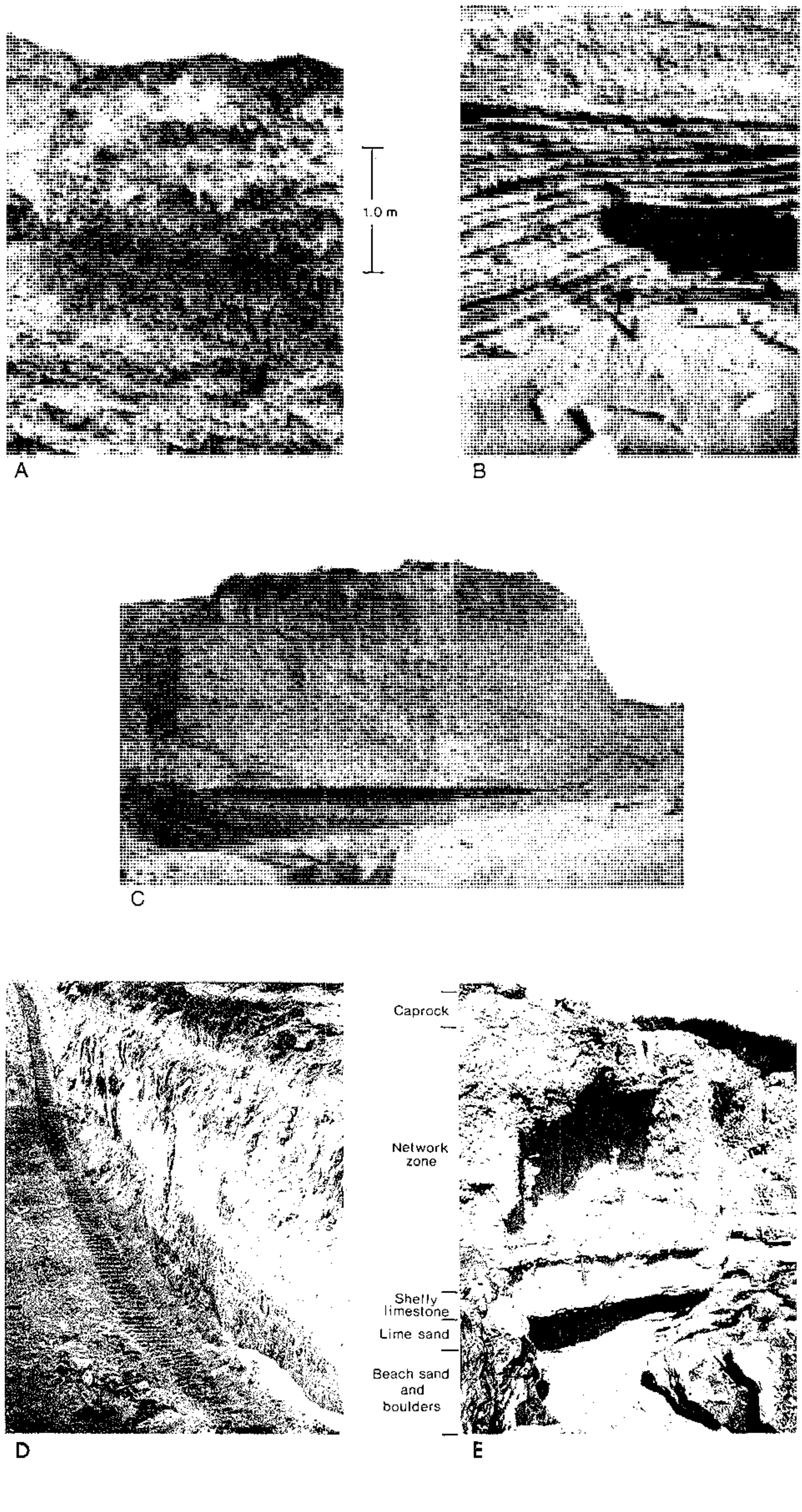
For the special purpose of this paper the Coastal Limestone has been divided into five types of material:—

(1) cemented rocks,
(2) calcretized rocks,
(3) rocks crystallized in cavities,
(4) sand,
(5) thin lenses of calcareous silt, clay, and marl.

Cemented rocks are grainstones and are mainly of eolian origin, but shallow-marine types, probably beach deposits, do occur, characterized by coarse-grained quartz (some of grit size), abundant shell fragments, and graded bedding. The degree and type of carbonate cementation is variable, the cement being either micrite or sparite. At depth sparite is more common. These rocks have also been variably leached by downward percolating water. Two distinct rock types occur. Calcareous quartz sandstone (quartzose arenite) contains greater than 50 per cent quartz grains. Limestone (calcarenite) is subdivided into eolian and shallow-marine (shelly) rocks.

Calcretized rocks described here are formed by secondary carbonate enrichment at or near the surface, the precipitated mineral being cryptocrystalline or microcrystalline calcite. The term calcrete is used similarly to Goudie (1971 and 1972) and Read (1974). Three structurally different rock types occur in the Perth metropolitan area. Caprock forms a thin duricrust which shows a marked increase in friability with depth. It appears to result from capillary action and the evaporation of vadose water containing dissolved carbonate, and may be as much as several metres thick. Distribution does not conform with any stratification in the sediments, but rather follows the general surface of the ground. There are differences from the idealized calcrete profile described by Read (1974) for the Shark Bay area. Around Perth laminar calcrete either crops out or is overlain by thin topsoil or eolian sand. At Shark Bay pisolitic soil forms the uppermost layer in the profile. Below the laminar calcrete zone, which is generally a few centimetres thick, lies the massive calcrete zone. This is structureless and quite dense, but becomes friable and powdery with depth. A transitional zone from calcrete to unaltered parent rock occurs in the lower part of the profile. The lower massive calcrete and transitional zones sometimes form a network zone (see figure 18 opposite).

Figure 18. (opposite). Geological structures in the Coastal Limestone.
A. Massive caprock overlying network zone containing abundant solution pipes and relict cross-bedding; quarry north of Mullaloo.
B. Bedding with alternating poorly cemented limestone and yellow quartz sand layers; Wanneroo Shire Council quarry.
C. Cross-bedded limestone disconformably overlying yellow quartz sand; Wanneroo Shire Council quarry.
D. Whitish calcareous shallow marine sediments with cross-bedding and graded bedding, disconformably overlying yellowish, slightly cemented quartz sand. Trench excavated 4·4 m deep, 2 km north of Mullaloo.
E. Typical profile of material north of Mullaloo, next to waters edge.


1.0 m
A
B
C
D
Caprock
Network zone
Shelly limestone
Lime sand
Beach sand and boulders
E

Pinnacles are either massive or concretionary and range in diameter from 0.2 m to 1.0 m. They may result from the break-up of caprock by penetrating plant roots, or alternatively they may form directly in carbonate-rich sediments where solution and precipitation occur in localized zones, such as adjacent to tap roots. Pinnacles formed in this way can be eventually infilled with carbonate.

The lower part of the caprock sometimes forms a network zone containing root matter (Figs. 18, A and E). Generally the organic matter has been partially or completely replaced by concretionary calcite to form solution pipes. These are usually 1 to 5 cm in diameter, and are separated by lime sand and voids.

Rocks crystallized in cavities in the zone below the surface and above the water table are known as dripstones. They generally consist of well-crystallized calcite and occur as stalactites, stalagmites, encrustations, and druses.

Yellow sand consists mainly of quartz and is sometimes bedded. It usually occurs where former dunes have been stabilized by vegetation, and forms thicker sequences in depressions. Yellow sand may also disconformably underlie rock strata. The colour is mainly due to iron oxides.

Calcareous silt, clay, and marl form thin lenses within the Coastal Limestone. These fossil horizons are either lacustrine deposits or subaerial humic deposits.

GEOLOGICAL STRUCTURES

Although the Coastal Limestone is essentially unjointed, structures that affect rock condition include slump planes, bedding, disconformities, and solution structures.

Bedding structures are gradually obliterated with depth. They include cross-bedding, bedding formed by the eolian deposition of thin, alternating carbonate-rich and quartz-rich layers (Fig. 18B), and graded bedding.

Three distinct types of disconformities have been observed. These are cross-bedded, cemented limestone disconformably overlying loose, yellow quartz sand with pinnacles (Fig. 18C); whitish, calcareous, shallow marine sediments disconformably overlying yellowish, slightly cemented quartz sand (Fig. 18D); and poorly to moderately cemented, bedded, shelly limestone disconformably overlying fine-grained lime sand (Fig. 18E).

Solution structures are divided into two types. Cavities formed by the solution of carbonate are generally irregular in shape, may be partially filled with sand, are variable in size (1 or 2 cm to several metres across), and may be iron stained or encrusted with calcite. Structures resulting from precipitation of dissolved carbonate include structures formed by near-surface zone calcretization and dripstone structures formed in cavities.

MECHANICAL TESTING

Fletcher (1933) utilized the results of uniaxial compressive strength testing for assessing Coastal Limestone as a building stone. Various tests were done by Brooksbank (1967) to determine the suitability and parameters of limestone as a road base-course material.

The tests described in this paper were primarily done to determine the ranges in strengths of rock types that could be encountered during mechanical excavation of tunnels. Although the penetration rate of tunnelling machines is often considered to be related to the compressive strength of the rock, this can be misleading. At present there is no single index or empirical test which can reliably forecast the advance rate of a machine for a given rock type. According to Bawa and Bumanis (1972), investigations indicate that a value based on abrasion and rebound is likely to best reflect the machine tunnelling advance rates. Physical properties were determined by means of the uniaxial compressive strength test, Los Angeles test, Schmidt Hammer test and Brazilian test.

In mechanical tunnelling and trenching, it is important to know the proportion of mechanically rippable rock, to rock requiring blasting. These properties were analysed using the methods of Duncan (1969).

Brooksbank (1967) in his study of the Coastal Limestone as a base-course material concentrated on the lower limit of suitable strength range. Because of compaction problems with some of the stronger rock, an upper strength limit is considered here from Los Angeles test results.

Rock properties that could be utilized in breakwater construction include increase in strength caused by the evaporation of pore water, case hardening due to alternate wetting and drying, and utilization of dense caprock for armour. Testing was done on rock from the W.A. Limestone Company quarry, Wattleup.

All rock testing was done in the Civil Engineering Department of the University of Western Australia by J. M. Campbell (in prep.) who is currently working on the application of rock mechanics techniques in the determination of mechanical properties of certain Western Australian rocks.

UNIAXIAL COMPRESSIVE STRENGTH TEST

Uniaxial compressive strength was determined with loading rates of 2.03 t/min for moist samples (containing pore water), 2.64 t/min for air-dried samples and 2.10 t/min for 7-day oven-dried samples (see Tables 12, 13, and 14). Although not all of the requirements of the standards adopted by the International Society of Rock Mechanics (Bieniawski and Franklin, 1972) could be met, the results should give a good indication of rock strengths. Rock tested included diamond drill cores and quarry caprock, and pinnacle samples. All hand specimens were cored in the laboratory. The drillholes have six digit numbers, with the first two referring to the year of drilling (75) and the next four indicating the distance(in metres) along the line from the start point. An upper case letter is used if more than one hole was drilled at a particular locality.

TABLE 12. UNIAXIAL COMPRESSIVE STRENGTHS OF MOIST SAMPLES

Sample location		Description	Uniaxial compressive strength	
Drill-hole no.	Depth (m)		MPa	psi
750100A	12·94–13·10	Well-cemented calcareous quartz sandstone	34	4 930
750100A	13·33–13·45	Moderately cemented calcareous quartz sandstone	13	1 890
750100A	15·13–15·27	Well-cemented limestone	47	6 820
750100B	10·10–10·41	Well-cemented limestone	41 58	5 950 8 400
750400	14·98–15·11	Poorly to moderately cemented calcareous quartz sandstone	5	730
750400	18·77–18·93	Well-cemented calcareous quartz sandstone	39	5 600
750400	19·57–19·70	Moderately to well-cemented calcareous quartz sandstone	25	3 630
750400	23·21–23·35	Moderately to well-cemented calcareous quartz sandstone	16 (failure along cavity)	2 320
750400	23·93–24·13	Moderately to well-cemented calcareous quartz sandstone	24 28	3 480 4 060
750400	25·65–25·78	Well-cemented limestone	38	5 510

TABLE 13. UNIAXIAL COMPRESSIVE STRENGTHS OF AIR-DRIED SAMPLES

Sample location: Drill-hole no.	Sample location: Depth (m)	Description	Uniaxial compressive strength: MPa	Uniaxial compressive strength: psi
750100B	10·51–10·63	Well-cemented limestone	50	7 250
750400	18·40–19·28	Well-cemented calcareous quartz sandstone	23 47	3 340 6 820
750400	24·42–25·65	Well-cemented limestone	35 35 58 31	5 080 5 080 8 410 4 500
750700	25·86–26·07	Well-cemented limestone	86 58	12 470 8 410
751000	22·28–22·52	Well-cemented calcareous quartz sandstone	47 50	6 820 7 250
751900	37·83–38·31	Poorly to moderately cemented calcareous quartz sandstone	4 6 6	580 870 870
752200	18·14–18·28	Moderately cemented limestone	24	3 480
752200	32·24–32·37	Moderately cemented calcareous quartz sandstone	9	1 310
752500	27·65–27·82	Moderately cemented shelly limestone	5	730
Caprock from north of Mullaloo		Calcretized rock	37 10	5 370 1 450
Caprock from near drill-hole no. 753100		Calcretized rock	21 30	3 050 4 350
Pinnacle from north of Mullaloo		a. Calcretized rock with core axis parallel to rock lamination	27 80	3 900 11 600
		b. Calcretized rock with core axis normal to rock lamination	16	2 320

TABLE 14. UNIAXIAL COMPRESSIVE STRENGTHS OF MOIST AND 7-DAY OVEN-DRIED SAMPLES

Sample location	Description	Uniaxial compressive strength: Moist MPa	Moist psi	Oven-dried MPa	Oven-dried psi
W.A. Limestone Co. quarry, Wattleup	Poorly to moderately cemented limestone	4 6	580 870	9 11	1 350 1 595
Caprock from near drillhole no. 753100	Calcretized rock	12 20	1 740 2 900	24 36 62	3 480 5 220 8 990

Discussion

The fracture appearance of the uniaxially failed rock is generally a straight split or conical splits. Rock laminated parallel to the core axis fails as a series of splits parallel to the laminations. Poorly to moderately cemented rock often has a barrel-shaped type of failure.

Table 15 represents the relationship between the degree of rock cementation identified in the field and the range of strength determinted in the laboratory.

TABLE 15.

	Poorly cemented rock	Moderately cemented rock	Well-cemented rock
Uniaxial compressive strength range	<3·5 MPa (<500 psi)	3·5–24·0 MPa (500–3 500 psi)	>24·0 Mpa (>3 500 psi)
Field identification	Rock is friable in the hand	Pieces of rock can be broken by hand	Hammer required to break rock

Although the main factor in the strength of the Coastal Limestone is the degree of cementation which is inversely related to rock porosity, there are rocks of equivalent porosities with differences in strength. This is due to the type of cement. Sparite cement forms a stronger bond than micrite cement, which generally contains impurities. On the other hand, caprock and pinnacles (which consist mainly of micrite), have similar strengths to well-cemented rocks with sparite cement. This is related to grain size. Tests show that rocks of uniform grain size are stronger than rocks with variable grain sizes.

All the rocks tested show a considerable increase in uniaxial compressive strength on drying. This is thought to be caused mainly by increasing molecular cohesive strength, but also by the evaporation of pore water containing $Ca(HCO_3)_2$ in solution and $CaCO_3$ in suspension, to form a carbonate cement.

LOS ANGELES TEST

Testing was done using 5 000 g of test sample (2 500 g passing the $\frac{3}{4}$ in. sieve size and retained on the $\frac{1}{2}$ in. size, and 2 500 g passing the $\frac{1}{2}$ in. size and retained on the $\frac{3}{8}$ in. size), 11 spheres, and 500 revolutions. After the completion of the test the material was sieved on a B.S.I. No. 10 sieve. The percentage of wear calculated is given in Table 16.

TABLE 16.

Rock type	Percentage of wear
Well-cemented limestone	32
Well-cemented calcareous quartz sandstone	45
Caprock	35

Discussion

Testing was restricted by the amount of core available, but the results do indicate the lower limits of wear of the Coastal Limestone.

The comparison of test results for rocks of different grain sizes can be somewhat misleading. For example, a poorly cemented rock with a grain size greater than a B.S.I. No. 10 sieve will give a lower wear percentage than a similarly cemented rock with grains smaller than the sieve size. In Los Angeles testing, if the bond strength between individual grains or between grains and cement within a rock fragment is sufficient to allow rounding rather than disaggregation of the fragment on impact, then meaningful interpretations of abrasion values can be made.

SCHMIDT HAMMER TEST

A standard type N Schmidt Hammer was used to determine rebound hardness. This test requires pressure against the head of an impact plunger to disengage the plunger. When the plunger is pressed against a rock face, the mass of the hammer is released. After the impact the mass rebounds to a height indicated by a pointer against a scale. The rebound height as a percentage of the forward travel of the mass can be read off the scale, and is called the rebound number (see Table 17).

Although essentially a field test to assess *in situ* rock strength, it was necessary to do some laboratory testing on core because of the lack of suitable outcrops of certain rock types. The laboratory results are expected to be more variable than the field results because of the difficulty of stabilising the core during testing.

TABLE 17

Sample location (m)		Description	Range of rebound numbers	Average rebound number
Drillhole no. 750400	18·40–18·78	Well-cemented calcareous quartz sandstone	21–24	32
	19·12–19·28	Well-cemented calcareous quartz sandstone	28–42	34
	19·28–19·37	Well-cemented calcareous quartz sandstone	38–46	42
	25·56–25·65	Well-cemented limestone	32–43 33–42 30–36	36 39 33
Caprock from north of Mullaloo		Calcretized rock....	36–58 15–50 11–40	51 30 24
Pinnacle from north of Mullaloo		Calcretized rock....	28–50 20–64	41 37

Discussion

The wide range in rebound numbers of individual samples is attributed partly to variation in degree of cementation and recrystallisation over short distances of rock, and partly to experimental error.

BRAZILIAN TEST

Indirect tensile strength was determined using a loading rate of 1.19 t/min. The results are given below in Table 18.

TABLE 18.

Sample location		Description	Indirect tensile strength	
Drill-hole no.	Depth (m)		MPa	psi
750100A	12·94–13·10	Well-cemented calcareous quartz sandstone	3	435
750100A	15·53–15·64	Moderately cemented calcareous quartz sandstone	1	145
750100B	10·10–10·41	Well-cemented limestone	3 5	435 725
750100B	13·06–13·14	Moderately cemented calcareous quartz sandstone	2	29

ENGINEERING SIGNIFICANCE

TUNNELLING AND OPEN EXCAVATION PROBLEMS

There are various problems in mixed-face tunnelling into material ranging from sand to well-cemented rock. The presence of loose sand and weak rock within more competent rock necessitates shield protection during tunnel excavation. Excessive sand-runs into a tunnel can be prevented by mounting hydraulic spilers. The thrust jacks for the shield and its excavating mechanism probably cannot use the tunnel walls as a footing, and may need a specially constructed support to bear against. The application of pressure to tunnel walls is precluded by the highly variable rock strength and the presence of cavities.

Solution cavities up to at least several metres across occur within the Coastal Limestone. These are hazardous if they exist just below tunnel invert level, but can be detected by probe drilling. Sand or sand/cement grouting would then be necessary. Rippability characteristics were determined for well-cemented rock and caprock (Fig. 19). The samples lie in the upper part of the rip field rather than the blast field. Although the Coastal Limestone is variable both vertically and horizontally, it often lacks structural discontinuities such as joints, which also assist in ripping. Therefore if more massive zones of caprock or well-cemented rock are intersected, conventional drilling and blasting, or percussion methods may be necessary, but should be used with caution.

Open excavations in sand will fret and need to be battered back or supported in some way.

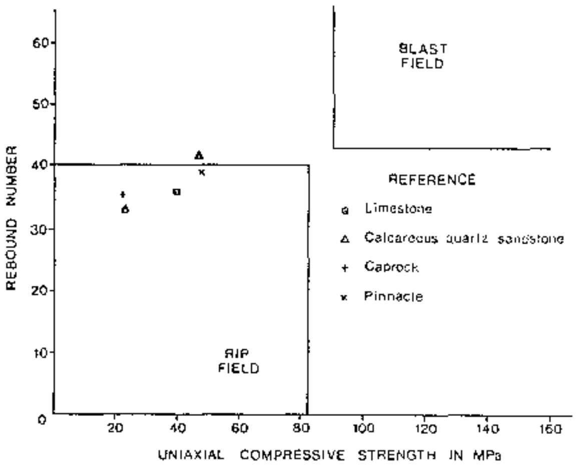


Figure 19. Relationship between rebound number and uniaxial compressive strength (after Duncan, 1969).

ROAD BASE-COURSE MATERIAL

The life-expectancy and maintenance of limestone-based roads compare very favourably with gravel-based roads. Limestone has the advantage of recementing in time to form a harder, firmer layer than when first laid. This is caused by the solution of finely divided carbonate by circulating groundwater, and precipitation to form a cement. When compared to gravel base course, the prime disadvantage is lack of cohesion, and therefore a thin sheeting of gravel or a greater thickness of bituminous surfacing is required. A bitumen seal will also not adhere directly to a limestone base course due to the fine, loose material which collects on top of the limestone.

Brooksbank (1967) has stated that the best material appears to have a carbonate content of between 60 and 85 per cent and a Los Angeles abrasion value of less than 60 per cent. The large spalls must also be broken down to less than 8 cm diameter, otherwise they will move under traffic and cause potholes. If caprock, pinnacles, solution tubes or well-cemented rock are used, breakdown will be hindered and differential compaction will occur. These rocks generally have a Los Angeles abrasion value of between 30 and 40 per cent.

Careful selection of quarries will facilitate quality control and minimise compaction problems. Site excavation where caprock is thin or discontinuous will minimise quarry development costs. When the lower caprock profile contains a network zone, greater excavation is required to reach suitable material. If quartz sand layers (Fig. 18B) occur within the limestone, or there are disconformities with quartz sand below the limestone (Fig. 18C), quality will be adversely affected by quartz contamination. These problems can be overcome by adequate investigation prior to excavation.

BREAKWATER MATERIAL

The economic attractiveness of using Coastal Limestone as breakwater rock is its proximity to construction areas. Prior geological investigation of proposed quarry sites will provide information about the quality and quantity of material available.

Design considerations for different wave sizes on the Garden Island Causeway were determined by Hicks, Foster, and Wilkinson (1973). Quarry run limestone was used for the core. Limestone armour was used for 2 m waves and granite armour for 4 m waves. A granite blanket was placed on the sea bed along each side of the core, to prevent erosion. Limestone was also used as a base-course material for the access road.

If extensive zones of massive caprock occur close to site areas, these could be used as armour for greater than 2 m waves. Caprock is one of the denser types of limestone and its resistance to wear is high.

The excavation of limestone for breakwaters requires controlled blasting to obtain a sufficient amount of large rock sizes. Excavation methods for the Garden Island Causeway have been described by Hicks, Buchanan, Fernie, and Tabert (1973). A small charge of ammonium nitrate fuel oil (ANFO) sufficient only to loosen the rock into required sizes, was introduced into the limestone through horizontal toe holes. Occasionally vertical drilling was necessary.

Large limestone blocks are susceptible to breakdown during handling. If the rock is stockpiled prior to transport the pore water will evaporate and the strength is increased. Once placed on the breakwater, the limestone gradually undergoes case hardening. A skin of hard, dense calcite, as much as several centimetres thick, is gradually formed by alternate wetting and drying of the rock.

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PETROLEUM EXPLORATION IN WESTERN AUSTRALIA IN 1975

by K. A. Crank

ABSTRACT

The tempo of oil exploration in Western Australia, which has declined steadily since 1972, showed an even more rapid decline in 1975. The number of test wells completed decreased by 70 per cent compared to 1974 and seismic activity was reduced by 75 per cent.

Drilling activity was restricted to the Perth and Carnarvon Basins, mainly offshore. The only onshore drilling was on Barrow Island where West Australian Petroleum Pty. Ltd's Biggada No. 1, a deeper pool test within the Barrow Field, revealed gas-bearing sands at a similar depth to those found at Barrow Deep No. 1 in 1973.

BOCAL Pty. Ltd. discovered significant gas-bearing sands at Tidepole No. 1 in a previously untested structure close to the Goodwyn Field. An oil-bearing section was also found in this well.

Only six wells were completed during 1975, and one was drilling ahead at the end of the year, for a total of 17 115 m. Geophysical activity was restricted to land and marine seismic surveys in the Perth, Carnarvon and Canning Basins.

During the year many onshore and offshore tenements were surrendered, relinquished or cancelled in almost all basins.

INTRODUCTION

Exploration drilling for petroleum in Western Australia showed a marked decline in 1975 compared to 1974 as is seen in the following table:

	Wells completed		Wells drilling on 31 December	
	1974	1975	1974	1975
New field wildcats	15	5	0	1
Extension wells	1	0	0	0
Deeper pool tests	0	1	0	0
Development wells	1	0	0	0
Stratigraphic tests	4	0	0	0
	21	6	0	1

Total effective drilling : 1974—46 626 m
1975—17 115 m*

* The aborted South Turtle Dove Nos. 1 and 1A, and Lewis No. 1, which drilled to 350, 330 and 265 m respectively, are not included in these tabulations.

Two successful wells were drilled in 1975: Biggada No. 1 is classified as a deeper pool test suspended gas discovery, and Tidepole No. 1 as a suspended gas/condensate/oil discovery.

Geophysical survey activity also declined compared to 1974. The totals for 1975 are shown below (with the 1974 figures in brackets). Geological survey totals are also listed:

Type of survey	Line km	Party months or geologist months
Land seismic	484 (559)	....
Marine seismic	2 737 (11 815)	....
Aeromagnetic	Nil (6 373)	....
Gravity land	....	Nil (1·0)
Gravity marine	....	....
Magnetic	....	....
Geological	....	5·0 (3·0)

PETROLEUM TENEMENTS

During 1975 large areas were relinquished, cancelled and surrendered in all major sedimentary basins. Large areas are currently available for application in all basins.

Twelve offshore and 20 onshore permits were surrendered or cancelled, 12 offshore and 10 onshore permits were partially relinquished, surrender was pending on one onshore permit, applications for renewal were under consideration on four onshore permits, and applications for one new offshore and one onshore exploration permit were being considered. Permits surrendered or cancelled are as follows:

Offshore: WA-2-P, WA-7-P, WA-15-P, WA-17-P, WA-21-P, WA-26-P, WA-27-P, WA-30-P, WA-39-P, WA-40-P, WA-50-P, WA-51-P.

Onshore: EP4, EP5, EP6, EP8, EP9, EP14, EP15, EP17, EP18, EP20, EP26, EP27, EP28, EP29, EP31, EP37, EP38, EP43, EP44, EP69.

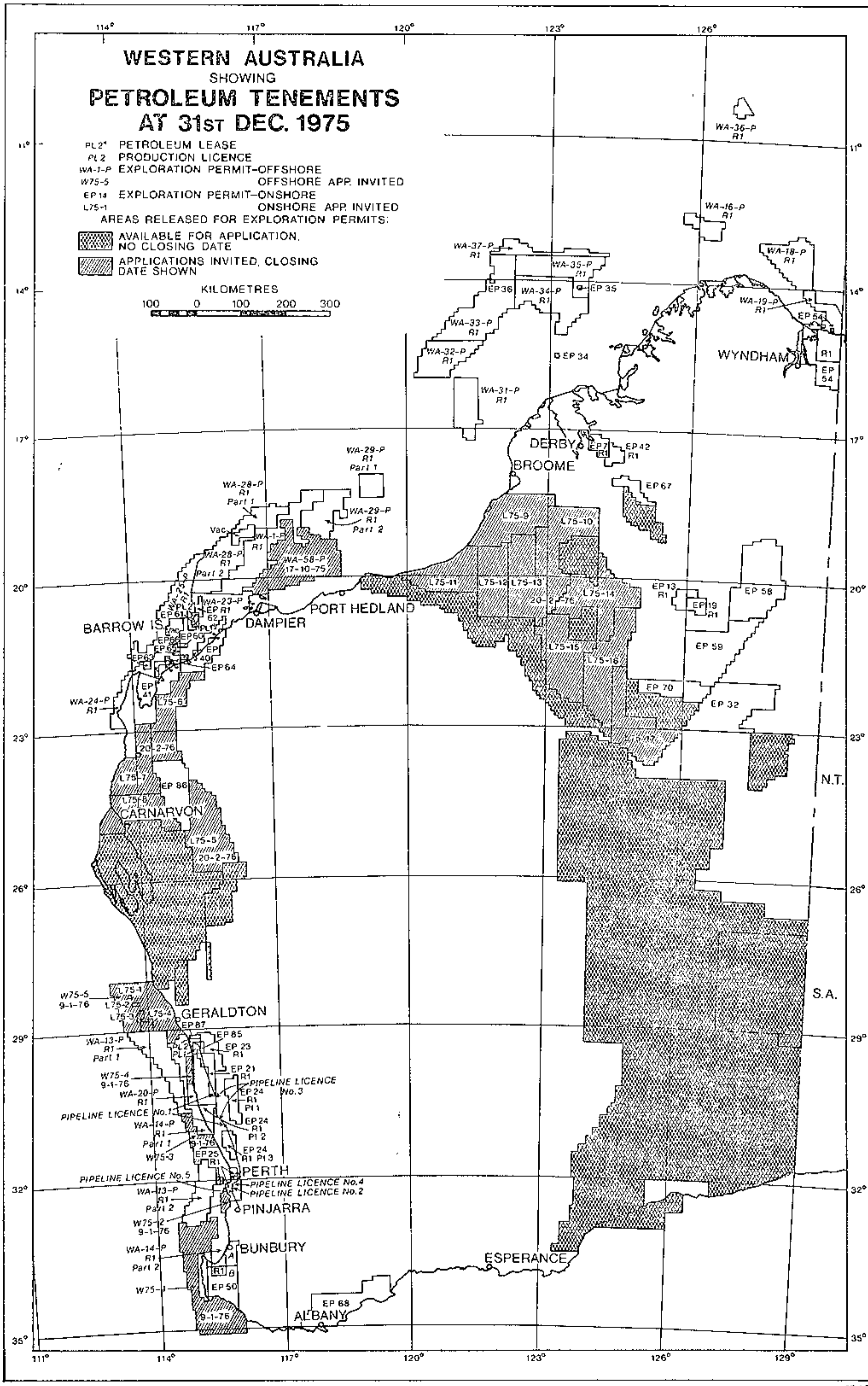

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Figure 20. Petroleum tenements at 31st December, 1975.

Petroleum tenements current on December 31st, 1975 are shown in Figure 20, and the following tabulation lists details of the various holdings:

PETROLEUM TENEMENTS UNDER THE PETROLEUM (SUBMERGED LANDS) ACT, 1967

Exploration Permits

Number	No. of graticular sections	Expiry date of current term	Registered holder or applicant
WA-1-P R1	178	14/11/79	Woodside Oil N.L., Shell Development (Aust.) Pty. Ltd., BOCAL Pty. Ltd.
WA-13-P			West Australian Petroleum Pty. Ltd.
R1 Part 1	110 } 194	29/8/79	
R1 Part 2	84		
WA-14-P			
R1 Part 1	77 } 198	29/8/79	
R1 Part 2	121		
WA-16-P R1	40	16/4/80	Arco Aust. Ltd., Australian Aquitaine Petroleum Pty. Ltd., Esso Exploration & Production Aust. Inc.
WA-18-P R1	105	16/4/80	
WA-19-P R1	49	20/3/80	Alliance Oil Development Aust. N.L.
WA-20-P R1	15	10/10/79	West Australian Petroleum Pty. Ltd.
WA-23-P R1	109	30/10/79	
WA-24-P R1	104	17/10/79	
WA-25-P R1	128	16/10/79	
WA-28-P			Woodside Oil N.L., Shell Development (Aust.) Pty. Ltd., BOCAL Pty. Ltd.
R1 Part 1	52 } 178	24/3/80	
R1 Part 2	126		
WA-29-P			Woodside Oil N.L., Shell Development (Aust.) Pty. Ltd., BOCAL Pty. Ltd.
R1 Part 1	36 } 120	18/5/80	
R1 Part 2	84		
WA-31-P R1	80	18/5/80	Woodside Oil N.L., Shell Development (Aust.) Pty. Ltd., BOCAL Pty. Ltd.
WA-32-P R1	100	2/7/80	Woodside Oil N.L., Shell Development (Aust.) Pty. Ltd., BOCAL Pty. Ltd.
WA-33-P R1	104	18/5/80	
WA-34-P R1	149	2/7/80	
WA-35-P R1	123	2/7/80	
WA-36-P R1	18	18/5/80	Woodside Oil N.L., Shell Development (Aust.) Pty. Ltd., BOCAL Pty. Ltd.
WA-37-P R1	59	2/6/80	
WA-58-P	222	Appn.	Western Energy Pty. Ltd.

PETROLEUM TENEMENTS UNDER THE PETROLEUM ACT, 1936

Petroleum Leases

Number	Area (square miles)	Expiry date of current term	Holders
1H	100	9/2/88	West Australian Petroleum Pty. Ltd.
2H	100	9/2/88	

PETROLEUM TENEMENTS UNDER THE PETROLEUM ACT, 1967

Exploration Permits

Number	No. of graticular sections	Expiry date of current term	Registered holder or applicant
EP 7 R1	24	27/8/80	West Australian Petroleum Pty. Ltd.
EP 13 R1	23	27/8/80	
EP 19 R1	18	27/8/80	
EP 21 R1	32	26/7/80	West Australian Petroleum Pty. Ltd.

Exploration Permits—continued.

Number	No. of graticular sections	Expiry date of current term	Registered holder or applicant
EP 23 R1	33	6/8/80	West Australian Petroleum Pty. Ltd.
EP 24			West Australian Petroleum Pty. Ltd.
R1 Part 1	30 } 85	6/8/80	
R1 Part 2	24		
R1 Part 3	22		
EP 25 R1	36	6/8/80	
*EP 32	200	15/4/76	Beach-General Exploration Pty. Ltd., Australian Aquitaine Petroleum Pty. Ltd.
EP 34	1	15/4/76	Woodside Oil N.L., Shell Development (Aust.) Pty. Ltd., BOCAL Pty. Ltd.
EP 35	1	15/4/76	
EP 36	1	15/4/76	
EP 40	67	26/7/76	West Australian Petroleum Pty. Ltd.
EP 41	180	18/7/76	West Australian Petroleum Pty. Ltd.
EP 42 R1	19	1/9/80	
EP 50	110	1/9/75	West Australian Petroleum Pty. Ltd.
R1	18	Appn.	
EP 54	128	22/9/75	Alliance Oil Development Aust. N.L.
R1	47	Appn.	
EP 58	200	20/7/76	Associated Australian Resources N.L., Australian Aquitaine Petroleum Pty. Ltd., Abrolhos Oil N.L., Ashburton Oil N.L., Flinders Petroleum N.L., Longreach Oil Ltd., Pursuit Oil N.L., West Australian Petroleum Pty. Ltd.
EP 59	186	18/7/76	
EP 60	2	Appn.	
EP 61	4	19/9/76	
EP 62	8	19/9/76	
EP 63	4	19/9/76	
EP 64	1	Appn.	
EP 65	2	19/9/76	
EP 66	1	19/9/76	
EP 67	29	25/10/76	
EP 68	175	27/7/77	W. I. Robinson
EP 70	71	25/9/77	Associated Australian Resources N.L., Australian Aquitaine Petroleum Pty. Ltd., Abrolhos Oil N.L., Ashburton Oil N.L., Flinders Petroleum N.L., Longreach Oil Ltd., Pursuit Oil N.L.
EP 85	4	19/7/80	Endeavour Oil Co. N.L., Target Minerals N.L., IOL Petroleum Ltd., Associated Australian Resources N.L., Alliance Minerals (Aust.) N.L.
EP 86	118	9/1/80	XLX N.L.
EP 87	3	Appn.	Elvert Exploration Pty. Ltd.

* Surrender Pending.

Production Licences

PL 1	5	24/10/92	West Australian Petroleum Pty. Ltd.
PL 2	4	24/10/92	

PETROLEUM TENEMENTS UNDER THE PETROLEUM PIPELINES ACT, 1969

Pipeline Licences

Number	Expiry date 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	

DRILLING

The positions of wells drilled for petroleum exploration in Western Australia during 1975 are shown in Figures 21 and 22. Details relating to wells drilled during the year are given in Table 19. All the petroleum exploration wells drilled in Western Australia up to the end of 1975 are listed in the Geological Survey Record 1976/1 (Crank, in prep.). A summary of the principal results of the drilling in each basin during the year is as follows:

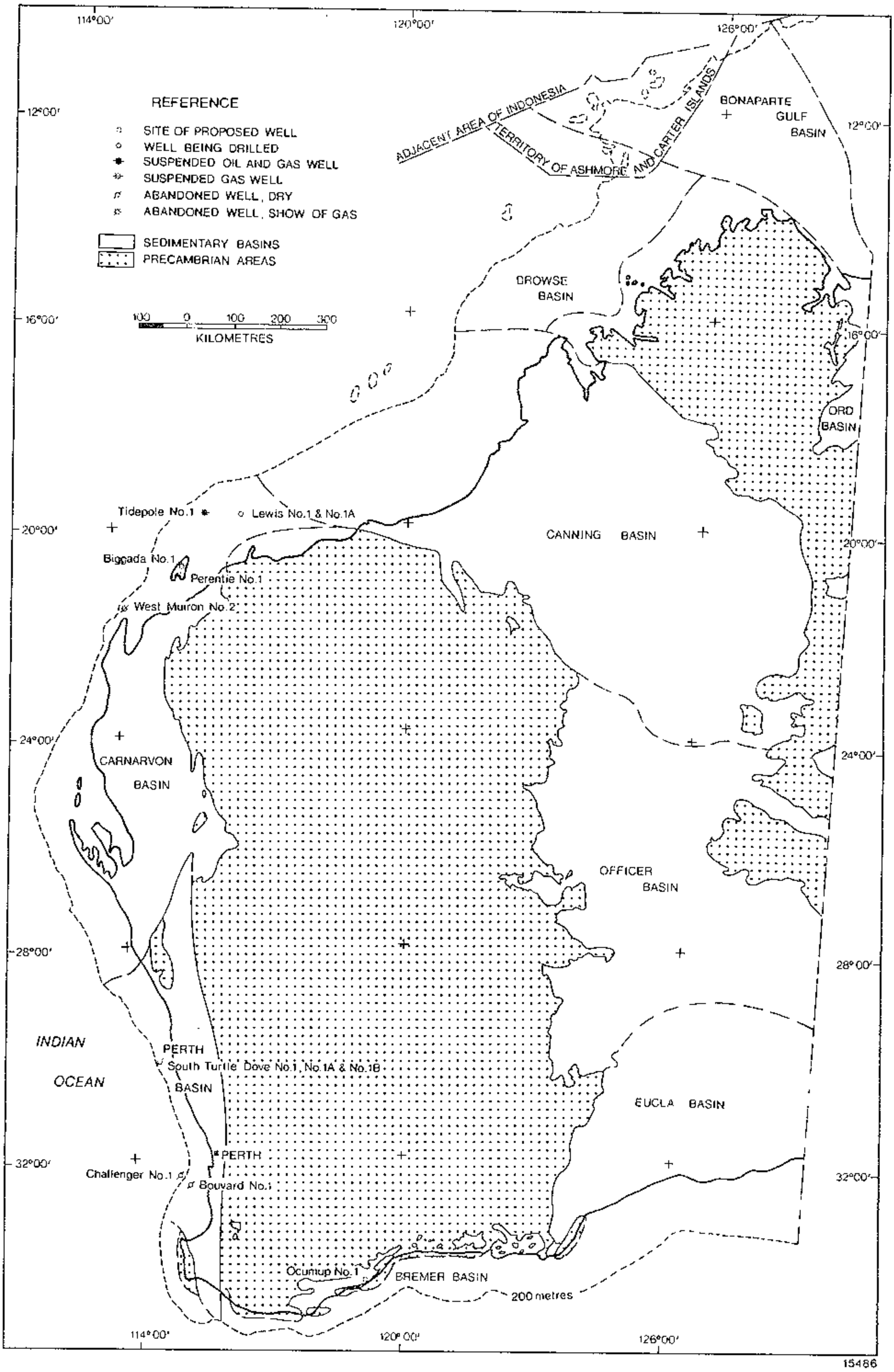

Figure 21. Wells drilled for petroleum exploration in W.A. during 1975.

PLATE 4

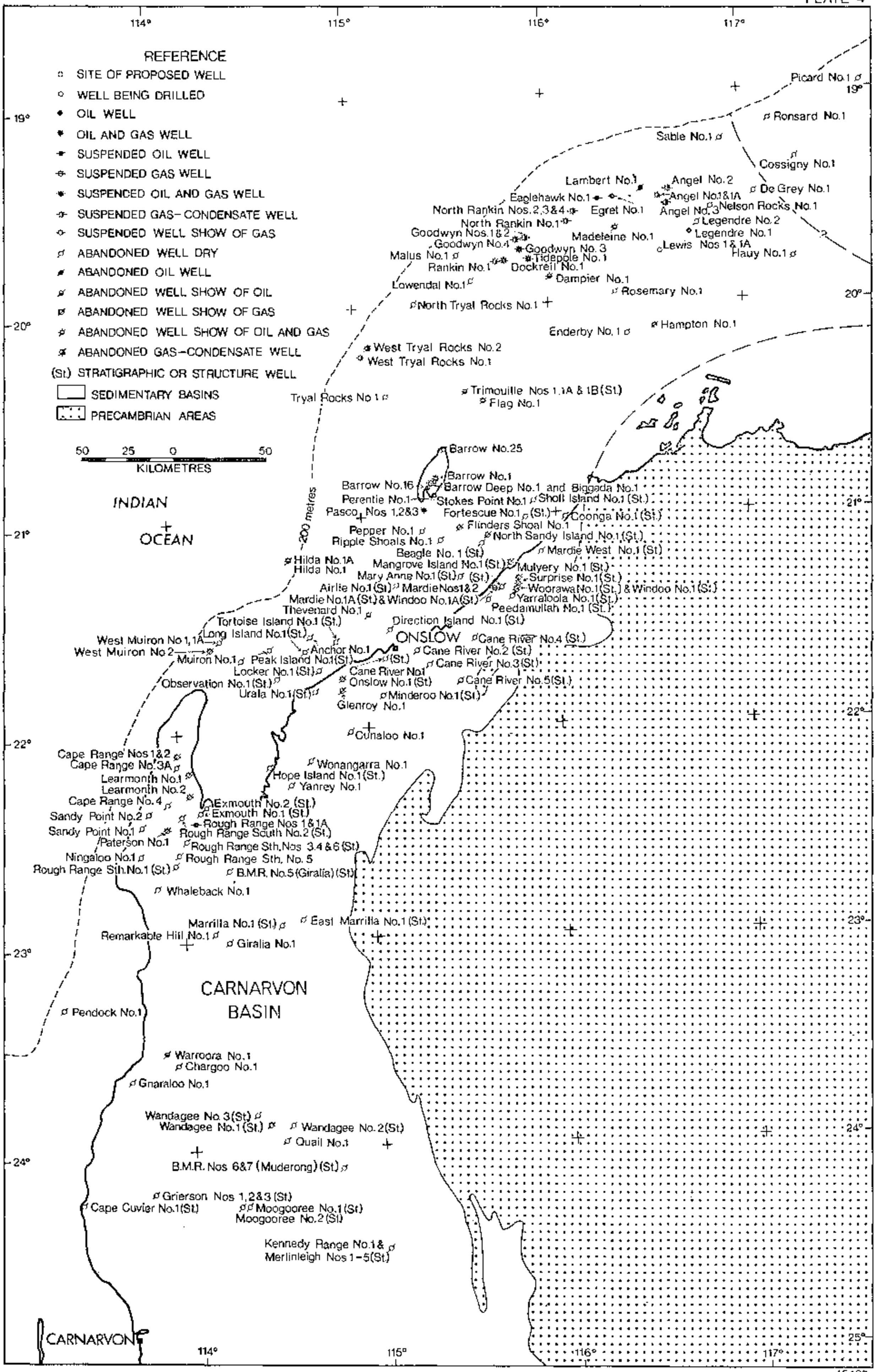

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Figure 22. Northern Carnarvon and southwestern Canning Basin showing wells drilled for petroleum to 31st December, 197

TABLE 19. WELLS DRILLED FOR PETROLEUM EXPLORATION IN WESTERN AUSTRALIA DURING 1975

Basin	Well	Concession	Operating Company	Type	Position		Elevation and water depth (metres)			Dates			Total depth (or depth reached) m	Bottomed in	Status on 31/12/75
					Latitude South ° ′ ″	Longitude East ° ′ ″	G.L.	R.T.	W.D.	Commenced	Reached T.D.	Rig released			
PERTH	Bouvard No. 1	WA-14-P	WAPET	NFW	32 31 26	115 15 11	....	12	51	3/1/75	28/1/75	3/2/75	1 980	L. Cretaceous	Dry, P & A
	Challenger No. 1	WA-13-P	WAPET	NFW	32 25 21	115 00 46	....	12	212	14/2/75	20/3/75	3/4/75	2 250	U. Jurassic	Dry, P & A
	S. Turtle Dove No. 1	WA-13-P	WAPET	NFW	30 07 46	114 38 12	....	30	63	16/4/75	23/4/75	....	350	....	Dry, P & A
	No. 1A	WA-13-P	WAPET	NFW	30 07 46	114 38 11	....	30	63	25/4/75	29/4/75	....	330	....	Dry, P & A
	No. 1B	WA-13-P	WAPET	NFW	30 07 46	114 38 11	....	30	63	4/5/75	15/6/75	6/7/75	1 830	L. Permian	Dry, P & A
CARNARVON	Biggada No. 1	PL-1H	WAPET	DPT	20 48 36	115 23 10	55	63	....	20/6/75	13/10/75	27/12/75	3 624	M. Jurassic	Suspended gas well
	W. Muiron No. 2	WA-24-P	WAPET	NFW	21 35 39	114 13 31	....	30	62	10/8/75	10/10/75	15/10/75	3 320	U. Triassic	Gas shows, P & A
	Tidepole No. 1	WA-28-P	BOCAL	NFW	19 46 07	115 53 06	....	30	110	18/10/75	26/11/75	17/12/75	3 491	Triassic	Suspended gas/cond./ oil well
	Lewis No. 1	WA-1-P	BOCAL	NFW	19 47 36	116 36 04	....	30	60	20/12/75	23/12/75	23/12/75	265	....	Dry. P & A
	No. 1A	WA-1-P	BOCAL	NFW	19 47 36	116 36 04	....	30	60	24/12/75	....	....	620	....	Drilling

BOCAL = BOCAL Pty. Ltd.
WAPET = West Australian Petroleum Pty. Ltd.
DPT = Deeper pool test well
NFW = New-field wildcat well
P & A = Plugged and abandoned

PERTH BASIN

Three wells were drilled by West Australian Petroleum Pty. Ltd. (WAPET) in the Perth Basin during 1975, all offshore. Bouvard No. 1 and Challenger No. 1 were both new-field wildcats in the southern part of the Vlaming sub-basin, designed to test culminations on anticlinal axes flanking the deepest part of the basin. No shows were encountered in either well and both were plugged and abandoned in the Yarragadee Formation, Bouvard No. 1 at 1 980 m and Challenger No. 1 at 2 250 m total depth.

South Turtle Dove No. 1B was located in the southwestern part of the Abrolhos sub-basin. The South Turtle Dove feature is a structural culmination on the Turtle Dove Ridge, a shallow basement high with an overall northwesterly plunge. The No. 1B well was plugged and abandoned at a total depth of 1 830 m in the Upper Permian after no shows were reported and the predicted Upper Permian and Lower Triassic sands were found to be absent. The South Turtle Dove No. 1 well was abandoned at 350 m and the No. 1A well, 15 m west of No. 1, was abandoned at 330 m, both due to mechanical problems.

CARNARVON BASIN

The only onshore well in Western Australia was Biggada No. 1 drilled by WAPET on Barrow Island. This was a deeper pool test, a follow-up to Barrow Deep No. 1 drilled in 1973, which was a Middle Jurassic gas discovery. After considerable problems with supernormal formation pressure, the well was eventually suspended as a gas well in the Middle Jurassic. Potential production is from several sands at a depth similar to those discovered in Barrow Deep No. 1. Production testing had not been completed at the year's end.

WAPET drilled one well offshore in the Carnarvon Basin, West Muiron No. 2, which was plugged and abandoned at 3 320 m in Late Triassic siltstone after encountering gas shows and abnormal pressures near the total depth. Mechanical problems contributed to the abandonment at this depth, but no potential pay zones were encountered.

BOCAL drilled one offshore well, Tidepole No. 1, which was located to evaluate Upper Triassic sands on a horst block adjacent to the oil-productive Goodwyn No. 3 block. The well was classed as a gas/condensate/oil discovery in the Triassic with a total net pay of 102 m including 17 m of oil. The oil zone tested 36° API gravity oil which flowed at the rate of 3 317 barrels per day. The average porosity of the sands was 23 per cent, calculated from wireline logs. BOCAL was drilling one well, Lewis No. 1, at the end of the year.

There was no drilling in any of the other basins during 1975.

GEOPHYSICAL SURVEYS

SEISMIC

During 1975 seismic surveys were conducted in the Perth, Carnarvon and Canning Basins. Details are as follows:

SEISMIC SURVEYS

Basin	Tenement	Company	Line kilometres	
			Marine	Land
Perth	EP 21	West Australian Petroleum Pty. Ltd.	....	4
,,	EP 23	,, ,, ,,	....	108
,,	EP 24	,, ,, ,,	....	80
,,	EP 25	,, ,, ,,	....	40
,,	PL–1	,, ,, ,,	....	94
,,	PL–2	,, ,, ,,	....	16
,,	WA–13–P	,, ,, ,,	85	....
,,	WA–14–P	,, ,, ,,	498	....
Carnarvon	EP 41	,, ,, ,,	....	38
,,	WA–1–P	BOCAL Pty. Ltd.	369	....
,,	WA–23–P	West Australian Petroleum Pty. Ltd.	347	....
,,	WA–24–P	,, ,, ,,	223	....
,,	WA–25–P	,, ,, ,,	150	....
,,	WA–28–P	BOCAL Pty. Ltd.	710	....
Canning	EP 7	West Australian Petroleum Pty. Ltd.	....	12
,,	EP 42	,, ,, ,,	....	42
,,	WA–29–P	BOCAL Pty. Ltd.	357	....

There were no gravity or magnetometer surveys during 1975.

GEOLOGICAL SURVEYS

XLX N.L. carried out 4 party months of surface geological surveys in the Carnarvon Basin (EP 86), while WAPET spent 1 party month, half in the Canning Basin (EP 42) and half in the Carnarvon Basin (EP 41).

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Crank, K.A., in prep., Wells drilled for petroleum exploration in W.A. to the end of 1975: West. Australia Geol. Survey Rec. 1976/1 (unpublished).

REVISED STRATIGRAPHIC AND FACIES NOMENCLATURE IN DEVONIAN REEF COMPLEXES OF THE CANNING BASIN

by P. E. Playford and A. E. Cockbain

ABSTRACT

Three basic facies are now distinguished in Devonian reef complexes of the Canning Basin: the platform, marginal-slope, and basin facies. The platform facies is subdivided into reef-margin, reef-flat, patch-reef, back-reef, and bank sub-facies, while the marginal-slope facies is subdivided into reefal-slope, fore-reef, fore-bank, and stromatolite sub-facies.

A new formation, the Nullara Limestone, is defined; it embraces the Famennian back-reef and bank deposits and was formerly included in the upper part of the Pillara Limestone. The Windjana Limestone is redefined so as to exclude the Frasnian reef deposits, which are now placed in the Pillara Limestone.

INTRODUCTION

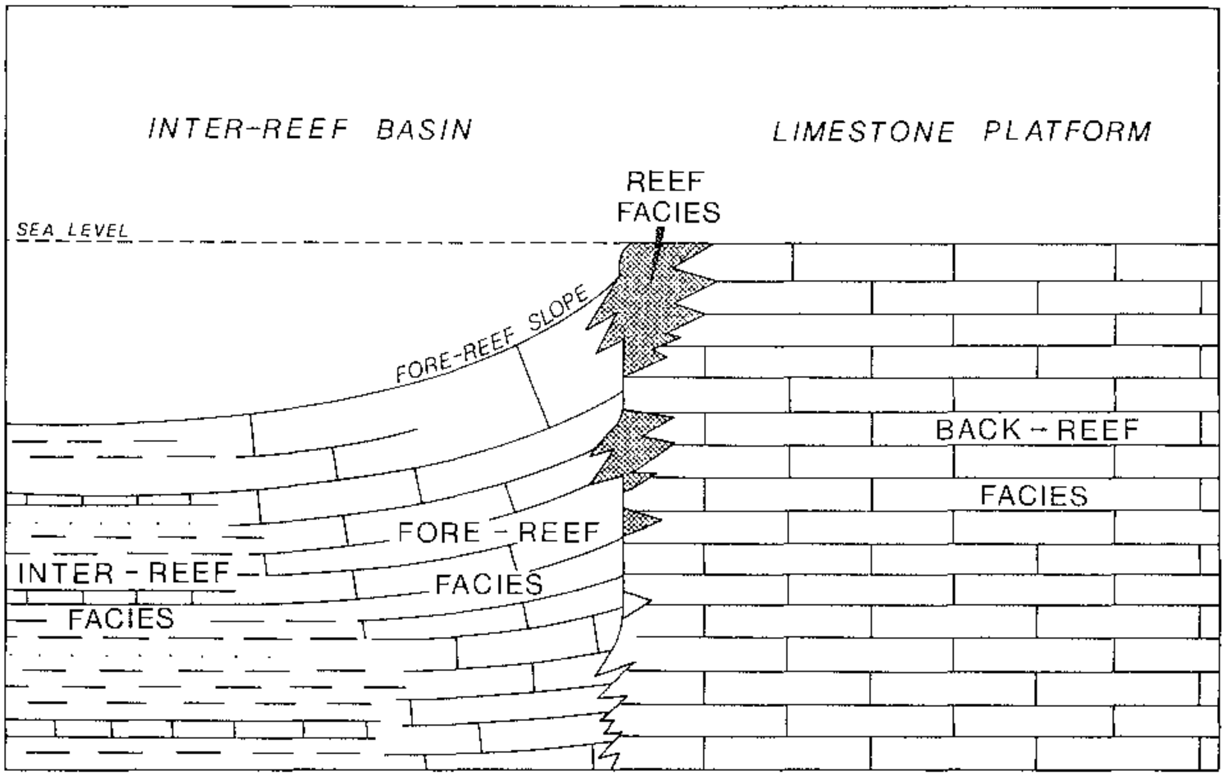
Since the Devonian reef complexes of the Canning Basin were described in Bulletin 118 of the Geological Survey (Playford and Lowry, 1966) more detailed studies have been carried out at Bugle Gap, Windjana Gorge, and other areas by the Geological Survey in association with the Bureau of Mineral Resources. As a result of this work it is desirable that the facies nomenclature adopted by Playford and Lowry be amended to facilitate more detailed description of the reef complexes. Some changes in the formal stratigraphic nomenclature are also now required.

The purpose of this paper is to formally introduce the new terminology so that it can be used in forthcoming publications.

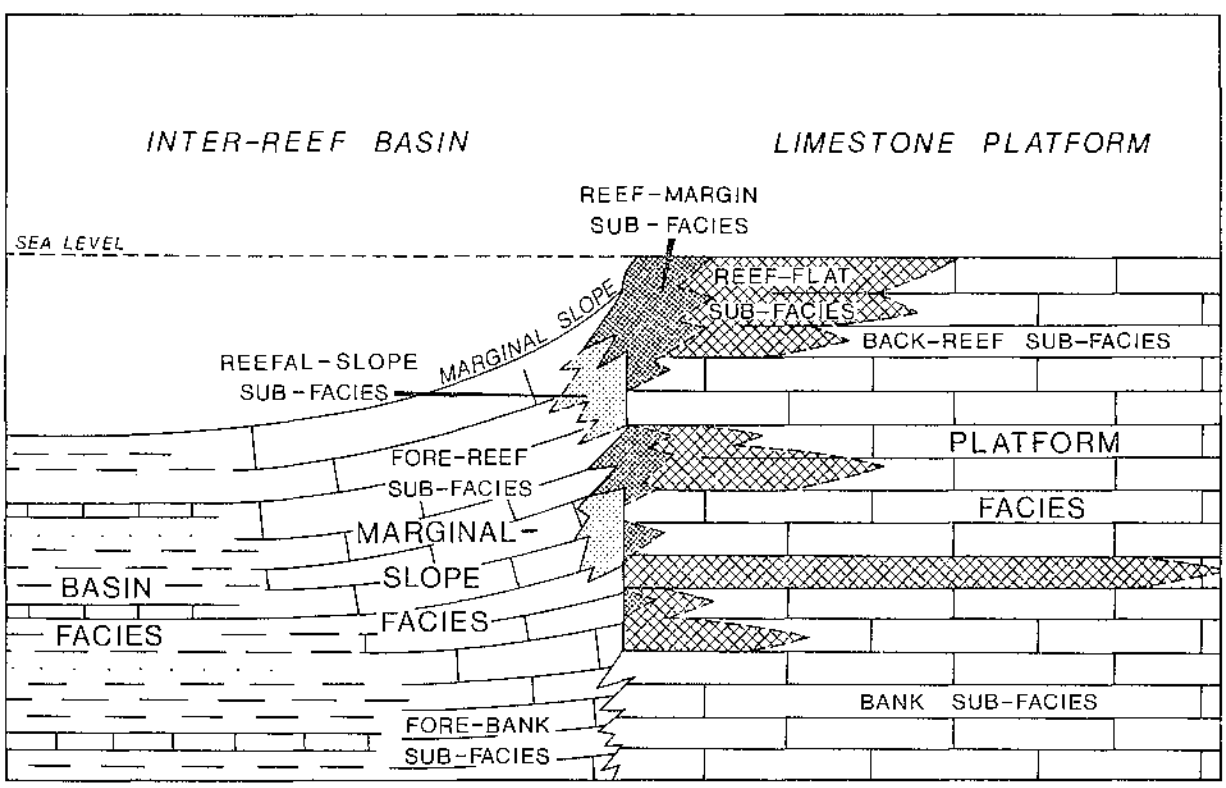
We wish to express our thanks to E. C. Druce and R. S. Nicoll of the Bureau of Mineral Resources and to M. H. Johnstone, D. N. Smith, W. J. Witt, and D. A. Lyons of West Australian Petroleum Pty. Ltd. (Wapet) for their co-operation and assistance in our work on the Devonian of the Canning Basin.

FACIES NOMENCLATURE

Playford and Lowry (1966) recognised four facies in the reef complexes, naming them the reef, back-reef, fore-reef, and inter-reef facies. This nomenclature proved to be adequate at the time for regional studies of the reef complexes. However, as pointed out by Playford (1969), it differs from the nomenclature applied to similar Devonian carbonate complexes in Canada. Moreover, it was realised that the terms fore-reef and back-reef facies were not appropriate in all cases, as these facies are not always separated by reef.



FACIES NOMENCLATURE OF PLAYFORD AND LOWRY (1966)



REVISED FACIES NOMENCLATURE

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Figure 23. Diagrammatic sections illustrating revised facies nomenclature for Devonian reef complexes of the Canning Basin compared with the nomenclature of Playford and Lowry (1966).

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The recent work has now shown that a more detailed facies terminology is desirable. The proposed new nomenclature is illustrated on Figure 23, where it is also compared with the older usage.

Three basic facies are now recognised in the complexes, and are named the platform, marginal-slope, and basin facies. Reef-margin, reef-flat, patch-reef, back-reef, and bank sub-facies are distinguished in the platform facies, and fore-reef, fore-bank, reefal-slope, and stromatolite sub-facies in the marginal-slope facies.

PLATFORM FACIES

The platform facies was constructed mainly by colonial organisms, but oolite and terrigenous sediments contributed substantially to the section in some places. Stromatoporoid and coral limestones are dominant in the Givetian-Frasnian platforms, while cryptalgal limestone and oolite characterize the Famennian platforms.

The *reef-margin sub-facies* consists of massive to crudely thick-bedded limestone, dolomitized in places, which forms a narrow rim around most limestone platforms. It was constructed largely by algae (skeletal and non-skeletal) and stromatoporoids and is believed to have been lithified penecontemporaneously.

The *reef-flat sub-facies* is commonly developed between the reef-margin and back-reef deposits. The reef-flat deposits are better bedded than those of the reef margin, but are otherwise similar, having been constructed largely by algae and stromatoporoids.

The *patch-reef sub-facies* consists of massive or crudely bedded stromatoporoid or algal limestone, forming masses that are generally less than 300 m across. It is also very similar to the reef-margin sub-facies, but it lacks associated reef-flat and back-reef deposits.

The *back-reef sub-facies* consists of well-bedded limestones with or without interbedded terrigenous deposits, which were laid down in widespread shelf lagoons behind reef margins and flats. Five main lithotopes (referred to by Playford and Lowry, 1966, as "sub-facies") are recognized in the back-reef deposits, and are termed the stromatoporoid, fenestral, coral, oolite, and oncolite lithotopes.

The *bank sub-facies* has lithological characteristics closely resembling those of the back-reef sub-facies. It was also laid down in widespread shelf lagoons, but the platforms lacked significant reef developments around their margins. The same lithotopes as those present in the back-reef sub-facies also occur in the bank sub-facies, but because of the lack of a reef rim they generally show evidence of more open circulation conditions (such as the presence of brachiopods and crinoid ossicles).

MARGINAL-SLOPE FACIES

The marginal-slope facies was laid down on slopes ranging from a few degrees to nearly vertical, flanking reefal limestone platforms or overlying drowned platforms. The facies was formed partly of material derived from the platforms, and partly of indigenous biogenic material and terrigenous sediments.

The *reefal-slope sub-facies* consists of poorly bedded to massive reef-like deposits which formed on the upper part of the marginal slope. It was built partly by organisms (mainly algae) and partly by sediment, derived from the platforms, which was trapped and bound by those organisms. The sub-facies is characterized by steep depositional dips, which range up to nearly vertical.

The *fore-reef sub-facies* makes up the major part of the marginal-slope facies. It consists of calcarenite, calcirudite, and megabreccia, with variable amounts of terrigenous material. Much of the clastic carbonate material is talus, derived from the platforms. Depositional dips in the fore-reef deposits are commonly up to 35°.

The *fore-bank sub-facies* consists of well-bedded calcarenite and calcilutite, made up of bank-derived sediment supplemented by indigenous biogenic material together with interbedded terrigenous sediment in some areas. They were laid down with only low depositional dips (commonly less than 10°).

The *stromatolite sub-facies* forms stromatolite bioherms and beds flanking and capping drowned reef pinnacles and ridges. It interfingers with other marginal-slope deposits and with basin deposits.

BASIN FACIES

The sediments of the basin facies were laid down in inter-reef basins between the reefal limestone platforms, in water depths ranging from perhaps 10 m to 200 to 300 m. The deposits consist mainly of terrigenous material (shale, siltstone, sandstone, and conglomerate) with some interbedded limestone, and were deposited nearly horizontally, or with very low initial dips.

STRATIGRAPHIC NOMENCLATURE

The revised rock-unit nomenclature for the reef complexes compared with that of Playford and Lowry (1966), is shown on Figure 24. The changes involve the introduction of a new name, Nullara Limestone, and redefinition of the limits of two formations, the Pillara and Windjana Limestones.

NULLARA LIMESTONE

Definition

The name Nullara Limestone is proposed for the unit of limestone with subordinate sandstone and siltstone, which overlies the Pillara Limestone (as redefined), overlies and interfingers with parts of the Windjana Limestone, interfingers with the Piker Hills Formation and the upper part of the Virgin Hills Formation, and is conformably overlain by the Fairfield Formation.

The name of the formation is taken from Nullara Spring near the northeastern end of the Oscar Range, and the type section is located nearby, extending from 17° 39′ 15″ S, 124° 56′12″ E to 17° 38′45″ S, 124° 54′ 20″ E.

The name "Nullara Oolite" was first used by Smith and others (1957) in an unpublished Wapet report. They nominated the type section near Nullara Spring, and believed that the formation was a fore-reef deposit equivalent to part of the "Oscar Calcarenite" and overlain by the upper part of that unit. Playford and Lowry (1966) included the "Nullara Oolite" and the overlying "Oscar Calcarenite" in the upper Pillara Limestone, recognising that these rocks formed part of the platform facies. They included the rest of Smith and others' "Oscar Calcarenite" in the Napier Formation.

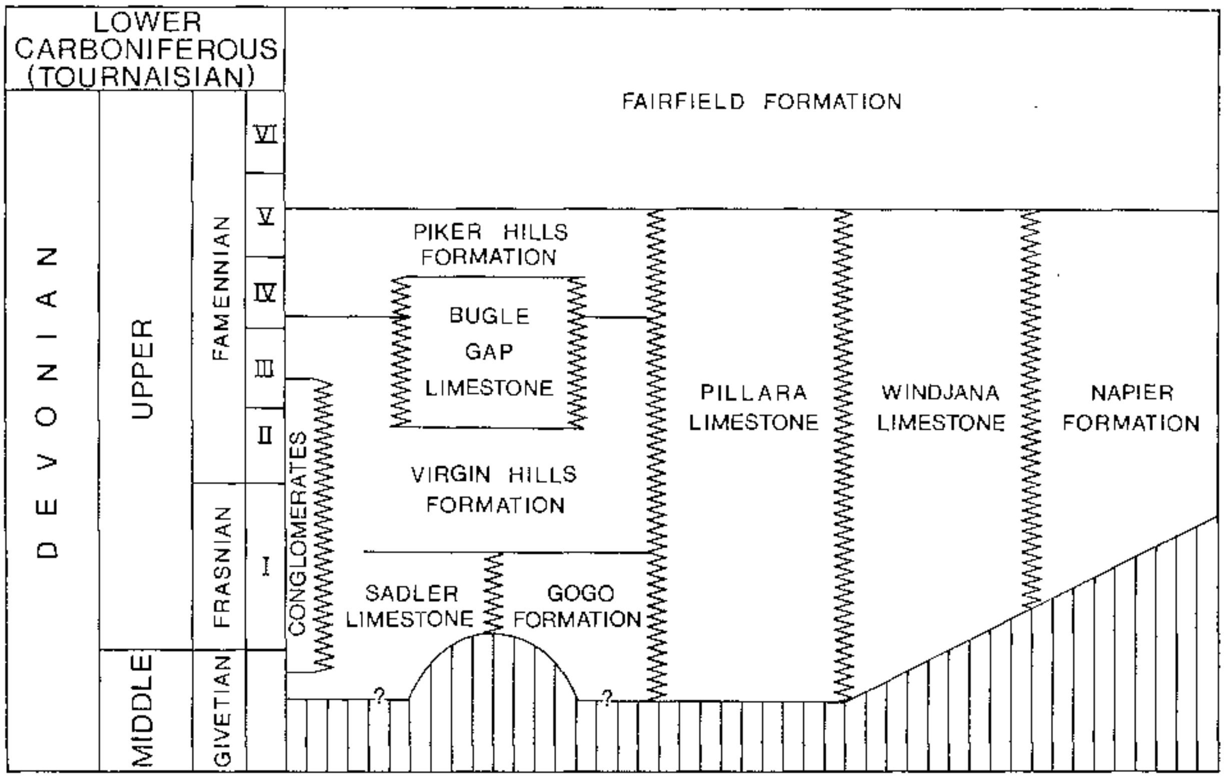
Recent studies have shown that the upper part of Playford and Lowry's Pillara Limestone can in fact be distinguished as a separate unit in both the surface and subsurface of the Lennard Shelf. Following discussions between ourselves and Wapet geologists (especially M. H. Johnstone, W. J. Witt, and D. A. Lyons) it was decided that it would be appropriate to apply the name Nullara Limestone to this unit, and it has since been used in a number of unpublished Wapet reports. The name "Nullara Formation" was also shown on a stratigraphic chart published by Read (1973) which was said to have been modified from an unpublished Wapet chart.

Lithology

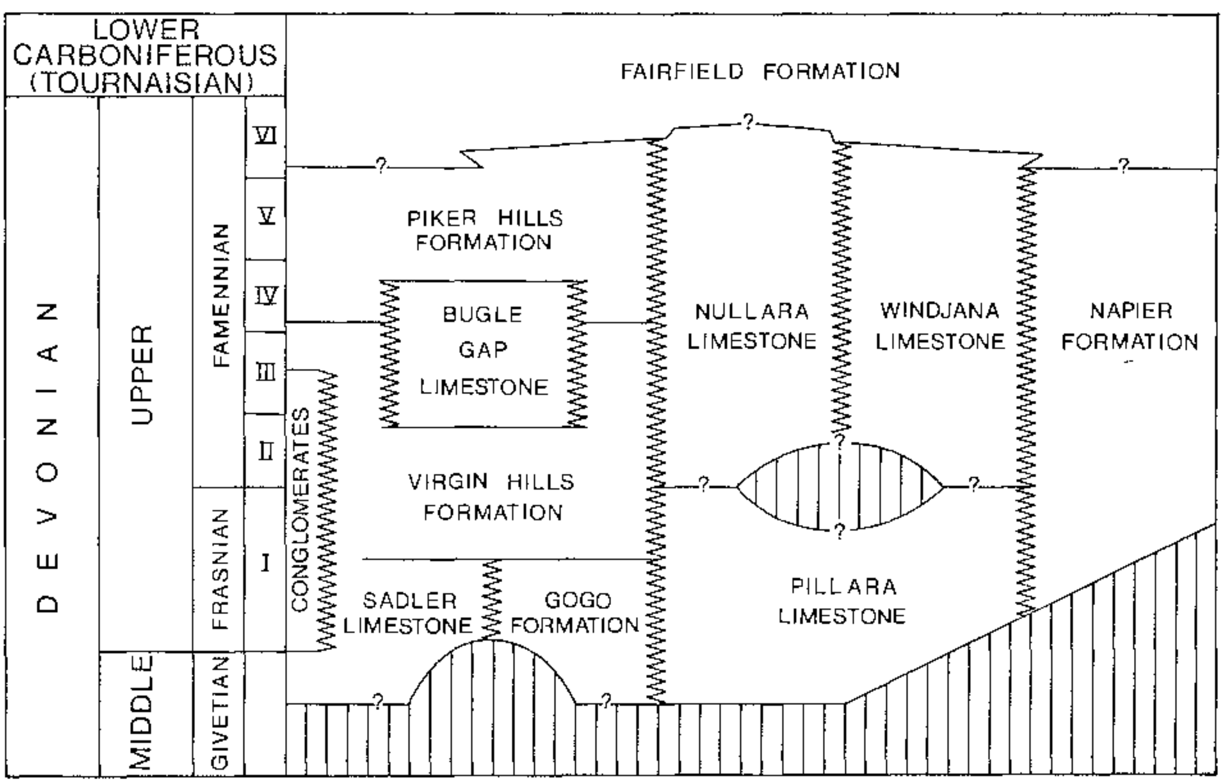
The Nullara Limestone is dominantly a unit of well-bedded fenestral (cryptalgal) calcarenite and oolite, with some interbeds of sandstone and siltstone. Oncolite-rich beds occur, and columnar stromatolitic structures are common in some areas.

Stratigraphic relationships

The Nullara Limestone is a back-reef and bank deposit, which, together with the Windjana Limestone, formed the Famennian limestone platforms. The formation overlies the Windjana Limestone in some areas (such as at the base of the type section in the Oscar Range), where the platform has expanded laterally at a low angle. Elsewhere it interfingers with the Windjana Limestone (in the Oscar and Napier Ranges) and interfingers with or is abutted by the Piker Hills and Virgin Hills Formations (in the Horseshoe Range area).



STRATIGRAPHIC NOMENCLATURE OF PLAYFORD AND LOWRY (1966)



REVISED STRATIGRAPHIC NOMENCLATURE

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Figure 24. Correlation charts illustrating revised stratigraphic nomenclature for Devonian reef complexes of the Canning Basin compared with the nomenclature of Playford and Lowry (1966).

The Nullara Limestone overlies the Pillara Limestone in Hawkstone Peak No. 1 well, but the two formations have not been seen in juxtaposition at the surface, and it is not known whether they are conformable. It is clear that rapid subsidence occurred in certain areas at about the Frasnian-Famennian boundary, drowning some of the Pillara Limestone platforms. However, it is possible that uplift and erosion of the platforms may have occurred in different areas, while other platforms may have continued growth without significant interruption.

The Nullara Limestone is overlain with apparent conformity by the Fairfield Formation in the Horseshoe Range and Red Bluffs areas and in a number of subsurface well sections.

Distribution and thickness

The Nullara Limestone is about 400 m thick in the type section at the northwestern end of the Oscar Range. The formation is also exposed in various parts of the Napier Range, and in the Horseshoe Range and Red Bluffs areas. It has been encountered in several wells drilled on the Lennard Shelf, where it is up to 320 m thick (in the Meda wells).

Fossils and age

The Nullara Limestone contains few fossils of value for precise dating. Most of the unit consists of cryptalgal limestone and oolite with few skeletal fossils other than thick-shelled gastropods and bivalves. Icriodid conodonts occur rarely, and there are also some stromatoporoids and brachiopods. These fossils indicate that the formation is of Famennian age, and E. C. Druce (written comm., 1973) suggests that it probably extends as high as *do* VI. As pointed out by Roberts and others (1971) there is no evidence of any early Famennian section in the Nullara Limestone (then regarded as the Famennian part of the Pillara Limestone). However, as mentioned previously, the older part of the Nullara Limestone is not exposed, and no definitive fossils have been found in it in the subsurface. We believe that there is no reason why the formation should not extend in age through most of the Famennian.

PILLARA LIMESTONE

The Pillara Limestone is revised so as to exclude the Famennian platform deposits now placed in the Nullara Limestone and to include reef deposits of Frasnian age that had previously formed part of the Windjana Limestone. As redefined, the Pillara Limestone embraces the whole of the Frasnian platform facies.

WINDJANA LIMESTONE

The Windjana Limestone is to be restricted to the massive limestone which underlies and interfingers with the Nullara Limestone. The formation embraces the reef-margin deposits of the Famennian platforms. It no longer includes Frasnian reef, which is now placed in the Pillara Limestone.

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PERMIAN STRATIGRAPHIC NOMENCLATURE, NOONKANBAH 1:250 000 SHEET

by R. W. A. Crowe[1] and R. R. Towner[2]

ABSTRACT

Mapping during 1974 on the Noonkanbah Sheet area has resulted in recognition of new mappable units in the Early Permian Grant Formation and Poole Sandstone. The topmost unit of the Grant Formation, consisting mainly of sandstone, is named the Millajiddee Member and the underlying siltstone unit containing tillite, the Wye Worry Member.

Within the upper part of the Poole Sandstone a coarse-grained sandstone and conglomerate sequence is named the Christmas Creek Member. Previously this member had been included in the overlying Noonkanbah Formation.

INTRODUCTION

In 1974, a joint party from the Geological Survey of Western Australia and the Bureau of Mineral Resources remapped the Phanerozoic Canning Basin part of the Noonkanbah 1:250 000 Sheet area. New stratigraphic units mapped in the Early Permian sequence in that area are defined below.

[1] Geological Survey of Western Australia.
[2] Bureau of Mineral Resources.

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SUBDIVISIONS OF THE GRANT FORMATION

The Grant Formation was originally defined by Guppy and others (1952), and Playford and others (1975) state that the Grant Range (lat. 18° 00′ S, long. 124° 10′ E), from which the formation is named, is also the type locality. In the Fitzroy Trough (see Fig. 25) three subsurface divisions of the Grant Formation can be identified in well logs (e.g. Saint George Range No. 1, Mount Hardman No. 1). These subdivisions consist of a "lower sandstone unit", a "middle shale unit" and an "upper sandstone unit" (Shannon and Henderson, 1966, Young and O'Shaughnessy, 1973). To the south of the Fitzroy Trough, in the southern part of the Canning Basin, the "upper sandstone unit" is missing and a "basal tillite unit" is present underlying the "lower sandstone unit" of the Fitzroy Trough (see Koop, 1966). These subdivisions of the Grant Formation have been tentatively correlated with named surface units in company reports but, as Playford and others (1975) point out, there is doubt about the validity of these correlations, and for this reason it is impossible to formally define the units at this stage.

Recent mapping on the Noonkanbah Sheet area has allowed subdivision of the exposed part of the Grant Formation in that area, and these surface subdivisions are herein defined as members of the Grant Formation. They are the uppermost Millajiddee Member and the underlying Wye Worry Member. Rocks below the Wye Worry Member were mapped as undivided Grant Formation.

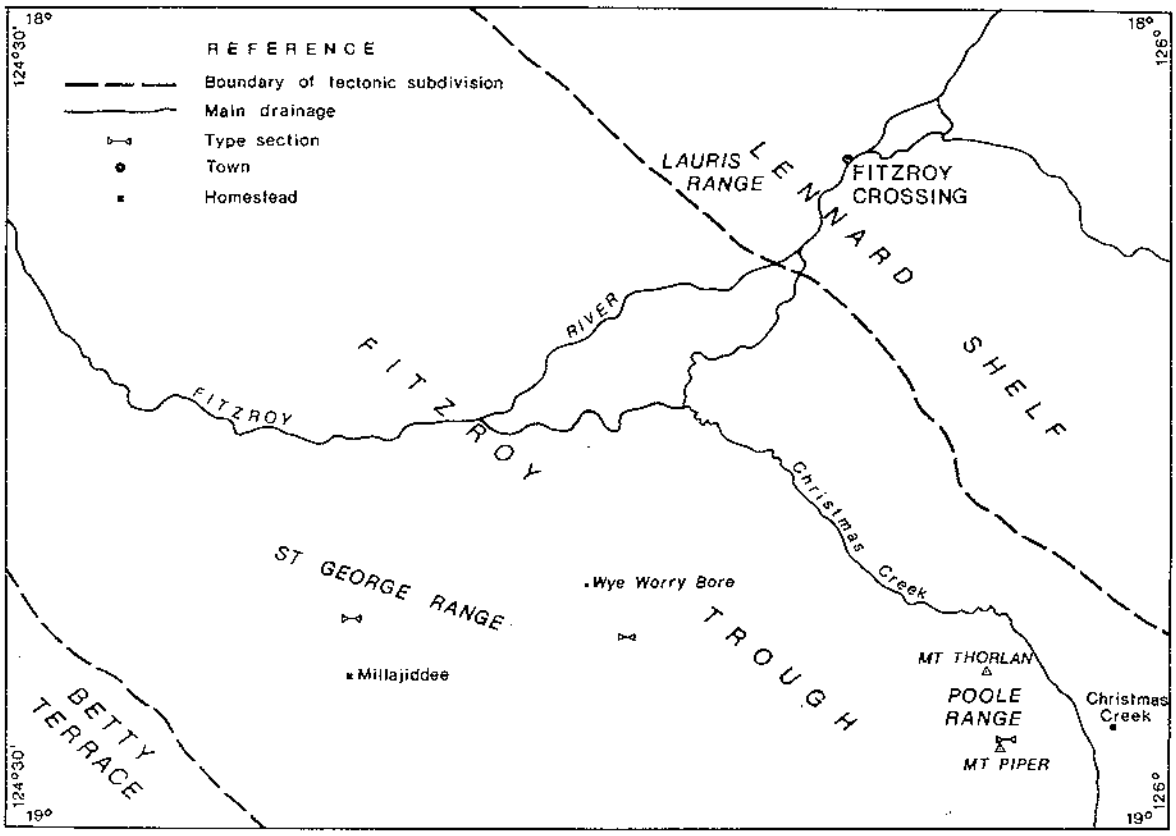

Figure 25. Sketch map of Noonkanbah 1 : 250 000 Sheet area showing localities referred to.

Saint George Range No. 1 well (Shannon and Henderson, 1966) spudded just below the base of the Wye Worry Member and shows that both of the newly defined members belong to the "upper sandstone unit" discussed above. When the correlatives of the units identified in subsurface are better known it may be possible to name them as formations and to upgrade the Grant Formation to group status.

PROPOSED NEW MEMBERS OF THE GRANT FORMATION

(1) *WYE WORRY MEMBER*

Derivation of name: Wye Worry Bore, lat. 18" 42' 25° S, long. 125° 15' 20" E, on Cherrabun Station in the Saint George Range.

Distribution: The member crops out in the Saint George Range and the Poole Range. It is also present in the Lauris Range and in isolated hills around Fitzroy Crossing, and it extends into the Mount Ramsay Sheet area to the east. It probably also crops out in the Mount Anderson Sheet area to the west, but has not yet been mapped in that area.

Lithology: At its type seetion the member consists mainly of sandy siltstone and shale with calcareous concretions and striated and faceted glacial dropstones. Near the base it contains varves of graded silt and clay, though in the middle and upper parts of the sequence silt and clay are not separated. The member contains lenses of tillitic conglomerate and it is sandy towards the top. In the western Saint George Range the member contains more sand than at its type section. In the Poole Range the member is slumped and deformed, so that it is mixed with parts of the overlying Millajiddee Member.

Type section locality: Lat. 18° 46' 45" S, long. 125° 18' 50" E in the eastern Saint George Range.

Thickness: The base of the member is not exposed at the type section, though at least 95 m is estimated to be present in this area. In the central Saint George Range the member is 25 m thick and in the western Saint George Range it is 65 m thick. In the Poole Range it is at least 45 m thick.

Fossils and age: Apart from trace fossils and indeterminate plant fragments, marine fossils were found in the middle part of the member. The fossils found have been identified by J. M. Dickins and are as follows:

Bivalves
- *Eurydesma*? sp. ind.
- *Deltopecten lyonsensis* Dickins 1957
- *Etheripecten* cf. *tenuicollis* (Dana) 1847
- *Streblopteria* sp.

Gastropods
- *Keeneia*? sp. ind.

Brachiopods
- Unidentifiable dielasmatids and spiriferids

Bryozoans
- *Fenestella* sp.

Crinoids
- *Calceolispongidae* sp. nov.

The fauna has much in common with the fauna of the upper part of the Lyons Group of the Carnarvon Basin, Western Australia, and similarly it is a cold water fauna and is of Sakmarian *sensu lato* (Early Permian) age (J.M. Dickins, written comm.).

Relationships: No clear exposure of the lower boundary was seen, but the member everywhere overlies undivided Grant Formation sandstone, probably disconformably. The Wye Worry Member is conformably overlain by the Millajiddee Member in most of the Saint George Range and probably in the Poole Range; however, in the southwestern Saint George Range and at Mount Thorlan, the Nura Nura Member of the Poole Sandstone rests unconformably on the Wye Worry Member. In the Lauris Range and in the southwestern Mount Ramsay Sheet area the Millajiddee Member rests disconformably on the Wye Worry Member.

(2) *MILLAJIDDEE MEMBER*

Derivation of name: Millajiddee homestead (lat. 18° 49' 00" S, long. 124° 55' 25" E) at the southwestern edge of the Saint George Range.

Distribution: Crops out in the Saint George Range and the Poole Range, although in the latter it is mixed with the underlying Wye Worry Member due to slumping. At Mount Thorlan and in the southwestern Saint George Range the Millajiddee Member is cut out by the unconformity at the base of the Poole Sandstone. The member is well exposed in the Lauris Range, and other more isolated exposures in the Noonkanbah Sheet area have been assigned to it. The member also occurs in the southwestern Mount Ramsay Sheet area and probably extends westwards into the Mount Anderson Sheet area.

Lithology: Consists mainly of sandstone and minor siltstone and conglomerate. The grain size is mainly fine though a medium and coarse-grained middle part is present. The bedding is commonly poorly defined so that the member characteristically forms cliffs on weathering. Both large and small-scale cross-bedding are common and the upper part of the unit is slumped in many areas.

Type section locality: Lat. 18° 45′ 00″ S, long. 124° 55′ 25″ E in the western Saint George Range.

Thickness: In the western Saint George Range, at the type section, the member is 70 m thick. It is 65 m thick in the centre and 75 m thick in the eastern part of the range although in the southeastern part it is estimated to be over 100 m thick. No other complete sections were measured, but it is at least 30 m thick in the Lauris Range.

Fossils and age: The lower part of the member locally contains abundant trace fossils. Indeterminate wood fragments are also present.

The age of the member can be taken as Sakmarian *sensu lato*. The underlying Wye Worry Member is dated as Sakmarian by the fossils it contains and the overlying Nura Nura Member of the Poole Sandstone contains marine fossils whose limits appear to be between late Sakmarian and early Artinskian (Thomas and Dickins, 1954; Glenister and Furnish, 1961). The Millajiddee Member does not appear to be younger than Sakmarian (J. M. Dickins, written comm.).

Relationships: The boundary with the underlying Wye Worry Member is gradational in the Saint George Range and probably in the Poole Range. In the Lauris Range and in the southwestern Mount Ramsay Sheet area the boundary is a disconformity. In the Noonkanbah Sheet area the Millajiddee Member is overlain by the Nura Nura Member of the Poole Sandstone. The contact is an unconformity and in places the Millajiddee Member is cut out by it.

SUBDIVISIONS OF THE POOLE SANDSTONE

Guppy and others (1952) defined the Poole Sandstone and designated the Poole Range (lat. 18° 50′ S, long. 125° 45′ E) as the type area. They also defined the basal Nura Nura Member, although the name had been used in previous unpublished company reports.

During the recent mapping a further member was recognised at the top of the Poole Sandstone in the eastern part of the area. This upper member, herein defined as the Christmas Creek Member, consists of coarse-grained sandstone and conglomerate. It was previously considered to be part of the overlying Noonkanbah Formation (Guppy and others, 1958). They described the contact between the Poole Sandstone and the Noonkanbah Formation thus: "the contact may be seen at Mount Synnot" (now called Mount Thorlan) "where a sandstone and conglomerate sequence capping Mount Synnot represents the base of the Noonkanbah. The persistent conglomerate bed at the junction of the two formations in the area between the Poole Range and the Saint George Range suggests that a disconformity separates the Poole Sandstone and the Noonkanbah Formation".

The contact between the fine-grained part of the Poole Sandstone and the Christmas Creek Member was clearly seen to be interfingering in the Poole Range, whereas the boundary between the Christmas Creek Member and the Noonkanbah Formation, although poorly exposed, appears planar and probably represents a disconformity. For this reason the Christmas Creek Member is identified by us as the topmost member of the Poole Sandstone.

PROPOSED NEW MEMBER OF THE POOLE SANDSTONE

CHRISTMAS CREEK MEMBER

Derivation of name: Christmas Creek, a tributary of the Fitzroy River which crosses the eastern part of the Noonkanbah Sheet area.

Distribution: The member crops out in the highest parts of the Poole Range and at Mount Thorlan. It is exposed discontinuously on the plains between the Pool Range and the Saint George Range and it occurs along the northern flank of the Saint George Range. The member is not present along the southern and western flanks of the Saint George Range, and was not identified elsewhere in the sheet area.

Lithology: The Christmas Creek Member consists of large-scale cross-bedded poorly sorted granule conglomerate and fine to coarse-grained sandstone. The beds are medium to thin and are graded in places. Asymmetrical ripple marks occur on many bedding planes.

Type section locality: Mount Piper in the Poole Range, lat. 18° 54′ 00″ S, long. 125° 47′ 30″ E.

Thickness: The thickest measured section was only 15 m thick, but the top is eroded. The maximum thickness is variable but is thought to be less than 25 m.

Age: Artinskian, based on the ages of the overlying and underlying units.

Fossils: No fossils were found in the member.

Relationships: The Christmas Creek Member overlies and laterally interfingers with undivided Poole Sandstone, although it is locally unconformable. The member is everywhere overlain by the Noonkanbah Formation, and the contact, although poorly exposed, appears planar. The unit wedges out to the south and west in the Saint George Range.

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ENVIRONMENTAL INTERPRETATION OF THE PERMIAN NURA NURA MEMBER OF THE POOLE SANDSTONE, NOONKANBAH SHEET AREA, CANNING BASIN: A GRADATION BETWEEN FLUVIATILE AND SHALLOW-WATER MARINE FACIES

by R. W. A. Crowe[1] and R. R. Towner[2]

ABSTRACT

During mapping in 1974, the late Sakmarian Nura Nura Member of the Poole Sandstone was mapped in the Noonkanbah Sheet area. In the western Saint George Range the member was laid down in shallow-water marine conditions, and in the eastern part of the range the deposits are interpreted as deltaic in origin. Further east, at Mount Hutton, a meandering-river environment of deposition is inferred and still further east, in the Poole Range, the evidence indicates higher energy deposits of the braided-river type. It is concluded that the late Sakmarian land surface probably sloped towards the west.

INTRODUCTION

In 1974 a joint party from the Geological Survey of Western Australia and the Bureau of Mineral Resources re-mapped the Noonkanbah 1:250 000 Sheet area. The area was originally mapped at a scale of 4 miles to 1 inch by Guppy and others (1958). This paper records the data collected from the Nura Nura Member of the Poole Sandstone (see Table 20), and presents an interpretation of the environment of deposition of this unit.

TABLE 20. PERMIAN STRATIGRAPHY: NOONKANBAH SHEET AREA

LIVERINGA GROUP—	
Hardman Formation	Cherrabun Member Hicks Range Sandstone Member Kirkby Range Member
Condren Sandstone	
Lightjack Formation	
Noonkanbah Formation	
Poole Sandstone	Christmas Creek Member middle Poole Sandstone Nura Nura Member
Grant Formation	Millajiddee Member Wye Worry Member Undivided

The name Nura Nura was first used by Wade (1937, and unpublished company reports) and the Nura Nura Member was later defined by Guppy and others (1952) as "calcareous sandstone, sandy limestone, and limestone, with bands of unsorted, coarser sediments". The middle part of the Poole Sandstone above the Nura Nura Member (herein referred to as the middle Poole Sandstone) has not been formally named (see Crowe and Towner, 1976, and Table 20).

In the Noonkanbah Sheet area, Guppy and others (1958) recorded "a marine, fossiliferous, lensing bed" in the southern and north-central portions of the Saint George Range (see Fig. 26) and they correlated this unit with the Nura Nura Member in the adjoining Mount Anderson Sheet area to the west. Further fossil collections made in 1974 have confirmed this correlation (J. M. Dickins, pers. comm.) and it is on this basis that the Nura Nura Member is identified in the Noonkanbah Sheet area. The fossils indicate an age of latest Sakmarian for the unit (Glenister and Furnish, 1961; J. M. Dickins, pers. comm.).

[1] Geological Survey of Western Australia.
[2] Bureau of Mineral Resources.
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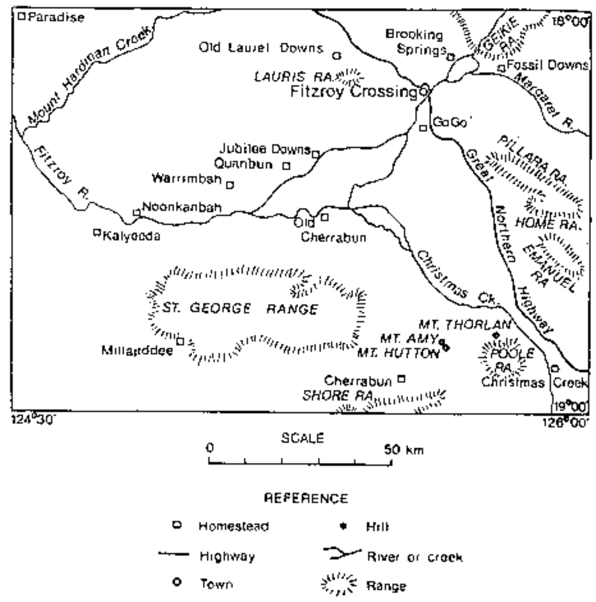

Figure 26. Sketch map of Noonkanbah 1 : 250 000 Sheet area showing localities referred to.

In the exposures described by Guppy and others (1952 and 1958) the Nura Nura Member lies with slight angular unconformity on the Grant Formation and is conformably overlain by fine-grained, ripple-marked, quartz wacke of the middle Poole Sandstone. The boundaries are relatively distinctive features and have been traced throughout the rest of the Saint George Range and into the Poole Range, enabling the Nura Nura Member to be mapped throughout these areas. Previously the member was not known to extend into the eastern Saint George Range and Poole Range. This paper deals mainly with the lateral variations within this member and the lithology and depositional environments are discussed for four different localities (shown in Fig. 26).

WESTERN SAINT GEORGE RANGE AREA

In the western Saint George Range area the Nura Nura Member unconformably overlies the Wye Worry Member (of Crowe and Towner, 1976) of the Grant Formation. The Millajiddee Member (of Crowe and Towner, 1976), which is the uppermost member of the Grant Formation (see Table 20), is cut out by the unconformity.

The base of the Nura Nura Member is marked by discontinuous conglomerate containing poorly sorted pebbles and boulders. The clasts are subangular and are mainly composed of quartzite and granite, and some of the boulders are faceted. These faceted boulders are believed to be derived from tillite in the underlying Wye Worry Member. Embedded in the sandstone matrix of the basal conglomerate are fossil shells, many of which are unbroken. The unbroken shells suggest a low-energy environment, so the larger clasts cannot have been transported far. This would explain the preservation of facets on the boulders.

Above the basal conglomerate in the western Saint George Range there are approximately 12 m of interbedded sandstone, siltstone and granule conglomerate. Fining-up cycles of 20 to 60 cm thickness are common. These contain ripple-marked tops and basal fossiliferous lag conglomerates, with vertical burrows and bioturbated zones. Scour-and-fill structures are present and the scour troughs are filled with fossiliferous intraformational conglomerate suggesting that these deposits were laid down by currents in channels. Marine channel deposits are commonly formed as a result of tidal action (Reineck and Singh, 1973, among others) and although additional data, particularly current readings, are needed, it is suggested that this part of the sequence was deposited in a tidal environment.

Above these deposits, the sequence grades into 5 m of wavy and lenticular, thin-bedded, medium to fine-grained lithic wacke and mudstone with minor flaser bedding (terms of Reineck and Wunderlich, 1968). This type of bedding is also very common in subtidal and intertidal zones where it is produced as a result of alternating high and low turbulence (Reinick and Wunderlich, 1968).

The top part of the Nura Nura Member in the western Saint George Range, around Millajiddee homestead, consists of approximately 10 m of massive, fine to very fine-grained, very well sorted sandstone containing faint, planar cross-bedding. These features indicate a high degree of winnowing of the sediment, and this is normally attributed to wave action in shallow-marine sediments. Consequently this deposit is tentatively interpreted as a beach or sand-bar deposit. The position of this part of the section in the vertical sequence (see below) suggests that it represents a barrier-bar deposit.

The overlying middle Poole Sandstone is fairly uniform throughout the entire Noonkanbah Sheet area, being composed of fine and very fine-grained, thin-bedded sandstone with abundant straight-crested, symmetrical ripple marks interbedded with fossil-root-filled beds. Crowe and Towner (in press) have shown from measurements of the ripple marks that they were probably formed by waves, indicating deposition in shallow water. The close association of the ripple-marked beds with fossil roots and the absence of a marine fauna and other sedimentary structures commonly found in shallow-water marine sediments suggests that the deposit is at least partly continental. Van Straaten (1954) has described probable lagoonal deposits in the Devonian of Belgium which are similar to the rocks of the middle Poole Sandstone, and in particular he discusses the abundance of wave-formed ripple marks, and points out that these structures, although actively formed in the tidal-flat environment, in fact stand little chance of preservation due to physical and organic reworking of the sediment. In the lagoonal environment, however, wave ripples stand a much better chance of being preserved due to the "discontinuous upward growth of the deposits" (van Straaten, 1954). As wave-formed ripple marks are very abundant in the middle Poole Sandstone, it is tentatively suggested that they were formed in a lagoonal environment. This suggestion gains credence when the whole sequence is considered in the vertical sense.

Visher (1965) has shown how, in a typical regressive marine sequence, the environment changes upwards from shallow marine to littoral to dune-barrier-bar and eventually to lagoonal. Although the dune phase was not identified in the western Saint George Range it is suggested that the deposits of the Nura Nura Member and the middle Poole Sandstone represent such a regressive sequence.

Towards the middle of the Saint George Range the Nura Nura Member could not easily be differentiated from the overlying middle Poole Sandstone as the lithologies of both units are similar. However, on the air-photographs of this area, the characteristic darker tone of the Nura Nura Member is clearly visible, allowing the member to be identified. Because the lithology of the Nura Nura Member in this area is similar to that of the middle Poole Sandstone, their depositional environments are also thought to be similar.

EASTERN SAINT GEORGE RANGE AREA

In the eastern Saint George Range the Nura Nura Member overlies the Millajiddee Member of the Grant Formation with a planar angular unconformity. At the base it consists of a poorly bedded, fine to medium-grained quartz wacke which contains abundant vertical burrows similar to those in the western part of the range. Other similarities with the western part of the range include the presence of the flaser bedding and lenses of intraformational mud-pellet conglomerate; however, fossils are absent in the east. Ascending the sequence, the lithology changes to well-rounded, well-sorted, medium and thin-bedded, medium-grained quartz arenite and quartz wacke, above which there is an erosional contact with the upper part of the member about 12 m above the base.

The upper 10 m of the member consists of a series of stacked, large-scale trough co-sets (each about 2 m thick) in which the grain size fines upwards. In each fining-upward cycle there is a conglomeratic base (both intraformational and extraformational) containing wood fragments and a top part with asymmetrical ripple marks. Superimposed on the fining-upward cycles is an overall upward graduation to coarser grained, well-sorted sediments. The Nura Nura Member is conformably overlain by the typically fine-grained, ripple-marked sediments of the middle Poole Sandstone, described above.

Lithologically, the lower part of the Nura Nura Member in the eastern Saint George Range is similar to the lower part of the section in the western part of the range except that it does not contain fossils and there is no basal conglomerate. It is consequently interpreted as a shallow-water deposit. In the upper part, the abundant trough cross-bedding and fining-upwards cycles are characteristic of lateral accretion by channels, and these cyclic sediments are interpreted as point-bar deposits (Allen, 1964). Point-bar deposits are laid down by meandering channels and can occur in an intertidal environment; however, the overall upward increase in grain size and sorting of the whole unit suggests that the Nura Nura Member at this locality represents a regressive marine sequence (see Visher, 1965). Moreover, the upward increase in grain size of the upper part of the member and the erosional contact at the base of this part suggest a regressive sequence of the deltaic type (see Selley, 1970).

MOUNT HUTTON

The Nura Nura Member is well exposed around the bases of Mounts Hutton and Amy, where it unconformably overlies slumped Grant Formation. In several places the member is absent but it reaches a thickness of 7 m on the west of Mount Hutton. This exposure is shown diagrammatically in Figure 27 and is described below.

The basal part of the member consists of large-scale, trough cross-bedded sandstone containing fossil root impressions. The cross-bedding indicates deposition from currents, and the roots indicate a continental environment, so it is suggested that these beds are fluviatile deposits.

The sequence passes either gradationally or abruptly upwards into massive, poorly sorted, medium-grained quartz wacke containing very abundant downward-bifurcating root impressions. These massive beds are interpreted as fossil soils, as they contain abundant root impressions. Lying either disconformably or conformably above these beds is ripple-marked sandstone, typical of the middle Poole Sandstone, except that at this locality it also contains scattered root impressions.

The interpreted fossil soil horizon in the Nura Nura Member interfingers laterally with poorly laminated mudstone, lacking fossil roots (see Fig. 27) but containing fossil leaves and scattered coarse sand grains. Because the fossil soil interfingers with this mudstone, it is evident that the mudstone beds must have been deposited at the same time that the soil was supporting vegetation. It must also be of similar lateral extent to the body of water in which it was deposited (5-10 m) and the absence of current structures in the mudstone indicates that deposition took place from suspension. The presence of fossil leaves supports this interpretation, as leaves need quiet conditions to be preserved. The scattered coarse grains of sand were probably carried into the water body by wind or on vegetation rafts.

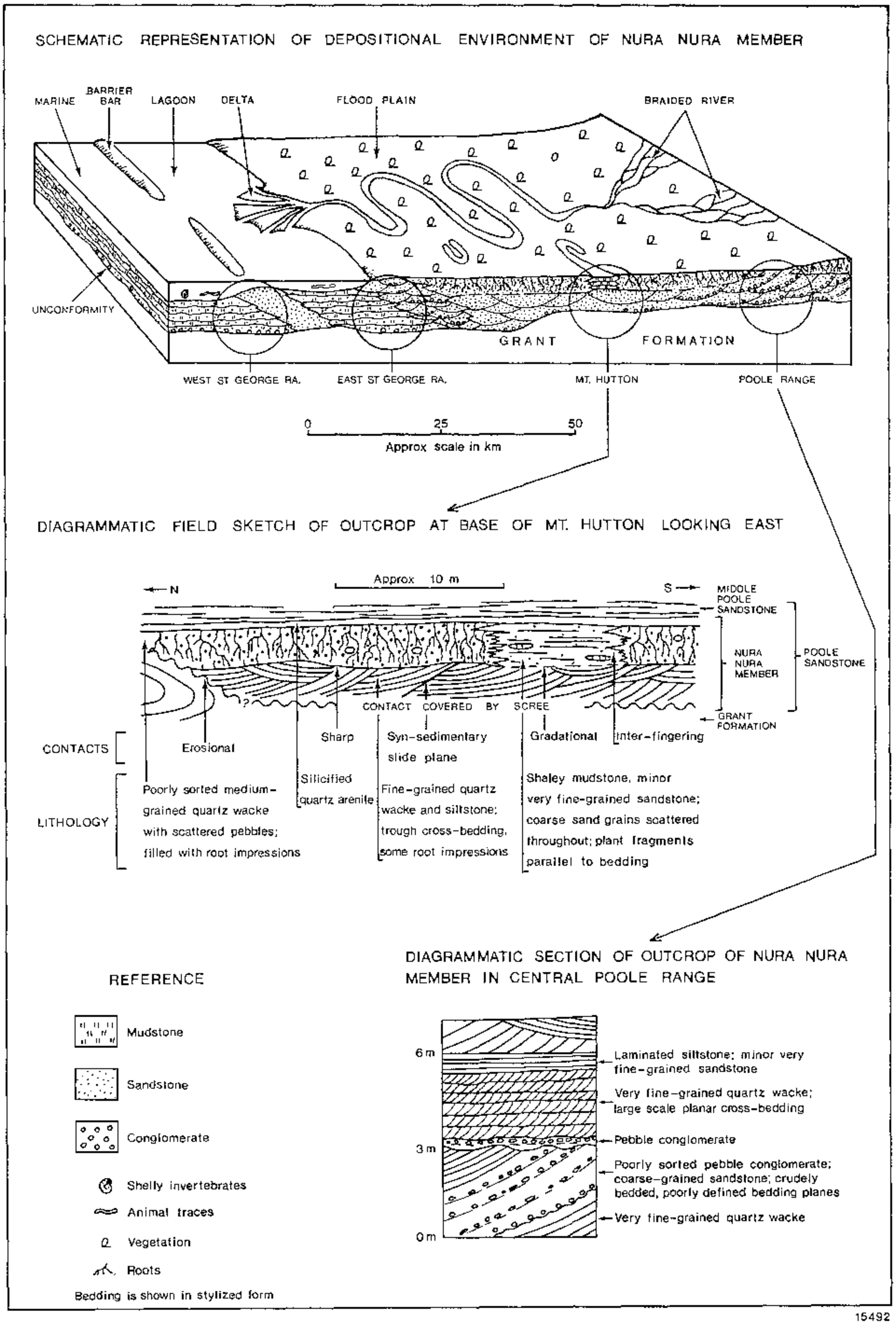

Figure 27. Schematic representation of depositional environment of Nura Nura Member.

The deposits of modern abandoned channel fills (Allen, 1964) are very similar to the mudstone body described above, and provide the best modern analogue for such a feature. Channel-fill deposits are formed when a river abandons part of its course and the resulting lake silts up with overbank deposits (e.g. ox-bow lakes). We therefore interpret a fluviatile environment of deposition for the Nura Nura Member at Mount Hutton and suggest that the rivers were of the meandering type, since abandoned channels of the type described are most commonly found in such regimes (Reineck and Singh, 1973).

POOLE RANGE AREA

In the Poole Range, the Nura Nura Member consists mainly of poorly sorted cross-bedded quartz wacke with occasional root impressions, indicating deposition in a fluvial environment. At one locality, overturned foresets are present. From laboratory experiments, McKee and others (1962) have shown that overturned foresets are formed by deposition of normal foresets followed by later disruption produced by strong, heavily laden currents. At another locality near the centre of the range, the member consists of a fining-upward sequence of large and small-scale, trough and planar cross-bedded, conglomeratic sandstone with unidirectional current readings. The style of the cross-bedding in this sequence is shown in Figure 27, which also shows the rather poor sorting of the sediment, and inclined conglomeratic foresets.

The section shown in Figure 27 is thought to be a braided-river deposit, as it bears a close resemblance to the typical braided-river sequence shown by Reineck and Singh (1973). This interpretation is supported by the evidence of high-velocity currents in the area (see above) as braiding of a river occurs where either the channel slope or the discharge is high. When combined with the suggestion of meandering-river deposition in the Mount Hutton area the information from the Poole Range tends to suggest that the latter locality was higher in the river profile.

Just to the north of the Poole Range, at Mount Thorlan, the lithology of the Nura Nura Member is different, consisting of graded beds of sandstone and siltstone which contain abundant fossil roots. Other structures are obscured by the disruption due to root growth, so it is difficult to interpret the environment of deposition of this locality, apart from saying that the deposits represent a fossil soil. Throughout the Poole Range area the Nura Nura Member is conformably overlain by typical middle Poole Sandstone.

CONCLUSIONS

The interpretations outlined above, though partly tentative, are strengthened when considered together. Figure 27 shows our reconstruction of the depositional environment of the Nura Nura Member and illustrates the relationships between the various facies and interpretations. The model shows the transition from fluviatile deposits in the east to shallow-water marine deposits in the west. This suggests that the late Sakmarian land surface sloped towards the west, although this may be an over-simplification because no data are available to the north and south of the belt of outcrop.

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EMERGED PLEISTOCENE MARINE TERRACES ON CAPE RANGE, WESTERN AUSTRALIA

by W. J. E. van de Graaff, P. D. Denman, and R. M. Hocking

ABSTRACT

Four emerged, marine erosion terraces are preserved on the western flank of the Cape Range Anticline. From oldest to youngest they are named the Muiron, Milyering, Jurabi, and Tantabiddi Terraces. The related old shoreline cliffs are named Muiron, Milyering, Jurabi, and Tantabiddi Scarps, and the respective terrace deposits are named the Muiron and Milyering Members of the Exmouth Sandstone and the Jurabi and Tantabiddi Members of the Bundera Calcarenite.

The terraces, which are distinctly warped, are believed to have formed during Quaternary interglacial high sea-level stands. The warping indicates significant Quaternary tectonism in the Cape Range area.

INTRODUCTION

Four emerged post-Miocene marine erosion terraces, at distinctly different elevations, were mapped on the western side of the Cape Range peninsula during 1975. The terraces, with associated shoreline cliffs, have a total elevation difference of some 50 m. Both constructional and erosional terraces have been recognized in the area, but in this paper we will use the term terrace only for the erosional surfaces that have been cut into the Miocene bedrock in step-like fashion. The sediments that were laid down on a terrace during or soon after its formation are called terrace deposits.

The terraces were first described by Condit (1935, p. 865) who commented: "The slopes rise in several successive steps as elevated sea cliffs and wave-cut terraces ranging from about 20 feet above sea level up to 180 feet. The lowest forms a continuous coralline bench one-half to one mile wide". Raggatt (1936, p. 166), Condit's co-worker, described them as follows: "The relics of wave-cut terraces at several levels, so beautifully exhibited on the west coast of North-west Cape, are eloquent testimony of the fact that the land has been rising in the recent past". Condon and others (1953, 2nd edn. 1955) recognized only the lowermost of these terraces, which is covered by the Bundera Calcarenite, and they mapped the older terrace deposits as Miocene Tulki Limestone and Pilgramunna Formation.

The initial mapping suggested that the terraces, believed to be of Pleistocene age, are gently warped. Significant Quaternary tectonism, indicated by the warping, has rarely been demonstrated in Western Australia, and to determine the amount of deformation we surveyed eight profiles across the terraces, and mapped them at 1 : 40 000 scale.

Field survey readings were taken relative to high water mark on the beach, as this was the only available datum. High water mark was taken to be 1.2 m above Mean Low Water Springs level at Norwegian Bay, which is in turn 0.4 m above the Learmonth datum (Aust. Nat. Tide Tables, 1975, p. 18). All elevations in this paper are given relative to Norwegian Bay Mean Low Wator Springs level. The survey lines were not closed, and no bench marks were available to tie into, so the accuracy of surveying is unknown and the results may not be very accurate. Checking of the surveyed elevations against parallax bar readings, 20 m-interval contour maps, and field data, suggested that results were reliable except for line D, to which minor adjustments were made.

Apart from these surveying limitations, accuracy is not possible because of uncertainties in pinpointing geologically significant levels in the field, as discussed below.

Marine erosion terraces form at or near low water mark (Fairbridge, 1961), but there may be considerable surface irregularities in such terraces (e.g. lines A and F—Milyering Terrace), and they may also slope seaward because of a rise in sea level during formation. From our observations along the shores of the Cape Range peninsula we believe that more accurate indicators of sea-level stands are available, in the form of *in situ* corals in reefal deposits and the transition from littoral to eolian deposits in clastic sequences. Another reason for using these two parameters as indicators of sea level instead of the terraces, is that terrace elevations can only be measured at a few spots on the second youngest terrace and not at all on the youngest one.

The sediments forming in the modern offshore reefs and lagoons on the west side of the peninsula are believed to be very similar to the younger terrace deposits. As the present-day reefs in the area can be seen to grow as high as low water mark, we have taken the uppermost occurrence of *in situ* corals in the terrace deposits as indicators of low water level at the time of deposition of the reefal sediments. Where we have done this, it is assumed that the corals in question did grow up to low water level and also that we observed the uppermost occurrence. It would be surprising if these assumptions held true with an accuracy of better than a metre.

The transition from littoral to eolian deposits in a clastic sequence has been taken to coincide with high water mark. In the older terrace deposits it is quite easy to recognize this transition, but again it is not possible to pick the contact with an accuracy of better than about a metre. A walk along a recent beach backed by dunes makes this difficulty clear.

DESCRIPTION OF TERRACES AND TERRACE DEPOSITS

The terraces on the western side of the Cape Range peninsula are recognizable from Vlaming Head in the north to Wealjugoo Hill in the south, a total distance of about 90 km. They have been carved out by the sea in the Miocene Tulki Limestone, Pilgramunna Formation, and Vlaming Sandstone. This last unit was discarded by Condon (1968, p. 40) who considered the Vlaming Sandstone as part of the Exmouth Sandstone, but we find it to be a valid mappable unit.

Figure 28 shows diagrammatically the relationships of the terraces and the nomenclature we propose, Figure 29 shows their distribution, and Figures 30 and 31 show the area around Yardie Creek homestead where the terraces are well developed.

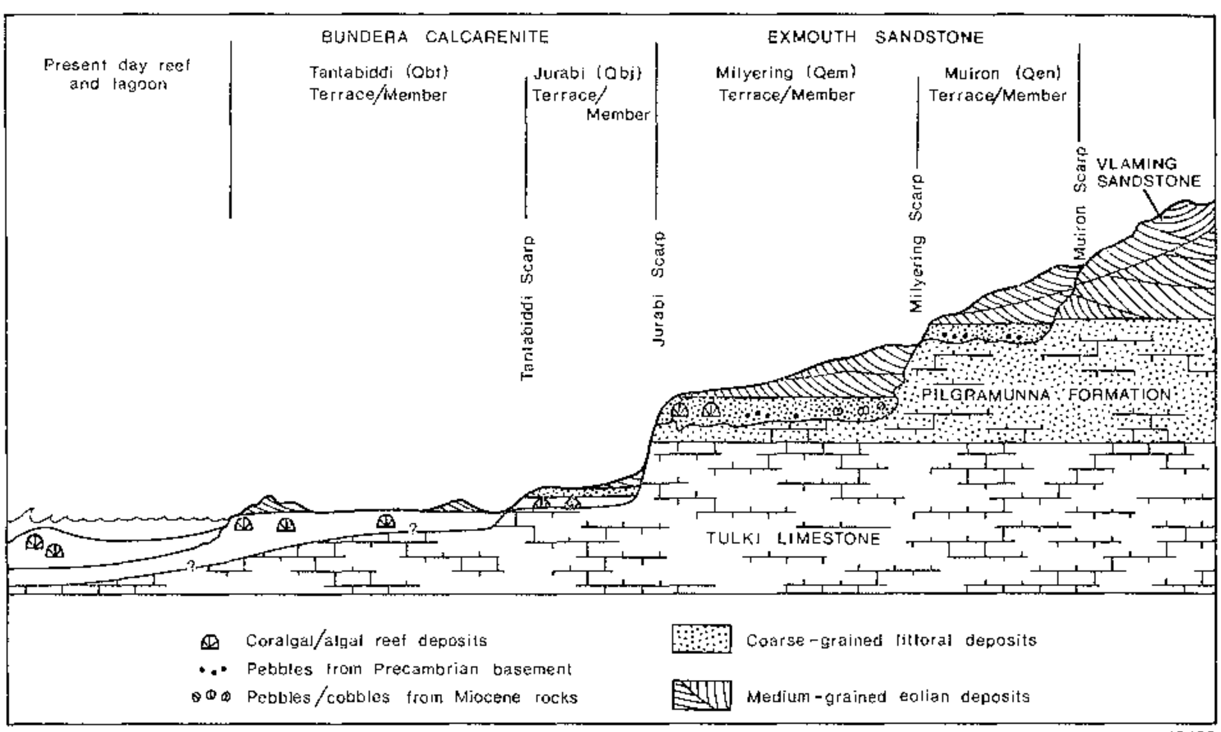

Figure 28. Diagrammatic sketch of terrace relationships and nomenclature used ; V/H≈5.

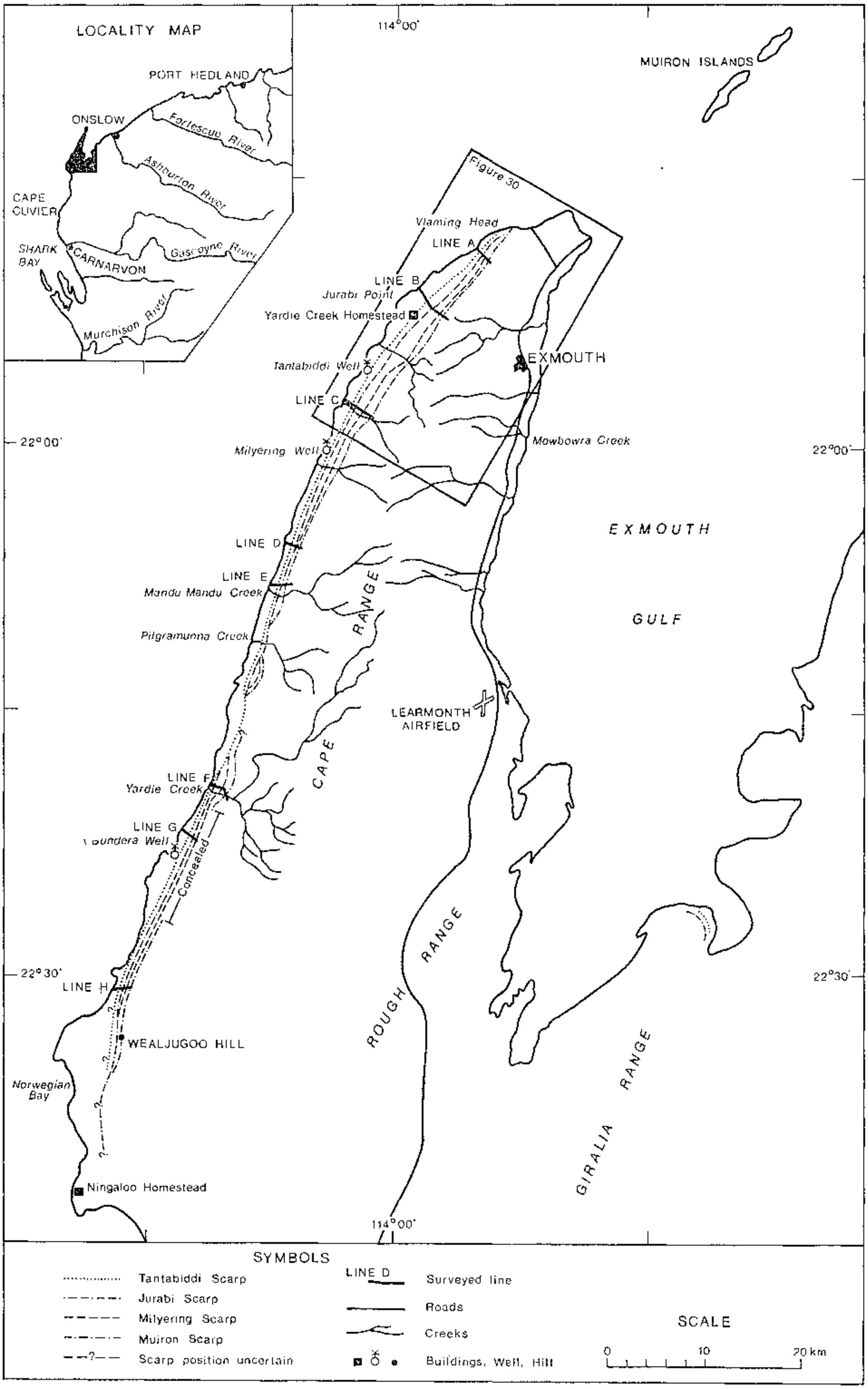

Figure 29. Shoreline scarps on the western side of Cape Range and on the Giralia Range.

To the south of Wealjugoo Hill the terraces may well exist but if so, they are completely obscured by extensive overlapping eolian deposits of various ages but very similar rock types. This concealment of the terraces also occurs in parts of the studied area, such as just north of Mandu Mandu Creek (Fig. 32E) and approximately 10 km north of Yardie Creek. Where this overlapping has occurred, it is difficult or impossible to map the various units which elsewhere are clearly recognizable.

On the eastern side of the Cape Range peninsula only the youngest terrace deposits have been recognized, but a distinct scarp has not formed. The likely reason for the absence of older terraces is that the eastern side of the peninsula is not as exposed to waves as the western side so that terraces and shoreline cliffs probably did not form.

The relative ages of the terraces and their deposits have been deduced from their position and preservation. The poorly preserved highest terrace is the oldest, and the lowest terrace, on which sedimentation still takes place, is the youngest. In descending order the terraces are here named Muiron, Milyering, Jurabi, and Tantabiddi Terrace, and the related scarps Muiron, Milyering, Jurabi, and Tantabiddi Scarps. The deposits on the two oldest terraces are named Muiron and Milyering Members of the Exmouth Sandstone, and those on the two youngest terraces the Jurabi and Tantabiddi Members of the Bundera Calcarenite. Formal definitions of these new stratigraphic names are given in the Appendix.

In places an older terrace has been completely eroded during the cutting of a younger terrace. North of Yardie Creek for example, the Tantabiddi Terrace cuts across both the Jurabi and Milyering Terraces. Where this has happened, a single scarp up to 20 m high is present, and is clearly visible from the coast road (Fig. 32F).

MUIRON TERRACE

The Muiron Terrace and its scarp and deposits have been extensively dissected and are discontinuously preserved. On a small scale (1-2 m) the terrace is smooth to irregular. Occasional grooves and pot-holes or shallow karst features have been noted, and at one locality the underlying Pilgramunna Formation has been extensively bored by organisms. Larger scale irregularities, such as occur in the Milyering Terrace, have not been seen but this is probably due to poor preservation.

The terrace deposits, which form the Muiron Member of the Exmouth Sandstone, consist in most places of up to several metres of calcareous quartz arenite which ranges from coarse-grained sand to pebbly granule conglomerate. This coarse-grained basal unit formed in a littoral environment, and grades up into well-sorted, mostly medium-grained quartzose calcarenite of eolian origin. Only where drainage patterns outline their shape can the dunes that formed the eolian part of the Muiron Member still be recognised (e.g. north side of Yardie Creek). Elsewhere the Muiron Member is too dissected for any of the original morphology to be preserved.

MILYERING TERRACE

The Milyering Terrace and its scarp and deposits are also extensively dissected, and in places the terrace has been exhumed through the stripping of its cover. The terrace is smooth to irregular on a small scale (1-10 m), and at a few places, e.g. line A, the terrace is deeply grooved. The grooves (Fig. 32A) may be as deep as 2.5 m, and they have a preferred orientation of 110°, which is determined by joints in the underlying Tulki Limestone. On the southern side of Yardie Creek the terrace is exposed in a cliff for some 250 m. At this locality the terrace slopes east towards the old shoreline, with a 4° angle over a distance of about 150 m. This shoreward slope is due to the stripping of a bedding plane in the underlying Tulki Limestone which dips gently to the east. Slopes of a similar scale have also been noted elsewhere.

The terrace deposits, which form the Milyering Member of the Exmouth Sandstone, consist at the base of minor algal boundstone and conglomerate which are overlain by and/or grade laterally into coarse-grained to pebbly calcareous quartz arenite and quartzose calcarenite. The algal boundstone contains rare colonial corals, gastropods, and bivalves, and appears to be restricted to areas that are deeply grooved. Along line A the boundstone grades laterally into conglomerate which fills many of the grooves in the terrace (Fig. 32A). The cobbles and boulders in the conglomerate are of local derivation, and consist of fragments of Tulki Limestone and Pilgramunna Formation. The pebble fraction, however, consists mainly of various types of quartz, chert, banded iron-formation, ?acid volcanics, tourmaline-quartz rock, and feldspar. This assemblage is identical in its components to the material carried by the Ashburton River where it flows into the sea near Onslow. Though conglomerate is rare in the Milyering Member, scattered pebbles of the Ashburton River assemblage are common in the coarse-grained basal part of the unit. The only fossils seen in this clastic part of the basal Milyering Member are rare irregular echinoids and large foraminifers. Low to medium-angle (5-15°) cross-bedding is locally preserved in this unit. As in the case of the Muiron Member, the coarse-grained basal part of the sequence is believed to have formed in a littoral environment. This grades upwards into well-sorted, mostly medium-grained, quartzose calcarenite of eolian origin. Although strongly dissected, the dune shape of this eolian part of the Milyering Member is still recognizable in places (Fig. 31), and large-scale, high-angle cross-bedding dipping toward the old shoreline is occasionally visible. This relationship is well exposed along line D, where the cross-bedded eolianite abuts against the very jagged shoreline cliff (Fig. 32D).

JURABI TERRACE

The Jurabi Terrace is extensively preserved and its scarp and sediments are dissected only by sizeable creeks. The terrace is poorly exposed but appears to be smooth to irregular on a small scale.

The terrace deposits, which form the Jurabi Member of the Bundera Calcarenite, consist of algal and coralgal boundstone and calciclastic sediments. Boundstone is the most common rock type exposed where the Tantabiddi Scarp cuts into Jurabi Terrace deposits, but clastic deposits predominate at the top of the member. This may represent a lateral change from a reef facies to a back-reef lagoon, as is the case along the present-day shore. At Mandu Mandu Creek the coralgal reef is laterally replaced by a limestone pebble to cobble conglomerate, but elsewhere the calciclastic deposits appear to contain little if any recognizable detritus from the Miocene rocks. Only minor occurrences of eolianite have been mapped as part of the Jurabi Member.

Locally an unnamed, poorly developed terrace, a few metres higher than the surface of the Tautabiddi terrace deposits, has been carved into the Jurabi Member. It is best preserved on line H.

TANTABIDDI TERRACE

The Tantabiddi Terrace is nowhere exposed, as sediments are still accumulating on it, and only negligible dissection of scarp and sediments has taken place.

The terrace deposits which form the Tantabiddi Member of the Bundera Calcarenite, consist of coral and coralgal boundstone and associated calciclastic deposits. The reefal boundstone is best exposed in low cliffs along the present shore and in intertidal platforms, but ?*in situ* corals have been found up to 1.8 km inland. These reefal deposits grade laterally, and probably also vertically, into calcarenite and calcirudite, which are believed, on the basis of a comparison with present-day offshore deposits, to have formed in lagoonal and littoral environments. These shallow-marine carbonates are in part overlain by eolianites, the oldest of which are lithified and contain karst features.

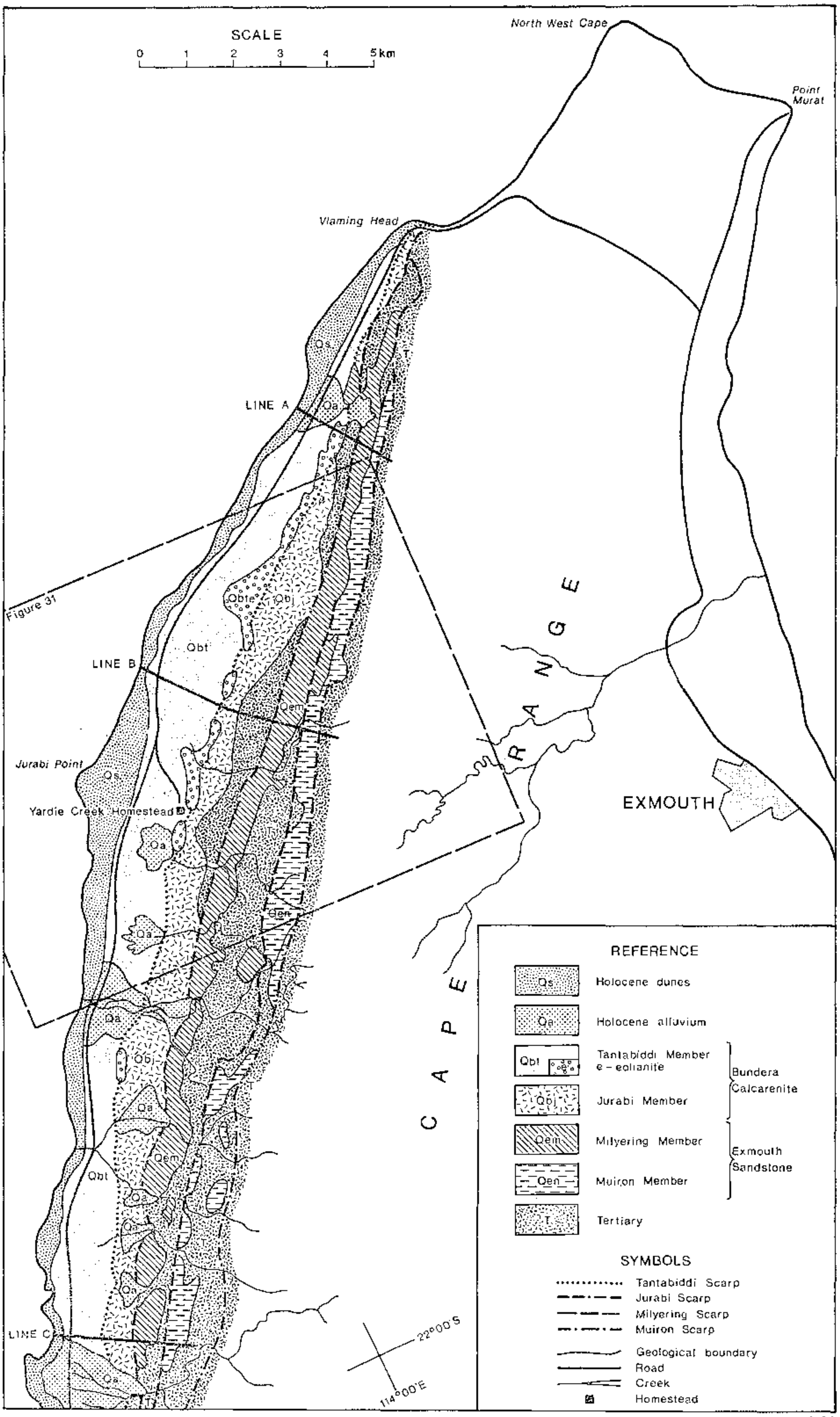

Figure 30. Shoreline scarps and associated deposits on the northwestern part of the Cape Range peninsula.

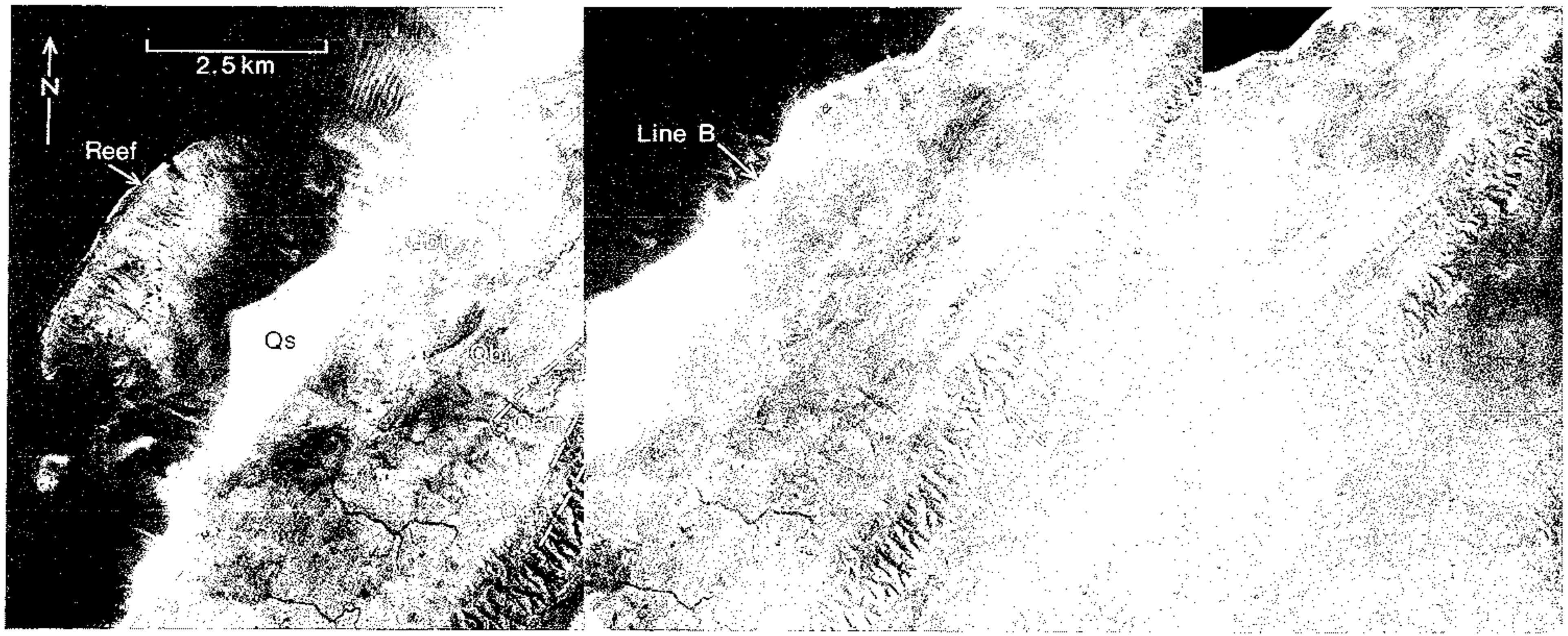

Figure 31. Stereoscopic triplet of part of Figure 30. Photographs Onslow (1963); run 15, Nos. 5264–66.

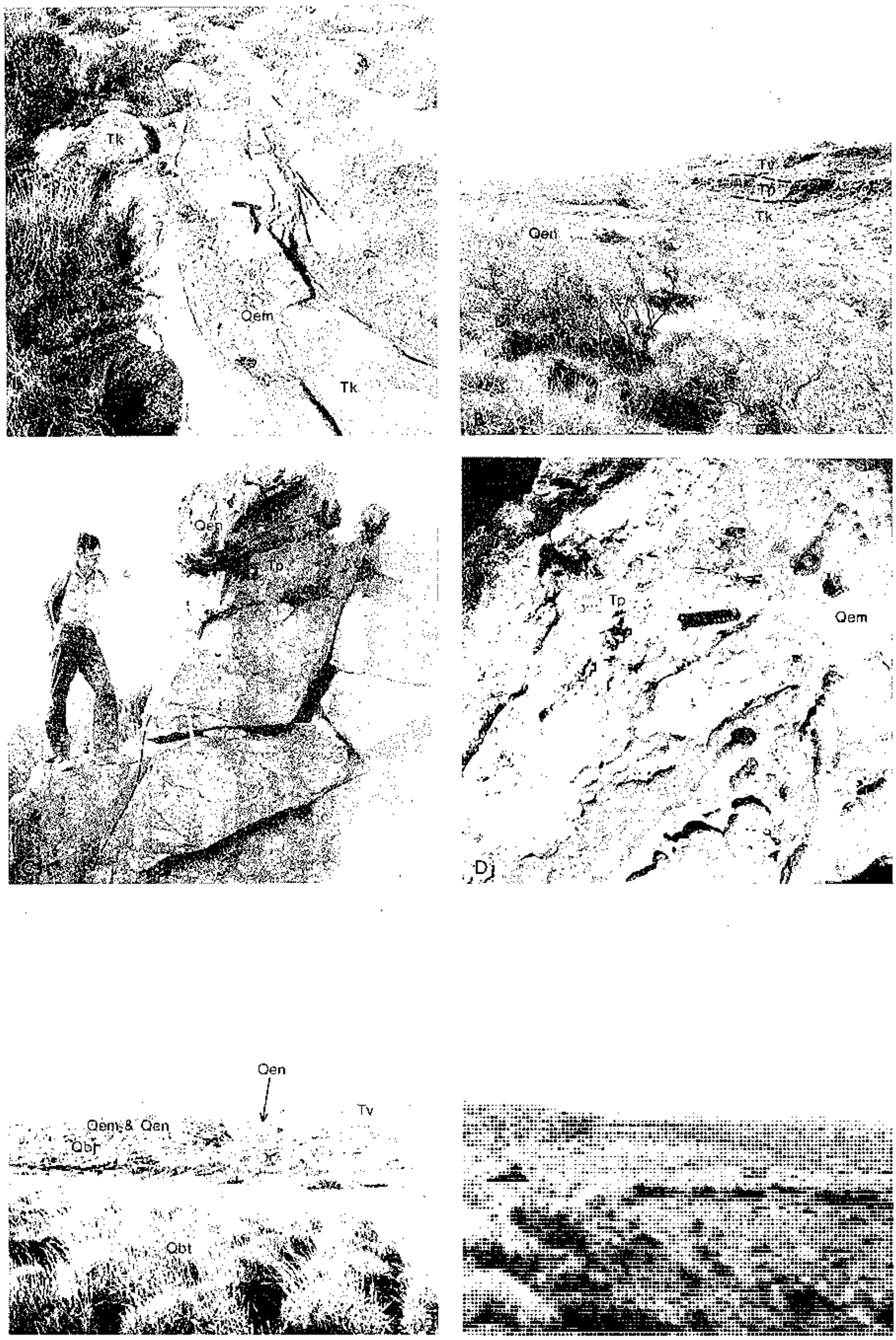
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Figure 32. (opposite).

A. Conglomerate-filled groove cut into Tulki Limestone, at base Milyering Member. Conglomerate contains both local and Precambrian components; Line A.
B. Ridge of Muiron Member eolianite abutting in the middle distance against the Muiron Scarp which is cut in Pilgramunna Formation; 1 km south of Line B, looking north.
C. Muiron Member eolianite abutting against Muiron Scarp, cut in cross-bedded Pilgramunna Formation, outcrop partly cleaned with HCl; Line A.
D. Milyering Member eolianite abutting against Milyering Scarp, here a very jagged cliff of light-coloured Pilgramunna Formation; Line D.
E. View of the range from the top of a Tantabiddi Member dune deposit. Tantabiddi Scarp in foreground. Jurabi Terrace and Scarp distinct in left half of photo, Milyering Member eolianite covering Milyering Scarp half way up the hill and overlapping onto Muiron Member and Vlaming Sandstone; Line E.
F. Tantabiddi Scarp in Tulki Limestone; about 7 km north of Yardie Creek looking south.

WARPING OF TERRACES

The surveying confirmed the initial impression that there has been significant deformation of these terraces. The results shown in Figures 33 and 34 and in Table 21 demonstrate clearly that the Muiron, Milyering, and Jurabi Terraces have been warped since their formation. The data are inconclusive for the Tantabiddi Terrace.

In Figure 34 the Muiron Terrace level cuts across the base of the Pilgramunna Formation. This is because the terraces do not everywhere cut the same distance into the flank of the Cape Range Anticline.

TABLE 21. LISTING OF SURVEYED ELEVATIONS
Datum is Mean Low Water Springs level at Norwegian Bay

	Data Set No. Surveyed Lines	A	B	C	D	E	F	G	H
	1 Contact Pilgramunna-Vlaming	52	74	....	78	(73)	(95)	76	(72)
	2 Base of Pilgramunna	(25)	(47)	≲9 (W) 62 (E)	42	(38)	(65)	39·5	(42)
EXMOUTH Muiron Mem. Qen	3 Contact littoral eolian ≳ HWM Qen	c	57·4	?48	57	61·6	(58)	55·8	62·5
EXMOUTH Muiron Mem. Qen	4 Base of littoral, = terrace level ?≲ LWM Qen	c	46·9	?46·3	55	57·5	51·5	54·6	57·3
EXMOUTH Milyering Mem. Qem	5 Contact littoral/eolian ≧ HWM Qem	19·8	33·3	31·4	46·6 (W) 42·6 (E)	42·1	?39·1 (W) 48·8 (E)	(38·2)	37·6
EXMOUTH Milyering Mem. Qem	6 Base of littoral, = terrace level ?≲ LWM Qem	14·2	29·5	24·9	40·1 (W) 38·0 (E)	36·0	35·6 (W) 29·6 (E)	34	32·2
	7 Interval between HWM (littoral-eolian contact) for Qen and Qem	?	24·1	(16·6)	14·4	19·5	(18)	(17·6)	24·9
	8 Interval between Qem HWM and max. ht. Qbj reef	?	24·5	22·3	25·1	24·2	23·9	(25·3)	23·3
BUNDERA Jurabi Mem. Qbj	9 Contact littoral/eolian ≧ HWM Qbj	c	10·3	a	c	?22	18·9	a	18·5
BUNDERA Jurabi Mem. Qbj	10 *in situ* coral = ?max. height of reef ≲ LWM Qbj	c	8·8	9·1	19·5	17·9	15·2+	12·8	14·3
BUNDERA Jurabi Mem. Qbj	11 Terrace level Qbj ?≲ LWM Qbj	c	c	c	c	c	12·4	10·2	c
BUNDERA Tantabiddi Mem. Qbt	12 Plain level = ?slightly above LWM Qbt	1-2	2·3	3·5	5·5	3–4	3	3–6	3–5
BUNDERA Tantabiddi Mem. Qbt	13 *in situ* coral = ?max. height of reef ≲ LWM Qbt	c	2·3	c	5·5	c	c	c	c
	14 Distances between survey lines in km — Vlaming Head	4·5	7	14	15	4·5	22	5·5	18

≲ approximately equivalent to or lower than.
≧ approximately equivalent to or higher than.
HWM = High Water Mark.
LWM = Low Water Mark.
(W) west side of relevant part of section.
(E) east side of relevant part of section.

a absent.
c concealed.
( ) estimated level; concealed, not surveyed, or extrapolated.
? level + or — 2 m; hard to place in field.
+ level effected by erosion, probably originaly higher.

In addition to the elevations of the four terraces, Table 21 also shows the elevation of the high water-mark indicators in the Muiron and Milyering Members, the low water-mark indicator in the Jurabi Member, and the vertical separation of these sea-level indicators. As argued before, these are better indices of sea-level stands, i.e. horizontal planes, than the terraces, and are therefore more suitable for establishing the amount of deformation.

The figures for the Muiron and Milyering Members show that their respective high water-mark indicators are significantly farther apart at the northern and southern ends of the area than in the middle. This indicates that when the Milyering Terrace formed, the Muiron Terrace had already been warped slightly downward in the middle of the area. After the cutting of the Milyering Terrace, movement reversed and the middle part of the area rose relative to the southern and especially to the northern part.

There is also evidence that, apart from the very gentle north-south warping, some tilting perpendicular to this direction has taken place.

On line D the Milyering Terrace can be seen in the field to have a gentle easterly dip. The surveyed elevations in the littoral/eolian contact in the Milyering Member (Table 21; surveying accurate in this part of line D) indicate a similar eastward dip of this water-level indicator. Although this indicator is difficult to pick accurately, a difference of 2 m over a distance of 130 m seems significant, and we believe it indicates eastward tilt of the terrace.

The Tantabiddi Terrace and its deposits are not obviously warped within the study area. However, it might be possible to establish warping, if elevations were obtained on coral-reef deposits in the Tantabiddi Member, which occur intermittently along the coast as far south as Cape Cuvier and as far east as Onslow.

A quick inspection of the Cape Cuvier and Rough Range Anticlines produced no conclusive evidence of any pre-Tantabiddi terraces, although steps in the elevation of eolianites in both areas may indicate buried terraces. On the northern point of the Giralia Range, the Tantabiddi Scarp and an older stripped terrace, which is thought to correlate with the Jurabi Terrace, are present. It is too poorly preserved for any warping, if present, to be obvious.

AGE OF TERRACES

The terraces have been cut into the folded Middle Miocene rocks of the Cape Range Anticline, and they are therefore post-Middle Miocene and probably post-Miocene, in age. Fossils collected did not permit a more accurate dating.

The warping of the terraces proves that there has been significant tectonism in the area since their formation, and it indicates the possibility that they formed due to intermittent uplift combined with a relatively stable sea level. In this interpretation the terraces would have formed during periods of tectonic quiescence which were

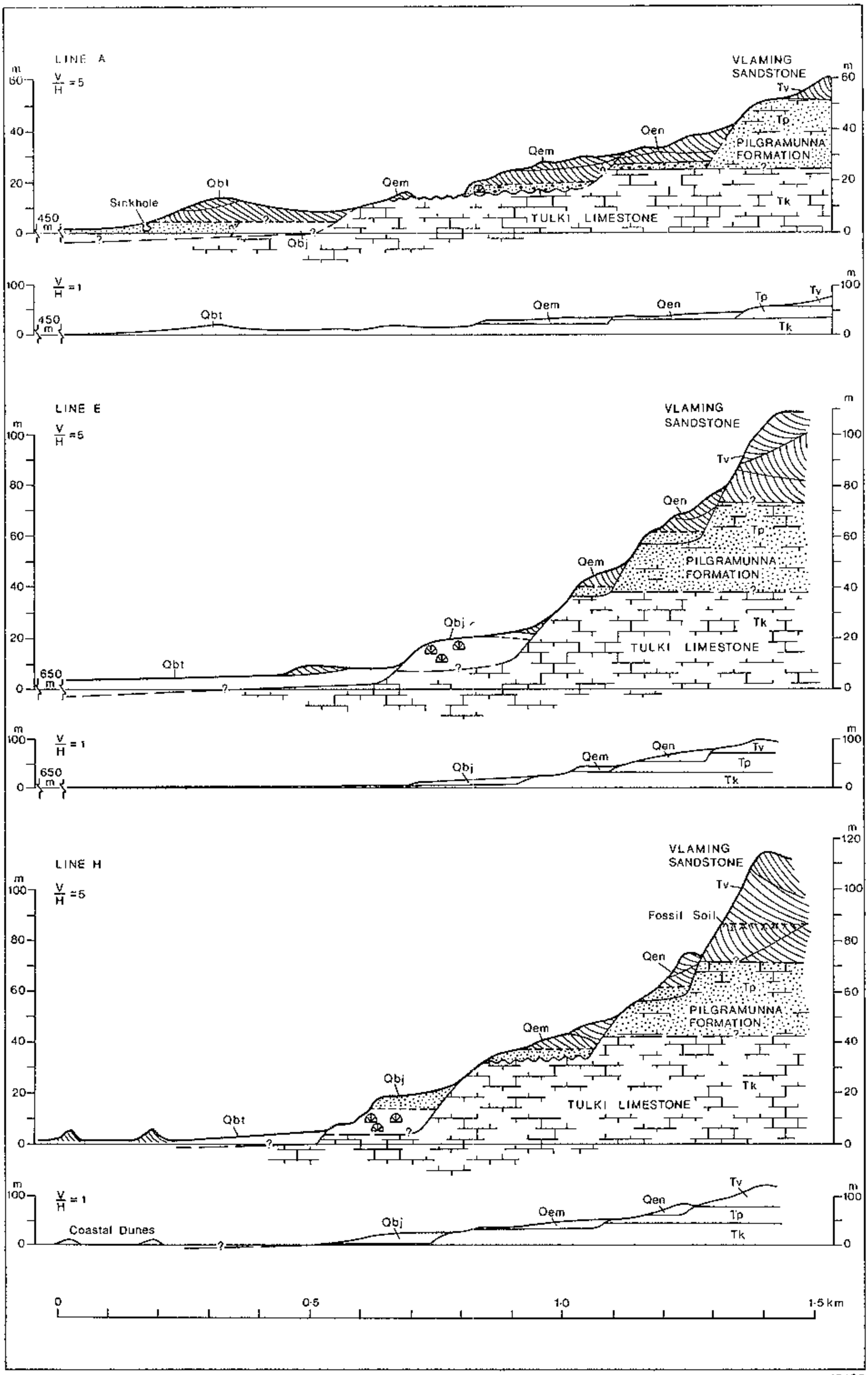

Figure 33. Cross-sections along surveyed lines A, E, and H ; symbols as in Figure 28.

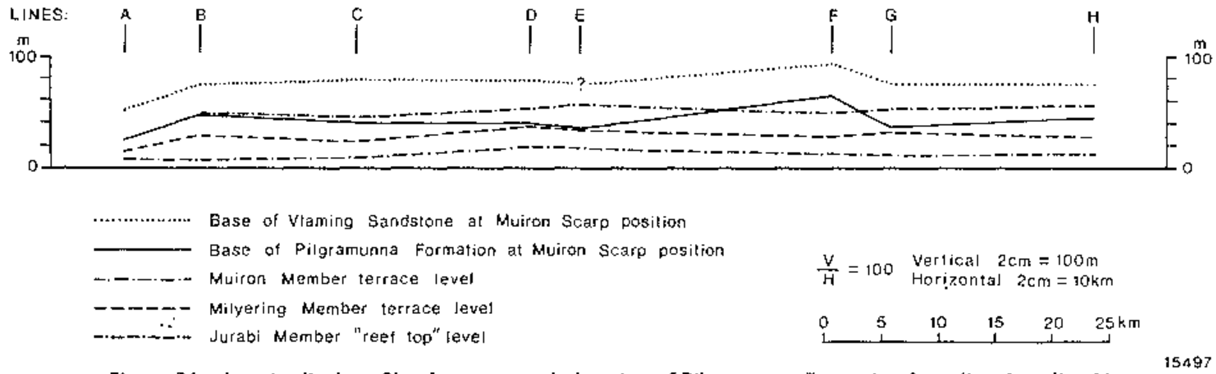

Figure 34. Longitudinal profile of terraces and elevation of Pilgramunna Formation from line A to line H.

separated by periods of uplift. An alternative interpretation is that the terraces formed during eustatic high sea-level stands of the interglacial periods of the Quaternary, and that they were simultaneously warped by fairly continuous deformation. We feel that the gentle warping of the terraces is more suggestive of continuous rather than abrupt and intermittent deformation, and tentatively interpret the terraces as having formed during successive Quaternary high sea-level stands. On the basis of this interpretation their age can be estimated by correlation of the terraces with known Quaternary high sea-level stands. For this purpose we made use of a curve published by Fairbridge (1961, p. 131) and modified by G. H. Low (unpublished).

The Tantabiddi Member, which covers the youngest terrace, is thought to have formed during the later part of the Riss-Würm interglacial, and it may be a correlative of the Bibra Formation in the Shark Bay area, which Logan and others (1970, p. 70) consider as older than 40 000 years. The Jurabi Terrace is believed to have formed during an early Riss-Würm high sea-level stand. The Milyering and Muiron Terraces, which must be considerably older because of their elevation and poor preservation, may have formed during the two main high sea-level stands of the Mindel-Riss interglacial.

CONCLUSIONS

The distinct warping of these terraces of probable Pleistocene age indicates that significant folding has occurred during the Pleistocene, and it seems likely that folding is still continuing. The amount of Pleistocene deformation suggests that the Cape Range structure, as exposed, may be a very young structure that formed in a few million years.

Reliable dating of the terrace deposits and a study of the offshore Cainozoic sediments are now required to confirm these conclusions.

ACKNOWLEDGEMENTS

The air-photographs of Onslow (Fig. 31) are published with permission of the Surveyor General, Department of Lands and Surveys, Perth.

We thank Mr. K. Graham, the Exmouth Shire Clerk, for the loan of surveying equipment, and Dr. P. G. Quilty, formerly of Wapet, for helpful discussions.

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APPENDIX—DEFINITION OF NEW STRATIGRAPHIC NAMES

The stratigraphic relationships on the western side of the Cape Range, as interpreted by us, differ considerably from the interpretation by Condon and others (1953, 1955) and Condon (1968). It is therefore necessary to revise the nomenclature.

The Exmouth Sandstone is divided into the Muiron and Milyering Members, which are lithologically very similar, but which can be easily recognized in the study area because of their occurrence on different terraces.

The Bundera Calcarenite is hereby redefined to incorporate lithologically similar deposits which have previously been mostly mapped as Tulki Limestone, but which disconformably overlie this Miocene unit. The redefined Bundera Calcarenite is divided into the Jurabi and Tantabiddi Members. The two members are lithologically similar, and can only be differentiated where their relationships are not obscured by overlapping younger eolianites.

Occurrence on a specific terrace, i.e. morphology and not lithology, is the most important criterion for recognizing these members. In other words, these units are not purely lithostratigraphic units, but like so many Quaternary map units, they are morphostratigraphic units in the sense of Frye and Willman (1962).

MUIRON MEMBER OF EXMOUTH SANDSTONE

Derivation of name: Muiron Islands, Onslow 1 : 250 000 Sheet area.

Distribution: Western side of Cape Range peninsula.

Type section: 22° 06′ 30″S, 113° 54′ E, about 150 m northwest of Vlaming Sandstone type locality.

Lithology: Calcareous quartz sandstone to pebbly granule conglomerate overlain by medium-grained well-sorted quartzose calcarenite.

Thickness: Up to about 25 m.

Relationships: Disconformably overlies the Miocene units of the Cape Range Anticline. Disconformably overlain by Milyering Member or younger eolianites.

Age: ?Pleistocene.

Previous usage: Condon and others (1953, 1955) included these deposits in the Pilgramunna Formation.

MILYERING MEMBER OF EXMOUTH SANDSTONE

Derivation of name: Milyering Well, Ningaloo 1 : 250 000 Sheet area.

Distribution: Western side of Cape Range peninsula.

Type section: 22° 06′ 25″S, 113° 53′ 50″E, about 400 m north-northwest of Vlaming Sandstone type locality.

Lithology: Calcareous quartz sandstone to pebbly granule conglomerate grading to quartzose calcarenite; minor conglomerate and algal boundstone. Overlain by well-sorted quartzose calcarenite.

Thickness: Up to about 30 m.

Relationships: Disconformably overlies the Muiron Member and the Miocene units of the Cape Range. Disconformably overlain by younger eolianites.

Age: ?Pleistocene.

Previous usage: Condon and others (1953, 1955) included these deposits in the Pilgramunna Formation.

JURABI MEMBER OF BUNDERA CALCARENITE

Derivation of name: Jurabi Point, Onslow 1 : 250 000 Sheet area.

Distribution: Western side of Cape Range peninsula.

Type section: 22° 06′ 20″S, 113° 53′ 40″E, about 800 m north-northwest of Vlaming Sandstone type locality.

Lithology: Algal or coralgal boundstone, calcarenite, and minor limestone conglomerate.

Thickness: Up to 20 m.

Relationships: Disconformably overlies the Exmouth Sandstone and the Miocene units of the Cape Range Anticline. Disconformably overlain by Tantabiddi Member.

Age: ?Pleistocene.

Previous usage: Condon and others (1953, 1955) included these deposits in the Tulki Limestone.

TANTABIDDI MEMBER OF BUNDERA CALCARENITE

Derivation of name: Tantabiddi Well, Ningaloo 1 : 250 000 Sheet area.

Distribution: Occurs along the coast at least from Cape Cuvier in the south to Onslow in the east.

Type section: 21° 50′ 10″S, 114° 04′ 18″E, in sinkhole on the western side of indurated dune; approximately 100 m south of track into road material quarry.

Lithology: Coral and coralgal boundstone, calcarenite to calcirudite.

Thickness: Up to about 20 m.

Relationships: Disconformably overlies Jurabi Member, Exmouth Sandstone, and Miocene units of Cape Range Anticline.

Age: Pleistocene to Holocene.

Previous usage: Condon and others (1953, 1955) mapped these deposits as Bundera Calcarenite, or, in a few places, as Tulki Limestone, or as Exmouth Sandstone.

STRATIGRAPHY, SEDIMENTATION, AND STRUCTURE IN THE WESTERN AND CENTRAL PART OF THE BANGEMALL BASIN, WESTERN AUSTRALIA

by A. T. Brakel and P. C. Muhling

ABSTRACT

The Bangemall Basin is a folded, Middle Proterozoic sedimentary basin with an arcuate east-west elongation, discordantly overlying the older tectonic units of the Western Australian Shield.

A regional facies change in the Bangemall Group occurs in the central part of the basin near the 119° E meridian and is the result of an easterly lensing out of dolomite, chert, and sandstone units. It partly corresponds to a major northeasterly trending zone of faulting and basement arches. Correlation of much of the eastern succession with the formations to the west and north is uncertain.

In the western portion of the basin most of the lower units were deposited in a shallow marine environment, but local, discrete lenses of coarse-grained, terrestrial alluvial fan deposits occur on the basal unconformity. These lower units of dolomite, lutite, and sandstone are characterized by lensing, interfingering, and lateral gradations. Near the top of these units is the Discovery Chert, representing a period of stable conditions over most of the western region. The rest of the sequence was laid down in deeper water and consists of laterally extensive lutites with interbedded sandstone sheets, two of which persist for distances of over 175 km.

In the central part of the basin the succession is simpler, with laterally persistant lutites and a prominent sandstone. The lower lutite rests on the basal uncomformity or is separated from it by locally developed sandstones and conglomerates.

Along the northern margin of the basin there is a thick dolomite-bearing sequence, equivalent to all the shallow water formations and some of the deeper water formations of the western succession.

Basic sills and dykes are common. The only confirmed felsic volcanic rock is a rhyolite near the zone of the regional facies change.

Folding has occurred on two arcuate trends, one concentric with the pre-Bangemall platform to the north, the other continuous with trends in pre-Bangemall rocks to the south. Variations in deformation style and orientation permit definition of structural provinces. Deformation has been by fragmentation of the basement along pre-existing structures, and the relative complexity of sedimentation and structure records the continuing instability of the basement blocks.

INTRODUCTION

The Bangemall Basin is a Middle Proterozoic sedimentary basin containing folded and slightly metamorphosed rocks of the Bangemall Group. The basin overlies older Proterozoic and Archaean units, and together with them forms the northern half of the Western Australian Shield (Fig. 35). The northern margin of the Bangemall Group overlies the Hamersley Basin, as well as localized deposits of Bresnahan Group sandstone and conglomerate, and some Archaean inliers. The Hamersley Basin rocks are metamorphosed in their southern extent, and west of the Bangemall Basin are intruded by Proterozoic granitic rocks; they appear to pass into the igneous and metamorphic rocks of the Gascoyne Province southwest of the Bangemall Basin. Thus the Bangemall Group seems to be a younger cover straddling the transition from older cratonized sedimentary basin to mobile belt. A Lower Proterozoic sequence in the Nabberu Basin extends eastwards from the Gascoyne Province between the Bangemall Basin and the Archaean rocks of the Yilgarn Block (Barnett, 1975; Hall and Goode, 1975; Horwitz, 1975). Stratigraphic relationships in the eastern portion of the Bangemall Basin, not discussed here, are dealt with by Williams and others (1976).

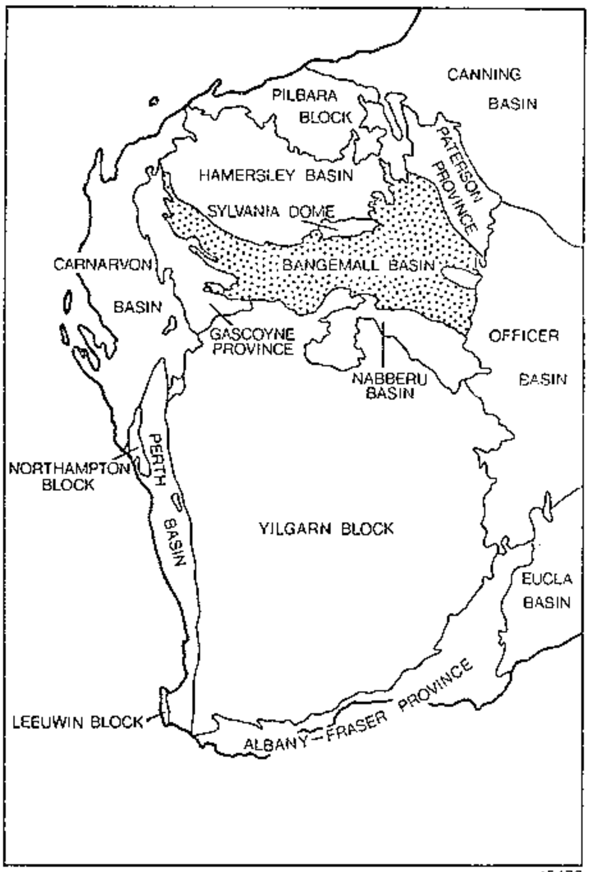

Figure 35. Regional setting of the Bangemall Basin.

Isotopic Sr/Rb age determinations on a black shale and felsic rocks in the Bangemall Group gave isochrons of 1 080 ± 80 m.y. (Compston and Arriens, 1968) and 1 096 ± 41 m.y. (Gee and others, 1976). Walter (1972) notes that a stromatolite which occurs in the Irregully Formation at the base of the group has an age range of 1 350 ± 50 to 950 ± 50 m.y.

Previous detailed geological mapping of the Bangemall Basin has been carried out by de la Hunty (1964), Daniels and MacLeod (1965), Daniels (1968, 1969, and 1970), and MacLeod (1970). Stratigraphic subdivision was first undertaken in the western region by Halligan and Daniels (1964) and modified by Daniels (1966a), who recognized the regional facies change between the northern and western areas of the basin. Daniels (1969) drew attention to the effect on sedimentation of northeasterly-trending basement structures in the Bangemall Group, and the increasing intensity of folding from north to south in the basin. Recent mapping in the centre of the basin has discovered another regional facies change and delineated distinct structural provinces.

Dolerite sills are common throughout the Bangemall Basin, and intruded before or during the main period of folding of the Bangemall Group. Dykes of dolerite occur either as feeders to the sills, or as later intrusions that transect the sills and the folds.

Localities referred to in the text are shown in Figure 36.

REGIONAL FACIES DISTRIBUTION

Figure 37 is a generalized geological map of the Bangemall Basin, west of the 120° E meridian. Three major facies provinces each with distinctive lithostratigraphic assemblages are recognized in the basin. The western facies has the thickest and most varied succession. The transition between the western and northern facies is the result of both rapid lensing out of some units from the west and changes in lithology along strike of others. The western and northern facies share the same upper three formations.

The change from the western to the eastern facies is due to the easterly lensing out of dolomite, chert, and sandstone units and the persistence of shale and siltstone beds. The eastern and northern facies provinces are juxtaposed by faults. Relationships between facies are shown diagrammatically in Figure 38.

WESTERN FACIES

The stratigraphy of this facies is mostly after Daniels (1966a), although it is now recognized that two additional units (Mount Augustus Sandstone and Tringadee Formation) are locally developed on the basal unconformity. Furthermore, the Jillawarra Formation is a new formation recognized immediately below the Discovery Chert, and the basal sandstone member of Daniels' Kurabuka Formation is separated out as the Mount Vernon Sandstone. The new stratigraphic units will be defined in Muhling and others (in prep.).

Thicknesses of formations in the Edmund region are given by Daniels (1969). Further work is in progress to establish formational thicknesses in other areas for later publication.

MOUNT AUGUSTUS SANDSTONE AND TRINGADEE FORMATION

Although apparently at the same stratigraphic level, there is no physical continuity between these two basal conglomeratic units. The Tringadee Formation, with a maximum thickness of at least 1 000 m, is conformably overlain by the Irregully Formation. The top of the Mount Augustus Sandstone is not exposed but is also probably conformable. The Mount Augustus Sandstone, estimated to be over 600 m thick at Mount Augustus, may be equivalent to the much thinner Yilgatherra Member at the base of the Irregully Formation in the Edmund Sheet area, because the Yilgatherra Member is similar in lithology and stratigraphic position.

The Mount Augustus Sandstone and the Tringadee Formation both consist of coarse, often pebbly sandstone and lenses of pebble, cobble, and boulder conglomerate. The clasts are mainly vein quartz, but granitic and metamorphic clasts are also widespread. Siltstone and fine-grained sandstone lenses are rare. Some sandstone in the Tringadee Formation is feldspathic. Tangential cross-stratification is common in the Mount Augustus Sandstone and indicates palaeocurrents from the northwest. No gross vertical grain-size variation through the formations or parts of the formations occurs. These rocks are considered to have been deposited subaerially by braided streams. The isolated developments on the unconformity suggest that they were discrete alluvial fans, originating in response to the down-warping of the basin. The upper portion of the Tringadee Formation contains some dolomite members, indicating alternations between terrestrial and marine conditions.

IRREGULLY FORMATION

Except where previously indicated, the Irregully Formation is the lowest formation of the Bangemall Group. It consists mainly of microcrystalline dolomite, shale, and mudstone, with minor chert, sandstone, conglomerate, and breccia. The dolomite is finely laminated or massively bedded, and stromatolites and algal bands have been found in places. Hematite and goethite cubes, presumably after pyrite, are locally abundant. Some desiccation cracks are present. In the Edmund and Wyloo Sheet areas Daniels (1965) records irregular sheets of sedimentary breccia, thought to be the result of local intraformational erosion. In the southwestern limb of the Candolle Syncline, the formation consists of shale and mudstone and only minor dolomite. The unit appears to be absent in the Cobra Synclinorium and in the regions around Edmund homestead and south of Mount Egerton.

The formation was deposited in shallow lagoonal and tidal flat conditions.

KIANGI CREEK FORMATION

The Kiangi Creek Formation, which generally overlies the Irregully Formation, consists of interbedded quartz arenite and shale. The arenite is medium grained, has a siliceous cement, and contains up to 20 per cent feldspar in places. Tourmaline is a common accessory. Most sandstone beds exceed 1 m in thickness and do not show cross-stratification, but in some beds this structure is abundant. The silica cement may be due to secondary surficial silicification. In general, the shale content of the formation increases from west to east, although rapid variations are common.

The formation interfingers with the Irregully Formation such that the two are laterally equivalent in part, and in some areas the Kiangi Creek Formation overlies the basal unconformity. Interbedded sandstone and dolomite occur at higher levels, for example, north and west of Mount Egerton and between Glen Ross Creek and the Ethel River.

The Kiangi Creek Formation appears to have been deposited in a near-shore marine environment, chiefly as shoals and barrier islands.

JILLAWARRA FORMATION

This newly named formation, with an estimated thickness of 1 400 m near Jillawarra bore, lies between the Kiangi Creek Formation and the Discovery Chert. It consists dominantly of grey, brown, and black silty shales and silty mudstones, together with minor chert, dolomite, and sandstone. Some chert beds resemble the Discovery Chert in appearance. The shales are commonly siliceous and chert-like in outcrop, a feature probably due to surface silicification. Crystal casts after pyrite, and possibly halite and gypsum are abundant in some beds.

The formation interfingers with the arenites of the Kiangi Creek Formation. The base of the formation is taken to be the top of the highest major sandstone underlying the shale interval. The unit apparently thins to the west and is absent in most of the Edmund Sheet area.

The sediments are interpreted as shelf muds laid down on the seaward side of the Kiangi Creek Formation sands, and the water was at times stagnant and hypersaline.

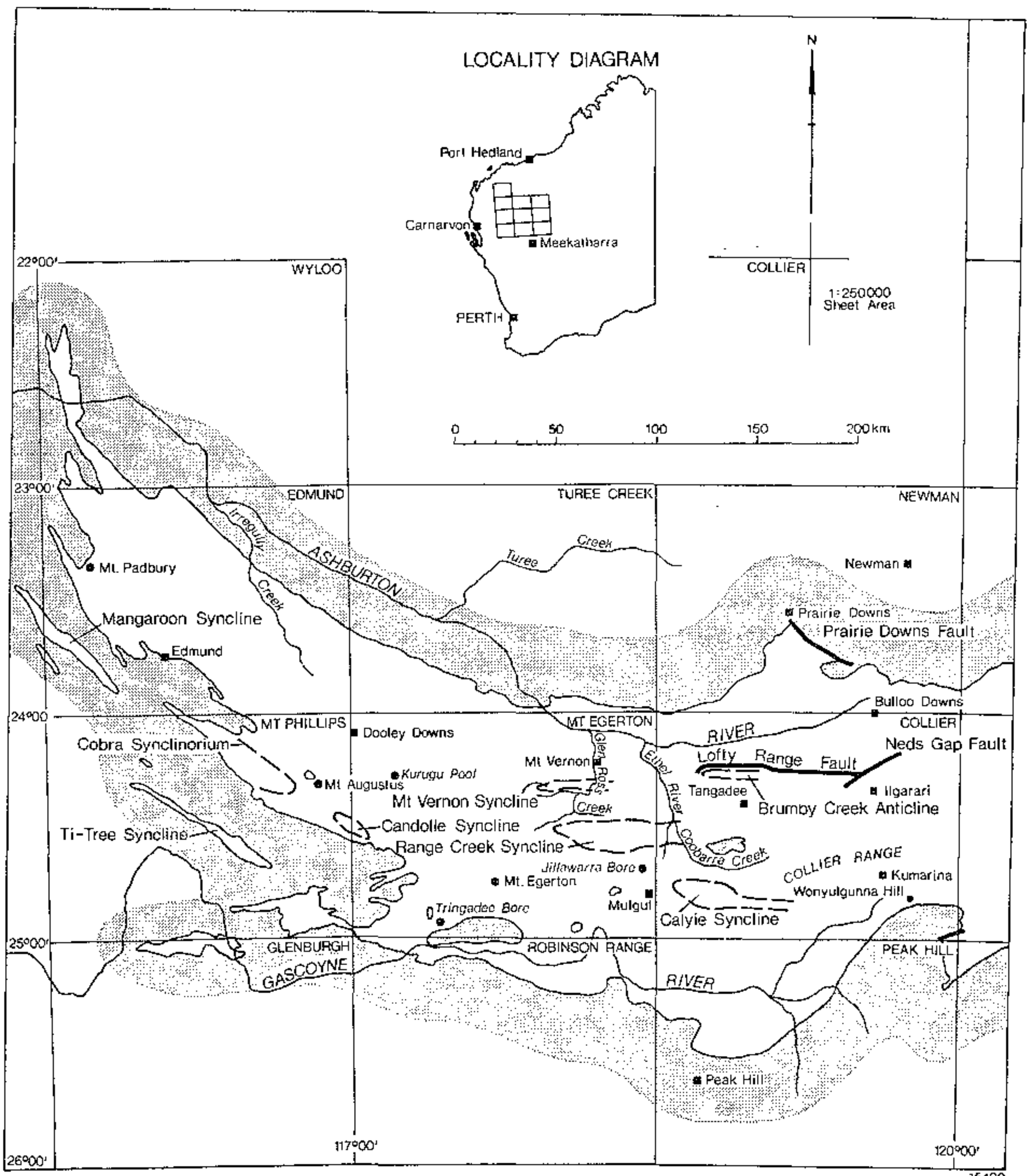

Figure 36. Location of 1 : 250 000 Sheet areas, and localities mentioned in the text.

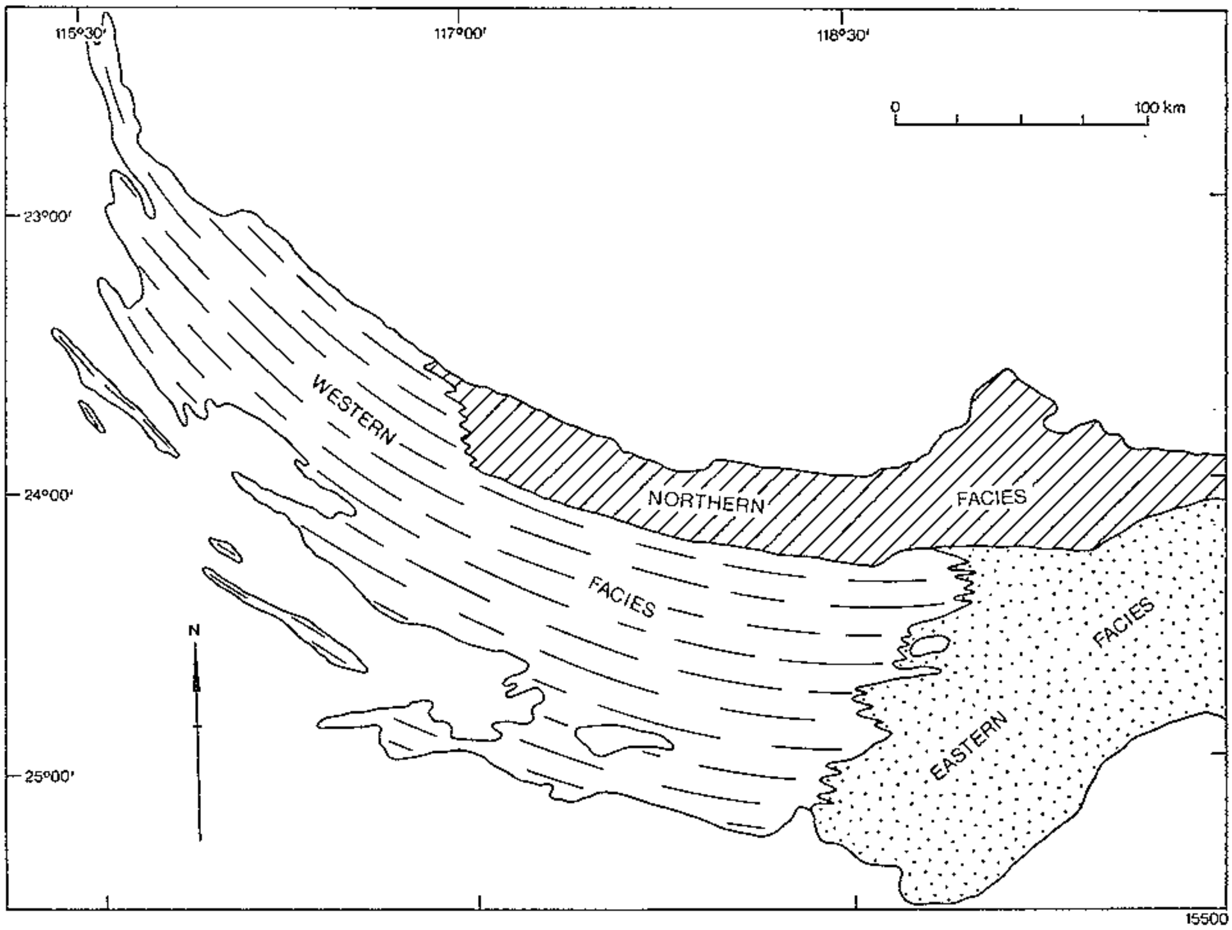

Figure 37. Facies provinces in the western and central Bangemall Basin.

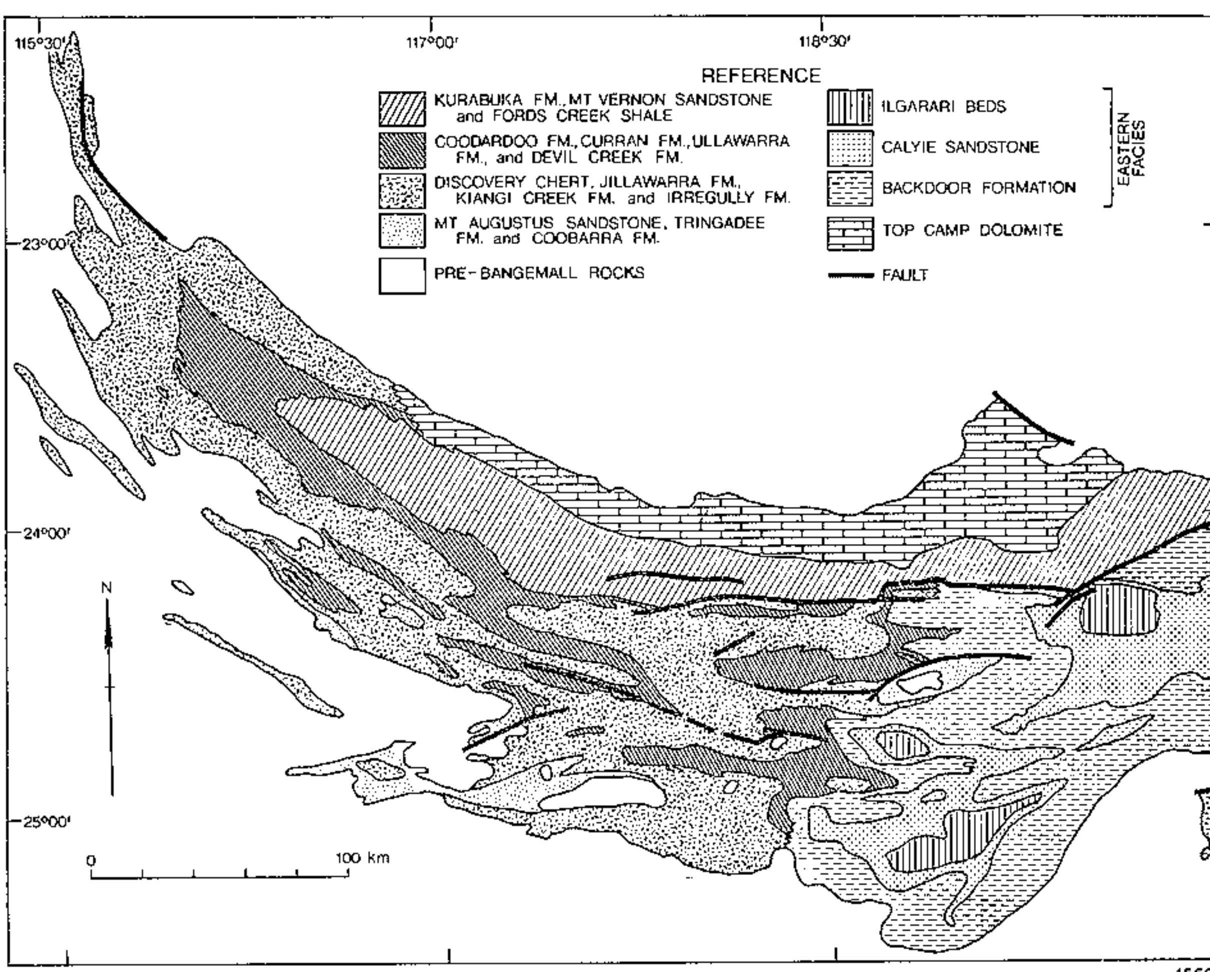

Figure 38. Generalized geological map of the Bangemall Basin west of the 120°E meridian.

DISCOVERY CHERT

The Discovery Chert, conformably overlying the Jillawarra Formation, is a distinctive, remarkably persistent chert unit which forms the best marker horizon in the Bangemall Group. On the northern margin of the basin in the Edmund Sheet area it overlies the Irregully Formation and lenses out eastwards. It consists of black, massive chert with diffuse light-coloured laminations that are either planar, wavy, or contorted. A streaky texture visible with a hand lens is characteristic. The bedding is generally 10 to 30 cm apart and is wavy, containing irregular depressions and swells. Crystal casts after pyrite are common. Possible gypsum casts are also present. A search for acritarch microfossils revealed black spherical bodies, 5 to 10 μ in diameter, possibly of organic origin. Iron oxide replacement prevented separation and positive identification of these spheres.

The upper and lower contacts are usually transitional over a thickness of about 3 m, the beds becoming thinner and less siliceous away from the chert. Daniels (1969) records some sharp lower contacts in the Edmund Sheet area, as well as a regional colour variation from black to grey and maroon to white.

The Discovery Chert is the first unit in the basin which does not show major facies variations. At this time the sedimentation pattern became simpler and tectonic conditions were relatively quiet. However, slump structures have been found in places and may indicate some seismic activity. The environment seems to have been that of shallow, stagnant, and at times hypersaline water in which silica was precipitated chemically in anaerobic conditions.

DEVIL CREEK FORMATION

The Devil Creek Formation is a dolomite and silty shale unit conformably overlying the Discovery Chert. The dolomite is similar to that of the Irregully Formation, but minor lenses of dolarenite and dolorudite occur. A 1 cm thick oolite band was seen 6 km west of Kurugu Pool. Stromatolites have been recorded (Daniels, 1966a).

The proportion of dolomite to shale varies, both vertically and laterally, and the dolomite itself may form discrete lenses. Dolomite is locally absent, for example in the Mount Vernon Syncline, so that the remaining lutite sequence is indistinguishable from the overlying Ullawarra Formation.

Hematite cubes after pyrite are widespread, and rare unaltered pyrite cubes have been found. Nodules up to 2 cm in diameter consisting of small cubes and octahedra after pyrite are also present.

Cross-stratified beds are a common but minor feature. They contain abundant medium and small-scale (Conybeare and Crook, 1968), shallow, interfering, trough-shaped, cross-strata (pi and nu-cross-stratification), some planar alpha-cross-stratification, climbing ripples (kappa and lambda-cross-stratification), and scoured surfaces.

The laminated dolomite is thought to have been precipitated on the floors of lagoons, originally as calcium carbonate, and the interbedded shale laid down during times of clastic sediment input. A tidal mudflat environment is possible, but because desiccation cracks and interfering sets of ripple marks have not been observed, deposition in the restricted waters of lagoons is more likely. The cross-stratified and coarser-grained dolomite beds point to a transient high-energy environment where the wave base impinged on the sediment-water interface, such as a shallow-water shoal.

ULLAWARRA FORMATION

Conformably overlying the Devil Creek Formation and in part laterally equivalent to it, is the Ullawarra Formation, which is composed of shale, mudstone, quartzose siltstone, and fine-grained sandstone, as well as minor bands of dolomite and chert. Alternating thin-bedded maroon and white shales are common. Load casts are abundant. Laminated or massive siltstone is present in beds up to about 0.5 m thick. Cubic crystal casts occur sporadically, but are not as abundant as in older formations. Alpha and kappa-cross-stratification occur in some of the quartzose siltstone beds. This rock may grade into fine-grained sandstone.

The environment of deposition ranged from that envisaged for the Devil Creek Formation, but with a greater influx of clastic sediment, to deeper water conditions. The quartzose siltstone and sandstone could represent offshore shoals. However, the upper portion of the unit may have been laid down completely in a deeper water open marine setting.

CURRAN FORMATION

The Curran Formation is a distinctive pale-weathering unit of shale, mudstone, and chert, extending over a distance of 85 km and overlying the Ullawarra Formation. At its most easterly point it is cut off by a fault north of the Mount Vernon Syncline. At the time of its deposition conditions were fairly stable and uniform.

COODARDOO FORMATION

The overlying Coodardoo Formation in the Edmund Sheet area is a well-bedded greywacke with beds of shaley siltstone near the top (Daniels, 1969). The base is a transition zone 20 m thick, consisting of alternating beds of dark grey-green to black shale and thin greywacke with abundant sole marks. In the Mount Egerton Sheet area, however, the Coodardoo Formation consists of poorly to moderately sorted quartz arenite and minor wacke. The formation has a sheet-like form at least 175 km long, and is better sorted to the east. It disappears from the sequence by lensing.

The sands were introduced into the basin from the northwest by turbidity flows and in part transported farther east by bottom traction currents. Daniels (1966a) considers that the land to the north was gradually elevated at this time, resulting in a change in conditions from those of the Curran Formation.

FORDS CREEK SHALE

The Fords Creek Shale which conformably overlies the Coodardoo Formation is a thick sequence of green micaceous shale and silty mudstone, with minor amounts of interbedded quartz arenite, chert, and greywacke. Groove casts, bounce casts, flute casts, current bedding, ripple marks, and slump structures have been recorded.

Deposition was on an open marine shelf, chiefly as fine-grained material settling out of suspension. The arenite intercalations appear to be traction current deposits, although they may have been emplaced by turbidity flows and subsequently reworked by bottom currents. In the Edmund Sheet area palaeocurrents indicate a provenance to the north (Daniels, 1966a).

MOUNT VERNON SANDSTONE

Formerly regarded as the basal member of the Kurabuka Formation, this unit has been elevated to formation status. It is about 300 m thick north of Mount Vernon homestead and forms a sheet with an east-west extent of over 300 km. At the top of the underlying Fords Creek Shale is a transition zone in which thin arenite members of the shale sequence increase upwards in frequency and thickness. The bulk of the sandstone is a well-sorted, medium-grained quartz arenite. Siltstone fragments, some as large as 10 cm in length, are locally abundant. Pi and omikron-cross-stratification commonly in herringbone arrangement, ripple marks, flute casts, groove casts, and bounce casts are common. Herringbone cross-stratification is generally regarded as an indicator of tidal activity.

The evidence points to deposition in a near-shore, high-energy regime, such as a barrier bar system lying parallel to the coast.

KURABUKA FORMATION

The youngest unit in the western facies is the Kurabuka Formation which consists chiefly of greenish-white and dark-grey shale and mudstone. Near its base, interbedded cherty siliceous shale is common. In the upper portion of the formation there are some carbonate bands a few centimetres thick.

The deposit may represent a lagoonal facies developed next to the Mount Vernon Sandstone. Temporary changes in water circulation and sediment input would have resulted in the siliceous shale and carbonate bands. During storms or exceptionally high tides, siltstone fragments could have been washed out to be incorporated in the sands of the barrier bar system.

The sequence from the Fords Creek Shale upwards is thus seen as a progradational one which could portray the last stage of the infilling of the basin before the end of marine deposition.

NORTHERN FACIES

TOP CAMP DOLOMITE

This basal sequence of the Bangemall Group along the northern margin of the basin consists of over 2 000 m of dolomite, green shale, siltstone, chert, and sandstone. Dolomite beds, some with stromatolites, occur at several levels. Some of the bedded cherts appear to be silicified lutites. The sandstones are dominantly fine grained, well bedded, and have internal lamination. Bedding surfaces commonly show current lineations, flute and groove moulds, load casts, and ripple marks. Intraformational conglomerate and slump structures have been noted.

South of Prairie Downs a thick wedge of arkose and conglomerate with jaspilite boulders, known as the Prairie Downs Beds (Halligan and Daniels, 1964), occurs within the Top Camp Dolomite. A nearby derivation from the north and northeast is postulated (Daniels, 1966b). The wedge thickens to the northeast and a disconformity has been recorded at its base. It appears this deposit originated as an alluvial fan related to contemporaneous tectonic activity on the Prairie Downs Fault.

North of Bulloo Downs the dolomite unit is absent, its place being taken by a succession of shale, sandstone, and rare dolomite overlying the basal unconformity. Although extensive Cainozoic deposits largely obscure the bed-rock, these rocks are thought to be equivalent to the Top Camp Dolomite, in which the dolomito members lens out to the east.

FORDS CREEK SHALE, MOUNT VERNON SANDSTONE, AND KURABUKA FORMATION

Along the regional axis of the basin, the northern facies shares the same upper three formations as the western facies, so that the Top Camp Dolomite is equivalent to the Coodardoo Formation and all the units below it.

In the Bulloo Downs area fine-grained laminated dolomite beds, some extensively stained by manganese, are present in the Fords Creek Shale. The upper portion of the Fords Creek Shale in the eastern Lofty Range grades into the Mount Vernon Sandstone through a 450 m thick transition zone represented largely by fine-grained sandstone and coarse-grained siltstone. Some thin glauconitic sandstone beds occur.

EASTERN FACIES

Four formations are recognized in this facies.

COOBARRA FORMATION

This thick accumulation of coarse-grained sandstone and conglomerate, analogous to the Mount Augustus Sandstone and Tringadee Formation, unconformably overlies a basement inlier of sheared granitic rocks. In its northwest extent, conglomerate makes up about half of this formation, but elsewhere sandstone predominates. The conglomerate contains well-rounded pebbles, cobbles, and boulders of vein quartz, together with clasts of jaspilite-bearing conglomerate that may be derived from the Lower Proterozoic Labouchere Formation (Barnett, 1975) on the southern margin of the Bangemall Basin. Other clasts include sandstone of intraformational derivation. The sandstones of the formation are medium to coarse-grained, moderately to well-sorted, pebbly quartz arenites. Cross-stratification is common.

Bedding trends in the formation are continuous with those in the adjoining Kiangi Creek Formation to the west, and the two units are equivalent in part (Fig. 39). The upper beds of the Kiangi Creek Formation overlie the western portion of the Coobarra Formation and consist of fine-grained, laminated dolomite, dolomitic sandstone, medium-grained quartz arenite, and minor siltstone and shale. The eastern portion of the Coobarra Formation is overlain by the Backdoor Formation. The base of the lowest siltstone or shale member of an overlying formation marks the top of the Coobarra Formation.

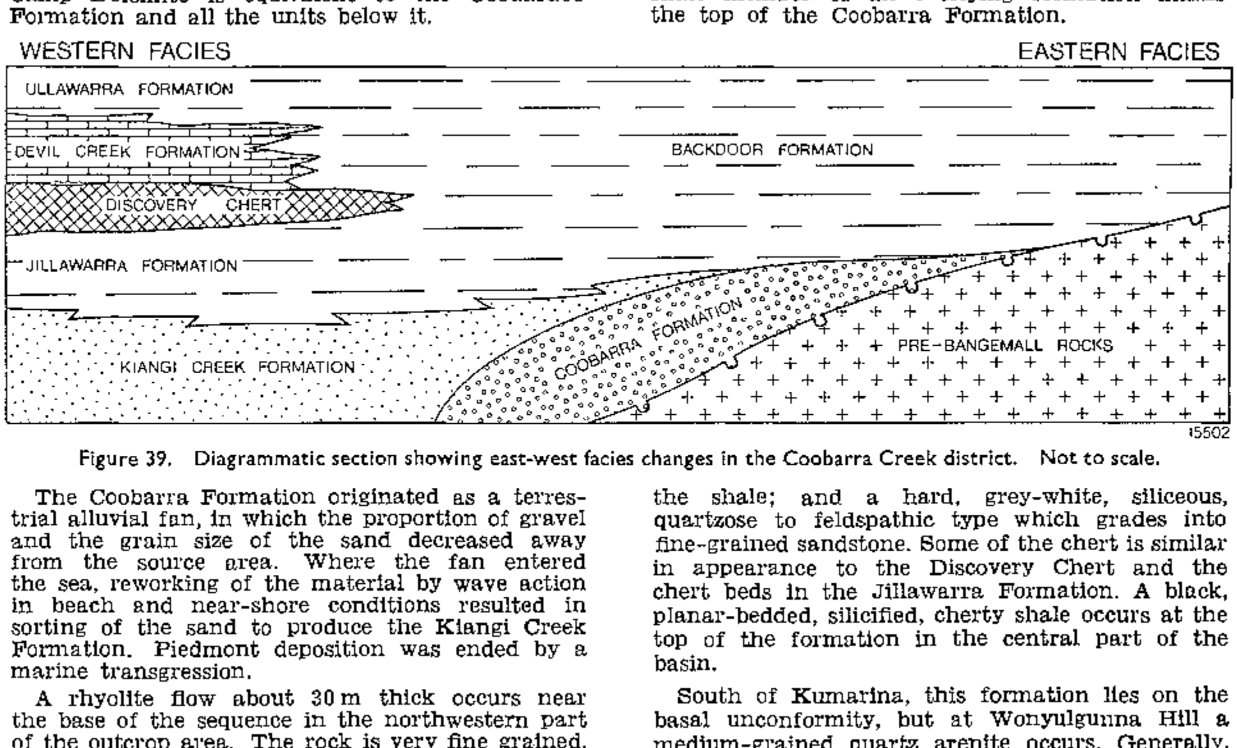

Figure 39. Diagrammatic section showing east-west facies changes in the Coobarra Creek district. Not to scale.

The Coobarra Formation originated as a terrestrial alluvial fan, in which the proportion of gravel and the grain size of the sand decreased away from the source area. Where the fan entered the sea, reworking of the material by wave action in beach and near-shore conditions resulted in sorting of the sand to produce the Kiangi Creek Formation. Piedmont deposition was ended by a marine transgression.

A rhyolite flow about 30 m thick occurs near the base of the sequence in the northwestern part of the outcrop area. The rock is very fine grained, has prominent flow banding, and contains pseudomorphs of beta quartz. This is the only confirmed outcrop of felsic volcanic rock discovered in the Bangemall Group.

*BACKDOOR FORMATION**

This lowest, laterally extensive formation of the eastern facies consists of shale and siltstone, with lesser amounts of chert, claystone, and lenses of dolomite and sandstone. Cubic crystal casts after pyrite are locally abundant. The siltstones are either laminated or massive and are of two types: a soft, earthy rock with a similar composition to the shale; and a hard, grey-white, siliceous, quartzose to feldspathic type which grades into fine-grained sandstone. Some of the chert is similar in appearance to the Discovery Chert and the chert beds in the Jillawarra Formation. A black, planar-bedded, silicified, cherty shale occurs at the top of the formation in the central part of the basin.

South of Kumarina, this formation lies on the basal unconformity, but at Wonyulgunna Hill a medium-grained quartz arenite occurs. Generally, in the transition area between the eastern and western facies the formation overlies the Devil Creek Formation. However, where the Devil Creek Formation and the Discovery Chert lens out, the lutite sequence extends down to the Jillawarra Formation level, and in the Coobarra Creek district overlies the Kiangi Creek and Coobarra Formations.

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* Name requires approval.

The sequence was deposited in a marine shelf environment, which was shallow enough to allow the formation of carbonates in places.

CALYIE SANDSTONE

Overlying the Backdoor Formation is the Calyie Sandstone, a prominent sandstone unit over 1 000 m thick. Beds are up to 3 m in thickness and are uniform in composition and grain size. Current grooving, ripple marks, and cross-stratification are present. Pyrite casts are present but uncommon, and fragments of siltstone are widespread. The rock is usually a medium-grained quartz arenite but both finer and coarser-grained feldspathic beds also occur, as well as interbeds of shale and siltstone. In the Kumarina area a glauconitic sandstone bed 10 m thick forms the base of the unit. The upper and lower limits of the formation are respectively regarded as the youngest and oldest laterally persistent sandstone member in this stratigraphic interval.

The unit forms a regionally uniform sheet about 150 km long in the area dealt with here, but it extends at least another 220 km farther east. It is considered to be a marine deposit.

ILGARARI BEDS

This is the top unit of the eastern facies, and consists chiefly of earthy white and brownish shale, siltstone, claystone, and fine-grained sandstone. Less commonly it is a hard, white quartz siltstone which grades into a fine-grained cross-stratified sandstone. In the area about 12 km east of Ilgarari thick manganese staining occurs in places on outcrops. The unit forms poor outcrops and its top has been eroded. It is thought to be a marine deposit.

CORRELATION OF EASTERN FACIES

The bottom portion of the Backdoor Formation is equivalent to the Jillawarra and Ullawarra Formations of the western facies, so that deposition was also contemporaneous with the Discovery Chert and Devil Creek Formation of the western facies. The relative stratigraphic position of the younger rocks of the eastern facies is uncertain. The Calyie Sandstone may be equivalent to either the Mount Vernon Sandstone or the Coodardoo Formation.

In the first case, the Fords Creek Shale correlates with the higher beds of the Backdoor Formation while the Kurabuka Formation is represented by the Ilgarari Beds. This necessitates major facies changes close to the Lofty Range and Neds Gap Faults. Green, fissile shales and mudstones are common in the Fords Creek Shale north of the Lofty Range, but this rock type is uncommon in the Backdoor Formation where grey, less fissile rocks predominate. The Calyie Sandstone east of Neds Gap Fault is thinner than the Mount Vernon Sandstone to the west and has no corresponding transition zone of fine-grained sandstone and coarse-grained siltstone at its base. The Kurabuka Formation is largely made up of greenish shale, mudstone, and chert, whereas the Ilgarari Beds contain white and brownish shale, mudstone, and fine-grained sandstone. Green rocks are rare in the latter unit, and have not been found at a depth of 60 m in the copper mine at Ilgarari.

Alternatively the Calyie Sandstone can be analogous to the stratigraphically lower Coodardoo Formation. It may therefore have been deposited in response to the same regional tectonic conditions, although the two formations were never physically continuous. The Ilgarari Beds then correlate with the basal portion of the Fords Creek Shale, and the black, planar-bedded chert at the top of the Backdoor Formation could be equivalent to the Curran Formation. However, there are also difficulties with this interpretation. There is no corresponding sandstone unit in the northern facies sequence, so that the thinning of the sandstone already noted north of Ilgarari would have to proceed to zero in the entire region north of the Lofty Range Fault. Another difficulty is the juxtaposition of the Calyie Sandstone with the Mount Vernon Sandstone across the Neds Gap Fault which would be a remarkable coincidence considering the large displacement required.

At present, the evidence for either view is inconclusive.

STRUCTURE AND TECTONICS

The Hamersley Basin is known to have been stabilized before deposition of the Bangemall Group, and in discussing basement—cover relationships, the informal term "Hamersley craton" is used here for the crustal block of Hamersley Basin rocks that form a basement to the Bangemall Group.

Two major fold trends are present in the Bangemall Basin. The dominant trend is arcuate from southeast to easterly, and is parallel to the major lithological and structural trend in the Hamersley craton (Daniels, 1966b). The other trend is a northeast to easterly arcuate trend which is roughly parallel to the northern margin of the Yilgarn Block (Fig. 40). Dips in the Bangemall Basin vary from horizontal to vertical, and even slightly overturned. Fold styles are essentially concentric, with well-developed, broad synclines and poorly developed cuspate anticlines. Slaty cleavage is only sporadically developed and metamorphism is minimal.

Regional variations in the intensity and orientation of folds outline four major structural provinces (Fig. 41). It is postulated that these provinces relate directly to the nature of the underlying basement.

NORTHERN PROVINCE

The Bangemall Basin is broadly synclinorial. The southern flank, which contains numerous folds, contrasts with the gently dipping northern flank. The northern province includes this northern limb which is a relatively undeformed apron around the periphery of the Hamersley craton.

WESTERN PROVINCE

This province extends in width from the synclinorial axis to the southern margin of the basin. It is characterized by relatively tight folds that have the typical southeasterly trend of Edmundian folds. Slaty cleavage is more common than in the other provinces. There is no diminution in intensity of folding at the southern margin, and some of the folds are slightly overturned to the north. The outliers of Bangemall Group in the Ti-tree and Mangaroon folds are tight synclinal keels.

Typically the folds are doubly plunging with lengths along the axes of about 20 to 75 km. The terminations of these folds usually occur in northeasterly trending zones. Palaeogeomorphic highs of basement rock are exposed through the Bangemall Group and form marked indentations in its southern margin, and some of these basement highs are the loci of basal conglomeratic beds. All these features together delineate northeasterly trending regional arches.

EASTERN PROVINCE

In the southeastern part of the basin, folding is gentle and is characterized by irregular-shaped domes and basins having a dominant east-northeast direction. Major faults are absent and the structural style indicates a stable basement.

INTERMEDIATE PROVINCE BETWEEN EASTERN AND WESTERN PROVINCES

This province is characterized by elongate folding with a principal direction that is distinctly arcuate from northeast to easterly. The boundaries of this intermediate province are defined by northeasterly trending lineaments which persist well to the northeast beyond the intermediate zone. The eastern boundary against the eastern province is marked by the Tangadee Lineament, which is expressed by two important features. Firstly there is a line of basement inliers that were highs during initial Bangemall Group sedimentation, and which influenced the formation of wedges of basal conglomerate and sandstone. Secondly there is a line of east-southeasterly or easterly trending faults arranged *en echelon*. One of these faults is arcuate, being convex to the north, and has a south-side-up movement. However, the northernmost faults on this line are parallel to the lineament and cut the easterly trending folds.

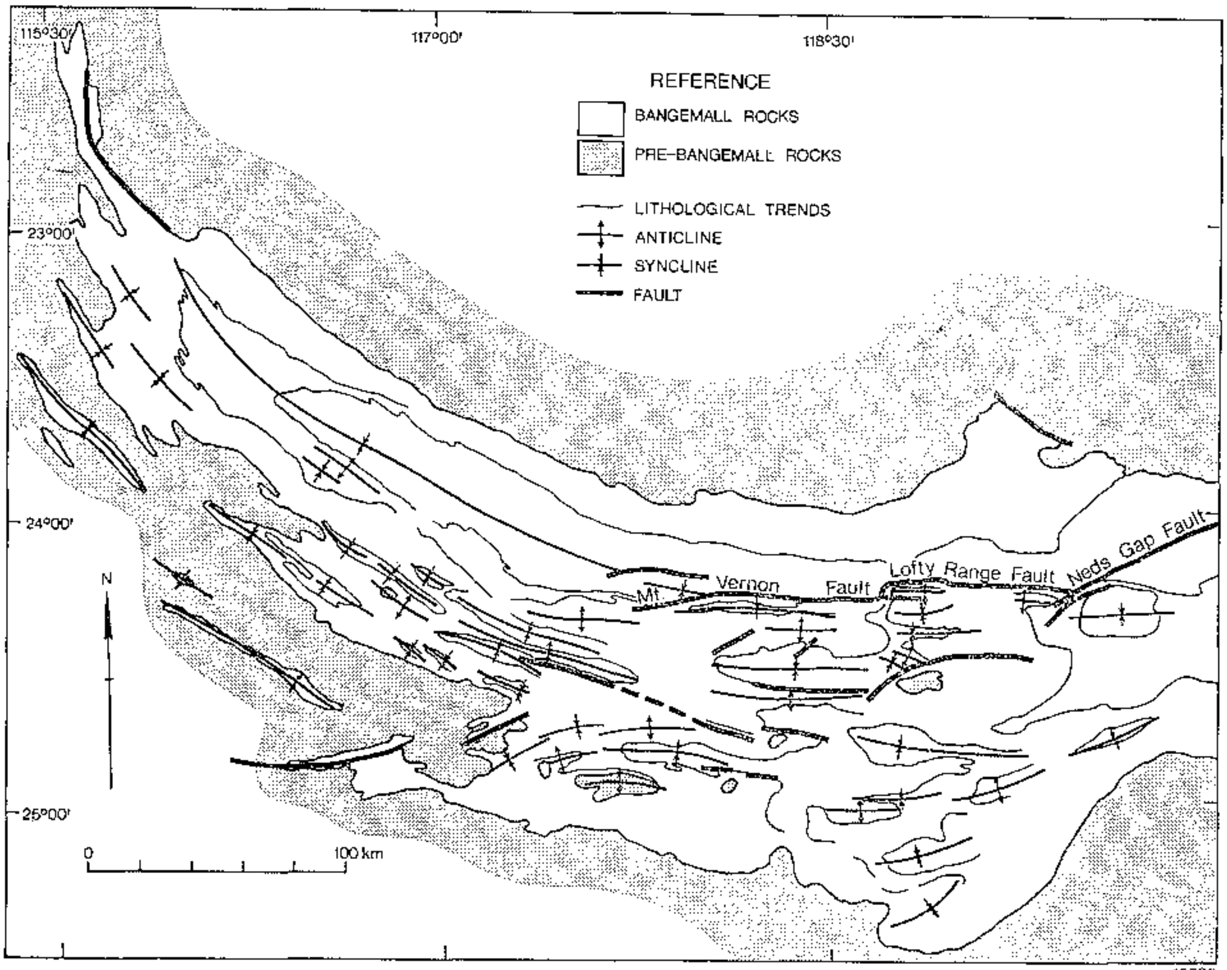

Figure 40. Structural sketch map of the Bangemall Basin west of the 120° meridian.

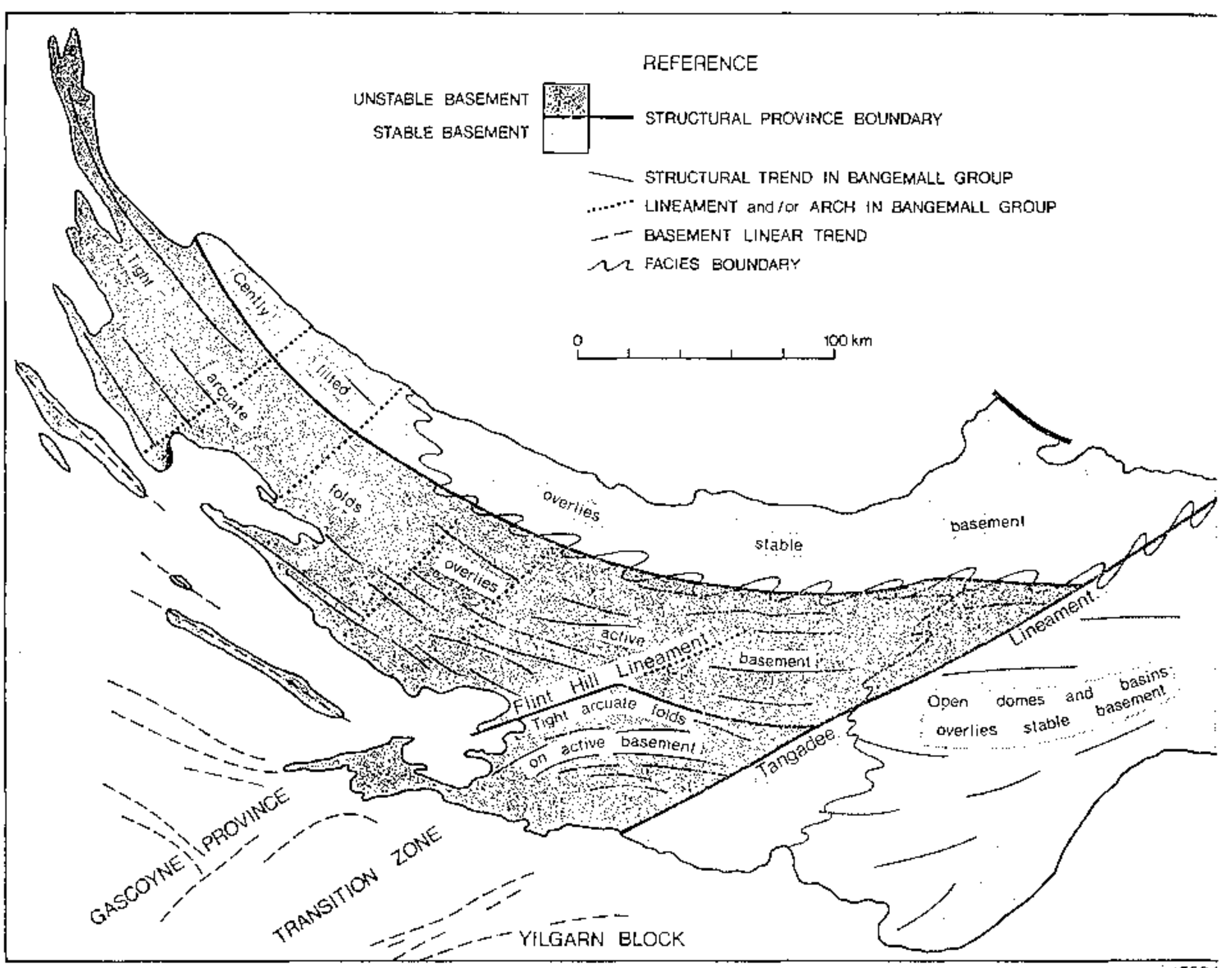

Figure 41. Structural provinces of the western and central Bangemall Basin.

The boundary of the transitional zone with the western province is called the Flint Hill Lineament. Apart from being a conspicuous photolineament, it is a line of structural mismatch whereby the southeasterly trending folds of the western province are replaced by northeasterly trending folds. Easterly trending faults in the central part of the basin and north of the intermediate province cut the axial trend of the east-southeasterly trending folds, and some of these faults are known to be south-side-up thrusts.

The age relationship of the northeasterly trending folds and the more typical southeasterly trend is uncertain and no superposition has been recognized. However, the deformation styles, which are notable for the paucity of cleavage make this relationship inconclusive. There is no marked mismatch of stratigraphy across the Flint Hill Lineament so that it is not interpreted as a sinistral wrench fault that dragged easterly trending folds into a northeasterly direction. Instead the regional fold patterns suggest synchronous formation of folds of all trends by independently behaving basement segments.

RELATION OF STRUCTURAL PROVINCES TO BASEMENT

A notable feature of fold trends in most of the Bangemall Basin, and especially the western province, is the parallelism with earlier Ophthalmian fold trends in the Hamersley craton (Daniels, 1966b), and those in the Gascoyne Province. A basement control to the Edmundian folding is therefore indicated. The transitional boundary between the northern and western structural provinces in the overlying Bangemall Group may reflect the position of the southern margin of the buried Hamersley craton.

Similarly, the northeast trend of the eastern province parallels the structural trend in the northern periphery of the Yilgarn Block, and a similar basement control is indicated. However, the irregular style of folding suggests an interaction with the trend of the western province.

The nature of the boundary between the Gascoyne Province and the Yilgarn Block is not properly understood at present, but it appears that on approaching the Yilgarn Block, the southeast trends of the Gascoyne Province are intersected by northeast trends that parallel those in the Yilgarn Block. The transitional zone is a migmatite complex about 70 km wide, trending northeast. The boundaries of this zone, when extrapolated into the Bangemall Basin correspond with the boundaries of the intermediate province, namely the Flint Hill and Tangadee Lineaments.

The structural provinces in the Bangemall Basin therefore appear to reflect movement of basement blocks, which formed by segmentation along the buried boundaries of the Hamersley craton, Gascoyne Province, and Yilgarn Block.

RELATION OF SEDIMENTATION TO TECTONICS

There is a correlation between the major sedimentary facies boundaries and structural province boundaries. Thus the change from the western to the eastern facies corresponds roughly to the Tangadee Lineament. Similarly, the northern facies corresponds largely with the northern structural province and the western facies occurs wholly within the western province.

Furthermore, there is a relationship between the complexity of sedimentation and the degree of deformation. Thus the stratigraphically simple northern facies is little deformed, whereas the western facies, which shows complex relationships between many stratigraphic units, is more strongly deformed. These regional variations in the style of sedimentation were therefore controlled by the stabilities of the individual basement segments.

CONCLUSIONS

The sedimentary history of the Bangemall Basin is one of progressive extension of the area of deposition accompanied by a marine transgression from west to east. Possible entrances for the sea were to the northwest through the Wyloo Sheet area and to the west across the Gascoyne Mobile Belt.

Early deposition was restricted to the region west of the 119°E meridian. Alluvial fans advanced into the basin from local topographic high points, and there was a gentle seaward gradient from the shoreline with a very broad intertidal and shallow lagoonal zone, in which the Irregully Formation and lower Top Camp Dolomite were laid down. The Kiangi Creek Formation originated as sandy shoals and islands near the basin axis. As the area of deposition extended, these zones migrated outwards, especially towards the south, and laminated muds of the Jillawarra Formation settled out of suspension in the deeper water. Lateral movements of province boundaries resulted in complex interfingering of the various sediments. The more pronounced and fluctuating migration of the southern margin can be attributed to a more tectonically active segment of basement rocks underlying this region. If the interpretation of some crystal casts as evaporite minerals is correct, there were periods when the water in the basin was restricted and hypersaline. During such a stagnant period, when tectonic conditions were quiet, the Discovery Chert was precipitated in shallow water, perhaps on a tidal flat over most of the existing basin area. Carbonates and muds of the Devil Creek Formation were deposited in lagoonal and shoal environments, while farther out to sea, muds of the Ullawarra Formation were laid down. The absence of medium-grained quartz sand in the shoal zone at this time reflects a lack of supply due to tectonic inactivity in the hinterland. Meanwhile, the sea was transgressing eastwards. Here fine-grained sediments were deposited on a fairly stable basement and the environment was generally unsuitable for the formation of carbonates except locally. Later sedimentation in the west took place on an open marine shelf and resulted in laterally extensive lutite formations in which green shales are conspicuous. At times, such as when the Curran Formation was deposited, tectonic conditions were quiet. On other occasions tectonic movements affected the basin hinterland and renewed the supply of sand, causing sheets of the material to cover large areas. At least one of these sheets was introduced into the basin by turbidity flows, and all show signs of working by bottom traction currents. Subsequently, barrier bar and lagoonal environments appear to have prevailed, and this shallowing of the basin could have been a prelude to the end of deposition.

After sedimentation ceased, the intrusion of dolerites and the movements of the Edmundian Fold Period took place. In the older crust activity on the boundaries of the basement tectonic units increased. Those segments which had shown greatest instability during sedimentation were again the most active, and the folding in the sedimentary cover overlying them was consequently most intense.

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THE STRATIGRAPHY OF THE EASTERN BANGEMALL BASIN AND THE PATERSON PROVINCE

by I. R. Williams, A. T. Brakel, R. J. Chin, and S. J. Williams

ABSTRACT

Stratigraphic reappraisals of the Paterson Province and northeast part of the Bangemall Basin, east of the Hamersley Basin and Pilbara Block, Western Australia, have produced important changes in the interpretation of the Proterozoic sequences of the region.

The oldest rocks of the area are the gneisses, schists, and igneous rocks of the Rudall Metamorphic Complex which forms the core of the Paterson Province. This metamorphic domain is unconformably overlain by the Yeneena Group, a moderately to strongly folded and faulted, mixed sedimentary succession of ?Lower or Middle Proterozoic age. Four formations, the basal Coolbro Sandstone, the Broadhurst Formation, the Choorun Formation, and the Isdell Formation are recognized within it in the Rudall Sheet area.

An unconformity is present between the Yeneena Group and the flat-lying to gently folded Middle Proterozoic Bangemall Group, which consists largely of sandstone. Two formations, the Skates Hills Formation and the McFadden Sandstone, comprise the Bangemall Group in its northeastern and eastern extent, while three formations, the Calyie Sandstone, the Backdoor Formation, and the Wonyulgunna Sandstone, believed to be facies equivalents, are present to the west.

The Bangemall Group—Yeneena Group boundary, regarded as the margin of the Bangemall Basin, can be traced southeasterly across the Rudall and Gunanya Sheet areas. An inlier of ?Lower Proterozoic sedimentary rocks is exposed in the southeast quadrant of the Trainor Sheet area. These older rocks may be correlatives of the Yeneena Group to the north or the Nabberu Basin rocks which lie to the south.

The McFadden Sandstone is unconformably overlain by small areas of the Proterozoic Durba Sandstone.

An isolated and uncorrelated, folded and faulted Proterozoic sedimentary sequence, the Karara Beds, is unconformable on the Rudall Metamorphic Complex and the Yeneena Group in the vicinity of Karara Well.

INTRODUCTION

This report outlines important stratigraphic reappraisals of the Proterozoic sedimentary sequences in the eastern part of the Bangemall Basin and the Paterson Province. The area, shown on Figure 42, lies largely in the southwestern part of the Great Sandy Desert and covers all of the Rudall, Gunanya, Trainor, and Buller 1:250 000 Sheet areas, and parts of the Paterson Range, Balfour Downs, Tabletop, Runton, Madley, and Stanley Sheet areas.

The significant changes to the 1973 edition of the Geological Map of Western Australia following recent mapping in this region are: the location of the northeastern margin of the Bangemall Group; the identification of a sedimentary sequence called the Yeneena Group, which unconformably underlies the Bangemall Group, and which forms the cover sequence of the Paterson Province; the extension of the Rudall Metamorphic Complex much farther to the southeast; the detection of an isolated sedimentary sequence of uncertain age but unconformable on the Yeneena Group in the Karara Well area; the recognition of a younger sandstone formation unconformably overlying the Bangemall Group at Durba Hills; and the discovery of an inlier of pre-Bangemall Group rocks in the southeast of the Trainor Sheet area. The derivation and detailed description of the type areas and sections for the Proterozoic units are given in the following Explanatory Notes, in preparation, belonging to the G.S.W.A. 1:250 000 Geological Series: Rudall (Chin and others), Runton (Crowe and Chin), Gunanya (I. Williams and S. Williams), and Trainor (Leech and Brakel).

The stratigraphy, as it is now understood, is shown in Table 22 and the regional distribution of the units is given on Figure 42.

TABLE 22. STRATIGRAPHY OF THE EASTERN BANGEMALL BASIN AND THE PATERSON PROVINCE

Buller 1:250 000		Trainor 1:250 000		Gunanya-Rudall 1:250 000		Tabletop-Runton 1:250 000
			Durba Sandstone		Durba Sandstone	
			unconformity		unconformity	
BANGEMALL GROUP	Calyie Sandstone	BANGEMALL GROUP	McFadden Sandstone	BANGEMALL GROUP	McFadden Sandstone	Karara Beds?
	Backdoor Formation		Skates Hills Formation			
	Wonyulgunna Sandstone					
			unconformity		unconformity	
		Unnamed ? Lower Proterozoic Formation		YENEENA GROUP	Isdell Formation	YENEENA GROUP
					Choorun Formation	
					Broadhurst Formation	
					Coolbro Sandstone	
					unconformity	unconformity
				RUDALL METAMORPHIC COMPLEX		RUDALL METAMORPHIC COMPLEX

RUDALL METAMORPHIC COMPLEX

The Rudall Metamorphic Complex forms the basement rocks in the Paterson Province. The complex extends for 100 km east-southeasterly through the Rudall, Gunanya, and Tabletop Sheet areas to the Runton Sheet area where it is unconformably overlain by Phanerozoic sedimentary rocks of the Canning Basin. A small inlier occurs in the McKay Range on the northern edge of the Gunanya Sheet area.

The complex is composed of two main lithological assemblages which are not distinguished on Figure 42. A gneissic assemblage is perhaps the oldest and consists largely of orthogneiss, gneissic amphibolite, and paragneiss. The gneisses have undergone retrograde metamorphism during a later period of metamorphism and deformation. This later period has also involved a second and possibly younger group of metasedimentary rocks including mainly quartzite and quartz-mica schist. Both assemblages have undergone polyphase deformation. Several periods of granitic, mafic, and ultramafic intrusions are evident.

YENEENA GROUP

The Rudall Metamorphic Complex is unconformably overlain by a thick ?Lower or Middle Proterozoic clastic and carbonate succession called the Yeneena Group. The unconformity is complexly folded and faulted, and along the western margin of the Rudall Metamorphic Complex thrusts, high-angle reverse faults, and fold axial planes in the Yeneena Group dip consistently northeast. The lower units of the Yeneena Group have undergone low-grade dynamic metamorphism. Both metamorphism and deformation decrease westwards in the Yeneena Group.

The group occupies the northwestern, northern, and central western parts of the Rudall Sheet area. It extends northwards across the western margin of the Paterson Range Sheet area and marginally into the Nullagine Sheet area (Hickman, 1975) where it unconformably overlies crystalline rocks and Lower Proterozoic sedimentary rocks in the Gregory Range area. The group also extends westwards into the Balfour Downs Sheet area (de la Hunty, 1964) where it unconformably overlies the Fortescue Group. On both sheets the unit has been called the Bocrabee Sandstone.

The Yeneena Group can also be traced southeastwards through the McKay Range, across the Gunanya Sheet area to the Lady Victoria Hills and into the Runton and Madley Sheet areas where it crops out in the Runton Range and Constance Headland.

A large inlier of folded and faulted Proterozoic rocks around the Telfer gold deposits in the Paterson Range Sheet area is believed to be equivalent to the higher formations in the Yeneena Group. In this area the succession has been intruded by granite at Mount Crofton which has been dated at 614 ± 42 m.y. (Trendall, 1974).

Four constituent formations are recognized in the Rudall Sheet area, but because of the discontinuous nature of the exposures, it is not possible to assign all the Yeneena Group rocks to formations.

COOLBRO SANDSTONE

The basal unit is the Coolbro Sandstone, a predominantly medium-grained quartz sandstone that is commonly cross-bedded. It contains at the base a discontinuous but locally conspicuous conglomerate unit with minor shale and siltstone beds. The clasts in the conglomerate are derived from the underlying metamorphic complex.

The Coolbro Sandstone is well exposed in the north central part of the Rudall Sheet area around Coolbro Creek and in the Throssell Range but it thins rapidly southwestward.

BROADHURST FORMATION

The Coolbro Sandstone is unconformably overlain by the poorly exposed Broadhurst Formation which consists of interbedded micaceous siltstone, mudstone, shale, graphitic shale, and fine-grained sandstone. Phyllite and graphitic shales occur in the vicinity of the Three Sisters Hills. The formation crops out in the Broadhurst Range and in the Three Sisters Hills area.

CHOORUN FORMATION

The Broadhurst Formation is comformably overlain by the Choorun Formation, a thick interbedded unit of fine to coarse-grained sandstone, micaceous siltstone, quartz pebble conglomerate, calcareous mudstone, and shaley dolomite. The formation occupies much of the central western part of the Rudall Sheet area and extends into the Balfour Downs Sheet area.

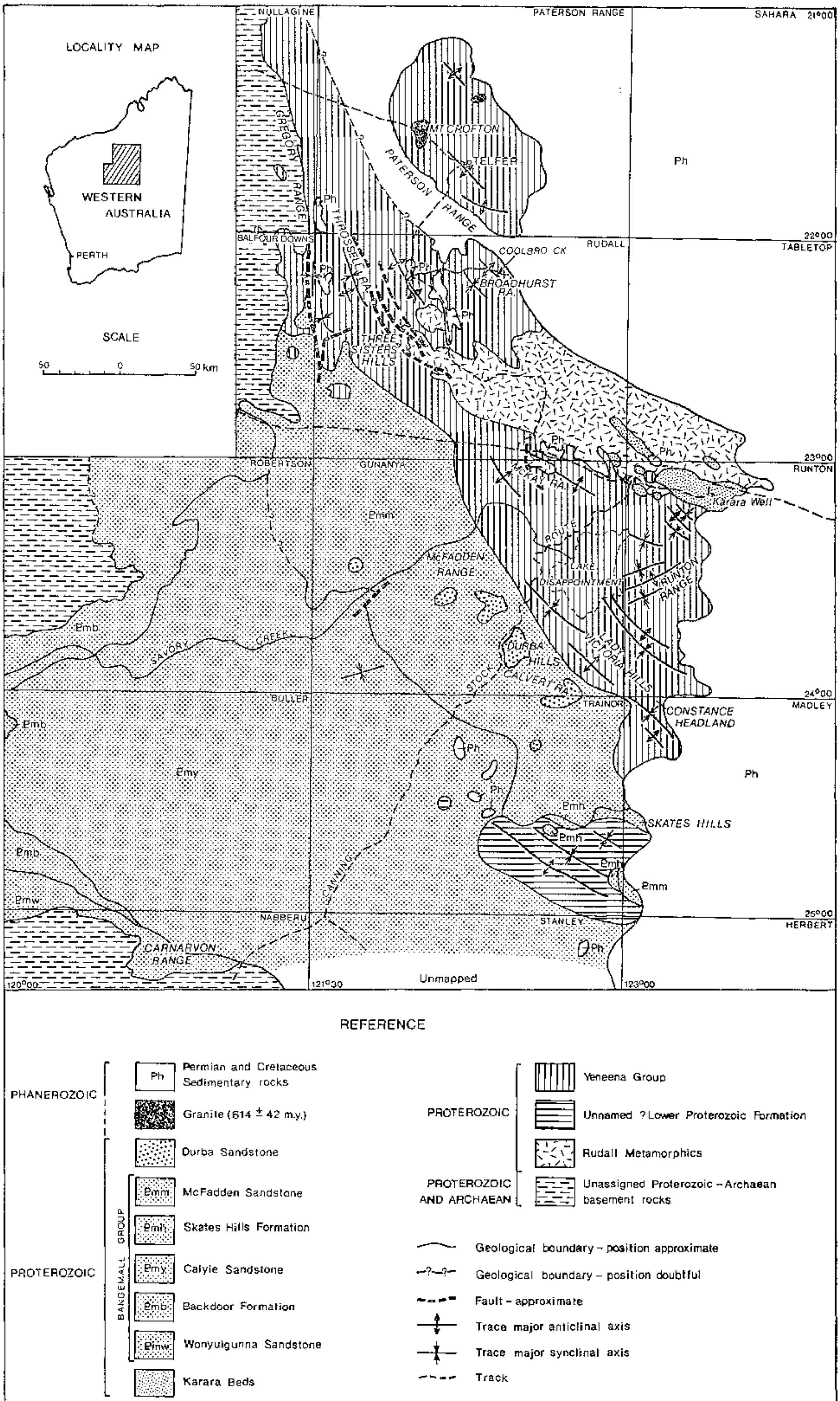

Figure 42. Solid geology of the eastern Bangemall Basin and Paterson Province.

ISDELL FORMATION

The uppermost formation of the Yeneena Group in the Rudall Sheet area is the Isdell Formation. It is predominantly dolomite and dolomitic shale, with variable amounts of interbedded sandstone, siltstone, and minor pebble conglomerate. The clastic components increase westwards. The formation occurs in a major synclinal structure in the northwest and along the north central margin of the Rudall Sheet area. This formation, and possibly the upper part of the Choorun Formation, may be correlatives of the carbonate-clastic sequences in the Paterson Range Sheet area.

KARARA BEDS

Near Karara Well, in the Runton Sheet area, a sequence of folded conglomerate, sandstone, and minor siltstone and dolomite lies unconformably on both the Yeneena Group and the Rudall Metamorphic Complex. These are called the Karara Beds and occur in a number of scattered, disconnected outcrops in the adjacent corners of Rudall, Tabletop, Runton, and Gunanya Sheet areas. Their regional stratigraphic position is uncertain. They may correlate with the Bangemall Group, the Durba Sandstone, or rocks to the south in the Runton Sheet area at present placed in the Yeneena Group.

They may also constitute a completely separate sequence, represented by erosional or non-depositional periods elsewhere in the Proterozoic succession.

UNASSIGNED ?LOWER PROTEROZOIC ROCKS IN THE TRAINOR SHEET AREA

An unnamed ?Lower Proterozoic formation occurs as an inlier in the southeastern portion of the Trainor Sheet area, and adjacent part of the Madley Sheet area. It is a hard siliceous sandstone unit with some micaceous siltstone and shale lenses. The sandstones vary from massively bedded to laminated quartz arenites. Cross-bedding is widespread but not conspicuous in outcrop.

The formation is overlain by gently dipping Bangemall Group rocks. Along the northern margin of the inlier there is a strong angular unconformity between the Bangemall Group rocks and the older rocks. However, along the southern margin both units dip in the same direction, so that the contact, which is not exposed, appears to be disconformable.

The traces of the major fold axes are parallel to those in the Yeneena Group rocks farther north (Fig. 42). However, direct correlation is not possible at this stage and the rocks may be the time equivalent of part of the Nabberu Basin sequence to the south, or the Yeneena Group to the north.

BANGEMALL GROUP

The Middle Proterozoic Bangemall Group occupies over half the area under discussion and its extent can now be taken as the limit of the Bangemall Basin. Most of its constituent formations are not developed over the whole region because of lateral facies changes.

SKATES HILLS FORMATION

At the base of the Bangemall Group in the Skates Hills (Madley Sheet area) and parts of the southeastern Trainor Sheet area is a succession of conglomerate, interbedded sandstone, shale, and siltstone, and finally stromatolitic dolomite, termed the Skates Hills Formation. The unit varies in thickness and lenses out in places. The basal boulder-bearing cobble conglomerate is likewise lenticular. The formation rests unconformably on the unnamed ?Lower Proterozoic sandstone unit mentioned previously.

McFADDEN SANDSTONE

The Skates Hills Formation is conformably overlain by the McFadden Sandstone. This formation consists largely of quartzose and feldspathic arenite and wacke. It is characterized by flaggy, well-laminated beds, and cross-bedding sets up to 8 m thick. Pebble and granule-bearing rocks are common.

The McFadden Sandstone unconformably overlies the Yeneena Group along the northeastern margin of the Bangemall Basin. It is also unconformable on the ?Lower Proterozoic sandstone unit in the southeast quadrant of the Trainor Sheet area. Westwards, the unit loses its characteristic features and it appears to grade laterally into the Calyie Sandstone.

In the southwestern corner of the Gunanya Sheet area around Savory Creek it appears to overlie part of the Calyie Sandstone. The extent of the unit in the adjoining Robertson Sheet area is unknown. The formation is best developed in the McFadden Range and is unconformably overlain by the Durba Sandstone in the Durba Hills and Calvert Range.

CALYIE SANDSTONE

The western half of the Trainor Sheet area and most of the Buller Sheet area are occupied by a sandstone unit which is a continuation of the Calyie Sandstone defined on the adjacent Collier Sheet area (Brakel and Muhling, 1976). The unit consists mainly of flat-lying and gently dipping quartz arenite with minor siltstone and conglomerate lenses.

The formation grades into the McFadden Sandstone and disconformably overlies the ?Lower Proterozoic sandstone unit in the southeast Trainor Sheet area.

BACKDOOR FORMATION

The Backdoor Formation is a sequence of shale, siltstone, chert, and fine-grained sandstone that occurs in the western part of the area under discussion. It also crops out extensively in the Collier Sheet area (Brakel and Muhling, 1976). It conformably underlies the Calyie Sandstone but appears to lens out near the boundary of the Nabberu Sheet area. The shale and siltstone of the "Manganese Group" (de la Hunty, 1969) which conformably underlies the Calyie Sandstone in the centre of the Robertson Sheet area are presumed to correlate with the Backdoor Formation.

WONYULGUNNA SANDSTONE

The newly recognized Wonyulgunna Sandstone is a prominent ridge-forming unit which lies conformably beneath the Backdoor Formation.

It unconformably overlies a basement that consists of schist and metamorphosed banded iron-formation intruded by granite.

DURBA SANDSTONE

The Durba Sandstone is a flat-lying, massive quartz arenite which unconformably overlies the McFadden Sandstone in the Gunanya and Trainor Sheet areas. The formation occurs as a series of scattered outliers situated along a rough south-easterly trend which may represent a very shallow depositional basin aligned parallel to structural trends in the older rocks of the Paterson Province. Its age and correlation are uncertain. Lithologically similar sandstone is present within the Calyie Sandstone in the Buller Sheet area, so that the Durba Sandstone may belong to the Bangemall Group, the unconformity being only of local significance. Alternatively the deposit may be of post-Bangemall Group age, representing a last, brief, and limited return of deposition at the close of the Proterozoic sedimentation in the region.

PHANEROZOIC ROCKS

A number of scattered Permian outliers of the glacigene Paterson Formation occur in the Paterson Range, Rudall, and Trainor Sheet areas. The Paterson Range, southwest of Telfer, is the largest Permian outcrop area separated from the Canning Basin.

No Cretaceous rocks have been recognized beyond the main boundary of the Officer and Canning Basins.

CONCLUSIONS

The geological history of the region can be briefly summarized as follows.

The oldest rocks form the metamorphic and igneous Rudall Metamorphic Complex, in which polyphase deformation is recorded. The rocks involved are probably Lower Proterozoic in age, and may include reworked Archaean terrains.

The complex is unconformably overlain by the Yeneena Group, a sedimentary sequence which was laid down in a shallow marine shelf environment and consists largely of detritus derived from the Rudall Metamorphic Complex. Initial gravel and sand accumulation was followed by lower energy conditions indicated by alternating sand and mud, and finally carbonate, silt, sand, and gravel sedimentation. This sequence may have resulted from migrating, contemporaneously adjacent subenvironments instead of only gross temporal variation. It is likely that this probable Lower or Middle Proterozoic deposition extended over a large area beyond the present outcrop limits.

The unnamed ?Lower Proterozoic sandstone in the Trainor Sheet area may also have been deposited at this time in a near-shore location. The region was subsequently modified by tectonism which decreased in intensity to the southwest and imparted to the rocks a general northwesterly structural trend.

In the Karara Well area a sedimentary sequence, possibly developed in a discrete marine basin, was laid down after an interval of erosion had effected the Yeneena Group. The age of these sediments is uncertain.

To the southwest a marine transgression, which was part of that taking place over the area of the Bangemall Basin, led to the deposition of shelf sediments which were dominantly sand, except for some lenses of gravel and dolomite. An east to west lateral change in facies was present due to the nature of the detritus supplied to the basin and differing depositional environments, such as deeper water to the west. Later movements accompanied by dolerite intrusions, caused some mostly gentle folding. In the centre of the region a last short depositional episode represented by the Durba Sandstone occurred after some erosion of the Bangemall Group rocks, in what may have been a small, very shallow basin elongated parallel to the older structural trends. The constituent sand was quite likely reworked from the underlying sandstone.

The final Proterozoic activity took place in the northeastern district which underwent further tectonism and metamorphism accompanied by the emplacement of granites in the Paterson Range area at the close of Precambrian time. No further record of geological activity is preserved in the region until the Late Palaeozoic when widespread Permian glaciation took place.

An important result of the recent mapping is the discovery of the pre-Bangemall Group rocks along parts of the western margin of the Officer Basin. These strongly imply that the eastern limit of Precambrian outcrops also marks the real eastern edge of the structural Bangemall Basin, which would not, therefore, continue as an unbroken subsurface unit into Central Australia. Separate Middle Proterozoic basins under the Phanerozoic cover cannot be ruled out. A structural reason for the location of the western margin of the Officer Basin is also implied.

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THE KALUWEERIE CONGLOMERATE: A PROTEROZOIC FLUVIATILE SEDIMENT FROM THE NORTHEAST YILGARN BLOCK, WESTERN AUSTRALIA

by P. D. Allchurch* and J. A. Bunting

ABSTRACT

An outlier of unmetamorphosed polymictic conglomerate and lithic arenite lying unconformably on Archaean granitic rocks, and considered to be Proterozoic in age, is interpreted as a fluviatile deposit. The sediments are immature and contain a variety of granitic and low-grade metamorphic rock fragments. The deposit is elongated east-west, is slightly sinuous, and was probably derived from the erosion of adjacent granitic rocks and the Booyigoo Range greenstone belt to the west.

The subhorizontal attitude of these beds and other probable Proterozoic outliers on the northeastern part of the Yilgarn Block, together with their lack of deformation illustrates the stability of the shield since Proterozoic times. It is suggested that the flatness of the shield surface relates to Proterozoic erosion and is not a more recent phenomenon.

INTRODUCTION

Outliers of Proterozoic sedimentary rocks from well within the area of the Archaean Yilgarn Block are rare and have not generally been recognized. The Kaluweerie Conglomerate is one such deposit. The purpose of this paper is to present a description of the rocks in the Kaluweerie Hill area, to discuss their depositional environment, and to compare them with other Proterozoic outliers in the region.

Kaluweerie Hill lies in the southwest corner of the Sir Samuel 1:250 000 Sheet area. It is approximately 620 km northeast of Perth and 140 km south of Wiluna.

*Australian Selection (Proprietary) Limited.

REGIONAL SETTING

The basement rocks of the area form part of the stable Archaean Yilgarn Block which consists of linear, arcuate belts of metavolcanic and metasedimentary rocks separated by large areas of granitic rocks. To the north and northeast this craton is bounded by Early and Middle Proterozoic sedimentary basins. A tongue of gently-dipping quartzite, shale, dolerite, and dolomite extends unconformably onto the Yilgarn Block as far south as Wiluna, and is the closest large area of confirmed Proterozoic sediment to the Kaluweerie area. Outliers of presumed Proterozoic sedimentary rocks also occur at Mount Lawrence Wells and Mount Yagahong (Fig. 43, insert).

The granitic rock in the vicinity of Kaluweerie Hill is mainly medium to coarse-grained adamellite, porphyritic in places, with a poorly developed foliation. Near-vertical quartz microdiorite dykes cut the adamellite. In places the dykes are distinctively vertically layered. They trend 080° and are thought to be equivalent to the Widgiemooltha Dyke Suite which is late Archaean or early Proterozoic in age. A series of quartz-filled fractures, of which Kaluweerie Hill is an example, also trend 080°, and the microdiorite dykes may be related to this fracture system. Associated with the quartz fractures is a peculiar epidote-quartz rock, which may have resulted from alteration of the adamellite during quartz deposition.

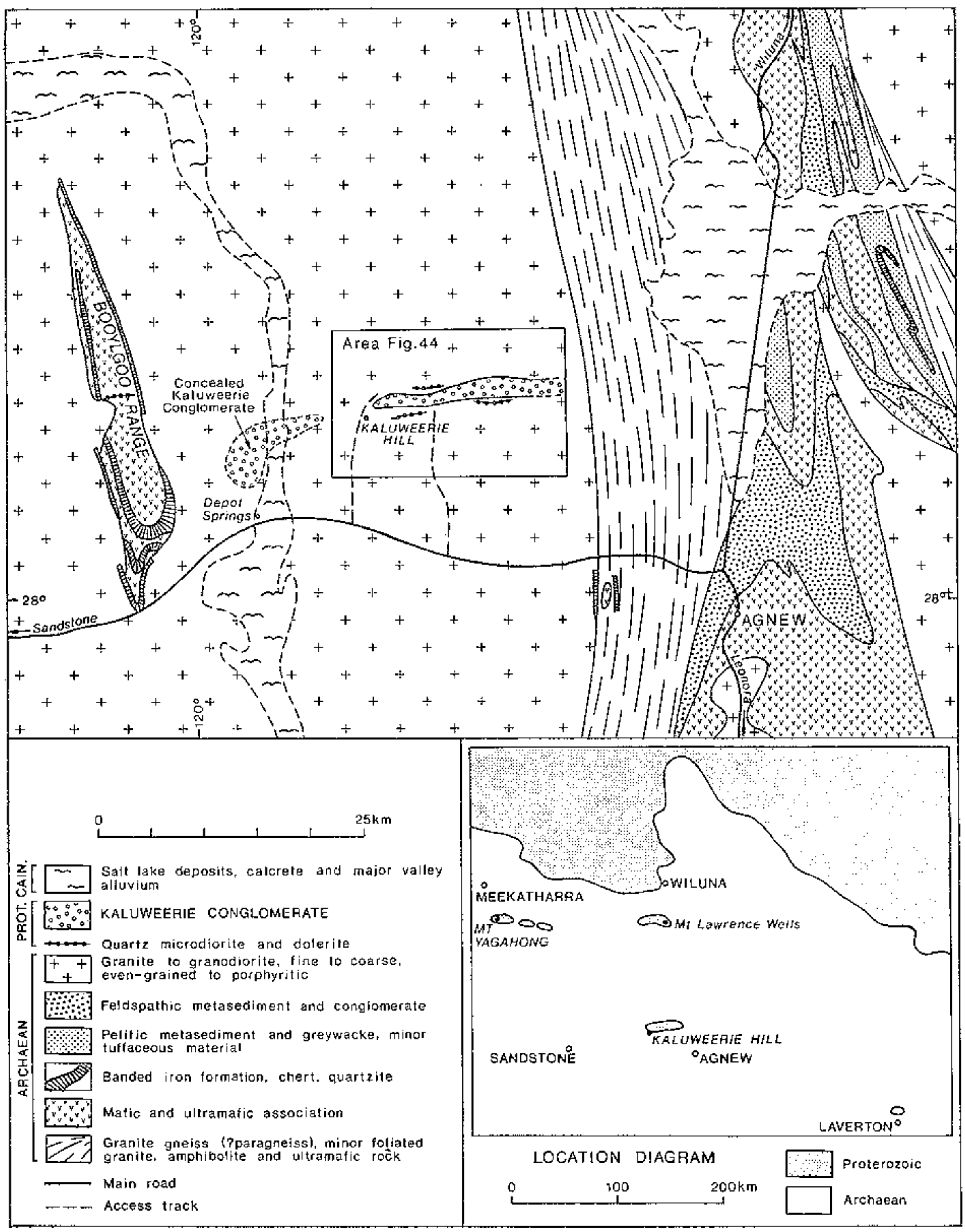


Figure 43. Regional geology, Agnew-Booylgoo Range area.

Between the adamellite and the Agnew-Wiluna greenstone belt to the east, is a poorly exposed north-trending belt of banded quartz-feldspar paragneiss with minor amphibolite, metamorphosed banded iron-formation, talc schist, and gneissic granite (Fig. 43).

THE KALUWEERIE CONGLOMERATE

The name Kaluweerie Conglomerate is proposed for a sequence of conglomerate and arenite that unconformably overlies Archaean granitic rocks and is overlain by Cainozoic superficial deposits. It is considered to be Proterozoic in age. Present exposure forms a sinuous belt trending roughly east-west, about 15 km long by 1.5 km wide (Fig. 44). The conglomerate has also been intersected in drillholes, through thin Cainozoic cover about 10 km west of the western outcrop limit. The name is taken from Kaluweerie Hill, 1 km south of the western end of the belt of outcrop. The type section is the hill at lat. 27°49'50"S, long. 120°11'40"E, 1.5 km north-northwest of Langford Well, where the maximum exposed thickness is about 25 m. In drillholes 10 km west-southwest of Kaluweerie Hill the conglomerate is 35 m thick.

LITHOLOGY

Two lithological types are present:—

(1) polymictic conglomerate and pebbly lithic arenite,

(2) fine to coarse-grained lithic arenite.

The conglomerate generally forms a lower unit, and arenite is dominant in the upper part of the occurrence.

Conglomerate

The conglomerate is a poorly sorted, well-indurated rock (Fig. 45A) in which grain size ranges from fine sand to boulders 60 cm across. Clay and silt fractions are absent or minor. In places there is a scarcity of clasts in the 2 mm to 10 mm range. The matrix/clast division is taken at 2 mm. Below this size the matrix is composed mainly of individual mineral grains, whereas in the coarser material rock fragments and composite grains are dominant.

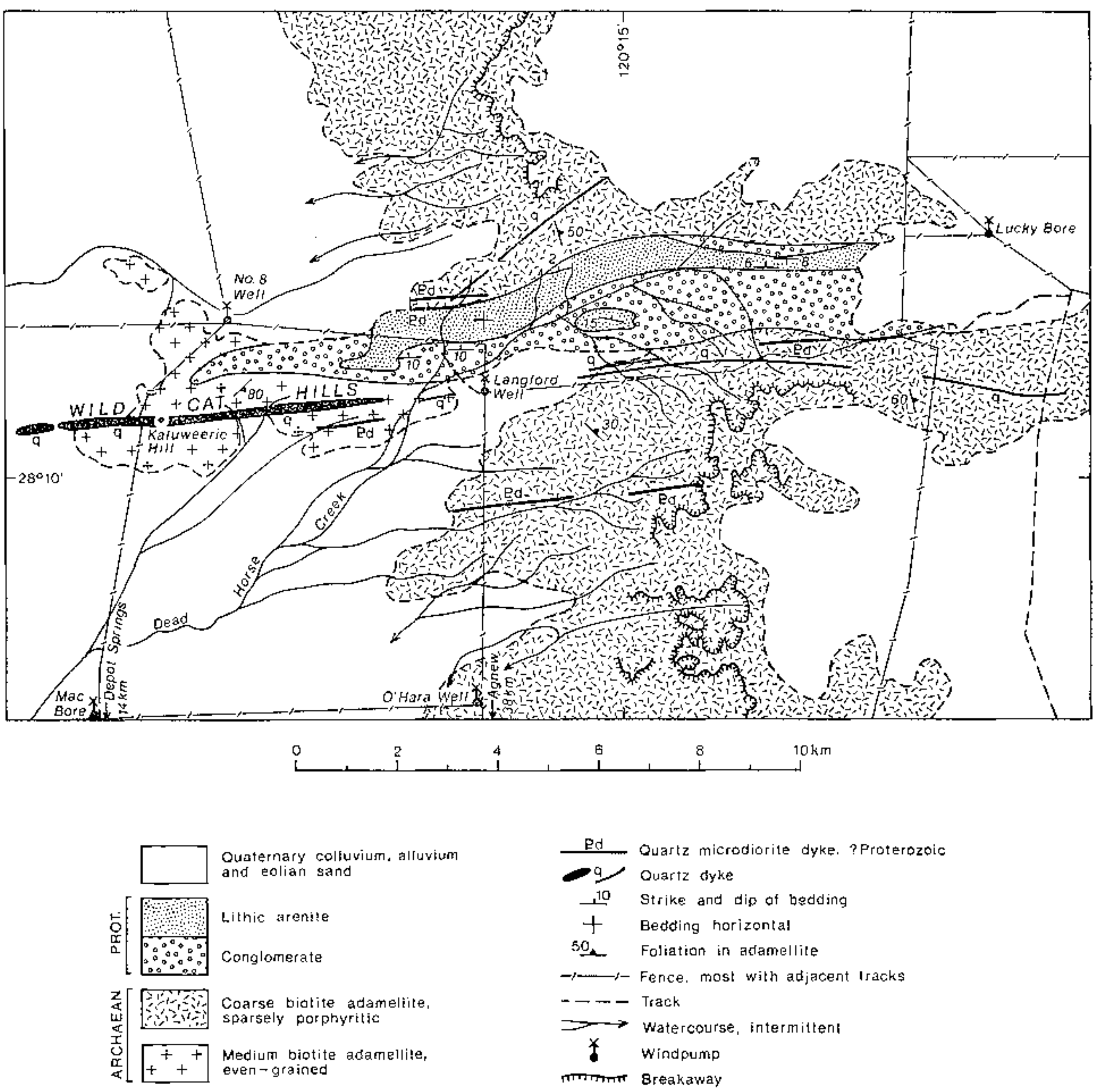


Figure 44. Geology of the Kaluweerie Hill area.

Clasts are variable in composition and include granitic rocks ranging from granite to tonalite, plus aplite, felsic gneiss, metabasalt, amphibolite, banded iron-formation, banded chert, chlorite schist, felsic volcanic rocks, metagabbro, metadolerite (including rare cobbles of porphyritic dolerite with feldspar phenocrysts up to 5 cm x 3 cm), and vein quartz. The clasts are generally subangular to rounded. Sphericity and shape depend largely on the rock type involved. High sphericity is characteristic of the granitic clasts and the more poorly foliated felsic volcanic and mafic rocks. Gneissic rocks, banded iron-formation, and chert form tabular clasts, whereas schistose rocks form elongate, bladed clasts.

The matrix of the conglomerate is moderately to poorly sorted and contains 50 to 60 per cent quartz, 15 to 20 per cent feldspar (mostly plagioclase with minor microcline and perthite), and 20 to 25 per cent chlorite, sericite, biotite, amphibole, and epidote. Carbonate, sphene, and iron oxide minerals account for about 5 per cent of the matrix. The constituent minerals are detrital except for minor secondary calcite around detrital carbonate grains (Fig. 45, C and D) and possibly the very fine white mica. Textures are similar to those in the arenite described below, but in places the scarcity of clay and silt allows for a closer packing of the larger grains (Fig. 45B). Lithification probably occurred by suturing of grain boundaries and remobilization of silica, suggesting a considerable depth of burial. Deep burial is also suggested by fracturing of plagioclase against quartz (Fig. 45E), kinking of chlorite and mica between compacted quartz grains, and a slight platy alignment of quartz grains parallel to bedding.

Lithic arenite

Lithic arenite is dominant towards the top of the succession but also occurs as lenses in the lower conglomeratic unit. In places there are gradations into conglomerate as the arenite becomes pebbly, and the matrix of the conglomerate is then indistinguishable from the arenite.

The arenite ranges from very fine grained to very coarse grained, with a tendency for finer material to occur near the top of the sequence. Sorting is moderate to good in the finer rocks, but becomes poorer in the coarse-grained varieties. In hand specimen the arenite is a hard, strongly lithified dark-grey to greenish-grey rock and apart from indistinct and irregular bedding (Fig. 45F) the rock is massive. It outwardly resembles basalt or dolerite, particularly in suboutcrop where it weathers to spherical boulders.

Typical arenite contains 50 to 70 per cent quartz, equal amounts of feldspar and mafic minerals, with minor detrital calcite, muscovite, sphene, and iron oxide minerals. Authigenic pyrite is interstitial to quartz (Fig. 46A). The mafic minerals are amphibole, epidote, biotite, and chlorite, both as individual detrital grains and as constituents in lithic fragments. Quartz and feldspar are very irregular in shape, and the close fitting of grains in some samples indicates considerable rearrangement and compaction. Clay matrix is usually a minor constituent, but may reach up to 10 per cent.

The very coarse lithic arenite contains a variety of lithic grains similar to those in the conglomerate, such as granite, felsic volcanic, dolerite, and chert, in addition to the normal medium-grained arenite lithology (Fig. 46, B, C, and D). Very fine-grained lithic arenite which occurs near the top of the exposed sequence in the type section consists of about 60 per cent quartz, 15 per cent epidote, 10 per cent green pleochroic amphibole, 10 per cent feldspar, and 5 per cent clay matrix and iron oxide. Possible local sources for the unusually large amount of epidote are the Archaean metavolcanic rocks, and the epidote-quartz rock associated with the quartz-filled fracture system.

About 1.5 km north-northwest of Lanfford Well, medium-grained lithic arenite contains irregular fragments of mudstone up to 5 cm long (Fig. 46, E and F), which probably indicates penecontemporaneous erosion of thin mud bands. At the margins of the fragments, grains of matrix quartz project into, and are in places enclosed by, the mudstone, indicating that the mudstone was plastic during deposition of the arenite.

DEPOSITIONAL FEATURES

Primary sedimentary structures within the conglomerate are poorly developed. Bedding is indistinct and irregular, and layers form discontinuous lenses and tongues (Fig. 45 F). Faint cross-bedding is present in some parts of the arenite. The generalized upward fining imparts an overall grading to the deposit. Graded beds are present but uncommon, and some examples show reverse grading. Within the conglomerate, discoidal pebbles tend to be aligned parallel to bedding, but the orientation of long axes within bedding planes appears to be random.

Dip measurements and the distribution of rock types indicate that the deposit forms a shallow asymmetrical synclinal trough elongated approximately east-west. This shape may be partly depositional and partly due to post-depositional compaction or minor tectonic warping. Dip of bedding planes is seldom more than 10°

DEPOSITIONAL ENVIRONMENT

Features such as coarseness, poor sorting, large proportion of feldspar, nature of the rock fragments, angularity of the sand fractions, and lack of clay and silt, indicate a local origin. The lack of well-defined bedding and the sinuous, elongate shape of the outcrop indicates a fluviatile environment, possibly in a partly confined channel. The rocks exposed form a topographic low between hills of vein quartz to the south and breakaways of granite to the north. The conglomerate shows some features characteristic of the rapid flow of water-lubricated material found in debris flow deposits close to areas of strong erosion (Reineck and Singh, 1973). The lack of preferred orientation of clasts is typical of such deposits, while the lack of attrition between sand-sized grains is shown by the high degree of angularity and the preservation of detrital epidote, amphibole, chlorite, and carbonate.

There may have been basement structural control of the river channel by the quartz and mafic dykes in the vicinity. The deposit hugs the northern side of the Wild Cat Hills quartz ridge from south of Lucky Bore to the point where it passes under the calcrete cover to the west—a distance of nearly 30 km. The quartz ridge is presently several tens of metres above the base of the conglomerate and was probably high ground during deposition of the conglomerate.

PROVENANCE

Banded iron-formation and ferruginous chert are absent from the Agnew-Wiluna greenstone belt to the east, and felsic volcanic rocks are uncommon. Although the Booylgoo Range has yet to be mapped in detail, it is known that banded iron-formation and chert form a major part of the sequence. The conglomerate therefore was probably derived from the west. The granitic clasts and the vein quartz fragments in the conglomerate, and the epidote in the arenite could all have been derived from the immediate area.

Further evidence for a western source is the scarcity of arenaceous layers in drillholes 8 to 10 km west-southwest of Kaluweerie Hill, where the sequence is dominantly pebbly. Thus, as well as fining upwards, there may also be lateral fining to the east. The vertical grading may represent a filling of the channel accompanied by a decrease in the amount of material being eroded from nearby uplands.

Figure 45. Petrographs and photomicrographs of the Kaluweerie Conglomerate (scale bar represents 1 mm except where stated otherwise).

A. 42869. Conglomerate, showing variety of clasts.

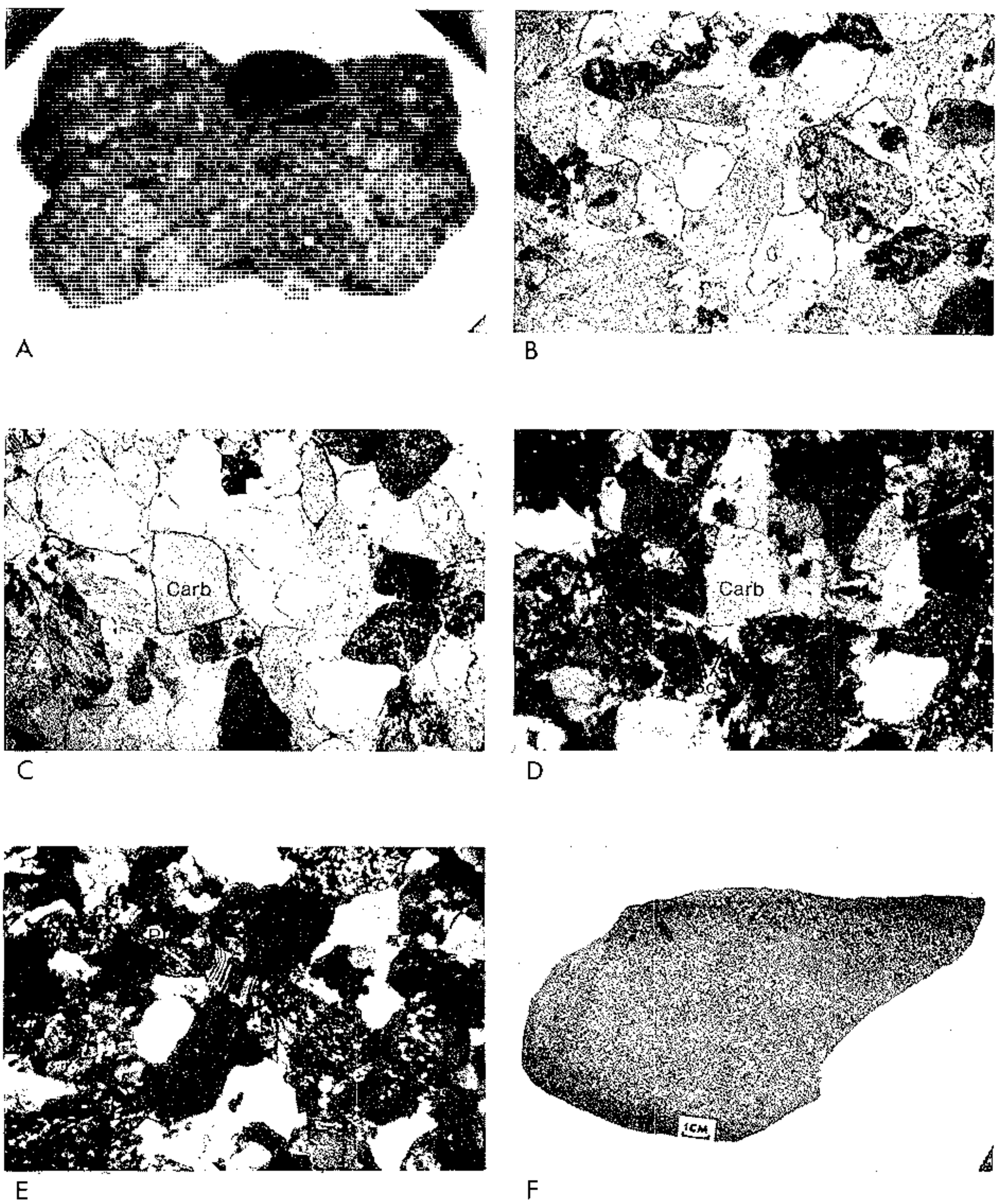
B. 42868. Conglomerate, matrix showing very close packing o detrital grains (plane polarized light).

C. 42871. Conglomerate matrix, showing detrita carbonate grain (carb) (plane polarized light).

D. Same as C, showing secondary carbonate growth (Sc) (crossed nicols).

E. 42868. Conglomerate matrix, showing pressure (load) fractured plagioclase (Pl) (crossed nicols).

F. 42870. Irregular bedding with reverse grading in lithic arenite.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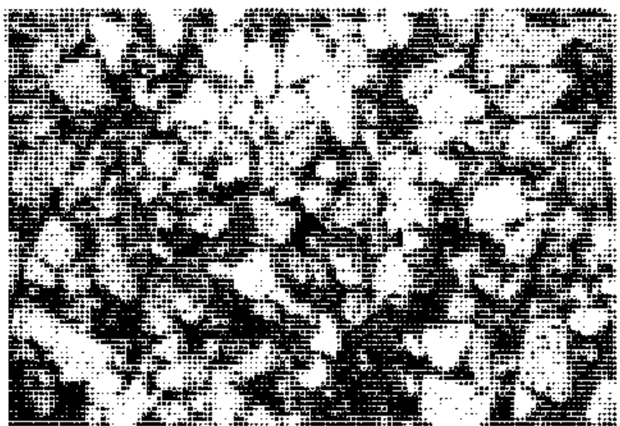

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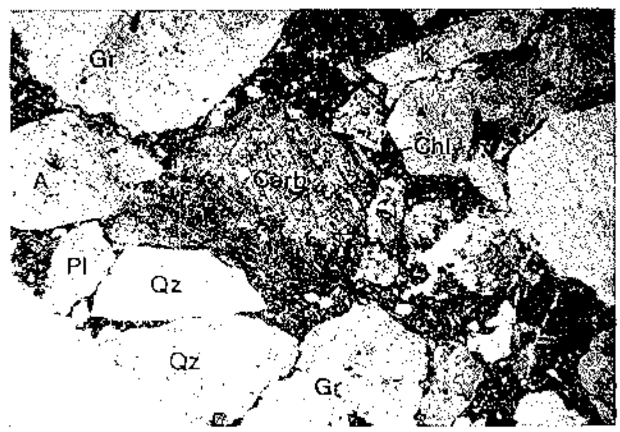

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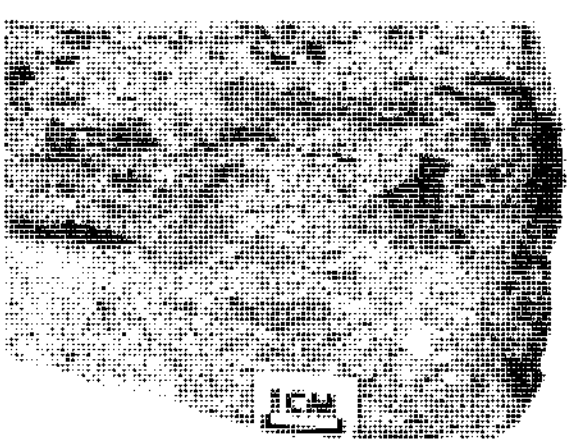

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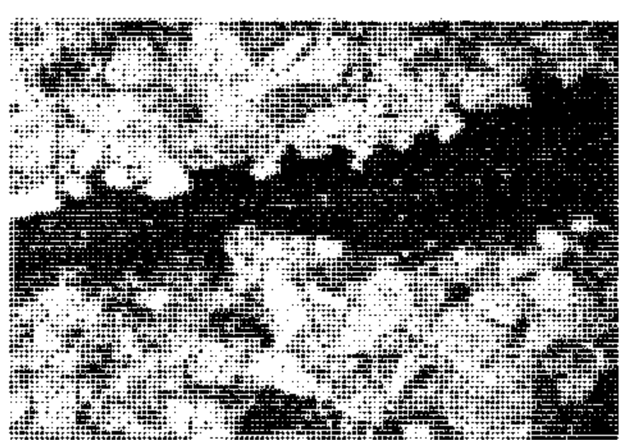

F

Figure 46. Petrographs and photomicrographs of the Kaluweerie Conglomerate (scale bar represents 1 mm except where stated otherwise).

A. 42862. Lithic arenite with ?authigenic pyrite (Py) (plane polarized light).

B & C. 42863. Variety of detrital grains in very coarse lithic arenite: Gr-granite, Carb-carbonate, Qz-quartz, Pl-plagioclase, K-alkali feldspar, A-aplite, Chl-chlorite, Fv-felsic volcanic, Grph-granophyre, M-muscovite, Do-metadolerite (plane polarized light).

D. 42863. Same as C, but with crossed nicols.

E. 42867. Mudstone intraclasts in lithic arenite.

F. 42867. Bedded mudstone intraclast in lithic arenite, showing penetration of quartz grains (plane polarized light).

OTHER POSSIBLE PROTEROZOIC OUTLIERS

Flat-lying, dominantly marine Proterozoic rocks occur west and northwest of Wiluna (140 km north of Kaluweerie Hill) as a southward projection onto the Yilgarn Block. The succession is described by Sofoulis and Mabbutt (1963) as consisting of basalt, argillaceous sediment, thin dolomite beds, and sandstone. An outlier of these rocks at Mount Yagahong is described by Sofoulis and Mabbutt as a sequence of basal conglomerate overlain by 6 m of basalt, 152 m of shale, and 30 m of upper basalt. However, Clarke (1916) and Gibson (1904) had previously considered the material overlying the basal conglomerate to be tuffaceous arkose which might be mistaken in hand specimen for fine-grained greenstone. Re-examination by the present authors of thin sections described by Gibson and Clark showed them to be very similar in mineralogy and texture to the fine and medium-grained lithic arenite from the Kaluweerie Hill area.

Field checking at Mount Yagahong and adjacent outliers revealed a sequence consisting of a basal conglomerate and lithic arenite similar in lithology to the Kaluweerie Conglomerate. It ranges in thickness from a few metres to more than 30 m and is overlain by about 120 m of dark-grey laminated shale and mudstone, which is in turn overlain by more than 40 m of arenite and lithic arenite. In most of the outliers only the basal unit is preserved.

The Proterozoic outlier at Mount Lawrence Wells (Fig. 43, inset) consists of 30 m of arkose unconformably overlying Archaean granite. The arkose contains blocks of white quartz and is overlain by 10 m of chert-breccia which is possibly a silicified dolomite.

A small area of conglomerate near Laverton is lithologically similar to that in the Kaluweerie Hill area and probably represents a similar continental environment. The variety of clasts is similar, with the addition of several boulders of limestone. The exposure, which is 3 m thick, overlies deformed Archaean conglomerate, although no contact is visible.

EVIDENCE OF AGE

Evidence for the Proterozoic age of the Kaluweerie Conglomerate is largely circumstantial. The exact contact with the underlying late Archaean granitic rocks is not exposed but must be unconformable because of the undeformed, unmetamorphosed, and subhorizontal nature of the sediments. The conglomerate is also younger than the post-granite mafic dykes which are generally regarded as being about 2 400 m.y. old.

In the field and in thin section the Kaluweerie Conglomerate is similar to the basal unit at Mount Yagahong, and is considered to be its stratigraphic equivalent. The age of the Mount Yagahong rocks has not been clearly established, but similarities between the upper part of the sequence and rocks within the main part of the Proterozoic basin to the northwest suggest an Early to Middle Proterozoic age. The stratigraphic relationship between Mount Lawrence Wells and the other outliers is not known.

The possibility that the conglomeratic outliers are Permian fluvioglacial deposits of the type that occurs in the Officer Basin to the east can be ruled out. Unlike the Kaluweerie Conglomerate the Permian conglomerates have a large proportion of clay and silt in the matrix and are probably tillites. Permian fluviatile conglomerates, which are not common, are characterized by a predominance of quartz clasts with minor exotic rock types. Furthermore, the Permian rocks are poorly indurated, usually strongly kaolinized, and generally lack authigenic pyrite and carbonate.

REGIONAL SIGNIFICANCE

Proterozoic rocks flanking the northern and northeastern edge of the Yilgarn Block are predominantly marine (Hall and Goode, 1975; Horwitz, 1975). They include ripple-marked sandstones and shales, dolomite, oolitic sandstone, and banded iron-formation, and minor conglomerate, intruded by basalt and dolerite sills. The presence of continental detrital sediments in the Kaluweerie Hill area, and possibly at Mount Yagahong and Laverton, indicates an eroding land mass in this part of the Yilgarn Block during Proterozoic times. The subhorizontal attitude of the beds and their lack of deformation illustrate the stability of the shield since then.

The presence of Proterozoic outliers at several places of similar elevation (about 500 m) on the northern Yilgarn Block, along with the uniform elevation of the Proterozoic unconformity along the northern margin of the block suggest that the flatness of the shield is a relic of Proterozoic erosion and not related to more recent peneplanation. The coarse, immature continental deposits in the Kaluweerie Hill area and at Mount Yagahong may represent the last phase of high energy degradation of the Archaean rocks prior to peneplanation and marine transgression from the north.

URANIUM POTENTIAL

Carnotite uranium mineralization has been detected in rotary percussion drilling in weathered Kaluweerie Conglomerate west of Kaluweerie Hill. Although the conglomerate is adjacent to Cainozoic calcrete containing minor carnotite, it seems likely that the conglomerate mineralization is Proterozoic in age and possibly of placer type. Although of no economic significance here, potential for economic accumulations elsewhere in the region is evident.

The occurrence of uranium in the Kaluweerie Conglomerate suggests a source other than Archaean granites for the uranium deposits in Cainozoic calcretes. Although granite seems the likely ultimate source, concentration of uranium in basal Proterozoic platform sediments during erosion of the Yilgarn Block is a possible precursor to deposition in Cainozoic calcrete following erosion of the Proterozoic. It is noteworthy that the Yeelirrie uranium deposit lies in calcrete between Kaluweerie Hill and the Proterozoic outliers near Wiluna, in an area which was almost certainly covered by Proterozoic sediments.

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STRIATED AND FACETED BOULDERS FROM THE TUREE CREEK FORMATION – EVIDENCE FOR A POSSIBLE HURONION GLACIATION ON THE AUSTRALIAN CONTINENT

by A. F. Trendall

ABSTRACT

A small proportion of the fine-grained sandstone and acid volcanic clasts in a conglomerate with scattered boulders (a mixtite) near Meteorite Bore (lat. 22°50'30"S, long. 117°02'30"E) are faceted and striated in a manner strongly suggestive of a glacial origin. The mixtite occurs within the Turee Creek Formation of the Wyloo Group, which is the uppermost of three groups of the Mount Bruce Supergroup, the formal stratigraphic name applied to the contents of the Lower Proterozoic Hamersley Basin. The siltstone matrix of the boulders is strongly cleaved, concordantly with the structural position of the locality, but the clasts themselves do not appear to have been significantly deformed. The occurrence of possible glacigene rocks within a sedimentary sequence with an age about 2 000 m.y. on the Australian continent invites comparison with glacigene rocks of similar age in the Huronian of Canada and in the Transvaal Supergroup of southern Africa, but no confident correlation can be made on the basis of presently available data.

INTRODUCTION

In 1962, in the course of his field mapping in the southwestern part of the Mount Bruce 1:250 000 Sheet area, Mr. L. E. de la Hunty drew my attention to exposures of conglomerate, near Meteorite Bore, which he considered on lithological grounds might be glacigene. Through lack of more specific evidence this possibility was not mentioned in his published notes on the area (de la Hunty, 1965, p. 17), or in contemporaneous derivative work (MacLeod and others, 1963, p. 50; MacLeod, 1966, p. 56); nor has any reference to it been published subsequently.

In 1975 a convenient opportunity arose to revisit the exposures briefly. Mr. J. G. Blockley and I spent a short time searching for boulders which might provide stronger evidence of a glacial association; several were found and collected. A brief early record of these boulders, which is provided in this paper, seems justified by their possible significance both for the interpretation of the Proterozoic development of the northwestern part of the Australian continent, and for intercontinental Proterozoic correlation. During 1976 it is planned to revisit the locality to collect data for the more complete description which its potential importance warrants.

REGIONAL STATUS AND SETTING OF THE TUREE CREEK FORMATION

The Turee Creek Formation is the lowermost unit of the Wyloo Group, which is the uppermost of the three constituent groups of the Mount Bruce Supergroup (MacLeod, 1966) of the Hamersley Basin. This Proterozoic, initially intracratonic, basin occupied the area now lying between the approximate latitude and longitude limits 20 to 25°S and 116 to 122°E about 2 300 to 1 800 m.y. ago.

The name Wyloo Group was first published by MacLeod and others (1963), but they emphasized the provisional nature of their named subdivisions. Halligan and Daniels (1964) used virtually the same names, but for authority referred to de la Hunty's Explanatory Notes on the Mount Bruce Sheet area, then in press. However, de la Hunty (1965) stated that his subdivision, set out below, was provisional:

Wyloo Group	Ashburton Formation Duck Creek Dolomite Mount McGrath Formation Beasley River Quartzite Turee Creek Formation

No type sections or areas were subsequently established for any of these units, and although their publication and widespread acceptance have conferred on them effective validity, this omission creates difficulties for subsequent stratigraphic work.

The stratigraphy of the two lower groups of the Mount Bruce Supergroup, the Fortescue Group and the Hamersley Group, is consistent with their deposition, largely as volcanogenic and chemogenic material respectively, in a developing intracratonic basin. The mainly terrigenous clastic material of the Wyloo Group is thought to have accumulated in a deeper arcuate trough which developed along the southern and western edges of the earlier basin, over a length of over 600 km (MacLeod, 1966). The Turee Creek Formation forms a recognizable unit over some 250 km of the southern part of this arc, as well as in a few synclinal outliers in the central part of the basin. It has been separately distinguished only in the Wyloo (Daniels, 1970), Mount Bruce (de la Hunty, 1965), and Turee Creek (Daniels, 1968) 1:250 000 Sheet areas. Its thickness in these areas is reported to range between about 37 m (120 ft) and "several thousand feet", and it is described as including a variable succession of greywacke, shale, dolomite, quartzite, and conglomerate (MacLeod, 1966).

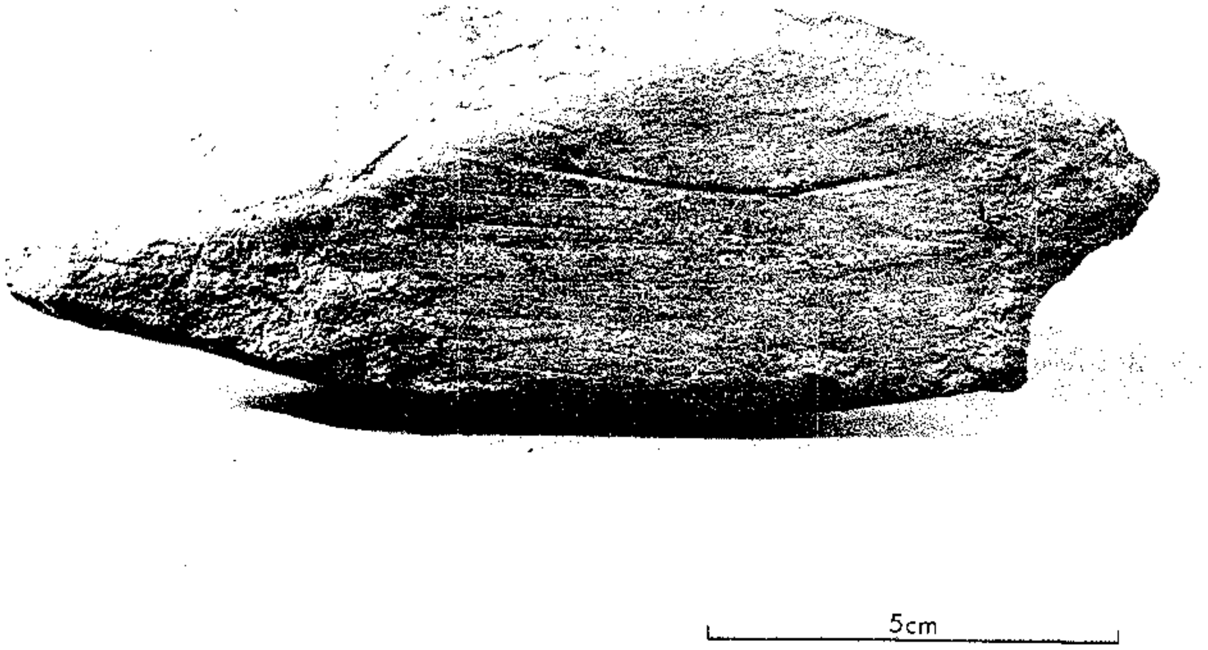
On a regional scale the contact between the Hamersley and Wyloo Groups along the southern and western edges of the basin is a line of general structural discordance. Despite this, wherever the top of the uppermost unit of the Hamersley Group, the Boolgeeda Iron Formation, is well exposed, there appears to be a conformable upward transition from its dark magnetic banded iron-formation into siltstone of the Turee Creek Formation. However, the recent denudational history of the area is such that only a small thickness of siltstone is ever visible in such situations, and an exposure gap invariably precludes certainty that no major stratigraphic discordance is present at some higher level within the Turee Creek Formation. Certainly at one locality along the contact between the Hamersley and Wyloo Groups both the Turee Creek Formation and the Boolgeeda Iron Formation are missing from the succession (Trendall and Blockley, 1970, p. 34), so that local discordance, or nonsequence, within the Turee Creek Formation would not be surprising.

MIXTITE NEAR METEORITE BORE

STRUCTURAL AND STRATIGRAPHIC SITUATION

Meteorite Bore lies near the southwestern corner of the Mount Bruce 1:250 000 Sheet area (de la Hunty, 1965), at lat. 22°50'30"S, long. 117°02'30"E, on the broad alluvial plain of the Beasley River. A low unnamed hill about 1 600 m long (east-west) and 800 m wide rises 10 to 20 m above the plain to the northeast of the bore, with its southwestern foot about 1 km distant.

Disregarding the Cainozoic alluvium and colluvium, the hill lies centrally within the mapped outcrop of the Turee Creek Formation, on the north-dipping southern limb of a westerly plunging syncline, known as the Hardey Syncline; this forms a continuously recognizable structure for a strike length of at least 50 km in this area (MacLeod, 1966). Although poor local exposure and the effect of deformation jointly prevent determination of the bedding dip, the probable outcrop width of the Turee Creek Formation of about 3 km, coupled with an expectation of steep dip from regional structural consideration, makes it likely that the formation is at least 1 km thick in this vicinity.



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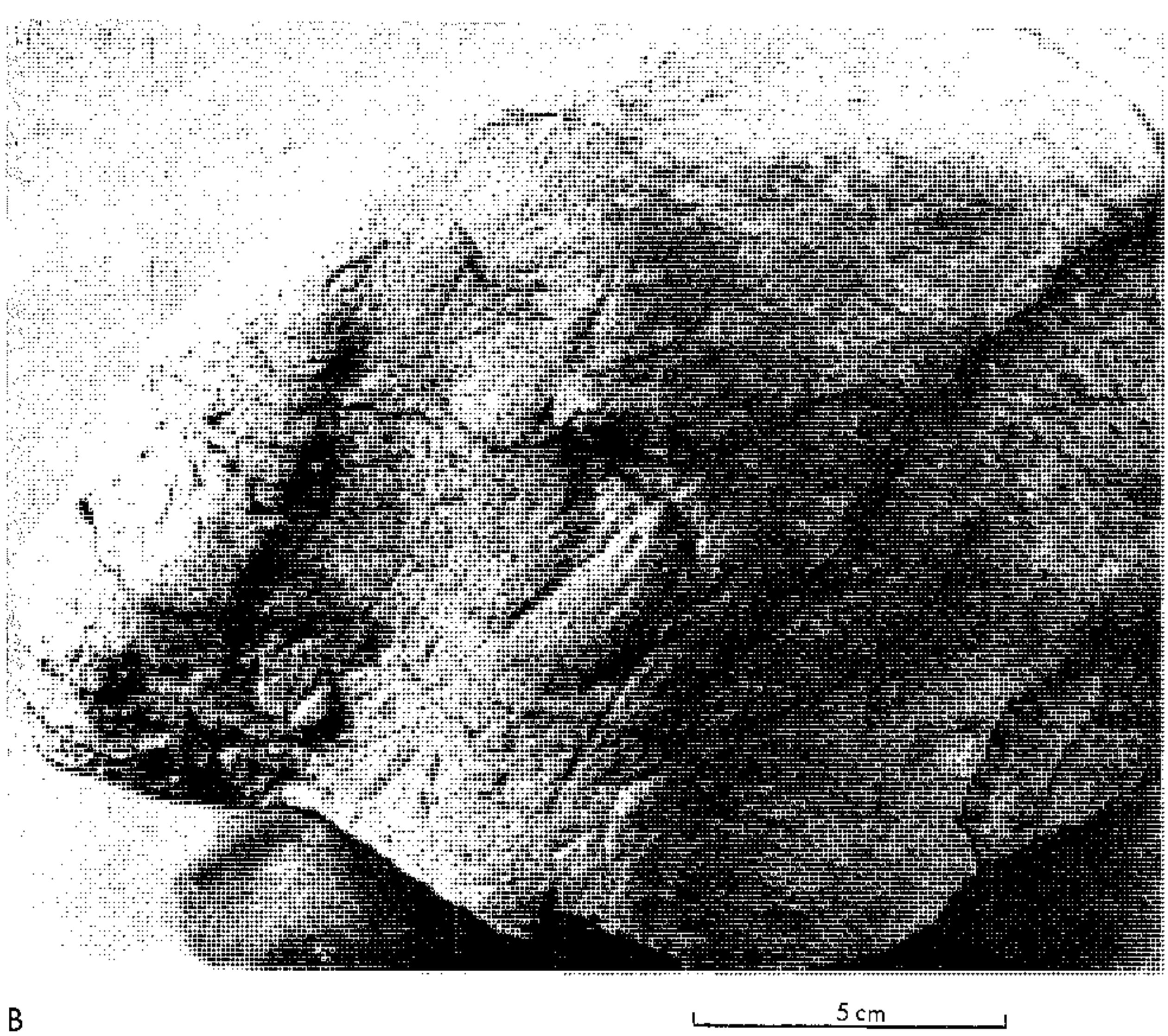

B

Figure 47. Two striated boulders from Meteorite Bore.

A. Small flat, striated clast of fine-grained sandstone, about 15 x 5 x 1 cm. The illustrated face bears a deep groove, curved through about 30°, superimposed on a set of straight, sub-parallel, finer striae along the mean direction of the curve. There is a deep equant indentation just above the deep curved groove near its left-hand end. Note that striae are parallel to the longest axis of the clast. Part of the upper left-hand edge appears tectonically fractured and slightly displaced. GSWA 42180A.

B. Part of a large boulder of fine-grained sandstone, about 20 x 25 x 15 cm. Although this boulder is well rounded, a shallow curved re-entrant face at one end, and its adjacent shoulders, are screened by short grooves in divergent directions along the direction of the face GSWA 42180G.

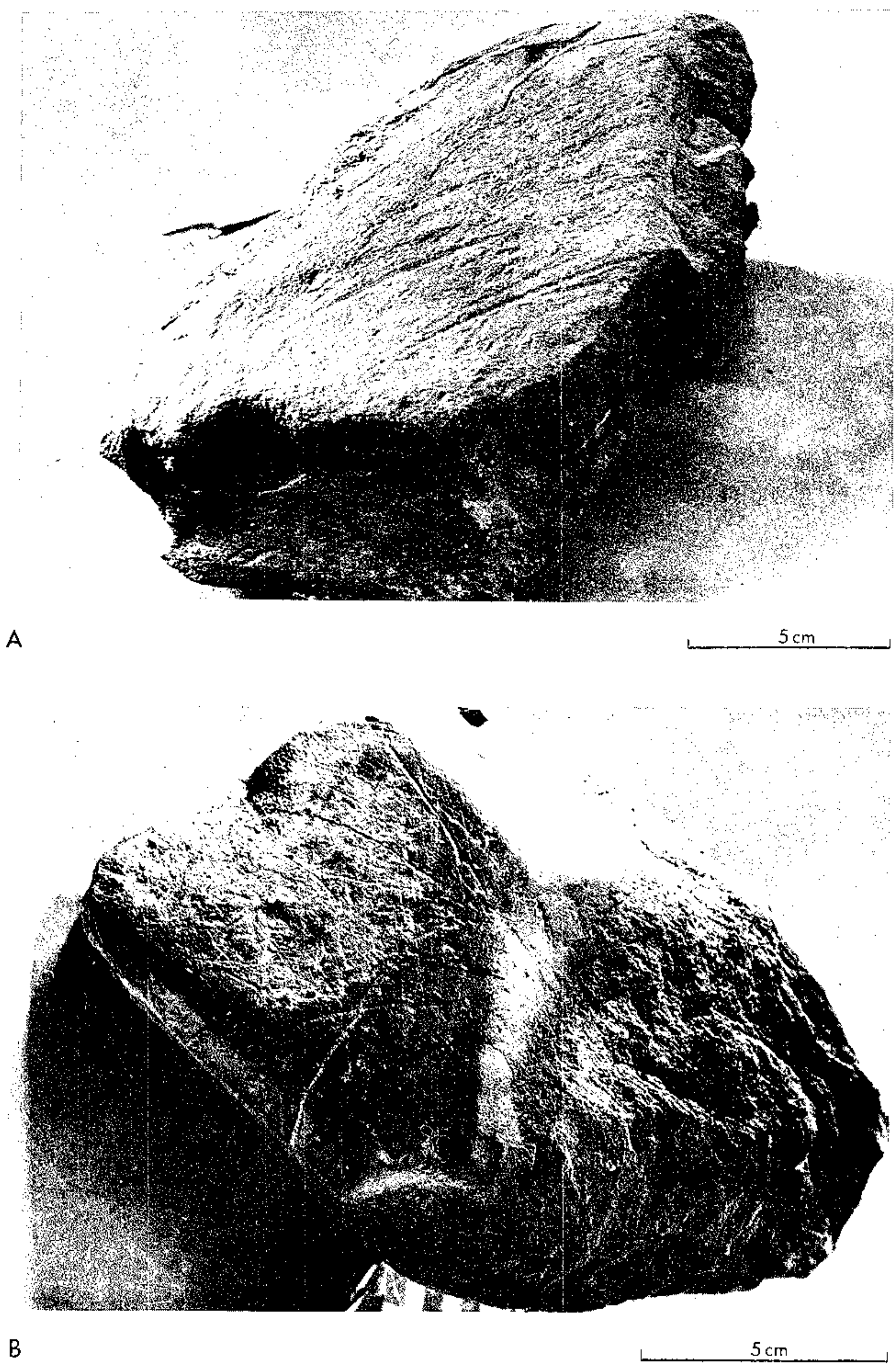

Figure 48. Two striated boulders from Meteorite Bore.

A. Flat, elongate boulder of fine-grained sandstone, about 20 x 10 x 5 cm. The illustrated top face has two deep, slightly curved, sub-parallel grooves with an asymmetric cross-section. GSWA 42180E.

B. Boulder of asphanitic, pale green, acid volcanic rock, about 15 x 10 x 7 cm. Three flat faceted faces met to define a corner in the upper centre of the photograph. The face below and to the left of this corner bears many short straight grooves in widely divergent directions. GSWA 42180B.

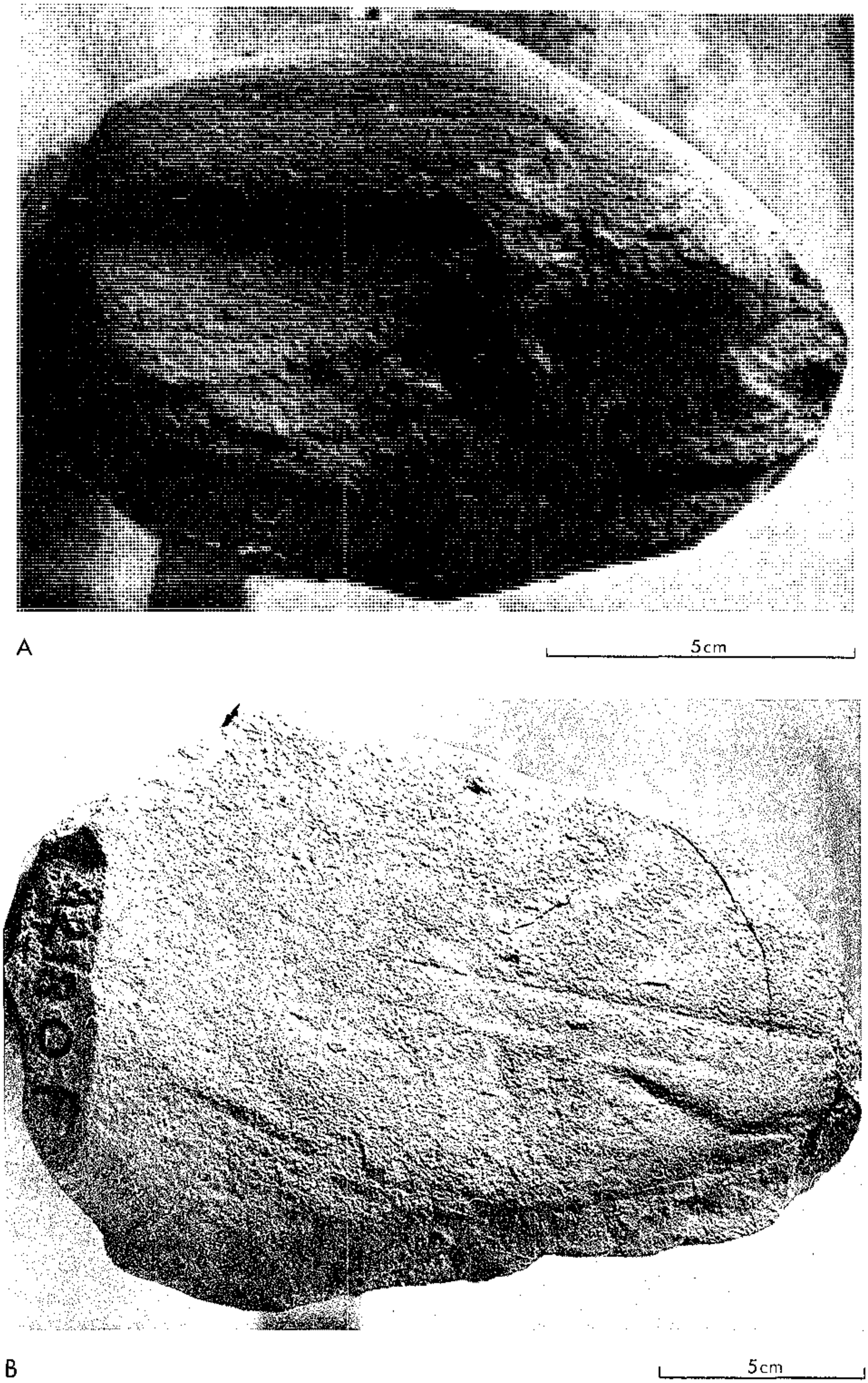

Figure 49. Two striated boulders from Meteorite Bore.

A. Flat, elongate boulder of fine-grained sandstone, about 14 x 10 x 4 cm. Many striae over the "stepped" face illustrated are generally sub-parallel, and are along the length of the clast, but a less well developed set cuts across these at about 30°, from upper left to lower right. GSWA 42180A.

B. Flat, elongate boulder of fine-grained sandstone, about 20 x 12 x 3 cm. By contrast with the many fine striae of boulder in A, above, the face shown bears only a few deep sub-parallel grooves. The longest of these is a multiple groove. GSWA 42180F.

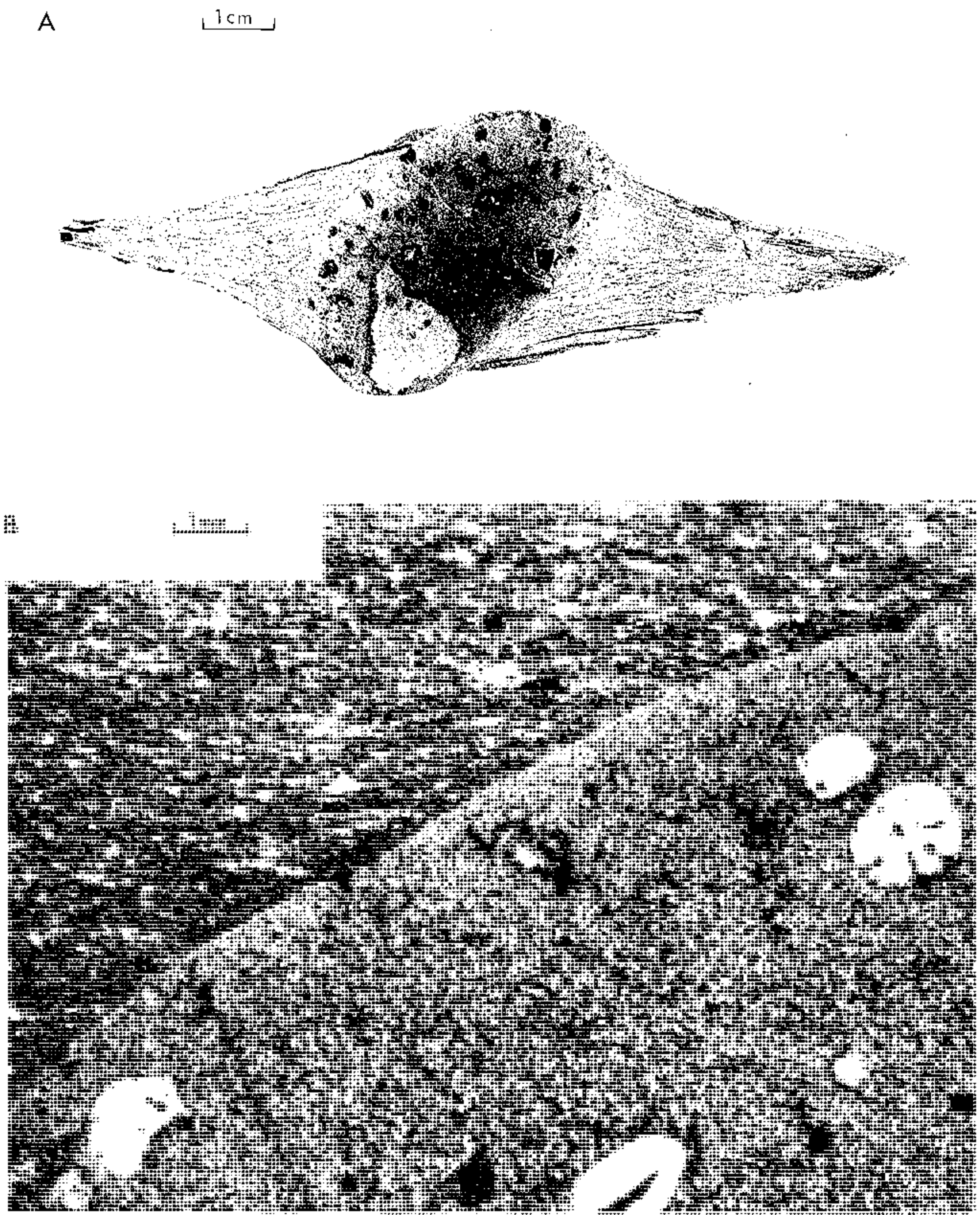

Figure 50. Cross-sectional appearance of a clast of porphyritic acid volcanic rock from Meteorite Bore. GSWA 42180A.

A. Sawn and smoothed cross-section showing the sharply defined edges of the rounded clast, with its adherent fringe of strongly cleaved siltstone.

B. Thin-section of a part of the boundary, showing the abrupt termination of the cleavage at the edge of the clast. Many sand-size grains of quartz lie within the matrix siltstone. Embayed phenocrysts of B-quartz lie in the undistorted mosaic of the clast, the margin of which is slightly modified.

LITHOLOGY AND STRUCTURAL EFFECTS

Mixtite (Schermerhorn, 1966) is well exposed over the slopes of the hill. Clasts, ranging from boulders over 1 m long down to pebbles a few millimetres across, are sparsely and randomly distributed in a matrix of greenish-brown siltstone; few, if any, of the clasts appear to be in direct contact. Primary bedding is not confidently identifiable, possibly due to a well-developed, near-vertical cleavage, penetrative in the matrix (Fig. 50), striking approximately east-west and clearly subparallel to the axial plane of the Hardey Syncline; however, east-west zones of apparently variable clast-type distribution may have a primary origin. The stress which imposed the strong penetrative cleavage of the matrix clearly had no structural effect on the more massive boulders (Fig. 50), but may have affected some of the others: the flat sandstone clast shown in Figure 47A appears to have been fractured at one edge, with some displacement of the broken part.

BOULDERS FROM THE MIXTITE

GENERAL CHARACTERS

During the brief visit on which this paper is based, attention was directed almost exclusively to boulders having a greatest dimension in the approximate size range 5 to 50 cm. In addition to those *in situ* the slopes of the hill are abundantly scattered with boulders clearly derived from the nearby bedrock. Many of these have a circumferential flange of adherent matrix in the plane of the cleavage, so that in total shape they form discs with swollen centres, reminiscent of the ringed planet Saturn (Fig. 50A).

The boulders consist mainly of fine brown sandstone, a lesser proportion of acid volcanic rock, and rare examples of carbonate and quartz. Most of the sandstone boulders have flat tabular shapes, with the ratio of least to greatest diameters as much as 1:10; in a projection parallel to the least diameter the outlines of such flat boulders may be either equant or as elongate as 1:3. However, some sandstone boulders, and all boulders of acid volcanics, have generally equant shapes. With the exception of the faceting and striation described below, the boulders are well rounded, with smooth surfaces. The flat boulders are generally aligned in the plane of the cleavage, and at least some have their longest axes oriented near vertically.

FACETING AND STRIATION

Although most of the acid volcanic clasts are equant and well rounded some have smooth flat faces separated by comparatively abrupt, but nevertheless smoothly bevelled, edges (Fig. 48B): they have the faceted shapes commonly described as characteristic of till stones (Pettijohn, 1957, Pl. 14). Most of the tabular sandstone clasts naturally also have two similarly flat faces, although the term "flat" here includes convex surfaces with large radii of curvature.

Certain of the boulders of the mixtite, both of sandstone and of acid volcanic rock, have surface striations, or grooves. No systematic count was made of the proportion so marked, and this would be difficult, since judging striation is for practical purposes subjective, and there is also the problem in the case of the loose boulders of assessing the effect of weathering; however, it is likely that the proportion of striated clasts lies between 1 and 5 per cent.

Striae occur mainly on flat faces, but also extend onto some rounded surfaces (Fig. 47B). They range in depth from about 1 mm to the lower limit of confident identification at about 0.1 mm. The longest continuous groove noted is 10 cm long, while the shortest ones amount to little more than slightly elongate indentations (Fig. 47A). In relation to the size of the faces on which they lie most striae seem to persist for about half the available length. Most grooves terminate gradually at each end, but a few have one abrupt termination. The majority of grooves are insufficiently well developed to show a clear cross-sectional shape, but some, which clearly depart from the simple symmetrical U-shape or V-shape which may be expected, are variously flat-bottomed, clearly asymmetrical (Fig. 48A), or are themselves more finely striated internally (Fig. 49B).

The striae are mainly straight, but may be curved (Fig. 47A). The most sharply curved groove observed has a 30° difference in direction from end to end, with a radius of curvature of about 15 cm; the direction of curvature is consistent in any one groove. Striae may occur either singly, or in subparallel sets (Figs 47A, 48A, 49A); such sets may include a large number of comparatively shallow and closely spaced striae, or may be made up of only a few deep widely separated grooves. More than one set in different directions, and single grooves in several widely divergent directions, may be present on a single face (Figs. 48B, 49A). Wherever a set of parallel grooves is present on the face of a markedly elongate platy boulder the grooves invariably diverge little in direction from the longest diameter of the boulder (Figs. 47A, 49A).

PETROGRAPHY OF MATRIX AND BOULDERS

In thin section the siltstone matrix appears as poorly sorted on a small scale as does the mixtite as a whole on a larger scale. There is a fine-grained quartz-sericite-chlorite groundmass in which the smallest quartz grains that can be accepted as clastic with reasonable confidence are about 0.05 mm across; the slightly finer quartz mosaic, which is closely intergrown with subparallel chlorite and sericite flakes of about the same size, appears to have been substantially recrystallized in response to the stress which imposed the cleavage. Within this groundmass lie gradationally larger angular, subangular, and rounded grains of quartz, both polycrystalline and monocrystalline. These are as large as 1 mm across, and all have their longer axes arranged parallel to the cleavage (Fig. 50A). Some of the larger grains are recognizably of acid volcanic rocks like those of the boulders. All the siltstone samples collected have abundant disseminated rhombs of carbonate, mainly 0.01 to 0.05 mm across, which are mainly weathered to goethite; this accounts for the brown colouring of the rock.

The fine sandstone of the boulders differs from the matrix siltstone in grain size, in sorting, and in grain composition. The estimated modal grain diameter is between 0.1 and 0.2 mm, so that the rock is close to the lower limit of sandstone grain size. Closely packed sharply angular and subangular grains close to this size form the bulk of the rock, the interstices being filled by a fine-grained quartz-sericite-chlorite groundmass similar to that of the matrix siltstone. Unlike that matrix, there is no scattering of conspicuously larger grains, but there is a resemblance to the enclosing siltstone in that the sericite and chlorite flakes of the groundmass, and the longer axes of elongate grains, have a preferred subparallel orientation. This direction is less strongly developed than in the siltstone, and in platy boulders is parallel to both the elongation of the boulder and to the cleavage outside. Some thin sections of the sandstone boulders bear disseminated carbonate rhombs like that of the siltstone matrix, whilst others do not.

It is evident that the preferred orientation of the sericite and chlorite of the matrix has developed as an axial-plane structure in response to stress associated with folding. However, it is at present not clear whether the similar orientation within the sandstone clasts represents a related structure, or was present, possibly as a diagenetic bedding-plane structure, before disruption of the parent strata.

The original mineral composition of the boulders of acid volcanic rocks appears in thin section to have suffered substantial modification, but there is no sign that this has been effected by stress, and it seems more likely that this alteration took place within the body of the rock before its fragmentation. There is a general matrix of even-sized but irregularly sutured quartz mosaic, of average grain diameter about 0.1 m, the detailed texture of which is concealed by abundant random flakes of pale green sheet silicate less than 10 microns across. The rock was probably a rhyolite with snowflake texture (Snyder, 1962; Torske, 1975) in which the original alkali feldspar is now texturally represented by sheet silicate. Only the evenly scattered embayed and rounded phenocrysts of clear quartz (Fig. 50B) provide a clear indication of the real identity of this rock; they are mostly 1 to 2 mm in diameter but some are as large as 3 mm. Subrectangular and rounded areas of the same order of size, occupied by microcrystalline sericite, presumably represent degraded feldspar phenocrysts.

DISCUSSION

AGE OF THE MIXTITE

The total available isotopic evidence for the age of the Mount Bruce Supergroup has recently been reviewed by Trendall (1976). As far as the Wyloo Group as a whole is concerned a younger depositional limit of 1 720 m.y. is provided by the Boolaloo Granodiorite, which intrudes the group farther west (Leggo and others, 1965). A younger limit for the sediments adjacent to the Woongarra Volcanics, probably at least 500 m stratigraphically below the mixtite near Meteorite Bore, is given by their reported age of 2 000 m.y. (Arriens, 1975); this age is described as defining a younger limit because these acid volcanic rocks are now thought to be intrusive rather than extrusive (de Laeter and others, 1974, p. 91). Only wide limits can be placed on the oldest possible depositional age of the mixtite. If the Black Range dolerite (Lewis and others, 1975) represents a feeder for Fortescue Group lavas, then its deposition cannot be older than about 2 300 m.y.

A key point concerning the age of the mixtite is the provenance of the acid volcanic clasts. These resemble rocks of the Woongarra Volcanics, and no other local source of such rocks is known. If they were so derived, then a much smaller older limit, of 2 000 m.y is placed on mixtite deposition.

ORIGIN OF THE MIXTITE

Over the last decade a substantial body of literature concerned with the interpretation of pre-Pleistocene till-like sedimentary rocks has appeared, under the especial stimulation of a paper by Schermerhorn and Stanton (1963), in which a non-glacial, gravitational flow origin was advocated for Precambrian rocks from western Africa, possessing many of the features formerly widely accepted as characteristic of glacigene sediments. Harland and others (1966) have provided an objective review of the relevant work to that date, while Spencer (1971), in the most detailed published description of any single occurrence of Precambrian glacigene mixtite, in the Dalradian of Scotland, has also critically analyzed the interpretation by Schermerhorn and Stanton (1963) of their African sequence, which has strikingly close similarities to the Dalradian example.

Many of the criteria that can contribute to the judgement of whether any given deposit is glacigene involve an assessment of its regional stratigraphic extent and relationships. The restricted information given in this brief record of the mixtite at Meteorite Bore does not justify a full analysis of the evidence for its origin; this section of the discussion is therefore restricted to brief comment on the likely significance of the striated boulders.

There appear to be only three possible origins for the striations described: they may have been produced by some effect associated with glaciations, by some mechanism of non-glacial flow, or by tectonic means during folding.

The third possible origin is here rejected immediately, for two reasons. Firstly, if the striation is tectonic, it is hard to see why only a small proportion of the boulders are striated: many of the boulders have a similar lithology, shape, orientation, and matrix, but comparatively few bear striae. Secondly, it is even more difficult to conceive of any tectonic process, even if selective for no clear reason, which could produce widely divergent intersecting sets of striae.

Although striations are known to have been produced by non-glacial mass movement or by other forms of boulder transport (Kayser, 1923), Harland and others (1966, p. 247) nevertheless believed that "Striations are so definitive, under the proper conditions, that when present they can be one of the most important criteria for glaciation". Also, there is no published record so far of the occurrence of abundant striated clasts closely similar to those of a glacigene deposit in a non-glacigene one. Of all the criteria listed by Schermerhorn and Stanton (1963) the presence of striated (and faceted) stones was the one they found most difficult to explain in a supposedly non-glacial rock, and they were forced to suggest that the striated siltstone cobbles which they described were scratched in a slide or slump while they were soft. For the siltstone boulders from Meteorite Bore, as for those described from western Africa by Schermerhorn and Stanton (1963), it seems hard to imagine that a siltstone sufficiently lithified and brittle to break into quite large coherent flat slabs would at the same time be sufficiently soft to be exceptionally susceptible to striation. Certainly at Meteorite Bore the presence of striated volcanic clasts discounts this argument; in any case, for the softer rocks to be more commonly striated is consistent with known glacial deposits (Wentworth, 1936).

It is not yet certain whether the flat slabby siltstone boulders at Meteorite Bore are so shaped through tectonic deformation, although the preservation of surface markings in strongly deformed clasts would surely be remarkable (cf. Spencer, 1971, p. 63-5); it seems more likely either that the initially random slabs have been rotated to near parallelism during folding, or that the slabs lay close to the bedding plane, which may in turn at this locality be close to the axial plane cleavage.

Trendall and Blockley (1970, p. 296) have specifically suggested the local collapse of lately deposited parts of the Hamersley Group southwards into the developing depositional trough of the Wyloo Group to explain local stratigraphic discordance at its base, and the presence of conglomerates within the Wyloo Group. Meteorite Bore lies within the general area to which this suggestion would refer, and perhaps the origin of the described boulders should be sought in such a mechanism. But the possibility of a glacial origin for these clasts is sufficiently strong for a brief examination of some of its consequences.

POSSIBLE INTERCONTINENTAL CORRELATION

In an earlier review paper Trendall (1968) compared the banded iron-formations of the Hamersley Range area of Western Australia with those of the Lake Superior ranges and those of the northern Cape Province and Transvaal areas of South Africa, in terms of the total geological environment of each. For this purpose the iron formations were considered to have been deposited in three major basins of similar, but not necessarily the same, age: the Hamersley Basin, the "Animikie Basin", and the "Transvaal System Basin". Both of these two latter terms were applied with stated reservations concerning their real validity. Partly to avoid confusing detail no reference was made to possible glacigene rocks as a feature requiring specific comparative comment, and this omission is here rectified.

For the "Animikie Basin" Trendall (1968, p. 1531) chose to simplify stratigraphic complications by suggesting that the deposition of the type Huronian rocks took place in a structurally separate basin from that in which the Animikie iron formations were laid down. Young (1973) has more recently summarized the occurrence of tillites in the Lower Proterozoic (Aphebian) of north America, and has re-emphasized his earlier contention (Young, 1966) that a correlation of the Fern Creek Formation (Pettijohn, 1943) of Michigan with the Huronian Gowganda Formation is consistent with both the stratigraphic and the isotopic age evidence. Roscoe (1969, p. 113), on other grounds, nevertheless agreed with Young that the iron formations of the Lake Superior ranges are likely to be younger than the type Huronian. If this view is accepted there exists, in the regional stratigraphy of the Lake Superior-Lake Huron area, a broad transition from glacigene and other clastic sedimentation to the chemical deposition of iron formation. The available isotopic evidence from this area (Van Schmus, 1965; Fairbairn and others, 1969) sets approximate limits of 2 100 to 2 500 m.y. for the time of this glaciation, with a most likely age about 2 300 m.y.

Young (1973) referred to glacial deposits of age comparable to the Huronian in the Witwatersrand System (= Supergroup of Wagener, 1972) of South Africa, and cited as authorities papers by Wiebols (1955) and Fuller (1958). These have mixed significance. The criteria used by Wiebols to argue an important glacial contribution to the deposition of all the major conglomerate horizons of the Witwatersrand Supergroup were largely general stratigraphic ones, and some of the specific criteria put forward to support his argument, for example the supposed presence of varves, were fairly certainly invalid (Truter, 1955). Other important criteria now regarded as critical, such as large penetrating dropped stones (Harland and others, 1966) were not described; in this respect it is surprising that Wiebols did not refer to the earlier description by Rogers (1922, p. 20) quoted in full by Fuller (1958), of a 25 ft (7.6 m) thick tillite within the Government Reef Series (= Hamberg Formation of Wagener, 1972) containing randomly scattered boulders, some of which are well striated and flattened on one or more sides. Du Toit (1954, p. 80) mentioned other, thicker, occurrences of similar material at the same stratigraphic level. However, no emphasis is currently placed on glaciation as a factor in the sedimentology of the Witwatersrand Supergroup (Pretorius, 1975), and it is not possible from published literature to determine whether, and if so, why, the evidence noted by Rogers (1922) has been reinterpreted. Hunter's (1974, p. 297) recent summary of the isotopic age evidence for Witwatersrand Supergroup deposition suggests limits of 2 340 to 2 720 m.y. so that Young's (1973) implied equivalence with the Huronian is possible within the approximate time span 2 300 to 2 500 m.y.

An alternative African equivalent, however, seems to be the tillite of the Transvaal Supergroup. This was first discovered, and very well described, by Rogers (1906, p. 162-4) from the northern Cape Province. Du Toit (1954, Pl.VII, 2) has illustrated two convincingly striated stones from it, and has summarized its occurrence at the same stratigraphic level, close below the Ongeluck Volcanics and above the main banded iron-formations, in both the northern Cape Province, where he refers to it as the Griquatown Tillite, and in the Transvaal, where it was called the Glacial Band at the base of the Ongeluk Quartzite of the Daspoort Group. In later stratigraphic reviews De Villiers (1967) and Truswell (1967) have amended the earlier nomenclature somewhat, but both these reviewers concur that the Transvaal Supergroup tillites have the stratigraphic status and extent as described by Du Toit. Hunter's (1974, p. 297) geochronological summary indicates that the Transvaal Supergroup has age limits of 1 950 to 2 340 m.y., which is consistent with a direct age of 2 220 m.y. for the Ongeluk Volcanics immediately overlying the tillite. This is once again within the Huronian limits.

A direct correlation of the Transvaal Supergroup tillites, overlying the main banded iron-formations, with the possible tillite at Meteorite Bore, above the banded iron-formation of the Hamersley Group, has obvious attraction. But if the acid volcanic clasts from Meteorite Bore are derived from the Woongarra Volcanics, and if these are 2 000 m.y. old, then apparently this correlation must be rejected. A close scrutiny of the isotopic data (not all published) may reveal a possibility that the Huronian and Transvaal Supergroup tillites were deposited coevally with the Meteorite Bore mixtite, perhaps at about 2 250 m.y., but from the total information now available it is impossible to verify such a hypothesis with acceptable confidence.

ACKNOWLEDGEMENTS

It is appropriate to emphasize my indebtedness to Mr. L. E. de la Hunty for introducing me to the Meteorite Bore exposures; to him must go the credit both for their discovery and for initial recognition of their probable glacial association.

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THE SADDLEBACK GROUP – A NEWLY DISCOVERED ARCHAEAN GREENSTONE BELT IN THE SOUTHWESTERN YILGARN BLOCK

by S. A. Wilde

ABSTRACT

A previously unrecorded 5 to 12 km wide sequence of weakly metamorphosed sediments, felsic and mafic volcanic and pyroclastic rocks extends for 43 km north-northwest from Mount Saddleback, near Boddington, to Mount Wells. This sequence is herein formally named the Saddleback Group and is subdivided into the Hotham, Wells and Marradong Formations. The rocks are poorly exposed and extensively faulted. Contacts with adjacent Archaean granitic rocks are largely fault-controlled, although adamellite intrudes all three formations in the southwestern part of the belt, near the Hotham River. The Saddleback Group is more closely similar to the greenstone belts of the eastern Yilgarn Block than any other rock units so far described from the southwestern part. It may have developed on a basement composed of earlier, 3 000 m.y old layered Archaean rocks.

INTRODUCTION

During regional mapping of the Pinjarra 1:250 000 Geological Sheet by S. A. Wilde and K. J. B. Hirschberg, a previously unrecorded sequence of metasedimentary and metavolcanic rocks was discovered near Boddington, 110 km southeast of Perth. The rocks occur in a belt trending approximately 160° and are enclosed within Archaean granite, migmatite and gneiss. They constitute the only definite volcanogenic "greenstone" sequence known in the southwestern Yilgarn Block.

The rocks are very poorly exposed and almost entirely covered by Tertiary and Quaternary deposits. Occasional outcrops occur along the major river valleys and in minor drainage dissections of the extensive laterite surface. Even where best exposed, the rocks are largely obscured by soil and colluvium (Fig. 51). Strongly defined lineaments on the air-photographs appear to represent lines of faulting. These bound the greenstone belt in all but the southwestern corner, as well as causing displacement of the major units within the belt (Fig. 51). However, it is possible to trace the main lithologies throughout the extent of the belt and subdivision into formations has been possible.

DEFINITIONS AND FIELD RELATIONS

SADDLEBACK GROUP

The name is derived from Mount Saddleback, the 575 m high summit of a prominent range occurring 19 km south of Boddington. The Saddleback Group consists of a sequence of sedimentary, pyroclastic and volcanic rocks, metamorphosed to greenschist or lower amphibolite facies. The group trends approximately 160° north-northwest from the Murray River, 4 km south of Mount Saddleback, to about 5 km north of Mount Wells—a total distance of 43 km. The width of the sequence varies from 5 to 12km. The group has a steep regional dip to the east and consists of three main mappable units. These have been named, in ascending structural order, the Hotham, Wells and Marradong Formations; there is no direct evidence for true stratigraphic sequence.

East of George Hill, near the Hotham River, even-grained adamellite appears to intrude all three formations. However, the actual contact is only exposed at one locality, 6 km east-southeast of George Hill. The contact zone is about 10 m wide and consists of elongate xenoliths of felsic volcanic rock enclosed in an extremely variable granitic matrix. Irregular areas and veins of adamellite occur within felsic pyroclastic rocks of the Wells Formation for up to 200 m from the contact.

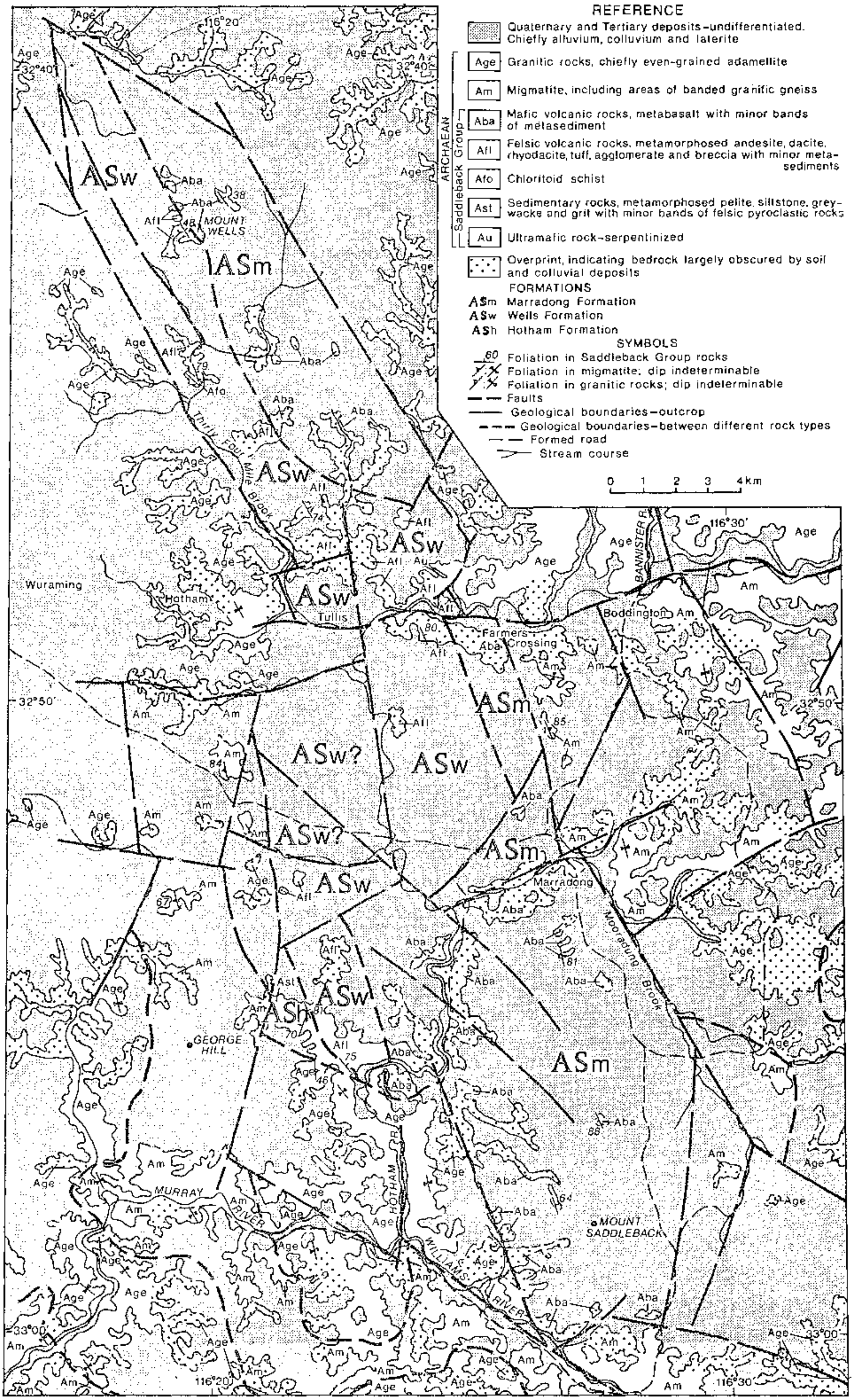


Figure 51. Geological map of the Mount Saddleback-Mount Wells area, showing formations.

Elsewhere, the group is strongly fault-bounded and chiefly margined by even-grained granite/adamellite. Migmatite occurs at places along the eastern, western and southern margins, whilst a strongly banded granitic gneiss adjoins the greenstone belt, 17 km south-southwest of Hotham. The major faults delineating the belt trend 160° and are subparallel to the general foliation trend of the rocks. The eastern boundary fault trending 150° and followed by the course of Mooradung Brook (Fig. 51) is marked by extensive shearing and alteration of the granitic rocks, whilst the major fault along the Williams River is paralleled by two zones of quartz veining. There is little evidence of faulting along the other contacts except for their strong linearity (often followed by stream courses) and the abrupt change in rock-type that occurs. Many later faults trending between 010° and 030° have displaced the boundary of the greenstone belt.

The northern limit of the greenstone belt is poorly defined. A fault trending 110° is postulated, parallel to a present creek (Fig. 51), although there is little evidence for this on the ground. Granitic rocks cropping out 8 km north-northwest of Mount Wells are characterized by a strong, braided, cataclastic foliation with linked quartz grains. Thin bands of mylonite and quartz are also present in these rocks and it appears that a later cataclastic foliation, trending 160°, has been superimposed on an earlier foliation, trending at about 140°. A similar braided foliation occurs in the greenstone belt rocks at Mount Wells and it is possible that the belt pinches out more gradually to the north. However, the total lack of exposure in the crucial area makes any interpretation speculative.

HOTHAM FORMATION

The formation is named after the Hotham River and is exposed on either side of a north-northwest-trending tributary, about 3 km east of George Hill. It consists of 1.6 km (maximum horizontal extent) of well-banded, silty metasediments with minor pyroclastic units. The foliation swings from 140° in the south to 005° in the north. A change in dip from moderate to steep westerly in the southwest to steep easterly in the northeast may be the result of folding. There is a local steep, north-plunging lineation, but no direct evidence of folding was observed. The total thickness of the unit is not exposed since it is fault-bounded to the west and intruded by adamellite to the south. The formation passes conformably into the overlying Wells Formation and the transition is marked by a rapid increase in felsic pyroclastic rocks.

The type area is on a ridge, 4.8 km east-southeast of George Hill. A 60 m wide sequence of grey and cream metasiltstone units ranges from a few millimetres to 20 cm in thickness and trends 141/75° E. A few thin bands containing ovoid lenses and felsic fragments are deformed agglomerate horizons.

An important feature is the presence of thin veins of fine, even-grained granite. These are generally parallel to the banding, but do locally transgress it. The metasiltstones can be traced to the northwest where they are underlain by a poorly exposed sequence of quartz-mica schist, metasiltstone, metatuff and fine-grained metagreywacke. It is often difficult to distinguish the tuffaceous rocks from metasediments.

WELLS FORMATION

The formation is named after Mount Wells, a prominent hill rising to 547 m, 17 km northwest of Boddington. Its maximum thickness is about 5.5 km, although it appears to thin to the south, being only about 2 km thick near the Hotham River. Rocks of the Wells Formation crop out for 32 km along the length of the greenstone belt. They consist of interdeveloped lavas (andesite, dacite and rhyodacite), tuffs, breccias, agglomerates and minor sediments, all variously deformed and metamorphosed. In general, lavas are more abundant in the north around Mount Wells, whilst pyroclastic rocks predominate south of the Bannister River. A further subdivision of the formation, based on the relative abundance of lavas and pyroclastic rocks, may be possible, but exposure is poor and there is insufficient data at present to justify a further breakdown.

Near the Hotham River, the Wells Formation conformably overlies the Hotham Formation and appears to be conformably overlain by the Marradong Formation. At Mount Wells, the junction with the overlying Marradong Formation appears sharp and conformable. There is a fairly abrupt change to metabasalt, although thin bands and lenses of metadacite occur within the basaltic rocks close to the contact. The western contact of the Wells Formation in this northern area appears to be fault-bounded.

The type area is on the western flank of Mount Wells. A 300 m section of metamorphosed dacites and rhyodacites (often porphyritic and schistose), with interbanded tuffs and minor sediments, is exposed in a west-trending gully. The porphyritic lavas contain oval quartz megacrysts up to 2 mm long, together with more diffuse megacrysts of feldspar. The rocks have a general trend of 148/64° E. It is often difficult to distinguish between fine-grained lavas, tuffs and sediments in the field.

Near Thirty Four Mile Brook, 4.6 km south of Mount Wells, schistose porphyritic dacite is underlain by chloritoid schist (trend 158/79° E). The schist is at least 10 m thick, but the base is obscured by laterite. It may represent a tuffaceous or pelitic horizon in the lava sequence.

Pyroclastic rocks of the Wells Formation are reasonably well exposed at Farmers Crossing and near the Hotham River. They consist chiefly of agglomerates, breccias and fine-grained tuffaceous rocks, with associated volcanogenic sediments, some of which are pyritic.

A serpentinized ultramafic rock occurs within the sequence, 4.2 km northwest of Farmers Crossing. It crops out for 50 m and lies subparallel to the volcanic rocks.

MARRADONG FORMATION

The formation is named after the townsite of Marradong, situated 7.5 km south-southwest of Boddington at the northern end of the Mount Saddleback range. It consists of 3 to 8 km of metabasalt, with apparently only minor intercalations of dark metasediment and rare metadacite. Exposure is very poor and the laterite cover is almost complete. The bauxite deposits of Mount Saddleback are developed over this formation.

The Marradong Formation conformably overlies the Wells Formation at Mount Wells. The junction is sharp, though a few bands and lenses of metadacite occur in the metabasalt close to the contact. The eastern boundary of the formation is everywhere faulted and its total thickness is unknown.

The type area is on Mount Saddleback, where the most continuous section is in a 400 m long "eye-shaped" incision into the laterite surface, 2 km south of Marradong. The rock is a fine-grained, schistose metabasalt with a general foliation trend of 166/31° E. Locally, thin, irregular, complexly folded veins of pink quartzo-feldspathic material traverse the rock. A 75 cm wide doleritic dyke cuts the sequence and is only distinguishable by its lack of foliation. Metabasalt devoid of quartzo-feldspathic veins is often more regularly schistose, with growth of amphibole along these surfaces.

An outcrop of metabasalt, 4 km northwest of Mount Saddleback summit, contains a 50 m wide intercalation of extremely fine-grained, pelitic metasediments associated with felsic volcanic/pyroclastic rocks. A smaller, 3 m wide, intercalation of felsic volcanic and pyroclastic rocks occurs 1.4 km northeast of Mount Wells.

INTERPRETATION

The main problem in interpreting the geology of the Saddleback Group is the paucity of exposure. Only four outcrops occur on the whole of the Mount Saddleback range, excluding a few fragmentary exposures (largely obscured by soil and colluvium) that are present along the flanks. Similarly poor exposure is typical of the whole greenstone belt. The natural diversity and rapidity of variation in such volcanogenic sequences also contributes to the uncertainty in correlation.

Correlation between such widely scattered outcrops is therefore hazardous and made even more so by the extensive block faulting that has affected the area (Fig. 51). Faulting on this scale of intensity is unusual in the Archaean of the southwestern Yilgarn Block. It appears to be related to the presence of the greenstone belt, although it does continue further eastward into the granitic terrain between Boddington and Wandering. In two fault-bounded blocks south of Tullis, no rock or colluvial fragments were found and grouping with the Wells Formation is thus open to question (Fig. 51).

A further complicating factor is the nature of the rocks themselves. With the exception of the agglomerates, it is extremely difficult to distinguish between the pyroclastic and sedimentary rocks in the field. This difficulty is enhanced by later deformation, so that sheared porphyritic dacite is virtually indistinguishable from certain deformed pyroclastic or gritty sedimentary rocks.

Examination of the rocks in thin section often throws little light on their origin. There has been extensive recrystallization associated with the deformation and metamorphism, so that few primary textures remain. The groundmass of original felsic lavas has been recrystallized and is now often similar, both in mineralogy and texture, to certain of the metasediments. The irregular distribution of constituents may help to differentiate tuffs from fine-grained lavas, but not from immature sediments, which also form part of the sequence.

The mafic volcanic rocks are generally distinct and consist of a fine-grained, ragged mosaic of amphibole and plagioclase, with minor quartz. Alteration to epidote and clinozoisite is often almost complete and primary textures are rare. However, the less altered rocks reveal an igneous rather than a metamorphic texture. The plagioclase laths have a fairly random orientation and are intergrown with the amphibole. This confirms the classification of the rocks as metabasalts rather than as amphibolites.

REGIONAL CONTEXT

The Saddleback Group appears to show a closer resemblance to the typical Archaean greenstone belts of the Eastern Goldfields Province of the Yilgarn Block, than any comparable rock sequence from the southwestern part of the block of which details have been published. It is a 5 to 12 km wide belt consisting predominantly of basalt and felsic volcanic and pyroclastic rocks, with minor sediments. The metamorphic grade is low and the original nature of the rocks is still discernible.

The group thus occupies an anomalous position, since all other known layered sequences within a distance of several hundred kilometres have a much higher metamorphic grade (amphibolite to granulite facies) and consist predominantly of metasediments and quartzo-feldspathic gneisses (of presumed sedimentary origin); no unequivocal mafic or felsic volcanic rocks have been recorded.

The presence of a weakly metamorphosed greenstone belt in a region characterized by vastly different layered sequences of higher metamorphic grade has important implications. The belt is intruded by even-grained granitic rocks, presumably formed during the 2 600 m.y. event common throughout the Yilgarn Block (Arriens, 1971). The rocks are thus older than this granite but probably younger than the more strongly metamorphosed layered rocks of the Jimperding Metamorphic Belt that date back to over 3 000 m.y. (Arriens, 1971). It is possible, therefore, that the Saddleback Group represents a younger Archaean greenstone belt assemblage that was deposited on a basement of pre-existing Archaean layered rocks, akin to the Jimperding Metamorphic Belt (Wilde, 1974). Granite gneiss and migmatite in the vicinity of Mount Saddleback may represent vestiges of this older layered sequence.

REFERENCES

Arriens, P. A., 1971, The Archaean geochronology of Australia: Geol. Soc. Australia, Special Pub. No. 3, p. 11-23.

Wilde, S. A., 1974, Explanatory notes on the Archaean rocks of the Perth 1 : 250 000 Geological Sheet, Western Australia: West. Australia Geol. Survey Rec. 1974/15 (unpublished).

RECENT EXPLORATION FOR URANIUM IN THE KIMBERLEY REGION

by J. D. Carter

ABSTRACT

Uranium exploration in the Kimberley region during the period 1968-1975 as reported to the Mines Department involved 31 operations. There was core drilling during eight of these. Total exploration expenditure was probably of the order of several million dollars.

No economic deposit of uranium was proved though five occurrences of secondary uranium minerals were discovered.

It is suggested that conglomerates in the Kimberley Basin, apparently promising for uranium accumulation, are unmineralized because when these were deposited, likely source rocks of uranium had not been uncovered by erosion.

Most operations were preceded by airborne radiometric surveys. This cover of important parts of the geology is such that it is unlikely that there are, in these districts, unidentified uranium-based radioactive anomalies of any consequence detectable by the method.

The review illustrates examples of repetitious operations obtaining similar results and has a purpose of helping operators to avoid further duplication of exploration ventures.

INTRODUCTION

Since 1968, the Kimberley region of Western Australia has been a scene of moderately intense exploration for uranium with many companies participating, though none have discovered an economic uranium ore body. On this exploration there is little published information and for this reason the main results of ventures described in reports to the Mines Department are now brought together. It is hoped that the review will assist industry contemplating uranium exploration in the Kimberley region and in particular will help to avoid duplication of exploration ventures. There are cases of repetitous exploration obtaining similar results. For example, during separate operations begun in 1969 and 1973, each involving airborne radiometric surveys and ground follow-up, the venturers both detected the same small body of radioactive conglomerate within the Pentecost Sandstone. This was the subject of follow-up work, with the similar conclusion being reached that thorium probably was responsible for the radioactivity (operations G.S.W.A. M* 445 and 1408, and Tables 24 and 29 this report).

*Reports on mineral exploration other than for oil, gas and coal received from the industry by the Geological Survey are prefixed by M.

Exploration for uranium in the Kimberley region has passed through two periods of heightened activity, the first between 1955 and 1961 and the second taking place since 1968. The earlier activity was in response to the work of Traves (1955) who drew attention to the similarity of the geology of the country near Katherine and Darwin in Northern Territory, where there are ore bodies of uranium (Rum Jungle), to the geology of the Halls Creek district in the east Kimberley region. A result was a high-level airborne reconnaissance scintillometer survey carried out by the Bureau of Mineral Resources, Geology and Geophysics (BMR) when radioactive anomalies were recorded (Goodeve, 1955). Parts of the survey area were reflown by the BMR at low level using scintillometer (Gardener, 1960). No economic uranium deposits were discovered. Dow and Gemuts (1969) record exploration results of this period, the most interesting being the find of minor secondary uranium mineralization near Dunham Hill where autunite coats joints in a basic dyke and torbernite infills shears in granite.

During the years now under review, between 1968 and 1975, there was an upsurge in mineral exploration throughout Western Australia generally and renewed interest was shown in the uranium potential of the Kimberley region. The majority of ventures were mounted in response to a combination of apparently favourable geology and encouraging results of airborne radiometric surveys. Much attention was given to a radioactive conglomerate within the King Leopold Sandstone, cropping out along the western margin of the Halls Creek mobile zone (Fig. 52). Exploration results, however, once more were disappointing. Anomalous radioactivity was found to stem mainly from thorium minerals. No economic uranium deposit was disclosed although three uranium occurrences were thought to be sufficiently attractive to merit detailed evaluation (M395, 648/1 and 648/2).

In Table 24, the operations reported, 31 in number, are listed; Figure 52 shows that the greater part of the work took place over the southern portion of the Halls Creek mobile zone and along the margin of the Kimberley Basin adjoining this zone. It should be understood that the total exploration effort for uranium is not represented in this review. Only those operations reported to the Mines Department are described. Exploration over open ground does not carry reporting obligations and preceding many of the operations summarized in Table 24, examinations of very much larger tracts of country than those listed took place (usually employing radiometry). Since unfavourable results were eventually obtained from ground selected as the more promising, it follows that the uranium potential of ground rejected initially should be less favourable.

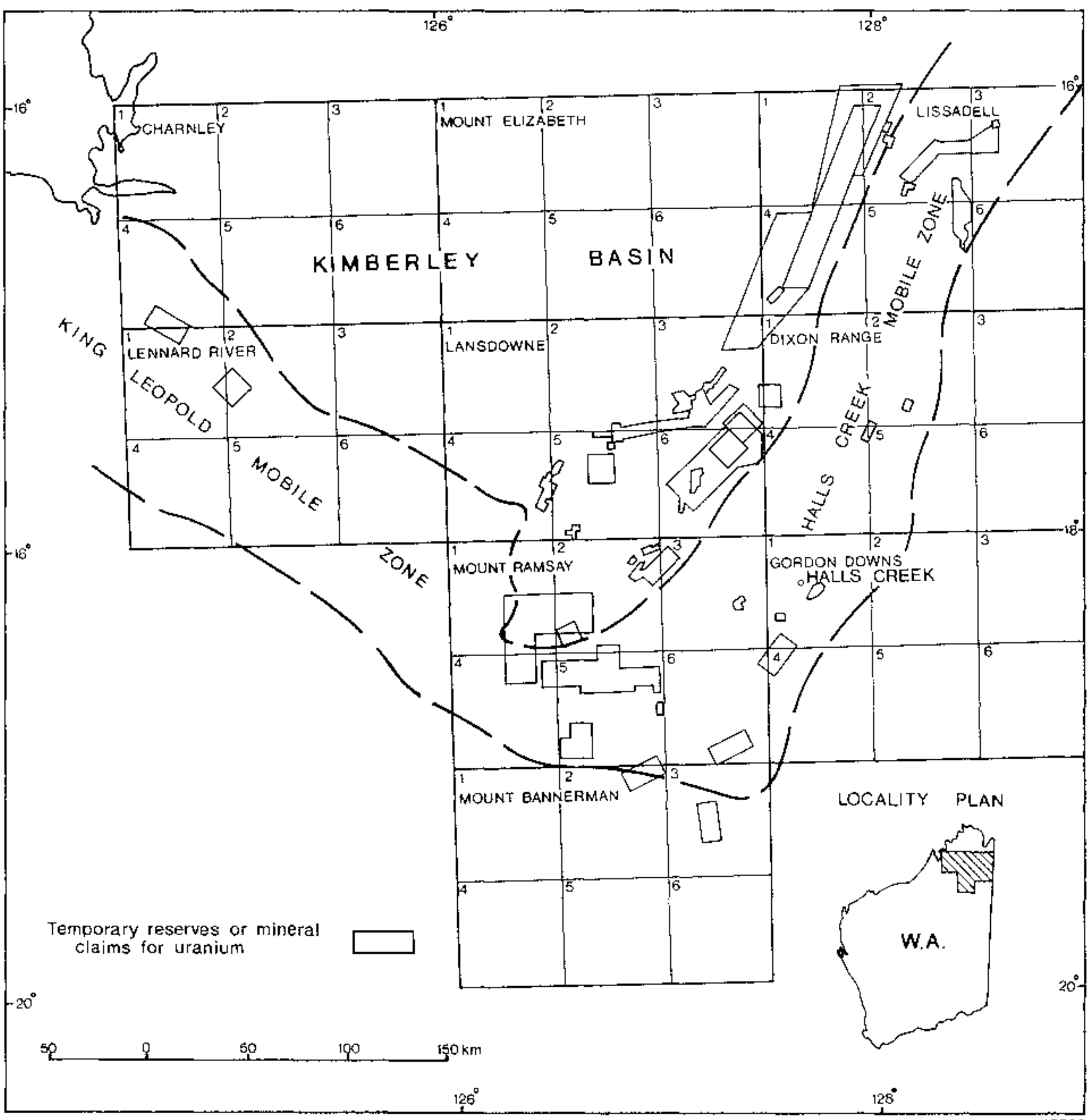


Figure 52. Kimberley region. Uranium exploration-principal locations.

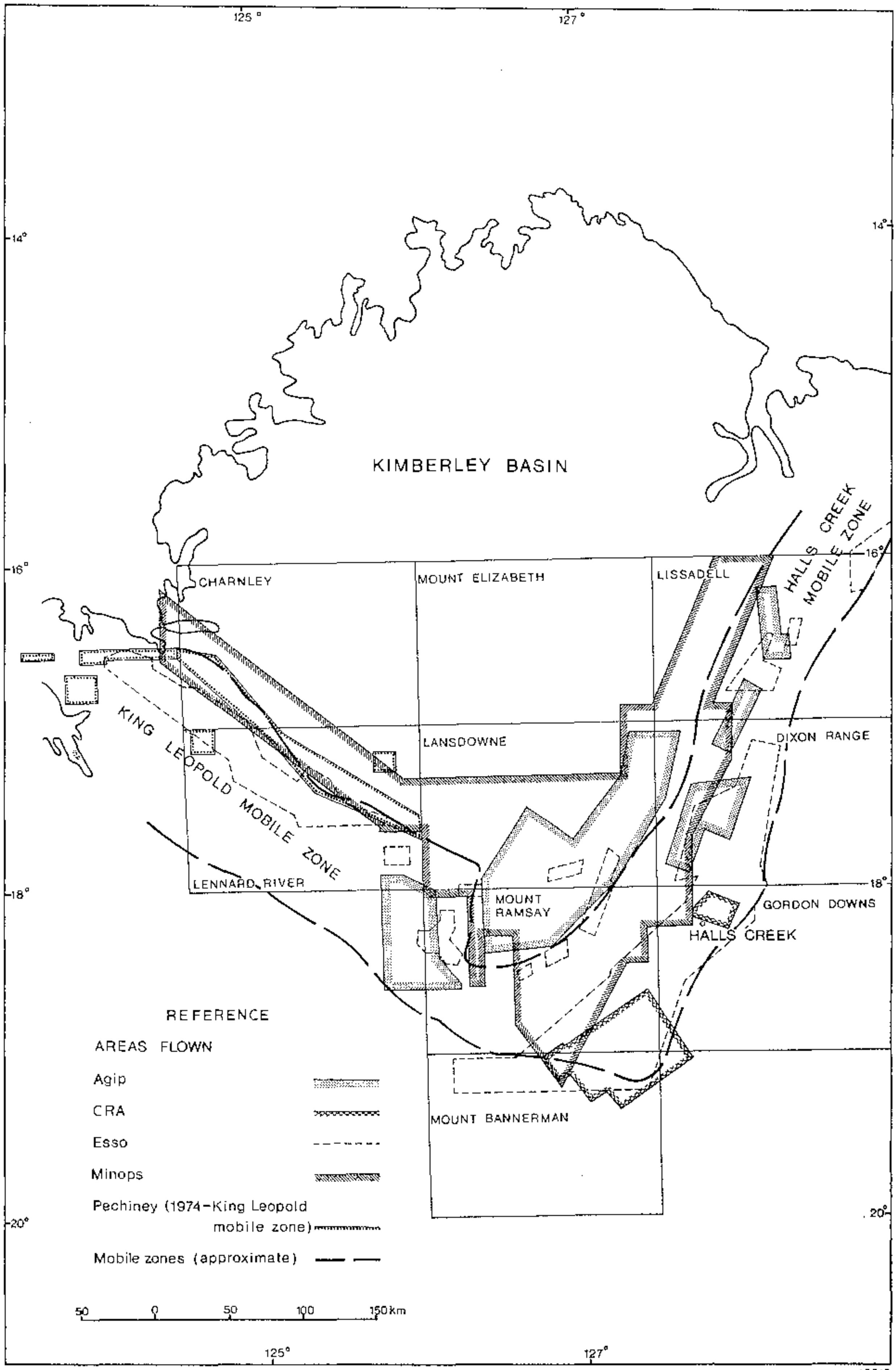


Figure 53. Selected regional airborne radiometric surveys.

The review is compiled from reports of operations chiefly made over mineral claims and Temporary Reserves* submitted to the Mines Department. The operating companies concerned are listed, together with abbreviations adopted to denote these companies:

Agip Nucleare Australia Pty. Ltd.—Agip

Australian Anglo American Ltd.—Aust Anglo American

Carpentaria Exploration Company Pty. Ltd.—Carpentaria

C.R.A. Exploration Pty. Ltd.—CRA

Durack Mines Limited—Durack

Esso Australia Ltd.—Esso

*Temporary Reserve (T.R.), Crown Land reserved for mineral exploration.

Gunn Land and Exploration Partnership—Gunn Land

Metals Miniere Ltd., M.M. Exploration Pty. Ltd. and Uranerzbergbau GmbH Co KG—MMEX-UEB

Newmont Pty. Ltd.—Newmont

Pickands Mather and Co. International—PMI

South Pacific Miniere Pty. Ltd.—South Pacific Miniere

The Broken Hill Pty. Co. Ltd.—BHP

Trend Exploration Pty. Ltd.—Trend

GEOLOGY

For descriptions of the geology of the Kimberley region, publications listed in References should be consulted, particularly Thom (1975) who provides the most complete account. In Table 23 the rock units which have been principal targets for uranium exploration are listed and their more important outcrop areas are shown on Figure 54.

TABLE 23. STRATIGRAPHY AND OPERATIONS.

Unit	Formation	Lithology	Operations G.S.W.A. M
Upper Devonian	Ragged Range Conglomerate Member	Quartz conglomerate (300 m+)*	648/1
Proterozoic Louisa Downs Group		Sandstone, siltstone, shale, conglomerate, dolomite and tillite (up to 3 800 m)	298
Kuniandi Group		Sandstone, greywacke, siltstone, shale and tillite (up to 1 600 m)	298
Carr Boyd Group	Hensman Sandstone	Massive silicified quartz sandstone (150–250 m)	648/8
Kimberley Group	Pentecost Sandstone	Quartz sandstone with minor conglomerate (1 150 m)	445; 1408; 1409
	Elgee Siltstone	Siltstone and shale with sandstone (65–300 m)	
	Warton Sandstone	Sandstone with minor shale (210–900 m)	
	Carson Volcanics	Basalt with sandstone (300–900 m)	
	King Leopold Sandstone	Quartz sandstone, feldspathic sandstone and minor conglomerate (1 400 m)	290 and 328; 305, 330 and 340; 445; 695/1, 2 and 3; 985
Speewah Group	Luman Siltstone	Siltstone, shale and minor sandstone (900 m)	
	Lansdowne Arkose	Feldspathic sandstone, arkose, shale and siltstone (up to 500 m)	328; 1410; 1404; 1495/1
	Valentine Siltstone	Siltstone, sandstone, rhyolite and tuff (30–70 m)	
	Tunganary Formation	Quartz sandstone, arkose and siltstone (up to 1 100 m)	
	O'Donnell Formation	Subgreywacke, sandstone and shale (up to 300 m)	395; 1410; 1495/2
	Revolver Creek Formation	Basalt with arkose, sandstone and slate (up to 1 200 m)	338
	Moola Bulla Formation	Arkose, greywacke, siltstone, sandstone, conglomerate and shale (3 000 m+)	67/50
Lamboo Complex	Whitewater Volcanics	Rhyodacite tuff, tuffaceous siltstone, sandstone and conglomerate	648/7
	Undifferentiated igneous rocks	Granodiorite, tonalite, gabbro and ultrabasic	
	Acid igneous rocks	Granite, quartz feldspar porphyry and rhyolite	298; 338; 435; 648/2; 1184; 1498; 1499; 1660
	Tickalara Metamorphics	Schist, paragneiss, orthogneiss, migmatite, amphibolite and calc-silicate rocks	1551
(?) *Archaean*	Undifferentiated	Schist, quartzite, siltstone and greywacke	
	Olympio Formation	Subgreywacke, arkose, siltstone, minor dolomite and conglomerate (3 000 m+)	1288; 1412; 1673
Halls Creek Group	Biscay Formation	Basic lava, greywacke, siltstone and dolomite (1 500–3 000 m)	1288; 1497
	Saunders Creek Formation	Quartz conglomerate, sandstone and greywacke (to 195 m)	

* Thicknesses in brackets

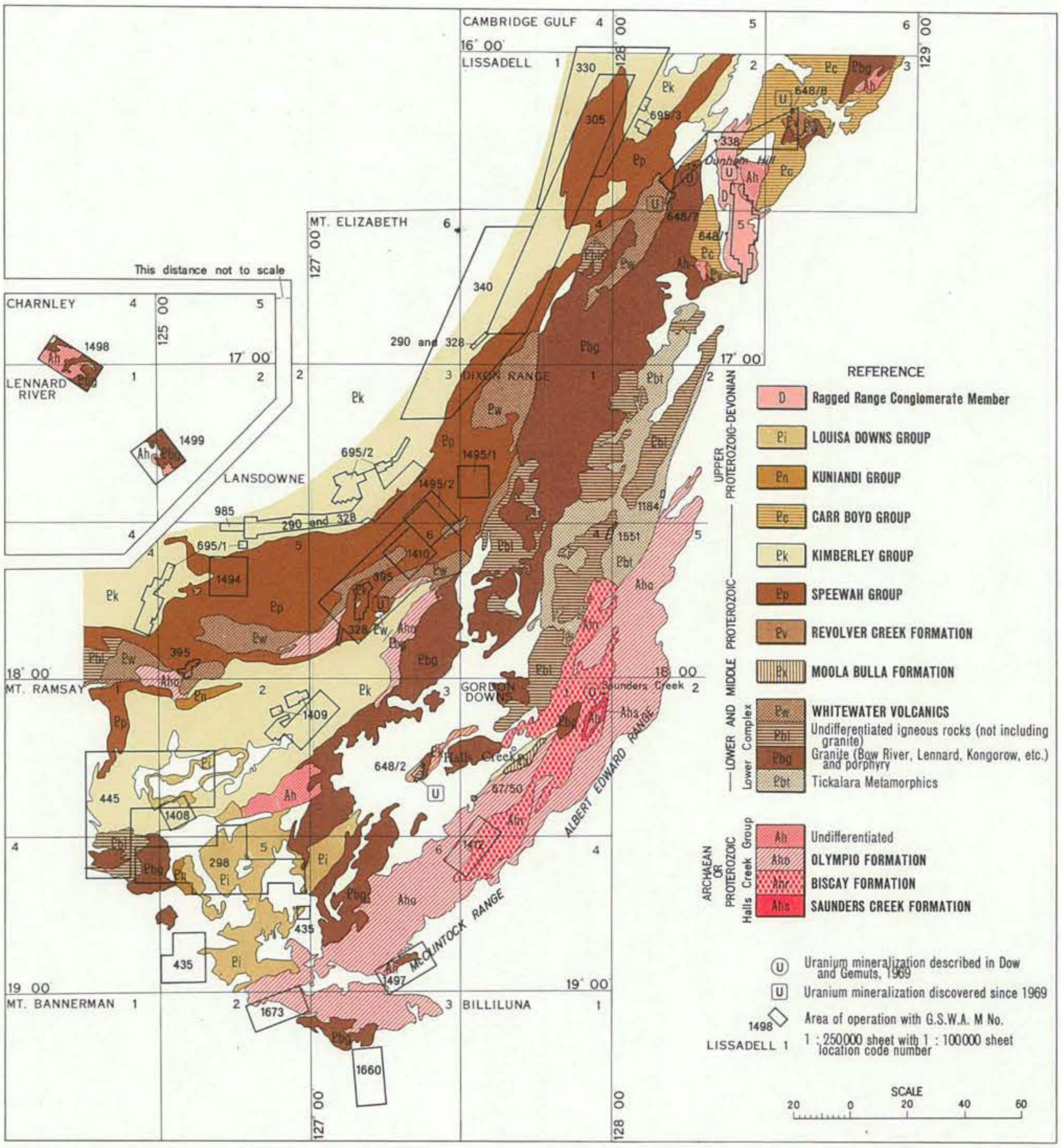
The essential features are the Kimberley Basin containing flat-lying sedimentary and volcanic rocks of the Middle Proterozoic, and the Lower Proterozoic geosynclinal sediments, metamorphic and igneous rocks of the Halls Creek Province which flank the basin to the east and southwest (Fig. 52). The eastern arm of the province is termed the Halls Creek mobile zone and the western, the King Leopold mobile zone. The oldest rocks are geosynclinal sediments of the Halls Creek Group which could be Archaean or Lower Proterozoic in age, and crop out along the mobile zones. The Halls Creek Group is intruded by a wide range of Lower Proterozoic igneous rocks including granite, quartz feldspar porphyry and rhyolite named the Lamboo Complex. Metamorphic rocks formed from the Halls Creek Group are termed Tickalara Metamorphics. These units are unconformably overlain by the gently folded but extensively faulted and largely unmetamorphosed, Middle Proterozoic and younger, sedimentary and volcanic rocks which form the Kimberley Basin.

EXPLORATION

GENERAL

Operations are listed in Table 24.

The Table does not incorporate ventures mounted to search for other commodities in course of which there may have been incidental exploration for uranium. Under "Principal Geological Targets" the rock units shown were those selected for the main exploration effort. Targets of casual operations, such as those performed to check sporadic radioactive anomalies of low priority, are not included. The "Location" code refers to the six 1:100 000 sheets of the quarter-million sheets of the International Grid. These have a four-figure code number in the International System but are designated here Nos. 1, 2, 3, 4, 5 and 6 (Fig. 52). "Area" refers to approximate areas of ground secured for operations under mineral claims and Temporary Reserves and as explained in the Introduction, the figures often represent the least extent of country examined.


CAMBRIDGE GULF
LISSADELL
MT. ELIZABETH
CHARNLEY
LENNARD RIVER
LANSDOWNE
MT. RAMSAY
GORDON DOWNS
MT. BANNERMAN
BILLILUNA
DIXON RANGE
Dunham Hill
Halls Creek
Saunders Creek
ALBERT EDWARD RANGE
McCLINTOCK RANGE
This distance not to scale
16° 00'
17° 00'
18° 00'
19° 00'
125 00
127 00
128 00
129 00
REFERENCE
D Ragged Range Conglomerate Member
Pi LOUISA DOWNS GROUP
Pn KUNIANDI GROUP
Pc CARR BOYD GROUP
Pk KIMBERLEY GROUP
Pp SPEEWAH GROUP
Pv REVOLVER CREEK FORMATION
Pk MOOLA BULLA FORMATION
Pw WHITEWATER VOLCANICS
Pbi Undifferentiated igneous rocks (not including granite)
Pbg Granite (Bow River, Lennard, Kongorow, etc.) and porphyry
Pbt Tickalara Metamorphics
UPPER PROTEROZOIC-DEVONIAN
LOWER AND MIDDLE PROTEROZOIC
Lower Complex
ARCHAEAN OR PROTEROZOIC
Halls Creek Group
Ah Undifferentiated
Aho OLYMPIO FORMATION
Ahy BISCAY FORMATION
Ahs SAUNDERS CREEK FORMATION
Uranium mineralization described in Dow and Gemuts, 1969
Uranium mineralization discovered since 1969
1498 Area of operation with G.S.W.A. M No.
LISSADELL 1 1 : 250000 sheet with 1 : 100000 sheet location code number
SCALE
20 0 20 40 60

15511

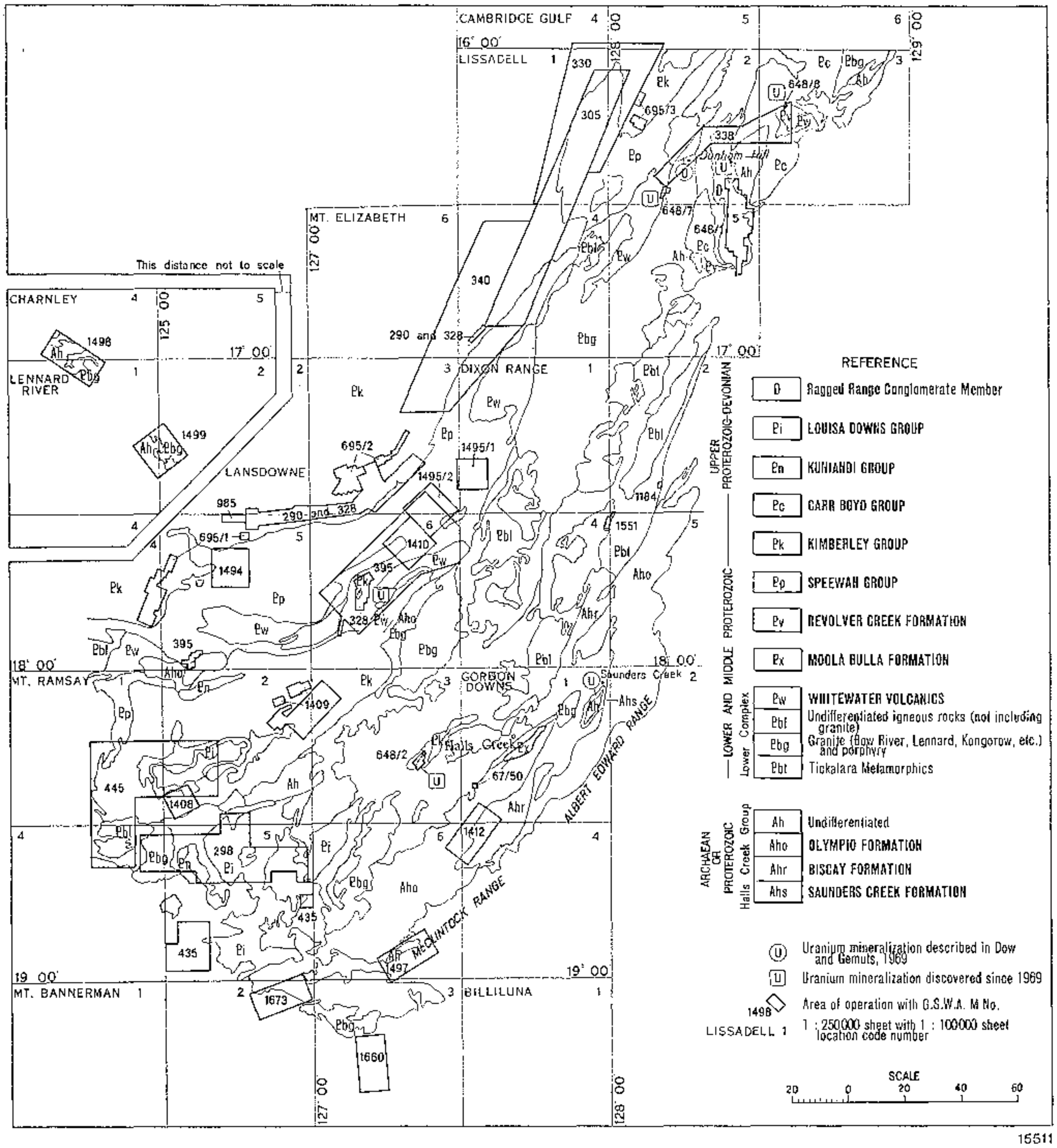


Figure 54. Geology and operations locations.

Types of uranium occurrences sought are usefully described following the method adopted by Bowie (1970) as either "peneconcordant", that is, deposits within conglomerates and sandstones, or, "discordant", referring to mineralization within features such as veins, shears and faults. For some operations the type of uranium occurrence sought is neither stated nor clear. In general however, during operations conducted over Halls Creek Group and Lamboo Complex units, uranium occurrences in discordant situations were considered ("Principal Geological Targets", Tables 24 and 25; Tables 26 and 27). Venturers over post-Lamboo Complex rocks such as the Speewah and Kimberley Groups generally searched for peneconcordant mineralization within sandstones and more particularly within conglomerates of the Lansdowne Arkose and King Leopold Sandstone ("Principal Geological Targets", Tables 24 and 25; Tables 28 and 29).

Exploration methods are summarized in Table 24. The general approach was to commission total radioactivity or gamma spectrometer airborne surveys to precede standard geological survey procedures, ground radiometric traverses and chemical assays. No other primary geophysical exploration method was reported though certain geophysical techniques including radon measurement were tested (M648/1). Drillholes were usually radiometrically logged. Geochemical methods of exploration were represented by a few drainage surveys, and soil surveys in two operations (M648/1, 2). Results of drainage surveys were apparently inconclusive, or negative. Soil surveys were considered useful in delimiting uranium anomalies. During some operations natural waters were analysed but no systematic hydrogeochemical survey appears to have been attempted. Of the sedimentary units examined, evidently only the King Leopold Sandstone was the subject of detailed sedimentological studies (M290 and 328).

TABLE 24.—OPERATIONS SUMMARY

G.S.W.A. M	Operating Company	Principal Geological Targets	Tenement	Location	Area km²	Duration	Principal Exploration Methods	Uranium Mineralization	Remarks
67/50	PMI	Moola Bulla Formation	....	Gordon Downs 1	130	1969–70	Airborne spectrometer survey, ground surveys, core drilling, assays	None	
290 and 328	BHP	Lansdowne Arkose King Leopold Sandstone	T.R.s 4742H and 5016H; mineral claims	Lansdowne 2, 3, 5, 6 Lissadell 4	500	1968–71	Airborne scintillometer survey, ground surveys, sedimentological studies, core drilling, assays	None	King Leopold Sandstone was explored in two localities (M290 and 328, Fig. 54); Lansdowne Arkose was explored in one locality (M328, Fig. 54)
298	BHP	Louisa Downs and Kuniandi Groups; Bow River Granite	T.R.4704H	Mount Ramsay 2, 4, 5	930	1968–72	Airborne spectrometer survey, ground surveys, assays	None	
305, 330 and 340	Durack	King Leopold Sandstone	T.R.s 4651H, 5001H and 5013H; mineral claims	Cambridge Gulf 4, 5 Lissadell 1, 2, 4 Mount Elizabeth 6 Lansdowne 3 Dixon Range 1	3 535	1968–72	Heli-borne, scintillometer surveys, ground surveys, core drilling, assays	None	Unified operation. Principal exploration was over the southern part of M340 (Lansdowne 3, Fig. 54)
338	BHP	Bow River Granite near Dunham Hill; Revolver Creek Formation	T.R.5051H	Lissadell 2, 3	438	1969–71	Airborne scintillometer survey, ground surveys assays	None	
395	South Pacific Miniere	Speewah Group, principally O'Donnell Formation	T.R.5112H	Lansdowne 3, 5, 6	1 183	1969–73	Heli-borne spectrometer survey, ground surveys, core drilling, assays	Phosphuranylite	Sporadic low-grade secondary uranium mineralization found in O'Donnell Formation was shown not to be economic
435	Gunn Land	(?) Bow River Granite	T.R.s 5082H and 5083H	Mount Ramsay 5	270	1969	Ground scintillometer traverses, assays	None	Very small-scale exploration in two localities
445	Newmont	Kimberley Group	T.R.4695H	Mount Ramsay 1, 2, 4	1 308	1969–71	Heli-borne scintillometer survey, ground surveys, shallow non-core drilling, assays	None	Radioactive anomalies were detected over Pentecost Sandstone only
648/1	MMEX–UEB	Ragged Range Conglomerate Member	Mineral claims	Lissadell 2, 5	200	1971	Heli-borne spectrometer survey, ground surveys including geochemical surveys, core drilling, assays	Carnotite	Trenching and drilling did not prove mineralization of economic potential

(10)—59638

648/2	MMEX-UEB	Lamboo Complex gneisses	Mineral claims	Mount Ramsay 3	12	1971–73	Heli-borne spectrometer survey, ground surveys including geochemical surveys, core drilling, assays	Carnotite	Mineralization considered not to be economic. Ground is now covered by T.R.5959H
648/7	MMEX-UEB	Whitewater Volcanics	Mineral claims	Lissadell 2	6	1971	Heli-borne spectrometer survey, ground surveys, assays	Secondary uranium minerals	Mineral claims surrendered
648/8	MMEX-UEB	Hensman Sandstone	Mineral claims	Lissadell 3	<1	1971–73	Heli-borne spectrometer survey, ground surveys, assays	Phosphuranylite, torbernite	No further exploration recommended; mineral claim withdrawn
695/1	CRA	King Leopold Sandstone	Mineral claims	Landsdowne 4, 5	135	1968–71	Airborne including heli-borne scintillometer surveys, ground surveys, core drilling, assays	None	Minops Pty. Ltd. was the initial operating company of M695/1, 2 and 3
695/2	CRA	King Leopold Sandstone	Mineral claims	Lansdowne 3	100	1968–71	Airborne scintillometer survey, ground surveys, core drilling assays	None	
695/3	CRA	King Leopold Sandstone	Mineral Claims	Lansdowne 2	35	1968–71	Airborne scintillometer survey, ground surveys core drilling, assays	None	
985	Carpentaria	King Leopold Sandstone	Mineral claims	Lansdowne 5	29	1970–71	Fixed wing spectrometer survey	None	
1184	Aust Anglo American	Lamboo Complex Granite	Mineral claims	Dixon Range 2	4	1973	Ground scintillometer surveys, assays	None	
1288	Trend	Biscay and Olympio Formations	....	Gordon Downs 1	....	1973	Ground spectrometer surveys, assays	None	BMR 1959 airborne survey radioactive anomalies examined are not shown on Fig. 54
1408	Agip	Pentecost Sandstone	T.R.5767H	Mount Ramsay 1, 2	100	1973–74	Fixed wing spectrometer survey, ground surveys, assays	None	
1409	Agip	Pentecost Sandstone	T.R.5768H; mineral claims	Mount Ramsay 2, 3	285	1973–74	Fixed wing spectrometer survey, ground surveys, pitting, assays	None	
1410	Agip	Speewah Group, principally Lansdowne Arkose	T.R.5769H	Lansdowne 6	189	1972–74	Fixed wing and heli-borne spectrometer surveys, ground surveys, assays	None	

TABLE 24.—OPERATIONS SUMMARY—*Continued*

G.S.W.A. M	Operating Company	Principal Geological Targets	Tenement	Location	Area km²	Duration	Principal Exploration Methods	Uranium Mineralization	Remarks
1412	Esso	Olympio Formation	T.R.5793H	Gordon Downs 1, 4 Mount Ramsay 6	200	1973–74	Fixed wing spectrometer survey, ground surveys, percussion drilling, assays	None	
1494	Agip	Speewah Group, principally Lansdowne Arkose	T.R.5897H	Lansdowne 5	196	1972–74	Fixed wing spectrometer survey, ground surveys, assays	None	
1495/1	Agip	Lansdowne Arkose	T.R.5898H	Dixon Range 1 Lansdowne 3	184	1972–74	Fixed wing spectrometer survey, ground surveys, assays	None	
1495/2	Agip	O'Donnell Formation	T.R.5899H	Lansdowne 3, 6	184	1972–74	Fixed wing spectrometer survey, ground surveys, assays	None	
1497	CRA	Biscay Formation	T.R.5918H	Mount Ramsay 6 Mount Bannerman 3	200	1974	Fixed wing spectrometer survey, ground surveys, assays	None	
1498	Esso	Lamboo Complex granites	T.R.5892H	Lennard River 1, 2	200	1973–74	Fixed wing spectrometer survey, ground surveys, percussion drilling, assays	None	Initial target was Halls Creek Group in the King Leopold mobile zone
1499	Esso	Lamboo Complex granites	T.R.5891H	Charnley 4 Lennard River 1	200	1973–74	Fixed wing spectrometer survey, ground surveys, assays	None	Initial target was Halls Creek Group in the King Leopold mobile zone
1551	Agip	Tickalara Metamorphics	Mineral claims	Dixon Range 2, 4, 5	12	1972–73	Fixed wing spectrometer survey, ground surveys, assays	None	
1660	CRA	Lamboo Complex granite	T.R.5950H	Mount Bannerman 3	200	1974–75	Fixed wing spectrometer survey, ground surveys, percussion drilling, assays	None	
1673	CRA	Olympio Formation	T.R.5956H	Mount Ramsay 5 Mount Bannerman 2	200	1974–75	Fixed wing spectrometer survey, ground surveys, assays	None	

REGIONAL AIRBORNE RADIOMETRIC SURVEYS

Information on 14 regional airborne radiometric surveys is listed in Table 25 and ground examined during five surveys is shown on Figure 53. Line kilometres flown totalled approximately 135 000. The majority of surveys were made over the Halls Creek mobile zone and adjoining parts of the Kimberley Basin. A number are not shown on Figure 53 (including important surveys by BHP: M382 and 333; MMEX-UEB; Pechiney (i) 1971; and South Pacific Miniere). These were flown over country lying within the eastern limit of surveys of Esso and the western limit of Minops' cover, and in general were directed towards King Leopold Sandstone outcrops and stratigraphy close to principal unconformities, particularly to the unconformity below the Speewah Group. Along the Halls Creek mobile zone, the density of airborne radiometric cover over ground near the principal unconformities immediately below the Kimberley Basin and the King Leopold Sandstone outcrop on their west is such that it is unlikely that radioactive anomalies of any importance detectable by the techniques employed remain unidentified.

Surveys reported over the King Leopold mobile zone are shown on Figure 53. These were flown over stratigraphy associated with unconformities at the base of the Kimberley Basin sequence, and the Halls Creek Group (Esso).

HALLS CREEK GROUP

The Halls Creek Group forms the basement within the Halls Creek and King Leopold mobile zones and consists of folded, often slightly metamorphosed geosynclinal sediments (Table 23). Similarities between the geology of these rocks and the geology of the uranium province of Rum Jungle were largely responsible for initiating uranium exploration in the east Kimberley region in the 1950s. Near the base of the group, radioactive sandstone and conglomerate of the Saunders Creek Formation occur. These were unsuccessfully explored for uranium by diamond drilling, when the highest core assay was 0.16 per cent equivalent U_3O_8 over 10 cm and thorogummite was shown to be the principal radioactive mineral (Mercer, 1961).

Four small operations, listed in Table 26, were mounted over the Biscay and Olympio Formations but no uranium minerals were found. Although the ground examined during these ventures constitutes a very minor part of the group's outcrop, its units within the Halls Creek mobile zone have been the subject of several airborne radiometric surveys and it may be assumed that the majority, if not all, of radioactive anomalies within them, detectable by current methods, have been assessed for uranium content and rejected.

LAMBOO COMPLEX

Igneous and high-grade metamorphic rocks of the Lamboo Complex are found principally within the Halls Creek and King Leopold mobile zones. On Figure 54 the geology of the complex is simplified, the members being grouped in three categories. Rocks usually of immediate relevance to uranium exploration such as granite and quartz-feldspar porphyry are represented separately while other igneous rocks are grouped together. The third category shown is main outcrop areas of Tickalara Metamorphics. One unit, the Bow River Granite, is noteworthy by reason of its close association near Dunham Hill with minor occurrences of torbernite and autunite, the only uranium minerals recorded in the east Kimberley region by Dow and Gemuts (1969).

Ten operations were reported and their main features are shown in Table 27. During the single large-scale venture (M648/2), carnotite mineralization was found within a shear in gneissic rocks. The prospect was the subject of detailed exploration including core drilling; no conclusion was reached about its economic potential. This mineralization is now being explored under T.R.5959H. One other minor occurrence of secondary uranium minerals was identified. These were found in fractures within Whitewater Volcanics (M648/7). An attempt to find extensions of the Dunham Hill secondary mineralization was unsuccessful (M338).

Esso describe exploration of the uranium potential of the King Leopold mobile zone, this representing the only operation on the ground in the western part of the Kimberley region. The outcome of Esso's airborne radiometric surveys (shown on Fig. 53) consisted of disappointing results obtained from examinations of granites emplaced within envelopes of undifferentiated representatives of the Halls Creek Group (M1498 and 1499).

As in the case of the Halls Creek Group, while the extent of Lamboo Complex exposure reported as being examined is not great, these rocks, particularly in the Halls Creek mobile zone, have been surveyed by several operators using airborne radiometric techniques and it is possible that most, if not all radioactive anomalies detectable by available instrumentation have been located (Fig. 53).

SPEEWAH GROUP

Sandstone, arkose, greywacke and siltstone characterize the essentially arenaceous Speewah Group. It lies unconformably on rocks of the Lamboo Complex. The group consists of five formations (Table 23), exposures of two of which, the basal O'Donnell Formation and the Lansdowne Arkose near the top, have been examined closely for uranium mineralization.

Features of six investigations over these rocks are listed in Table 28. The largest operation (M 395) was directed towards the basal portion of the O'Donnell Formation around a small anticline near Mad Gap Yard exposing Whitewater Volcanics and Lamboo Complex granite (Lansdowne 6). Sporadic, low-grade secondary uranium mineralization represented by phosphuranylite was found but no commercial potential has been demonstrated as yet. Exploration was conducted principally in two separate large-scale programmes, each involving substantial core drilling, and conclusions from both were that there is no significant depth extension of the small surface mineralization. Some 30 km northeast of Mad Gap Yard, no uranium mineralization was detected during two operations over the O'Donnell Formation where the geological setting is similar (M1410 and 1495/2).

Radioactivity of the Lansdowne Arkose has been shown so far to stem mainly from thorium minerals. During the largest operation, radioactive conglomerates were explored by core drilling in the Carola Syncline. The conglomerates were found to be oxidized to at least depths of 300 m where their low radioactivity appeared to be thorium-based (M328).

Although the proportion of outcrop of the Speewah Formation explored on the ground for uranium is not great, a much larger part has been covered by airborne radiometric surveys (Fig. 53) and the lack of response to results of these, in terms of work on the ground, downgrades the uranium potential of this group in these areas.

KIMBERLEY GROUP

Formations of the Kimberley Group (Table 23) are essentially arenaceous, consisting mainly of quartz sandstone with siltstone and dolomite, and a basaltic formation, being altogether some 3 000 m thick. The group lies conformably on the Speewah Group although locally it is unconformable, transgressing the Speewah Group to rest on older rocks. It underlies the entire area of the Kimberley Basin. Of the five formations, the King Leopold Sandstone at the base of the group and the Pentecost Sandstone at the top have been principal targets for uranium exploration, but no uranium mineralization has been reported from any formation.

TABLE 25. REGIONAL AIRBORNE RADIOMETRIC SURVEYS 1968-74

Operating Company	G.S.W.A. M	Contractor	Aircraft	Instrument	Line km (Area km²)	Terrain Clearance/ Line Spacing metres	Principal Geological Targets	Remarks and Data Held
Agip*	1408, 1409, 1410, 1494, 1495 and 1551	Hunting Geology and Geophysics Ltd.	Fixed wing	Nuclear Enterprises NE 8424 Mark 15 spectrometer	18 140	90/800	Halls Creek Group, Lamboo Complex, Speewah and Kimberley Groups	
BHP	298	Geophysical Resources Development Co.	n.a.**	Spectrometer	6 100	90/800	Louisa Downs and Kuniandi Groups, Lamboo Complex	Survey data and plans showing total count and 1·6 to 2·0 Mev contours
BHP	328 and 338	n.a.	Fixed wing Helicopter	Spectrometer Scintillometer	40 250 16 100	n.a. n.a.	Principally sediments of the Kimberley Basin; Dunham Hill secondary uranium mineralization	
Carpentaria	985	Geophysical Resources Development Co.	Fixed wing	Exploranium DGRS 1000 spectrometer	790	90/200	King Leopold Sandstone	Plan showing thorium anomaly spots
CRA*	1497, 1660 and 1673	Geometrics International Corporation	Fixed wing	Exploranium DIGRS 3001 spectrometer	(i) 2 900 (ii) 120	n.a. / 1 500 n.a. / 5 000	McClintock Range geology Albert Edward Range geology	
Esso*	(i) 1412 (ii) 1498 and 1499	Geometrics International Corporation Aero Service (Australia) Pty. Ltd.	Fixed wing Fixed wing	Exploranium DIGRS 3001 spectrometer Hammer-Harshaw 10 crystal spectrometer	about 7 300 5 600	150 / 1 600 & 3 200 (infill 800 and 400) 120 / 800 and 1 600 (infill 400)	Halls Creek Group in Halls Creek mobile zone Halls Creek Group in King Leopold mobile zone	
Minops Pty. Ltd.*	695/1, 2, and 3	Hunting Geology and Geophysics Ltd.	n.a.	Harwell series 1531A scintillometer	about 18 000	120–150 / 1 600	Halls Creek and King Leopold mobile zones, and adjoining parts of the Kimberley Basin	Plans showing anomaly spots
MMEX-UEB	648/1, 2, 7 and 8	Terratest AB (Stockholm)	Helicopter	Spectrometer	11 362	n.a. / 200	Parts of Halls Creek Group and Lamboo Complex in Halls Creek mobile zone and principal unconformities above these. Ragged Range Conglomerate Member	Plans showing anomaly spots
Newmont	445	n.a.	Helicopter	Scintrex GIS–2 scintillometer	(260 km²)	30 / 400	Kimberley Group	Plan showing anomaly spots

Pechiney (Australia) Exploration Pty. Ltd. (No ground survey was carried out; this operation is not listed in Table 24)	1681	(i) 1971	Fixed wing	SPAT 3 scintillometer	1 620	(?75 / 800)	King Leopold Sandstone and adjacent formations cropping out between Lansdowne 3 and Lissadell 2	Anomalies were not checked on the ground which was examined largely during operations M 290 and 328; 305, 330 and 340, and 695/3
		(ii) 1974*	Fixed wing	DGRS 1002 spectrometer	2 620	75 / 800 and 1 600	Parts of Speewah Group and Kimberley Group, particularly basal sections; Devonian Van Emmerick Conglomerate (Lennard River 1)	No anomaly warranted checking on the ground
South Pacific Miniere	395	Terratest AB (Stockholm)	Helicopter	Spectrometer	5 488	20 / 200	O'Donnell Formation	Plans showing total count, K40 channel and U channel contours
Western Nuclear Australia Ltd.	290	n.a.	n.a.	n.a.	n.a.	n.a.	King Leopold Sandstone conglomerates on Lansdowne Sheet	Airborne scintillometer survey

* The approximate extent of ground flown is shown on Figure 53.

** n.a.—information not available.

TABLE 26. HALLS CREEK GROUP EXPLORATION SUMMARY

G.S.W.A. M	Initial Target	Drilling	Geophysical Response Max. X Background (*Spectrometric)	Max. Chemical Assay ppm U_3O_8	Conclusions	Remarks
1288 (Trend)	BMR 1959 airborne survey radioactive anomalies over Biscay Formation	....	....	37	No anomaly showed a significant uranium content when examined by spectrometer	A "Rum Jungle situation" was sought
1412 (Esso)	Airborne survey radioactive anomalies over Olympio Formation	73 non-core holes for 4 450 m	4-5X*	383	Ironstones within Olympio Formation and sheared dolerite carry low uranium values	Ironstones are assumed to be of intense ferruginization
1497 (CRA)	Biscay Formation	....	No radioactive anomalies of interest detected by airborne spectrometer survey	<10	No promising host lithologies are present. Environment is not similar to that of Rum Jungle	Ground selected on basis of possible favourable lithologies near McClintock Range Granite
1673 (CRA)	Airborne survey radioactive anomalies over (?) Olympio Formation	....	1·2X*	50	Anomalous uranium value in ferruginized quartzite due to scavenging by secondary iron minerals	

TABLE 27. LAMBOO COMPLEX EXPLORATION SUMMARY

G.S.W.A. M	Initial Target	Drilling	Geophysical Response Max. X Background	Max. Chemical Assay ppm U_3O_8	Conclusions	Remarks
298 (BHP)	Airborne survey radioactive anomalies over Bow River Granite	....	....	....	Low-order thorium mineralization causes radioactive anomalies	
338 (BHP)	Minor secondary uranium mineralization in Bow River Granite at Dunham Hill	....	....	....	Low-level airborne scintillometer traverses failed to detect extensions of known uranium mineralization	
435 (Gunn Land)	BMR 1954 airborne survey radioactive anomalies over (?) Bow River Granite	....	....	50	Operation terminated following negative results of scintillometer and geochemical traverses	Very small-scale exploration
648/2 (MMEX-UEB)	Airborne survey radioactive anomalies over gneissic rocks	8 core holes for 757 m; vacuum drilling	(Carnotite prospect)	(Carnotite prospect)	Carnotite mineralization in shear zone; mineralization considered not to be economic	Ground covered by T.R. 5959H
648/7 (MMEX-UEB)	Airborne survey radioactive anomalies over Whitewater Volcanics	....	(Secondary uranium minerals)	(Secondary uranium minerals)	....	Preliminary investigations were not followed up. The mineral claims were withdrawn
1184 (Aust Anglo American)	Ground survey radioactive anomalies over granite with cupriferous quartz veins	....	....	B.L.D.	Radioactive anomalies due either to potassium, or very minor thorium or uranium concentrations	
1498 (Esso)	Airborne survey radioactive anomalies over granites including Lennard Granite	13 non-core holes for about 670 m	2X (fixed-wing survey)	6 446	Uranium enrichment within shears in granite	No uranium minerals were reported. Drilling undertaken to determine lithologies
1499 (Esso)	Airborne survey radioactive anomalies over granites including Lennard and Kongorow Granites	....	2X (fixed-wing survey)	38	Minor uranium enrichment within shears in granite	
1551 (Agip)	Airborne survey radioactive anomalies over high-grade schists and gneisses of the Tickalara Metamorphics	....	5X	20	Operation terminated following discouraging results of ground follow-up	Very small-scale exploration
1660 (CRA)	Airborne survey radioactive anomally over Bow River Granite	37 non-core holes for about 962 m	....	13	Radioactivity caused by thorium minerals in pisolite veneer on granite	

Table 29 lists the main features of uranium exploration. Radioactive conglomerates up to about 10 m thick within the King Leopold Sandstone attracted attention by reason of similarities between their general geology and the geology of uranium-bearing conglomerates at Elliot Lake, Canada. Examinations of the conglomerates took place over a strike length of some 250 km (from Lissadell 2 to Lansdowne 4) and included percussion and diamond drilling. An unconformity situated within the King Leopold Sandstone below the conglomerates was demonstrated which is not shown on available geological maps (M290 and 328). A conclusion of the same sedimentological and structural study was that the conglomeratic horizons are of marine shoreline origin, representing coarse beach gravels with boulder deposits derived from headlands.

Drilling the conglomerates was performed primarily to determine whether there had been leaching, and redeposition of uranium at depth. A study of surface and drill-core samples showed a majority of samples were out of radioactive equilibrium (M695/1). However, the conclusions reached from each of the operations involving drilling was that uranium values were substantially the same both in outcrop and in depth. Near Mount Bedford (Lansdowne 3), the conglomerate was shown to be oxidised to a depth of at least 183 m (M290 and 328). Anomalous radioactivity of the conglomerates was attributed in all operations chiefly to the presence of thorium-bearing minerals, such as thorogummite.

TABLE 28. SPEEWAH GROUP EXPLORATION SUMMARY

Formation	G.S.W.A. M	Initial Target	Drilling	Geophysical Response Max. X Background (Spectrometric*)	Max. Chemical Assay ppm U_3O_8	Conclusions	Remarks
Lansdowne Arkose	328 (BHP)	Airborne survey radioactive anomalies	6 non-core holes for 937 m; one core hole for 210 m	Bore probes <2½ X	<50	Radioactivity is due to thorium	
	1410 (Agip)	Airborne survey radioactive anomalies	....	....	424 (red flue sandstone)	Radioactive anomalies are caused by thorium minerals	
	1494 (Agip)	Airborne survey radioactive anomalies	....	....	672 (heavy mineral sandstone)	Radioactive anomalies are caused by thorium minerals	
	1495/1 (Agip)	Airborne survey radioactive anomalies	....	....	731 (heavy mineral band)	Radioactive anomalies are caused by thin, discontinuous and only locally anomalous heavy mineral bands	
O'Donnell Formation	395 (South Pacific Miniere)	Geological setting of O'Donnell Formation	26 core and non-core holes for 1536 m	(phosphuranylite)	(phosphuranylite)	Low-grade secondary uranium mineralization occurs as sporadic surface enrichment with no significant extension in depth	
	1410 (Agip)	Airborne survey radioactive anomalies	....	....	<20	Radioactive anomalies located by fixed-wing survey were due to higher background values	No radioactive anomalies were detected during a heli-borne spectrometer survey
	1495/2	Airborne survey radioactive anomalies	....	....	47	Radioactive anomalies caused by lithological contrasts	

TABLE 29. KIMBERLEY GROUP EXPLORATION SUMMARY

Formation	G.S.W.A. M	Initial Target	Drilling	Geophysical Response Max. X Background	Max. Chemical Assay ppm U_3O_8	Conclusions	Remarks
Pentecost Sandstone	445 (Newmont)	Airborne survey radiometric anomalies	7 non-core holes for 14 m	5X	70	Thorium content of conglomerates is responsible for radioactive anomalies	Horizons examined were also prospected during M1408
	1408 (Agip)	Airborne survey radiometric anomalies	....	....	33	Radiation is due to a thorium mineral, probably thorogummite	
	1409 (Agip)	Airborne survey radioactive anomalies	....	10X	35	Radioactive anomalies due to thorium sources	
King Leopold Sandstone	290 and 328 (BHP)	Airborne survey radioactive anomalies over conglomerate	2 core holes for 339 m; 6 non-core holes for 750 m	....	118	Main radioactive element down to 183 m is thorium	Two separate outcrop areas of conglomerate were examined (Fig. 54)
	305, 330 and 340 (Durack)	Airborne survey radioactive anomalies over conglomerate	3 core holes for 604 m	....	68	Radioactivity is due mainly to thorium minerals in matrix of conglomerate	Principal exploration and drilling took place near the southern boundary of M340 (Fig. 54)
	445 (Newmont)	....	....	....	....	No radioactive anomaly was detected during a heli-borne scintillometer survey	
	695/1 (CRA)	Airborne survey radioactive anomalies over conglomerate	17 core holes for 1 117 m	....	125	Radioactivity stems mainly from thorogummite	
	695/2 (CRA)	Depth extensions of radioactive conglomerate	....	....	....	....	No drilling
	695/3 (CRA)	Airborne survey radioactive anomalies over conglomerates	1 core hole for 246 m	60X	2	Radioactivity stems mainly from thorogummite	
	985 (Carpentaria)	....	....	....	....	No pronounced uranium anomalies were detected during an airborne spectrometer survey	

A similar conclusion, that thorium-bearing minerals are mainly responsible for anomalous radioactivity of the Pentecost Sandstone, was reached during the three operations reported over this formation (Table 29). There were minor examinations of other formations including sandstones of the Carson Volcanics, the Warton Sandstone and the Elgee Siltstone but again, thorium was considered to be the principal radioactive element.

OTHER UNITS

Other units explored for uranium were the Devonian Ragged Range Conglomerate Member and the Proterozoic Louisa Downs Group, Kuniandi Group, Carr Boyd Group, Revolver Creek Formation and Moola Bulla Formation. Only the Ragged Range Conglomerate Member and the Moola Bulla Formation were subjects of more than minor exploration.

Exploration of the Moola Bulla Formation took place a few kilometres east of Halls Creek, and some 25 km south of the town near Koongie Park over sediments which may be an outlier of Moola Bulla Formation (M67/50). East of Halls Creek, operations included drilling a core hole for 116 m through anomalously radioactive sandstone and conglomerate. It was concluded that much of the radioactivity was due to thorium. At Koongie Park, where anomalous radioactivity was discovered in the 1950s, a core hole for 198 m was sunk in fine-grained clastic sediments. No uranium mineralization was recorded. Selected parts of the core were assayed, the highest result being 26 ppm U_3O_8.

Over the Louisa Downs Group and Kuniandi Group in the Lubbock and Kuniandi Ranges, no radioactive anomalies were detected during an airborne radiometric survey (M298).

In the Hensman Sandstone of the Carr Boyd Group secondary uranium minerals including phosphuranylite and torbernite coat joints and fractures close to the Revolver Creek Fault (M648/8). This mineralization is spotty, extremely irregular and very limited in extent. It was formed apparently by near-surface uranium enrichment. There is no evidence to suggest this mineralization is connected with the Revolver Creek Fault. It was concluded that no uranium of commercial importance could be expected at depth at this prospect. Anomalous radioactivity of the Revolver Creek Formation was apparently thorium-based (M338).

During operations over the Ragged Range Conglomerate Member which included trenching, shaft sinking for 17 m and 23 core holes for 1 120 m, secondary uranium mineralization represented by carnotite was shown to have no commercial potential (M648/1). The secondary uranium mineralization is restricted to "a top layer of unconsolidated iron-rich conglomerates and sandstones".

CONCLUSIONS

No economic uranium mineralization has been identified in the Kimberley region despite histories of moderately intense exploration between 1955 and 1961, and since 1968.

Over large tracts of the King Leopold and Halls Creek mobile zones and immediately adjoining areas of the Kimberley Basin, the understanding of geology and radiometry is high. In these it is unlikely that there remain unidentified uranium-based radioactive anomalies of any consequence detectable by available airborne instrumentation. It must be concluded that the uranium potential of this country is low though there are important gaps in knowledge. The uranium geochemistry of granites and other possible source rocks and the uranium content of natural waters on a regional scale which may indicate areas of leaching and redeposition of the mineral apparently have not been studied. During further exploration it should be assumed that deposits are concealed and lack surface radiometric response and thus sub-surface exploration methods such as hydrogeochemistry and radon measurement will be required. Possible subjects for investigation are the numerous major faults which characterize the mobile zone. Near Dunham Hill and some 15 km to the south in the Whitewater Volcanics (M648/7) uranium mineralization is found near the Dunham Fault.

On the central and greater part of the Kimberley Basin there is no information on uranium exploration, an absence of exploration attention which is probably explained by the geology of the rocks. For most of the sediments within the basin a marine environment within "a steady ocean current (of the Gulf Stream type)" is suggested by Gellatly and others (1970) on the bases of facies changes and consistency of palaeocurrent directions. Such an environment is not favourable for uranium accumulation (p. 358, International Atomic Energy Agency, 1970). A possible explanation for the low uranium content of the conglomerates of the Kimberley Group and to some extent the Speewah Group is indicated also by the results of Gellatly and others. The conglomerates are considered to have accumulated during temporary reversals of current direction when previously deposited sediments of the basin, principally the Speewah Group, were eroded during uplifts of nearby parts of the mobile zones. A general absence of clasts of igneous rocks within the conglomerates suggests that possible uranium source rocks of the mobile zones were largely uncovered. It appears therefore the conglomerates were chiefly derived from sediments themselves deposited within an environment unfavourable for the accumulation of uranium. Exploration within the basin would need to aim at finding depositional environments of types which present eveidence suggests may not be widely developed.

Elsewhere within the Kimberley region, arenaceous rocks of the Phanerozic, such as the Devonian of the Hardman Basin, which are not known to have been the subject of exploration for uranium, offer possibilities for investigation.

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THE ORD RANGE TIGER-EYE DEPOSITS

by J. G. Blockley

ABSTRACT

Attractive tiger-eye opal formed from crocidolite and set in red, brown and black jaspilite is mined from Archaean iron formation in the Ord Range near Mount Goldsworthy and sold under the trade name "tiger iron". The deposits appear to be the only recorded occurrences of crocidolite in Archaean iron formation.

The original asbestos was best developed in drag folds and later silicification to tiger-eye is related to a duricrusted peneplain surface, which also bears deposits of iron ore.

Of the four deposits of tiger-eye prospected, two are capable of yielding a total of about 150 to 300 t of the gemstone. It should be possible to mine the tiger-eye without interfering with later extraction of nearby iron ore deposits.

INTRODUCTION

Several years ago Perth gem shops began displaying an attractive rock made up of thin, closely spaced bands of golden tiger-eye opal (silicified asbestos) set in red and black jaspilite. It was obvious that the stone did not come from any of the known tiger-eye deposits in the Hamersley Range, but its exact place of origin for a time remained a mystery. Eventually, various sources of information placed its location in the Ord Range, between Port Hedland and Goldsworthy. The early reticence on the location of the deposits was apparently due to their being on a Temporary Reserve for iron ore, and to the consequent difficulties in obtaining mining titles.

The descriptive name "tiger iron" has been coined to refer to the tiger-eye-bearing jaspilite. Although it is now widely used in the gem trade, the term is in fact a trade name registered by the owners of M.C.7686 and should only be used for material from that claim.

The deposits were inspected by Dr. A. Hickman and the writer on May 24th, 1975 and again by the writer on September 15th, 1975. On neither occasion were the claims being worked, and there was no sign of activity in the period between the two inspections.

LOCATION AND ACCESS

The tiger-eye deposits are located at latitude 20° 17′ S, longitude 119° 09′ E, about 4 km on a bearing of 325° from the Survey Station on Mount Saint George (Fig. 55A). Access from the Port Hedland to Goldsworthy road is by way of a winding track branching off near the crossing of the Strelley River. The deposits are on either side of a steep gully which ends in a waterfall over a prominent line of cliffs. One branch of the access track leads to a rock hole at the foot of the waterfall and another climbs a spur and gives direct motor access to the deposits. The claims can also be reached by a former Goldsworthy Mining Ltd. exploration track which connects with the old Broome road west of the Ord Range.

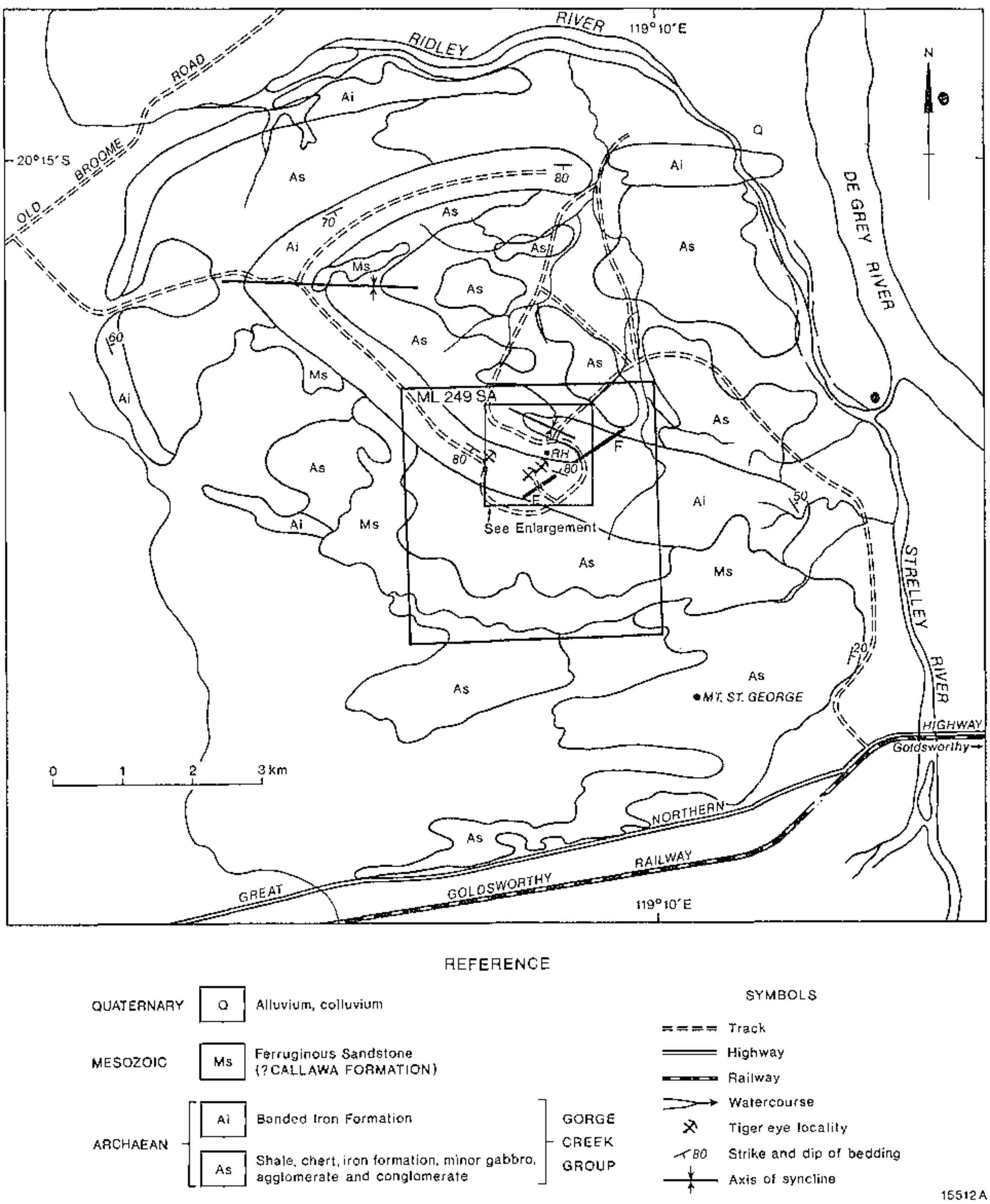


Figure 55. Plans showing locality and regional geology of the Ord Range Tiger-eye deposits.
A. Regional geological map showing access routes to the deposits.

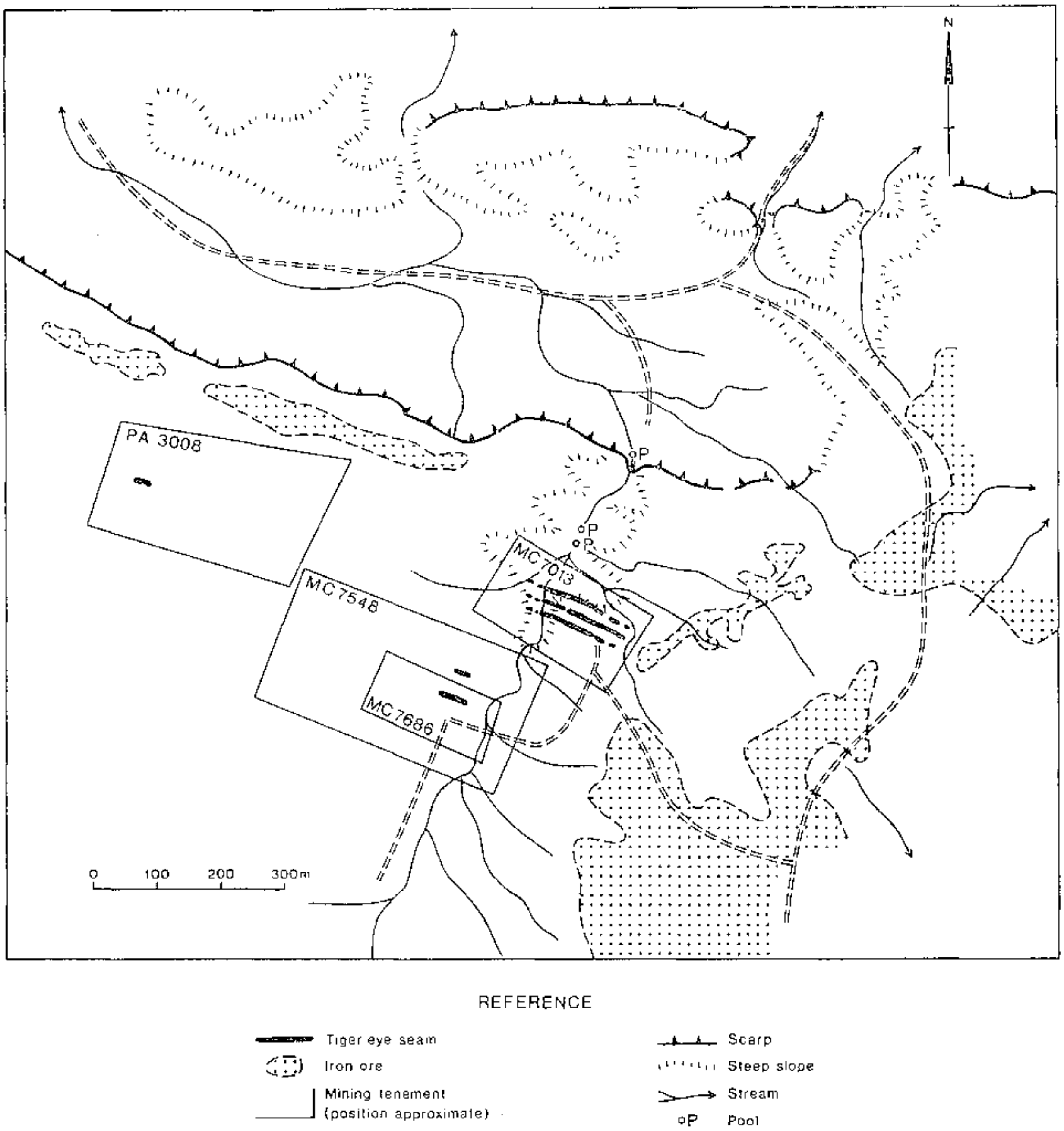


Figure 55B. Plan showing relationship of tiger-eye deposits to mining tenements and iron ore deposits. (Tenement boundaries are approximate only).

HISTORY AND TENURE

The first tenement registered for gemstones in this area, P.A. 2988 (now M.C. 7686), was taken up by J. Glass in November 1971. This was quickly followed by P.A. 2995 (now M.L. 7013) pegged by A. Williams and A. Davies, and a year or so later by P.A. 3008, applied for by R. Gray and subsequently refused. The current tenement situation is:—

- MC 7013 Ord-Riddley Mining Pty. Ltd. (Approved)
- MC 7548 Ord-Riddley Mining Pty. Ltd. (Approved)
- MC 7686 Gelene Holdings Prop. Limited (Approved)
- PA 3008 R. Gray (Refused)

All claims lie within Section 9 of M.L. 249 SA covering iron ore deposits of Goldsworthy Mining Ltd. The lease was formerly part of iron ore T.R. 2574H. Locations of the various tiger-eye tenements are shown in Figure 55B.

No production of gemstones has been reported to the Mines Department from this locality, although the widespread distribution of the "tiger iron" in Perth gem shops and specimen cabinets indicates that a significant quantity has been mined.

GEOLOGICAL SETTING AND CONTROLS OF THE DEPOSITS

The tiger-eye deposits are situated within the thickest banded iron-formation (BIF) member of a sequence of chert, iron formation, ferruginous shale and volcanic rocks correlated with the Archaean Gorge Creek Group (Low, 1965; Hickman and Lipple, 1975). A prominent horseshoe-shaped ridge formed by the outcrop of the main BIF member reflects regional folding about a west-plunging syncline axis lying north of the deposits. South of the tiger-eye prospects, a regional antiform with an ill-defined axis passing through Mount Saint George is picked out by a sinuous ridge of chert. Drag folds on all scales from hundreds of metres to a few centimetres are common, and in places form local structurally complex areas.

Figure 56. Photographs of structures associated with the tiger-eye.

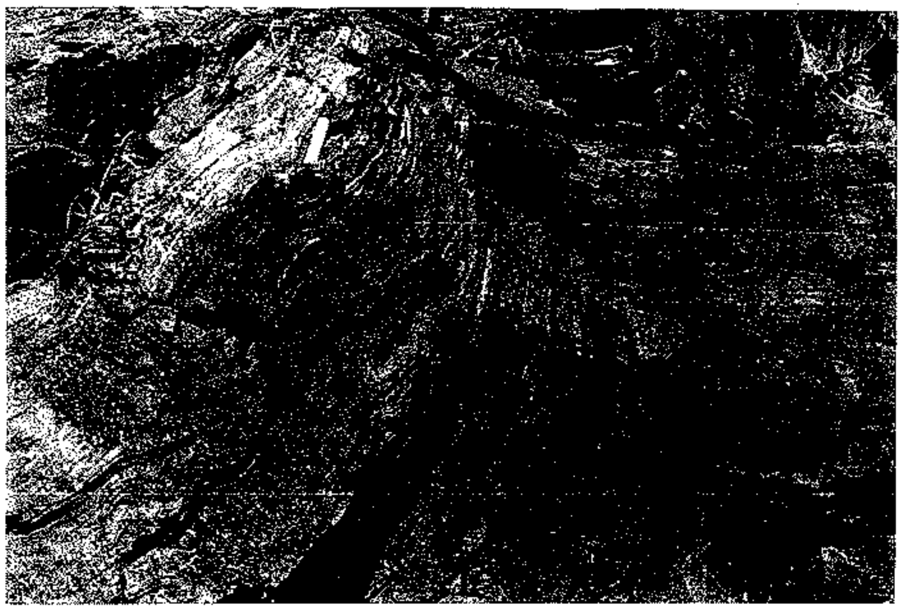
A. Several seams of tiger-eye developed in steeper limb of a small monocline, with greatest concentration near the hinge line of the fold.

B. Specimen of small drag fold with tiger-eye is of the type highly regarded by gemstone dealers. The cross fibre has formed only in the more open limbs of the fold.

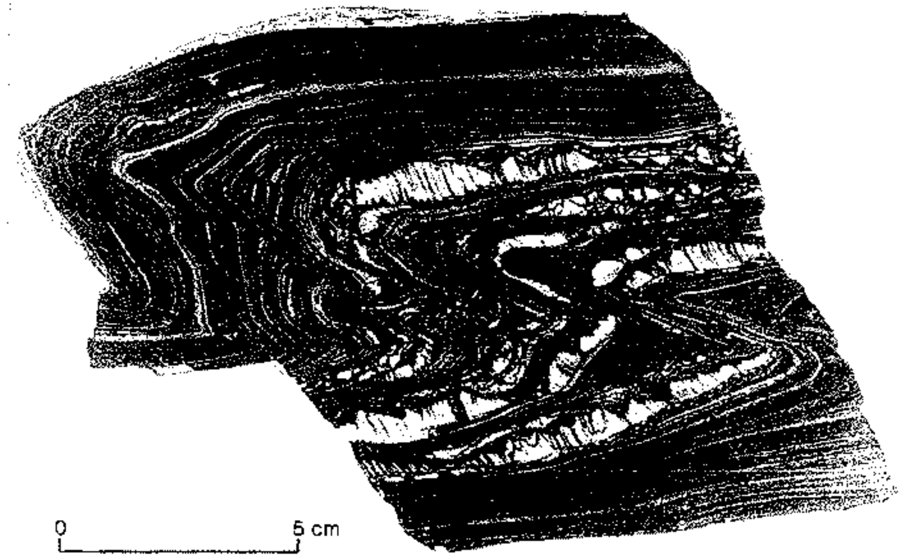
C. Typical seam of tiger-eye showing lenticular habit of individual bands, central parting of iron oxides, and cone structures.

D. Typical monoclinal step fold photographed looking easterly along axis. A seam of fibre is present in the steep southern limb.

A



B



C

D

Overlying the Archaean rocks and flanking the main BIF ridge are several mesas of flat-lying ferruginous sandstone, regarded tentatively as outliers of the Upper Jurassic Callawa Formation.

Remnants of an old (?Tertiary) peneplain on the crests and upper slopes of the BIF and chert ridges are capped by duricrust and canga, which in a number of places can be considered as potential iron ores.

The main BIF member is about 600 m thick where least folded. It consists mainly of red, black and brown magnetite-rich jaspilite, but also contains banded grey, white and red chert, ferruginous shale, and nearly structureless jasper. Features resembling cross pods and small macules (Trendall, 1966) are common. Ripple-like structures on many bedding surfaces follow the expected drag-fold direction and are almost certainly of tectonic rather than sedimentary origin.

A section of the upper part of the main BIF member as exposed in the gully traversing the tiger-eye claims is, from top to bottom:

Approximate thickness (m)	Description
10 to 15	Brecciated, poorly banded jasper
120	Thinly mesobanded magnetite-rich BIF with red cherts
30 to 40	Black, pink and white BIF with thicker (3-5 cm) pink microbanded cherts spaced at intervals of 10 to 20 cm
70	Shaley iron formation weathering out to form a strike valley
+200	Thinly mesobanded red, black and brown magnetite-rich BIF with tiger-eye

The BIF with the thicker pink chert bands may constitute a usable marker horizon within the unit.

The cross-fibre asbestos parent of the tiger-eye appears to be confined to the lowermost of the units described above, but any more precise stratigraphic control could not be identified. It appears that the fibre may appear anywhere within the unit where geological conditions are favourable.

Structure has been an important agent in localizing the asbestos. All of the richer concentrations are situated in zones of crumpling and drag folding. Where a mineralized horizon can be traced away from a drag-folded zone into a relatively undisturbed area the fibre content decreases markedly. A small-scale example of structural control on a drag fold is shown in Figure 56A. On a broader scale the whole area of the deposits is situated at the margin of an extremely complexly folded zone and it is also close to a northeasterly-trending fault.

The tiger-eye opal was formed by replacement of the asbestos in parts of the BIF close to the duricrust capping. The best material is within 5 m or so of the duricrust; in the gorge which cuts the deposits, the tiger-eye is paler and more friable. Another feature which varies with depth is the colour of the associated chert, which is redder near the old surface.

MINERALOGY AND STRUCTURE OF THE TIGER-EYE

The tiger-eye opal was formed by oxidation and silicification of a pre-existing amphibole asbestos. Optical and X-ray studies carried out by the Government Chemical Laboratories in 1972 on fibres extracted from a sample of the opal indicate that the original fibre was crocidolite. Further samples of apparently less silicified fibre submitted to the Government Chemical Laboratories in 1975 failed to produce any positive indication of the identity of the parent asbestos.

The best of the silicified material is golden yellow with a strong chatoyancy. Its effect is enhanced where the tiger-eye bands are closely spaced and where the intervening chert bands are red. The most prized specimens are those in which the banding is folded (Fig. 56B).

Fibre bands are typically 0.5 to 1.0 cm wide, but each band varies considerably in width due to cone structures and pinch and swell effects. Kink bands in the fibre add a second dimension to the chatoyancy of the tiger-eye. Most bands have a central iron-oxide parting of irregular shape (Fig. 56C). Typical seams (i.e. groups of bands clustered closely enough to be extracted as a unit) range from 10 cm to 2 m in stratigraphic thickness.

True quartz fibre, as distinct from the tiger-eye, is also present in places.

COMMENT ON THE AGE OF THE DEPOSITS

Elsewhere in the world, crocidolite has been recorded from iron formations only in the Cape Province of South Africa, the Hamersley Range of Western Australia and the Lake Superior and Labrador regions of North America. All of these iron formations are of Proterozoic age.

Current geological mapping by this Survey has confirmed the Archaean age of the BIF in the Ord Range, and it appears that the occurrence of crocidolite here is the only one of this early age so far reported.

DESCRIPTION OF DEPOSITS

M.C. 7013

The most extensive deposits are on M.C. 7013 where the iron formation is folded into a series of monoclinal steps (Fig. 56D). Fibre occurs over a horizontal width of 30 to 40 m in which about three seams have been worked. The better tiger-eye is on the steeper limbs of the monoclines. Mining has been carried out by breaking the surface exposure with a bulldozer and ripper, followed by further hand breaking to extract the saleable material. It is not possible to estimate the amount of material removed as there are no well-defined openings whose volume can be measured. However, about 30 or 40 200 l drums on site probably give an idea of the scale of the claim holders' envisaged future operations.

M.C. 7686

In this claim tiger-eye has been mined from seams spread over a width of about 20 m and a length of 100 m. The host BIF is contorted, with the fibre particularly well developed in drag folds. The seams are less abundant than on M.C. 7013 but the average quality of the stone is better, probably because the claim is closer to the duricrust. Workings consist of a costean, probably 3 or 4 years old, and surface bulldozing. Again no estimate of production can be made on the ground, but the lease holders state that they have about 100 t stockpiled in Perth.

M.C. 7548

This claim surrounds M.C. 7686 and covers tiger-eye in an horizon 30 or 40 m above that worked in M.C. 7686. No development has been done and in general the fibre bands are too widely spaced to give good quality commercial stone.

P.A. 3008

This area is on strike with and about 500 m west of the deposit on M.C. 7548. A few pits have been excavated on comparatively sparse seams of tiger-eye in zones of minor drag folding. Between P.A. 3008 and the other deposits the BIF dips steeply and uniformly north and contains very little fibre.

CONFLICT WITH IRON ORE INTERESTS

Because the tiger-eye deposits are within a mineral lease (formerly a Temporary Reserve) for iron ore there has been a predictable conflict of interests. From a geological point of view, mining the tiger-eye can have no detrimental effect on the reserves of enriched ore in the lease and only an insignificant effect on the reserves of taconite ore. The conflict arose mainly because the area of any tenement granted for gemstones is automatically excised from the iron ore tenement, and the holders of the iron ore rights would have been denied access to certain of their deposits had all gemstone areas been granted. However, the best deposits are now within approved mineral claims and ample supplies of tiger-eye are available for the gem market.

ESTIMATED RESERVES

Given conservative assumptions that only about 1 per cent of material in the ore zones is suitable for polishing, and for reasons of fall-off in quality or difficulties of mining, the material can only be quarried to a depth of 1 m, then estimated reserves amount to about 100 to 200 t in M.C. 7013 and 50 to 100 t in M.C. 7685. These reserves are sufficient to maintain the sale of gemstones but could not long support any more ambitious programme to produce facing stones from the material.

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Trendall, A. F., 1966, Second progress report on the Brockman Iron Formation in the Wittenoom-Yampire area: West. Australia Geol. Survey Ann. Rept. 1965, p. 75-87.

GEOLOGY AND GEOCHRONOLOGY OF ALTERED RHYOLITE FROM THE LOWER PART OF THE BANGEMALL GROUP NEAR TANGADEE, WESTERN AUSTRALIA

by R. D. Gee, J. R. de Laeter*, and J. R. Drake

ABSTRACT

The Bangemall Basin is the youngest major Proterozoic sedimentary basin in the Western Australian Shield. Approximately 60 m above the basal unconformity in the central part of the basin, there occurs a line of six small rhyolite bodies within Bangemall Group conglomerates. The attitude of contorted flow banding indicates these bodies erupted as viscous lava domes or plugs. Initially the rocks were glassy rhyolites with quartz and sanidine phenocrysts, but subsequent alteration has resulted in extreme enrichment of K_2O, and depletion of Na_2O. Rb-Sr isotopic data give an isochron of 1 098 ± 42 m.y. which probably dates the alteration event. This age accords well with previous scant isotopic dates elsewhere in the Bangemall Group. The rhyolite probably formed by local melting on a movement plane in the basement granitoid during early development of the Bangemall Basin.

INTRODUCTION

A small but well-exposed occurrence of altered, flow-banded rhyolite was recently encountered at lat. 23° 37′ 00″ S, long. 118° 47′ 00″ E near Tangadee by J. C. Barnett of this Geological Survey during regional mapping in the central part of the Bangemall Basin. This occurrence, which appears to be one of the few unequivocal examples of felsic volcanic rocks in the Bangemall Group occurs at a stratigraphically low level, only about 60 m above the basal unconformity, at a point where a relatively large basement high of probable Lower Proterozoic granitoid is exposed in the axial part of the basin.

The Bangemall Group is composed of a sequence of conglomerate, carbonates, sandstone, chert, and shale that forms the youngest major Precambrian sedimentary basin in the Western Australian Shield. Both unpublished company exploration reports and published literature, including the review by Gee, 1976, refer to volcanic or volcanogenic material, especially at the stratigraphic level just below the Discovery Chert. Unusual siliceous and potassium-rich shales appear to be widespread at this general level, although their precise volcanic content is uncertain.

Daniels (1969) refers to a felsic volcanic occurrence near Mount Palgrave in the western part of the Bangemall Basin, found by Westfield Minerals (W.A.) N.L. This occurrence is believed to be a dyke and related flow (J. L. Daniels, pers. comm.) in siliceous shale immediately beneath the Discovery Chert. Daniels (1969) also refers to tuffaceous sandstones in the Kiangi Creek Formation, which is low in the sequence.

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The discovery of rhyolite near Tangadee, although of small extent and at an unexpected stratigraphic level, is therefore important, as it establishes felsic volcanic activity in this part of the Bangemall Group, and also provides material that may date the beginning of the Bangemall Group. Compston and Arriens (1968) have previously obtained a poor Rb-Sr isochron of about 1 080 m.y. from the Mount Palgrave felsic rocks, and also a Rb-Sr age of 1 080 ± 80 m.y. from shale in the Curran Formation which lies about 700 m stratigraphically above the Discovery Chert. These represent the only previous geochronological controls of the Bangemall Group.

The purpose of this paper is to document the Tangadee occurrence, to discuss its origin and significance, and to report on its age.

FIELD OCCURRENCE

ENVIRONMENT OF ERUPTION

The rhyolite occurs within a basal conglomeratic unit. The underlying rocks are predominantly cobble and granule conglomerate composed of quartz clasts in a gritty matrix of single-crystal quartz and feldspar grains derived from the basement granitoid. Beds of fairly well-sorted and cross-bedded sandstone occur within the underlying conglomerate. The overlying conglomerates are much coarser, consisting of well-rounded boulders and cobbles of quartz, jaspilite (presumably of distant origin), and sandstone. Festoon cross-stratified beds about 1 m in thickness are present. Granite and rhyolite clasts are generally absent, and except for one important occurrence discussed below, the conglomerate is devoid of volcanic clasts.

The rhyolite was erupted onto sheets of well-washed clastics that were deposited in shallow water, and then covered by coarse fluvial rubble that was deposited from fast, pebble-laden braided streams.

THE RHYOLITE BODIES

Six plugs (designated as shown in Figure 57) occur over a strike length of 2.5 km, along a line trending east-northeast. Only bodies A and B have been examined in detail; however, they are all characterized by broadly concordant tops and bases, steep discordant walls, and complex flow layering. On the northwestern end of body F a cleft is present in the top of the rhyolite as it dips under the overlying conglomerate. In this cleft is a bed of conglomerate about 1 m in thickness which sits on the rhyolite and contains angular fragments of rhyolite. The rhyolite fragments are about 5 cm in diameter. This important feature establishes clearly that at least one rhyolite plug broke through to the surface.

There is a surprising lack of any thermal metamorphic effects, even at the bases. Consequently the steep discordant walls are difficult to interpret. They may either be walls of intrusives, or the walls of steep-sided domes that stood up above the sediments.

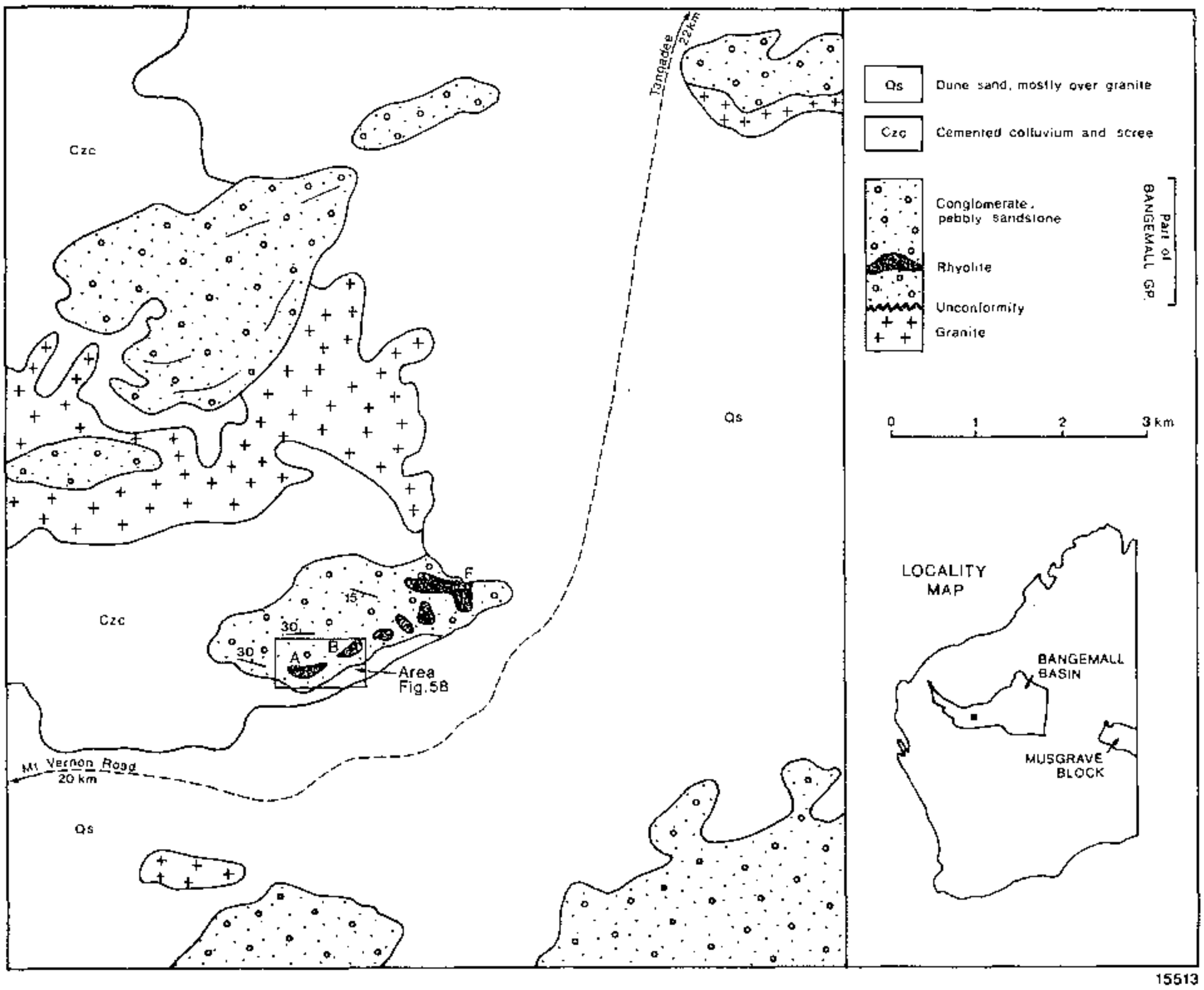


Figure 57. Locality diagram showing geological setting of rhyolite bodies near Tangadee.

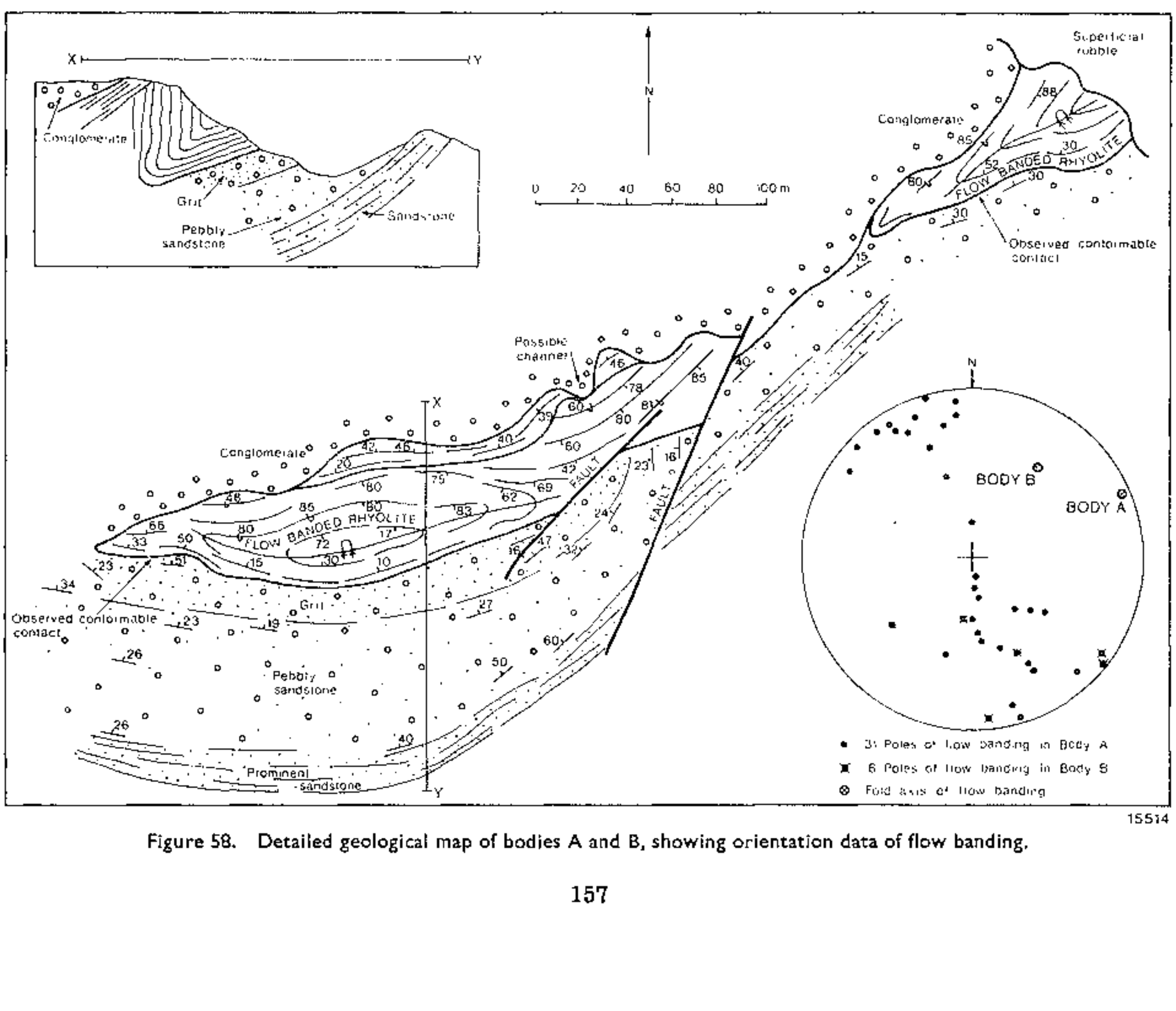


Figure 58. Detailed geological map of bodies A and B, showing orientation data of flow banding.

MORPHOLOGY OF BODIES A AND B

Figure 58 is a detailed map of body A and the exposed part of body B. A most interesting feature is the flow layering which forms an overturned synformal fold whose upper limb is, in places, truncated and capped by a thin planar layer of rhyolite. The enclosing conglomerates dip about 20 to 30° north, and if this dip is flattened, the synform would be recumbent. Except where complicated by later faulting the bottom contacts are invariably conformable, and the actual contacts are observable at the points shown on Figure 58. Orientation data for the banding are shown stereographically in Figure 58.

The fold axis in body A is almost horizontal, and the apparent canoe-shaped outline of the traces of the flow banding is an apparent effect due to topography. In body B, the axis plunges moderately northeast, but would rotate to subhorizontal if the dip of the enclosing sediments was turned back to horizontal about the east-northeast strike. Bodies A and B therefore appear to comprise the same synform. The overturning indicated on the traces of flow banding is relative to the lower contact which is concordant and therefore upward facing.

The planar capping on body A is present only on the central and thickest portion. At the extremities, gently dipping conglomerate directly overlies the vertically banded rhyolite. The overlying conglomerate appears to transgress the different parts of the body, although the true relationship is difficult to establish conclusively because the exposure of conglomerate is expressed only as a thin veneer of bouldery rubble on a flat hill top. In a few places small areas of conglomerate have been stripped off by recent erosion, exposing a smooth flat top to the vertically banded rhyolite.

A depression occurs in the top of the body at the position shown in Figure 58. This depression cuts down through the planar capping to intersect the vertically banded part. Although no fragments of rhyolite occur in this depression, it has the form of an erosional channel.

These features of the upper contact of body A, together with the cleft in the top of body F, are taken to indicate an erosional top that was washed clean and smooth prior to covering by the conglomerate.

GENERALIZED RECONSTRUCTION OF THE PLUGS

The alignment of the bodies, the concordant bases but disconformable walls, the recumbent folding of the banding which is discordantly capped by planar-banded rhyolite, and the eroded tops are depicted diagrammatically in Figure 59. The rhyolite appears to have erupted along a fissure, forming a line of viscous domes that grew upward and outward as the earlier extruded rhyolite was shouldered aside by later extrusions and slumped laterally. The plugs were then subject to active scouring that removed most of any associated debris. Based upon this model, the total volume of rhyolite extruded would not exceed 0.02 km^3. The amount removed by erosion is unknown, but could be of the same order of magnitude.

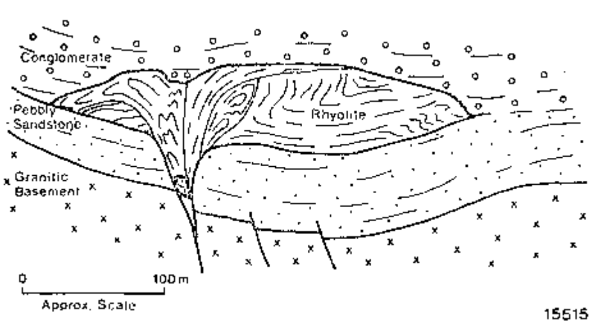


Figure 59. Generalized reconstruction of a rhyolite plug.

FLOW BANDING IN THE RHYOLITE

The flow banding is a varicoloured delicate lamination invariably showing fine crumpling and in places also fragmentation. The rhyolite is aphanitic with a pearly lustre, and mostly colour banded in tones of pale cream and buff. The more oxidized varieties are pallid but the banding is accentuated by very thin pale green and pink laminae, whereas those fresh specimens still retaining unoxidized pyrite are streaked with black and dark grey.

Individual laminae, which vary in thickness from paper-thin to a few centimetres, are laterally continuous over distances of several centimetres to several metres. Termination of laminae is mostly due to intricate folding which produces attenuation of limbs, microscopic detachment planes parallel to the banding, and minute detached fold cores (Fig. 60, A and B). The laminae also show regular pinching and swelling that predates the folding. All these features impart to the rock a streaky eutaxitic banding.

Phenocrysts of quartz and feldspar, up to 3 mm in diameter are wrapped by the flow banding, and commonly have coronas and tails of rolled-up laminae.

The folds vary in style from angular crumpling to truly isoclinal, and even crumpled isoclinal cores. There is a general tendency for the axes of microfolds to align with the main overfold, and in places this is strong enough to give the rock a conspicuous lineation. However, this is not a stretching or flow lineation along the direction of flowage, which is deduced to be perpendicular to the axis of the overfold.

Fragmentation is clearly the result of *in situ* disruption of once continuous laminae by folding. Where this fragmentation is strong the texture is dominated by small sinuous vermiform pale-coloured fragments completely encircled by darker material (Fig. 60D). There is no evidence whatsoever of primary fragmental texture in the form of shards and streaked pumiceous fragments and so the rock is not considered to be a welded ash-flow.

PETROGRAPHY

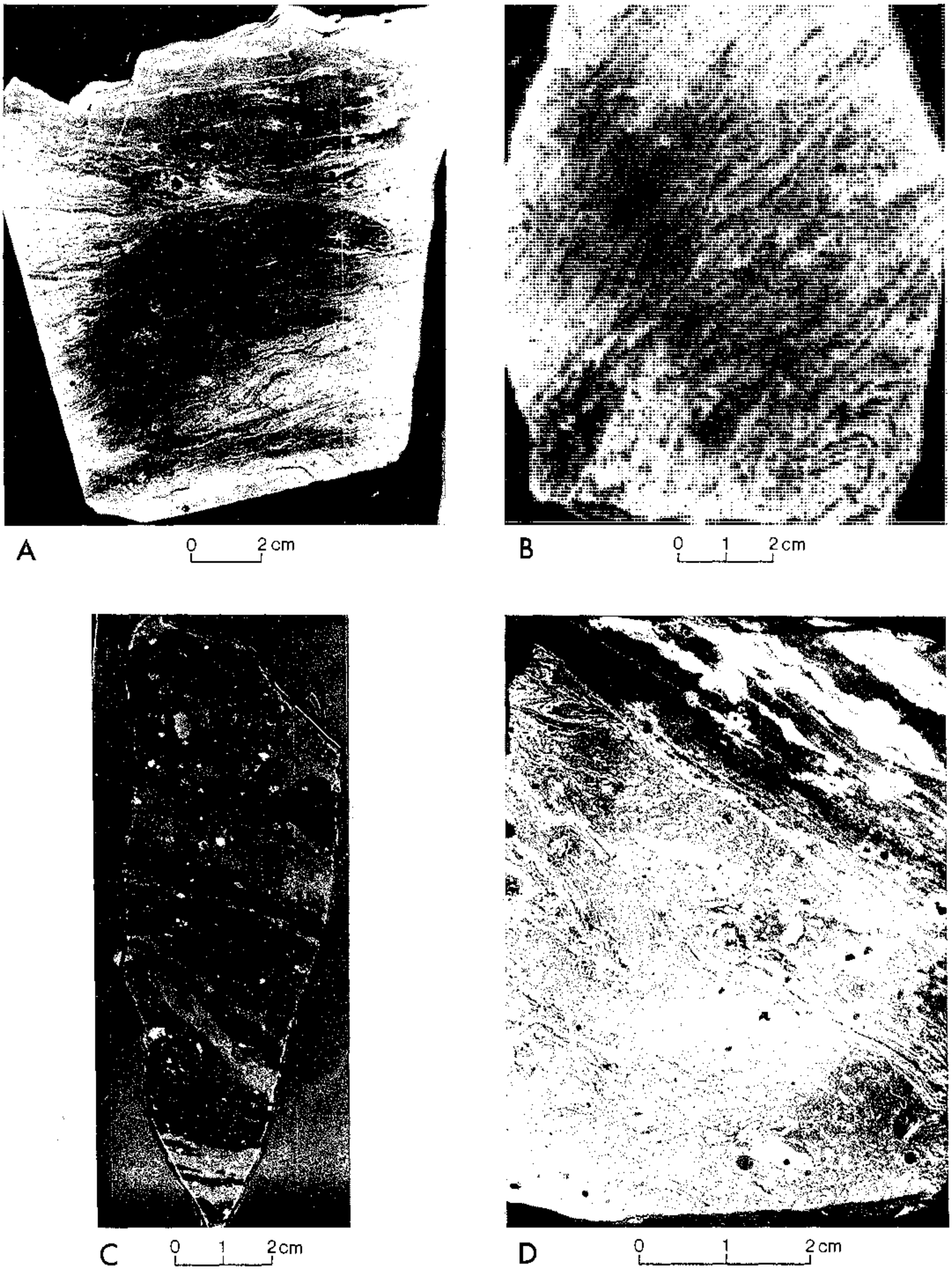
In thin section the rhyolite consists of euhedral quartz and feldspar phenocrysts, in a cryptocrystalline groundmass of mainly quartz and microcline, with accessory biotite, chlorite, zircon, and opaques. The overwhelming predominance of quartz and microcline in the mode is confirmed by X-ray diffraction.

The quartz phenocrysts are hexagonal (Fig. 61A) or rhomboidal in section (Fig. 61B), preserving the bipyramidal shape of β-quartz. Most phenocrysts are embayed by the groundmass, and many have become well rounded. Fragmentation of phenocrysts is rare, although many show healed cracks.

The feldspar phenocrysts now consist of granular intergrowths of quartz and microcline with small rosettes of chlorite and are euhedral with a monoclinic pseudohexagonal outline (Fig. 61C). These are considered to have been sanidine phenocrysts. Quartz and former sanidine phenocrysts amount to about 5 per cent of the rock, and commonly form glomeroporphyritic aggregates.

Irregular or distinctly spherical-shaped lithophysae, generally less than 2 mm in diameter, are sparsely distributed. These bodies generally contain quartz and microcline with a diffuse concentric structure, but also contain chlorite, carbonate, ilmenorutile, and sulphide. The dark square spots in Figure 60A consist of poikilitic pyrite (now oxidized) intergrown with quartz, and this structure is encircled by concentric rings of a quartz and microcline mosaic. Fresh skeletal pyrite with intergrowths of quartz especially in the cores, is shown in Figure 60C (the clear white phenocrysts in this photograph are altered microcline).

Figure 60. Flow banding on polished slabs of rhyolite near Tangadee.
A. Specimen 47025. Eutaxitic flow banding. Note detached microfold in centre, intricate crumpling of fine microlamination lower centre, and small lithophysae (primary sphenulites) with opaque cores.
B. Specimen 47021. Strongly folded, irregular lamination; however, note paper-thin internal laminae in isoclinally folded pale coloured band in centre of photograph.
C. Specimen 4 030. Dark grey and black irregularly streaked rhyolite. Larger white subhedral phenocrysts are altered sanidine, the smaller darker spots are intergrowths of quartz in skeletal pyrite.
D. Specimen 47024. Disrupted and fragmental laminae. Note wrapping of small lithophysae by laminae. Fragmented layer is capped by planar banded rhyolite with continuous microlaminae.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B
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D
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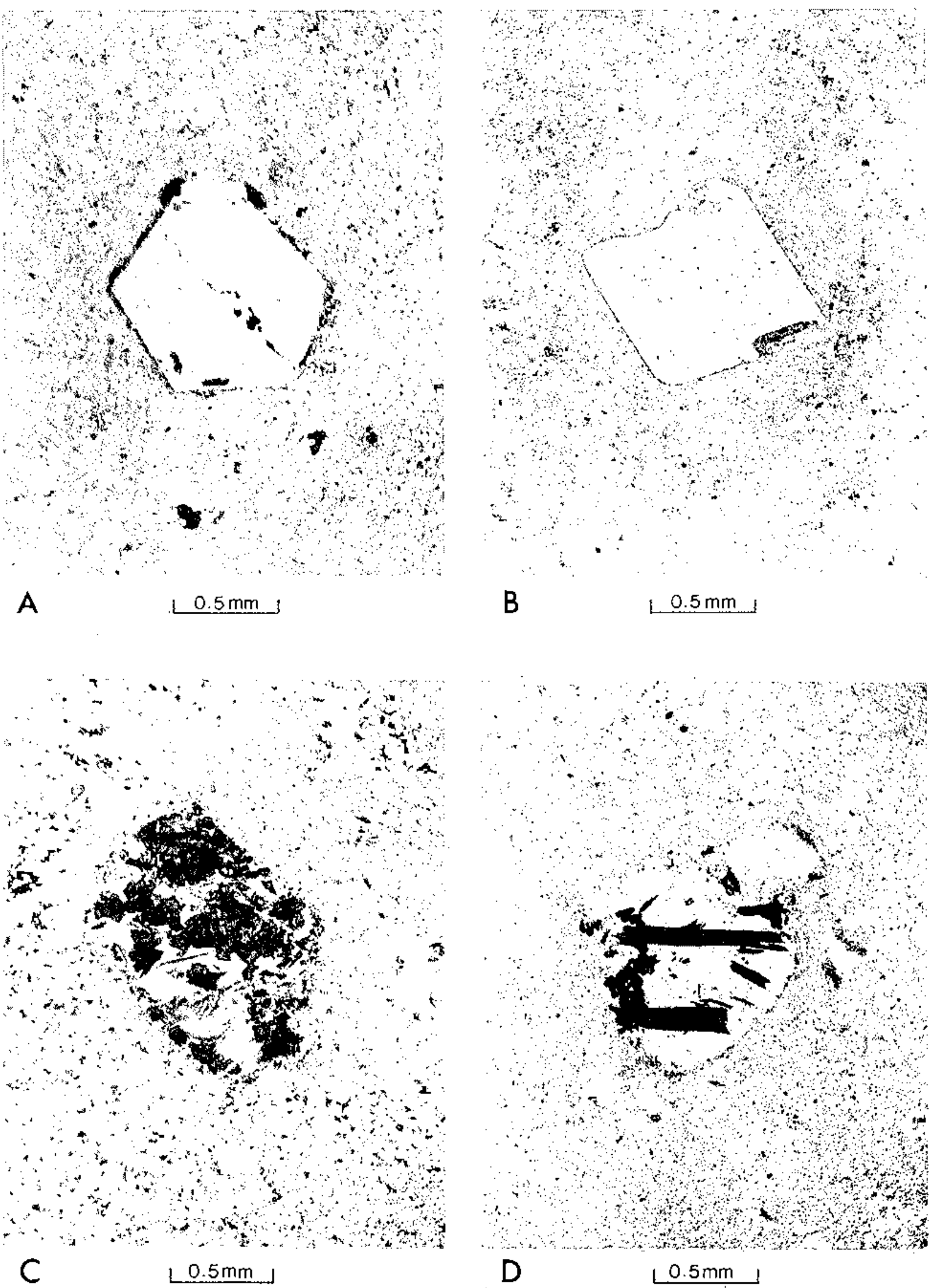
A
0.5mm
B
0.5mm
C
0.5mm
D
0.5mm

–· re 61. Photomicrographs of rhyolite near Tangadee.

A. Hexagonal cross section of original B-quartz phenocryst in fine-grained groundmass. A healed fracture crosses the phenocryst. Plane polarized light.
B. Partially resorbed bipyramidal phenocryst of original B-quartz. Curved trails of fluid inclusions in phenocryst may be healed fractures. Plane polarized light.
C. Euhedral phenocrysts, formerly of sanidine in fine-grained groundmass. The phenocrysts is now microcline, with abundant inclusions of chlorite. Plane polarized light.
D. Irregular-shaped body infilled with fine-grained quartz and microcline, and containing needles of black ilmenorutile. Plane polarized light.

Figure 61D illustrates another type of lithophysae, in this case black needles of ilmenorutile are encased in a globular aggregate of quartz and microcline. A partial analysis of the ilmenorutile gave the following ratios by weight; TiO_2:FeO: Ta_2O_5 : Nb_2O_5 = 84 : 7 : 0.6 : 8.

These lithophysae are wrapped by the flow banding, and therefore were in existence as solid objects while the lava was still flowing.

Despite the perfect preservation of the thin laminae that is conspicuous on polished faces, in thin section the groundmass is a featureless cryptocrystalline mosaic probably resulting from the devitrification of glass. These is no evidence of shards or perlitic cracking. Although patches of "snowflake" texture are visible under a hand lens, a texture considered by Anderson (1970) to be indicative of an ash-flow tuff, but refuted by Green (1970), the balance of evidence is that these rocks were lavas and not welded tuffs.

In summary these rocks were initially extruded viscous glassy lava that contained phenocrysts of β-quartz and sanidine. The origin of the flow banding is uncertain, as the original geochemical and textural contrasts, if any, between laminae are not known.

GEOCHEMISTRY

Chemical analyses of three samples from body A are given in Table 30. They show a chemistry most unusual for rhyolite, but compatible with the modal predominance of microcline and quartz. Normatively they average 36 per cent *q*, 56 per cent *or*, and 1.5 per cent *an*. Also included in this table for comparison, is the average calc-alkali rhyolite of Nockolds (1954), and also an analysis of the Hilda Rhyolite of the Cassidy Group from the Warburton Range (Daniels, 1974). This latter analysis is included because it is the most potassic and siliceous rhyolite in that area, and it is of similar age to the rhyolite at Tangadee. Clearly the rhyolite near Tangadee is highly altered, as emphasized by extremely high K_2O and extremely low Na_2O.

TABLE 30. CHEMICAL ANALYSES OF RHYOLITE NEAR TANGADEE

Oxides (%)	1	2	3	4	5
SiO_2	78·0	76·1	74·9	73·06	71·34
Al_2O_3	11·1	12·3	12·3	13·45	12·64
Fe_2O_3	0·12	0·21	0·13	1·25	2·73
FeO	0·49	0·37	0·84	0·75	1·72
MgO	0·02	0·02	0·23	0·32	0·79
CaO	0·10	0·06	0·04	1·13	0·00
Na_2O	0·15	0·15	0·20	2·99	2·87
K_2O	9·06	9·21	10·45	5·35	6·13
H_2O+	0·51	0·80	0·29	0·78	0·34
CO_2	0·02	0·02	0·02	....	<0·01
TiO_2	<0·01	<0·01	<0·01	0·22	0·31
P_2O_5	<0·01	<0·01	<0·01	0·07	0·30
SO_3	0·04	0·03	0·03	....	....
Cr_2O_3	0·32	0·26	0·04	....	<0·01
V_2O_5	<0·01	<0·01	<0·01	....	0·01
MnO_2	<0·01	<0·01	<0·01	0·03	0·10
Total	99·97	99·57	99·87	....	....
Elements (ppm)					
Cu	45	190	110		
Li	<5	<5	<5		
Mo	<10	<10	<10		
Pb	110	110	65		
Rb	150	160	180		
Sn	<20	20	<20		
Sr	20	20	20		
W	5	<5	<5		
Zn	17	16	15		

1, 2, 3: G.S.W.A. Samples 41839A–C, rhyolite near Tangadee, body A. *Analyst:* Government Chemical Laboratories. Major oxides by classical methods, trace elements by atomic absorbtion and colorimetric methods.
4: Average calc-alkali rhyolite from Nockolds (1954)
5: Hilda Rhyolite quoted by Daniels (1974)

TABLE 31. ALKALI AND RELATED TRACE ELEMENT GEOCHEMISTRY FOR RHYOLITE NEAR TANGADEE

G.S.W.A. sample no.	Rhyolite body	* Na_2O (%)	* K_2O (%)	Rb (ppm) *	Rb (ppm) †	†Sr (ppm)	K/Rb	†Rb/Sr
47019	A	0·12	9·42	150	....	....	521	....
47020	A	0·15	10·2	150	155	10·6	545	14·4
47021	A	0·13	8·02	130	130	9·1	512	14·3
47022	A	0·14	9·84	150	....	....	545	....
47023	B	0·15	7·79	170	167	10·9	387	15·5
47024	A	0·16	7·92	140	156	10·7	420	14·4
47025	A	0·12	5·74	110	118	8·2	403	14·5
47026	A	0·14	7·60	140	145	11·1	440	13·1
47027	B	0·20	9·97	170	189	12·6	438	15·2
47028	F	0·10	7·15	140	237	7·7	250	31·2
47029	F	0·17	7·35	145	166	8·2	369	20·1
47030	F	0·19	8·37	115	168	8·0	413	21·0

**Analyst:* E. Tovey, Government Chemical Laboratories—atomic absorption.
†*Analyst:* J. R. de Laeter. The Rb and Sr concentrations, and the Rb/Sr ratios have been measured by X-ray fluorescence spectrometry. The Rb and Sr concentrations have been determined by comparison with a number of standard rocks from an assessment of the mass absorption coefficient of each sample, and are accurate to ± 7 per cent. The Rb/Sr ratios are accurate measurements and do not correspond exactly with the ratio derived from the separate Rb and Sr determinations. K/Rb ratios derived from de Laeter data where available.
Rb determinations by different analysts are made from different crushings of the same sample.

In order to examine this unusual geochemistry of the alkalis, an additional 12 samples from scattered locations in bodies A, B, and F were analyzed for K_2O, Na_2O, and Rb (Table 31). These samples formed the pool of samples for isotopic mass spectrometry, and independent Rb and additional Sr values are also included in Table 31.

These figures confirm remarkably constant levels of potassium enrichment and sodium depletion. There is no correlation between Na_2O and K_2O, there being a variation of 5.7 to 10.2 per cent K_2O with virtually fixed values of negligible Na_2O. There is no correlation between K_2O and Rb, thus similar values of K_2O (specimen 47023 and 47030 in Table 31) produce the widest range of Rb. The rubidium values are not excessively high, comparing favourably with the value of 115 ppm Rb for the average Andean calc-alkaline rhyolite of Solomon and Griffiths (1975). However, the strontium is severely depleted in comparison with the value of 123 ppm Sr for the same average rhyolite. Unreasonably high values of K/Rb, in comparison with that for a calc-alkaline rhyolite of about 350 ppm also points to a strong enrichment of potassium relative to rubidium.

Geochemically these rocks bear no comparison to any known volcanic rock series, however, they do bear comparison to some altered rhyolite in alteration zones and fumarolic mounds within otherwise normal rhyolite. For example Ratté and Stevens (1967) quote a range of 7 to 11 per cent K_2O and 1.3 to 0.40 per cent Na_2O in the Batchelor Mountain rhyolite in the Creede Caldera. Similar, but not quite so extreme values were obtained from fumarolic mounds in a Pleistocene rhyolite ash-flow tuff by Sheridan (1970).

The presumed alteration processes include a slight increase in SiO_2, dramatic increase in K_2O together perhaps with an increase in Rb, almost total loss of Na_2O, and loss of CaO and related Sr. These trends are consistent with weathering; however, the very low values of H_2O^+, the presence of fresh sulphides, the geochemical homogeneity, the general clarity of the microcline, together with the hard flinty appearance of the rock suggests that the alteration considerably predated any recent weathering.

Geochemically the rhyolite is comparable to an analysis of the Woongarra Volcanics published by Trendall (1972, p. 72). Additional unpublished analyses of the Woongarra Volcanics (A. F. Trendall, pers. comm.) show an inverse variation between Na_2O and K_2O to extremes that match the rhyolite at Tangadee.

The geochemistry is also directly comparable to unusually high-potash shales with volcanogenic content in a transition zone between dolomite and banded iron-formation in the Lower Proterozoic Hamersley Group, noted by Davy (1975, p. 94). Davy (1975, p. 97) discusses mechanisms for potassium enrichment, involving fixation of potassium ions from sea water on to montmorillonite clays that may form in the early stages in the devitrification of volcanic glass shards. The net result is the formation of nearly pure authigenic potash feldspar.

Another possible mechanism involves initially the conversion of both the feldspar phenocrysts and glassy groundmass, both of which should have contained a considerable molecular proportion of albite, to analcime and other zeolites, during incipient burial metamorphism. Shephard and Gude (1973) have shown petrographically that zeolites can then be completely replaced by pure potash feldspar. They envisage this to be a low-temperature ion-exchange reaction of Na^+ in the zeolite for K^+ in circulating bore water, in an alkaline and slightly saline environment.

Because of the complete textural and chemical reconstitution of the rhyolite near Tangadee, there are no clues to the mechanism and timing of the alteration. The cryptocrystalline nature of the groundmass points to complete devitrification of the groundmass, to which was probably related the alteration of the sanidine. There is no indication that zeolite was, or was not present, so that either mechanism outlined above is possible.

From the geochronological point of view, it seems that the last isotopic homogenization would date the alteration event, and not the primary crystallization of the lava.

GEOCHRONOLOGY

The experimental procedures of Rb-Sr isotopic analysis are essentially the same as those described by Lewis and others (1975). However, an additional step was introduced in the ion-exchange chemistry to remove alkali and alkali earth impurities. The eluate from cation exchange column was redissolved in 11M HCl and loaded on a small cation column. After washing with several column volumes of 11M HCl, the Sr was eluted with 2.5M HCl and then loaded in the mass spectrometer. The value of $^{87}Sr/^{86}Sr$ for the NBS 987 standard measured in this laboratory is 0.7102 ± 0.0001, normalized to 8.375 2 for $^{88}Sr/^{86}Sr$. The value of $1.39 \times 10^{-11} yr^{-1}$ was used for the decay constant of ^{87}Rb. The measured Rb/Sr and $^{87}Sr/^{86}Sr$ ratios, as well as the calculated $^{87}Rb/^{86}Sr$ for 10 samples are given in Table 32.

TABLE 32. ANALYTICAL DATA FOR THE RHYOLITE NEAR TANGADEE

G.S.W.A. sample no.	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
Samples Included In Isochron			
47026	13·1	39·5 ± 0·4	1·3023 ± 0·0002
47020	14·4	43·0 ± 0·4	1·3552 ± 0·0001
47024	14·4	44·0 ± 0·5	1·3582 ± 0·0002
47027	15·2	47·2 ± 0·5	1·4290 ± 0·0002
47030	21·0	66·6 ± 0·7	1·7092 ± 0·0002
47028	31·1	104·6 ± 1·0	2·3011 ± 0·0003
Samples Not Included in Isochron			
47023	15·5	48·0 ± 0·5	1·4702 ± 0·0002
47025	14·5	45·1 ± 0·5	1·5024 ± 0·0001
47021	14·3	43·7 ± 0·5	1·3166 ± 0·0001
47029	20·1	62·7 ± 0·7	1·5304 ± 0·0002

The data are plotted in Figure 62. The errors are at the 95 per cent confidence level. Six points form an isochron, which, using the regression analysis of McIntyre and others (1966) give a Model 3 isochron of $1\,098 \pm 42$ m.y., with an initial $^{87}Sr/^{86}Sr$ ratio of 0.6881 ± 0.0334. The other four samples scatter both above and below the isochron, presumably the result of removal of ^{87}Rb or loss of total Sr respectively. There is no petrographic or geochemical basis for the exclusion of the four samples from the isochron; the basis of selection is that the other six samples lie on the isochron within experimental error.

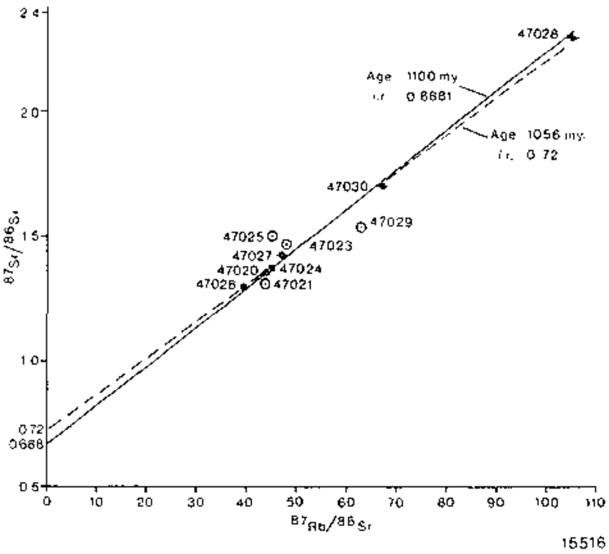

Figure 62. Isochron plot of samples from rhyolite near Tangadee. Open circles are analyses not used on isochron. Broken line is Model 2 isochron generated by assuming initial ratios of 0·72.

An initial ratio of 0.6881 ± 0.0334 is geologically and theoretically untenable. A mantle-derived mafic rock of this age should have an initial ratio of about 0.702, and crustal-derived silicic rocks should have an initial ratio as high as 0.720, according to the strontium evolution curve of Faure and Powell (1972, p. 45). As an exercise to determine the effect of an assumed initial ratio, by successively including initial ratios at 0.005 increments up to a realistic maximum of 0.720 in a Model 2 regression, five additional isochrons are generated, as shown in Table 33. It can be seen that this progressively reduces the slope of the isochron, to a minimum age of $1\,056 \pm 20$ for an initial ratio of 0.720. This isochron is plotted for reference also on Figure 62. Furthermore, all the isochrons generated in this way fall within the ± 42 m.y. error of the uncontrolled Model 3 isochron.

This means that the isotopic age of $1\,098 \pm 42$ m.y. is realistic and meaningful, although the experimental data yield no indication of the true initial ratio, and hence no isotopic evidence of the origin of the rhyolite.

TABLE 33. VARIATIONS OF ISOCHRON AGE WITH INITIAL $^{87}Sr/^{86}Sr$ RATIO

Initial ratio	Isochron (m.y.)
Model 3 derived i.r. 0·6881 ± 0·0334	1098 ± 42
Model 2 assumed i.r. 0·700	1083 ± 15
0·705	1076 ± 16
0·710	1070 ± 17
0·715	1063 ± 19
0·720	1056 ± 20

CONCLUSIONS

Evidence of the origin of the rhyolite includes the restriction of small plug-like bodies along an east-northeast trend, and its occurrence about 60 m above the granite basement. The most likely origin is localized melting along a plane of movement in the basement granitoid. Sedimentological and stratigraphic evidence (Brakel and Muhling, 1976) indeed shows that the early stages of Bangemall Group sedimentation in this central part of the Bangemall Basin were influenced by basement faults of this trend.

The isotopic evidence is not inconsistent with this origin, and the range of possible ages accords well with the approximate age of 1 030 m.y. obtained by Compston and Arriens (1968) for both acid igneous rocks at Mount Palgrave, and shale of the Curran Formation. The isotopic age of the rhyolite near Tangadee is taken to register either early devitrification of the volcanic glass, or early burial metamorphism.

The significance of these rather dramatic chemical changes is uncertain, but it may be related to the general problem of the high-potash and highly siliceous rocks that occur at stratigraphically higher levels in the Bangemall Group.

Finally, the similarity of isotopic ages of Bangemall Group rocks with the 1 060 m.y. ages (Compston and Nesbitt, 1967) from acid volcanics of the Bentley Supergroup in the Musgrave Block, should be noted. This supergroup is largely composed of thick sequences of potassic rhyolite lavas, ignimbrites, pyroclastics, and related cauldron subsidence areas (Daniels, 1974). This area represented a major centre of explosive felsic volcanic activity, evidently contemporaneous with Bangemall Group sedimentation, and whose influence must have been felt for considerable distances.

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TECTONIC SUBDIVISIONS AND GEOCHRONOLOGY OF THE NORTHEASTERN PART OF THE ALBANY-FRASER PROVINCE, WESTERN AUSTRALIA

by J. A. Bunting, J. R. de Laeter,* and W. G. Libby

ABSTRACT

The northeastern part of the Proterozoic Albany-Fraser Province can be divided into four main subdivisions: 1) Transition Zone, in which the Archaean rocks of the adjacent Yilgarn Block are reworked, and intruded by Proterozoic granites; 2) Western Gneiss and Granite Zone, of predominantly amphibolite facies, grading to granulite facies, Proterozoic rocks with no Archaean remnants; 3) Fraser Complex, consisting of mafic rocks predominantly of granulite facies; and 4) Eastern Gneiss and Granite Zone which is largely unexposed. New Rb-Sr age determinations give isochrons of 2 592 ± 25 m.y. for Archaean gneissic granite, 1 725 ± 149 m.y. for adamellite and mafic rock within the Transition Zone, 1 592 ± 36 m.y. for a rapakivi granite-mafic hybrid complex within the Western Zone, and 1 289 ± 21 m.y. for muscovite-bearing rocks within granulite facies gneisses at Salt Creek, near the Western Gneiss and Granite Zone—Fraser Complex boundary. The Salt Creek granulites do not form a good isochron, but must be at least 1 730 m.y. old. This represents a period of granulite facies metamorphism older than that which affected the Fraser Complex (about 1 330 to 1 300 m.y.), and one which probably preceded the emplacement of the Fraser Complex source rocks.

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INTRODUCTION

The Archaean greenstone belts and granitic rocks of the Yilgarn Block are flanked to the south and east by a Proterozoic mobile belt, the Albany-Fraser Province. The boundary between these two major tectonic units is marked by a sharp increase in metamorphic grade from greenschist and amphibolite facies in the Archaean rocks to a high-grade terrain in the mobile belt, and by the truncation of the north-northwest trends of the Yilgarn Block by northeast-trending structures in the Albany-Fraser Province (Fig. 63). These features prompted Wilson (1969a) to compare the boundary, which he believed coincided with the Fraser Fault, with the Grenville Front in Canada which also separates a stable Archaean craton (the Superior Province) from a high-grade Proterozoic orogenic zone (the Grenville Province). This comparison may still be valid, although the Albany-Fraser Province boundary is now placed 10 to 25 km west of the Fraser Fault. The exact placing of the boundary in the area of this study (Fig. 64) depends largely on the parameters chosen to define it. For present purposes it is taken as the western limit of Proterozoic igneous and metamorphic activity, that is, the western margin of the Transition Zone (Fig. 63). Along most of its length it is affected by strong shearing. The transitional nature of the boundary is indicated by the presence in the Transition Zone of much reworked and remnant Archaean material, and by brittle fracture and cataclastic effects in typical Archaean rocks up to 20 km from the boundary.

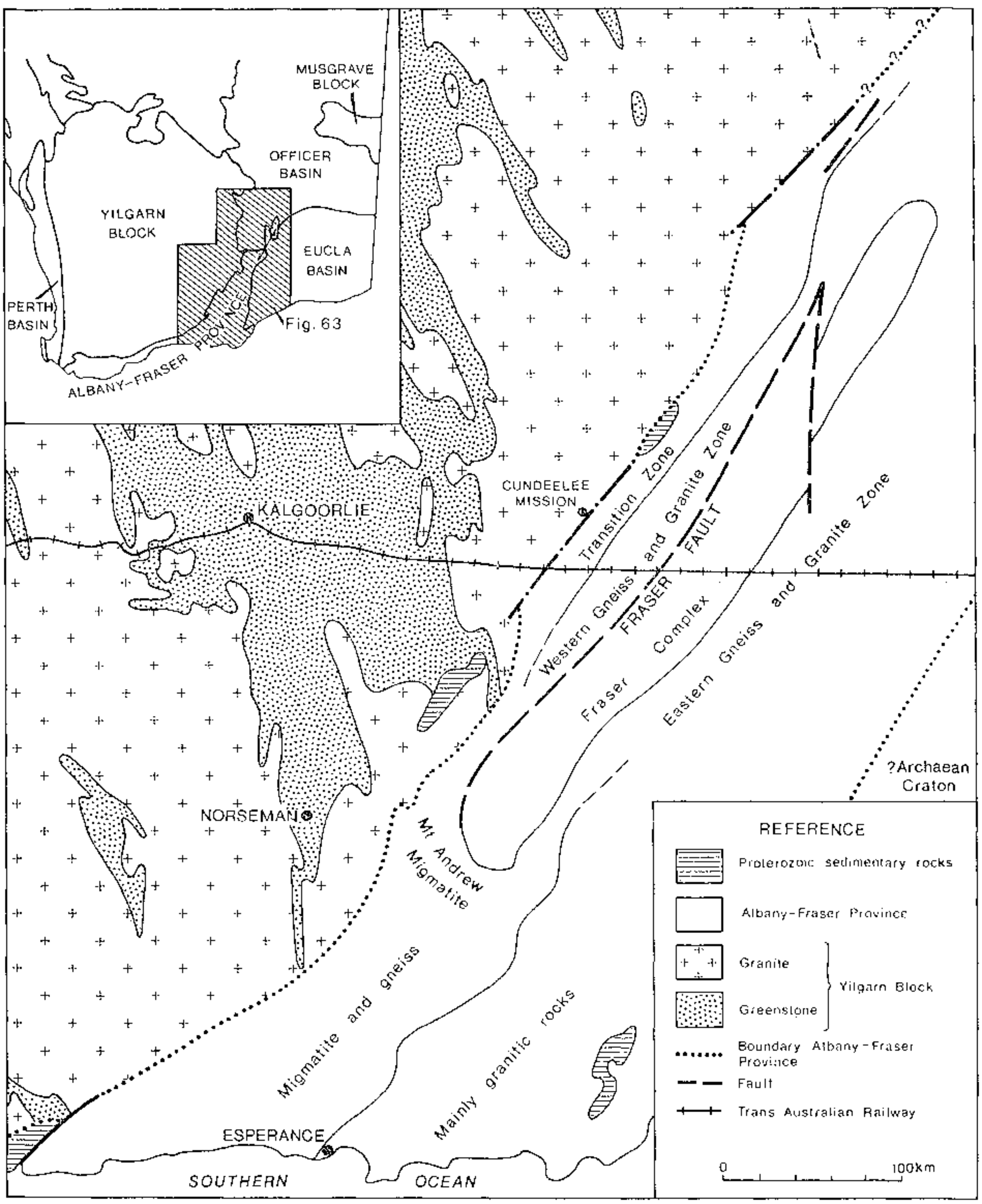

Figure 63. Precambrian tectonic subdivisions, northeast Albany-Fraser Province.

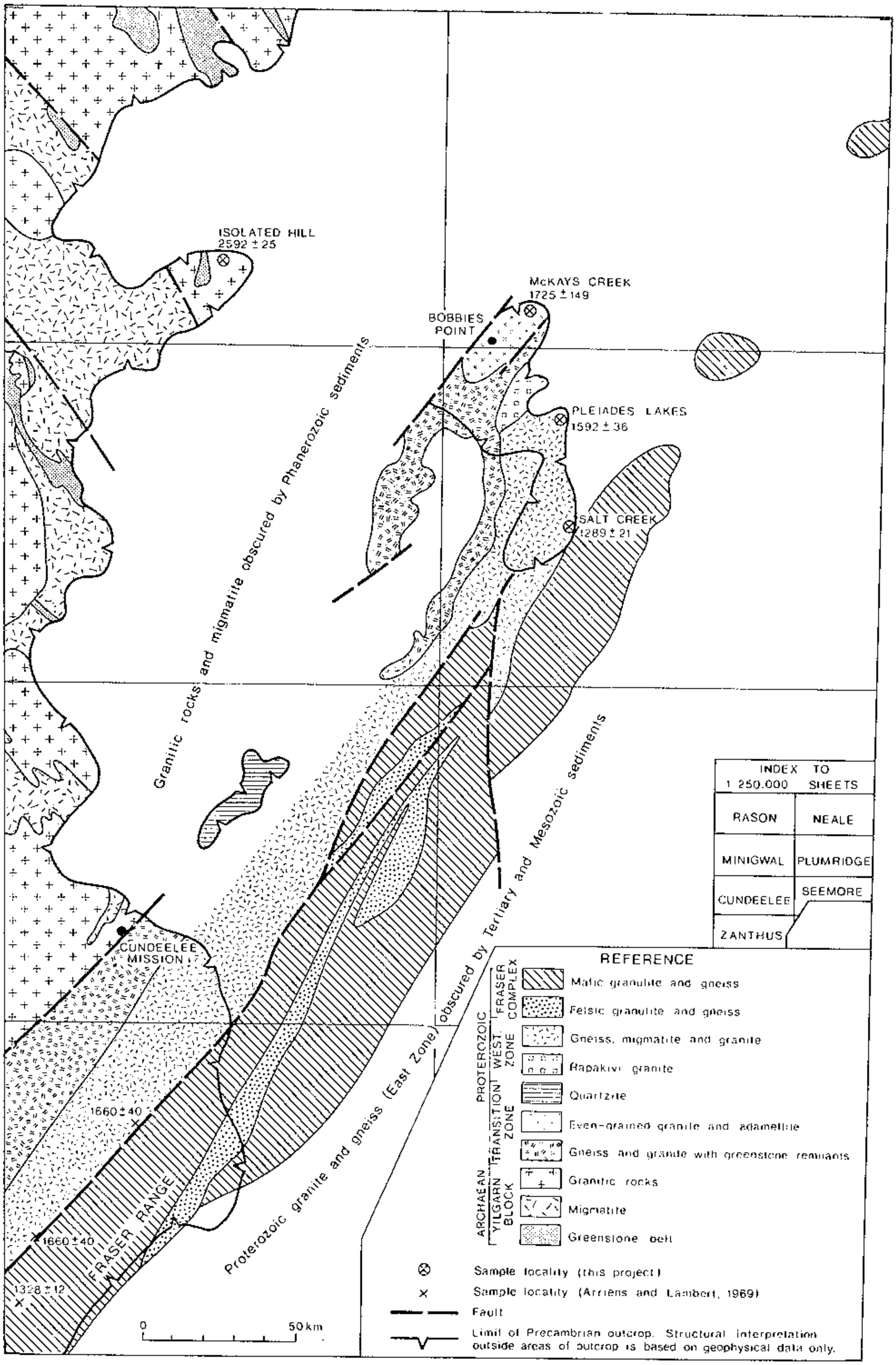

Figure 64. Geology and sample localities, northeast Albany-Fraser Province and adjacent Yilgarn Block.

The regional significance of the high-grade rocks in the Fraser Range area was first appreciated by A. F. Wilson in 1952. His numerous publications describing the granulites and gneisses of the Fraser Range, along with a history of geological investigations of the area, are summarized in Wilson (1969a). Doepel (1969 and 1973) and Doepel and Lowry (1970) describe the regional geology of the area south of, and including, the Fraser Range. The most comprehensive review of the Albany-Fraser Province is by Doepel (1975).

Wilson and others (1960) report a Rb-Sr age of 1 280 m.y. and K-Ar age of 1 210 m.y. for muscovite in a pegmatite from the Fraser Range. Arriens and Lambert (1969), in a more comprehensive study of the Fraser Range area, report Rb-Sr ages of 1 328 ± 12 m.y. for granulite facies rocks, and 1 660 ± 40 m.y. for gneiss and granite immediately west of the granulite belt.

Systematic regional mapping of the area north of the Fraser Range (Fig. 64) was carried out during 1972, and the results have been published as preliminary editions of explanatory notes (Van de Graaff, 1973, Gower and Boegli, 1973; Van de Graaff and Bunting, 1974a and b; Bunting and Van de Graaff, 1974; Bunting and Boegli, 1974). During the mapping difficulties were encountered in trying to delineate the extent of the tectonic units, mainly because the Precambrian rocks are largely obscured by more recent sediments of the Officer and Eucla Basins, but also because of the ambiguous nature of much of the evidence from the rocks. As an aid to the tectonic interpretation an isotopic age determination programme was organized in conjunction with the Western Australian Institute of Technology.

The aim of this paper is to present a tectonic synthesis of the northeastern part of the Albany-Fraser Province incorporating the 1972 mapping, the new geochronological and petrological data, and earlier work by various authors in the Fraser Range area to the south.

TECTONIC SUBDIVISIONS

The area of this study (Fig. 64) can be divided into five main subdivisions. From northwest to southeast these are:—

Yilgarn Block.
Transition Zone.
Western Gneiss and Granite Zone.
Fraser Complex.
Eastern Gneiss and Granite Zone.

All except the Yilgarn Block form the northeast part of the Albany-Fraser Province, and all of these four form linear belts trending northeast. This dominant northeast direction is also marked by major faults and mylonite zones, and is the predominant trend of fold axes in each subdivision.

YILGARN BLOCK

The eastern margin of the Yilgarn Block is characterized by a predominantly granitic terrain enclosing small north-northwest-trending greenstone belts. These belts consist of mafic volcanic, ultramafic, sedimentary, and felsic volcanic rocks metamorphosed in the upper part of the greenschist or lower part of the amphibolite facies.

The granitic rocks are equally divided between migmatite and homophanous granitoid. Typically the migmatite is well banded, with a foliated melanocratic granodiorite or tonalite paleosome and a leucocratic adamellite or granite neosome. The homophanous granitoids range from granite te granodiorite. In patches the rock is porphyritic, and a strong penetrative foliation is commonly developed near the margins of the greenstone belts.

TRANSITION ZONE

The Transition Zone forms a belt up to 50 km wide in which Archaean remnants are affected by Proterozoic metamorphism and igneous intrusion. The Archaean remnants contain rocks typical of the greenstone belts of the eastern Yilgarn Block.

Proterozoic intrusive rocks include the adamellite from McKays Creek, dated at 1725 m.y. (see below), and small intrusions penetrating the Archaean rocks. The adamellite from McKays Creek shows peralkine affinities (Van de Graaff and Bunting, 1974a), and is intruded by riebeckite-bearing rhyolite porphyry. Cataclastic deformation is common, and a strong fracture cleavage strikes consistently northeast.

An unusual metamorphosed layered gabbro 35 km southwest of McKays Creek varies from mafic to ultramafic. The predominant rock type is a faintly banded metagabbro containing green amphibole (after pyroxene), epidotized plagioclase, and abundant garnet. Quartz, yellow epidote (Cr-bearing pistacite), green clinopyroxene, and brown hornblende are minor constituents in some samples. The clinopyroxene is a high-alumina (4.74 per cent) salite, while the garnet contains almandine (55 per cent), grossular (7), andradite (22), spessartine (2), and pyrope (11). Microprobe analyses (analyst: R. B. W. Vigers, CSIRO) of the yellow epidote, garnet, and clinopyroxene are discussed in unpublished petrology reports of the Geological Survey of Western Australia (Nos. 633 and 635).

At least two metamorphic events are recorded in the metagabbro: a high-grade event producing the garnet and possibly pyroxene and brown hornblende, and a later intermediate-grade metamorphism giving green hornblende and epidote. The ages of these events and the original igneous crystallization are not known.

Tightly folded quartzite crops out as northwest-trending strike ridges near McKays Creek (Neale Sheet area), in the northwest of the Plumridge Sheet area, and northeast of Cundeelee Mission. At the latter locality it contains pale-green muscovite, kyanite, garnet, and tourmaline. Bunting and Van de Graaff (1974) suggest a possible correlation with the Woodline Beds, 100 km southwest of Cundeelee, which were dated by Turek (1966) at 1 620 ± 100 m.y.

In the Zanthus Sheet area (Fig. 64) a belt of mixed granitic rocks mapped by Doepel and Lowry (1970) falls within the Transition Zone. In this belt Proterozoic leucocratic granite intrudes Archaean porphyritic, even-grained and gneissic granitic rocks.

WESTERN GNEISS AND GRANITE ZONE

This zone contains Proterozoic igneous and metamorphic rocks with no recognizable Archaean remnants and with predominantly amphibolite facies metamorphism. It includes the rocks dated by Arriens and Lambert (1969) at 1 660 ± 40 m.y., and also the Pleiades Lakes and Salt Creek localities of this paper. The zone is equivalent to the Mount Andrew Migmatite east of Norseman (Doepel, 1973).

The area is characterized by a variety of felsic gneisses, including migmatite, which have been intruded by mafic and ultramafic rocks, rapakivi granite, and leucocratic granite. The predominant gneiss is a banded microgneiss (a medium-grained rock with gneissic structure) which commonly contains alkali feldspar, quartz, and minor biotite. Garnet is common in the Salt Creek area. Textures are granoblastic with a poorly developed foliation. The pre-metamorphic rock was probably a quartzo-feldspathic sediment.

At several places within the zone there is a distinctive assemblage which includes microgneiss, metadolerite, metagabbro, and rapakivi granite. The mafic rock is even grained and contains orthopyroxene, amphibole, lath-like plagioclase (labradorite), and minor biotite, indicating metamorphism in the granulite or pyroxene hornfels facies with later retrogressive uralitization. In the rapakivi granite, phenocrysts of perthitic microcline, plagioclase, and a pale-blue milky quartz are set in a coarse adamellite matrix. A few microcline phenocrysts are mantled by plagioclase.

At Pleiades Lakes a group of hybrid rocks is associated with the metadolerite and rapakivi granite. Inset grains of pale-blue milky quartz, plagioclase-mantled microcline, and plagioclase aggregates with orientated grains, all occur in a matrix ranging from a biotite-rich felsic to mafic composition. The percentage of insets decreases as the matrix becomes more mafic. The aggregates of plagioclase have probably partly replaced alkali feldspar phenocrysts.

The presence of mantled feldspars in rocks ranging from mafic (hybrid rock) to felsic (rapakivi granite) requires explanation. Typical rapakivi granites from Scandinavia and elsewhere have long been accepted as products of magmatic crystallization (Sederholm, 1932; Marmo, 1962), and such an origin is reasonable for the porphyritic rapakivi granite in the Albany-Fraser Province. For the hybrid rocks a likely origin is the invasion of a partly crystallized granite magma by a mafic magma. Quartz phenocrysts were resorbed on contact with the mafic magma, and plagioclase replaced alkali feldspar in microcline phenocrysts, thus releasing silica which generated a plagioclase-quartz rim around the phenocrysts. The potassium released may have then combined with magnesium and iron to form biotite in the matrix. Intrusive relationships in outcrop are ambiguous; in places the more felsic hybrids intrude mafic hybrids while elsewhere the reverse is the case.

Intermittent exposure is present for about 20 km along the north-south line of Salt Creek. The northern end is predominantly migmatite in which a paleosome of banded biotite-garnet-quartz-feldspar gneiss with amphibolite lenses is intruded by a leucocratic granite or pegmatite neosome. Unlike the microgneiss elsewhere in the zone, the feldspar is predominantly plagioclase.

Near the southern end of Salt Creek the regional garnet-biotite-orthoclase microgneiss is cut by sheared crystalloblastic granitic or pegmatitic rocks containing garnet, muscovite, and microcline. In places the garnet is being replaced by muscovite. The muscovite-bearing rocks probably were derived from the regional microgneiss by recrystallization accompanied by metasomatic introduction of potassium along shear or joint planes.

FRASER COMPLEX

The Fraser Complex (Doepel and Lowry, 1970) forms a linear belt of mafic granulite, with minor felsic granulite, gneiss, granite, and metagabbro. These rocks are well exposed in the Fraser Range, but to the northeast are largely obscured by Phanerozoic sediments. However, their subsurface extent is easily defined by an intense gravity ridge and strong magnetic relief. At the southern end of Salt Creek mafic and ultramafic granulites occur as bands within microgneiss which is itself compatible with, although not diagnostic of, granulite facies metamorphism. Arguments put forward later in this report show that the Salt Creek granulites are older than the Fraser Complex, and that the mafic rocks indicated by geophysical anomalies to the south of Salt Creek belong to the Fraser Complex but may not have reached granulite facies.

In the Fraser Range area the contact between the Fraser Complex and the Western Gneiss and Granite Zone is a major fault (the Fraser Fault) which is marked by a sharp change in facies and rock type across a zone of intense shearing. Wilson (1969b) interprets the movement on the fault to be reverse and sinistral, whereby the main granulite block moved up and northwards.

Wilson (1969a) suggests that the mafic granulites were derived from a sequence of extrusive basalts and minor gabbro, with some of the felsic bands representing originally quartzo-feldspathic sediments. Doepel and Lowry (1970) found no evidence for supracrustal material and believe that the mafic granulites were derived from a uniform rock mass of basaltic composition . However, the weight of evidence, for example the presence of thin quartzite layers, rounded zircons in felsic granulite bands, and possible amygdales and pillows in mafic granulites, supports Wilson's hypothesis.

EASTERN GNEISS AND GRANITE ZONE

This zone is almost totally unexposed in the study area (Fig. 64), but a flat magnetic relief suggests a granitic or gneissic terrain. Between the Fraser Range and the south coast Doepel (1969) describes a variety of porphyritic, leucocratic, and mixed granitic rocks. To the east of this zone, gravity patterns indicate a possible concealed Archaean block underlying the Eucla Basin (Fraser, 1973).

METAMORPHISM

It is probable that Archaean rocks in the Transition Zone have been affected by Archaean and Proterozoic regional metamorphism, although none of the episodes have been positively identified. At least two periods of metamorphism, the earlier one reaching at least upper amphibolite facies, are present in the garnetiferous mafic and ultramafic rocks 35 km southeast of McKays Creek.

Metamorphic grade within the Western Gneiss and Granite Zone increased from north to south, that is, towards the granulite facies rocks of the Fraser Complex. This is best illustrated by the Salt Creek section. In the migmatite of the northern part, plagioclase, apparently in equilibrium with epidote, varies southward from sodic oligoclase to calcic oligoclase and finally labradorite. Associated with this increase of calcium in plagioclase is a progressive bleaching of garnet, a decrease in the amount of epidote, and an increase in grain size.

Towards the southern end of Salt Creek garnet appears and untwinned alkali feldspar (?orthoclase) replaces microcline in regional microgneiss. Heier (1961) has suggested that a change from triclinic to monoclinic feldspar closely defines the transition from amphibolite to granulite facies, but evidence from Broken Hill, New South Wales (Binns, 1964) and elsewhere throws doubt on the accuracy of the transition as a grade indicator. It may be significant that at Salt Creek the alkali feldspar change in the microgneiss corresponds to the first appearance of metamorphic orthopyroxene (indicating granulite facies) in mafic bands. Polymetamorphism is suggested by some samples of microgneiss in which biotite replaces garnet along cracks.

In the mafic granulites at the southern end of Salt Creek, the presence of hornblende and orthopyroxene in equilibrium indicates a position low in the granulite facies. Upper granulite facies rocks, predominantly augite-hypersthene-plagioclase granulite, with no hornblende, occur in the Fraser Range.

GEOCHRONOLOGY SAMPLING AND PETROLOGY

Samples were collected from four main localities (Fig. 64), plus some from intervening areas, in order to give a series of determinations across the predominant strike in the study area. Isolated Hill was included as it represented the nearest undoubted Archaean to the presumed Proterozoic rocks in the Plumridge and Neale Sheet areas. Brief descriptions of the four areas follow. Petrographic descriptions of individual samples are given in the Appendix. Sample numbers of the Geological Survey of Western Australia are used throughout the article.

ISOLATED HILL

Porphyritic gneissic hornblende-biotite adamellite is intruded by leucocratic gneissic granite and shallow-dipping pegmatite dykes. The foliation and a strong subhorizontal lineation (mineral elongation) trend 353°.

McKAYS CREEK

This area is dominated by medium-grained granite and adamellite of alkaline affinities. Apart from a few thin veins of aplite minor intrusions are lacking. Samples of these rocks were collected together with hybrid rocks at the margins of large mafic xenoliths, and also riebeckite porphyry which intrudes the granite at Bobbies Point, 15 km southwest of McKays Creek.

PLEIADES LAKES

A variety of metamorphosed mafic and rapakivi-textured granitic and associated hybrid rocks intrude augen gneiss and microgneiss. These are in turn intruded by leucocratic granite, aplite, and pegmatite.

SALT CREEK

Samples were collected from the regional microgneiss and also from cross-cutting foliated muscovite pegmatite and granite. The gneisses in the vicinity of the muscovite-bearing rocks also contain minor muscovite.

All samples were analyzed for Na, K, and Sr in order to give some guidance to the final choice of geochronology samples. Twenty-six samples were finally chosen from the four main localities. Two more were added later from the Salt Creek area in an attempt to clarify the isochrons from that locality. Full chemical analysis has not been attempted, but analyses of examples of most rock types were reported by Van de Graaff and Bunting (1974, a and b).

EXPERIMENTAL PROCEDURES

All instruments and methods used in this study are the same as those described by Lewis and others (1975), page 84.

RESULTS OF ISOTOPIC ANALYSIS

The measured Rb/Sr and $^{87}Sr/^{86}Sr$ ratios, as well as the calculated $^{87}Rb/^{86}Sr$ ratios are given in Table 34. Errors accompanying the data are at the 95 per cent confidence level. The data are plotted as isochrons in Figure 65. A value of 1.39 x 10^{-11}/yr was used for the decay constant of ^{87}Rb.

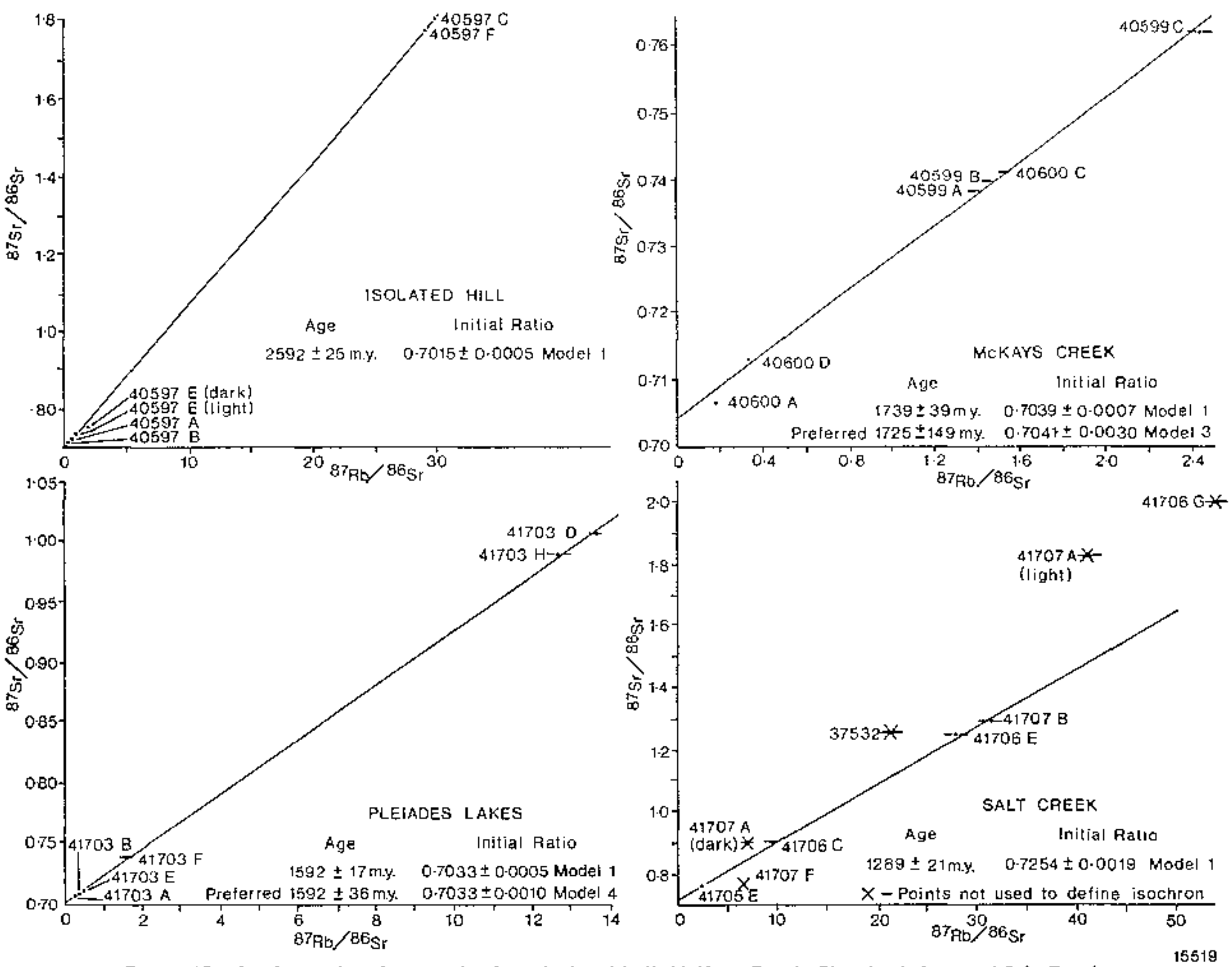

Figure 65. Isochron plots for samples from Isolated Hill, McKays Creek, Pleiades Lakes, and Salt Creek.

TABLE 34.—ANALYTICAL DATA FOR SAMPLES FROM ISOLATED HILL, McKAYS CREEK, PLEIADES LAKES, AND SALT CREEK.

Sample no.	Rb (ppm)	Sr (ppm)	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
Isolated Hill					
40597B	67	580	0·115 ± 0·001	0·332 ± 0·003	0·71383 ± 0·00010
40597A	67	578	0·116 ± 0·001	0·335 ± 0·003	0·71402 ± 0·00012
40597E (dark)	128	522	0·247 ± 0·003	0·715 ± 0·008	0·72738 ± 0·00009
40597E (light)	164	290	0·566 ± 0·007	1·64 ± 0·02	0·76155 ± 0·00011
40597F	323	36	0·085 ± 0·1	28·9 ± 0·4	1·7637 ± 0·00018
40597C	245	26	9·36 ± 0·1	29·9 ± 0·4	1·7985 ± 0·00019
McKays Creek					
40600A	32	507	0·061 ± 0·001	0·176 ± 0·003	0·70644 ± 0·00008
40600D	53	490	0·113 ± 0·002	0·33 ± 0·004	0·71329 ± 0·00008
40599A	93	196	0·480 ± 0·005	1·30 ± 0·02	0·73376 ± 0·00009
40599B	95	190	0·505 ± 0·005	1·46 ± 0·02	0·74032 ± 0·00009
40600C	95	178	0·533 ± 0·006	1·54 ± 0·02	0·74151 ± 0·00009
40599C	106	125	0·846 ± 0·01	2·45 ± 0·03	0·76242 ± 0·00010
40598A*	110	5	22·75 ± 0·3	73·6 ± 1·0	1·93236 ± 0·00016
Pleiades Lakes					
41703A	31	340	0·0904 ± 0·001	0·261 ± 0·003	0·70882 ± 0·00009
41703B	33	332	0·0998 ± 0·001	0·288 ± 0·003	0·70902 ± 0·00008
41703E	39	352	0·112 ± 0·001	0·32 ± 0·003	0·71069 ± 0·00008
41703F	136	250	0·542 ± 0·006	1·57 ± 0·02	0·73932 ± 0·00011
41703H	360	85	4·27 ± 0·05	12·7 ± 0·15	0·98881 ± 0·00012
41703D	536	115	4·63 ± 0·06	13·7 ± 0·02	1·0064 ± 0·00015
Salt Creek					
41705B	100	122	0·828 ± 0·008	2·40 ± 0·02	0·76827 ± 0·00009
41707F*	200	88	2·28 ± 0·02	6·61 ± 0·07	0·76662 ± 0·00009
41707A (dark)*	195	82	2·37 ± 0·02	6·97 ± 0·07	0·89401 ± 0·00013
41706C	245	75	3·24 ± 0·03	9·53 ± 0·1	0·90183 ± 0·00010
37532*	358	51	7·06 ± 0·07	21·5 ± 0·3	1·2522 ± 0·0002
41706E	234	26	9·16 ± 0·1	27·8 ± 0·3	1·21890 ± 0·00011
41707B	285	28	10·25 ± 0·1	31·3 ± 0·3	1·29091 ± 0·0002
41707A (light)*	257	20	12·85 ± 0·1	41·2 ± 0·4	1·8280 ± 0·00028
41706G	200	12	16·56 ± 0·2	53·9 ± 0·6	2·01001 ± 0·00021

* Indicates samples not used in final isochron calculations.

NOTE: The Rb and Sr concentrations have been determined by comparison with a number of standard rocks. Although no assessment of the mass absorption coefficient of individual samples was made we believe the values are accurate to about ±7 per cent. The Rb/Sr ratios do not correspond exactly with the ratios that would be derived from the separate Rb and Sr values shown.

Regression analyses of the data were carried out using the programme of McIntyre and others (1966). The ages derived from the data are 2 592 ± 25 m.y. (Model 1) for the Archaean gneiss at Isolated Hill, Rason 1:250 000 Sheet area, 1 725 ± 149 m.y. (Model 3) for the granitic and mafic plutonic rocks from McKays Creek, and 1 592 ± 36 m.y. (Model 4) for the metamorphosed mixed plutonic rocks at Pleiades Lakes. Four muscovite-bearing late granitic rocks at Salt Creek provided an age of 1 289 ± 21 m.y. (Model 1). Other rocks in the Salt Creek area gave a scatter of values to which a reliable isochron could not be fitted.

For the McKays Creek and Pleiades Lakes isochrons the mean square of the weighted deviates is greater than unity implying a scatter in the data points greater than can be expected from experimental uncertainties alone. Either or both of the assumptions that the initial $^{87}Sr/^{86}Sr$ ratios were homogeneous, and that all samples were closed to Rb and Sr, therefore, do not hold for these suites of samples. The programme has examined each set of data for geological variation and indicated that the rocks comprising the McKays Creek isochron had the same initial $^{87}Sr/^{86}Sr$ ratios but slightly different ages (Model 3), whereas the rocks within the Pleiades Lakes isochron had slightly different initial ratios and ages (Model 4). The scatter of points from the Isolated Hill and Salt Creek localities is within experimental error, and therefore a Model 1 isochron is preferred.

DISCUSSION OF RESULTS

ISOLATED HILL

The age of 2 592 ± 25 m.y. from the adamellite gneiss and related minor intrusive granitic rocks at Isolated Hill is within the error limits of many granitic rocks of the Eastern Goldfields Province of the Yilgarn Block and is towards the end of the middle period (2 700 to 2 550 m.y.) of acid magmatism and metamorphism delimited by Arriens (1971). The strong gneissic foliation and lineation developed in the rocks at Isolated Hill suggests the age is that of metamorphic rather than igneous crystallization, and probably represents one of the last phases of Archaean tectonism. The initial $^{87}Sr/^{86}Sr$ ratio of 0.7015± 0.0005 is consistent with an immediate mantle derivation for the granitic rocks.

McKAYS CREEK

The biotite adamellite to hornblende granodiorite plutonic and hypabyssal rocks at McKays Creek provide an age of 1 725 ± 149 m.y. The large uncertainty factor is due to the preference for a Model 3 isochron and probably reflects genuine age differences in the samples. A magmatic event may be recorded here. Alteration of the rocks is limited to dusting of plagioclase and, in some samples, saussuritization. The initial $^{87}Sr/^{86}Sr$ ratio of 0.7041 ± 0.0030 does not distinguish between immediate derivation from the mantle and derivation from older crustal rock with a low Rb/Sr ratio, that is, mafic rocks.

No other rocks in the Albany-Fraser Province have yielded comparable ages.

A single sample of porphyritic riebeckite rhyolite (40598A) from Bobbies Point shows a high Rb/Sr value, and the point does not lie near any of the isochrons.

PLEIADES LAKES

The metamorphosed igenous complex at Pleiades Lakes provides an isochron at 1 592 ± 36 m.y. The date probably reflects the age of metamorphism rather than the age of the complex igneous processes which resulted in the rapakivi textures and hybridization of magmas in this area. Metamorphyic recrystallization has affected most of the rocks which have been studied. Minor igneous activity, represented by aplite (sample 41703H) and pegmatite (sample 41703D) may have accompanied metamorphism. These rocks are not notably metamorphosed.

The initial $^{87}Sr/^{86}Sr$ ratio of 0.7033 ± 0.0010 is not significantly different to that from McKays Creek, but when the younger age at Pleiades Lakes is considered, the ratio indicates that the material which formed the igneous rocks at Pleiades Lakes must have been derived from the mantle only a short time before the event recorded in the 1 592 m.y. isochron.

The preference for a Model 4 isochron may reflect incomplete homogenization during metamorphism of originally complex igneous rocks which had slightly different initial $^{87}Sr/^{86}Sr$ ratios.

The rocks at Pleiades Lakes are of the same types and occur in the same tectonic zone as samples described by Arriens and Lambert (1969) 300 km to the southwest which gave an age of 1 660 ± 40 m.y. The 1 660 m.y. isochron includes samples of gneiss, porphyritic granite, and rapakivi granite, and probably represents a metamorphic event which affected the gneiss and which also deformed the rapakivi granite to produce an augen gneiss.

SALT CREEK

The isochron at 1 289 ± 21 m.y. from the Salt Creek locality is formed by four muscovite-bearing rocks (41705B, 41706C, 41706E, and 41707B). This date may be the age of potassic metasomatism which formed replacement dykes in shear zones in garnet-bearing microgneiss, and affected the gneiss in the vicinity of the dykes. The 1 289 m.y. age is similar to an age of 1 280 m.y. for muscovite from pegmatite in the Fraser Range (Wilson and others, 1960), but it is slightly younger than the 1 328 ± 12 m.y. of mafic granulites in the Fraser Complex (Arriens and Lambert, 1969).

The initial $^{87}Sr/^{86}Sr$ ratio for data from the muscovite-bearing samples from Salt Creek is 0.7254 ± 0.0019, significantly greater than 0.7049 ± 0.012 reported by Arriens and Lambert (1969) for the Fraser Complex. The high initial $^{87}Sr/^{86}Sr$ ratio of the Salt Creek rocks seems to indicate that these rocks have been extant in the crust longer than the mafic granulites of the Fraser Range which have the same isotopic age. They are not derived directly from the mantle or derived by differentiation from the Fraser Complex.

The isotopic data are consistent with petrographic suggestions that the muscovite-bearing rocks of Salt Creek may be derived from the regional microgneiss (which they cut) by recrystallization accompanying shearing and metasomatic introduction of potassium along joints or minor shears. These processes would have occurred late in the Fraser Range metamorphism and would have been contemporaneous with the emplacement of pegmatite in the Fraser Range area.

While the muscovite-bearing rocks at Salt Creek can be correlated with events in the Fraser Range, the regional microgneiss which they cut seems clearly older. There is no reliable isotopic age for the microgneiss but points on the isochron diagram plot well above the isochron at 1 289 m.y. generated by the muscovite-bearing rocks. The slope of the line formed by the light and dark phases of sample 41707A gives an age of about 1 900 m.y. and this may represent a minimum age of granulite facies metamorphism in the Salt Creek area. Sample 41706G falls below this line, but it has been affected by two periods of deformation, the second of which can be related to the shearing associated with the muscovite-bearing rocks of the 1289 m.y. isochron. The shearing may have caused loss of radiogenic strontium, giving a lower age than that of the unaffected gneisses.

Two further samples were analyzed in an effort to improve the older isochron. Sample 37532 falls slightly below the line formed by the two phases of sample 41707A. Sample 41707F, for unknown reasons, has suffered almost total loss of radiogenic strontium.

Small pods of mafic rock enclosed in the regional microgneiss at Salt Creek carry metamorphic orthopyroxene indicating metamorphism in the granulite facies and implying that the enclosing microgneiss has also been subjected to granulite metamorphism. Arriens and Lambert (1969) and Wilson (1969b) have suggested that emplacement of the Fraser Range basalts preceded metamorphism (at 1 329 ± 12 m.y.) by no more than 300 m.y. Thus if the argument for metamorphism of the microgneiss at about 1 900 m.y. or earlier is acceptable, the Salt Creek rocks would have experienced metamorphism in the granulite facies before emplacement of the (now granulite facies) basalts of the Fraser Complex. On the assumption that granulite facies metamorphism at 1 330 m.y. at Salt Creek would have reset the isotopic ratios, two periods of granulite facies metamorphism are required. Granulite facies metamorphism of the later (Fraser Range) period did not reach the Salt Creek area (Fig. 66), but lower grade effects are evident in the metasomatic and retrogressive features of the rocks. This hypothesis implies that some of the mafic rocks towards the northeast end of the Fraser Complex (now completely obscured by sand) did not reach granulite facies. Thus the Fraser Complex may have to be redefined to include not only the mafic granulites, but all of the predominantly mafic rocks that were emplaced in the same episode as the basalts which were later metamorphosed to give the Fraser Range granulites.

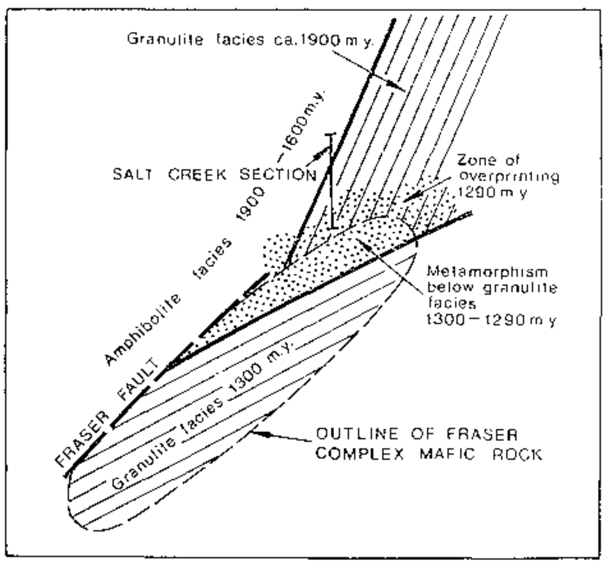

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Figure 66. Schematic map of possible metamorphic facies relationships, northeast Albany-Fraser Province.

EVOLUTION OF THE NORTHEAST ALBANY-FRASER PROVINCE

In early Proterozoic times a thick sequence of quartzo-feldspathic sediments accumulated in a subsiding basin flanking the southeast edge of the Yilgarn Block. This was followed by metamorphism, igneous intrusion, and tectonism, at various times from about 1 900 to 1 590 m.y., which affected both the sediments and the adjacent Yilgarn Block. The intrusion of granitic rocks at McKays Creek, metamorphism to amphibolite and granulite facies at Salt Creek, and tight folding along northeast axes occurred during this period. The emplacement of mafic rock, rapakivi granite, and leucogranite at Pleiades Lakes and west of the Fraser Range probably represents an intrusive event towards the end of this period of orogeny.

Further development of the basin, accompanied by northeast-trending fractures, resulted in accumulation of thick piles of mafic rock with associated minor sediments—the source rocks for the Fraser Complex. A second orogenic period at 1 330 to 1 280 m.y. metamorphosed the rocks in the Fraser Range area to granulite facies, and in the Salt Creek area produced metasomatic and retrograde effects in the earlier granulite rocks.

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APPENDIX—PETROGRAPHIC DESCRIPTIONS OF GEOCHRONOLOGY SAMPLES

ISOLATED HILL

40597A Adamellite

This gneissic, myrmekitic, epidote-bearing hornblende-biotite adamellite has plagioclase megacrysts of moderate size and large euhedral microcline megacrysts. Sphene is brown-orange. Quartz has been severely strained.

40597B Adamellite

Similar to 40597A. Oscillatory zoning in plagioclase megacrysts suggests an igneous origin.

40597C Micro-adamellite

This inequigranular micro-adamellite consists of abundant irregular to rounded coarse megacrysts of microcline and less plagioclase in a medium-grained quartzo-feldspathic groundmass with minor small grains of biotite. Strained quartz and irregular grain shape suggest recrystallization after cataclasis. Plagioclase is sodic oligoclase.

40597E (light and dark) Biotite adamellite gneiss

Feldspar megacrysts are set in a matrix of coarse, strained quartz and fine or medium-grained feldspar. Accessory sphene ranges from colourless to orange-brown, in part metamict.

Plagioclase has been altered but biotite is fresh.

40579F Adamellite

A grossly inequigranular, seriate, leucocratic adamellite. Biotite is rare, dark brown. The rock is cataclastic.

McKAYS CREEK

40598A Riebeckite rhyolite

Phenocrysts of irregular to euhedral coarse perthitic microcline, and rounded, irregular to rarely subhedral strained quartz are set in a fine-grained matrix of perthitic poikilitic K-feldspar, anhedral quartz, biotite, riebeckitic amphibole, and opaques.

Secondary carbonate is common. The groundmass and probably the marginal part of phenocrysts have been metamorphically recrystallized. Quartz is strained.

40599A Biotite adamellite

This is a plagioclase-dominant medium to coarse-grained biotite adamellite cut by fine-grained porphyritic dykelets. Oligoclase is euhedral with oscillatory zoning. Subhedral to vermicular fine-grained plagioclase is poikilitically enclosed by quartz to form a very unusual texture. The texture is developed generally throughout the rock but cores of some quartz grains are free of inclusions.

40599B Biotite adamellite

Similar to 40599A, but poikilitic quartz is less general.

40599C Porphyritic rhyodacite

Phenocrysts of K-feldspar, plagioclase, and quartz as well as lithic aggregates of coarse quartz, feldspar, and granophyre are set in a fine, probably recrystallized quartzo-feldspathic groundmass.

Some insets have the irregular intergrowth between coarse quartz and fine plagioclase which is characteristic of 40599A and B. The rock probably is hypabyssal.

40600A Hornblende granodiorite

Euhedral elongate grains of plagioclase are set in coarse masses of quartz and untwinned K-feldspar. Apatite, magnetite, and sphene are common, as are secondary chlorite and epidote. Saussuritization has been intense. More mafic than the 40599 series, but possibly texturally related.

40600C Biotite adamellite

Very coarse elongate plagioclase grains are set in a coarse, even-grained, hypidiomorphic granular groundmass of quartz, subhedral microcline, and zoned plagioclase with less biotite.

40600D Biotite granodiorite

Even-grained, coarse-grained; saussuritization has been intense.

PLEIADES LAKES

41703A Metadolerite

Heavily saussuritized coarse to medium-grained blotchy to lath-like plagioclase, now with irregular margins, is felted among lath-like or elongate mafic grains now altered to a complex of very fine stubby elongate grains of green amphibole and medium-size grains of biotite. The apparent colour index is about 50. The present plagioclase composition is about An_{40} (optical).

41703B Metadolerite

Similar to 41703A but the plagioclase has much less epidote; instead, many grains are filled with green amphibole which surrounds abundant opaque inclusions.

41703D Microcline

This sample is microcline with quartz inclusions from a quartz-microcline pegmatite dyke. The quartz has been cataclastically granulated.

41703E Metamorphosed quartz gabbro

Similar to 41703A and B. The lath-like plagioclase suggests an igneous origin. The mafics have been altered to pseudomorphous masses of green amphibole similar to uralite. Biotite is common. A few quartz grains, interstitial to plagioclase, are scattered through the rock.

41703F Hybrid rapakivi rock

Very coarse euhedral microcline, coarse grains of rounded quartz, and coarse euhedral plagioclase are set in a crystalloblastic matrix of quartz, epidote-filled plagioclase, and very abundant biotite (about 20 per cent of rock?). The margins of the very coarse microcline grains are an aggregate of fine to coarse-grained plagioclase in microcline, giving a mantling effect similar to rapakivi texture. In part, the internal portions of microcline grains consist of subhedral grains of plagioclase and of microcline set in interstitial, almost poikilitic, quartz. The coarse microcline phenocrysts seem incongruous in the rock which is dominated by biotite and epidote. This together with evidence of reaction suggests a hybrid origin.

41703H Microgranite

Medium-grained, subhedral, commonly elongate microcline, and mosaic to sutured aggregates of quartz with less biotite are the dominant minerals. Quartz appears to be recrystallized. Dusky-blue tourmaline is an accessory.

SALT CREEK

37532 Garnet-quartz-feldspar microgneiss

This is a garnet gneiss, but medium rather than coarse grained, hence the name microgneiss. Fine to medium-grained felsic minerals are sutured and weakly elongated. K-feldspar is untwinned. Garnet is abundant but biotite is an accessory.

This is part of the regional microgneiss suite in the Salt Creek area.

41705B Biotite microgneiss

Thin layers of strongly oriented biotite with epidote are interleaved with thicker layers of equidimensional felsic minerals dominated by quartz and microcline but including plagioclase. Colourless mica, carbonate, and green biotite (?ferrostilpnomelane) are minor.

The rock is distinguished from the regional microgneiss of sample 41707 by M-twinning of microcline, the association of epidote and plagioclase, the presence of colourless mica, and the absence of garnet.

41706C Muscovite granite gneiss

This is a cataclastic gneiss consisting mainly of quartz and microcline with less plagioclase, muscovite, and biotite. Garnet and opaques are accessories. Quartz is strongly oriented; biotite and muscovite are less strongly oriented.

41706E Garnet and muscovite-bearing granite pegmatite

Quartz and microcline are dominant, with less albite or oligoclase, biotite, and garnet. Trains or patches of felsic minerals, including muscovite, suggest healed cataclasis. Garnet is associated with muscovite and partly altered to biotite.

41706G Garnet-biotite gneiss

Principal minerals are quartz and mesoperthitic K-feldspar with less plagioclase, brown to green biotite, and scattered garnet. Elongate, anhedral quartz, and included wisps of feldspar are oriented obliquely to the compositional layering, defined by concentration of biotite and garnet. Some biotite is oriented parallel to the compositional layering, some parallel to quartz elongation. Neither muscovite nor epidote is present.

41707A (light) Garnet-biotite-feldspar-quartz microgneiss

Untwinned K-feldspar, quartz and less plagioclase are the dominant minerals, accompanied by minor garnet and less biotite. The felsic minerals are of medium grain size and are interlocked with sutured boundaries. There is no pronounced foliation. This is the leucocratic phase of the regional microgneiss of the Salt Creek area.

41707A (dark) Garnet-biotite-feldspar-quartz microgneiss

This sample and 41707A (light) are dark and light phases of the same specimen. The two phases are similar, though in the dark phase biotite and garnet are abundant. With the presence of dark minerals foliation can be recognized; biotite is strongly oriented and sharply concentrated in layers 0.25 mm thick. Garnet is distributed evenly through the rock. There is minor alteration of garnet to biotite. Muscovite is rare. This is a member of the regional microgneiss suite.

41707B Garnet-bearing muscovite granite

The sample is from a dyke 0.5 m wide which cuts the regional microgneiss of sample 41707A. Quartz and strongly twinned microcline are dominant; muscovite and sodic oligoclase are less abundant. Garnet is common. Muscovite is poikiloblastic, quartz forms mosaic to sutured masses as well as blebs and vermicular intergrowths in plagioclase. Plagioclase tends to be globular with sutured margins and microcline normally is irregular but forms a few small subhedral insets. Fragments of garnet seem to be partly replaced by muscovite. The overall aspect is granoblastic.

41707F Garnet-biotite-feldspar-quartz microgneiss

This sample is almost identical to 41707A (dark), with somewhat stronger orientation of elongate quartz. Felsic minerals are intricately sutured; garnet is weakly elongate. Biotite is strongly oriented and concentrated in thin layers. K-feldspar is untwinned. This is a part of the regional microgneiss suite.

Rb-Sr WHOLE-ROCK AND MINERAL AGES FROM THE GASCOYNE PROVINCE

by J. R. de Laeter*

ABSTRACT

A Rb-Sr geochronological study of 14 whole-rock samples and 11 mineral separates from the southern portion of the Gascoyne Province has provided additional isotopic data for this geologically complex region. Three suites of whole-rock samples gave ages of 1 672, 1 776 and 2 208 m.y. The associated initial $^{87}Sr/^{86}Sr$ ratios support the geological evidence, namely that the granitic and migmatic rocks have been derived from older Archaean rocks admixed with younger magmatic or supercrustally reworked material. Seven mineral isochrons give ages ranging from 739 to 809 m.y. with an average value of 780 m.y. The uniformity in mineral ages throughout the area indicates a widespread time of relatively fast cooling, possibly related to folding and uplift of the Bangemall Basin.

INTRODUCTION

In 1969, the Regional Geology and Mineral Resources Divisions of the Geological Survey carried out joint photogeological and reconnaissance traverses in the Glenburgh and Mount Phillips 1:250 000 Sheet areas, in support of the preparation of a summary of the geology of the Gascoyne Province, to be incorporated in a publication dealing comprehensively with the geology of the State; that publication (Geological Survey of Western Australia, 1975) has now been completed and issued, and it includes the resultant account of the Gascoyne Province (Daniels, 1975). The results of isotopic analyses of samples collected during those traverses carried out in 1970-71 have not been published. It was planned to combine their publication with sufficient further geological detail to fully illustrate their significance; but this has not proved practicable, and the purpose of this paper is to publish these results within a more limited geological context, so that the conclusions which may nevertheless be drawn from them are made generally available.

THE GASCOYNE PROVINCE

Daniels and Horwitz (1969) used the term Gascoyne Block to denote a triangular area of igneous and metamorphic rocks, about 65 000 km^2 in extent, bounded on the west by the eastern margin of the Phanerozoic Carnarvon and Perth Basins, on the northeast by Middle Proterozoic sedimentary rocks of the Bangemall Basin, and on the southeast by Archaean igneous and metamorphic rocks of the Yilgarn Block. Daniels (1975) applied the term Gascoyne Province to a more restricted area, of about 41 000 km^2, the decrease being due to a northward adjustment of the southeastern margin.

According to Daniels (1975, Fig. 6) the rocks of the Gascoyne Province are the final product of a complex sequence of interrelated tectonic, magmatic, and metamorphic events. An initial Archaean association of folded greenstone belts and dominantly granitic intrusions was subjected to migmatization in late Archaean or early Proterozoic times. Deposition of the Lower Proterozoic rocks of the Mount Bruce Supergroup was accompanied by faulting and followed by further magmatization, granite emplacement, and further movement along established fault zones. After deposition of the Middle Proterozoic Bangemall Group further folding and renewed faulting took place. As a result it might be expected that the granitic and migmatitic rocks of the province may be variously derived from older Archaean granitic rocks and greenstones, admixed with younger magmatic or supercrustally reworked material and variously affected by metamorphic events of different kinds.

Limited geochronological information was available in the Gascoyne Province prior to this study. Aldrich and others (1959) reported Rb-Sr ages of 980 and 940 m.y. for two pegmatitic muscovites from Yinnietharra together with associated K-Ar ages of 905 and 890 m.y. respectively. These large pegmatites are emplaced in east-west-trending metamorphic rocks which yield an age of 1 730 ± 240 m.y. from seven whole-rock samples of gneisses collected some 60 km northwest of Yinnietharra (Compston and Arriens, 1968). Compston and Arriens (1968) also report an age of 1 690 m.y. from granite at Minnie Creek homestead which is of comparable age to the Boolaloo granite dated by Leggo and others (1965) at 1 720 m.y. in the Wyloo Group. Black shales from the

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Curran Formation in the Bangemall Group give an isochron of 1 080 ± 80 m.y. (Compston and Arriens, 1968) and a similar age is obtained from acid lavas in the same region.

The Poona-Dalgaranga area in the northwest corner of the Yilgarn Block, adjacent to the south-east portion of the Gascoyne Block contains a batholith of granitic rocks which has been dated by Muhling and de Laeter (1971) by the Rb-Sr whole-rock technique. Indicated ages are 2 590 ± 23 m.y. for the granitic batholith and 2 605 ± 51 m.y. for several disconnected granitic masses on the eastern edge of the complex. The ages and initial ratios of these granites are typical of the younger period of granitic emplacement in the Archaean of Western Australia distinguished by Compston and Arriens (1968) from 2 750 to 2 600 m.y. These authors also defined an older episode from 3 050 to 2 900 m.y.

MATERIAL ANALYSED

Fourteen whole-rock samples were analysed for Rb and Sr, and for Sr isotopic composition. Biotite separated from seven of the samples was similarly analysed, and from three of these seven, muscovite was also obtained and analysed; microcline was additionally analysed from one of the samples used for whole-rock, biotite and muscovite analysis.

All the samples consisted either of migmatite thought to have altered Wyloo Group as paleosome, or of granitic rock. All were medium-grained rocks of granitoid mineralogy (mainly quartz and feldspars, with subordinate micas) and appearance, with some degree of foliation or banding normally developed. The nominal identity of each is included in Table 35, and localities appear on Figure 67. The selection of samples was made so that the influence of dolerite dykes was not encountered.

TABLE 35. ANALYTICAL DATA FOR 14 WHOLE-ROCK SAMPLES AND 11 SEPARATED MINERALS FROM THE GASCOYNE PROVINCE.

Sample number	Rock type	Material analysed	Rb (ppm)	Sr (ppm)	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
20804E	G	WR	175	200	0·90 ± 0·01	2·62 ± 0·02	0·780 8 ± 0·000 8
		BT	....	....	4·8 ± 0·1	14·1 ± 0·3	0·907 9 ± 0·001 5
20807A	G	WR	115	115	1·0 ± 0·02	2·01 ± 0·05	0·787 9 ± 0·000 8
20813B	M	WR	45	255	0·18 ± 0·002	0·52 ± 0·01	0·728 2 ± 0·000 7
		BT	....	....	7·1 ± 0·1	20·9 ± 0·4	0·936 3 ± 0·001 2
20814B	M	WR	103	150	0·69 ± 0·007	1·96 ± 0·02	0·764 1 ± 0·000 7
20817B	G	WR	6·5	310	0·021 ± 0·001	0·06 ± 0·003	0·715 5 ± 0·001 0
20828	G	WR	83	380	0·22 ± 0·004	0·64 ± 0·01	0·725 3 ± 0·003 1
		BT	....	....	10·8 ± 0·21	32·3 ± 0·6	1·083 6 ± 0·001 3
20836B	G	WR	48	245	0·20 ± 0·004	0·58 ± 0·01	0·731 5 ± 0·001 0
20836D	G	WR	32	272	0·124 ± 0·002	0·36 ± 0·007	0·725 0 ± 0·001 2
		BT	....	....	3·39 ± 0·07	9·91 ± 0·2	0·833 1 ± 0·001 4
20846	M	WR	40	420	0·1 ± 0·001	0·28 ± 0·01	0·719 6 ± 0·000 6
		BT	....	....	1·20 ± 0·02	3·5 ± 0·06	0·753 0 ± 0·001 3
		MT	....	....	0·29 ± 0·005	0·84 ± 0·02	0·725 3 ± 0·001 2
20852	M	WR	56	83	0·681 ± 0·009	1·98 ± 0·03	0·789 8 ± 0·001 0
20857	G	WR	205	205	1·0 ± 0·01	2·91 ± 0·03	0·783 0 ± 0·000 7
20863A	M	WR	295	120	2·48 ± 0·04	7·3 ± 0·1	0·886 0 ± 0·000 9
		BT	....	....	32·2 ± 0·6	104 ± 2·0	1·939 9 ± 0·001 8
		MT	....	....	11·44 ± 0·22	34·6 ± 0·7	1·192 6 ± 0·001 1
20871B	G	WR	280	95	3·03 ± 0·04	8·94 ± 0·1	0·922 1 ± 0·000 9
20872	G	WR	345	60	5·9 ± 0·1	17·8 ± 0·3	1·123 7 ± 0·000 9
		BT	....	....	133 ± 3	652 ±13	7·840 ± 0·006
		MT	....	....	115 ± 2	532 ±10	6·853 ± 0·004
		MCL	....	....	6·8 ± 0·1	20·5 ± 0·3	1·152 0 ± 0·001 5

Notes: 1. G—granitic rock, M—migmatite, WR—whole rock, BT—biotite, MT—muscovite, MCL—microcline
2. The Rb and Sr concentrations have been determined by comparison with a number of standard rocks using X-ray fluorescence spectrometry. An assessment of the mass absorption coefficient of individual samples was made and it is estimated that the values are accurate to ± 7 per cent, although the accuracy of the Rb/Sr ratios are in general accurate to about ± 1 per cent. The Rb/Sr ratios do not correspond exactly with the ratios that would be derived from the separate Rb and Sr values shown.

EXPERIMENTAL PROCEDURES

About 200 g of each sample was reduced to —200 mesh using a jaw crusher and a Tema mill. Approximately 0.4 g of each powdered sample was then taken into solution using a $HF-HClO_4$ mixture, and the Rb and Sr extracted by ion-exchange chemistry. Details of the chemical extraction and mass spectrometry are given by Lewis and others (1975).

Replicate analyses of Eimer and Amend standard strontium carbonate were made, to give a mean value of $^{87}Sr/^{86}Sr$ of 0.7081 ± 0.0001, normalized to a $^{86}Sr/^{88}Sr$ value of 8.3752. A value of 1.39 x 10^{-11} $year^{-1}$ was used for the decay constant of ^{87}Rb.

X-ray fluorescence was used to select rocks with favourable Rb/Sr ratios for mass spectrometric analysis, and also to determine precise values of the Rb/Sr ratio for the selected whole-rock samples. The Rb/Sr ratios of the mineral separates were determined by isotope dilution. Accurately weighed quantities of ^{87}Rb and ^{84}Sr spikes were added to the samples prior to dissolution. Each sample was then dissolved in a $HF-HClO_4$ mixture and the rubidium and strontium separated by cation-exchange chemistry as before. Blank determinations using the isotope dilution technique showed that the Rb and Sr contamination introduced by the chemical processing was less than 10^{-9} g and 10^{-8} g respectively. Full details of the isotope dilution techniques used in this laboratory are given by de Laeter and Abercrombie (1970).

RESULTS AND DISCUSSION

The analytical results are listed in Table 35. The errors accompanying the ratios are at the 95 per cent confidence level. The isotopic data from the 14 whole-rock samples are plotted at different scales, together with selected isochrons, in Figure 68A and B.

Regression analyses of the $^{87}Rb/^{86}Sr$ and $^{87}Sr/^{86}Sr$ data were carried out using the programme of McIntyre and others (1966). All the data (except 20852) were regressed to give an apparent age of 1 626 ± 73 m.y. (95 per cent limits) and an initial $^{87}Sr/^{86}Sr$ ratio of 0.7190 ± 0.0060. The fit of the data is worse than predicted for experimental error alone. The programme examined the data for geological variation and indicated that the distribution of the residuals suggests that the rocks have the same age but different initial $^{87}Sr/^{86}Sr$ ratios. This is not surprising in view of the large geographical distribution of the samples and the geology of the province.

Sample 20852 was excluded from the regression analysis because of its high $^{87}Sr/^{86}Sr$ value. If this sample point is joined to an assumed initial ratio of 0.71 it gives a model age of 2 842 m.y. It is possible that this sample is a remnant of the initial Archaean association of greenstones and granitic rocks which has survived the full effects of the metamorphic and magmatic events described above.

The subset of samples 20872, 20871B, 20863A, 20857 and 20846 gives an isochron which, if fitted to experimental errors alone, has an apparent age of 1 672 ± 18 m.y. and an initial $^{87}Sr/^{86}Sr$ ratio of 0.7131 ± 0.0002. These samples have been collected over a large area in the same general location as Yinnietharra and Minnie Creek homestead, where ages of 1 730 ± 240 m.y. and 1 690 m.y. were obtained by Compston and Arriens (1968) on gneisses and granites respectively. The age of 1 672 m.y. as measured in this project is therefore a more precise estimate of the age in this locality.

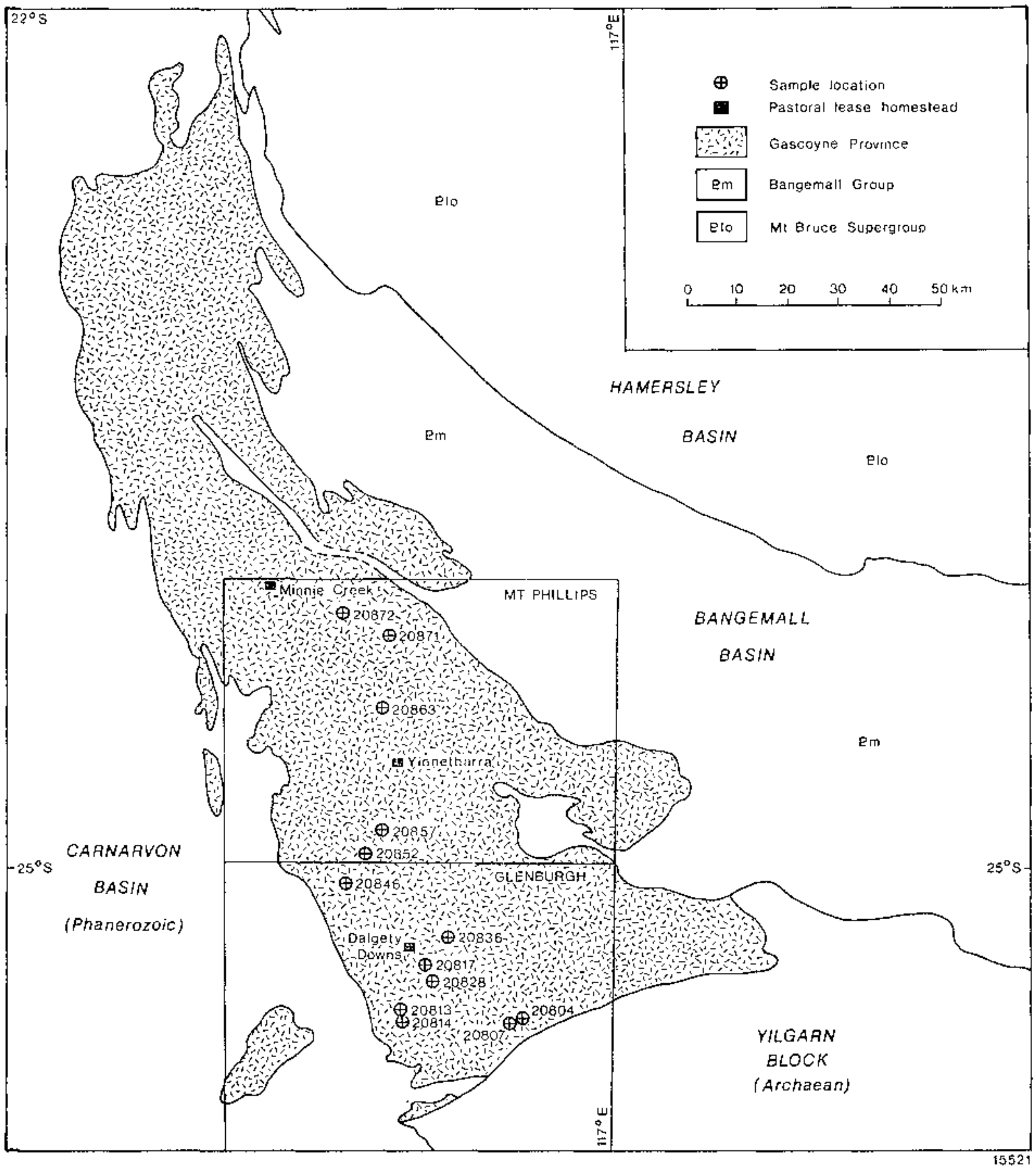

Figure 67. Map showing the position and extent of the Gascoyne Province, the boundaries of the Mount Phillips and Glenburgh 1 : 250 000 Sheet areas, and locations of analysed samples.

The four samples 20807, 20804, 10814B and 20813B, which are located in the southern portion of the Gascoyne Province, give an isochron (labelled II in Fig. 68) and regress within the assigned limits for experimental error to give an apparent age of 1 776 ± 18 m.y. and an initial $^{87}Sr/^{86}Sr$ ratio of 0.7152 ± 0.00034. This age is significantly older than the 1 672 m.y. isochron (labelled I in Fig. 68). The initial ratios of these two suites of samples are consistent with the hypothesis that these samples have been derived from older Archaean rocks, admixed with younger magmatic or supercrustally reworked material.

Three of the four remaining samples (20817B, 20836D and 20836B) have an excellent fit to an isochron (labelled III in Fig. 68) which regresses to give an apparent age of 2 208 m.y. and an initial $^{87}Sr/^{86}Sr$ ratio of 0.7136. These samples were collected from the Dalgety Downs area, (see Fig. 67) and this age is significantly older than the rocks to the south and north, again reflecting the complex geological history of the province.

The 11 mineral separates listed in Table 35 have been plotted with their corresponding whole rocks in Figure 69. A visual inspection of the resulting seven mineral isochrons indicate a uniformity of ages throughout this series of analyses. The mineral ages range from 739 m.y. to 809 m.y. with an average value of 780 m.y. There is no significant difference between the mineral ages derived from biotite and those derived from the muscovites and microcline. As the temperature in this region decreased, the minerals became closed systems with respect to Rb and Sr. The temperature decrease must have been rapid to enable all the minerals to reflect essentially the same age (of 780 m.y.).

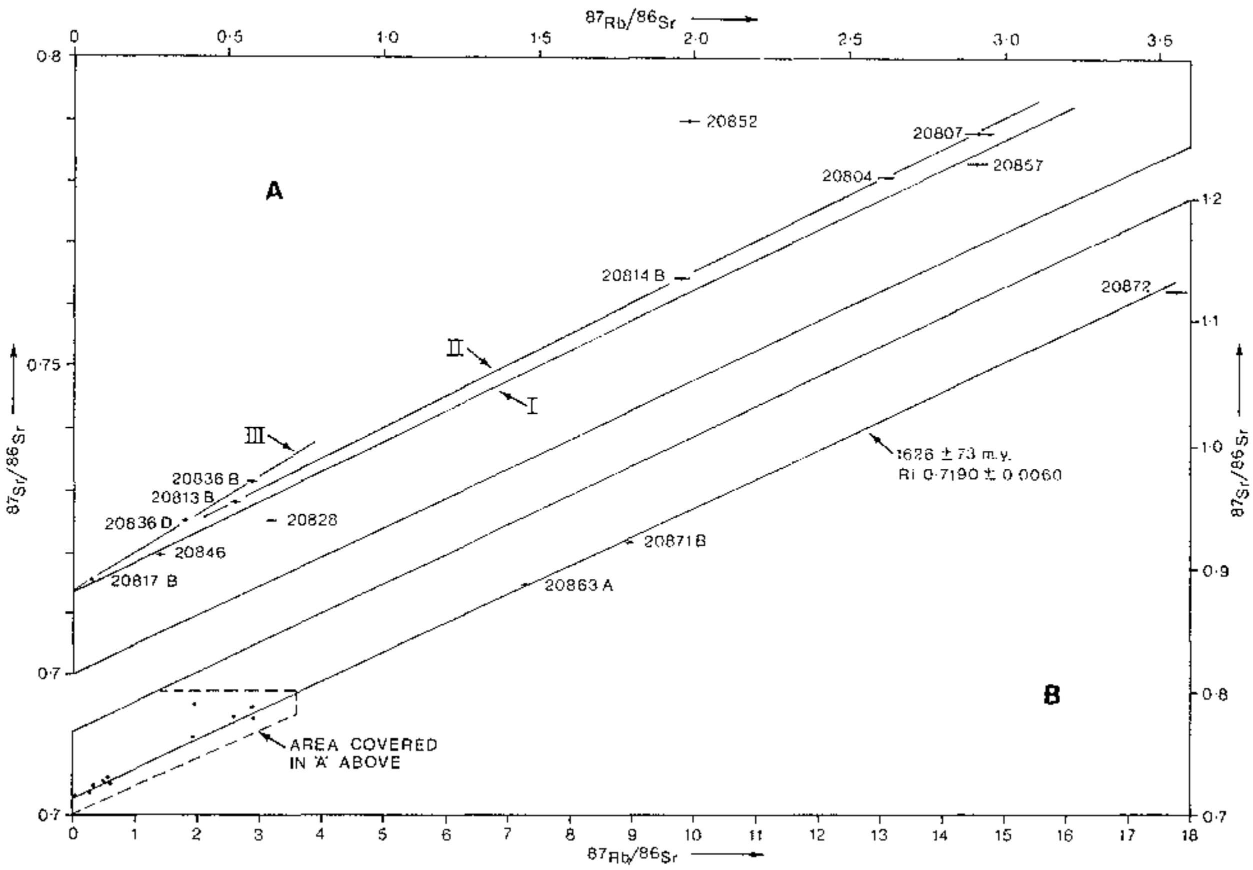

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Figure 68. Isochron plot for data of Table 35 ; the upper diagram 'A' is an expanded representation of the small part of 'B' indicated.

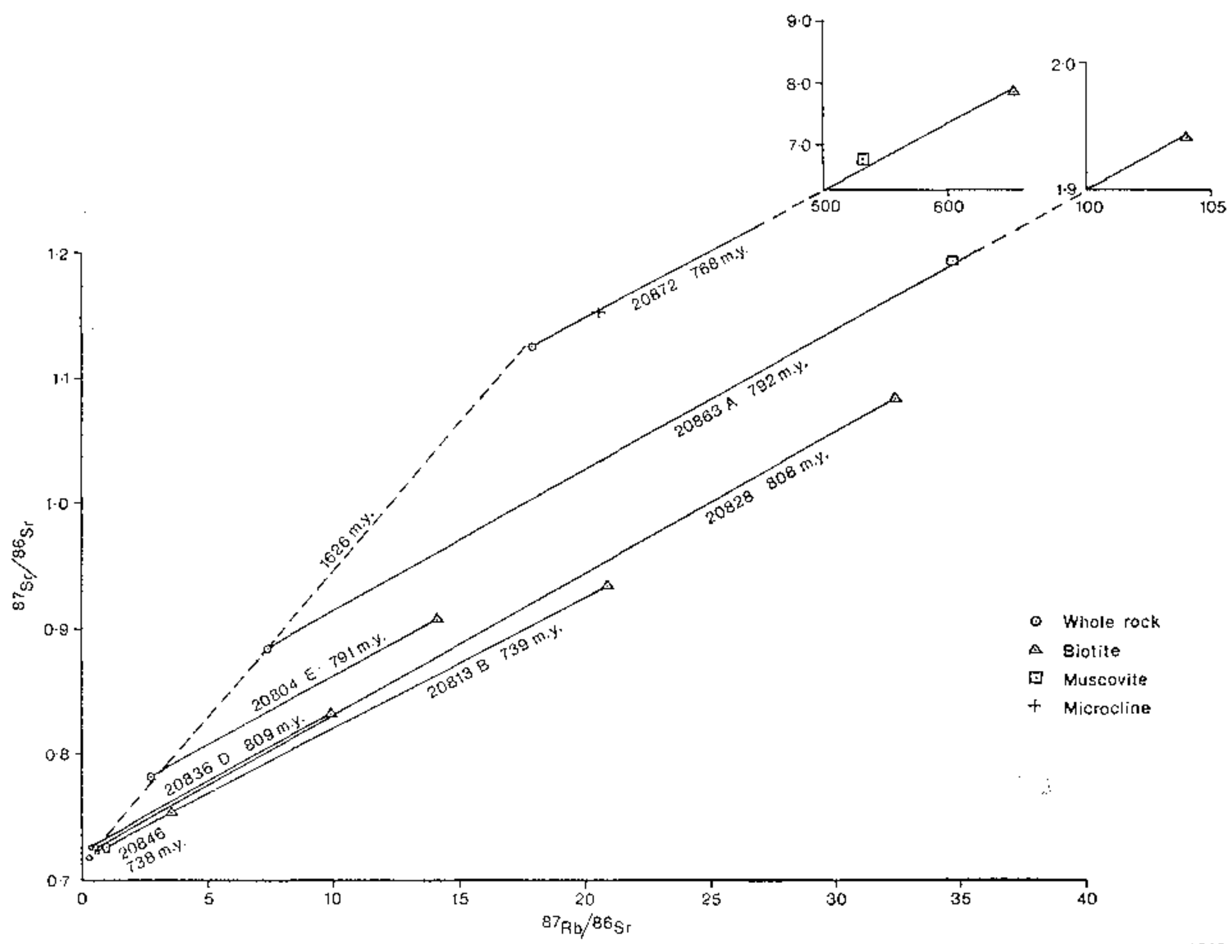

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Figure 69. Mineral ages for seven of the samples plotted in Figure 68. The lower five lines each join a single mineral analysis with its parental total rock sample (two of these lines are in fact superposed). The two upper lines represent the mean ages derived from the two or more mineral analyses shown.

The data do not allow a distinction to be made between a short later regional thermal event and the final termination of a period of elevated temperature which had persisted since initial metamorphism. However, it possible that more rapid cooling took place at this time in association with the uplift and folding of the Bangemall Basin.

ACKNOWLEDGEMENTS

This project was initiated at the suggestion of Dr. J. L. Daniels, who collected the samples used and offered much valuable advice during the course of the work. The author would also like to thank Mr. I. D. Abercrombie and Mr. W. W. Thomas of the Department of Physics, Western Australian Institute of Technology, for technical assistance during this project.

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ZONED ULTRAMAFIC ROCKS FROM THE CANNING TUNNEL

by J. R. Drake

ABSTRACT

Small (5 to 40 cm) mineralogically and texturally zoned ultramafic bodies occur in Archaean banded gneiss in the Canning Tunnel, near Roleystone. They consist of an outer layer of tangential biotite, followed by layers of massive and/or radial tremolite prisms around cores composed either of intergrown talc and calcite, or of decussate tremolite with interstitial chlorite. The ultramafic bodies formed by boudinage of ultramafic layers during deformation, accompanied by amphibolite facies metamorphism, of a mafic/ultramafic igneous sequence. A static greenschist facies metamorphism/metasomatism followed the tectonism, and under these conditions reaction, by cation diffusion, took place across the chemical gradient between the mafic and ultramafic rocks. Reaction was incomplete, which left the zoned ultramafic pods as metastable inclusions in the banded gneiss.

INTRODUCTION

In 1972, the Perth Metropolitan Water Supply, Sewerage and Drainage Board decided to amplify the Perth water supply by driving a tunnel from Canning Dam (one of the two major reservoirs providing water for Perth) to Roleystone. The tunnel was constructed during 1973-74, and passed through the Darling Range, the physical expression of the Darling Fault which forms the western margin of the Yilgarn Block (see Fig. 70). The Yilgarn Block is a stable Archaean nucleus consisting of elongate "greenstone" belts enclosed by granites and gneisses. In the eastern half, metamorphic grade is generally low, but in the west, rocks of high metamorphic grade are found and granites, gneisses, and migmatites predominate.

The major rock types encountered during excavation of the Canning Tunnel were banded gneiss and massive granite of Archaean age, and altered dolerite of younger Precambrian age. Zoned ellipsoidal ultramafic bodies from 5 to 40 cm across were found in the banded gneiss, and a project to determine the origin of these bodies was undertaken.

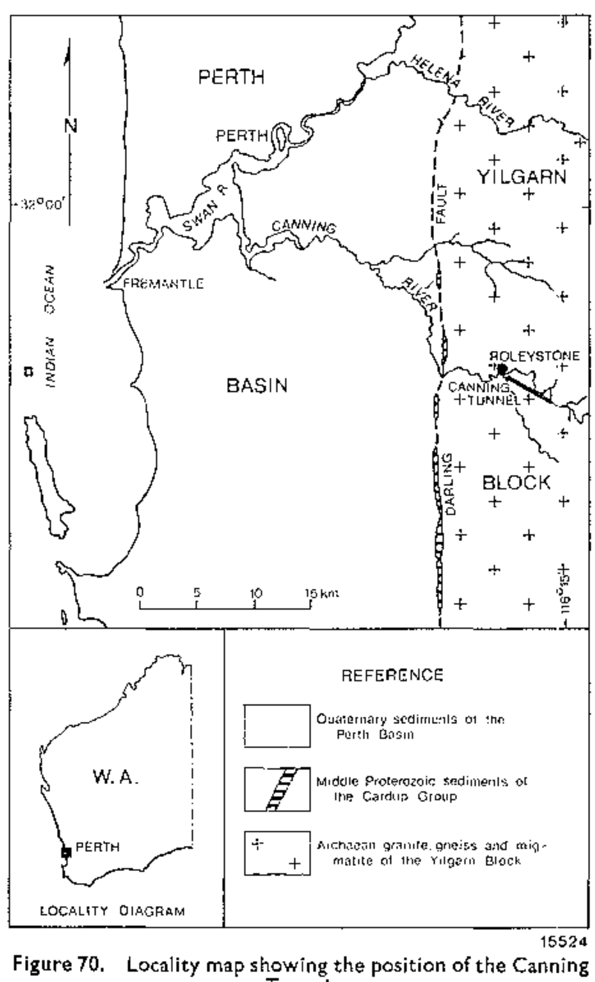

Figure 70. Locality map showing the position of the Canning Tunnel.

Previous work in the area dates from 1915, when Feldtmann (1916) reported on the geology of the Canning Dam site. Other studies were those of Clarke and Williams (1926) in the Roleystone area; of Prider (1940 and 1942) at Armadale and Canning Dam respectively; more recently of Klenowski (1973) who worked on the geology, particularly the engineering geology, of part of the Canning Tunnel; and of Wilde (in prep.) who mapped the area at a scale of 1:250 000.

GEOLOGY

The general geology of the Canning Tunnel area was determined by Prider (1940 and 1942). The oldest rocks are mafic xenoliths which occur in Archaean banded gneiss termed "hybrid gneisses" by Prider. The banded gneiss consists of alternating mafic and felsic bands, and is discordantly intruded by massive granite; both gneiss and granite are cut by aplites, pegmatites, and quartz veins which are probably late phases of the massive granite. The youngest rocks in the area are altered dolerite dykes which cut across all other rock types.

PETROLOGY OF THE BANDED GNEISS

Description

The gneiss is banded on a macroscopic scale, with bands greater than 5 cm (see Fig. 71), and a mesoscopic scale with bands of approximately 1 cm width. The mesoscopic bands are mafic, felsic or porphyroblastic, and although each macroscopic band contains all three types, each is dominated by one. Some of the felsic bands, however, such as the prominent ones in Figure 71, may be veins which were intruded parallel to the banding during or after metamorphism, and they are composed predominantly of quartz and oligoclase.

The mafic bands consist of intergrown subhedral prisms of green-brown hornblende, which are commonly rimmed or almost completely replaced along cleavages by khaki biotite; biotite not obviously after hornblende is also common. Albite, packed with epidote, may be a minor constituent in the mafic bands; sphene, apatite, and pyrite are typical accessories.

Intergrown anhedral albite crystals about 1 mm across are the major components of the felsic bands. The albite crystals are invariably crammed with epidote inclusions; minor hornblende and biotite, and accessory sphene, apatite, and pyrite are generally present.

The porphyroblastic bands contain porphyroblasts and glomeroporphyroblasts of albite more than 5 mm across, in a mafic groundmass. The plagioclase, as in the other bands, has been heavily epidotized and may also have been sericitized. The groundmass is predominantly green-brown hornblende showing minor replacement by actinolite and biotite; sphene, apatite, and pyrite are disseminated accessories.

Origin

The banded gneiss is a deformed and metamorphosed sequence of mafic igneous rocks. The rocks recrystallized as hornblende-plagioclase amphibolites under amphibolite facies conditions, but were subsequently retrogressed and metasomatized in the greenschist facies, with partial replacement of hornblende by biotite and actinolite, and calcic plagioclase by albite and epidote.

The banding is due to metamorphic differentiation, but when and how differentiation took place is not clear. It could have been a mechanical segregation during tectonism, a diffusive segregation during amphibolite facies metamorphism, or a diffusive segregation during metasomatism and greenschist facies metamorphism. The last mentioned is the most likely mechanism as diffusion would have been aided by the presence of a fluid phase.

ULTRAMAFITES

OCCURRENCE

Ultramafic rocks in the gneiss of the Roleystone area have only been found in the Canning Tunnel; however, this may be a function of preservation, as such rocks would probably have weathered out of surface exposures.

Distribution

The ultramafic rocks are not found in the gneiss throughout the length of the tunnel, but only occur in the 1 100 ft (330 m) section from 6 800 ft (2 070 m) to 7 900 ft (2 400 m) which is approximately the middle of the tunnel. The ultramafites are irregularly distributed through the gneiss in this section, but generally occur in the mafic bands. However, where the banding in the gneiss is finer they may be in contact with several bands, including felsic and porphyroblastic ones (see Fig. 71).

Size and shape

The size and shape of the ultramafic bodies are variable; however, most are triaxial ellipsoids with their two longest axes lying in the plane of the banding of the enclosing gneiss. In size, the pods range from rounded bodies about 5 cm across, to ellipsoids with longest axes up to 40 cm, with a fairly even distribution between these limits.

MINERALOGY AND TEXTURE

The most interesting feature of the ultramafic bodies is that they are mineralogically and texturally zoned (see Fig. 72). All of them have an outer layer of tangential biotite, usually about 1 cm thick, with minor though variable amounts of hornblende and chlorite, and accessory sphene, apatite, and pyrite. In most of the specimens examined, the biotite layer is drawn out into a flange in the plane of the two longest axes, which indicates that the ultramafic pods have been tectonically flattened.

The ultramafites usually have three or four layers from 1 mm to 2 cm across, of alternately massive and radial tremolite around cores of either talc and calcite, or tremolite with chlorite.

The massive layers are made up of acicular or equant tremolite prisms about 1 mm long, with interstitial chlorite, and scattered magnetite and pyrite. The radial layers have elongate tremolite prisms up to 1 cm long, and again interstitial chlorite, and scattered magnetite and pyrite. The total width of the outer tremolite layers varies from approximately 1 to 5 cm for different bodies. In the talcose ultramafites, the outer tremolite layers may grade, with increasing talc and calcite and decreasing tremolite content, into massive talc-calcite rocks, while in others the boundaries of the tremolite and talc-calcite layers are sharp. In some specimens, the talcose cores are also zoned into talc-rich and calcite-rich layers. Partially replaced euhedral tremolite prisms are present in minor amounts in the talc-calcite cores, and magnetite and pyrite are accessories.

In the predominantly tremolitic ultramafites, an outer massive layer is followed by a layer composed of radial tremolite prisms 2 to 3 cm long, which branch slightly towards the centre, indicating that they grew inwards from the margin. The cores of these ultramafites are made up of decussate tremolite prisms 2 to 3 mm long, with minor interstitial chlorite, and accessory magnetite and pyrite (see Fig. 72).

ORIGIN

The ultramafic rocks represent parts of original ultramafic flows or intrusions which were interlayered in a predominantly mafic sequence. The sequence was deformed and metamorphosed in the amphibolite facies, and during deformation the ultramafic rocks broke up into small pods due to boudinage. Static greenschist facies metamorphism/metasomatism followed the tectonism, and under these conditions reaction, probably by cation diffusion, took place across the chemical gradient between the mafic and ultramafic rocks. Unfortunately, the mineralogical composition of the ultramafic rocks before reaction is not known, so it is impossible to estimate the exact movements of elements during the reaction. However, it is likely that the ultramafic rocks gained silicon, aluminium, potassium, and calcium from aqueous solution and the enclosing mafic rocks, while their chief loss was of magnesium. Reaction was incomplete, and the mineralogically zoned ultramafic rocks remained as metastable pods in banded gneiss. A fluid phase was probably necessary to allow the reaction to proceed at all, since activation energies of liquid diffusion processes are orders of magnitude lower than those of corresponding solid state processes (Curtis and Brown, 1969), and evidence for such a phase is provided by the metasomatism, and perhaps also by the metamorphic differentiation of the banded gneiss. The presence of a fluid phase may account for the size and radial structure of some of the tremolite prisms, as it does, for example, in igneous pegmatites.

Mineralogical zoning around the borders of metamorphosed ultramafic rocks has been reported from many parts of the world and from several metamorphic environments. Gillson (1927), Hess (1933), Phillips and Hess (1936), Chidester (1962), and Jahns (1967) described zoning attributed to metamorphic reaction and differentiation around serpentinites in greenschist facies rocks from vermont. Misar (1973) and Sørensen (1954) found and documented metamorphic reaction zones around ultramafites in amphibolite and granulite facies rocks respectively, while Kalsbeek (1970) found similar reaction zones where ultramafic rocks were cut by pegmatites, and Bondesen (1964) found reaction zones where ultramafic inclusions occurred in an intrusion breccia.

The most recent account of the chemical processes and kinetics involved in forming zoned ultramafic bodies is that of Curtis and Brown (1969). They describe the ultramafites from Unst, Shetland, which were originally described by Read (1934). The idealized zonal sequence at Unst is from country rock, through phlogopite, chlorite, actinolite, and talc, to antigorite, although the chlorite zone is rarely developed, and in some cases antigorite has been completely replaced. Therefore, although the bodies at Unst are larger (30 cm to 6 m), they are very like those of the Canning Tunnel, and the chemical processes responsible for the two occurrences are likely to have been very similar.

CONCLUSION

The zoned ultramafic pods from the Canning Tunnel formed by boudinage of ultramafic layers during deformation of a mafic/ultramafic igneous sequence. Deformation was accompanied by amphibolite facies metamorphism, which was followed by retrogressive greenschist facies metamorphism in the presence of a fluid phase which caused diffusive reaction across the chemical gradient between the mafic and ultramafic rocks. Unfavourable reaction kinetics prevented the reaction from going to completion, which left the zoned ultramafic rocks as metastable pods in the enclosing mafic gneiss.

ACKNOWLEDGEMENT

I am indebted to Mr. W. L. Powe of Dampier Mining Co. Ltd., formerly of the Metropolitan Water Supply, Sewerage and Drainage Board, who first drew my attention to the ultramafic rocks in the Canning Tunnel, and who helped me with sample collecting on subsequent excursions.

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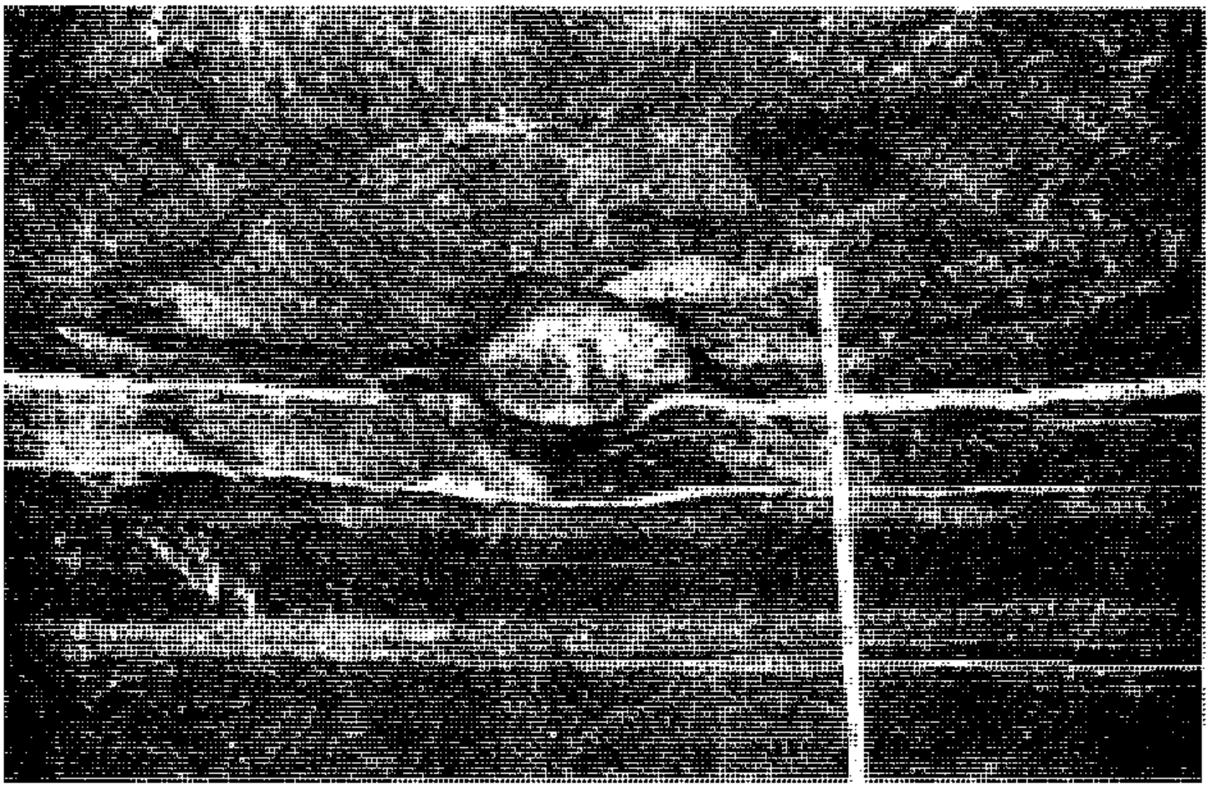

Figure 71. Zoned tremolitic ultramafic body within banded gneiss, south wall of tunnel at 7 600 feet (2 300 m).

a. is a broad mafic macroband.
b. is a thin quartz-oligoclase vein.
c. is a hornblende-biotite mafic microband.
d. is an albitic felsic/porphyroblastic macroband. The scale is in centimetres.

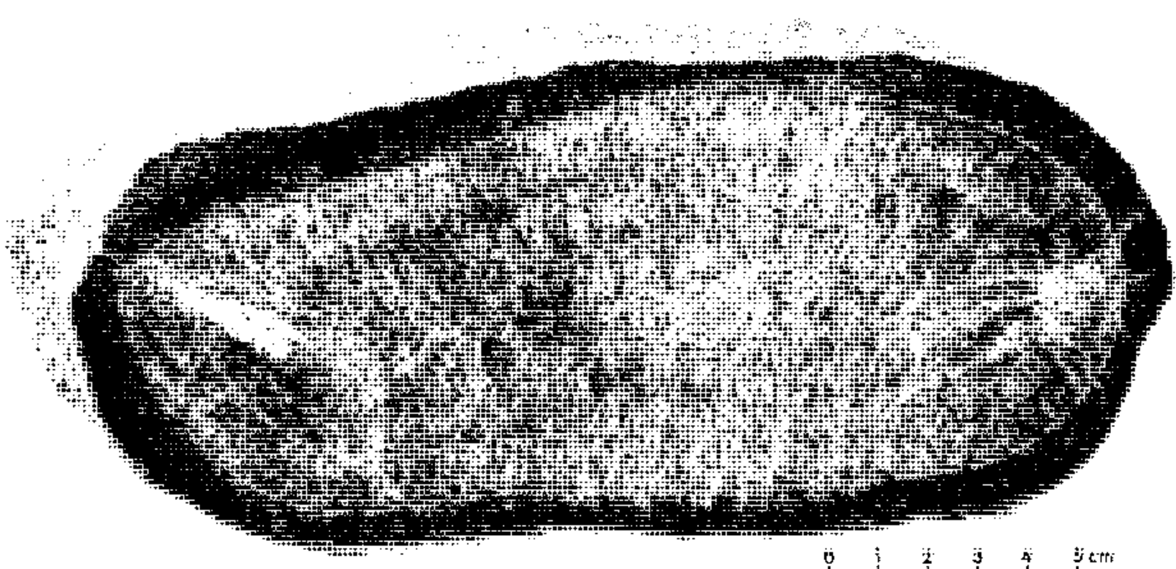

Figure 72. Tremolite ultramafic pod showing mineralogical and texturing zoning.

a. is the outer rim of tangential biotite.
b. is massive tremolite.
c. is radial tremolite.
d. is the core of decussate tremolite.

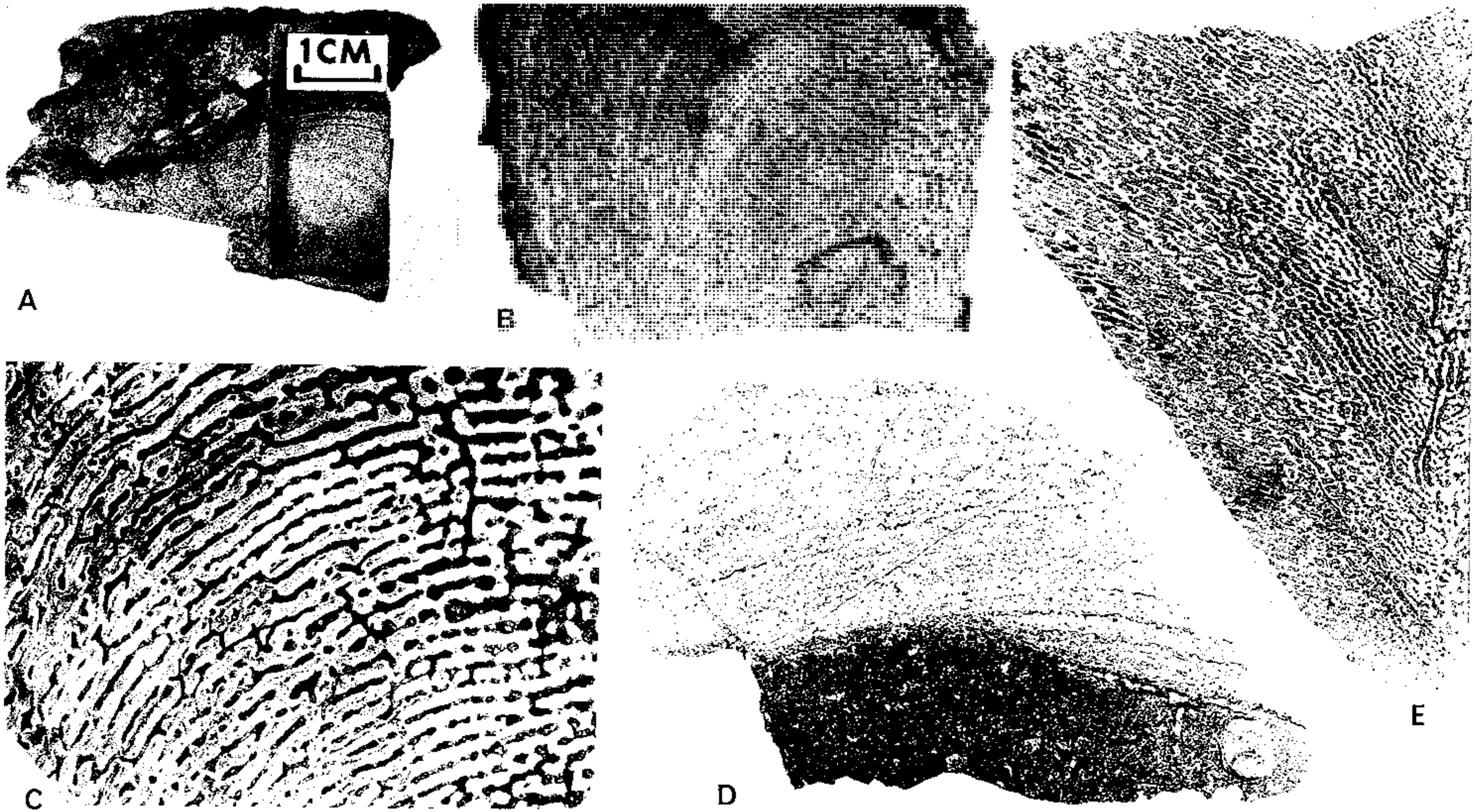
1CM
A
B
C
D
E

Figure 73. *Stromatoporella kimberleyensis* Etheridge Jr. All figures are of the holotype (Australian Museum registered numbers F16810 and AM990) collected from the Napier Formation near old Napier Downs homestead, Napier Range, by Dr. H. Basedow in 1916.

A. General view of holotype : F16810.

B. Longitudinal section, x4 : AM990a.

C. Enlargement of part of AM990a, x15.

D. Longitudinal section, x4 : AM990b

E. Tangential section, x4 : AM990c.

STROMATOPORELLA KIMBERLEYENSIS ETHERIDGE Jr. 1918 IS A PIECE OF BONE

by A. E. Cockbain

ABSTRACT

The species *Stromatoporella kimberleyensis* Etheridge Jr. 1918 is shown to be a piece of arthrodire bone and is figured for the first time. Kimberleyensis bone has only been found in rocks of Famennian age belonging to the Napier Formation and Nullara Limestone.

INTRODUCTION

In 1918, Etheridge Jr. described, but did not figure, three new species from the Devonian of the Lennard Shelf under the names *Actinostroma subclathratum*, *Stachyodes dendroidea*, and *Stromatoporella kimberleyensis*. The types of all three species are housed in The Australian Museum, Sydney. Through the kindness of Dr A. Ritchie, Curator of Palaeontology, I have been able to examine the specimens. *Actinostroma subclathratum* and *Stachyodes dendroidea* are typical representatives of their respective genera and will be described and figured as part of a study of the stromatoporoids from the Lennard Shelf Devonian reef complexes. However, *Stromatoporella kimberleyensis* is not a stromatoporoid and the purpose of this note is to figure the species and show that it is arthrodire bone.

SYSTEMATIC PALAEONTOLOGY

"*Stromatoporella kimberleyensis*" Etheridge Jr.
Figure 73.

1910 coccostean bone: A. Smith Woodward in Glauert, p. 112, 113.

1918 *Stromatoporella kimberleyensis* Etheridge Jr.: p. 259.

1919 *Stromatoporella kimberleyensis* Etheridge Jr.; Maitland: p. 29, 32.

1922 *Stromatoporella kimberleyensis* Etheridge Jr.; Benson: p. 167.

1966 *Stromatoporella kimberleyensis* Etheridge Jr.; Playford and Lowry: p. 61, 70.

1968 *Stromatoporella kimberleyensis* Etheridge Jr.; Flügel and Flügel-Kahler: p. 221.

Type material: One specimen, Australian Museum registered number F16810, and 3 slides (all Australian Museum registered number AM990) in The Australian Museum; Napier Formation, Napier Range near Old Napier Downs homestead (LNR1); collected by Dr H. Basedow in 1916.

Other material: G.S.W.A. registered number F327, Napier Formation, Barker Gorge (LNR2); G.S.W.A. registered number F5727, Napier Formation, 4 km northwest of Windjana Gorge (LNR3); G.S.W.A. registered number F5728, Napier Formation, Cycad Hill (LNR4) (see Fig. 74 for localities).

Description: The original description of *kimberleyensis* by Etheridge Jr. (1918, p. 259-260) is as follows:—

"*Sp. Chars.*—Coenosteum apparently forming a thick laminar expansion (25 mm), but whether incrusting, or attached by a peduncle evidence is lacking. Concentric laminae gently undulated (thereby probably indicating the absence of mamelons on the surface), averaging from four to five in the space of one millimetre, and possessing a peculiar structure of their own, in that they are composed of parallel wavy fibres concentric around the interlaminar spaces, but without any median clear line; interlaminar spaces appear to be quite subordinate to the concentric laminae, are oval or circular, without septa; radial pillars stout, short, and confined to their respective interlaminar spaces; zooidal tubes not observed. A tangential section displays the cut ends of radial pillars, or sections of the concentric laminae, thereby indicating a considerable degree of reticulation."

If the stromatoporoid terminology is omitted, then Etheridge's description is entirely appropriate for bone structure.

The holotype is a piece of bone 60 x 50 x 25 mm in size. The bone has a spongy texture and consists of a network of trabeculae 0.13 to 0.2 mm in diameter, with a ramifying system of canals 0.05 to 0.2 mm in diameter between them. The trabeculae tend to be arranged in layers (about 4 per mm) parallel to the outer surface of the bone; the layers are not continuous sheets but are themselves reticulate networks. However, the layering and networks are far from regular. The trabeculae have a concentric lamellation around the canals and contain lens-like specks or lacunae.

X-ray diffraction analysis of G.S.W.A. registered number F5727 shows that the bone consists of apatite and the canals between the trabeculae are filled with calcite and a little common opal (Western Australian Government Chemical Laboratories, written comm., October, 1975). The apatite has a fibrous habit. In holotype slide AM990a (Fig. 73) the bone has been extensively replaced by carbonate, although patches of fibrous apatite do occur.

Remarks: Etheridge's comments on the species are given below (1918, p. 260):

"*Obs.*—The state of preservation of the tissues is very uneven. In one radial or longitudinal section the structure of the concentric laminae is preserved, but in a second taken close to the first the whole of the tissues are obliterated, and represented by clear mineral matter, and in a tangential section the same occurs.

"Nicholson's description of the structure of *S. eifelensis* [sic] so aptly fits that of this form I am feign to quote it: —'owing to the thickness of the laminae, the interlaminar spaces are comparatively narrow, and the correspondingly thick radial pillars usually run from lamina to lamina, but do not extend beyond the interlaminar space within which each originates.'

"'There is another aspect of this fossil seen in longitudinal sections difficult of interpretation, viz., large branching canals, or tubes, vertical or oblique, often running through more than one concentric lamina, in fact passing through four or five direct, and filled with clear mineral matter. For a long time I was much puzzled to account for these passages, and I can only do so now on the hypothesis of structural decay, whereby the tissue of certain of the radial pillars has decayed and the channels thus formed 'ran together' with some of the interlaminar spaces, and so formed these unsymmetrical tubular spaces. Here and there it is possible to see one, or perhaps two superimposed replaced radial pillars combining with a similarly infilled interlaminar space."

(12)—59638

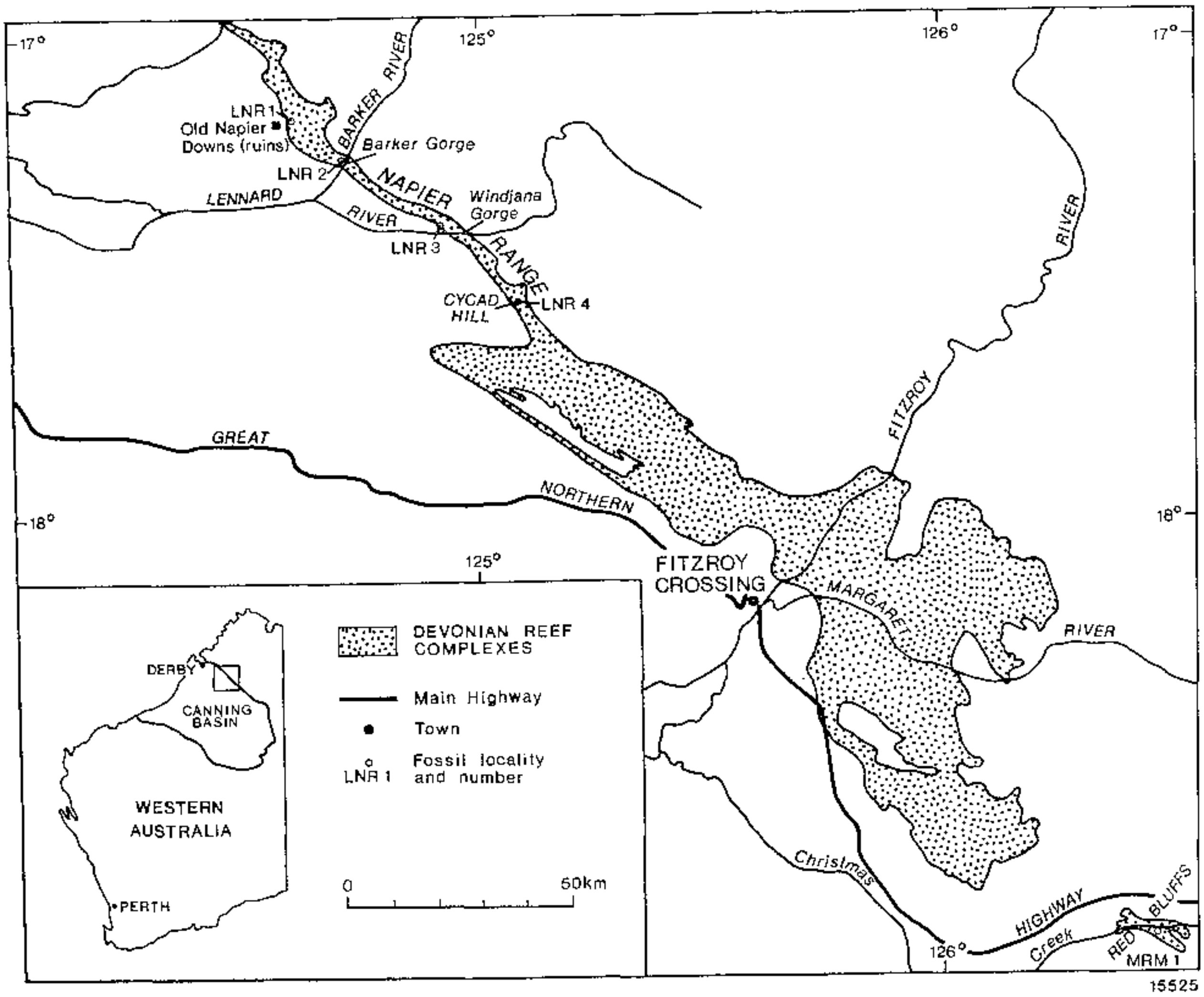

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Figure 74. Localities with *kimberleyensis* bone.

He was obviously puzzled by the structure of *kimberleyensis*, suggesting "structural decay" to account for the appearance in thin section. Similarly, Flügel and Flügel-Kahler (1968, p. 221) commenting on photographs of the material stated: "Der Vertikalschliff zeigt eine mit *Stromatoporella* vergleichbare Struktur, wobei jedoch extrem dicke Skelettelemente auffallen." ("The vertical section shows a structure comparable to *Stromatoporella*, but extremely thick skeletal components are a striking feature".) The peculiar appearance of "*Stromatoporella kimberleyensis*" is at once resolved when it is realized that the type specimen is a piece of bone.

Photographs of slides cut from the type specimen and of a polished surface of G.S.W.A. registered number F327 were sent to Dr R. S. Miles of the British Museum (Natural History) who stated (written comm., July, 1975): "All of your photographs clearly show pieces of arthrodire bone . . . How many species in all are involved cannot be judged, as bone varies in character from one part of the armour to another, and yet may look alike in different species."

TABLE 36. LOCALITY DATA

Fossil locality no.	Co-ordinates E	N	Locality	Formation	Sample no. and collector
Lennard River 1:250 000 map sheet					
LNR 1	Precise locality not known		Napier Range, near Old Napier Downs homestead	Napier Formation	H. Basedow, 1916 ; AM 990 F16810
LNR 2	Precise locality not known		Napier Range, Barker Gorge	Napier Formation	H. P. Woodward, 1906 ; F327
LNR 3	273 400	2 812 500	Napier Range 4 km N.W. of Windjana Gorge	Napier Formation	P. E. Playford, 1962 ; sample 11653
LNR 4	293 100	2 793 500	Napier Range, Cycad Hill	Napier Formation	P.E. Playford, 1962 ; sample 11654
Mount Ramsay 1:250 000 map sheet					
MRM 1	453 000	2 635 000	Red Bluffs, 2·5 km S.S.W. of Nippers bore	Nullara Limestone	P.E. Playford, 1966 ; sample 3428

Distribution: (Fig. 74 and Table 36) *kimberleyensis* bone has been recorded from the Napier Formation near Old Napier Downs homestead (LNR 1) (Etheridge Jr., 1918), at Cycad Hill (LNR 4), and 4 km northwest of Windjana Gorge (LNR 3) (Playford and Lowry, 1966), and from Barker Gorge (LNR 2) (Glauert, 1910). Near Windjana Gorge the bone fragments are up to 37 cm long (P. E. Playford, pers. comm., October, 1975). Playford and Lowry (1966) also record the bone from the Nullara Limestone (formerly mapped as Pillara Limestone) at Red Bluffs (MRM 1). The rocks at all these localities are of Famennian age.

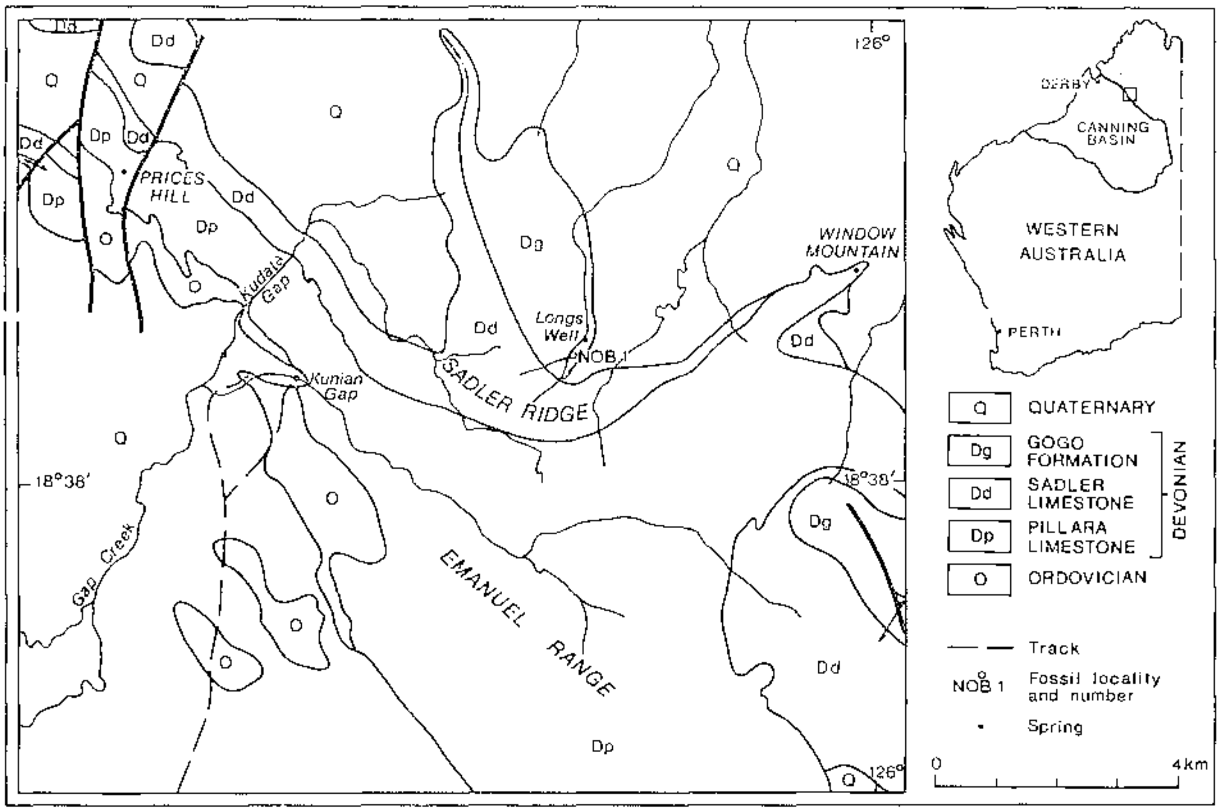
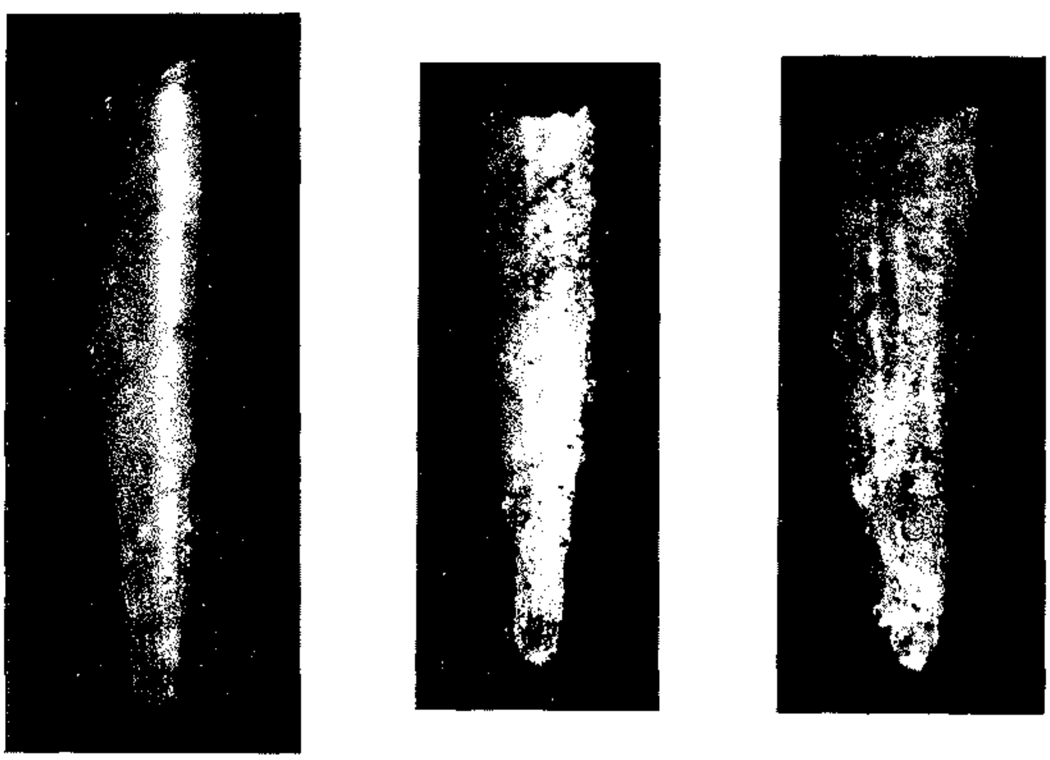


Figure 75. Locality map.



A B C

Figure 76. *Striatostyliolina striata* (Richter)—all x 50.

A. F9262/1—showing ribs in early portion of shell.
B. F9262/2—showing ribs extending over apical bulb.
C. F9262/3—showing prominent longitudinal ribs.

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DEVONIAN TENTACULITIDS FROM THE CANNING BASIN REEF COMPLEXES

by A. E. Cockbain

ABSTRACT

The first Australian record of *Striatostyliolina striata* is from Gogo Formation strata of 1α age. This is in broad agreement with the lower Adorfian occurrence of the species in Germany. The age of some of Sherrard's (1975) tentaculitid records is reassessed and her Givetian species are considered to be probably Frasnian in age.

INTRODUCTION

Tentaculitids are small conical shells of uncertain affinities which have been shuffled back and forth between several phyla. Lately, they have been considered to belong to a new class of Mollusca (Fisher, 1962). Although tentaculitids have been studied for many years, it is only within the last two decades that their biostratigraphic potential has been tested (see, for example, Boucek, 1964, 1967; Zagora, 1964; Lyashenko, 1967; and references therein).

The earliest record of tentaculitids from the Devonian reef complexes of the Canning Basin is probably that of Teichert (1949) who listed *Tentaculites* sp. from the *Manticoceras* zone. Recently, Sherrard (1975) has recorded 9 species in open nomenclature from 4 formations in the reef complexes. Sherrard's specimens came from samples collected by West Australian Petroleum Pty. Ltd. (Wapet). None of them came from the Gogo Formation. This unit frequently contains tentaculitids (Glenister and Crespin, 1959; Playford and Lowry, 1966) which are silicified at some localities. This report documents one such locality where specimens of *Striatostyliolina striata* are associated with abundant radiolarians.

The locality (NOB 1) is situated about 0.4 km southwest of Longs Well near Sadler Ridge and is on a section line measured through the Gogo Formation (Fig. 75). Conodonts collected from this section belong to the lower and/or middle *asymmetricus* zone (1α) (Druce, 1971).

SYSTEMATIC PALAEONTOLOGY

Class TENTACULITA Boucek (1964)

There seems to be no universally accepted name for the tentaculitids. Lyashenko (1959) placed them and the hyolithids in the new Class Coniconchia; Fisher (1962) considered the tentaculitids and hyolithids to be unrelated and erected two new classes, the Cricoconarida for the tentaculitids and the Calyptoptomatida for the hyolithids. Boucek (1964) accepted the separation of these two groups but united the tentaculitids and the cornulitids in the Class Tentaculita. There is a good case for retaining a familiar name for the class which includes the tentaculitids and as the law of priority is not binding at the class level, I prefer Boucek's name Tentaculita.

Order DACRYOCONARIDA
Family STYLIOLINIDAE

Striatostyliolina striata (Richter)

Figure 76.

1854 *Tentaculites striatus* Richter: p. 288, pl. 3, figs. 30-33.

1864 *Styliola richteri* Ludwig: p. 321, pl. 50, figs. 16a-c (new name for *S. striatus* (Richter) not Rang).

1964 *Striatostyliolina striata* (Richter); Boucek: p. 134.

1964 *Striatostyliolina striata* (Richter); Zagora: p. 1246.

Material: G.S.W.A. registered number F9262 (about 20 specimens) from G.S.W.A. sample number 19656, Gogo Formation. Fossil locality NOB 1, Noonkanbah 1 : 250 000 Map Sheet, co-ordinates (yards) 394 640 E, 2 663 820 S, 0.4 km southwest of Longs Well.

Description: The conical shell is up to 2.7 mm in length, 0.5 mm in diameter at the apertural end and 0.15 mm in diameter at the apical end. The apical bulb is bluntly rounded; the shell is initially cylindrical for a short distance and then becomes conical, the angle of the cone being about 7 to 8 degrees. Internally the shell is smooth. On the outside are up to 14 widely spaced, thin, prominent longitudinal ribs which continue over the apical bulb. No growth lines can be seen.

Remarks: All specimens are silicified and were extracted from the rock using hydrochloric acid. The longitudinal ribs are poorly preserved, possibly as a result of the extraction technique. The species has not been recorded previously from Australia.

Distribution: *S. striata* occurs in the Gogo Formation from strata which have yielded a lower-middle *asymmetricus* zone (1α) conodont fauna. The species occurs in the lower Adorfian of Germany (Boucek, 1967). Zagora (1964) shows it to range through the upper part of the *asymmetricus* zone (*dubia* zone on his chart) into the lower part of the *triangularis* zone, (that is, upper 1α/β to lower 1γ) in Thuringia; its absence from the lower part of the *asymmetricus* zone is probably due to unsuitable facies.

TENTACULITID DISTRIBUTION IN THE REEF COMPLEXES

The tentaculitids identified by Sherrard (1975) came from the Pillara and Sadler Limestones and the Virgin Hills and Napier Formations. On the basis of Lyashenko's work she compiled a table showing the age of the tentaculitid species occurring in the reef complexes. Using the data given by Sherrard together with some further locality details in Seddon (1970) and provided by Wapet (written comm., October 1975), Table 37 has been drawn up summarizing the distribution of tentaculitids in the reef complexes of the Canning Basin.

TABLE 37. DISTRIBUTION OF TENTACULITIDS IN DEVONIAN FORMATIONS, CANNING BASIN

Species	Formations					Tentaculitid ages (Sherrard, 1975)	Conodont datings (Sherrard, 1975)	Age suggested herein
	Dg	Dp	Dd	Dr	Dn			
Uniconus aff. *livnensis*					X	Upper Frasnian	1δ-post 1δ	
Tentaculites aff. *donensis*		X			X	Middle Frasnian	$1\beta/\gamma$–1γ	
Uniconus aff. *kremsi*		X				Middle Frasnian	$1\beta/\gamma$–1γ	
Multiconus cf. *schimanskii*			X			Middle Frasnian	none	Frasnian
Dicricoconus aff. *lansiformis*		X	X			Middle Frasnian	none	Frasnian
Homoctenus aff. *krestovnikovi*		X	X	X	X	Middle Frasnian	1γ (Dr)	Dn-probably Famennian ; rest Frasnian
Dicricoconus aff. *tagangaevi*		X	X			Upper Givetian	1α (β)	Frasnian
Tentaculites aff. *maslovi*		X				Middle Givetian	none	Frasnian
Dicricoconus aff. *mesodevonicus*		X	X			Middle Givetian	none	Frasnian
Striatostyliolina striata	X					Not recorded		1α

Dg Gogo Formation
Dp Pillara Limestone
Dd Sadler Limestone
Dr Virgin Hills Formation
Dn Napier Formation

Whilst the ages suggested by the tentaculitids agree in general with those indicated by the conodonts (as Sherrard pointed out), there are some discrepancies. Most noteworthy are the species considered Middle Givetian by Sherrard; the localities from which these were collected (BC 83 and 85 in the Lawford Range) are more likely to be Frasnian on stratigraphical grounds. The record of *H. krestovnikovi* from Lloyd Hill (BC 21) is probably 1α in age (Druce, 1971) whereas the Napier Formation occurrence of this species (BC 128, near Windjana Gorge) is possibly Famennian, and the species has a long range. The BC numbers are those of the Wapet localities from which Sherrard's specimens came.

In the present state of our knowledge it is too early to state how precise a tentaculitid time scale may prove to be. Some species are obviously quite good (for example, *S. striata, U. livnensis*); others appear to be ambiguous (for example, *H. krestovnikovi, T. maslovi*). The fact that some tentaculitid species were widespread (presumably because they were pelagic organisms) and had a limited vertical range (for example, *S. striata*) offers hope that they may be useful in interregional correlation.

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GEOCHEMICAL VARIATIONS IN ARCHAEAN GRANITOIDS IN PART OF THE NORTHEAST YILGARN BLOCK

by R. Davy

ABSTRACT

Regional variations in Archaean granitoids have been identified during the course of a regional rock geochemical programme on the Rason, Laverton, and Leonora 1 : 250 000 Sheet areas. The mean values of magnesium, nickel, and vanadium rise consistently from east to west across lineament boundaries from the Sefton to the Ida Lineaments, whilst potassium and rubidium reach a peak between the Sefton and Laverton Lineaments, falling away on either side. The causes of these systematic variations are as yet unknown, but they may be related either to crustal thinning (from east to west) or to deeper penetration of the crust by major disruption zones.

INTRODUCTION

In 1972, the Geological Survey of Western Australia initiated a programme of regional sampling to investigate the potential of bed-rock geochemistry as a strategic exploration tool and as an adjunct to regional mapping. The area chosen for preliminary study included the Archaean rocks, in particular the Archaean igneous rocks (or their metamorphosed equivalents), from parts of the Rason, Laverton, and Leonora 1 : 250 000 Sheet areas (Fig. 77). During the programme some 1 200 "fresh" samples and 300 altered or weathered samples were collected, emphasis being given to the collection of samples from major outcrop zones with the proviso that the samples should be as representative of the various rock types as possible. Seventeen elements and oxides* were determined by X-ray fluorescence analysis on compressed powder briquettes, and one element, uranium, was determined by chromatography (Plamonden, 1968). All analyses were carried out by the Western Australian Government Laboratories.

A detailed report is in preparation and will be published elsewhere (Davy, in prep.). The present report is confined to an examination of regional variations, particularly in granitoids, which have become apparent during interpretation of the results.

Williams (1974) discussed the structural subdivision of the Eastern Goldfields Province, splitting it into three subprovinces. The Kalgoorlie (central) and Laverton (eastern) Subprovinces are relevant to this paper. Williams postulated that a number of major linear zones (hereafter called lineaments) trend generally north (or up to 45° west of north) through the area. Major lineaments recognized in the area under study are, from east to west:—

(1) Sefton.
(2) Laverton.
(3) Celia.
(4) Keith-Kilkenny.
(5) Ida.

For the purposes of this paper it is assumed that the lineaments are real and that the rocks sampled can be considered grouped in inter-lineament zones. Additional granitoids were sampled from within the Keith-Kilkenny greenstone belt, separate from the main inter-lineament zones. In this paper the inter-lineament and greenstone zones discussed are referred to (from east to west) by zone letters:—

(1) east of the Sefton Lineament	zone A
(2) Sefton to Laverton Lineaments	zone B
(3) Laverton to Celia Lineaments	zone C
(4) Celia to Keith-Kilkenny Lineaments	zone D
(5) Keith-Kilkenny greenstones	zone E
(6) Keith-Kilkenny to Ida Lineaments	zone F

*Ba, CaO, Cr, Cu, total iron as Fe_2O_3, K_2O, MgO, Na_2O, Ni, Pb, Rb, SiO_2 (Laverton and Leonora Sheet areas only), Sr, TiO_2, V, Zn, Zr.

RESULTS

Weathering conditions, with associated formation of silcrete, laterite or kaolinized rocks, did not allow for the collection of samples from every available outcrop.

Analyses of those samples which were obtained have been considered in two ways:—

(1) allowing an equal weighting to each sample, and
(2) with samples grouped either by outcrop area or by rock type.

In the latter case, where a batholith has been sampled, distinction was made between the same rock type recurring at widely spaced outcrops, and different types of rock (for example, a porphyritic and an even-grained phase) occurring at the same outcrop. Equal weighting for each sample can create problems of over-emphasis where excessive sampling has occurred in a small area. The second approach reduces this bias but it is realized that neither treatment gives a truly representative picture of the chemistry as a whole.

A summary of the results as applied to K_2O and MgO is given in Table 38. It will be seen that when the mean values are considered there is a peak of K_2O in zone B with a sharp falling off of K_2O content to the west, and with some tendency for the value to fall eastwards in zone A. The same trend is shown when the results are considered by rock type-outcrop area, though the fall-off to the west is less smooth, with a minor rise shown in zone D. By contrast, the MgO contents of the granitoids rise from east to west.

TABLE 38. A COMPARISON OF K_2O AND MgO VALUES IN GRANITOIDS IN THE RASON, LAVERTON, AND LEONORA SHEET AREAS.

			Average % K_2O in Granitoids		Average % MgO in Granitoids	
Zone	No. of samples (n)	No. of rock types/outcrop zones (t)	$\frac{\sum x}{n}$	$\frac{\sum \bar{x}}{t}$	$\frac{\sum x}{n}$	$\frac{\sum \bar{x}}{t}$
A	58	15	4·4	4·2	0·27	0·25
B	71	23	4·9	5·0	0·51	0·58
C	58	15	3·5	3·3	1·2	1·3
D	53	12	3·2	3·5	1·5	1·4
E	8	5	3·1	2·5	1·7	2·3*
F	8	2	2·3	2·6	1·8	1·3

Note : The granitoids are grouped in inter-lineament zones.

*1·4 if one high value is excluded.

$\sum x$ = the sum of values for n samples.

$\bar{x}$ = the mean value for any particular rock type at any single outcrop zone.

$\sum \bar{x}$ = the sum of $\bar{x}$ values.

t = the number of rock types and/or outcrop zones considered as separate entities for this assessment.

Any sample taken at random may, or may not, be higher than a sample taken from an adjacent zone. However, taken as a whole, the results show that regional trends are present.

Table 38 makes no allowance for the standard deviation or the scatter of results. Various methods have been used to overcome this, the two most successful being Na_2O-K_2O-CaO triangular diagrams, and cumulative frequency probability curves. To illustrate this, Na_2O-K_2O-CaO diagrams are given for the granitoids in zone C (Fig. 78A) and zone B (Fig. 78B). In these diagrams the variations within individual rock types can be assessed by the scatter of the points. Again, though there is overlap, particularly of adamellitic rocks, there is a marked shift from K_2O-rich samples in zone B to Na_2O-rich samples in zone C.

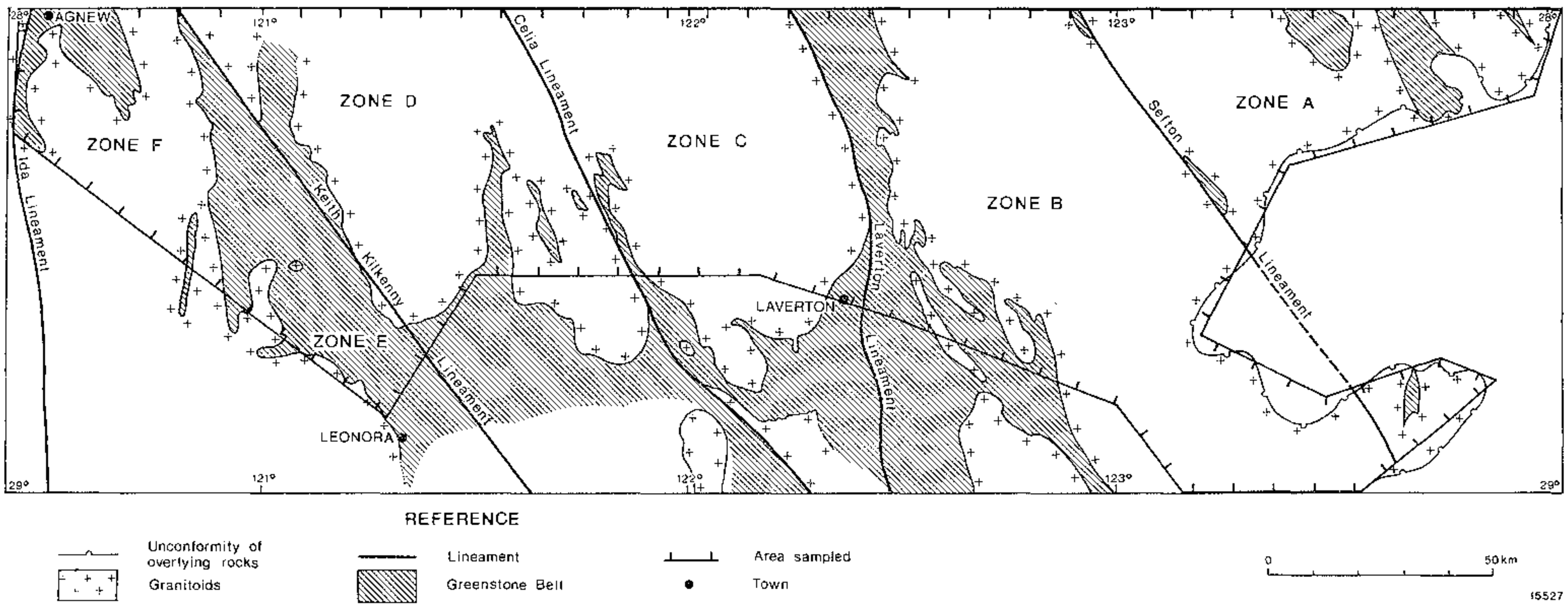

Figure 77. Generalized geology of the Leonora, Laverton and Rason Sheet areas showing approximate areas sampled. Base maps taken from Thom and Barnes, 1974 ; Gower, 1974 ; Gower and Boegli, 1973.

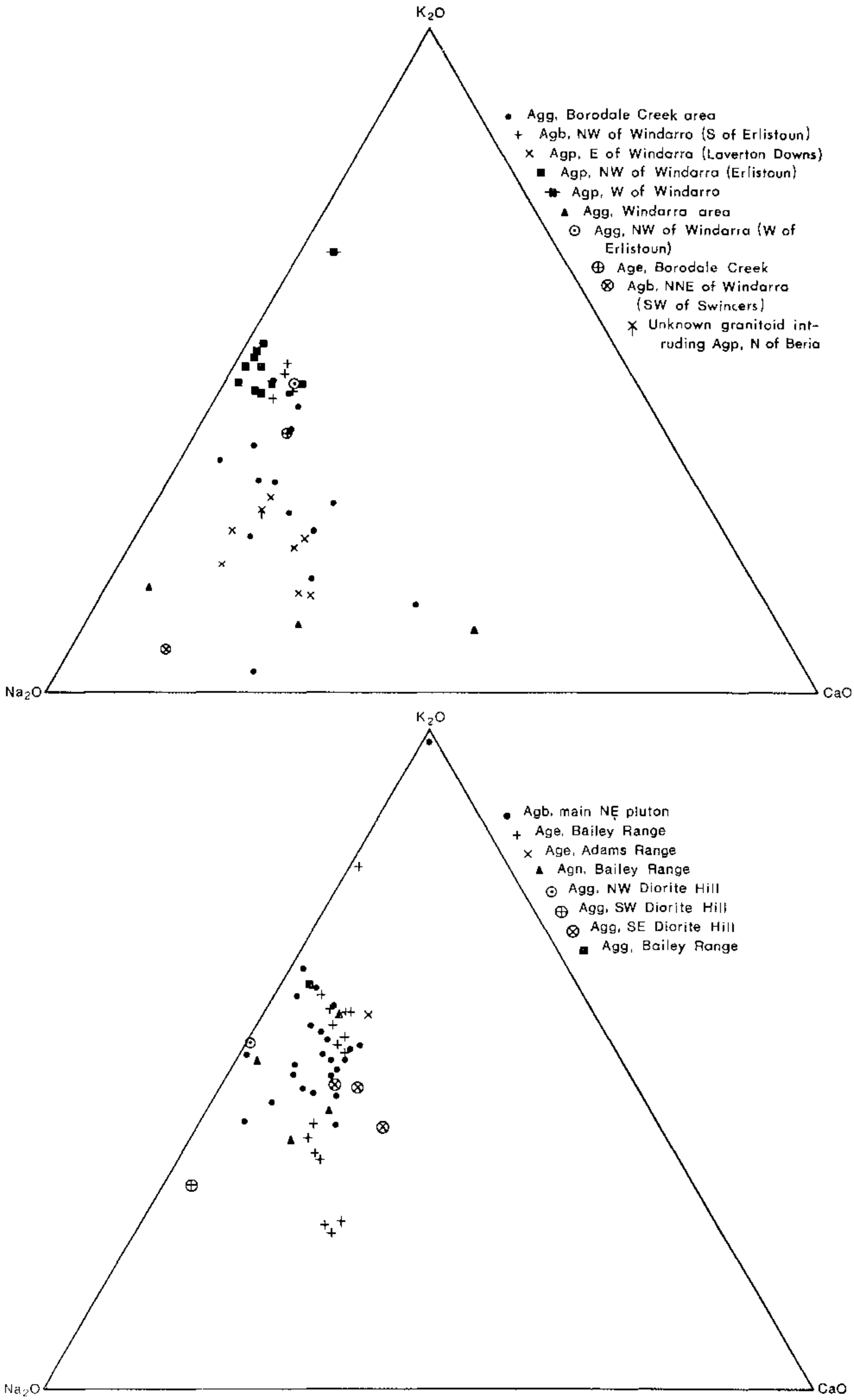

Figure 78. A. Na_2O-K_2O-CaO diagram for granitoids between the Laverton and Celia Lineaments (zone C). B. Na_2O-K_2O-CaO diagram for granitoids between the Laverton and Sefton Lineaments (zone B).

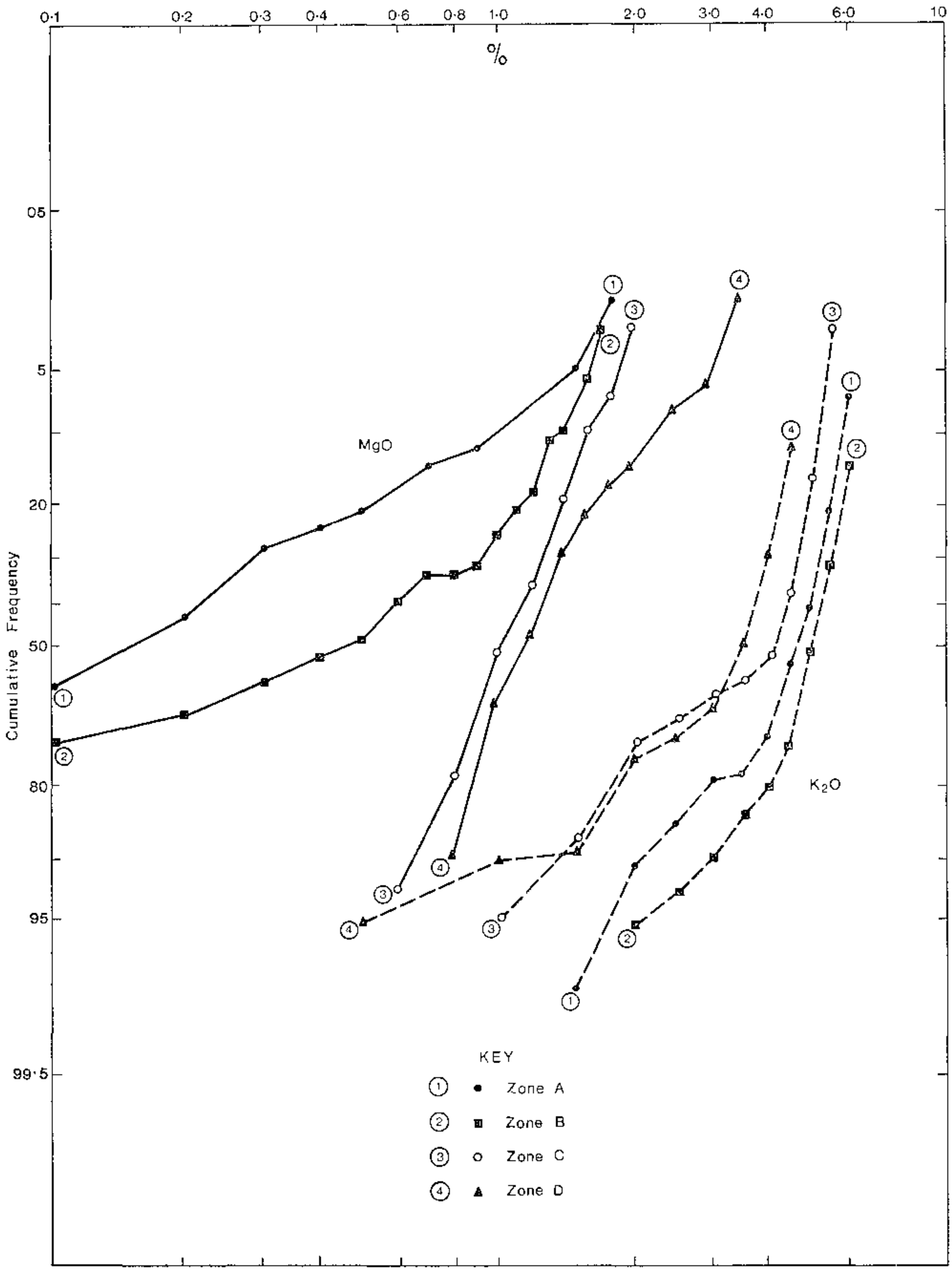

Figure 79. Cumulative frequency probability curves for K_2O and MgO for granitoids on the Rason, Laverton, and Leonora 1 : 250 000 Sheet areas.

Cumulative frequency probability curves have been drawn for the four eastern inter-lineament zones (A, B, C, and D). Of these the diagrams for K_2O and MgO are reproduced here (Fig. 79). These diagrams show clearly the increasing magnesium content of the inter-lineament zones as they are traversed from east to west. The two eastern zones have similar profiles for MgO but the curve for zone B is transposed towards the higher MgO values compared with that for zone A. Many of these rocks contain no detectable magnesium, they are in sharp contrast with the rocks west of the Laverton Lineament which contain at least 0.5 per cent MgO and overall are much higher in magnesium.

The patterns for K_2O are slightly less clear. The curve for zone A lies between the curves for zone B and zone C (suggested by the mean values) and does not overlap either. Zone D has lower (and fewer) high values than zone C but for a short distance this curve overlaps the zone C curve. The diagram shows that on both a mean and a cumulative basis the maximum potassium values occur in zone B, with values falling off on either side.

Cumulative frequency probability curves could not be drawn for zone F because of insufficient samples. A few samples were collected from granitoids within the greenstones of the Keith-Kilkenny greenstone belt (zone E). Though the results from these samples cannot be considered as representative of the whole zones, they support the general trends (see Table 39).

TABLE 39. MEAN VALUES FOR GRANITOIDS IN THE RASON, LAVERTON, AND LEONORA SHEET AREAS.

Zone	A	B	C	D	E	F
No. of samples	58	71	54†	63	8	8
Ba	970	1 200	870	640	860	780
CaO	1·2	1·1	1·2	1·1	1·9	2·4
Cu	11	14	11	17	24	13
Fe_2O_3*	1·9	1·8	1·7	2·1	2·4	2·3
K_2O	4·4	4·9	3·5	3·2	3·1	2·3
MgO	0·3	0·5	1·2	1·5	1·7	1·8
Na_2O	4·0	4·1	4·9	4·8	5·5	4·8
Ni	17	18	22	22‡	63	27
Pb	32	44	24	19	29	26
Rb	180	190	120	120	89	88
SiO_2	72	71	71	72	70	69
Sr	270	270	320	240	330	380
TiO_2	0·3	0·3	0·2	0·2	0·3	0·4
U	2	2	1	1	2	4‡
V	16	18	22	22	32	36
Zn	47	47	33	33	41	94
Zr	170	200	110	170	105	150

Values are expressed in % (oxides) and ppm (elements).

* Total iron as Fe_2O_3.

† Values of the Mount Boreas adamellite taken from Gower (1974) are included for Ba, CaO, Fe_2O_3, K_2O, MgO, Na_2O, Rb, SiO_2, Sr, TiO_2 and the total number of samples is 58.

‡ Excluding in each case, one grossly anomalous value.

Other elements (Table 39; showing mean values only) do not show the same regularities of behaviour, though rubidium closely follows potassium, and nickel and vanadium closely follow magnesium. Iron, titanium, and zinc are low in zone C (with similar values for titanium and zinc in the adjacent zone D) with an apparent rise on either side. Other elements are quite variable though calcium possibly rises towards zone F.

It is notable that the SiO_2 values, though rather variable, maintain consistently high values in the vicinity of 69 to 71 per cent and that there is no evidence that the systematic variations noted above are related to differentiation trends. Plots of the data on a spatial basis reveal neither general trends nor zonations within the inter-lineament zones. However, discrete fractionated phases of separate plutons can sometimes be recognized; thus the biotite granite and the porphyritic microgranite northwest of Mount Windarra appear to be related chemically, with high potassium values. Though texturally similar to these rocks, the biotite granite and porphyritic microgranite east of Mount Windarra (west of Laverton Downs station) are chemically unrelated and have low potassium values. These two groups of granitoids appear to have undergone parallel evolution.

This paper is concerned mainly with the granitoids. However, it is worth mentioning that the trend to increased magnesium to the west is shown not only by the granitoids but also by mafic and ultramafic rocks. Cumulative frequency probability curves for MgO for all rocks analyzed from the Leonora Sheet area are compared with the same curves drawn for all rocks analyzed from the Laverton Sheet area in Figure 80. For all three types of rock the curve for Leonora samples is offset towards higher magnesium values.

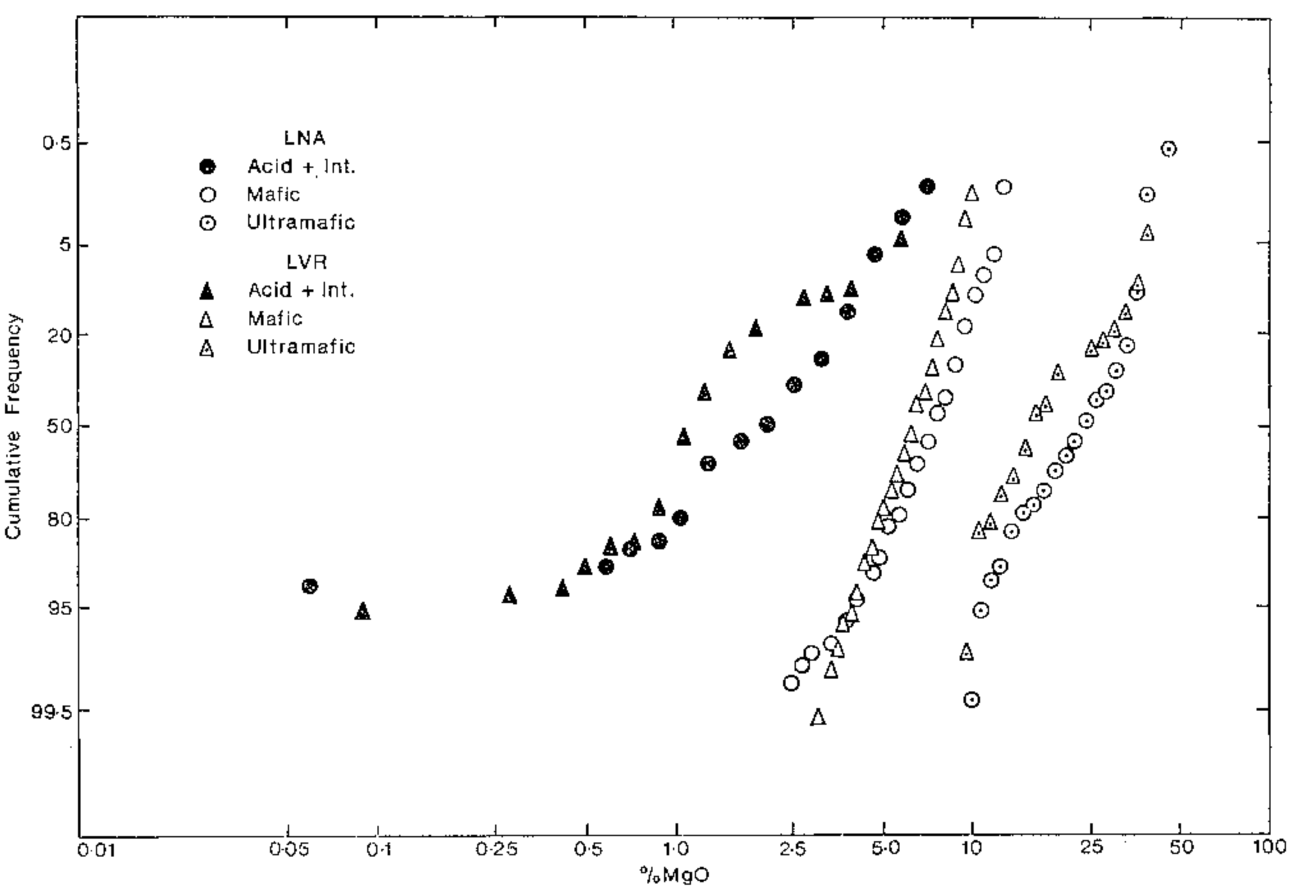

Figure 80. Cumulative frequency probability curve for MgO.

SUPPLEMENTARY DATA

In his Bulletin on the geology of the Blackstone region, Daniels (1974) included mineral unit cell dimensions of moderate accuracy based on powder X-ray data together with some highly accurate parameters based on single crystal data. The powder work is now superseded by further single crystal studies, and other supplementary data is presented to be applied to Bulletin 123 as indicated with each group of figures.

Table 15, Analysis of brown amphibole from Jameson Range Gabbro and comparison analyses, p. 160-1, is supplemented in column 1 by:

S.G. 3·276
a 9·907 ± 0·002 5 Å
b 18·097 ± 0·001 5
c 5·332 ± 0·003 5
β 105°56′ ± 2·5′

Table 24, p.175, and accompanying notes are wholly superseded by:

TABLE 24. UNIT CELL DIMENSIONS OF OLIVINES FROM THE GILES COMPLEX.

Specimen No.	Fa	a (Å)	b (Å)	c (Å)
		BLACKSTONE RANGE GABRO		
519	35·3	4·780 ± 0·001	10·303 ± 0·000 5	6·023 ± 0·000 5
577	41·3	4·784 ± 0·001	10·322 ± 0·001 5	6·029 ± 0·001 5
581	35·2	4·780 ± 0·001	10·300 ± 0·001 5	6·021 ± 0·001
582C	31·6	4·778 ± 0·001	10·295 ± 0·002	6·017 ± 0·002
585	30·5	4·777 ± 0·002	10·292 ± 0·003	6·018 ± 0·003
		JAMESON RANGE GABBRO		
1 241	54·5	4·795 ± 0·001	10·360 ± 0·005	6·045 ± 0·003
1 247	35·99	4·782 ± 0·001 5	10·308 ± 0·003	6·024 ± 0·002 5
1 251	39·0	4·781 ± 0·001	10·310 ± 0·001 5	6·028 ± 0·001 5
1 257	39·5	4·785 ± 0·000 5	10·316 ± 0·001	6·029 ± 0·001
1 259	39·7	4·784 ± 0·001	10·314 ± 0·002	6·027 ± 0·002
1 260	38·2	4·784 ± 0·001	10·314 ± 0·002	6·027 ± 0·002

Notes:

1. Determinations by M. Pryce, Government Chemical Laboratories. The possible error limits are reported as five times the estimated standard deviation.
2. The cell dimensions were obtained from single crystal methods.
3. The localities of the specimens may be found by reference to Figures 43, 51, 52 and 56.

In Table 27, Chemical, physical and optical properties of orthopyroxenes from the Jameson Range Gabbro, p. 180, a, b and c are superseded by:

Specimen No.	1 252	1 253	1 263
a	18·306 ± 0·003	18·315 ± 0·002	18·291 ± 0·001 Å
b	8·905 ± 0·003	8·902 ± 0·001 5	8·875 ± 0·001
c	5·217 ± 0·002	5·215 ± 0·001 5	5·210 ± 0·001 5

and on p. 181, a° (obs), b° (obs) and c° (obs) by:

a° (obs)	18·306 ± 0·003	18·315 ± 0·002	18·291 ± 0·001
b° (obs)	8·905 ± 0·003	8·902 ± 0·001 5	8·875 ± 0·001
c° (obs)	5·217 ± 0·002	5·215 ± 0·001 5	5·210 ± 0·001 5

Table 28, Chemical, physical and optical properties of clinopyroxenes from the Jameson Range Gabbro, p. 182, is supplemented by:

Specimen No.	1 253	1 256	1 263
a	9·758 ± 0·003 5	9·748 ± 0·002	9·749 ± 0·004 5 Å
b	8·934 ± 0·001	8·919 ± 0·000 4	8·924 ± 0·000 5
c	5·278 ± 0·001	5·260 ± 0·001	5·259 ± 0·003
β	105°57′ ± 2′	106°6′ ± 2′	105°59′ ± 5′
S.G.	3·389	3·349	3·368

REFERENCE

Daniels, J. L., 1974, The geology of the Blackstone Region, Western Australia: West. Australia Geol. Survey Bull. 123.

DISCUSSION

It seems clear that two opposing regional trends are shown by the analyses. Potassium and rubidium increase to the east reaching a peak in zone A. Magnesium, nickel, and vanadium increase steadily from the east to west. Though other elements show a more variable distribution there is no reason to doubt that these are genuine trends reflecting major changes in the crustal composition. As far as is known no regional variations such as these have been reported from other Archaean cratonic areas.

Differences caused by weathering have been considered as causes of the chemical changes but have been rejected as the more obviously weathered samples have been excluded from these results. Moreover, in most normal weathering situations calcium, magnesium, potassium, and sodium are among the first of the major elements to be leached. This feature is clearly seen in analyses of kaolinized or silicified granitoids (Davy, in prep.).

The presence of highly magnesian ultramafic rocks with associated nickel mineralization in zone F might suggest the higher values of magnesium and nickel in the adjacent granitoids are caused by contamination. Contamination by nickel has been recognized in granitoids near Mount Windarra but high nickel values are not conspicuous elsewhere, and the highest values of magnesium, nickel, and vanadium are not necessarily found adjacent to greenstones. If contamination has taken place it must have occurred prior to the intrusion of the granitoids.

Williams (1974) considers that the lineaments reflect deep-seated faults and postulates that, in the area studied for this paper, west-down block faulting is the most common form of faulting. This might suggest that the rocks of the Agnew-Leonora area are the youngest rocks represented in the area. He recognized that rocks of differing ages do occur within the inter-lineament zones. Older rocks are exposed in the cores of anticlines, some granitoids are recognizable as intrusive into their host rocks. Few of the rocks in the area have been dated. The Boreas Adamellite (Laverton Sheet area) has been dated at 2 480 ± 30 m.y. (J. C. Roddick, pers. comm.) and granitoids at Isolated Hill (Rason Sheet area), northwest of Mount Windarra (Laverton Sheet area), Borodale Creek (Laverton Sheet area) and at Dodgers Hill (Leonora Sheet area) have been dated at 2 592 ± 25 (Bunting and others, 1976), 2 260 ± 60 (J. C. Roddick, pers. comm.), 2 615 ± 25 (J. C. Roddick, pers. comm.), and 2 580 ± 16 m.y. (Worden and Compston, 1973) respectively. These suggest no regional younging to the west nor, indeed, any regional pattern. If a hypothesis of granitoids younging to the west is correct the granitoids would appear to become less potassic and more magnesian as they get younger, an unusual feature.

The presence of abundant iron formation in the Rason Sheet area and its relative absence from the Leonora Sheet area suggests that the Rason Sheet area was once possibly a shelf environment with relative tectonic stability. The Leonora sediments, on the other hand, were formed in deeper water or an oceanic environment. The majority of the basaltic rocks analyzed are similar in composition to present-day deep oceanic tholeiites. The observed trends may be related either to a thinning of sialic crust or to successively deeper fractures of the crust progressing from the Rason Sheet area towards the Leonora Sheet area. The lesser thickness, or the deeper fractures, may have resulted in a greater contamination of the sialic crust by simatic material.

It seems that, though east-west trends in the granitoids in the Rason, Laverton, and Leonora Sheet areas are real, the origins of these trends are not yet clear. It would be interesting to investigate similar rocks beyond the Ida Lineament to examine whether the trends continue or are reversed (Williams, 1974, postulates east-down block faulting in this area), and to extend the investigation north and south to determine whether the trends are present on an areal rather than a linear basis.

ACKNOWLEDGEMENTS

The assistance of members of the Western Australian Government Chemical Laboratories, particularly Messrs. N. Marsh and A. Thomas in the production of the analytical data and in the computer manipulation of this data, is gratefully acknowledged.

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SUPPLEMENTARY MINERAL DATA FROM GABBROS OF THE GILES COMPLEX

by M. Pryce*

ABSTRACT

Accurate unit cell dimensions and related data are provided for one amphibole, six olivines, three orthopyroxenes, and three clinopyroxenes from the Jameson Range Gabbro, and for five olivines from the Blackstone Range Gabbro. The data supplement or supersede those previously published in Bulletin 123 of the Geological Survey of Western Australia.

*Government Chemical Laboratories.

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DIVISION V

Report of the Head of The Petroleum Branch for the Year 1975

Under Secretary for Mines

I hereby submit my Annual Report for the Petroleum Branch for 1975.

PETROLEUM RESERVES

The proved and probable recoverable petroleum reserves of the State are estimated to stand at 20.96 x 10^6m^3 of oil, 59.85 x 10^6m^3 of natural gas liquids and 426.91 x 10^9m^3 of raw gas. The breakdown between basins and fields is shown in Table I. Oil reserves have decreased during the year by the extent of production from the Barrow Island and Dongara Fields. Natural gas reserves have been reduced by the extent of production from the Dongara, Mondarra and Gingin Fields. However, this reduction was offset by the evaluation of gas reserves in the West Tryal Rocks Field amounting to 58.91 x 10^9m^3 (excluding inerts) and a 14% increase in the gas reserves of the Angel Field, owing to re-interpretation.

A gas/condensate discovery was made by BOCAL in Tidepole No. 1, only 4 km south of Goodwyn No. 3, late in 1975. The total net pay thickness is 102 m, including a 20 m-thick oil leg. This may lead to an appreciable increase in the gas reserves of the Goodwyn-Tidepole area when the discovery is appraised by further drilling. The gas/condensate discovery made by BOCAL in Scott Reef No. 1, within the Browse Basin, in 1971 is still awaiting evaluation.

TABLE I

ESTIMATE OF PROVED AND PROBABLE RECOVERABLE PETROLEUM RESERVES (UNDISCOUNTED) IN WESTERN AUSTRALIA AS AT 31/12/75

Company	Area and Field	Oil $m^3 \times 10^6$	N.G.L. $m^3 \times 10^6$	Raw Gas $m^3 \times 10^9$
	CARNARVON BASIN			
BOCAL	Angel	....	9.47	40.40
BOCAL	Goodwyn	0.20	14.94	72.80
BOCAL	N. Rankin	....	29.17	242.70
WAPET	Barrow Island	20.73	0.32	1.58
WAPET	West Tryal Rocks	....	5.89	58.91
	Sub Total	20.93	59.79	416.39
	PERTH BASIN			
WAPET	Dongara	0.03	0.05	10.13
WAPET	Mondarra	....	0.01	0.35
WAPET	Yardarino	....	neg.	0.04
WAPET	Gingin	....	neg.	neg.
	Sub Total	0.03	0.06	10.52
	Grand Total	20.96	59.85	426.91

PETROLEUM EXPLORATION OPERATIONS

Petroleum exploration operations during 1975 were again at a greatly reduced level compared with the previous year.

Expressed in rig months overall operations declined by 52.5 per cent from 33.6 rig months in 1974 to 16 rig months in 1975. Onshore drilling activity declined by 21 per cent from 7.5 rig months in 1974 to 5.9 rig months in 1975. Offshore drilling activity declined by 61.5 per cent from 26 rig months in 1974 to 10 rig months in 1975. Marine seismic surveys, in terms of line kilometres, declined by 87 per cent from 11 815 in 1974 to 2 737 in 1975 and land seismic surveys declined by 13 per cent from 559 in 1974 to 484 km in 1975.

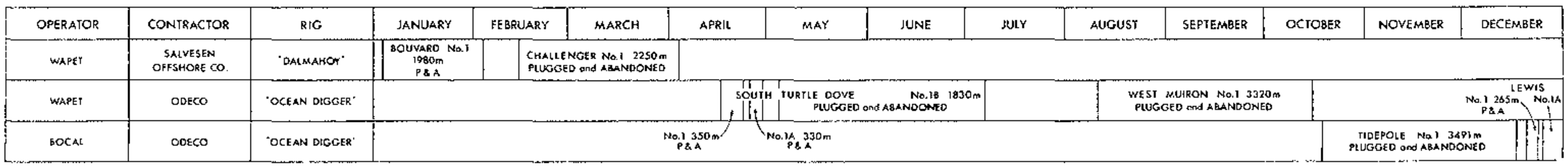
A total of three rigs, namely two offshore and one onshore, were operating during the year (Figure 1). During the first quarter of 1975 the drilling ship M.V. "Dalmahoy" (Salveson Offshore Company) drilled two wells in the Perth Basin area after which the vessel departed from West Australian waters. Following the departure of the M.V. "Dalmahoy", the semi-submersible rig "Ocean Digger (ODECO), returned to West Australian waters, at the beginning of the second quarter of 1975, to complete the offshore drilling programmes during the remainder of the year.

The "Ocean Digger" was taken out of service for four weeks during July and August for a routine inspection by the American Bureau of Shipping under which the vessel is classified. This inspection was performed in Shark Bay.

A total of eleven tropical cyclones were active in the areas of petroleum operations off the Western Australian coast during 1975, of which eight occurred during the first five months of the year to May 25th and three during December. The drilling of the Perth Basin well, Challenger No. 1, was interrupted in mid-March by Cyclone Vida. There was no loss of life or injury although some minor damage occurred to anchor winch hold-down plates on the M.V. "Dalmahoy" as a result of high seas. In early December Cyclone Joan caused the evacuation of the "Ocean Digger" during the drilling of Tidepole No. 1 and the shut down of the rig drilling Biggada No. 1 on Barrow Island.

Details of petroleum exploration activity during 1975 are given in the report by K. A. Crank in the Sedimentary Division Section of the Annual Report of the Geological Survey Branch.

1975 OFFSHORE DRILLING OPERATIONS



1975 LAND DRILLING OPERATIONS

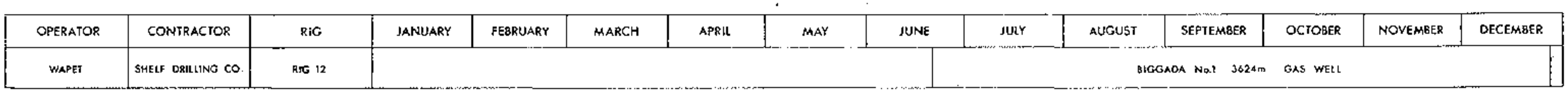


Figure 1. Drilling rig operations during 1975.

PETROLEUM DEVELOPMENT

Barrow Island Field

(Operator—West Australian Petroleum Pty. Limited)

WAPET carried out well-servicing and remedial work throughout the year using the Ideco H-35 rig in conjunction with the Cooper well-servicing unit. The status of the 508 wells within the field, as at the end of 1975, is shown in Table II.

TABLE II

BARROW ISLAND FIELD WELL STATUS BY RESERVOIRS AT 31st DECEMBER, 1974

Reservoir	Flowing	Pumping	Gas Lift	Closed in	Water Injection	Water Source	Water Disposal	Total
Lower Gearle	1	0	0	0	0	0	0	1
Windalia	9	169	98	32	166	9	7	490
Muderong	2	3	3	0	0	0	0	8
Jurassic 5 500′	0	0	0	1	0	0	0	1
Jurassic 6 200′	0	0	0	1	0	0	0	1
Jurassic 6 600′	0	0	0	1	0	0	0	1
Jurassic 6 700′	0	2	0	3	0	0	0	5
Jurassic 11 250′	0	0	0	1	0	0	0	1
Total	12	174	101	39	166	9	7	508

The principal reservoir is the "Windalia Sand Member" of the Muderong Shale, in respect of which 490 wells were operating at the end of the period. The status of wells with respect to the Windalia Sand reservoir, at the end of the year, is shown in Figure 3. One formerly producing Windalia well (B-17) was abandoned, four were converted to water injection wells and one water injection well was converted to a producer. These changes were in part necessitated by the east-west breakthrough of water owing to preferred permeability in this direction. The well T-78, re-completed in the Windalia Radiolarite Formation (overlying the "Windalia Sand Member") in 1974, was fractured and pump-tested in 1975 but failed to produce oil. The well K-24 was re-completed on the Lower Gearle Formation but production declined steadily to the end of the year. Studies are in progress by WAPET to evaluate the extent and significance of the Lower Gearle reservoir and of other shallow petrophysical anomalies which have been recognised in various wells across the field. The basal Muderong sands have continued to produce from eight wells. Following the abandonment of L-32, the Jurassic 6 700′ sand is the only Barrow Formation reservoir still producing oil at the end of 1975.

North Rankin, Goodwyn and Angel Fields

(Operating Permittee Company—
BOCAL PTY. LTD.)

BOCAL applied for a Primary Production Licence covering the full five block entitlement in Location 2 (North Rankin) on 31st December, 1975 as shown in Figure 2.

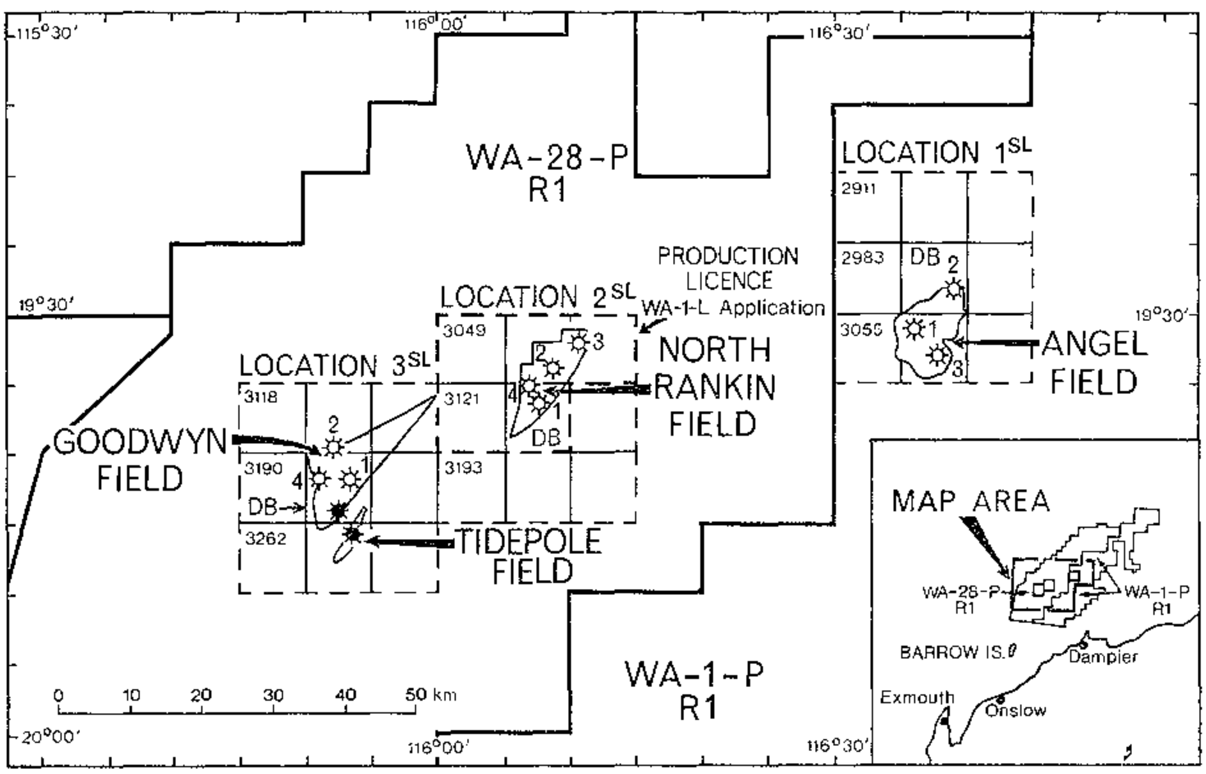


Figure 2. Locations 1SL, 2SL and 3SL. DB—Discovery Block. 2911—Graticular block number on Cape Keraudren Sheet, 1:1 000 000 Map Series. Inset map shows situation on Northwest Shelf.

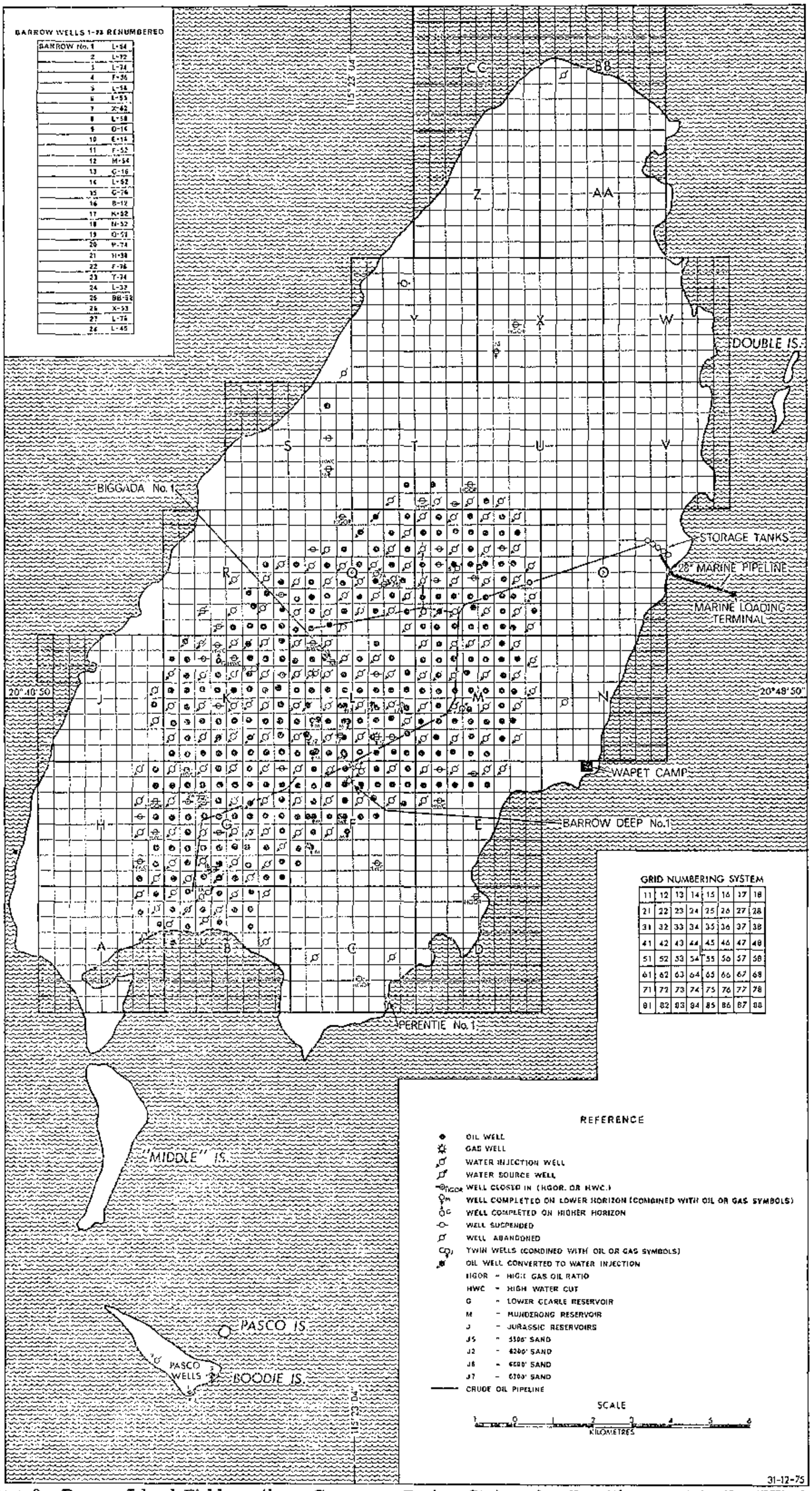


Figure 3. Barrow Island Field, northern Carnarvon Basin. Status of wells with respect to the "Windalia Sand" reservoir on 31st December, 1975.

Dongara Field

(Operator—West Australian Petroleum Pty. Limited)

Prolonged testing of the oil leg was commenced in July 1975 with the object of establishing the productive potential and individual characteristics of each of the five oil wells No's 8, 10, 14, 17 and 19. Test production has so far been from No's 10 and 17. The average daily production of oil from the two wells during December 1975 was 36m³.

In order to maintain gas deliverability from the Dongara Field four 1 000 horse power compressors are being installed and will be commissioned in 1976. The status of wells in this field on 31st December, 1975 is shown in Figure 5.

PETROLEUM PRODUCTION

Barrow Island

The production of liquids and gas from the various reservoirs during 1975 and the cumulative production are shown in Table III.

Oil production decreased by 5.5% from 1974. The main producing horizon, the Windalia Sand, is subject to a water injection scheme and produces about 97% of the Barrow crude. A small quantity of oil was produced from the Lower Gearle Formation for the first time. Production ceased from the Jurassic 6 600' sand reservoir of the Barrow Formation. About 45% of the original estimated recoverable Barrow Island oil reserves have now been produced. The daily average production of crude oil for each month from the start of production to the end of 1975 is shown in Figure 4.

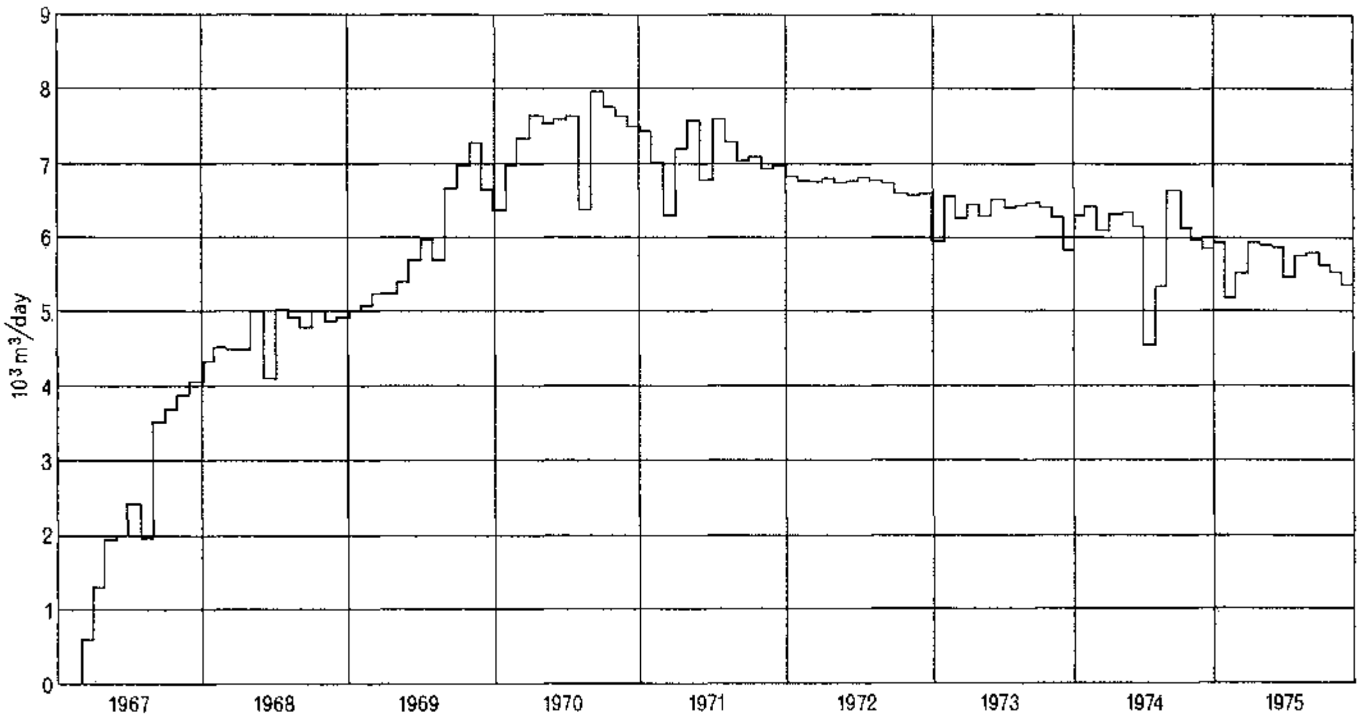


Figure 4: Barrow Island Field (Petroleum Lease 1H), northern Carnarvon Basin. Average daily production per month of crude oil between March 1967 and 31st December, 1975.

Gas Production is shown in Table IV. Of the associated gas produced with the crude oil, some 13% is used as field fuel and the remainder flared after the extraction of L.P.G. and natural gasoline. The natural gasoline is mixed with the crude oil for sale while the L.P.G. is sold to markets in the north-west of the State.

Quantities of oil, liquid petroleum gas and natural gas which are either sold or used as field fuel, together with total royalties paid during the year, are shown in Table III. On 17th September, 1975 the existing crude oil price agreement expired. As from 18th September the Federal Government granted a price increase of 50c/barrel for Barrow Island crude to $2.73/barrel f.o.b. Kwinana.

TABLE III

BARROW ISLAND FIELD OIL AND GAS DISPOSAL DURING 1975

	Oil m³ (bbls)	L.P.G. m³ (bbls)	Gas m³ x 10³
Total Production	2 060 702 (12 961 406)	3 494 (21 977)	.... 133 520
Field Fuel	.... (0)	356 (2 240)	.... 17 278
Sales	2 040 430 (12 833 894)	1 979 (12 450)	....

Royalty paid : $A1 208 760

(13)—58638

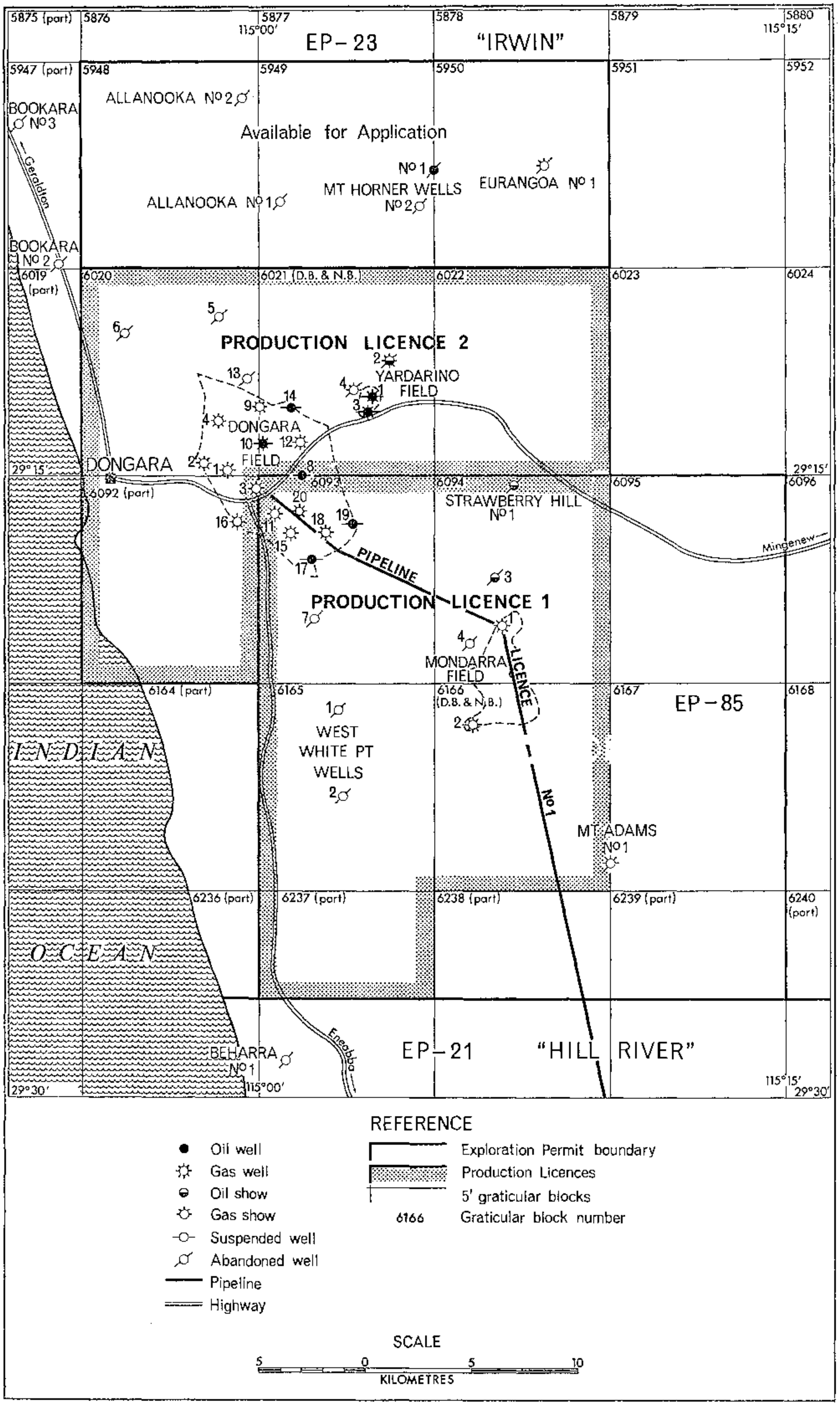


Figure 5. Dongara area, northern Perth Basin. Status of petroleum tenements and wells at 31st December, 1975 (Perth Sheet 1:1 000 000 Map Series).

TABLE IV
BARROW ISLAND FIELD PETROLEUM PRODUCTION DURING 1975

Reservoir	Average daily prod. oil in m^3 and (bbls) during December 1975	Production for year 1975					Cumulative production				
		Oil in m^3 and (bbls)	L.P.G. in m^3 and (bbls)	N.G. in m^3 and (bbls)	Water in m^3 and (bbls)	Gas 10^3m^3	Oil in m^3 and (bbls)	L.P.G. in m^3 and (bbls)	N.G. in m^3 and (bbls)	Water in m^3 and (bbls)	Gas 10^3m^3
Lower Gearle	33 (209)	21 202 (133 359)	0	0	108 (679)	.... 2 488	21 202 (133 359)	0	0	108 (679)	.... 2 488
Windalia	5 198 (32 695)	2 004 740 (12 609 414)	3 494 (21 977)	2 769 (17 418)	791 017 (4 975 341)	.... 119 378	18 366 041 (115 518 723)	13 392 (84 230)	13 602 (85 551)	4 345 524 (27 332 484)	.... 1 751 890
Muderong	54 (340)	19 961 (125 551)	0	0	13 750 (86 485)	.... 3 567	194 566 (1 223 784)	0	0	58 116 (365 538)	.... 29 942
Jurassic 5 500′	0	0	0	0	0	 0	2 477 (15 580)	0	0	16 158 (101 628)	.... 14 626
Jurassic 6 200′	0	0	0	0	0	 0	9 140 (57 489)	0	0	19 707 (123 952)	.... 80 926
Jurassic 6 600′	0	4 006 (25 197)	0	0	8 304 (52 230)	 365	63 396 (398 748)	0	0	115 450 (726 161)	.... 22 800
Jurassic 6 700′	27 (171)	10 726 (67 461)	0	0	10 649 (66 979)	.... 6 333	196 584 (1 236 471)	0	0	68 338 (429 830)	.... 110 168
Jurassic 10 600′	0	0	0	0	0	 0	*212 (1 334)	0	0	18 (113)	.... 1 805
Jurassic 10 900′	0	0	0	0	0	 0	*180 (1 131)	0	0	120 (754)	.... 1 085
Jurassic 11 250′	0	67 (424)	0	0	15 (93)	.... 1 389	*287 (1 803)	0	0	116 (728)	.... 11 649
Total Field	5 312 (33 415)	2 060 702 (12 961 406)	3 494 (21 977)	2 769 (17 418)	823 843 (5 181 807)	.... 133 520	18 854 085 (118 588 422)	13 392 (84 230)	13 602 (85 551)	4 623 655 (29 081 867)	.... 2 027 379

Water injected during 1975 : 4 335 590 m^3 (27 269 991 bbls). Cumulative water injected : 37 446 257 m^3 (235 529 470 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.

TABLE V

DONGARA, MONDARRA AND GINGIN FIELDS: PETROLEUM PRODUCTION DURING 1975

Field	Number of producing wells at 31/12/75	Average daily production during December, 1975			Production for year 1975				Cumulative production			
		Gas 10^3m^3	Condensate m^3 and (bbls)	Oil m^3 and (bbls)	Gas 10^3m^3	Condensate m^3 and (bbls)	Oil m^3 and (bbls)	Water m^3 and (bbls)	Gas 10^3m^3	Condensate m^3 and (bbls)	Oil m^3 and (bbls)	Water m^3 and (bbls)
Dongara	 13	.... 2 154	8 (50)	36 (224)	.... 752 119	3 624 (22 794)	5 383 (33 858)	2 877 (18 096)	2 860 870	15 314 (96 322)	5 383 (33 858)	11 687 (73 509)
Mondarra	 1	 109	2 (13)	....	.... 54 545	841 (5 290)	....	315 (1 981)	.... 222 772	4 154 (26 128)	....	1 025 (6 447)
Gingin	 1	 13	1 (6)	....	.... 7 544	442 (2 780)	....	1 670 (10 504)	.... 47 964	3 130 (19 692)	....	3 378 (21 247)
Total	 15	.... 2 276	11 (69)	36 (224)	.... 814 208	4 907 (30 864)	5 383 (33 858)	4 862 (30 581)	3 131 606	22 598 (142 142)	5 383 (33 858)	16 090 (101 203)

Total gas sold in 1975 = 810 920.54m^3 x 10^3 Total royalties paid = $A281 932

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.

Dongara, Mondarra and Gingin Fields

Table V shows the quantities of the various types of petroleum produced from the northern Perth Basin during 1975, the cumulative production since 1971 and the average daily production at the end of 1975.

Two additional gas wells were brought in during the year, No. 10 (which is also producing oil) and No. 20. There was a 1.2% increase in gas production from the Dongara Field compared with 1974 and a 16% decrease from the Mondarra Field. Overall, 0.7% more gas was produced from the northern Perth Basin in 1975 than in 1974. Some 26% of the estimated original gas reserves have been depleted since production commenced in October, 1971. The monthly gas production from the northern Perth Basin between 25th October, 1971 and 31st December, 1975 is shown in Figure 6. On 29th May, WAPET was authorised by the Minister for Mines to produce the relatively minor remaining gas reserve in the Gingin Field, then estimated to be in the order of 20 x 10^6m^3. Production started on 11th June and 85% of the originally estimated recoverable reserve had been produced by the end of the year.

Following the approval by the Minister for Mines on 6th September, 1974 of the proposal to test four Dongara Field oil wells, test production commenced on 9th July, 1975. The purpose of the test is to ascertain the feasibility of development. Test production of oil from Dongara No's 10 and 17 and all condensate production was disposed of to local brick manufacturers.

PETROLEUM PIPELINES

Dongara to Pinjarra Natural Gas Pipeline

Several crossings of the pipeline were made by public utilities, namely by:—

(a) the S.E.C. with overhead wooden pole power lines between Forrest and Miguel Roads at Jandakot, and in the Wanneroo-Muchea area;

(b) the Metropolitan Water Supply Board, with the 54" Canning water trunk main; and

(c) the Railway Department with the new railway, which is to service the Eneabba beach sands project. A total of four crossings over the pipeline by the railway were required, for which especially designed, re-inforced, ventilated, protective concrete culverts were approved.

A total of 275 work proposals from the various Public Utilities were received and processed with reference to pipelines during 1975.

INSPECTION OF PETROLEUM OPERATIONS

Two inspections were made of each of the offshore drilling vessels M.V. "Dalmahoy" and S.S. "Ocean Digger". A special check was made on the diving facilities on the M.V. "Dalmahoy" in January in view of the Direction as to Diving which was then imminent. A further inspection of this vessel in January was prompted by a fire which caused damage to two cabins. There were no injuries to personnel.

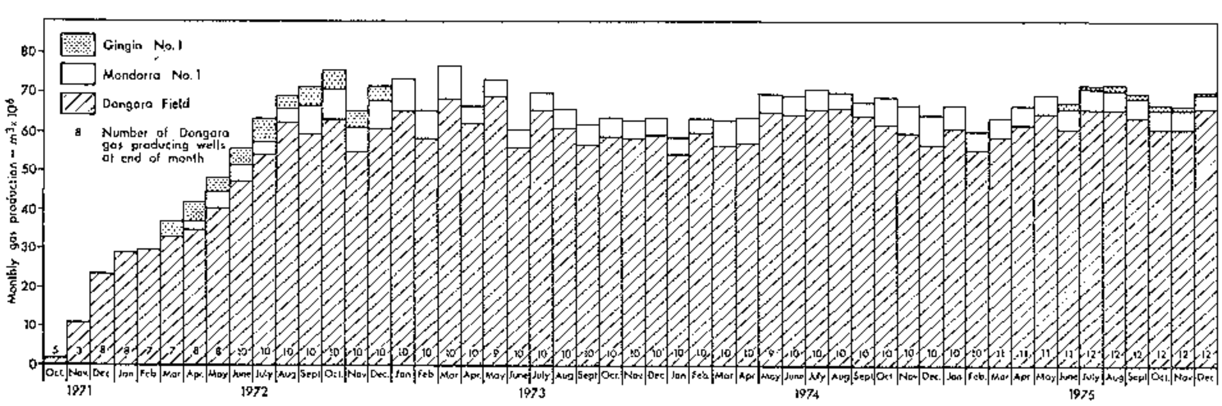


Figure 6. Mondarra, Dongara and Gingin Fields, northern Perth Basin. Monthly gas production between 25th October, 1971 and 31st December, 1975.

Direction No. 6, "Direction as to Diving", was served on all offshore permittees by the Designated Authority in February. Work has proceeded on the drafting of other Directions and Regulations under the Petroleum (Submerged Lands) Act, 1967, in collaboration with other States.

Three inspections of the Shelf Drilling Company Rig 12 were made. In addition to general safety, special attention was given to well-control practices when entering and drilling through abnormal pressure zones.

Production installations were inspected at Barrow Island and Dongara for good oilfield practice and for any evidence of corrosion or other deterioration.

The final abandonment of Cape Range No. 2 (previously only partially abandoned) by WAPET was witnessed. Restoration of the three Walyering Field well sites was inspected prior to the surrender of Production Licence No. 3.

SAFETY

A summary of all accidents reported from the petroleum exploration production and pipeline industry during 1975 is presented in Table VI. No fatalities occurred.

TABLE VI

ACCIDENT STATISTICS RELATING TO THE PETROLEUM EXPLORATION, PRODUCTION AND PIPELINE INDUSTRY DURING 1975

PETROLEUM INDUSTRY CATEGORIES

	Drilling Activities		Barrow Island Oil-Field	Dongara Gas Field	Natural Gas Transmission Pipeline	Seismic Activities		Totals
	Onshore	Offshore				Onshore	Offshore	
NATURE OF INJURY	**NUMBER OF INJURIES**							
Head	1	4	2	....	....	....	....	7
Eye	1	3	4	....	....	....	....	8
Trunk	3	7	13	....	....	2	....	25
Arm	3	4	2	....	....	2	....	11
Hand	7	14	13	....	....	1	....	35
Leg	4	15	10	....	....	2	....	31
Foot	2	1	3	....	....	2	....	8
Occupational Diseases	....	2	....	....	....	....	....	2
Other Injuries and Shock	....	2	....	....	....	....	....	2
AGENCY OF INJURY	**NUMBER OF INJURIES**							
Machinery in Operation	2	10	2	....	....	....	....	14
Vehicles	1	....	3	....	....	1	....	5
Tools—Hand	1	1	11	....	....	....	....	13
Tools—Power	1	....	2	....	....	....	....	3
Manual Handling	4	14	8	....	....	3	....	29
Harmful Contacts	2	....	4	....	....	....	....	6
Persons Falling or Striking	8	17	14	....	....	5	....	44
Objects Flying or Falling	2	8	9	....	....	....	....	19
Other	1	4	1	....	....	....	....	6
MAGNITUDE OF INJURY	**NUMBER OF ACCIDENTS**							
Minor	5	39	35	....	....	....	....	79
Serious	14	14	9	....	....	9	....	46
Fatal	....	....	....	....	....	....	....	....
TIME FACTOR	**EXPOSURE TIME AND TIME LOST**							
Thousands of Manhours exposure	95	237	241	15	16	53	14	671
Days Lost	123	214	102	....	....	119	....	558

The frequency rate and severity rate variations by quarters for 1975 are graphed in Figure 7 as a continuation from those for 1974. The curves relate to serious injuries only, namely those requiring treatment by a medical practitioner and which are beyond the scope of normal first aid. The rates are calculated as recommended by the Standards Association of Australia (Australian Standard CA6-1966).

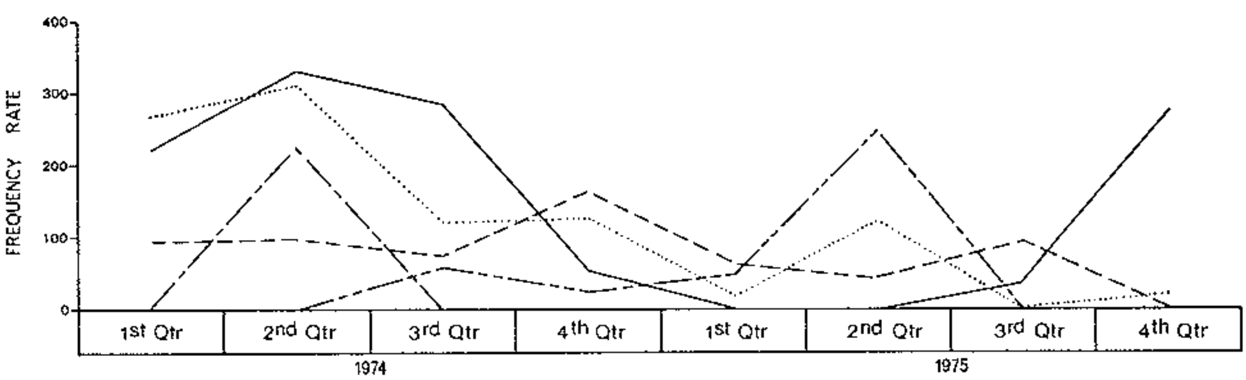
From Figure 7 it will be seen that when 1974 is viewed together with 1975 a marked downward trend has occurred in both frequency and severity rates for offshore and for Barrow Island activities. Accident frequency and severity in onshore drilling and onshore seismic operations still require some improvement, as is reflected by the sharp peaks in the respective curves in Figure 7. There were no onshore drilling operations during the first half of 1975 and no seismic operations during the second half of the year. There were no accidents reported either for the West Australian Petroleum Pty. Limited gas producing field at Dongara, or for the West Australian Natural Gas Pty. Ltd. pipeline operations.

A highly successful simulated fire control exercise held at one of the gathering stations, using an especially adapted modern fire control unit, ambulance and radio network was witnessed on WAPET's Barrow Island oilfield. The exercise was part of on-going training in safety and fire-control which is organised by this Company.

TITLES

Offshore

Owing to the large number of permits reaching the end of their first term there were an unusually large number of renewals (12) and expiries (7) (see Table VII). Two permits were surrendered and one was cancelled. Five Access Authorities were granted. One area (in the Carnarvon Basin) was advertised inviting applications for Exploration Permits under Section 20 (1) of the Petroleum (Submerged Lands) Act, 1967, with a closing date before the end of the year and one application was received. A further five areas (in the Perth Basin) were advertised under Section 20 (1) with a closing date early in 1976. The location of tenements regarding which there were dealings and of areas advertised is illustrated in Figure 8.



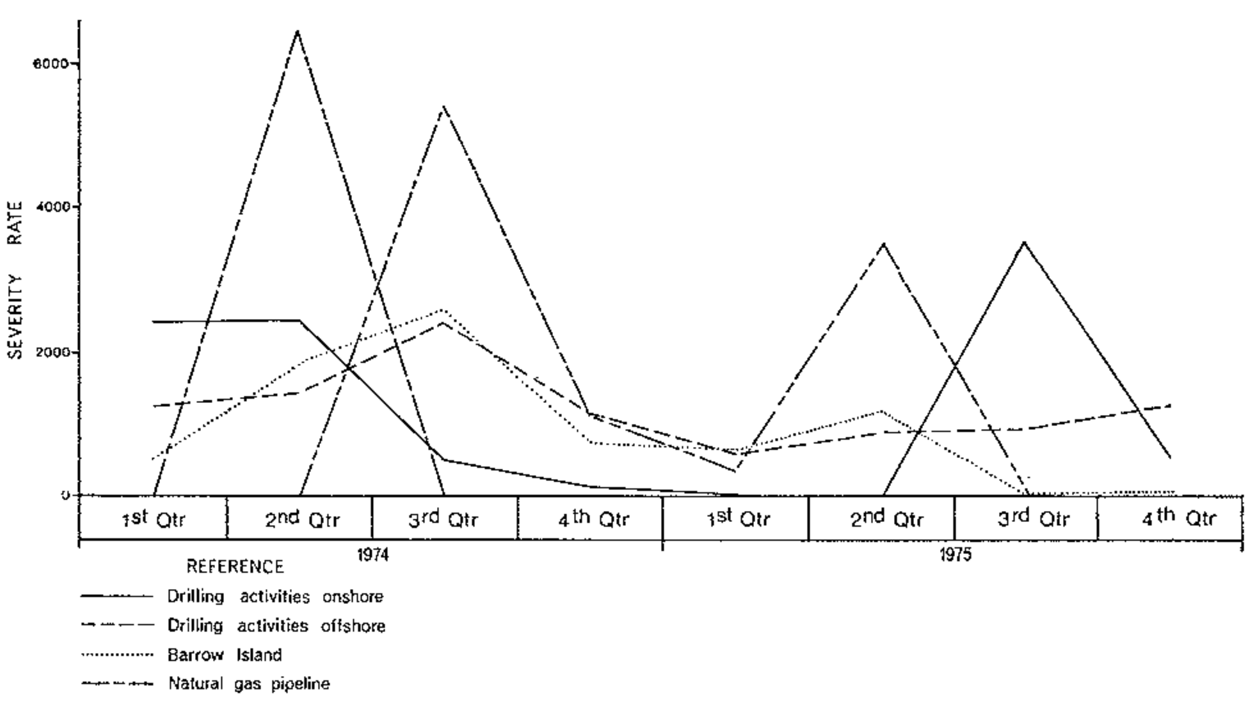


Figure 7. Serious injuries in the petroleum exploration and pipeline industry during 1974 and 1975: Frequency and severity rates.

TABLE VII

CHANGES AFFECTING TITLES UNDER THE PETROLEUM (SUBMERGED LANDS) ACT, 1967 DURING 1975

PERMIT RENEWALS

Permit Number	Permittee	Basin	Date Renewal Approved	Commencement Date of Renewal	Original No. of Blocks	No. of Blocks Renewed
WA-16-P	ARCO *et al*	Bonaparte Gulf	25/6/75	17/4/75	354	40
WA-18-P	ARCO *et al*	Bonaparte Gulf	25/6/75	17/4/75	322	105
WA-19-P	AODA	Bonaparte Gulf	30/6/75	21/3/75	142	49
WA-28-P	BOCAL *et al*	Carnarvon/Canning	5/6/75	25/3/75	375	178
WA-29-P	BOCAL *et al*	Canning	5/6/75	19/5/75	400	120
WA-31-P	BOCAL *et al*	Canning/Browse	9/7/75	19/5/75	400	80
WA-32-P	BOCAL *et al*	Browse	25/7/75	3/7/75	395	100
WA-33-P	BOCAL *et al*	Browse	5/6/75	19/5/75	389	194
WA-34-P	BOCAL *et al*	Browse	25/7/75	3/7/75	397	149
WA-35-P	BOCAL *et al*	Browse	25/7/75	3/7/75	400	123
WA-36-P	BOCAL *et al*	Bonaparte Gulf	5/6/75	19/5/75	57	18
WA-37-P	BOCAL *et al*	Browse	5/6/75	3/6/75	118	59
					3 749	1 215

PERMIT APPLICATIONS

Permit	Permittee	Basin	Date	No. of Blocks	Status
WA-58-P	W.E.	Carnarvon/Canning	17/10/75	222	Pending

PERMITS EXPIRED

Permit Number	Permittee	Basin	Date Expired	No. of Blocks
WA-7-P	C.O.C.A.	Carnarvon	10/7/75	135
WA-15-P	ARCO *et al*	Bonaparte Gulf	20/3/75	352
WA-17-P	ARCO *et al*	Bonaparte Gulf	22/4/75	378
WA-26-P	C.S. *et al*	Carnarvon	22/12/74	400*
WA-30-P	BOCAL *et al*	Canning	2/7/75	400
WA-39-P	B.P. *et al*	Carnarvon	12/3/75	104
WA-40-P	B.P. *et al*	Carnarvon/Perth	12/3/75	102
				1 871

*Renewal applied for over 37 blocks but refused and permit expired as at termination of first six year period.

PERMIT SURRENDERS

Permit Number	Permittee	Basin	Surrender Date	Original No. of Blocks	Surrendered Blocks
WA-50-P	Esso	Bremer	17/3/75	330	330
WA-51-P	Esso	Bremer	11/4/75	278	278
				608	608

PERMIT CANCELLATIONS

Permit Number	Permittee	Basin	Cancellation Date	No. of Blocks
WA-27-P	C.S. *et al*	Carnarvon	31/1/75	294

ACCESS AUTHORITIES

Number	Permittee	Basin	Operating Permit	Permit or Locality	Duration
30SL	WAPET	Perth	WA-14-P(R1) Part 2	Vacant Areas	5/2/75-4/5/75
31SL	WAPET	Carnarvon	WA-25-P(R1)	Vacant Areas	15/2/75-14/5/75
32SL	BOCAL *et al*	Carnarvon	WA-28-P .... WA-1-P(R1)	WA-25-P	9/3/75-8/6/75
33SL	BOCAL *et al*	Carnarvon	WA-28-P .... WA-1-P(R1)	Vacant Areas	9/3/75-8/6/75
34SL	BOCAL *et al*	Carnarvon	WA-28-P .... WA-29-P .... WA-32-P .... WA-35-P WA-37-P	Vacant Areas	3/12/75-2/2/76

ADVERTISEMENTS INVITING APPLICATIONS FOR EXPLORATION PERMITS WITH A CLOSING DATE PURSUANT TO SECTION 20(1)

Area Number (or Former Permit Numbers)	Basin	Date Gazetted	Closing Date	No. of Blocks
WA-1-P(Part) WA-23-P(Part)	Carnarvon/Canning	20/6/75	17/10/75	222
W75-1	Perth	19/9/75	9/1/76	231
W75-2	Perth	19/9/75	9/1/76	16
W75-3	Perth	19/9/75	9/1/76	44
W75-4	Perth	19/9/75	9/1/76	14
W75-5	Perth/Carnarvon	19/9/75	9/1/76	190
				717

Abbreviations:

AODA	Alliance Oil Development Australia N.L.
ARCO *et al*	Arco Australia Limited Australian Aquitaine Petroleum Pty. Limited Esso Exploration and Production Australia Inc.
BOCAL *et al*	Shell Development (Australia) Pty. Ltd. Bocal Pty. Ltd. Woodside Oil No Liability
B.P. *et al*	B.P. Petroleum Development Australia Pty. Ltd. Abrolhos Oil No Liability
C.O.C.A.	Continental Oil Company of Australia Limited
C.S. *et al*	Canadian Superior Oil (Aust) Pty. Ltd. Australian Superior Oil Company Ltd. Phillips Australian Oil Company Sunray Australian Oil Company Inc. Genoa Oil N.L. Pexa Oil N.L. Flinders Petroleum N.L. Hartog Oil N.L. Crusader Oil N.L.
ESSO	Esso Exploration and Production Australia Inc.
WAPET	West Australian Petroleum Pty. Limited
W.E.	Western Energy Pty. Ltd.

Onshore

As with offshore tenements, dealings were at an unusually high level owing to the fact that many first term expiries fell within the year (see Table VIII). Regarding Exploration Permits, 14 were surrendered, one was cancelled, six expired and eight were renewed. One Production Licence was surrendered. As a result of surrender, expiry and renewal, large areas have become vacant during 1974 and 1975. Two permits were granted as a result of advertisements in 1974, and a further application was pending at the end of 1975. Some 17 areas (potential permits) were advertised inviting applications for Exploration Permits under Section 30 (1) of the Petroleum Act, 1967, but in all cases the closing date was in 1976. Eight former exploration permit areas were advertised under Section 30 (3), making these areas available for application without a closing date. Figure 8 illustrates the location of tenements which underwent change in status and of areas advertised.

TABLE VIII

CHANGES AFFECTING TITLES UNDER THE PETROLEUM ACT, 1967 DURING 1975

PERMIT RENEWALS

Permit Number	Permittee	Basin	Date Renewal Approved	Commencement Date of Renewal	Original No. of Blocks	No. of Blocks Renewed
EP 7	WAPET	Canning	8/8/75	28/8/75	200	24
EP 13	WAPET	Canning	8/8/75	28/8/75	200	23
EP 19	WAPET	Canning	8/8/75	28/8/75	200	18
EP 21	WAPET	Perth	25/8/75	27/7/75	90	32
EP 23	WAPET	Perth	25/8/75	7/8/75	156	33
EP 24	WAPET	Perth	8/8/75	7/8/75	163	85
EP 25	WAPET	Perth	8/8/75	7/8/75	96	36
EP 42	WAPET	Canning	8/8/75	2/9/75	200	19
EP 50*	WAPET	Perth	....	....	110	18*
EP 54*	AODA	Bonaparte Gulf	....	....	123	47*
Total					1 538	270

*Refers to applications for renewal received but not yet approved and are not included in total number of blocks renewed.

PERMIT APPLICATIONS

Permit Number	Applicant	Basin	Date Applied For	No. of Blocks	Status
EP 87	E.E.	Perth	9/12/75	3	Pending

PERMITS GRANTED

Permit Number	Permittee	Basin	Date Approved	No. of Blocks
EP 85	E.O. *et al*	Perth	20/7/75	4
EP 86	XLX N.L.	Carnarvon	10/1/75	118
Total				122

PERMITS EXPIRED

Permit Number	Permittee	Basin	Date Expired	No. of Blocks
EP 5	WAPET	Canning	26/7/75	132
EP 6	WAPET	Canning	27/8/75	199
EP 17	WAPET	Canning	27/8/75	200
EP 18	WAPET	Canning	27/8/75	86
EP 43	WAPET	Canning	1/9/75	163
EP 44	WAPET	Canning	1/9/75	113
Total				893

PERMITS SURRENDERED

Permit Number	Permittee	Basin	Surrender Date	Original No. of Blocks	Surrendered Blocks
EP 3	WAPET	Canning	11/7/75	200	200
EP 8	WAPET	Canning	11/7/75	192	192
EP 9	WAPET	Canning	11/7/75	200	200
EP 14	WAPET	Canning	11/7/75	200	200
EP 15	WAPET	Canning	11/7/75	200	200
EP 20	A.A.P.	Canning	28/7/75	199	199
EP 26	B.P. *et al*	Carnarvon	27/6/75	1	1
EP 27	B.P. *et al*	Carnarvon	27/6/75	2	2
EP 28	B.P. *et al*	Perth	27/6/75	4	4
EP 29	B.P. *et al*	Perth	27/6/75	7	7
EP 31	B.G.E. *et al*	Canning	16/5/75	200	200
EP 32*	B.G.E. *et al*	Canning	Pending	200*	200*
EP 37	WAPET	Canning	11/7/75	149	149
EP 38	WAPET	Canning	11/7/75	130	130
EP 69	S.O.	Perth	17/1/75	82	82
Total				1 766	1 766

*Refers to Application for Surrender received but not yet approved. Blocks not included in total.

PRODUCTION LICENCE SURRENDERED

Production Licence No.	Licensee	Basin	Surrender Date	Original No. of Blocks	Surrendered Blocks
3	WAPET	Perth	29/8/75	5	5

PERMIT CANCELLATIONS

Permit Number	Permittee	Basin	Cancellation Date	No. of Blocks
EP 71	C.P.	Eucla	22/8/75	81

ADVERTISEMENTS INVITING APPLICATIONS FOR EXPLORATION PERMITS WITH A CLOSING DATE PURSUANT TO SECTION 30(1)

Area Number	Basin	Date Gazetted	Closing Date	No. of Blocks
L75-1	Carnarvon	19/9/75	9/1/76	1
L75-2	Carnarvon	19/9/75	9/1/76	2
L75-3	Perth	19/9/75	9/1/76	4
L75-4	Perth	19/9/75	9/1/76	7
L75-5	Carnarvon	24/10/75	20/2/76	188
L75-6	Carnarvon	24/10/75	20/2/76	137
L75-7	Carnarvon	24/10/75	20/2/76	133
L75-8	Carnarvon	24/10/75	20/2/76	132
L75-9	Canning	24/10/75	20/2/76	200
L75-10	Canning	24/10/75	20/2/76	200
L75-11	Canning	24/10/75	20/2/76	146
L75-12	Canning	24/10/75	20/2/76	138
L75-13	Canning	24/10/75	20/2/76	172
L75-14	Canning	24/10/75	20/2/76	193
L75-15	Canning	24/10/75	20/2/76	194
L75-16	Canning	24/10/75	20/2/76	200
L75-17	Canning	24/10/75	20/2/76	192
Total				2 239

ADVERTISEMENT MAKING AREAS AVAILABLE FOR APPLICATION WITHOUT A CLOSING DATE PURSUANT TO SECTION 30(3)

Former Permit No.	Basin	Date Gazetted	No. of Blocks
EP 33	Canning	6/6/75	123
EP 45	Carnarvon	6/6/75	197
EP 46	Carnarvon	6/6/75	199
EP 47	Carnarvon	6/6/75	199
EP 48	Carnarvon	6/6/75	199
EP 72	Officer	6/6/75	198
EP 73	Officer	6/6/75	198
EP 75	Officer	6/6/75	198
Total			1 511

Abbreviations:

A.A.P.	Australian Aquitaine Petroleum Pty. Limited
AODA	Alliance Oil Development Australia N.L.
B.G.E. *et al*	Beach-General Exploration Pty. Ltd. Australian Aquitaine Petroleum Pty. Limited
B.P. *et al*	B.P. Petroleum Development Australia Proprietary Limited Abrolhos Oil No Liability
C.P.	Coastal Petroleum N.L.
E.E.	Elvet Exploration Pty. Ltd.
E.O. *et al*	Endeavour Oil Company No Liability Target Minerals N.L. Associated Australian Resources N.L. I.O.L. Petroleum Limited Alliance Minerals (Australia) N.L.
S.O.	Sunningdale Oils Proprietary Limited
WAPET	West Australian Petroleum Pty. Limited

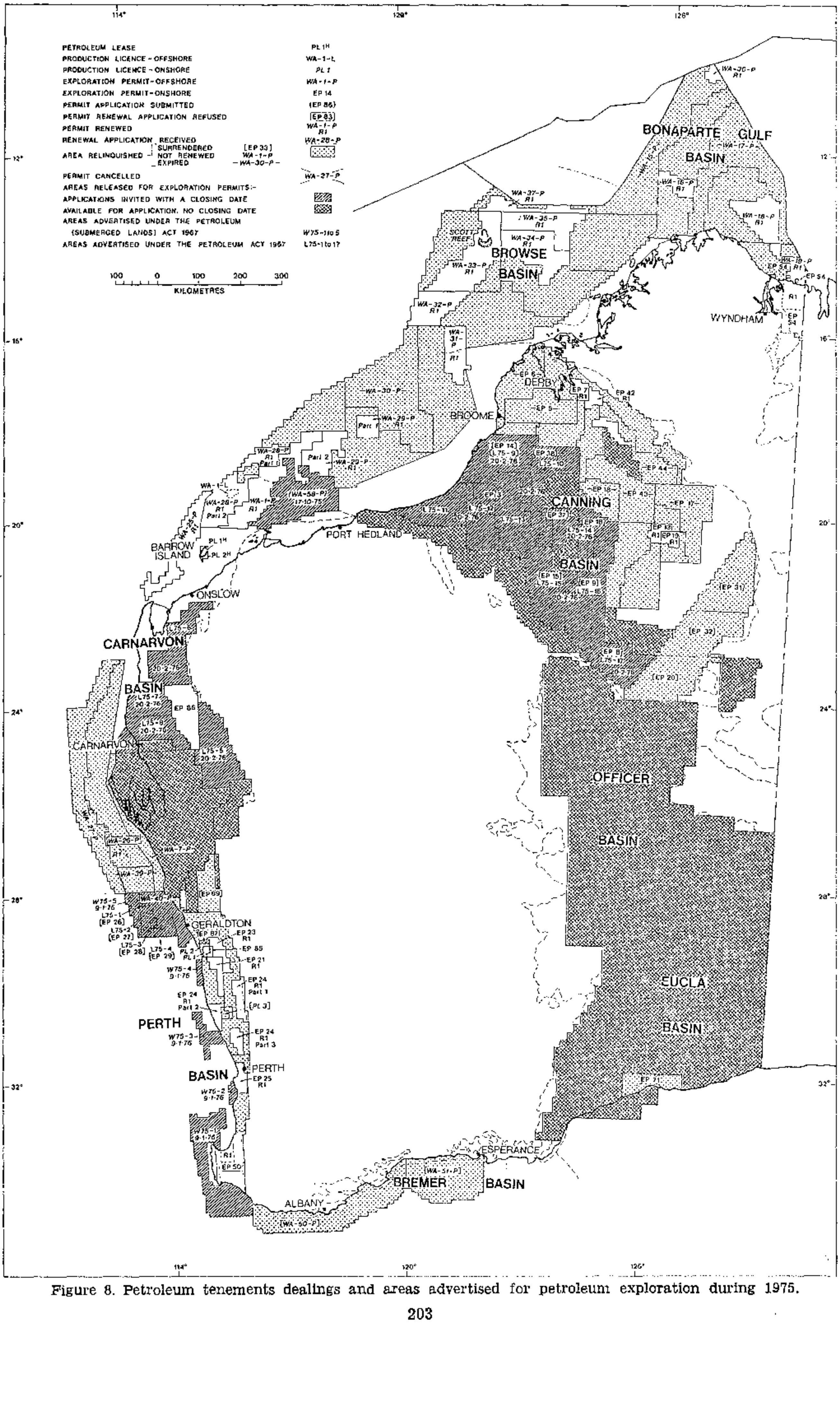


Figure 8. Petroleum tenements dealings and areas advertised for petroleum exploration during 1975.

STAFF

The staff of the Petroleum Branch during 1975 were as follows:—

A. J. Sharp—Senior Petroleum Engineer (Level 5) and Acting Branch Head.

A. H. Pippet—Reservoir Engineer (Level 4).

P. H. J. Hammett—Petroleum Engineer (Operations) (Level 4).

R. N. Cope—Production Geologist (Level 4).

T. D. Tanner—Typist/Receptionist (C-V), resigned 27/3/75.

I. M. Dienaar—Typist/Receptionist (C-V), 2/4/75 to 31/12/75.

A. J. SHARP,
Acting Head.

DIVISION VI

Report of the Superintendent Surveys and Mapping for the Year 1975

The Under Secretary for Mines

For the information of the Hon. Minister, I submit my report on the activities of the Surveys and Mapping Division for the year ended 31st December, 1975.

STAFF

The membership of the staff now totals 118 comprising the following categories:

Professional	59
Clerical	10
General	25
Technical	7
Trainee Draftsmen	17
	118

The staff are disbursed throughout the 3 Branches which each have responsibility for a major function as part of the overall Divisional activity within the Department. This spread is designed to achieve a full use of each officers ability and all Divisions work harmoniously as a whole.

Field survey activity has been performed by a team of Practitioner Surveyors who continue to operate in an efficient and economical manner. The number of individual surveyors authorised by the Hon. Minister to perform cadastral surveys for the Department now stands at 76.

The accumulated balance of deposited survey fees which stood at $2 327 874 at the beginning of the year was reduced to $1 858 377 as at 31st December.

The value of surveys performed rose to $690 334, as against $370 411 for the previous year—see graph. This is accounted for by an increase in the number of tenements surveyed, additional connection surveys made to the State geodetic framework, and the inclusion in this years amount of some heavy items of expenditure on some of the iron-ore leases being carried forward and finalised in this year, plus of course, the heavy burden of increasing costs common throughout the community.

All dealings under the Petroleum and Mining Legislation, including Special Act Agreements have been handled expeditiously and all maps and plans show the up-to-date situation at any given time. Departmental public plans are being continuously renewed both in the District Offices and in Perth.

The drawing of maps and diagrams for the Geological Survey Division continues to be a heavy demand on this Division.

Itemised reports of the activities of the three main Branches of the Division are appended hereto.

A. A. HALL,
Superintendent
Surveys & Mapping.

8th July, 1976.

Survey Branch

1. Survey Activity

1.1 *Field.* Surveys of mining leases, claims, special act mining leases and other tenements were carried out during the year by Licensed Surveyors by commission from the Department and in accordance with its regulations and requirements. Survey work done is summarised in the following table:—

Number of Surveyors	32	
Number of tenements surveyed	2 219	
Number of field books lodged	300	
Number of connection stations established horizontal	28	
Number of connection stations established vertical	55	
Total boundary line run	4 812	km
Total traverse line run	324	km
Total area delineated by survey	190 392	ha
Total distance travelled	19 116	km
Total value of cadastral survey	$631 012	
Total value of connection survey	$ 59 332	
Total	$690 334	

1.2 *Surveyors.* The work performed by Survey Practitioners is itemised in the following table:—

Surveyor	Surveys	Hectares
Benetti Croghan & Associates—		
*K. J. Croghan	243	27 743
R. J. Benetti	138	14 594
McKinmie Jamieson and Partners—		
*T. L. Markey	144	5 982
G. S. Chignell	43	2 442
*K. McAllister	....	....
A. E. Smythe	27	1 699
W. N. Thompson	11	1 191
F. R. Rodda—		
F. R. Rodda	156	16 195
P. R. Blackadder	52	5 463
J. S. Ranieri—		
J. S. Ranieri	81	6 891
G. G. Bateman	54	5 161
M. M. Fisher and Associates—		
*M. M. Fisher	190	17 659
McCarthy Smirk and Associates—		
J. Zuideveld	172	15 166
D. F. V. Wilson and Associates—		
*D. F. V. Wilson	207	15 277
Kimberley F. Patterson—		
R. G. Agnew	109	5 077
A. R. Williams	52	5 919
K. F. Patterson	16	111
Warren F. Johnson Pty. Ltd.—		
*M. R. Piowczyk-Kruk	74	8 343
K. W. Bartlett	23	2 552
A. C. Watson	18	2 160
Hille and Thompson—		
A. G. Thompson	78	8 437
P. J. Hille	23	2 664
W. A. Berryman	60	7 070
Associated Surveys Pty. Ltd.—		
G. E. Roughan	73	5 400
A. K. King & Co.—		
K. R. Maguire	28	2 095
A. K. King	25	1 340
*Australian Aerial Mapping Pty. Ltd.	....	....
P. Meleug	36	433
L. J. Burkett	44	2 172
M. J. Byrne	9	240
M. R. McMullen	3	364
Bebb and Bratton Pty. Ltd.—		
R. G. Agnew	18	462
I. M. Gordon	10	63
Compiled	2	....

*Includes connection surveys.

1.3 *Fees and Estimates.* The practice of estimating, as recently introduced by the Department, was further developed during the year. It has not yet been possible to achieve uniformity in methods of costing at this stage. However, more realistic costing practices are emerging. A new scale of fees was gazetted, operative as from the 1st July, 1975, and these themselves have not yet stabilised the situation.

1.4 *Field Inspections.* Survey activities in the field and associated marking and other procedures were inspected by senior officers of this Branch as follows:—

1.4.1 *Pilbara Area.* This was to inspect the terrain and conditions being encountered in the Port Hedland-North Pole-Tamborah and Marble Bar and Bamboo Creek areas. (Dawson)

1.4.2 *Kalgoorlie.* This was to select and evaluate suitable control positions in the active area of the Golden Mile The need for a surveyor to operate in the vicinity of Coolgardie was also investigated, together with some outstanding survey checks. (Stewart-Dunne)

1.4.3 *Yalgoo (Golden Grove).* This was to carry out an on-site inspection of horizontal and vertical control points established in the vicinity of the ore-body being evaluated by Electrolitic Zinc Co. Ltd. together with the extensive claim survey pattern. (Moore-Walsh)

2. SURVEY PROJECTS

2.1 *Cadastral.* These surveys, totalling 2 219, were carried out at many localities, from Kununurra to Esperance, and they serve as the fundamental framework for tenement positioning and enable positive applicant identification of tenement boundaries both on the ground and on plans.

2.2 *Control Projects*

2.2.1 *Shay Gap,* Pilbara Goldfield. This project entailed the connection of the Special Mineral Lease, 249SA, to the nearest control. An extension of 149 km was required, necessitating the measurement of 7 lines with angles resulting in the establishment of 4 permanent stations plus one old station upgraded. Surveyor K. McAllister.

2.2.2 *North Pole—Normay,* Pilbara Goldfield. Three control stations were established in the vicinity of the barite, copper and gold mines. Surveyor K. McAllister.

2.2.3 *Golden Grove,* Yalgoo Goldfield. This project included two phases, vertical and horizontal. The vertical survey was arranged by the Department and paid for by the mining company who required the survey for their exploration and mine development purposes. It consisted of a levelling traverse of 100 kilometres between 2 standard bench marks in which a tetal of 38 new marks were set and levelled to. The resulting data has been handed to National Mapping. Surveyor W. Johnston.

The horizontal survey was completed as a separate exercise in which a total of 9 standard marks were placed and closed measurements were made. Connections were made at optimum positions in the claim survey pattern. Surveyor E. A. McKinnon and K. J. Croghan.

2.2.4 *Bulong-Kanowna,* Eastern Goldfields. The second phase of this survey was completed in April and comprised measurement to 15 permanent stations together with cadastral connection. Surveyor M. M. Fisher.

2.2.5 *Soansville-Tamborah,* Pilbara Goldfield. This was a connection survey for tenements scattered over a wide locality. The discrete groups are now tied together by a total of 6 permanent stations. Surveyor K. McAllister.

2.2.6 *Millstream-Fortescue Valley,* Ashburton Goldfield. At the request of the Hydrological Section who required the data for evaluation of water drilling and investigation of the underground water potential, a total of 17 stations were levelled to National Mapping second order standards and a further 47 stations established in proximity thereto for bore hole correlation. Surveyor W. N. Thompson.

2.2.7 *Tabba Tabba-Pippingarra,* Pilbara Goldfield. Two connections to control were made at these centres with upgrading of existing marks.

2.2.8 *Coppins Gap,* Pilbara Goldfield. In association with private survey control established in the localised vicinity of Coppins Gap for aerial mapping control, one existing mining station was upgraded with five supplementary points established and connected to National Mapping Stations. Surveyor D. F. V. Wilson.

2.2.9 *Robe River,* Ashburton Goldfield. Surveys were completed of the initial Sections of ML 248 SA, held by Robe River Iron Ore Associates. A minor set of sub-control stations were established inter-connecting the scattered sections in the valley of the Robe River and ready for tying to the State network. Surveyor D. F. V. Wilson.

3. *Office Activity*

3.1 *Staff.* Three additional Level 1 Draftsmen were appointed from outside the Department to fill vacancies within the Survey Branch created by previous resignation. The Branch is currently fully staffed.

3.2 *Equipment.* The Branch was re-equipped with 16 pocket calculators, Hewlett Packard Model 21. This is equivalent to one unit for every two officers. This particular model is considered eminently suitable for our purposes and when coupled with the capacity of the existing HP Model 9810 creates a powerful capacity for all types of routine office calculation.

3.3 *Field time.* The practice of allowing field-time to the Department's Trainee Draftsmen was re-introduced during the year. It has proved to be an invaluable method of acquainting our officers with the practical aspects of surveying to supplement their theoretical learning in the office environment. A total of 10 Trainees and Draftsmen have received a total of 194 field days attached to 6 different surveyors.

3.4 *Project work.* In addition to the activity of survey instruction, survey examination and general drafting, an increasing amount of time is now being spent on measurement and computation of connections to the geodetic network of the State. This has been necessary because of the demand for more accurate maps coupled with requests for accurate control for more detailed investigations by private organisations. The computations performed on these measurements are the most up-to-date according to contemporary survey practices. A summary of the projects is:—

3.4.1 *ML 244SA-Mt. Newman.* This comprises a recomputation and adjustment of the B.H.P. Co. control network onto the Australian Map Grid and a redefination of the lease boundaries in terms of the new adjustment. Proceeding.

3.4.2 *ML 4SA-Hamersley Range* The photogrammetric surveys, completed in 1968 and 1972 respectively, were integrated with the survey control and the lease corner co-ordinate data into CADMAPS, with plan plots thereof. Finalised.

3.4.3 *Yeelirrie Photogrammetric Survey.* This project was completed as in paragraph 3.4.2. Finalised.

3.4.4 *Barrambie Photogrammetric Survey.* This project was also completed in the same manner as described in paragraph 3.4.2. Finalised.

3.4.5 *Patterson Range.* Computations for the geodetic connections were finalised. Co-ordination of lease and claim corners will be commenced at a later date. Control finalised.

3.4.6 *Agnew-Leinster Downs.* Computation and adjustment of the control was suspended pending clarification and investigation by the field surveyors. Considerable progress has been made on the co-ordination of the extensive cadastral pattern in this area utilising the standard traverse technique. Proceeding.

3.4.7 *Golden Grove.* Geodetic computation was finalised. Co-ordination of claim corners is almost completed. Proceeding.

3.4.8 *Bulong-Kanowna.* Some minor problems in adjustment were encountered and attempts were made to overcome these by additional field work and office evaluation of loop closures. No standard traversing is planned for this area as yet. Suspended.

3.4.9 *Hyden-Forrestania.* Claim Co-ordination. Connection of Departmental surveys onto extended Lands and Surveys control is at an advanced stage. Proceeding.

3.4.10. *Kalgoorlie Lease Re-surveys.* Following an investigation of the best method of re-marking the lease surveys in the Golden Mile area at Kalgoorlie, a system of precalculation of the theoretical corners with their subsequent lay-in by angle and distance radiation from a central control point was devised, making use of electronic distance measuring equipment. The system devised is akin to that of a "pre-computed" subdivision as is now extensively used by other authorities in townsite and urban development layout.

A departure from conventional re-establishment of leases was found to be necessary at Kalgoorlie because of the extensive loss of the original marks which has occurred over the years in this much used area. In this particular project the co-ordinate values will be obtained from the actual original survey measurements rather than from an idealised situation as is generated in the conventional pre-computed subdivision. It is considered that this project is an important development in advancement and application of new survey techniques to the mining situation.

At the end of the year, all relevant survey information data had been collated and preliminary traverses completed on arbitrary co-ordinates. Experimentation with program GALS from the Surveying Department at the W.A.I.T. was carried out on the proposed control network design. From this, and the field check carried out by Mr. Stewart in October, a control pattern was selected. Proceeding.

3.5 Filing and Index systems. During 1975 a review of the current methods of indexing and filing geodetic control, cadastral traverse and photogrammetric survey data was carried out. Procedures are outlined as follows.

3.5.1 All Geodetic Control Work, either computed by the section or lodged by outside companies is registered in numbered Geodetic Calculation Folders. A total of 13 folders have so far been registered, containing work completed or work still in progress.

3.5.2 All Mines Dept. geodetic control work is indexed on transparent copies of the equivalent Lands Department horizontal control sheets.

3.5.3 Computer listings of standard traverse and photogrammetric survey co-ordinates are combined and filed within 250 000 mapsheet computer folders. Folders for the following mapsheet areas have been initiated:

Kalgoorlie
Boorabbin
Sandstone
Mt. Bruce—Wyloo
Roebourne
Yalgoo.

3.5.4 All standard traverse and photogrammetric surveys are indexed or referenced on standard 1/50 000 map sheets.

3.5.5 A provisional index sheet has been prepared covering the whole state. This sheet shows all Mines Dept. 1/250 000 horizontal control sheets that have been prepared, together with those areas covered by 1/50 000 standard traverse index sheets.

4. *STANDARD PLANS*

Standard plan transparencies, at scale 1:50 000 have been prepared directly from the computer plots. This has been done for the following projects:

Coolgardie-Burbanks—24 map sheets
Hamersley Range—24 Map Sheets
Yeelirrie—6 map sheets

A number of standard plans in the Roebourne area have also been re-drafted with the aid of computer plotting.

5. *IMPLEMENTATION OF CADMAPS INTO MINES DEPARTMENT*

5.1 CADMAPS is a computer data base system developed by the Lands and Surveys Department in 1974 for the storage of survey traverse and control co-ordinate data, together with automatic computer plotting of this data on base grid sheets. The system is administered by the Lands and Surveys Department for the purpose of updating and maintaining the master CADMAPS file and for creating and issuing user's WORKFILES upon request. The user is in complete control of all CADMAPS system computer work on his own WORKFILE and upon completion of the file notification is given to the Lands Department for copying the user's file data onto the master file. The user's WORKFILE is then destroyed. Subsequent WORKFILES for the same project area can be created for as many times as the user requires.

The system has the advantage of allowing a large amount of common information to be shared by different users and to make users aware of any overlap of work which may occur between departments in the same project areas. The need for users to store large quantities of data in the form of punched cards is also eliminated.

Mines Department together with the M.W.B. became participant users of CADMAPS in 1975. Mines Department Surveys Section was the first external user to request a WORKFILE. Between May and December 1975 a total of 5 WORKFILES were created for use by the Surveys Section.

6. *COMPUTER SYSTEM DEVELOPMENT*

6.1 W.A.R.C.C.-CYBER Computer and Plotter. As a participant user the Surveys Section has made effective use of these facilities during 1975. Most production work has been carried out using programs and systems already established. At present a transformation program is being developed which will be initially tested on the CYBER than modified for the PDP 11/40 Computer installed in the Govt. Chemical Laboratories.

In April 1975 arrangements were made for the Mines Dept. to use the Lands and Surveys Dept. terminal to the CYBER. The main problem at present is the lack of a suitable facility for card punching.

6.2 *Future development.* The Main Roads Department have recently installed a CYBER 172 computer using the same operating system as at the W.A.R.C.C. It is anticipated that from early March 1976 the Lands and Surveys Department will change their terminal connection from the W.A.R.C.C. at University to the new M.R.D. CYBER. All existing programs and systems at present used by this section will be accessible on the M.R.D. computer. Proposals are being considered for the installation of a new flat-bed plotter.

6.3 *W.A. Government Chemical Laboratories Computer.*

6.3.1 The Chemical Laboratories have installed their own D.E.C. PDP 11/40 Computer mainly for on-line processing work within their own divisions. Surveys Section, in contributing towards the cost, have a remote DEC-writer terminal to this system which at present is housed on the 7th Floor and is waiting final installation and connection. Some basic features of the hardware are:

Accessible memory of 28 K
1 x RK 11 disk drive (over 600 000 words)
TC 11 dual-unit DEC tape system.

The system operates under RSX-11M (Version 2) operating system. Surveys Section have a complete set of the manuals supporting this software.

6.3.2 Some further features which will increase the storage capacity and efficiency have been allowed for in the 1975-1976 budget. These include:

1 x KT 11D Memory Management Option
1 x MM 1 16K core memory
1 x RKO 5 disk drive

6.3.3 The Surveys and Mapping Division has been represented on the Chemical Laboratory Computer Committee though which the latest developments are disseminated to participant users. The Chemical Laboratories have so far generated the operating system and have carried out some program development and testing. The Computer is not yet housed in its final location, awaiting work to be completed by the P.W.D. Interfacing of peripheral devices and terminal connections still has to be carried out. The exact requirements by this Section and Geological Survey, who will also have access to our terminal, is yet to be determined.

8. *PETROLEUM.*

Petroleum drafting activity has been in the nature of preparation of descriptions for tenement renewals and drafting work for the preparation of plans for renewal documents, relinquishment areas, areas advertised under the Petroleum Acts together with the continual updating of the State Petroleum Tenement Map and the various Public Plan series.

During the year the following statistics were generated:—

Permits renewed	— 22	from total of	55	— 40%
Blocks renewed	— 1550	from total of	11546	— 13%
Blocks applied for	— 225	from total of	3758	— 6%

The State Map continues to be the principal vehicle for public use and is probably the most effective medium for notification of areas available for exploration. The map is distributed quarterly, when 80 copies are distributed to 50 subscribers. This is in addition to routine public sales.

MAPPING DIVISION

Although interest in Mining generally slowed down, Mapping and general drafting remained constant and heavy.

The details of each section is set out below.

Cadastral Mapping.

A total of 38 new Australian Map Grid sheets at a scale of 1:50 000 were prepared of Dampier, Roebourne and Laverton.

A further 12 new Australian Map Grid sheets at scale 1:100 000 were completed in the Kimberleys covering Gordon Downs and Lissadell.

Revision has also been completed of Roy Hill, Southern Cross and Barlee.

All new sheets are now prepared on Australian Map Grid co-ordinates.

Geological Mapping—1:250 000 Series

This series is our major mapping program and the following sheets were published during the year.

Malcolm-Cape Arid
Dongara-Hill River
Murgoo
Mason
Seemore

Other first edition sheets completed and sent for publication were:—

Yalgoo
Leonora
Laverton

Preliminary editions, which are published in 3 line colours prior to the first edition were completed and published as follows:—

Duketon
Sir Samuel
Mt. Egerton

Work continued on the sheets of Perth, Marble Bar, Nullagine and new sheets commenced were Paterson Range, Yarrie.

Other Work

The 1:1 000 000 series of Kalgoorlie and Esperance was continued and brought near to completion. *1:50 000 Series.* A new urban geological series was commenced to assist local councils, planners and engineers. Two sheets were commenced, completed and published in 3 line colours of Moore River and Gingin.

Other sheets are to follow south of Perth and will probably be published in full color.

Bulletins

Black and white drawings for the following Bulletins were brought to completion.

TIN, MINERAL SANDS, PERTH BASIN, and CARBONIFEROUS AREAS.

Four color plates at 1:100 000, 2 at 1:500 000 and 3 at 1:1 000 000 were still in progress.

State Map

Revision of the Mines Dept. State Map and Gazetteer was commenced at 1:1 000 000 scale.

Over 500 drawings were prepared for various publications such as Annual Report, Bulletins, pamphlets and other similar publications. Many drawings were prepared for 35 mm projection slides in color and black and white and 20 certificates were inscribed for the State Mining Engineer's Branch.

Microfilming

The microfilming programme continued with two 35 mm cameras being used one at the P.W.D. operated by the Microfilm Steering Committee and one at the M.R.D. operated by our own staff.

Preparation of Petroleum relinquishment packages was very slow with limited staff and technical problems in filming had to be solved.

92 Rolls of film were prepared and 73 copies were made for sale purposes.

62 rolls of film were prepared to cover the old mining tenement registers of the Registration Branch.

Assistance was also given to the West Australian Government Railways with their microfilming programme and 12 rolls of film were done and put onto cards.

Photographic Section

Lack of adequate space and additional staff again resulted in this section having difficulty in meeting all the demands made on it.

Overtime had to be continued to cope with color work and the more urgent projects.

The process camera was in constant operation with 2 286 items being handled, over 2 300 items were put through on the vacuum frames, 84 metal plates were produced and there was a 175% increase in general photographic work with over 7 200 items being produced.

Of this, 2 200 were color items, a tremendous increase as predicted in 1974.

Plan Printing

This section remained steady again with 32 750 paper and film prints being made, 1 900 photo copies and 1 100 plans prepared with mounting cloth.

APPLICATIONS AND PUBLIC PLANS

The following applications were received during 1975:

Mineral Claims	3 976
Mineral Leases	295
Gold Mining Leases	369
Licenses to Treat Tailings	111
Prospecting Areas	382
Coal Mining Leases	113
D.C.s, W.R.s, G.A.s, Q.A.s, T.L.s, M.H.L.s, R.A.s, R.L.s, M.Y.L.s, D.L.s, etc.	111
	5 357

353 applications for Temporary Reserves were handled in the Section for the following minerals:

Iron	28
Gold	292
	(284 in one block)
Coal	17
Other Minerals	16

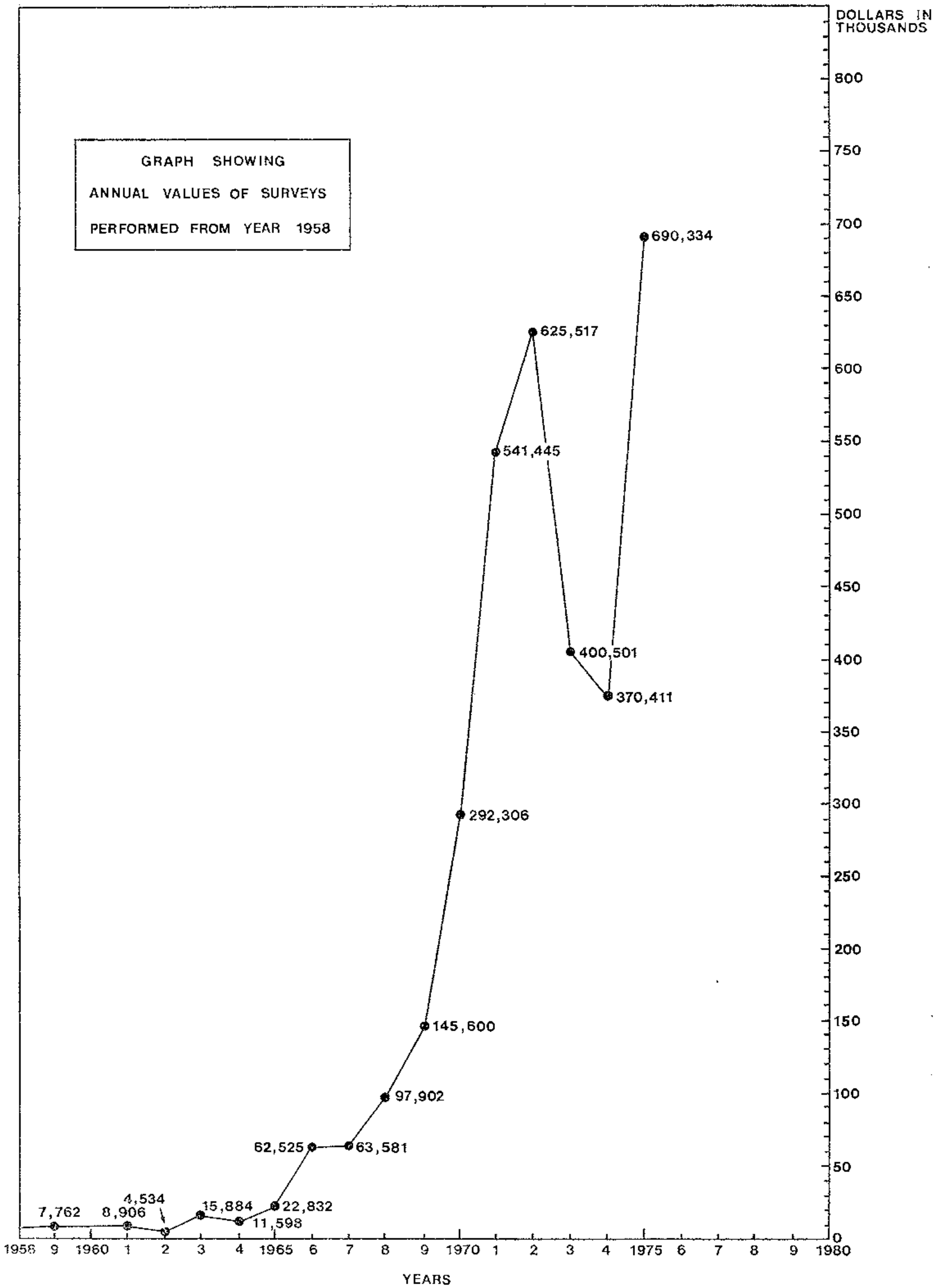
Head Office plans sales totalled $7 875.48 for supply of:

Dyelines	8 201
Transparencies	194
Photo copies	3 715
Iron T.R. List	31
Other Minerals T.R. List	32
State Maps	114
Gazetteers	5
Mineral Occurrence Map	126
Gold Bearing Areas Map	73

Much time has been spent cross-checking records and renewing and replacing old Public Plans.

No overtime has been worked and no abnormal backlogs have occurred.

(14)—58638


GRAPH SHOWING
ANNUAL VALUES OF SURVEYS
PERFORMED FROM YEAR 1958
DOLLARS IN THOUSANDS
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
690,334
625,517
541,445
400,501
370,411
292,306
145,600
97,902
62,525
63,581
22,832
15,884
11,598
4,534
8,906
7,762
1958 9 1960 1 2 3 4 1965 6 7 8 9 1970 1 2 3 4 1975 6 7 8 9 1980
YEARS

DIVISION VII

Government Chemical Laboratories Annual Report—1975

Under Secretary for Mines:

I submit the Annual Report on the operations and functions of the Government Chemical Laboratories for the year ending December, 1975.

Administration:

At the end of 1975 the Laboratories consisted of 5 Divisions on the Plain Street site: Agricultural Chemistry; Food, Drug, Toxicology and Industrial Hygiene; Industrial Chemistry; Mineral; and Water Divisions, at Bentley, Engineering Chemistry Division and at Kalgoorlie the Kalgoorlie Metallurgical Laboratory. These Divisions with the Library, Office and Administration are under the control of the Director (Government Mineralogist, Analyst and Chemist) as follows:

Director—R. C. Gorman, B.Sc., M.A.I.A.S., F.R.A.C.I.

Deputy Director—H. C. Hughes, B.Sc., M.A.I.A.S., A.R.A.C.I.

Agricultural Chemistry Division—J. Jago, B.Sc., A.R.A.C.I. Chief of Division.

Engineering Chemistry Division—B. A. Goodheart, B.Sc., M.I.E. Aust., A.R.A.C.I., A.M. Aust. I.M.M. Chief of Division.

Food, Drug, Toxicology & Industrial Hygiene Division—Vacant.

Industrial Chemistry Division—E. B. J. Smith, B.Sc., D.Phil., M.A.I.A.S., A.R.I.C., A.R.A.C.I., A.P.I.A., Chief of Division.

Kalgoorlie Metallurgical Laboratory—G. H. Muskett, A.W.A.S.M., M. Aust. I.M.M., Officer in Charge.

Mineral Division—D. Burns, B.A., B.Sc., A.R.A.C.I., Chief of Division.

Water Division—N. Platell, B.Sc., A.R.A.C.I. Chief of Division.

Office—R. W. Fryer, Senior Clerk.

Librarian—J. Bryant, B.Sc., Dip. Ed., Dip. Lib.

The close association of these Laboratories with respect to service, research and advice to other Government Departments and kindred organisations was maintained and extended during 1975. A continuing effort was made during the year to extend the value of our assistance to other departments beyond supplying only an analytical service but in also providing a fully professional advisory and consultative service.

A number of staff have served as members of over 30 various statutory, official and ad-hoc inter departmental and professional committees during the year. Many of these committees especially the Food & Drug Advisory Committee, Laporte Effluent Disposal Committee, Pesticides Advisory Committee, Swan River Conservation Board and Water Purity Advisory Committee have been time consuming not only in attendance at meetings but also in preparation of advice for the various committees.

The committees on which staff have served cover a wide range of interests and scientific disciplines and the value of a centralised laboratory service has been repeatedly demonstrated through these committees, in the co-ordination and cross communication of information on work being done by the breadth of the activities of these Laboratories.

Because of the increasing volume and type of work carried out by the Food, Drug, Toxicology and Industrial Hygiene Division it has been necessary to obtain Public Service Board approval for the splitting of this Division into two new Divisions. From the beginning of 1976, there will be a Food and Industrial Hygiene Division primarily concerned with work for the Public Health Department and a Toxicology and Drug Division primarily concerned with forensic work for the Police Department. This will allow greater specialisation by the officers concerned and improved efficiency to the client Departments. Until some minor building additions can be obtained these two Divisions will operate from separate ends of the old combined Division with a number of facilities used by both.

In the early part of the year a major review of the Road Traffic (Breath Analysis) Regulations was made in co-operation with the Road Traffic Authority and the Crown Law Department. The implementation of these and the new Road Traffic (Blood Sampling and Analysis) Regulations as from 1 June, 1975 had some initial teething problems. These were all rapidly sorted out and both sets of Regulations are operating satisfactorily and requiring less time in Court by officers of these Laboratories.

Staff:

The total number of staff has increased by only one since 1973. This one position was not a direct allocation to us, but was a result of objections made to the Public Service Board of duplication of our function by another Department and the transfer of a position created there to these Laboratories. The tentative approval for 3 new staff in 1974-5 never eventuated and the effect of staff growth restriction is having an escalating effect on the efficiency of our service. With no control over the work load submitted by any of the numerous Departments we serve, staff restrictions have necessitated increased time being spent on service work and less on research and development areas. Without a proportionate part of officers' time spent on investigation work, the value of our service and advisory and consultative service will inevitably decrease.

There have been a number of staff changes and retirements during the year. Mr. N. R. Houghton retired from the position of Chief of the Food, Drug, Toxicology and Industrial Hygiene Division after occupying that position for 20 years and after a total of 36 years in these Laboratories. Mr. G. H. Payne retired from the position of Chief, Mineral Division after 18 years in that position and after 24 years in the Laboratories. Both these officers have contributed greatly in their long years of service and their retirement means the loss to us of many years of very valuable experience.

Mr. D. Burns was promoted to Chief of Mineral Division and Mr. S. C. Baseden was appointed as Assistant Chief of the Agricultural Chemistry Division.

There have been a number of conferences, seminars and in-service training courses attended by staff during the year. The attendance at these is vital for both staff training and keeping abreast with scientific developments. Because of financial restrictions there has been pressure on us to reduce attendance at out-of-State conferences. Because of the scientific isolation of this State such a policy inflexibly applied would lead to a severe depreciation of scientific service to State Departments. The expenditure on scientific visits and conferences by these Laboratories is a very minor proportion of our overall expenditure and any reduction would be a false economy.

Library

The continued growth of the Library has required a reorganisation of storage, classification and culling of our books, journals, pamphlets and index catalogues. During the year, 3 066 new items were added, consisting of 323 monographs, 2 294 journal issues and 449 official publications. A further three new journal titles were added to our collection and one was discontinued.

Building

Building alterations and additions required by the Water Division for the Australian Water Resources Council National Survey did not eventuate. This was because of a further delay in the decision to proceed with this major project because of financial restrictions.

The lack of additional pilot plant and storage space for the Engineering Chemistry Division at Bentley continues to hamper the operation of that Division.

A further respite has been given in the need for the re-building of the Kalgoorlie Metallurgical Laboratory. Because of the financial position of the School of Mines with respect to Commonwealth Government funds and the indecision on the future of the School of Mines there is no immediate requirement by the School of Mines for the site occupied by the Kalgoorlie Metallurgical Laboratory. However once this site is required, there will be an urgent need to rebuild the Metallurgical Laboratory. Because of the expense involved a serious review of the future and function of the Metallurgical Laboratory will be needed before such expense will be justified.

Building alterations of four rooms in the Agricultural Chemistry Division, to house the computer and reorganisation of equipment in the Division for linkage to the computer should be completed early in 1976.

Long term planning with respect to the Plain Street site and future of building on the site has been commenced.

Equipment

The main major piece of equipment received this year was a Digital PDP 11/40 computer which will be linked with X-ray fluorescence, gas chromatography, amino acid analyser and atomic-absorption spectrophotometer equipment in four Divisions. By combining with the Mapping and Survey Branch of Mines Department, a larger memory and capacity computer was obtained, which will be of added benefit to both Branches of the Department at no additional cost.

Additional equipment obtained included Orion specific ion meter, Varian spectrophotometer, Pye-Unicam spectrophotometer, Sharp electronic calculator, Canon programmable calculator, Leeds & Northrop multipoint chart recorder, voltage stabiliser, Cyclosizer and a Dynavac freeze drier.

General

Fortunately the large increase in samples received in 1974 did not continue this year or it would not have been possible to cope. There was a decrease of 8 per cent in samples received compared with 1974 but this is still an appreciable increase on 1973 with no corresponding increase in staff. The reduced number of samples occurred primarily in the Agricultural Chemistry and Mineral Divisions. The number of samples is of course only a rough guide to the work received as some samples may only require a simple single determination while others may require several months of investigational work.

The number and source of samples and their allocation to various Divisions is given in Table 1. The total numbers shown in Table 1 is less than that given by the sum of the total samples for all Divisions given in their individual reports. This is because in many cases samples or investigations are allocated to two or more Divisions because of the complexity of the work requiring the knowledge and experience of specialists in more than one Division.

TABLE 1

SOURCE AND ALLOCATION OF SAMPLES RECEIVED DURING 1975

Source	Division						Total
	Agricultural Chemistry	Engineering Chemistry	Food and Drug	Industrial Chemistry	Mineral	Water	
STATE—							
Aboriginal Affairs Authority	....	....	....	....	5	....	5
Agriculture Department	10 564	....	338	....	....	21	10 923
Community Welfare Department	....	....	....	....	....	3	3
Consumer Affairs Bureau	....	....	5	....	2	2	9
Crown Law Department	....	....	5	....	....	....	5
Department of Corrections	....	....	1	....	....	....	1
Department of Environmental Protection	2	....	....	....	56	124	182
Department of Industrial Development	3	....	....	24	1	4	32
Education Department	28	....	3	....	....	....	31
Fisheries and Wildlife Department	....	....	243	....	....	98	341
Geological Survey	....	1	1	....	332	156	490
Government Chemical Laboratories	1	48	48	12	167	38	314
Government Stores Department	....	....	46	....	....	....	46
Harbour and Light Department	....	....	....	6	....	....	6
Labour and Industry Department	....	....	128	4	....	....	132
Lands and Surveys Department	....	....	....	1	....	....	1
Leschenault Inlet Advisory Committee	....	....	....	....	....	40	40
Main Roads Department	....	....	3	1	....	7	11
Medical Department	....	....	....	....	7	....	7
Metropolitan Water Board	....	3	2	4	2	2 816	2 827
Mines Department	....	....	1	....	364	....	365
Office of the North West	1	7	....	....	2	....	10
Peel Inlet Advisory Committee	11	....	....	....	....	87	98
Police Department	....	....	2 083	....	22	....	2 105
Public Health Department	501	1	2 162	12	1 073	55	3 804
Public Works Department	....	....	256	75	27	1 951	2 309
Road Traffic Authority	....	....	568	....	2	....	570
State Energy Commission	....	2	....	4	2	....	8
State Housing Commission	....	....	....	2	8	1	11
Swan River Conservation Board	....	....	....	....	....	520	520
Tender Board of W.A.	....	....	....	89	....	....	89
W.A. Fire Brigades Board	....	....	....	....	....	1	1
W.A. Museum	....	....	....	....	2	....	2
COMMONWEALTH—							
Various Departments	....	....	9	....	1	3	13
PUBLIC—							
Free	3	....	1	....	33	8	45
Pay	79	175	1 168	21	441	500	2 384
TOTAL	11 193	237	7 071	255	2 549	6 435	27 740

The summarised reports of the individual Divisions which follow, emphasise the range of subjects dealt with by the Laboratories. They also show their increasing involvement in ecological, environmental and consumer protection matters in addition to the more traditional subjects. As a consequence of this, officers of the Laboratories are making a fuller professional contribution to these fields rather than purely a service one of supplying analytical data. The greater involvement by staff in the entire problem presented to us and the direct contribution they are making is resulting in far greater job satisfaction besides providing a more valuable and useful scientific service to the State.

R. C. GORMAN,
Director.

AGRICULTURAL CHEMISTRY DIVISION.

General

As usual most of the year's work was related to applied and basic experimental agriculture embracing the fields of plant nutrition, crop production, soil fertility and animal health, but the involvement in environmental studies which has developed in recent years was maintained.

A significant step toward provision of information to aid the efficient production of food protein, of which there is a world shortage, was the data obtained on amino acid composition of plant and animal proteins by instrumental methods of analysis.

The phosphorus status of soils was examined in a joint project with the Department of Agriculture, designed to improve the efficiency of using phosphatic fertilisers in W.A.

In addition to coping with a variety of work, the back-log remaining from the previous year was reduced. This could not have been achieved without the continued co-operation of the staff, and assistance from technical officers on loan from the administration section with work in the main laboratory and in the sample preparation section.

It was the more commendable in view of the disruption of the Division's operations caused by the decision to locate the Laboratories' computer in the Division. Building alterations, and installation of electrical services and air-conditioning were necessary to convert a balance room to house the computer and ancillaries. The opportunity was taken to refurbish three adjacent rooms to accommodate instruments which are to be linked to the computer, and the resulting building activity and associated dust and noise resulted in a major upheaval in staff accommodation and work areas. These conditions prevailed for the latter half of the year and were reminiscent of the makeshift operations following the fire of early 1972.

Investigational work was again restricted and unless additional staff can be obtained it is difficult to see a solution either to this unsatisfactory situation, or to the reduction of the amount of work oustanding.

The programme of lectures promoted in the Division is an important aspect of staff training and was resumed, after a lapse in 1974. One invited speaker and seven members of the Division spoke on topics related to our work.

Liaison with other departments and organisations was actively encouraged to allow staff to become more acquainted with the increasing amount of novel investigations with which we are associated.

Nature of Samples

The Department of Agriculture contributed most towards the total of 11 210 samples received. The nature and sources of work are shown in Table 2.

The total receivals was 2 650 less than in 1974 but showed a continuation of the sudden increase in work compared with the average number of samples (7 300) for the five-year period 1969 to 1973 noted in our Annual Report 1974. At the end of the year 5 300 samples remained outstanding compared with 7 300 at the beginning of the year, and meant that the number of samples dealt with during 1975 was greater than receivals.

TABLE 2
AGRICULTURAL CHEMISTRY DIVISION

	Agriculture Department	Education Department	Pay	Peel Inlet/ Harvey Estuary	Public Health Department	Other	Total
ANIMAL—							
Bone	49	....	....	....	....	....	49
Fat	70	....	....	....	....	....	70
Kidney	12	....	....	....	....	....	12
Liver	126	....	....	....	....	....	126
Minced meat	591	....	....	....	....	....	591
Tissue	13	....	....	....	....	....	13
Urine	174	....	1	....	....	....	175
Viscera	50	....	....	....	....	....	50
Various	8	....	2	....	....	....	10
CEREAL—							
Barley	42	....	....	....	....	....	42
Maize	117	....	....	....	....	....	117
Oats	70	....	1	....	....	....	71
Wheat	1 385	....	7	....	....	....	1 392
Various	1	....	....	....	....	1	2
FERTILISER—							
Fertiliser (Act)	68	....	....	....	....	....	68
Various	15	....	11	....	....	4	30
HORTICULTURE—							
Apple leaves	699	....	....	....	....	....	699
Cauliflower	20	....	....	....	....	....	20
Citrus leaves	48	....	....	....	....	....	48
Grapevine leaves	217	....	....	....	....	....	217
Orange leaves	173	....	....	....	....	....	173
Peach leaves	46	....	....	....	....	....	46
Plant tops	34	....	....	....	....	....	34
Potato plant tops	28	....	....	....	....	....	28
Tomato tissue	10	....	....	....	....	....	10
Various	25	....	....	....	....	....	25
MISCELLANEOUS—							
Filter paper	....	....	....	....	316	....	316
Human viscera	....	....	....	....	177	....	177
Sediment	....	....	....	11	....	....	11
Silage	35	....	....	....	....	....	35
Various	25	....	4	....	2	12	43
PASTURE AND FODDER—							
Broiler feed	21	....	....	....	....	....	21
Clover	71	....	....	....	....	....	71
Feeding stuffs	210	23	14	....	....	3	250
Feeding Stuffs Act	100	....	....	....	....	....	100
Hay	779	....	....	....	....	....	779
Kikuyu grass	41	....	....	....	....	....	41
Lucerne	200	....	1	....	....	....	201
Lupins	987	....	1	....	....	11	999
Pangola grass	34	....	....	....	....	....	34
Pasture	1 800	5	2	....	....	....	1 807
Silage	24	....	....	....	....	....	24
Various	17	....	2	....	2	1	22
SOIL—							
Soil	2 129	....	27	....	....	5	2 101
TOTAL	10 564	28	73	11	497	37	11 210

The reduction in total receivals compared with 1974 was almost entirely due to less work on pastures because of the completion of field experiments connected with a three year project to develop a soil test for potassium.

Following are comments on some of the more important aspects of the work done on samples within the listed groups in Table 2.

Soil

Projects to establish or refine data for chemical soil testing, designed to improve the economical use of fertilisers, formed a greater part of the work on soils, although the usual chemical work tracing changes in soil properties cause by a range of different fertiliser and management practices was required.

Interest in soil testing from private farmers was very limited, which indicates that the demand for this type of information is met by private concerns. Agricultural advisers, however, have begun to appreciate that soil tests can be a guide in assessing soil fertility, and requests for analysis of samples for phosphorus, potassium, copper, manganese, zinc and boron extracted by various solutions were received.

In cases where the work is for a farmer, advice is given on the meaning of the results, but he is instructed to discuss our report with his local adviser from the Department of Agriculture who can modify the interpretation of the soil test by consideration and experience of local conditions.

A collection of samples representative of soils in W.A. did not exist until a few years ago, when this Division began retaining samples from various districts and interesting experiments in the State. The collection has grown in size, and because of impending demands on storage space for laboratory purposes, arrangements were made to transfer the samples to the Department of Agriculture where a similar collection has been commenced.

Phosphorus

Recent increases in the price of phosphatic fertilisers have accentuated the need for more precise data from which predictions of the most economic rates of phosphate application to a wide range of crops can be made. The "Decide" model, developed jointly by the Department of Agriculture and C.S.I.R.O., is a significant and unique advance, allowing more reliable and precise predictions of phosphate requirements in the field. "Decide" takes into account a number of factors, including economics, the responsiveness of various soil types, and the phosphate history of farm paddocks.

Work begun in 1974, in collaboration with the Department of Agriculture, was continued and is aimed to provide more reliable estimates of the residual value of past applications of superphosphate and the responsiveness to phosphate additions, of different soil types under different climatic conditions.

In addition to estimates of residual phosphate obtained by extracting soils with 0.5M sodium bicarbonate solution, phosphate absorption data were obtained. From the slope of the absorption isotherms the buffering capacities of the soils were obtained. The buffering capacity or "phosphate fixing capacity", together with climatic factors is used to predict the responsiveness of the soil to addition of phosphate fertiliser.

Nitrogen

Chemical work was begun on samples from a three-year project investigating the feasibility of a soil test for nitrogen. A test for nitrogen which could be used to predict requirements of nitrogenous fertiliser would be useful in situations where a cereal crop was to be sown on land where soil nitrogen had been accumulated by several years of legumes. Evidence seems to indicate that total nitrogen and organic carbon in soil are not sufficiently well correlated with crop responses to be of use, and other soil parameters are being studied.

Nitrogen and organic carbon in topsoils from a grazing trial showed slightly higher levels from plots under Daliak than from plots under Dwalganup or Geraldton clover grazed at the same stocking rate, but there were no differences at another site where serradella and clover were compared, at two different stocking rates.

Fallowing a heavy soil at Merredin gave no change in organic matter content or total nitrogen in topsoils compared with cropping, pasture, early cultivation, and combinations of these practices.

Ammonia nitrogen released by anaerobic incubation of soil revealed differences in fertility of relatively new land after being sown to lupin, serradella, clover and combinations of these legumes. Total nitrogen and organic carbon figures had given no explanation for better yield of cereal crops grown after lupins. Incubatable nitrogen from lupin-clover plots was higher than for each of the other legumes, either alone or in combination, which in turn were about twice the values found in samples of virgin soil.

Other work on nitrogen in soils included:

(a) total nitrogen, to provide data for a computerised study of the crude protein in wheat grown in southern districts;

(b) total nitrogen and organic carbon in samples from a number of sites to provide basic data for future reference for long term trials aimed at tracing soil nitrogen changes under legumes for a following cereal crop;

(c) total nitrogen in samples from the Nullarbor Plain near Eucla, which ranged between 0.05 and 0.32 per cent.

Other

Soil analysis assisted in making recommendations to the Pyrton Training Centre to overcome difficulties in establishing ornamental shrubs and trees.

Iron deficiency causing chlorosis in pastures was not explained by soil properties measured in a glasshouse trial. Analyses were made for aluminium, iron and manganese as total and extractable forms in soil, before and after liming and waterlogging treatments. Iron extracted by 1 M ammonium acetate, pH 4.8, was increased by flooding but not affected by liming, and levels found were similar to those quoted overseas as likely to cause chlorosis only in plants which are very sensitive to iron deficiency. Extractable manganese was decreased by liming and increased by flooding.

Samples collected from field situations in which copper and manganese deficiencies in crops were evident were analysed for copper extracted by ammonium oxalate solution and manganese soluble in water, ammonium acetate and ammonium acetate-hydroquinone solutions, but the results provided little assistance in clarifying the deficiencies.

Boron in hot water extracts of soil from a peanut trial at Kununurra ranged between 0.2 and 0.4 p.p.m. which was sufficiently low to make boron deficiency a possibility.

Organic carbon and mechanical analyses were carried out to determine chemical and physical changes occurring in association with long term soil structure studies at Merredin Research Station.

Animal

An increase of 50 per cent in samples of animal origin compared with the previous year was due mainly to receipt of minced meat samples from investigations of sheep meat quality. Analysis of this material for ash, moisture, fat and protein was carried out to establish the relationship between chemical composition of carcasses, and the amount and distribution of fat in live rams, ewes and wethers of different breeds as predicted by measurements of live weight and tritiated water space. Excellent agreement between the chemical composition of replicate subsamples of individual carcasses showed that the difficult task of sampling such a heterogeneous material was accomplished satisfactorily.

Iodine numbers of samples of fat from pigs confirmed previous findings (Annual Report 1972) that the iodine number increased as the proportion of lupin seed in rations increased. Lupin at 30, 50 and 70 per cent in rations gave mean iodine numbers in fat of 59, 64 and 67. These figures provide an assurance that the feeding of lupins to pigs is unlikely to induce the condition known as 'soft fat', which is associated with iodine numbers of 70 or greater.

Fluoride contents of urine samples were monitored in relation to pig nutrition. Pig rations containing lupin and cereals as protein sources require supplementing with calcium and phosphorus. The cheapest supplement is phosphate rock and Christmas Island rock has been used for many years because it has a lower fluoride content (1.5 per cent or less) than rock from other parts of the world. Some samples analysed in recent years have contained nearer 2 per cent fluoride and this led to trials to measure any effects of increased fluoride intake on pig production.

Two trials in which fluoride concentration in urine was measured in samples taken at intervals as the trials progressed showed that, although higher levels of phosphate rock in rations caused reduced growth rate, the concentration of fluoride in urine was not proportional to levels in the rations. This may have been due to an upset of renal function which apparently caused animals on the higher phosphate rock diet to void greater volumes of urine.

In one trial, urine output from a 1.8 per cent phosphate rock diet was 44 per cent higher than a 1 per cent phosphate rock diet and 29 per cent higher than a nil phosphate rock diet. Fluoride excretion was greatest for the 1 per cent diet, being 4.6 times greater than for the nil rock diet. Phosphorus excretion was similar for both rock diets which were greater than the nil diet. Calcium excretion was lower for the higher rate of phosphate rock, but the difference was not statistically significant. Results are shown in Table 3.

TABLE 3

PIG URINE—EFFECT OF PHOSPHATE ROCK

			per cent			
Phosphate rock in diet	0		1·0		1·8	
			litres			
Urine voided, per 3 days	8·5		7·6		11·0	
			mg per litre			
			in urine, mean values			
Calcium, Ca	140	(1 190)	140	(1 065)	40	(440)
Fluoride, F	4	(35)	20	(150)	9	(100)
Phosphorus, P	570	(4 845)	960	(7 300)	550	(6 050)

Figures in brackets are amounts in milligrams excreted in 3 days.

Mercury analyses in animal tissues are usually carried out on fresh samples as received and reported on a fresh weight basis. It was shown that samples of pig tissues (liver, kidney, muscle) suffered no losses of mercury when oven dried at either 85°C or 104°C overnight. Samples in which other trace elements are required are oven dried and ground for ease of storage, and it is convenient to know that this method of preparation can be used, if necessary, in cases requiring total mercury estimations.

Mercury levels in tissues of four sows were less than 0.02 p.p.m., and may be an important finding in relation to pig breeding. These animals had been fed for six months on experimental rations containing whale products, and were then changed to a diet of meatmeal-cereals for a further six months. Tissue from other animals on the whale-meal rations contained high amounts of mercury as reported previously (Annual Reports 1973, 1974). While it could be expected that the mercury content of muscle tissue could be reduced during the continued growth of the animals on rations free of whale products, it is unusual that the levels of mercury in the livers and kidneys also fell, since mercury is regarded as being cumulative. Other samples examined confirmed that the use of restricted amounts of whale products in rations gave levels of mercury in tissues which would be within acceptable limits for human consumption.

The work on mercury uptake by stock resulted in an amendment to the Feeding Stuffs Act which limits the amount of mercury permitted in pig and poultry feeds to 0.07 p.p.m.

Whalemeal and whale solubles manufactured at Albany by excluding liver and kidneys from the process, contained 6.2 and 2.1 p.p.m. of mercury. These levels are about one quarter less than levels in normal products, in which the viscera are included. The difference is of no significance from a marketing aspect.

Most of the other samples were analysed for either cobalt and selenium in connection with continued experiments on sheep and cattle, or for other major and trace elements (calcium, magnesium, phosphorus, copper, manganese, molybdenum) to assist with diagnosis of disease or nutrition problems for which a continual prompt service was provided.

Human Tissue

Estimation of selenium concentrations in tissues was continued in a study of causes of cot death syndrome. A total of 369 specimens representing 134 cases has been received. Although immunology studies are believed to present the most promising approach to solution of this sad problem, the work on selenium has provided valuable data which will contribute to a better understanding of selenium nutrition in humans.

Chromium was determined in a specimen of synovial fluid in connection with a failure of a metal implant.

Cereal

Wheat

Nearly all the wheat samples received were from nitrogen soil test calibration trials. They were received late and remained outstanding at the end of the year.

Nitrogen content of wheat grain ranged from 1.38 to 5.31 per cent in a glasshouse trial in which nitrogen application was either stopped or commenced at each of 15 stages of growth of the plants from one-shoot stage to milky ripe stage. Lowest nitrogen content in the grain was produced by stopping nutrient supply at the stage when leaf sheaths were erect, and highest levels were obtained by commencing nitrogen addition at the next stage, when the first stem node was visible. Regardless of treatment, and despite the high levels in the grain, the proportion of nitrogen present as non-protein form (soluble in 5 per cent trichloroacetic acid) was constant at about 12 per cent of the total nitrogen and only one to three per cent was present as amide, ammonia and nitrate nitrogen.

Nitrogen uptake by wheat was used to evaluate changes in soil fertility caused by cereal or sweet lupin crops grown in the previous year. In two out of four trials, plots previously sown to lupins produced a higher level of nitrogen in the tops than plots previously sown to cereals.

Oats

Gyplap is a mixture of limestone and effluent from titanium oxide production. It was compared with ferrous sulphate in trials in the Albany district. Yield and colour response of oat tops was better for the ferrous sulphate plots, but there was no difference in concentrations of aluminium, iron, nitrogen or phosporus in the tops. There may have been a slight depression, but not to deficient levels, of manganese content in plants receiving ferrous sulphate.

Urea fertiliser and different seeding rates had no effect on nitrogen content of oat tops or grain in a trial at Avondale.

Ammonium nitrate applied to oats and wheat at up to 120 kg/ha improved nitrogen content of the dry matter only marginally. A wheat and ryegrass mixture showed little residual value of nitrogenous fertilisers applied over a period of 11 years in a continuous cropping experiment.

Oats and wimmera ryegrass mixtures from a hay production trial were checked for crude protein content to evaluate the use of ammonium nitrate fertiliser applied either at seeding or with additional later applications after the crop had been grazed.

Barley

Ammonium nitrate was applied to barley at two rates at sowing and up to eight weeks afterwards at Wongan Hills. There was a close relationship between the protein content of the grain and the rate of fertiliser and the time of deferment of its application. For the whole tops cut earlier, this relationship was true only for the higher rate of fertiliser.

Other work on cereals included:

(a) evaluation of pig and poultry feed constituants for Agricultural High Schools and Medina and Wembley Research Stations. These included barley samples from selected areas which contained 0.008 and 0.034 p.p.m. selenium compared with a control sample containing 0.15 p.p.m.;

(b) certification of export grain shipments for moisture and crude protein;

(c) wheat leaves from Goomalling which were found to contain 6 p.p.m. boron.

Fertiliser

Fertilisers Act

Sixty-eight samples were received compared with 116 received in 1974. Eighty-seven Certificates of Analysis were issued including 36 for samples brought forward from 1974. Deficiencies or excesses were found in 34 (39 per cent) of the samples examined. Individual deficiencies (47) and excesses (3) were relatively fewer than in samples examined in 1974. The three excesses were in respect of phosphorus in each case and were accompanied by deficiencies in nitrogen and/or potassium, indicating either poor mixing during manufacture or segregation before packaging.

Samples of superphosphate, gypsum, limestone and phosphate rock were evaluated before use in field trials or for private individuals who required checks on alleged composition. Pig excreta and dairy effluent were analysed for fertiliser value.

Feeding Stuffs

Feeding Stuffs Act

One hundred samples were received compared with 134 in 1974. Certificates of Analysis were issued for 140 samples examined, including 56 brought forward from 1974. Excesses or deficiencies were found in 109 (70 per cent) of the samples examined. Deficiencies were due to crude protein (47 cases), calcium (20 cases), crude fat (18 cases), phosphorus (15 cases) and sodium chloride (12 cases). Excesses were due to crude fat (32 cases), sodium chloride (24 cases), crude fibre and phosphorus (23 cases each), and calcium (13 cases).

Mixed Feed

Amino acids

Lack of information of the amino acid composition of local feed materials such as cereal and legume grains, meatmeal and fishmeal has been very frustrating for animal nutritionists, because the correct balance of amino acids in pig and poultry rations is important for optimum production of meat protein. This lack of information is due to the extremely time-consuming and tedius nature of manual methods of amino acid analysis, and has led to the use of data extrapolated from overseas.

The Divisions's Beckman instrument which was occupied for most of 1974 in carrying out calibration tests, provided long-awaited amino acid analyses of mixed feeds for experimental work.

Individual feed constituents were analysed for amino acid composition so that this could be taken into account when calculating the nutritional value of mixed feeds and the requirement for added synthetic amino acids. Detail of some analytical results is given in the section headed Lupin Grain. A survey of the protein quality of meatmeals was commenced.

The usual proximate analyses were provided for experimental rations at Research Stations and Agricultural High Schools. A gas chromatographic method for determination of linoleic acid in feeds was established.

Horticulture

The work was mainly a continuation of surveys of nutrient levels in leaves of apple and citrus trees and grapevines.

Experiments located at Stoneville and Manjimup Research Stations and growers' properties investigated fertiliser treatments, rootstock selection, soil management practices and foliar spray nutrition of apples. Zinc in apple leaves from one experiment ranged from 19 to 30 p.p.m. dry basis, but neither sprays at dormancy or post harvest, nor soil applications of zinc were effective in correcting zinc deficiency symptoms. Another experiment comparing times and rates of spraying increased zinc content of leaves from 13 p.p.m. in controls to 40 and 70 p.p.m. by spraying 0.1 or 0.2 per cent zinc in spring.

Citrus leaves were analysed for calcium, nitrogen, phosphorns and potassium to assess fertiliser effectiveness in a large trial at Stoneville Research Station.

Grapevine leaves separated into blades and petioles were received in increasing numbers for nutritional studies, including a detailed trial at Frankland River where severe potassium deficiencies were detected. Other vine nutrition problems were mainly confined to the sandy soils near Wanneroo and Mooliabeenie where potassium deficiency was diagnosed. Over-zealous use of potassium chloride fertiliser on another property induced chloride toxicity problems.

Peach leaves analysed in connection with an urgent investigation of decline of canning peach varieties showed that nutritional disorders were not involved.

Pineapple leaves from Carnarvon Research Station and ornamental palm leaves from a nursery in the metropolitan area were analysed to assist in finding reasons for poor growth.

Peanut leaves and shells were received from Kununurra. Chemical analysis revealed a complex situation from which it was too difficult to draw any conclusions about the nutrient status of the crop.

Vegetable

Cauliflower leaves showed no chemical explanation for tip burn, either in metropolitan gardens or at Manjimup. Cabbages treated with a combination of nitrogen, phosphorus and potassium fertilisers were analysed for those elements. Potato tops from the Bunbury area were analysed for potassium to assist in establishing a diagnostic tissue test. A nutrient solution and samples of tomato leaves were checked for calcium content regarding an occurrence of blossom-end rot in glasshouse plants.

Pasture, Hay and Fodder Crops

About one third of the total number of samples received by the Division were plant samples falling into this category. Much of the work carried out was on samples outstanding from the previous year arising from short and long term experiments, and is based on chemical analysis for nitrogen, phosphorus, potassium and sodium. In certain districts information on calcium, magnesium, sulphur and trace elements cobalt, copper, selenium and zinc content of pastures is necessary. The amount of effort spent in manually transcribing the chemical data and the associated field data necessary for sensible interpretation of the results, has increased enormously in the years 1974 and 1975. The rate of output of data has increased since most of the chemical work is done by automated instruments and this has aggravated the problem. A standard form used for recording data for sample receival relieved the position but the layout of the form is capable of improvement. Resolution of the problem has assumed greater urgency since the instrument outputs are to be linked to computer.

The experiments concerned with this aspect of agriculture were mainly in the dairy and beef producing areas of the State and included:

Pasture

(a) Pasture trials for calibration of a soil test for potassium. Pasture was separated into clover, grass and weed components and calcium, magnesium and potassium contents were obtained. The data was included in statistical analysis of the trials by computer at the Department of Agriculture. A noticeable effect was that as rates of potassium fertiliser were increased from 0 to 300 kg/ha, the nitrogen content of clover decreased, especially for later cuts. The effect was less obvious for grass.

(b) Ill thrift in dairy cattle in the lower South West and South Coastal areas. Cattle lose weight in autumn and a suggested cause is a fungus growing on kikuyu grass. Monitoring of kikuyu pastures which had been sprayed with a broad-spectrum fungicidal spray was introduced to ensure that nutritional deficiencies were not involved. Copper levels were relatively high (greater than 10 p.p.m.) in some May and June cuts.

In another trial investigating "ill thrift", samples of pasture had very low levels of cobalt, eight out of a batch of ten samples having less than 0.03 p.p.m.

(c) A time of calving and stocking rate trial, and a long term trial investigating cobalt deficiency in cattle at Denmark Research Station. The latter trial has had regular analyses for major and trace elements, the majority of which have been at adequate levels in pasture samples. Selenium concentrations, however, have been consistently low for several years and it is the rule rather than the exception to find selenium concentrations of 0.01 p.p.m. dry basis.

(d) Evaluation of nitrogenous fertiliser usage on pasture in the Armadale district. Samples were separated into clover, grass and weeds (mostly capeweed) and examined for total nitrogen and nitrate nitrogen. Details of the experiment and results of intensive soil sampling and analysis were presented in the Annual Report for 1974.

The first harvest showed that increased fertiliser caused increased total and nitrate nitrogen in the pasture. Clover contained more total nitrogen than grass, which contained more than capeweed. Capeweed had higher nitrate nitrogen than grass. Later cuts showed that nitrogen concentration in the pasture decreased with age of the plants, probably due to a combination of growth effects and depletion of soil nitrogen. At 10 weeks after application of fertiliser, the treatment effects on nitrogen concentrations in the pasture were no longer evident, but clover contained more nitrogen than capeweed which contained more nitrogen than grass.

The experiment showed that, in the existing economic circumstances, the use of nitrogenous fertilisers on dairy pastures is not advisable, since the fertiliser caused a decrease in the clover content of the pasture and the yield increase did not outweigh the cost of the added fertiliser.

(e) An attempt at establishing irrigated pasture on a sand-covering up to 15 cm thick over intractable saline soil in the Dardanup area. Kikuyu, paspalum and rye grasses containing up to 5.6 per cent of chloride were produced, although reasonable pastures were grown on the 15 cm depth of sand, and these plants contained the lowest levels of sodium. The salt could have arisen from the underlying clay soil or the irrigation water, which is recirculated in the area.

(f) Response to sulphur fertiliser at Kelmscott, which produced pasture having 0.22 per cent sulphur from treatment with ferrous sulphate, and a deficient level of 0.12 per cent without.

(g) Pasture samples from a trial comparing the value of a commercial liquid fertiliser (Liquiphos) with superphosphate. The liquid fertiliser cost about 10 times as much as superphosphate on a unit phosphorus basis. Superphosphate applied at a rate equivalent to one quarter of the cost of the liquid gave equal or higher concentration of phosphorus in the pasture dry matter.

Hay

(h) Hay quality surveys requiring values for produce made on farmers' properties as a general check on quality, and more intensive studies of samples taken prior to cutting and after baling to assess changes in quality and losses during production.

(i) Methods of haymaking and other means of fodder conservation such as the mechanical method using the American "Stack Hand" machine, baling or fodder roll storage methods. A trial at Denmark Research Station showed no differences in nitrogen, calcium, magnesium, phosphorus, potassium or sodium content of hay produced by fast drying times, cutting with reciprocal mower, tedding, windrowing and various combinations of the treatments.

(j) Oaten hay produced at Kununurra and harvested at different stages of maturity, analysed for crude protein and crude fibre in anticipation of sale to a Japanese buyer.

Clover

Very few samples were received. These were from particular problem areas where soil infertility was suspected of inducing plant nutrient deficiencies. Results of interest were copper determinations in sub-clover and naturalised legumes from old copper fertiliser trials commenced in 1967 and to which no copper had been applied since. Sub-clover from plots on a Mungite loam which had originally received 4.4 kg/ha of bluestone, and which still showed large growth response, had a mean of 6.6 p.p.m. copper compared with 3.0 p.p.m. from control plots. The corresponding levels on Forest Grove gravelly sand were 5.3 p.p.m. and 1.9 p.p.m. copper. At both sites the naturalised legumes contained similar concentrations of copper, 6.0 and 6.5 p.p.m. for fertilised plots and 2.6 and 2.2 p.p.m. for controls.

Grass

Pangola grass, kikuyu and paspalum had fairly similar levels of potassium but pangola grass had levels of sodium between 0.41 and 1.46 per cent, which was higher than paspalum (0.15 and 1.32 per cent) and kikuyu (0.12 and 0.79 per cent).

A trial with ryegrass measured the effects of nitrogen fertiliser in terms of milk production and chemical composition, and other samples came from a trial comparing the value of four varieties of kikuyu grass as dairy pasture.

Lucerne

Samples came from a number of production studies located at different centres in which it was shown that at a Donnybrook property irrigated lucerne had lower crude protein (21.5 per cent) than dryland lucerne (26.5 per cent), and that effects of fertilisers were negligible in comparison with irrigation effects.

Selenium in lucerne from Manjimup Research Station was at marginal level for good animal health (0.08 p.p.m.). These samples were submitted in relation to poor growth of animals in the district.

Other samples came from diseased and healthy plants at Medina Research Station, and from Harvey where a trial comparing rates of potassium chloride fertiliser showed no differences in levels of nitrogen, phosphorus, sulphur, iron or manganese.

Lupin Plant

Although some varieties of lupin grow wild in W.A. the growing of sweet lupin crops is not free of problems and a major one is the occurrence of split seeds which can reduce yields by 75 per cent.

Manganese requirements of lupin plants are important in relation to the split seed problem and resulted in many trials in the Moora district involving applications of manganese fertiliser either sown with seed or as foliar sprays or combinations of both. Leaves, petioles and inflorescences sampled at various stages of growth were analysed separately and results are summarised below.

(a) Manganese sulphate applied as a spray to the soil at 20 kg/ha gave no increase in manganese content of the plant parts, which in two experiments averaged 4 or 6 p.p.m. in dry matter for inflorescences, 9 or 12 p.p.m. in petioles and 20 or 80 p.pm. in first or second leaves.

(b) Foliar sprays had no effect on manganese content of any of the parts of the plants. Sprays were applied at concentrations of 4 and 8 per cent manganese sulphate at intervals up to 12 weeks after germination of the plants.

(c) Manganese content of lupin tops was raised from 30 p.p.m. in dry matter for nil treatment, to 180 p.p.m. and 310 p.p.m. by drilling 15 kg/ha or 30 kg/ha of manganese sulphate with the seed. Spray applications in the same experiment had no corresponding effect, and confirmed results elsewhere which indicated that foliar sprays for manganese uptake are effective only in cooler, southern districts such as Esperance.

Cobalt in tops was increased by applications of cobalt sulphate either top dressed or drilled, but only where nil treatments were low (0.05 p.p.m.). Copper and zinc fertilisers had no effect on levels of these elements in tops.

Potassium nutrition of lupins in the Eneabba district was evaluated from analysis of plant parts and measurement of dry matter and grain yield. The critical levels estimated for diagnosing deficiency of potassium showed good agreement between the criteria used as shown in Table 4. The best indicator was the first fully formed young leaf and this is the most convenient to sample in the field.

TABLE 4

POTASSIUM IN LUPIN—CRITICAL LEVELS

Part of plant	Critical Level of Potassium per cent dry basis A	B
Leaf, old	0·38	0·44
young	0·95	1·02
Petiole, old	0·35	0·53
young	0·82	1·05
Tips	1·50	1·68

A = based on dry matter yield.
B = based on grain yield.

There was neither an effect on potassium content of grain nor any differences in levels of potassium, nitrogen and manganese in tops of good and poor growth in an experiment at Bolgart. It appeared that fertiliser rates had been too low to correct a soil potassium deficiency.

Lupin Seed

Chemical Composition

Lupin is an important crop which can help to satisfy the heavy world demand for additional protein. Lupin seed production is increasingly important to W.A. both as a stock food and because of its potential use as a human food. Much interest is centred around the quality of the protein, and the chemical composition of lupin products. To assist with marketing, work was carried out on locally produced seed for the Grain Pool of W.A. including the determination of proximate constituents, gross energy value, major and trace elements, fatty acids, free fatty acids and iodine value of the oil, sugar and starch, urease and lipoxidase activities, and amino acids.

Products prepared from lupin seed for the Department of Industrial Development by Industrial Chemistry Division were analysed to allow evaluation of the processes employed.

The Laboratories are represented on the Lupin Seed Technology Committee which was established to co-ordinate research in these areas. This research is conducted in co-operation with other organisations such as the Western Australian Institute of Technology and the Department of Agriculture.

Amino acids

The importance to nutritionists of a knowledge of amino acid composition of food proteins has been mentioned in the section headed Feeding Stuffs. In view of the increasing use of lupins as a feed constituent the amino acid composition of four cultivars of sweet upin seed was determined. The results are shown in Table 5.

TABLE 5

AMINO ACIDS IN SWEET LUPINS

Cultivar	Uniwhite	Uniharvest	Unicrop	L. albus
		per cent		
Moisture	10·0	10·1	10·0	11·2
Crude protein (N x 6·25)	31·0	30·6	33·6	36·8
Amino acids				
Aspartic acid	3·86	3·62	4·14	4·23
Threonine	1·04	1·03	1·11	1·31
Serine	1·70	1·71	1·90	1·96
Glutamic acid	8·72	9·01	9·54	9·35
Glycine	1·35	1·27	1·42	1·48
Alanine	1·03	0·96	0·90	1·17
Cystine	0·39	0·42	0·36	0·50
Valine	1·33	1·25	1·50	1·50
Methionine	0·18	0·17	0·17	0·21
Isoleucine	1·12	1·09	1·15	1·61
Leucine	2·10	2·09	2·19	2·72
Tyrosine	1·25	1·14	1·28	1·71
Phenylalanine	1·19	1·13	1·26	1·29
Lysine	1·34	1·31	1·21	1·63
Histidine	0·69	0·69	0·74	0·73
Arginine	3·41	3·16	3·63	4·20

Arginine

Russian workers reported that when alkaloid biosynthesis is stopped (or reduced as in sweet lupins) the content of arginine increases. Samples of seeds of five sweet and three bitter varieties grown in Moora, Albany or Esperance districts confirmed that arginine in the protein of sweet varieties is higher than in bitter, but there was no relationship with incidence of split seeds. Results of mean values are shown in Table 6.

TABLE 6

ARGININE IN LUPIN SEED

District	Albany		Esperance		Moora	
			per cent			
Split seed incidence	20		70		90	
Variety	sweet	bitter	sweet	bitter	sweet	bitter
			g per 16 g of N			
Arginine	9·9	9·5	11·4	10·4	11·4	10·4

Maize

Maize planted at Bunbury in November had half the nitrogen content of plantings made at Harvey at the same time, when both sites were sampled in mid-January. By mid-February the plants at Harvey had nitrogen levels which had fallen to half the values found in January.

Native Pasture

Increased attention to rangeland management in the pastoral areas of the State was responsible for a steady flow of work for measurement of feeding value of annuals, perennials and herbs indigenous to the North-West. Whereas in previous years crude protein determinations were sufficient to differentiate feeding value, more information is now required and trace elements and major elements are determined in a greater proportion of the samples. Some difficulty was encountered in the determination of cobalt in birdwood grass having a high ash content.

At Drysdale River Station a fertiliser trial on Stylosanthes, grass and other species, gave low levels of nitrogen in S. hamata at two sites on yellow lateric and red earth soils. On Pago sand, levels were more satisfactory. Phosphorus in dry matter was low (0.04 to 0.09 per cent) on all soils, and fertiliser rate had no effect. It would have to be corrected for grazing stock which require levels of 10 to 20 times greater to maintain condition. The ratio of calcium to phosphorus was also higher than the desired ratio of 3 to 1. The calcium-phosphorus relationship is common to S. humulis in the Northern Territory.

Silage

Quality of silage made by different methods was compared. At Bramley Research Station the lactic acid content, indicative of silage quality, was higher in samples from conventionally prepared material than in formic acid treated material, although the dry matter and mineral constituents were very similar.

Formic acid sprayed onto green material as it was cut for preparation, made no difference to the chemical composition of the silage, compared with conventional methods.

Covered stacks gave a product with higher available crude protein than uncovered stacks when in vitro digestibility of samples was taken into account. Pastures, and hay and silage prepared from the same materials were compared for feed value with residues of the cut material left to die off naturally on plots treated with potassium fertiliser, with or without gypsum. Advantages of conservation were clearly demonstrated.

Environmental

Filter papers impregnated with lime before exposure to the atmosphere in a vineyard at Middle Swan, and grapevine leaves from the same area were analysed for fluoride content to monitor emissions from nearby brickworks. This exercise was run in conjunction with the Departments of Agriculture and Public Health and was not completed at the end of the year. Early indications were that fluoride content of papers and leaves correlated well, and the values will be related to hourly measurements of fluoride concentrations in the air, and weather conditions.

Sediments from the bottom of the estuary of Peel Inlet were examined to establish whether nutrients were present which could contribute to the recent increase in growth of algae in the waters of the estuary. The concentrations of nitrogen and phosphorus found in the sediments were of the same order as in topsoils of the Pinjarra Plain and adjacent Dune system, and were of low nutrient status as classified by workers overseas.

Miscellaneous

Fruit fly bait which had lost its effectiveness was checked for crude protein content.

A sample of 'All-bran' was checked for fibre content for the Diet Therapy Department, Perth Medical Centre.

Crayfish shells were treated to separate protein and mineral material from the polysaccharide chitin. This material has industrial uses. The yield of chitin was disappointingly low.

Cooking margarine was examined for fatty acid composition to determine whether the product had the required proportions of beef fat and vegetable oil.

ENGINEERING CHEMISTRY DIVISION

The main activities of the Division remained unchanged in 1975 and centred on a core of several major research projects.

There was a consistent demand from industrial and mining companies and Government Departments for a wide variety of testwork. The results of these sponsored investigations, which were carried out at both laboratory and pilot plant level, remain confidential to the client.

Additionally, progress was maintained on selected Departmental projects in which the general aim was to achieve results and information of overall interest to industry and of probable long term benefit to the State.

Equipment

Among major items acquired during the year were the following:

a stainless steel grinding mill; a portable multi-point chart recorder for monitoring output signals from the rotary kiln control system; a Cyclosizer unit for wet classification of fine particles in the sub-sieve range of approximately 10 to 50 micrometre; a Canon Canola SX100 programmable calculator.

Investigational Projects

Utilisation of Western Australian diatomite deposits

Diatomite is a material of sedimentary origin, consisting mainly of an accumulation of skeletal remains of the silica shells of diatoms, which are single celled microscopic plants related to algae. Processed diatomite has a number of unique physical properties and this has resulted in diversified industrial utilisation.

The Australian consumption rate of diatomaceous earth products is of the order of 12 000 tonnes per annum, with a projected rate of increase of the order of 5 per cent. Filter aid usage (for example in swimming pools) accounts for much of this consumption. Australian requirements have largely been met by importing expensive purified diatomite—principally from the United States. In more recent years, exploration and development groups have shown significant interest in the Western Australian deposits and against this background in 1972, the Engineering Chemistry Division commenced an evaluation of the technology for development of typical Western Australian deposits.

Diatomite is normally subjected to a refining process before marketing. This comprises a sequence of operations, which may include crushing, drying, classifying and calcining. Three basic types of refined product are produced—one "natural" grade without calcining and the other two either straight (without flux addition) or flux calcined.

Flux calcined is the most important of these grades and the growth of the diatomite industry has been closely allied to the development of flux calcined filter aid grades for specialised applications.

The testwork carried out by the Division was initially directed to a wide range of samples originating from the better known of the scattered sources along the western coastal margin of the State from Dongara in the north through to Jandakot, south of Perth.

Laboratory and pilot plant evaluation and processing trials have been carried out and have provided base line data for an overall assessment.

In general, Western Australian diatomite deposits vary considerably in quality and are influenced by the proportion of impurities present and the size, type and proportion of contained genera.

The majority of occurrences are in thin, shallow lens-type deposits and recovery of high quality filter aid grade products from suitable head material is likely to be in the 30 to 70 per cent range on a dried ore basis. Moisture levels associated with typical occurrences are usually in excess of 25 per cent.

The experimental programme has confirmed that the better quality head materials can be upgraded by straight and flux calcination and associated processing to the equivalent of premium grade imported products.

Economic assessments have shown that the viability of commercial production from Western Australian resources could hinge on the marketing of a diversified range of products and acquisition of extensive export markets to enable a production output of the order of 25 000 tonnes per annum.

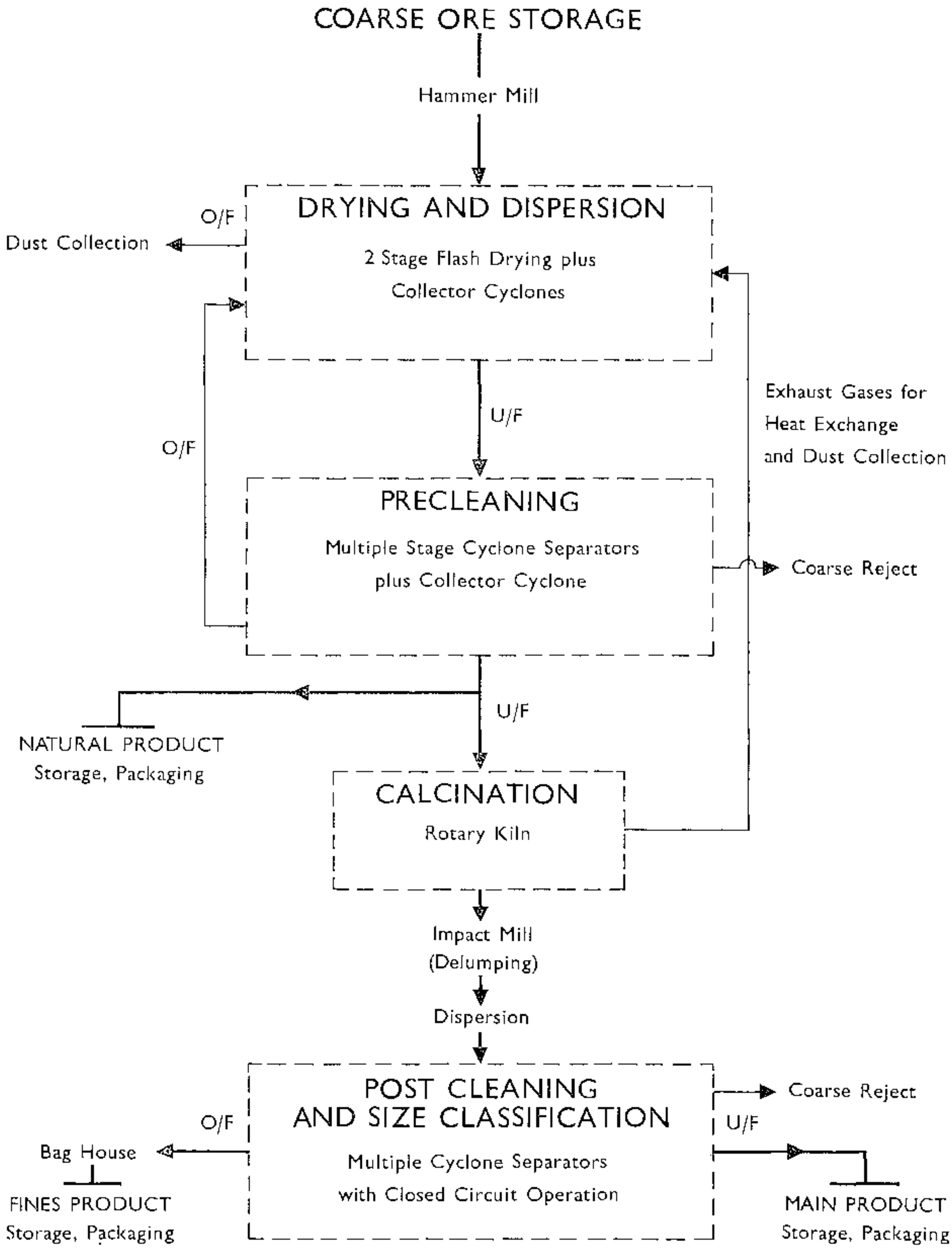
A schematic flowsheet for a predicted process for treatment and refining of a typical Western Australian diatomite deposit is shown in Figure 1.

A major Australian company which was carrying out a pilot plant assessment of diatomites taken from deposits in the Irwin River area during 1975, submitted several product samples to the Division for determination of physical and chemical properties and comparison against standard grade materials.

Copper processing

The Division commenced an investigation into the potential of processing copper by the acetonitrile route during the latter half of 1974. This technique had been originated and developed by Professor A. J. Parker, who is now at Murdoch University, and close collaboration with Professor Parker's group was maintained during the 1975 experimental programme and joint study.

Figure 1



The broad basic chemistry of the process had been well defined so the emphasis of the work carried out by the Division was on the need for pilot scale development studies.

The process is best described as hydrometallurgical and some of the main general advantages of this type of processing are

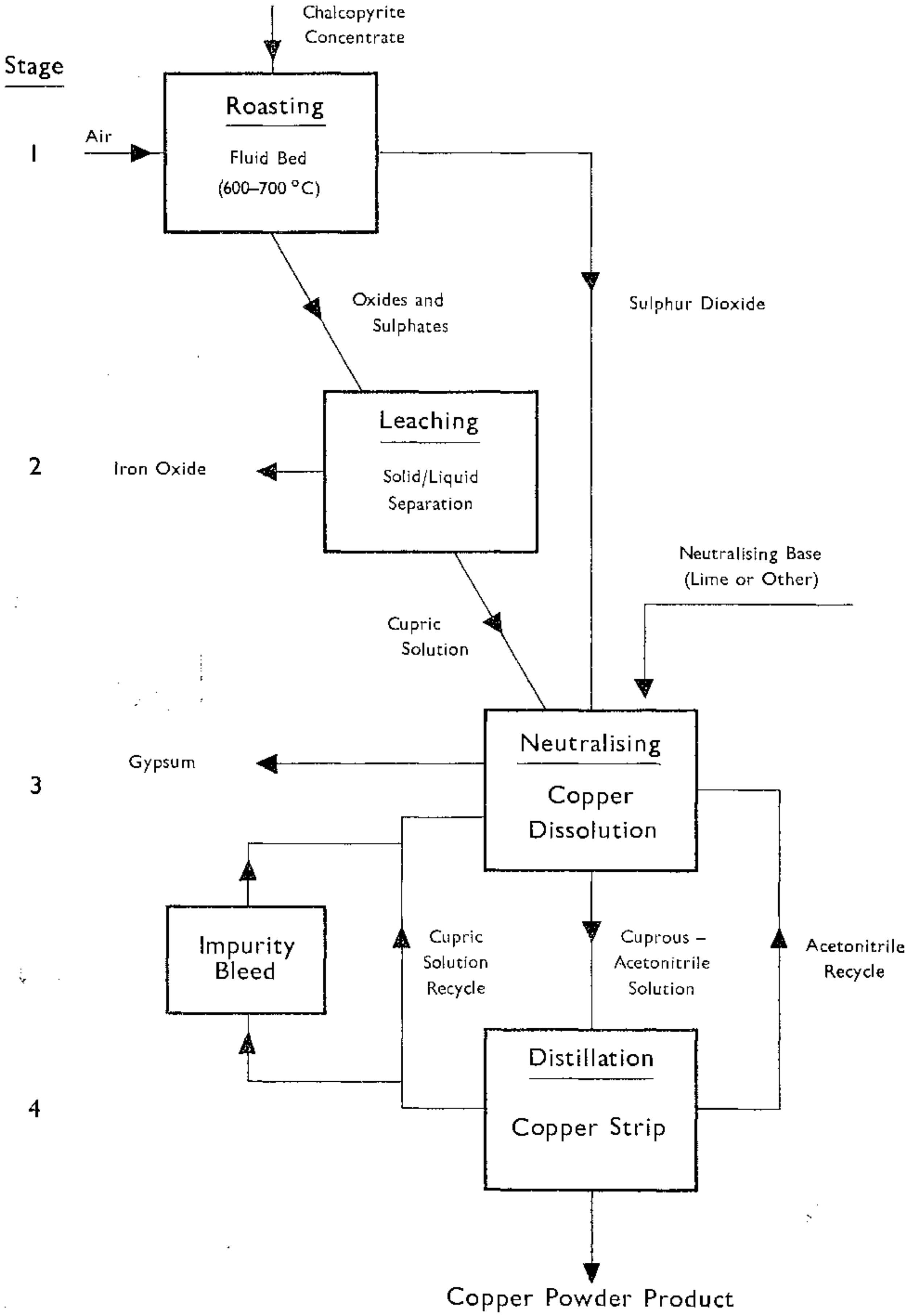
(i) Reduced liability to pollution problems. Potential to recover sulphur in a useful form.

(ii) Increased flexibility. Capability of processing mixed and low grade ores.

(iii) Costs less dependent on capacity, which is attractive to minor producers and an encouragement to process "on site" in remote locations.

However, overall economics is in competition with these advantages and currently is in favour of the conventional pyrometallurgical (smelting) methods of extraction of copper.

There are many potential options for the use of the acetonitrile process. For example, it could be used as an alternative to conventional refining procedures or in combination with other proven operations for complete ore to metal powder treatment. A highly simplified flowsheet for a potential process for treatment of chalcopyrite concentrates is as follows:



The novelty of the process relates to the method of recovery of the final copper product and is represented by Stages 3 and 4 of the Flowsheet. For chalcopyrite processing this could be integrated with proven operations as depicted as Stages 1 and 2. The keynote is the highly selective stabilisation of cuprous ion relative to other constituents in the organic solvent-water mixture. Acetonitrile is the organic solvent which has received most attention and has been used in the test work of this Division. It is a by-product resulting from the manufacture of acrylonitrile, which is produced world-wide at a substantial rate. Other solvents such as liquefied ethylene could also be used.

The experimental programme has established the important parameters for the leaching and distillation steps. Based on these findings a very broad, first order of magnitude economic viability assessment has been made as applied to a plant located in Western Australia.

This preliminary appraisal has indicated that the process for refining copper from impure copper should be economic when operated on a reasonable scale of throughput. Further development on a 10-50 kg per hour pilot plant has been proposed. Its purpose will be to thoroughly evaluate the process, to provide essential design data for a commercial operation and to provide information for more reliable technical and economic process assessments. This programme will be continued in 1976.

A few further trials were carried out on the E.D.T.A. (ethylenediaminetetra-acetic acid) method of leaching of copper ores, which was described in detail in the 1974 Annual Report. A Report of Investigation entitled "A Leaching Process for Oxidised Copper Ores" has been compiled on this topic.

In situ gasification of coal

The idea of "in situ" gasification of coal is more than 100 years old and the objective of gasification of coal in place is the recovery of energy without mining.

In response to a proposal from the then Fuel and Power Commission, the two Senior Officers of the Division joined a work party formed to review the prospects of the application of this technique in Western Australia and to initiate research to enhance this possiblity.

In situ gasification offers the prospect of improved coal energy recovery, which would extend the economic reserves of Western Australia's known coal resources. Thus the technology, if it can be developed to an economic stage, has potential long term benefits for Western Australia. Extensive experimental work on underground gasification has been carried out in several parts of the world but problems, both technical and economic, have been encountered and little commercialisation has resulted.

The major coal deposit of the State is situated at Collie and it is logical to initially review in situ gasification prospects in relation to that area. There is no doubt that Collie coal would produce a combustible gas because its performance in carburetted water gas plants and automatic gas producers is well documented.

A review of relevant basic data from Government Chemical Laboratories records has been made and the following parameters assessed for pertinence to underground gasification.

Proximate and ultimate analyses of Collie coals
Gross energy values.

Fusion characteristics of Collie coal ash

Reactivity of Collie coal

Gasification and carbonisation characteristics

Consideration is now being given to the possibility of simulating seam gasification by carrying out laboratory trials on a block of coal. Testwork of this nature is aimed to define

(i) the operating efficiency of the process
(ii) the location and control of the combustion, reduction and carbonisation zones
(iii) the effect of factors such as process—air rates and cross sectional area and length of the combustion path.

Potential utilisation of local building materials in the North West

As a result of an approach from the Office of the North West, a study was commenced into the feasibility of using lime stabilised soil from the North West in form work, building bricks and related structural components. The motivation for this study was that the use of indigenous materials may offer the dual advantages of being cheaper than hauling building materials long distances from the metropolitan area and at the same time provide work for the local population.

Stabilised earth bricks can be manufactured by compacting selected soils blended with small quantities of cement, lime or other suitable cementing agent to form hard durable masonry blocks. Such processes have been applied with varying success in several parts of the world and among the advantages are

(a) Suitable for small scale production.
(b) Relatively low cost of establishing plant.
(c) Simple process, thus requiring a minimum of skilled labour.

An initial test programme was mounted to assess the prospects of lime stabilisation of typical lateritic soil from the Broome area. The effect of variables such as brick size, lime content, aluminous and siliceous additives, curing temperature, curing time, intermittent curing and degree of compaction was explored.

In terms of compression strength and coherence, the testwork has shown that good quality "compacts" can be produced from Broome sands. The optimum level of lime was found to be of the order of 10 per cent by weight and the ultimate strength achieved was a function of available lime content.

Refinements to the initial process have been made by exploring the incorporation of certain additives and examining the effect of curing methods. In particular, the extreme relevance of "saturation" curing has been demonstrated for the materials under test. 60 degrees Celsius was considered to be a realistically achievable atmospheric curing temperature for North West conditions and 7 day saturation curing at this temperature resulted in compacts of compression strength of the order of 20-25 MPa, which compares favourably with the strength typical of conventional non load-bearing bricks.

Other soils from the Kununurra and Port Hedland areas have been examined with encouraging results and Portland cement has been investigated as an alternative bonding agent. The comparative quality and relative cost differential between cement and lime based bricks seems likely to be marginal if both cementing agents are to be transported from the metropolitan area. On the other hand, a local North West source of quality lime would definitely favour production of lime stabilised lateritic soil bricks on site.

Several building bricks and similarly shaped compacts, that were reputed to have been fabricated on site in areas such as Broome and Fitzroy Crossing, were received and appraised in comparison with the products resulting from the Division's own test programme. A wide range of product quality was found and this was attributed to the varying manufacturing techniques employed rather than the deficiencies of the indigenous raw materials used.

It has recently been confirmed that an experimental prototype house structure will be built on the site of the Broome nursery and that the structure will incorporate a range of the experimental building materials as defined by the Division's investigational programme. This structure will enable evaluation of the test materials and methods under actual construction and utilisation conditions.

Laboratory testwork on the development of lime stablised materials is continuing and is being expanded to review possible use in roof and flooring tiles.

Recovery of lead from batteries

Following a request from the Public Health Department, a search for an improved method of recovery of scrap lead from accumulator type batteries has commenced.

The methods used currently are wholly manual and primitive and the industry requires continuous surveillance by Public Health Department inspectors to safeguard the health of the workers. An improved method of recovery would protect workers and reduce the degree of surveillance necessary.

The problems have two main areas

(i) fracture of the battery casing

(ii) separation of lead from plastic and other contaminating materials.

Testwork is under way on each of these aspects.

Benefication of primary iron deposits

This Divisional research programme was initiated in 1974 to explore the possibility of beneficiating samples from the vast banded ironstone formations of the Hamersley Basin with the objective of producing a high iron "taconite" type product suitable for pelletisation.

Early test results defined that size reduction down to the order of 50 micrometres was necessary to achieve sufficient liberation of ore from gangue to produce a high grade concentrate.

Further experimentation during 1975 confirmed that wet magnetic separation was the most promising beneficiation technique and the benefit of stage grinding of head samples down to each of 53, 45 and 37 micrometres before magnetic separation was investigated. The preliminary programme showed that no justifiable increase in iron oxide liberation was obtained by grinding below 53 micrometres. A marginal increase in the degree of iron recovery was achieved by use of a two stage magnetic separation process.

The testwork has confirmed that wet magnetic separation will produce a "super" concentrate, which is low in the deleterious elements phosphorus and aluminium. Analyses of the magnetic and non magnetic fractions resulting from single pass Davis Tube (current intensity 1.0 amp) wet magnetic separation of a typical core sample from the Dales Gorge Member, Junction Gorge resulted as follows—

	Magnetics		Non Magnetics	
	Composition	Distribution	Composition	Distribution
	per cent			
Fe	60·4	76·3	12·3	23·7
Fe (II)	23·0	77·6	3·51	22·4
P_2O_5	0·018	4·4	0·23	95·6
Al_2O_3	0·02	1·9	0·57	98·1
SiO_2	3·41	2·8	70·9	97·2
CaO	0·028	1·6	1·16	98·4
MgO	0·16	2·8	3·15	97·2
CO_2	0·13	1·6	4·55	98·4
K_2O	0·021	25·8	0·037	74·2
Na_2O	<0·001	1·1	0·046	98·9

A larger quantity of core sample was acquired late in the year and this will enable extension of the scale of the testwork and the carrying out of a grindability evaluation, which is important since the energy costs for fine grinding are an important factor in the overall economics of a taconite type processing operation.

Additional work of a similar nature was carried out for an exploration company, which submitted 47 iron ore chip samples for beneficiation trials.

Blast furnace reductants

A comprehensive test programme was commenced in 1974 at the request of a local company, which was faced with a shortage of blast furnace reductant material, and continued during the year.

The earlier work, which had been directed to establishing suitable briquetting methods for a waste dump material, was extended to include other carbonaceous materials and a wide range of bonding agents.

The laboratory trials clarified an acceptable process, which was adopted by the company on a semi-commercial scale late in the year. Close collaboration has been maintained with the operating company during his recent development stage and this has involved assessment of many additional samples and evaluation of several process variations with the overall aim of achieving complete correlation with earlier laboratory findings.

Surface treatment of heavy mineral sands

A problem encountered by mineral sand mining companies operating within the State is caused by the presence of adherent surface coatings on the individual mineral grains. These surface coatings are undesirable for two reasons—causing separational difficulties in the treatment plant and influencing the quality of the final products, which are normally marketed to tight quality specifications.

Earlier testwork carried out by the Division had defined that the composition of the coatings ranged from organic materials and clays to various iron oxides and that the adherent material was frequently resistant to standard washing and cleansing techniques.

At the request of a local company a further investigation was mounted during the second half of the year and the promising results obtained from laboratory trials were being translated to pilot scale testwork at the end of the year.

Gold recovery

At the request of a mining company, investigational work on a volatilisation method of gold recovery had been carried out during the period 1972-74.

Although overall results were encouraging some problems remained unsolved and this prompted a comprehensive review of the published results of other workers. Such chloridising volatilisation processing has long been recognised and the complex chemistry and equilibria involved have been studied in numerous laboratories. The literature search showed that there is an incomplete understanding of the complex equilibria that exist between the various forms of gold chlorides and other metal chlorides when they are volatilised. These "other metal" chlorides arise from gangue in the original ore and their presence may be fortuitous because certain elements significantly affect the degree of volatilisation of the gold.

An attempt has been made to use the data of published researches to interpret the results of the practical trials and to postulate alternative means of recovering the volatilised metal values.

A Report of Investigation on the topic of gold volatilisation is in the final stages of preparation. Its title will be "Volatilisation of Gold by a Chloridising Roast Technique".

Rotary kiln calcinations

A request was received to compare the products arising from calcination of bulk samples from three different sources of calcium carbonate and to optimise the conditions of calcination.

This involved the pre-processing of approximately 25 tonne batches of each of the head materials and the operation of the rotary kiln on a 3 shift continuous operation basis for three, one week periods.

Testwork of a similar nature was carried out for a major Australian company, when several tonnes of zinc oxide were processed through the kiln under trial conditions.

Sponsored work

Examples of further test programmes that were carried out during the year at the request of various companies, and individuals are the following:

(i) Flotation and acid leach testwork was carried out on a batch of four copper sulphide ore samples at the request of an exploration company.

(ii) A bulk quantity of fine charcoal was processed with an appropriate blending agent to prepare a suitable material for rotary extrusion.

(iii) A patented process for enhancement of the agglomerating and metallising of iron ore by incorporation of selected additives was evaluated for potential application to Western Australian conditions.

(iv) The liberation characteristics of severely indurated heavy mineral sands from the Eneabba area were examined at the request of a mining company.

(v) Various carbonaceous materials were submitted for chemical and physical evaluations. Typical of these were samples of carbonaceous shale, anthracite, coal char, and carbonaceous briquettes.

Consultative and advisory

The Division continued to provide advice and information on all matters relevant to its sphere of activities. Typical examples concerned recovery of tantalum and niobium from local stibiotantalites; substitution of local carbon sources for unprocurable imported graphitic materials; methods for drying of fertiliser mixtures.

Detailed appraisals have been carried out as a result of requests received from within the Department and from other Departments. Included were a review of the mineral sands industry and of the prospects for secondary processing of zircon and monazite.

FOODS, DRUGS, TOXICOLOGY AND INDUSTRIAL HYGIENE DIVISION

Mr. N. R. Houghton retired after twenty years as Chief of Division and a total of 34 years service in these Laboratories. The retirement of Mr. Houghton closes the chapter of those officers who served in the original Wellington Street laboratory.

The Division received over 7 000 samples, an increase of 12 per cent on 1974 and the most ever received.

Table 7 gives the summary of sources and types of samples received during 1975.

TABLE 7

FOODS, DRUGS, TOXICOLOGY AND INDUSTRIAL HYGIENE DIVISION

	Agriculture Department	Departmental	Fisheries and Wildlife Department	Government Stores Department	Greyhound Racing Control Board	Hospitals	Labour Department	Metropolitan Water Board	Pay—Public	Police Department	Public Health Department	Public Works Department	Road Traffic Authority	Western Australian Trotting Association	Other	Total
FOODS—																
Beans	....	....	....	....	....	....	....	....	....	....	15	....	....	....	....	15
Bread	....	....	....	....	....	....	....	....	....	....	29	....	....	....	....	29
Coconut	....	....	....	....	....	....	....	....	....	....	369	....	....	....	....	369
Confectionery	....	....	....	....	....	....	....	....	....	....	20	....	....	....	....	20
Fish	....	1	2	....	....	....	....	....	....	....	215	....	....	....	....	218
Food wrapping	....	....	....	....	....	....	....	....	....	....	56	....	....	....	....	56
Fruit juice	35	....	....	....	....	1	....	....	....	....	27	....	....	....	....	63
Liquor	....	....	....	....	....	....	....	....	....	1	70	....	....	....	1	72
Milk	61	....	....	....	....	....	....	....	....	....	3	....	....	....	....	64
Oysters	....	....	....	....	....	....	....	....	....	....	15	....	....	....	....	15
Prawns	....	....	....	....	....	....	....	....	....	....	333	....	....	....	....	333
Sausages	....	....	....	....	....	....	....	....	....	....	18	....	....	....	....	18
Seasoning	....	....	....	....	....	....	....	....	....	....	18	....	....	....	....	18
Shark	....	....	....	....	....	....	....	....	....	....	313	....	....	....	....	313
Tripe	....	....	....	....	....	....	....	....	....	....	35	....	....	....	....	35
Vegetables	....	....	....	....	....	....	....	....	....	....	12	....	....	....	....	12
Various	4	....	....	....	....	3	....	....	4	....	112	....	....	....	5	128
INDUSTRIAL HYGIENE—																
Air	....	....	....	....	....	....	....	....	....	....	268	1	....	....	3	272
Inspections	....	....	....	....	....	....	....	....	....	....	21	....	....	....	....	21
Urine	....	1	....	....	....	....	127	....	121	1	48	....	....	....	1	299
Various	....	....	....	....	....	....	1	....	3	....	23	....	....	....	1	28
MISCELLANEOUS—																
Animal tissue	73	....	....	....	....	11	....	....	....	....	19	....	....	....	....	103
Bait	3	....	....	....	....	....	....	....	1	6	3	....	....	....	....	13
Chemicals	....	....	....	....	....	....	....	....	....	....	14	....	....	....	3	17
Copper solution	....	12	....	....	....	....	....	....	....	....	....	....	....	....	....	12
Criminal	....	....	....	....	....	....	....	....	2	145	....	....	....	....	7	154
Crockery	....	....	....	....	....	....	....	....	....	....	33	....	....	....	....	13
Detergent	....	22	....	....	....	....	....	....	....	....	1	....	....	....	....	23
Dog urine	....	....	....	....	109	....	....	....	....	....	....	....	....	....	....	109
Drugs	....	1	....	....	....	....	....	....	....	280	....	....	....	....	1	282
Feeding stuff	54	....	....	....	....	....	....	....	....	....	8	....	....	....	....	62
First Aid Dressing	....	....	....	46	....	....	....	....	....	....	....	....	....	....	....	46
Fish tissue	....	....	233	....	....	....	....	....	....	....	....	....	....	....	....	233
Grain	24	....	....	....	....	....	....	....	....	....	....	....	....	....	....	24
Horse urine	....	....	....	....	....	....	....	....	....	....	....	....	....	345	....	345
Maritime pollution	....	....	....	....	....	....	....	....	10	16	....	....	....	....	....	26
Pesticide	14	2	....	....	....	1	....	....	....	....	3	1	....	....	....	21
Silt	....	....	....	....	....	....	....	....	....	....	....	11	....	....	....	11
Soil	2	....	....	....	....	....	....	....	....	....	7	44	....	....	2	55
Toy	....	....	....	....	....	....	....	....	....	....	16	....	....	....	....	16
Water	....	17	....	....	....	1	....	12	4	....	5	199	....	....	2	240
Various	31	27	3	....	3	1	....	2	9	....	39	....	10	....	7	132
TOXICOLOGY—																
Animal	50	....	5	....	....	....	....	....	3	11	....	....	....	....	....	69
Human	....	....	....	....	....	....	....	....	....	1 012	....	....	....	....	....	1 012
Sobriety	....	....	....	....	....	....	....	....	76	390	....	....	385	....	....	851
Specimens from patients	....	....	....	....	....	104	....	....	356	....	14	....	....	....	....	474
Traffic deaths	....	....	....	....	....	....	....	....	....	221	....	....	173	....	....	394
TOTAL	351	83	243	46	112	122	128	14	589	2 083	2 162	256	568	345	33	7 135

(15)—56538

Foods

The number of food samples received this year is nearly five hundred more than the previous year. The bulk of these samples continue to come from the Public Health Department.

The suspected breakdown of ships' freezers with the consequent deterioration of the cargo was responsible for the large increase in the number of prawn samples received. These samples were examined for total volatile bases as a measure of chemical breakdown.

The incorrect storage of chemicals near foodstuffs during transport continues to cause spoilage of foods. Two examples of this type of spoilage that occurred this year are given below. The residents of a country town complained that the local bread had an "off-taste" and was not edible. Samples of the bread and the flour used were forwarded and on examination it was found that the "off-taste" was due to the herbicide 2.4D ester. It was later established that drums of 2.4D ester were stowed in close proximity to the flour. A consignment of sweets when placed on sale in a city store were the subject of numerous complaints about a "petrol taste". The "taste" was found to be present in the chocolate outer coating of the sweets. Although the "taste" was not positively identified it was later established that a spillage of solvent had occurred in the same rail car as the sweets were consigned.

Two batches of samples were received from shops where foodstuffs were contaminated by fogging of the premises with pesticides to control vermin. In both cases no attempt had been made to cover the foodstuffs to protect them from the deposition of the fog. In one case chlorpyrifos was used and in the other diazinon. The residue levels found were within those allowed by the Food and Drug Regulations but all the samples tasted of hydrocarbons rendering them unfit for human consumption.

Two samples of "salt substitute" were submitted. When purchasing these samples the Public Health Officer specifically requested "salt substitute" and was assured that both samples were "salt substitute". One sample was indeed the salt substitute potassium chloride but the other contained about twenty-five percent organic matter and the remainder was sodium chloride.

Of the thirty-five samples of tripe examined all were free from formaldehyde but seven of the samples had a pH in excess of 7.5. The highest pH reported was 8.5.

In several of the samples of prepared seasoning received nitrate was detected. It was established that the nitrate was only present in the herbs and not in the breadcrumbs or as free sodium or potassium nitrate. It is known that most herbs contain a proportion of nitrate as a natural constituent.

Two samples of sausage skins were examined following a complaint of high sulphur dioxide levels in sausages. Both sausage skins were packaged in a strong solution of sodium bisulphite which had not been washed from the casing before use.

Following a complaint that coconut had an "off" flavour after cooking 369 samples of coconut were received. All of these samples were examined for methyl bromide and a large proportion were also examined for total bromide and sulphur dioxide content. It is well known that foodstuffs fumigated with methyl bromide can break down the methyl bromide to form a brominated compound which in turn imparts the "off" flavour. Consequent on this problem two officers of the Public Health Department were invited by the coconut manufacturers to visit their manufacturing plants in the Philippines and investigate the handling procedure. It is understood that certain changes in the handling and method of shipping of coconut to Australia have resulted from this visit.

A sample of margarine was received which was alleged to have been tampered with. Examination of the sample showed the presence of 1,1,1 trichloroethane. An aerosol can of a cleaning substance from the same residence was also found to have 1,1,1 trichloroethane as its active ingredient.

Pigmented and printed plastic bags used for food packaging were examined for lead. A number of yellow bags imported into Australia were found to be pigmented with lead chromate whereas similar bags manufactured in Australia contained no lead. Several plastic bags with printing on the external surface were found to contain lead in the pigment of the ink.

The Public Health Department samples imported fish at its point of entry into the State. Examination of these samples falls broadly into three categories: mercury, colouring and total volatile bases. The mercury levels of this fish are generally well below 0.5 mg/kg. Annatto was the only colouring found in fish although tartrazine was found in the crumb type batter surrounding some precooked fish products. The total volatile bases analyses frequently confirm the suspicion of freezer breakdown during transport.

Two large batches of shark comprising a total of one hundred and ninety seven samples were received for mercury determination from Fisheries Research via the Public Health Department. The Public Health Department also regularly samples shark for mercury content, from the fish markets. Of interest were two large white pointer sharks which were caught for sport and not human consumption. The mercury content of the sharks were 8.1 and 11.6 mg/kg respectively.

Four toffee apples were examined for colouring matter. The permitted colourings amaranth and carmoisine were the only colourings detected.

A survey of various types of bread was conducted during the year. Of the twenty-one samples in the survey only three failed to comply with the appropriate standard. These three samples were milk breads and were deficient in milk solids content.

Several sundry samples were received for examination for foreign substances such as dirt or rodent excreta. Many of the liquor samples examined were low in spirit strength or were falsely described. A number of orange juice samples, particularly reconstituted juice, were found to be low in orange juice content.

Two samples of milk submitted by the Department of Agriculture because of abnormal depression of freezing point were found to contain sucrose.

Drugs

The Police Drug Squad submitted 267 exhibits from 140 cases in connection with illicit drug charges. This is an increase on the previous year. The drug most frequently encountered was Cannabis (105 cases) which came in the form of the resin and the oil but more frequently as the plant material. A number of cases were also received in which the plant material was wrapped around a cane stick, a form commonly known as a "Buddha Stick".

A feature of the drug work during the year was the size of the samples compared to previous years. One exhibit submitted consisted of 3 445 "Buddha Sticks" involving 5 574 grams of Cannabis. Another haul consisted of 102 bags of Cannabis plant with a total weight of 3 757 grams. In a third case 3 640 grams of Cannabis plant was received. In each of these three cases the Cannabis was received already broken down into small amounts for re-sale. The largest sample of drugs other than Cannabis was 274 grams of heroin which contained approximately 30 per cent of diacetyl morphine.

These large hauls are indicative not only of the increase in the illicit drug trade but also of the greater success of the Drug Squad in apprehending dealers.

The number of hours spent in court by analysts involved in drug cases increased markedly during 1975, with hearings as wide spread as Geraldton and Esperance. More drug cases are now being defended and it is obvious to the analyst in the witness box that defence lawyers are gaining in experience and knowledge resulting in more probing cross-examination of expert witnesses.

Details of drug cases are listed in Table 8.

TABLE 8.

DRUGS—POLICE DRUG SQUAD.

Type of drug	No. of positive identifications
Cannabis	109
L.S.D.	9
Heroin	5
Morphine	4
Methadone	3
Codeine	2
Amphetamine	1
Cocaine	1
Dextromoramide	1
Opium	1
Pholcodeine	1
Non-narcotic drugs	7
	144

In a number of the above cases more than one drug was received. There were only 5 cases of samples submitted where no drugs were detected.

Human Toxicology

Over 1 000 exhibits were received from 526 cases of sndden death which were the subject of police investigation. Of this number 197 cases were submitted for examination for drugs or poisons.

Drugs or poisons were detected in 79 of these cases and of these 26 had various levels of alcohol in the blood. In an additional 44 cases, alcohol was found, 19 having a blood alcohol level in excess of 0.15 per cent.

In addition to the above blood and/or urine was submitted from 108 cases where a full toxicological examination was not required. Generally the cause of death was already determined e.g. drowning, shooting, hanging etc. Of these 108 cases, alcohol was not detected in 58 of the bloods submitted, whereas 40 had greater than 0.08 per cent, 34 had greater than 0.15 per cent, 24 had greater than 0.25 per cent and 12 had greater than 0.30 per cent alcohol in the blood.

One of the highest blood alcohol levels recorded at these laboratories came from a person found dead with an empty methylated spirits bottle nearby. The blood alcohol level was 0.610 per cent. In another case a level of 0.457 per cent blood alcohol was found. The information supplied in this case was that the deceased had been drinking "all day" and then consumed a quarter bottle of vodka in one swallow.

During the year blood samples were received from seventeen cases of adult drowning. Of these no alcohol was present in eight cases but five fell within the range of 0.259-0.422 per cent alcohol.

Details of drug and poison cases are listed in Table 9.

TABLE 9.

DRUG AND POISON CASES.

Drug or Poison	No. of positive cases
Carbon monoxide	24
Pentobarbitone	10
Amylobarbitone	8
Diazepam	6
Phenobarbitone	5
Orphenadrine	4
Propoxyphene	4
Thioridazine	4
Methadone	3
Phenytoin	3
Trichlorethanol (from chloral)	3
Imipramine	2
*Various	22

*amitriptyline, caffeine, codeine, cyclizine, dextromoramide, dibenzepin, digoxin, diphenhydramine, ethchlorvynol, glutethimide, meprobamate, methaqualone, paracetamol, paraldehyde, pericyazine, pethidine, quinalbarbitone, quinine, salicylate, secbutobarbitone, thiopentone, trichlorophan.

With reference to Table 9 on a number of occasions one or more drugs may have occurred in the one case. Also the concentrations of drugs present in the organs in certain cases were such that their toxicological significances were uncertain.

As in previous years the most common poison was carbon monoxide from car exhaust fumes. Of the 24 deaths from carbon monoxide, alcohol was present in twelve cases and in ten of these the level was greater than 0.08 per cent.

Three cases of fatal methadone overdosage were received during the year. In each of these cases the information supplied indicated methadone as the cause of death. In each of the three cases the methadone level in the liver was approximately 1 mg/kg, a level which possibly would not have been detected in the normal screening of the liver. Higher levels of methadone were detected in the urine in two of these cases (12 and 33 mg/kg respectively). The experience gained from these cases stresses the importance of screening urine samples particularly for narcotics where levels found in the organs of drug addicts are often low.

The importance of treating the advice notes which accompany postmortem exhibits, with reserve was stressed as a result of one case received which involved a massive overdose of chlorpromazine. In this case the advice given to the toxicologist was that the deceased died from an overdose of stellazine, the proprietary name for the drug trifluoperazine. Chemical analysis of the extracts from the tissues showed that the drug involved was chlorpromazine. Trifluoperazine and chlorpromazine are both phenothiazine drugs and have several similarities which stresses the need for a complete identification even in cases where the advice to the toxicologist is written in unequivocal terms.

Blood Alcohol (Traffic Deaths)

Three hundred and ninety four samples of blood and/or urine were received from the Police Department and Road Traffic Authority in connection with the investigation of fatal traffic accidents. Table 10 shows the distribution of blood alcohol figures for the various categories of persons killed in traffic accidents.

TABLE. 10.

TRAFFIC DEATHS —BLOOD ALCOHOL LEVELS

Alcohol per cent	Motor vehicle drivers	Passengers	Pedestrians	*Motor cycle riders	Pillion passengers	Unknown
			Number Involved			
Negative	33	27	16	7	1	1
0·050 and less	13	4	1	....	....	1
0·051 to 0·079	2	5	....	....	....	....
0·080 to 0·099	3	4	1	....	....	1
0·100 to 0·149	13	5	....	5	1	3
0·150 to 0·200	14	5	2	3	....	....
0·201 to 0·250	12	4	4	....	....	1
0·251 to 0·300	9	2	3	1	....	....
More than 0·300	4	2	7	....	....	....
TOTAL	103	58	34	16	2	7

* Includes motor scooters.

It is emphasised that the above figures apply to the samples of post morten blood received for analysis at these Laboratories.

Table 10 shows that 38 per cent of fatally injured drivers whose blood was analysed, had a blood alcohol figure of 0.150 per cent or more, while the corresponding figure for passengers and pedestrians was 22 per cent and 47 per cent respectively and that for motor cycle riders was 25 per cent.

Blood alcohol levels of 0.08 per cent or more were recorded for 53 per cent of motor vehicle drivers, 38 per cent of passengers, 50 per cent of pedestrians and 56 per cent of motor cycle riders.

Negative results (i.e. no blood alcohol) were recorded for 32 per cent of motor vehicle drivers, 46 per cent of passengers, 47 per cent of pedestrians and 44 per cent of motor cycle riders.

Blood Alcohol (Traffic Act)

Table 11 gives the results of alcohol in the blood analyses (calculated to the time of the alleged offence) of blood samples received under the Road Traffic Act, 1974.

TABLE 11.

TRAFFIC ACT—BLOOD ALCOHOL LEVELS

Alcohol per cent	No. of Cases	Per cent of Cases
0·050 and less	34	4·0
0·051–0·079	29	3·4
0·080–0·099	53	6·2
0·100–0·149	167	19·6
0·150–0·200	234	27·5
0·201–0·250	203	23·9
0·250–0·300	86	10·1
More than 0·300	45	5·3
TOTAL	851	100·0

The results in Table 11 show that 66.8 per cent of drivers tested had over 0.150 per cent. alcohol in their blood.

This high percentage of drivers over 0.150 per cent has been fairly consistent over a number of years and continues to emphasise the potential hazard to themselves and other road users of the drunk driver on the roads.

Specimens from Patients

There has been a large increase in the number of specimens from patients received this year. Part of this increase is due to 249 samples of seminal fluid taken from patients of a doctor who was investigating the relationship of zinc concentration to infertility. The other samples received were predominately urine samples and were submitted from hospitals and doctors to assist in medical diagnosis. The different types of analyses performed in this connection are detailed in Table 12.

TABLE 12.

SPECIMENS FROM PATIENTS—ANALYSES.

Analysis	Number
Arsenic	44
Boron	2
Cadmium	2
Lead	35
Mercury	72
Nickel	4
Thallium	76
Zinc	249
*Various (one of each)	6

*Amphetamine, copper, fluorine, lithium, manganese and silver.

Animal Toxicology

Twenty three samples were submitted as baits or suspect feeding stuff. Nineteen of these samples were found to be negative, two samples contained strychnine, one cyanide (sudan grass) and one methiocarb. Forty eight post mortem samples from various animals were examined. Thirty two were found to be negative, six contained strychnine, three phenobarbitone, two dieldrin, two metaldehyde and one each, BHC, methiocarb and phorate.

Dog and Horse Doping Control

This has been the first full year in which these Laboratories have received urine samples of dogs from the Greyhound Racing Control Board. Of the 109 samples submitted one containing caffeine, theophylline and theobromine was the only positive detected.

The West Australian Trotting Association submitted 345 samples of horse urine. One sample containing caffeine, theophylline and theobromihe was the only positive detected.

Industrial Hygiene

The number of samples received in connection with industrial hygiene has more than doubled on the number of samples received last year. The number of urine samples has previously always accounted for the bulk of samples received but this year this number was nearly surpassed by air samples.

Of the 299 samples of urine received 234 were from workers who have an industrial exposure to lead. These samples are taken to monitor the workers' uptake of lead. Workers with 80 $\mu g/l$ or less lead content accounted for 55.1 per cent of these samples, 90 to 150 $\mu g/l$ 27.3 per cent, 160 to 200 $\mu g/l$ 9.0 per cent and greater than 200 $\mu g/l$ 8.6 per cent. Some of the workers with high lead urine concentrations were transferred to other work not involving lead exposure until their urinary lead concentration was greatly reduced.

Twenty six samples of urine were submitted from workers engaged in the addition of fluorides to water supplies. No abnormally high fluorine concentrations were found. Following work commenced last year a further 37 samples of urine have been received from people with industrial exposure to thallium.

The use of Clerici's solution (a mixture of thallium formate and malonate) for mineral separation is the source of this thallium hazard.

Three air samples and 13 urine samples were received for examination for mercury in connection with the use of this element in the gold mining industry. A further 7 air samples for mercury were collected from dental surgeries.

Six oil samples taken from transformers being salvaged for copper were examined for PCB's to eliminate the likelihood of PCB's affecting the workers engaged in melting down the copper.

An industrial exposure to arsenic while treating hides resulted in two urine samples and one air sample.

A total of 28 samples of air were examined for vinyl chloride. These samples were from manufacturing plants using PVC to make containers. Various other air samples were taken from industrial situations and included examination for acrylamide, diazinon, dichlorvos, hydrogen fluoride, hydrogen sulphide, isocyanates, lead, nitrogen dioxide, sulphur dioxide and xylenes.

Following a request to the Occupational Health Division of the Public Health Department by anaesthetists, 191 samples of air from operating theatres were taken by chemists of this Division. These samples taken from Sir Charles Gairdner, Royal Perth and Princess Margaret Hospitals were examined for anaesthetic gases. Through co-operation with the anaesthetists, hospital engineers, anaesthetic equipment manufacturers and the staff of this Division a substantial reduction in the anaesthetic gases concentration in operating suites has been achieved at Sir Charles Gairdner and Royal Perth Hospitals. It is anticipated that further work next year will result in a similar reduction in the anaesthetics concentrations in Princess Margaret Hospital operating theatres.

Our thanks are due to the S.E.C. Gas Works Laboratory for the use of their "Miran Infra Red Gas Analyzer", which was used for much of this work.

Seven inspections of ships and waterfront installations resulted from complaints made to the Australian Stevedoring Industry Authority by waterside workers. Two complaints involved fumes from LP gas fork lifts and the other five the spillage of cargoes.

A greater number of requests are being made for chemists to personally inspect and evaluate industrial situations where a chemical hazard may exist. It is very desirable for chemists to examine the various problems in situ and not just report on the result of analysis of various samples, that may or may not have any bearing on the problem.

Miscellaneous

Criminal

Criminal exhibits were received this year from the W.A. Police Force, the Commonwealth Police Force and the Laverton Royal Commission.

Table 13 gives a summary of the cases investigated this year.

TABLE 13

CRIMINAL CASES

Nature of Investigation	No. of Cases
Suspected arson (houses, factories, vehicles)	22
Indecent assault	2
Suspected poisoning	4
Assault by chemicals	3
Explosions	3
Various	10

It is regretted that no opportunity to address Detective Training Schools was available this year due to the cancellation of these schools because of Police staff shortages. It is felt that this is a valuable avenue of reaching the Police and informing them of the assistance these Laboratories can give in providing expert evidence in criminal investigations.

Maritime Pollution

Ten exhibits relating to an oil spillage at Port Hedland were submitted by the Port Authority. Chemical analysis indicated that the spillage in the harbour could have come from one vessel and eliminated three other vessels. The 16 other samples of oil received from spillages were from the Fremantle area.

Pesticides

During the year several samples of heptachlor for use in argentine ant control submitted by the Department of Agriculture were below specification. These samples were low in heptachlor concentration and when mixed with water gave a very unstable emulsion.

The Laboratory took part in a collaborative study organised by the Association of Official Analytical Chemists. The A.O.A.C. is an organisation of analytical chemists in the United States of America and is of very high international repute. Samples of simazine formulations were distributed to collaborating laboratories together with gas chromatography column packing, standard simazine and a copy of the method. Because of the delay in receiving the materials our analyses were too late for inclusion in the study report. However it is gratifying to note that our results were well within the standard deviation of the average results of the study report.

Only a few samples were received for monitoring formulations used by pest control operators. From what have been received it is noted that they were either well below strength or contained pesticides other than those they were claimed to contain.

Pesticide Residues

Table 14 gives a resume of the types of samples received and analyses of pesticide residues conducted.

TABLE 14.

PESTICIDE RESIDUE ANALYSIS

Sample (and analyses)	Number
Waters	
Ord Area (O.C.'s O.P.'s)	94
S. W. River (O.C.'s, herbicides)	106
Swan River (O.C.'s, O.P.'s)	16
Soil and Silt, Ord Area (O.C.'s O.P.'s)	57
Fish tissue, Ord Area (O.C.'s)	235
Lupins (O.C.'s)	26
Ovine fat (O.C.'s)	68
Milk ex treatment plants (O.C.'s)	35
Sausages (O.C.'s)	7
Lima beans (O.C.'s)	8
Fruit and vegetables (O.C.'s O.P.'s) carbamates)	23
Feeding Stuff (O.C.'s O.P.'s)	56

The samples from the Ord irrigation area and the South West Rivers are received on a regular basis. These samples are examined for the pesticides and herbicides known to be used in the respective area or catchment area. The samples from the Swan River were sampled monthly until May. Since May these samples have been taken quarterly. It is emphasised that samples of this nature are examined for residues at very low levels which are of possible environmental significance only.

The 235 samples of fish tissue taken from the Ord River by the Fisheries and Wild Life Department, were received in connection with environmental studies on the pesticides used in the Kununurra irrigation area.

The samples of lupin and ovine fat were from feeding trials at the Badgingarra Research Station.

The bulk milk supply continues to be monitored for pesticides and this year we have also commenced examining these samples for inorganic iodine levels.

The samples of lima beans are of interest in that high levels of BHC were detected on the surface of the beans. These beans were rumbled to remove the BHC and resulted in an acceptable level of residue on the beans.

A blood and urine sample were received from a pesticide operator to ascertain if the levels of organo-chloride pesticides which he was using were abnormally high.

This year the first "Trace back" pesticide samples were received. Four samples of cream were examined from the suppliers of a butter factory where butter with high dieldrin level had been reported. A consignment of pork with high HCB level resulted in several samples of feeding stuff being examined. Unfortunately there were excessive delays from the initial reporting of the high pesticide level and the submitting of the "trace back" samples.

The large number of pesticide residues samples submitted and the great variety of types of determinations requested placed a great strain on the instrumental facilities which are available to the Division.

Other samples received include:

Eleven motor cycle helmet visors for light transmission tests were submitted by the Road Traffic Authority. The Australian Standard states that visors must have 85 per cent transmission of light over the visible spectrum. Only three visors complied with the standard and one visor had less than 20 per cent light transmission over the visible spectrum. This visor if worn at night would be extremely dangerous.

Samples of porcelain lined saucepans, crockery, plastic garbage bins and childrens toys were examined for "leachable" heavy metals.

Wine casks and plastic bags were examined for PCB's.

A teething ring which consisted of a circular plastic tube containing fluid was examined. The fluid was found to be water containing a cationic detergent which was probably added as a bactericide.

The Education Department submitted three samples of chemical reagents for compliance with the appropriate analytical reagent standard.

Two fuel samples from the Bureau of Consumer Affairs were examined in connection with a dispute over an engine which seized while operating.

A sample of paraffin wax was examined for paraffin oil content.

A sample of liquid oxygen was examined for hydrocarbons following an explosion in an oxygen plant.

Two samples of gas from the head space of bitumen tanks were examined following a fire in another bitumen tank.

A recommendation not to use a wet strength tissue followed the finding of extractable formaldehyde in the tissue.

A number of detergents were received. These samples were for comparison with their stated formula. The results are taken into account when Tender Board recommendations are made.

Forty six surgical dressings were submitted by the Tender Board for comment on their compliance with the appropriate BPC standard.

A "Frost Box" containing a viscous liquid was submitted by a hospital after a patient had consumed some of the liquid. The liquid was identified as water which had been thickened with sodium carboxymethylcellulose.

Eleven samples of rabbit faeces and liver were analysed for silver content. These samples were in connection with medical experiments on the absorption of silver sulphadiazine, a drug used for burns treatment.

Numerous enquiries for technical information and advice were received and dealt with during the year. Expert evidence was tendered in various Courts as required by officers of the Division in connection with their official duties. The long distances travelled to attend Court in many country centres and the consequent loss in working time is placing a strain on the Division's resources.

INDUSTRIAL CHEMISTRY DIVISION

The Division dealt with an increase in numbers of samples during the year. There has also been no falling off in the number of enquiries received on a wide range of subjects. This consultative work arises from other Government Departments, private companies and the general public. Many short literature searches were necessary in order to answer a number of these enquiries and as usual interest in plastics materials was considerable.

Dr. Smith again delivered the final lecture of the Annual "Know your Plastics" series organised by the Plastics Institute of Australia. He also gave one lecture in a short series to a class at Graylands Teachers College also arranged by the Plastics Institute of Australia. A lecture on plastics was delivered at a meeting of the Royal Australian Chemical Institute and a short talk on some aspects of plastics packaging at a meeting of the National Packaging Association. He also acted as a member of several judging panels for the Industrial Design Council.

Dr. Smith acted as Chairman of a seminar organised by the Australian Fire Protection Association, the Fire Brigade and the University Extension Service.

1. Materials Testing.

(a) Paint:

(i) On behalf of Public Works Department, Architectural Division, 27 samples of paint made by a new local manufacturer referred to in our last Annual Report were submitted to our standard test procedures. The samples were found to be generally satisfactory, but sometimes only marginally so and some improvement in quality is needed.

(ii) Twenty-one samples were submitted by the Tender Board representing the paints selected for the 1974 tender. Results were compared with those of the reference samples originally submitted for the tender. Generally, the samples compared well with the reference samples. There were, however, seven samples in which property variations exceeded those allowed in the appropriate specification, although sometimes only slightly.

(iii) The State Electricity Commission required assistance in the testing of a coal tar epoxy coating applied to the sea water filters at Kwinana Power Station. Our spark-testing equipment was used in conjunction with their porosity testing apparatus to determine whether the coating already applied was satisfactory. In addition, we submitted a test panel to 130 hours in our salt spray apparatus with satisfactory results.

(iv) Two samples of latex paint were submitted by State Housing Commission for routine testing and also checking the identity of the binder resin. The binder in both cases should be 100 per cent acrylic. The tests showed that both samples matched the reference sample quite well, but the resin binder in both samples and in the reference sample was found not to be 100 per cent acrylic. The problem here is that in the paint industry the word "acrylic" is used very loosely to cover a range of polymers and copolymers, not all of which are 100 per cent acrylic in fact.

(v) As a result of the above finding, it is our intention to check the resin binder in all the latex paints submitted for the tender. Six further samples have also been received. This work is still in progress.

(vi) A total of 59 samples of paint were received for examination for the 1976 paint tender. As members of the Government Paint Committee, reported in the previous Annual Report, we have now adopted their procedures and specifications. All manufacturers were required to supply a record of test for each paint item submitted, giving the information requested in the tender document. Our test work was limited to checking wet hiding power and viscosity figures and as a result we were able to make a report to the Paint Advisory Committee in a much shorter time. Nine manufacturers submitted tenders but only five complied fully with the requirements of the tender documents, which clearly stated that samples of all paints submitted together with records of test had to be supplied to these Laboratories at the time of submitting the tender to the Tender Board. As a result only these five manufacturers were considered.

(vii) Two samples of paint for producing a textured finish on off-form concrete walling were submitted by Public Works Department. Various physical tests, such as durability, adhesion, filling qualities, abrasion resistance, have been requested. This work is still in progress, being held up by operating problems with our U.V. weatherometer.

(b) Building Materials:

(i) Three samples of plywood used for concrete formwork were submitted by Main Roads Department. Problems were being experienced with a powdery surface on off-form concrete and it was thought that some extract from the wood might be acting as a retarder. In addition some of the plywood was delaminating in use indicating that it was not marine ply. Tests showed that the three samples submitted were all marine ply. By casting cement blocks on to the plywood, one of the samples was found to produce the powdery surface effect. It was considered to have been caused by the very porous nature of the surface ply, causing a loss of water in the cement in contact with it.

(ii) After a minor fire in the hospital being built at Rockingham, Public Works Department asked for our advice on methods for cleaning walls and metal parts affected by the smoke. The fire was caused by welding operations near a stock of hard rubber and polyurethane foam insulating materials in a basement room. Both materials, but particularly the rubber, would give rise to acid fumes on burning and there was visible corrosion on metal support trays for electric cables. After some experimental work suggestions were made for treatment of the affected areas.

(iii) Five samples of carpet were tested for the Furniture Section, Public Works Department. The tests were as described in previous Annual Reports and results were generally similar.

(iv) Two samples of concrete underlay were tested for the Architectural Division, Public Works Department.

(v) During a visit to Adelaide, Dr. Smith attended a meeting of the Materials Testing Committee of the Public Buildings Department. Some of our work on the examination of building materials was discussed, including exterior cladding panels, carpets and concrete underlays. We were asked to supply a summary of all these results and this has now been done.

(vi) An enquiry was received from Medical Department concerning the cleaning of grouting between ceramic floor tiles in kitchens. This grouting quickly becomes dirty and is not cleaned by the scrubbing machines normally used. Various chemical treatments were also tried without success. After some consideration and enquiries in the building industry we were unable to provide a satisfactory answer for existing grouting other than partial removal and replacement at suitable intervals.

Synthetic grouts based on epoxy resins or polysulphide rubbers are an improvement but still discolour eventually. The suggestion was made that, whatever grout was used, it should be pigmented a dark colour, preferably black.

(vii) During the year fire test equipment for carrying out AS 1530 Part 3, "Early Fire Hazard Test of Materials", was constructed in the Division for the testing of building materials. Although tests can be run and have been, with the equipment, it will not be fully operational until some modifications are carried out to improve operator safety in particular in smoke dispersal.

Tests have been carried out on vinyl and rubber flooring, and vinyl coated steel sheet. In addition the equipment was used to test the flammability of several types of paint spray booth filter materials for the Department of Labour and Industry. The object was to decide what material was acceptable and filters made from fibreglass were found satisfactory.

(viii) A number of samples of sarking and insulating materials were submitted by Public Works Department for determination of Flammability Index. As we do not have the equipment to determine this Index, the samples were tested by means of our standard cabinet fire test.

(c) Plastics:

(i) Five samples of fibreglass reinforced plastics obtained from boats under construction were submitted by Harbour and Light Department for determination of resin/glass ratio and weight of glass per square metre.

(ii) The Harbour and Light Department also submitted a sample of polyethylene foam which was claimed to be self-extinguishing. The sample was tested according to ASTM D1692-68 and was in fact found to be self-extinguishing by this test.

(iii) A number of rubber gaskets have been submitted by Metropolitan Water Board. It was necessary to determine whether the rubber composition complied with the appropriate specification. Two were of natural rubber as required and a number of others consisted of various synthetic rubbers in which no natural rubber could be detected.

(iv) The Metropolitan Water Board also submitted a sample of fibreglass reinforced plastic cut from a tank proposed for use as a domestic hot water cylinder. They wished to know whether this material was suitable for the purpose and in particular whether it was possible for glass fibres to enter the water from the tank.

Two tests were used. The first involved immersion in boiling distilled water and the second application of a constant stress applied to strips immersed in an oil bath with the temperature being raised at a standard rate.

After 5 hours in boiling water the gel coat had started to develop surface cracks and after 20 hours the surface was seriously cracked. Such cracks in time would penetrate through the gel coat and reach the glass laminate. At this stage it would be possible for glass fibres to enter the water as the structure of the tank started to disintegrate. An acceptable product should be able to withstand 100 hours in boiling water without any sign of cracking.

In the second test, samples failed by fracturing only after the temperature had reached 130°. One sample finally fractured at a temperature of 153°.

The resin used was identified as an isophthalic polyester and it is unsuitable for use in hot water cylinders. A satisfactory product could be made from bisphenol or vinyl ester type polyesters.

(v) The Construction Engineer at Kwinana Power Station extensions asked us to investigate the failure of a plastic connecting rod in a circuit breaker imported from Italy. Large numbers of these circuit breakers are used and their operation must be completely dependable. The equipment is tested in the factory before despatch and the connector was found to be broken on arrival. The break must have occurred during testing but was somehow not noticed. The break occurred at the base of the connector where a hole had been moulded in to take a metal axle. This is an area where poor flow could occur during the moulding operation.

The material was identified as a glass reinforced alkyd moulding compound. A piece of the broken end was sectioned, polished and photographed. Heavy and badly distorted swirl lines were clearly shown and it could be clearly seen that the material had fractured along swirl lines. There was also some evidence of poor "wetting" of the glass fibres by the plastic. Similar examination of unbroken connectors showed improved appearance and a much more regular swirl pattern.

(vi) Two samples of plastics materials were submitted by Metropolitan Water Board. One sample was a rigid sheet and was the outer container of a water softening unit. The other sample was a flexible material used as a bag to hold the ion exchange resin. The first sample was identified as an ABS resin and the second as a PVC/PVA copolymer plasticised with a phthalate plasticiser. The second material was considered to be suitable for its proposed use.

(vii) The Harbour and Light Department approached us to undertake the fire testing of plastic fuel tanks for boats. In this State plastic fuel tanks in permanent positions in boats are not permitted, but their use is allowed in the other States.

The fire test to be applied was to be the test described in the "Safety Standards for Small Craft" of the American Boat and Yacht Council. This test required the fabrication of a mock-up hull section and this was undertaken by Harbour and Light Department who also fabricated a steel tank. Five gallon and 10 gallon plastic tanks had been donated by suppliers for the tests.

The Navy provided staff and their facilities at Woodman's Point to carry out the tests.

The plastic tanks were of high density polyethylene and behaved as expected. They caught fire, melted in parts and exposed the fuel charge to the flames. A fairly severe fire then developed. In the case of the smaller tank a clear plastic cover over the contents gauge also blew out and caused a moderately severe "blow-torch" effect. During the testing of the steel tank a section of weld failed with a minor explosion and a very severe "blow torch" effect developed. On examination after the test the weld in the failed area was found to be of poor quality and in a properly welded tank the failure would not have occurred.

(d) Miscellaneous:

(i) The Home Economics Department at the Western Australian Institute of Technology requested exposure of 12 samples of curtain materials in the UV weather-ometer. The samples were then returned for their own assessment.

(ii) Department of Lands and Surveys requested assistance in making up a photographic eradicator solution. After some experimentation a suitable solution based on copper chloride was produced.

(iii) The Australian Broadcasting Commission asked for identification of tarry deposits on records which were causing very light-weight pick-up heads to jump tracks. It was discovered that they were using outer covers made from building paper. This material consists of two layers of kraft paper bonded together with a layer of bitumen. We were able to show that the deposits on the records were in fact bitumen from the building paper.

(iv) Medical Department submitted three hospital sheets for fire tests. Two samples had been treated with a proprietary fire-proofing treatment, one being unwashed and the other having been subjected to a number of severe washings. The third sample was an old untreated sheet. The samples were tested according to BS 2963:1958, "Tests for the Flammability of Fabrics", Method A; vertical strip test.

The untreated sheet was completely consumed in the test. The two treated samples behaved well, there being no significant difference in the results. Both were classified as "flame not propagated". The results showed that the severe washings had not affected the flame proofing treatment.

2. Assistance to Industry.

(a) Solvent Extraction.

Further work has been done in the pilot plant on the Cavsol isopropanol solvent extraction process for the production of protein concentrates. The work involved the processing of both linseed and rapeseed.

(b) Processing of Lupin Kernels.

This State is the major grower of lupins in Australia and there is already a valuable export market in lupin seeds. This could be substantially increased if the quality of the kernels, or flour produced from them, could be improved. We were asked to extract the lupins with dilute acid at the protein isoelectric point, where protein solubility in water is at its lowest.

White lupin kernels and flour were processed on a laboratory and pilot plant scale. The results were somewhat disappointing in that protein content was only increased to a small extent although flavour was improved to a satisfactory degree.

(c) Plastic Louvres.

A local plastics fabricator was interested in supplying protective louvres for new houses in Darwin. The louvres were shaped from cellulose acetate butyrate sheet and rivetted into an aluminium channel section frame. The plastic louvres had to withstand an impact test specified by the Darwin Reconstruction Commission.

The first louvre unit submitted was fabricated from a light gauge aluminium channel. In the impact test the louvre blades pulled away from the aluminium but the blades themselves were virtually undamaged. Further units were supplied with the frame made from a heavier aluminium channel. The impact test broke the louvre blades and an attempt was made to determine the maximum impact the blades could withstand, but work was stopped before this figure could be determined.

(d) Light Transmission of Plastic Sheet.

A sample of fibreglass reinforced plastic sheet was submitted for determination of light transmission. The material was to be used for controlled environment production of vegetables in Darwin. A light transmission curve was produced which was similar in shape to that of glass.

(e) Plastic Letters for Headstones.

Metallic lead has for a long time been used for lettering on headstones in cemeteries. In recent years plastics such as epoxy and polyester resins have been used to cast the letters directly in the recesses cut into the stone. In a number of cases, in particular with marble headstones, many of these plastic letters have been falling out after a relatively short period of outdoor exposure. The Monumental Masons Association through the Perth Chamber of Commerce asked us to investigate the problem.

A number of marble pieces were supplied with letters of various sizes and types cut into them, some with dowel holes, some without. Letters were cast into them using epoxy, polyester and polyurethane resin systems. The sample pieces were then subjected to alternate periods of temperature cycling and accelerated weathering in our UV weatherometer with intermittent water spray.

It was concluded that epoxy resin letters gave best results with little shrinkage and good adhesion to the marble. Polyurethane letters were almost as good but showed more shrinkage during casting. The polyester letters were not satisfactory, showing shrinkage during casting, further shrinkage during the course of the tests and poor adhesion. They were usually quite easy to lift out after the completion of the test period.

3. Investigational.

(a) The work on production of printers rollers, polyester drafting film and enzyme chemistry was completed and reported during the year. The karri timber painting project is due to be completed at the end of this year and will be reported early next year. Work on rust treatment, clear lacquers for timber, wood waste utilisation and testing of polishes was continued as time allowed.

(b) Laporte Effluent.

Work was continued on some aspects of the chemistry of this effluent. In addition a study was started on its reaction with low grade phosphate rock from Christmas Island to investigate whether useful phosphatic fertilisers could be produced.

4. Consultative.

A wide range of consultative work was undertaken and a selection from enquiries is given below:

- Formulation of detergents and insecticides.
- Chemical testing of plastics.
- Manufacture of plastic craypots.
- Use of plastics in a new design of fire fighting unit.
- Manufacture of straw/cement panels.
- Surfactant formulation for bubble blowing kits.
- Formulation of slow release insecticide blocks for mosquito control in drains, ponds, etc.
- Materials of construction for a modular house design.
- Manufacture of fibreglass reinforced plastics septic tanks.
- Manufacture of fire lighters.
- Painting of Steel Water Tanks.

KALGOORLIE METALLURGICAL LABORATORY

General

Three hundred and twenty-three certificates were issued during the year, of which two hundred and ninety were for analyses from various sources, and thirty were issued for research into various methods of treatment.

The analyses carried out are shown in Table 15. The total number of assays carried out for 1975 increased by 57 per cent over 1974.

The increased throughput was due to excellent staff co-operation and to having a large number of samples on hand, so that laboratory preparation of the samples was always well ahead of assay requirements.

TABLE 15

ASSAY OF SAMPLES RECEIVED

Analyses	State Departments	Public Free	Public Pay
Gold—			
Ores	9	2	1 475
Tailings	....	....	981
Bullion bars	....	....	40
Nickel	....	....	83
Copper	....	....	135
Arsenic	1	....	73
Silver	....	....	280
Lead	....	....	37
Zinc	....	....	24
Iron	....	....	34
Sulphur	....	....	56
Other	....	....	171
TOTAL	10	2	3 389

Consultative and Advisory

Many companies and prospectors sought advice on treatment problems and the discussions were most useful to outline methods of treatment and to examine the troubles encountered.

Of the research work carried out for companies and prospectors, seventeen were on oxidised gold samples, others were on gold-sulphide ores, oxidised copper-gold ores, heavy mineral separations, mine waters, activated carbon, sulphide copper and chloride fume.

Research work is being carried out on some W.A. charcoals and coal chars to see if they are a suitable source of activated carbon for precipitating gold from a cyanide solution.

The most important factors the activated carbons must contend with are—

1. Can the activated carbon remove all of the gold from a cyanide solution to trace values?
2. The rate of stripping must be rapid, requiring not more than 2 hours to remove 4 or 5 grams of gold per tonne of cyanide solution to trace values.
3. The gold loading of the activated charcoal must be in excess of 200 ounces of gold per tonne of charcoal.
4. The activated carbon must be hard and able to withstand considerable abrasion without loss of fines if it is to be used in an agitated pulp and subjected to continuous screening in returning the carbon to the pulp agitator.

During the year, work on an old tailings dump which contained charcoal (from dumped wood ashes) proved to be very difficult to treat. The tailings originally contained cyanide soluble gold and the gold was absorbed onto the charcoal and then allowed to age in the dump for 30 years or so. This charcoal today can neither by floated, recovered by gravity or cyanided satisfactorily.

The answer could lie in use of a powerful collector capable of floating the charcoal as it is very resistant to the normal run of flotation reagents.

A particularly slimy sample from an old tailings dump which was impervious to percolation leaching with cyanide became amenable to treatment by adding an excess of lime to charge and allowing it to stand overnight. The excess lime and time of contact were both apparently necessary to achieve a satisfactory rate of leaching.

Two samples of copper ore presented difficult treatment problems. One sample contained disseminated malachite, which could not be separated by gravity from its gangue, but could possibly be handled by the latest heavy media units which can handle particles down to 65 mesh.

The second copper ore contained massive pyrite coated with a thin layer of copper sulphide. The only method of treating this ore satisfactorily appeared to be by heap leaching using bacteria. The soluble copper released by the bacteria would then be precipitated by scrap iron.

MINERAL DIVISION

General

Changes of significance in the work of the Division in recent years have been in the nature of the mineral matter examined. Whereas earlier the work was almost entirely on the potential of ores and identification of minerals, lately a large concentration of interest has been on dusts throughout the mining and other industries and other potential threats to the environment by way of waste disposal.

Increased attention has been given also to advising the Bureau of Consumer Affairs. Aid to investigations of the police and other authorities has also increased.

Support for the mapping of regional geology remains a major function, and a feature of the activities of the Division this year has been the reporting of over 28 000 determinations on a group of samples which were in hand at the beginning of the year.

The year commenced with a total of 2680 samples in hand, many of which involving a great deal of work. At the close of the year the backlog had been largely overcome so that new work could be accepted with confidence of the provision of early results.

The total number of samples received into the Division in 1975 was 2655 associated with the work of seventeen Government clients, mainly other Branches of the Mines Department, the Public Health Department, the Conservation and Environment Department and the Police Department.

Details of the sources and type of samples are shown in Table 16.

Twenty one per cent of the samples were received from the public and consisted mainly of mineral identifications and gold assays. One hundred and fifty eight were examined at a concession fee when information for record purposes was provided.

Of the 392 samples examined on a commercial basis a considerable number were experimental products from plant investigations conducted by the Engineering Chemistry Division. Mineral records

TABLE 16.

MINERAL DIVISION

	Conservation Environment Department	Geological Survey	Government Chemical Laboratories	Mines Department	Police Department	Public Health Department	Public Works Department	Other	Public			Total
									Pay	Concession	Free	
Dusts	....	....	4	336	....	1 059	....	....	6	....	....	1 405
Geochemistry	....	133	....	....	....	....	....	....	1	2	....	136
Mineral Identifications	....	46	132	6	....	2	1	8	64	50	8	317
Police Exhibits	....	....	....	....	28	....	....	....	....	....	....	28
Miscellaneous	4	4	....	11	....	13	4	14	29	17	....	96
Ores and Mineral Products—												
Building Material	....	6	....	....	....	....	19	8	3	....	....	36
Clay	....	....	1	....	....	....	4	....	4	....	....	9
Diatomite	....	1	23	2	....	....	....	....	2	....	....	28
Gold Ores	....	....	2	8	....	....	....	....	192	53	23	278
Limestone	....	6	....	....	....	....	....	....	12	....	....	18
Magnesite	....	17	....	....	....	....	....	....	....	....	....	17
Zircon	....	....	....	....	....	....	....	....	48	....	....	48
Other	....	4	21	1	....	....	....	4	22	3	2	57
Sediments	52	....	....	....	....	....	....	....	....	....	....	52
Silicate Analyses	....	115	1	....	....	....	....	....	2	....	....	118
Thermometer Calibrations	....	....	....	....	3	....	....	2	7	....	....	12
TOTAL	56	332	184	364	31	1 074	28	36	392	125	33	2 655

were expanded to a large extent due to donations of specimen material by companies and individuals active in the mining industry.

Mineral Identifications

Identifications of mineral samples numbered only 317 of which less than 40 per cent were for members of the public. Most of the work was for Branches of the Mines Department. A large number were on samples examined as a study of exposures in developing mining areas and others together with minor chemistry were to assist and test geological interpretation. These included X-ray diffractometer traces and trace element analyses to test the sedimentary origin of some talc schists.

A number of species from tin mining areas at Greenbushes included a monazite with abnormally high yttrium, a metamict microlite, staurolite, apatite and stibiotantalite.

A State Battery crushing of material from Tower Hill, Gwalia, contained vein quartz with molybdenite and scheelite. From 18 km south east of Ravensthorpe coarsely crystallised pyrite was identified in bands in a schist. Also from Ravensthorpe was a sample of andalusite in a sericite schist, aud from 1 km north of Ravensthorpe a specimen of brochantite was received.

Other sulphide material included arsenopyrite and minor pyrite in quartz from the Golden Crown, Day Dawn; pyrite, pyrrhotite and chalcopyrite with chlorite and serpentine from Wyndham area; and tetrahedrite from Dunham River.

Bright green veins in rock from Robinson Range consisted of a chromiferous muscovite with chromium 0.21 per cent. Inclusions of dark green muscovite in quartz contained a high iron content and 0.32 per cent chromium. A blue green clay proved to be chromiferous kaolin with 0.04 per cent chromium.

Material from Paynes Find contained some columbite in a quartz, plagioclase, grossularite, mica pegmatite.

Pumpellyite in the form of spherules was received from Table Hill on Talbot Station and as radiating acicular crystals from Norseman.

An examination of hand picked fibres and heavy media fractions of a rock was made to determine the presence of any fibrous amphibole residual after general replacement with fibrous quartz. None was observed.

Material from the upper Devonian-Napier limestone suspected of being fossilised bone consisted of finely powdered calcite, with fragmeuts of apatite containing pores filled with calcite.

An interesting aspect of establishing the structure of the new mineral carrboydite has been an X-ray fluorescence study of the co-ordination bonding of the contained aluminium.

A meta gabbro which on polishing appeared useful as a facing stone was received from between Greenbushes and Bridgetown.

An electron microprobe study was done on a vanadiferous titano martite from Coates Siding.

Other samples included baryte from Rothsay; beryl with an iron oxide coating from Mt. Narryer Station Mullewa; clinozoisite with quartz, clay and iron oxides from 3 km north east of Ora Banda; finely powdered gypsum from South Stirling and possible pecoraite with minor magnesite and serpentine from Lionel. This sample contained 27.2 per cent nickel and 0.008 per cent copper. Also received was topaz from Lennard River and a dark green tourmaline in quartz with a little iron oxide from 16 km south of Wittenoom.

New Mineral Localities

Listed below are localities from which specific minerals were recorded for the first time at these Laboratories.

Greater detail of localities may be available on application depending on the source of the material. Species identified for the first time in Western Australia are marked with an asterisk*.

Kimberley Division

beryl	Cone Hill
brochantite	Dunham River area
celadonite	Ragged Range
galena	Noonkanbah Station
nontronite	Cape Leveque
partzite	Dunham River area
smithsonite	Noonkanbah Station
sphalerite	Noonkanbah Station
tetrahedrite	9.5 km N of Dunham River Homestead
tripuhyite	Dunham River area

North West Division

alunite	18 km NE of Wonyulgunna Hill
alunite	Sawback Range
antlerite	21 km ENE of Wonyulgunna Hill
aragonite	Milgun Station
bastnaesite	Spear Hill, Marble Bar
beryl	Friendly Creek, Sherlock Station
brockite	ML 86, Wodgina
chalcocite	South of Kumerina
copiapite	Palm Pool, Fortescue River
coquimbite	Palm Pool, Fortescue River
digenite	South of Kumerina
*fluocerite	Spear Hill, Marble Bar
ilmenorutile	Ethel River area
kyanite	NW Coastal Highway crossing of Dampier-Tom Price Railway
malachite	South of Kumerina
*metastrengite	13 km E of Yarlarweelor Homestead
*soda alum	Millstream District
strengite	13 km E of Yarlarweelor Homestead
tetrahedrite	Bamboo Creek
variscite	18 km NE of Wonyulgunna Hill
variscite	Sawback Range

Murchison Division

*boltwoodite	Wilgie Mia
boleite	Batavia Shipwreck
cotunnite	Batavia Shipwreck
manganite	Milljanna Hill
phosgenite	Batavia Shipwreck
pseudoboleite	Batavia Shipwreck
rhodonite	Milljanna Hill
vivianite	Edamurta Range
xenotime	Wardawarra MC 35
zircon	Wardawarra MC 35

Central Division

bismutite	MC 227 Koolyanobbing
*carrboydite	Carr Boyd Nickel Mine
chromite	Salt Creek, Plumridge Lakes
copiapite	Bulong
molybdenite	Tower Hill, Gwalia
natroalunite	Karonie
opal—precious	Karonie
prase	9.5 km E of Menzies
scheelite	Tower Hill, Gwalia
spodumene	1 km N of Tantalite Hill

South West Division

brochantite	Ravensthorpe
chalcopyrite	Coates Siding
fluorite	Yandanooka, 5 km E
holmquistite	Greenbushes
malachite	8 km N of Boxwood Hill, Nanga District
montebraesite	Greenbushes
*mossite	Greenbushes
pyrrhotite	Coates Siding
uraninite	Ravensthorpe, 1.5 km N
whewellite	Bridgetown

The mineral takovite recorded from the nickel deposits at Agnew in 1974 and at Carr Boyd, Kambalda, and Widgiemooltha in 1972 has been found to be eardleyite, a mineral which differs from takovite in that it contains a small amount of carbonate.

Mineral Collections

The Division Mineral Collection was expanded to a total of 5636 specimens by the inclusion of material representing newly recorded mineral occurrences in the State. These local entries included representative samples from the iron ore bodies of each of the companies operating in the Pilbara area. Also specimens of accessory minerals associated with the Greenbushes tin deposits were added together with vanadium bearing laterite, fresh gabbro and selected pieces of drill core containing sulphides in gabbro from the project at Coates Siding. These samples were either donated or collected by the courtesy of the mining companies involved.

Fifty specimens from overseas included groups of rare or new Japanese minerals and pegmatite phosphates from the United States of America which were acquired to further projects on Western Australian minerals.

In all 292 additions to the collection were made.

Silicate Rock Analyses

An increasing percentage of the work output of the Division in recent years has been in multi element analyses, an example of which is silicate rock analysis.

Prior to the commissioning of the X-ray fluorescence-spectrometer the number of such analyses approximated 30 per year. The average over the last 5 years has been 312 per year.

The largest group of samples cleared this year numbered 1673 in connection with the preparation of the Geological Survey Branch report on the Laverton-Leonora-Rason geological map sheets, including a study of geochemical trace elements in the areas of these sheets. The report involved the estimation of 17 elements on 1673 samples, a total of 28 441 determinations. As an expedient in handling major element analyses of large batches of samples originally submitted for trace elements, the examination was made on pressed powder discs.

Though not the preferred method for silicate analyses the accuracy attained was acceptable. Statistical treatment of the analytical results generated a large volume of interpretive data. This included 272 histograms, 272 tables of correlation coefficients, 272 sets of statistical parameters and 1 144 inter-element scatter plots.

Geochemistry

Apart from the samples associated with silicate rock analysis, geochemical trace element analysis has been done on gossanous cappings and siliceous cappings for comparison with rock types.

Fifty shale samples were examined for gallium, rubidium and strontium as part of a geochronology study.

Some attention has been given to establishing limits of detection with the emission spectrometer available, the intention being to eliminate unnecessary quantitive work. The levels attained could be considerably improved with a more sophisticated instrument.

Ores and Mineral Products

Building materials and products: A number of concrete aggregates collected from the vicinity of the proposed Gregory Gorge dam site were examined for potential alkali reactivity. One was potentially deleterious and three were classified as potentially innocuous. Of these, one contained 70 per cent chalcedony, 20 per cent carbonate and approximately 1 per cent pyrite. Material of this mineral composition could, in some circumstances, be reactive. Extended mortar bar tests are proceeding.

Aggregates examined from La Grange included one which was classified as potentially reactive. It was a fine grained sandstone with a chert matrix. The reactivity was probably due to opaline material.

Forty-three other aggregates were examined mineralogically to supply data for a proposed publication on aggregates throughout the State.

Several investigations of building materials have been concerned with failure of mortar and concrete and the need to establish the actual mix used as compared with the specification.

At a Health Centre, a render backing coat specified to be 4 sand : 1 cement proved to be 7 : 1, 6 : 1; 8 : 1 and 7 : 1 in various rooms.

Mortar from a High School specified to be 6 : 1 : 1, sand: cement: lime was actually 10 : 1 : 1.4.

At a State Training Centre a concrete was specified as 1 cement : 1½ sand : 2¼ coarse aggregate of size 5-10 mm. The actual mix was 1 cement : 4 sand and no aggregate coarser than 5 mm.

Mortar from a medical centre specified as 1 cement : 2 lime : 5 sand contained 1 cement : 0.2 lime : 5 sand and at another part of the site where a cement/lime "bag mix" was used, the ratio of sand to "bag mix" was 7 : 1 instead of the specified 3 : 1.

Materials were received from a country town from different sites but concerned with the same problem, that of efflorescence on concrete masonry blocks and on adjacent window frames. From one site an analysis for arsenic was requested since it was feared that the blocks may have been made from arsenical sands resulting from past mining activity. The efflorescence was calcite which is not infrequently observed on this type of block. Subsequent examination led to the advice that the cause of the efflorescence was insufficient control in the curing stages of manufacture of the block at a local factory.

Masonry blocks from metropolitan works and proposed for use in a Government building were submitted for advice regarding the relative potential to efflorescence.

Analysis and X-ray diffraction studies were made of a briquette produced commercially from lateritic soil and also of the soil concerned. This work was preliminary to a study by the Engineering Chemistry Division of the manufacture of bricks from lime stabilised soil. This was part of a general project to provide low cost Aboriginal housing in remote areas using indigenous materials.

Samples were also examined of bricks hand made by natives from a mixture of sand, cement and clay soil.

Specimen slabs of marble were submitted for examination of the effect of extreme temperatures. Possible effects are a cumulative warping at high temperatures, and a disruption of the fabric at temperatures below freezing. Published specifications for building marble indicate that it should be sound and free from spalls, cracks, open seams, pits and other defects to impair the durability and appearance. It is obvious that a limited sampling programme could not provide reliable information regarding the whole of production. However since markets in low temperature areas were under consideration the specimens were subject to a freezing (−13°C) and thawing programme. No apparent structural change had occurred after 50 cycles. No accepted slabs were available for comparison.

An examination was made of facing blocks of the old Court House, Fremantle, preliminary to cleaning operations. The black scale formation was essentially gypsum.

In November the first sample concerned with "pop-outs" from wall plaster was submitted. In that one sample the expansive core was found to consist of an intergrowth of coarse lime CaO, with soft fine grained calcium hydroxide $Ca(OH)_2$ and a hard green silicate material. This consists of coarse crystals which are a calcium silicate (approximately $4CaO.SiO_2$) in a ground mass of calcium aluminate (approximately $3CaO.Al_2O_3$). Crystalline $3CaO.Al_2O_3$ and larnite ($2CaO.SiO_2$) are also present. The damaging agent in the core is slowly hydrating lime. The presence of the silicates would tend to shield the lime from hydration.

Clays

A large amount of work was concluded with the reporting of semi quantitative estimations of the content of various clay species in soils which form part of Agricultural Department potassium calibration trials. Bulked samples of 80 soils from Mandella were examined with other groups of 112 and 153 soils.

The impossibility of producing results which could be called quantitative in this type of work is stressed. Material of fineness less than 2 μm is necessary for X-ray diffractometry and estimates made on that fraction of the soil cannot be directly applied to other size ranges. Factors affecting the reliability of calibrations in this work are imperfections in and degree of crystallinity, presence of mixed layer crystals, shape of crystals, range of size and preferred orientations.

The mineral species measured in this series included kaolinite, smectite, illite-mica, chlorite, inter layer mixtures, meta halloysite, goethite and gibbsite.

The ranges used in reporting were:

Range	per cent
abundant	more than 60
common	20-60
little	10-20
trace	less than 10

Another group of clays which have required comprehensive testing have been those related to possible failure of foundations of buildings and dam walls. Considerable discussion has taken place as to the most useful type of testing that can be done. Conferences have been held with Departments using the test results, relative to interpretation of the data. Samples have been examined from Moochalabra Creek Damsite and the site of the Rocky Gully excavated tank for clay species, exchangeable ions and cation exchange capacity.

Diamond drill core from the Gregory Gorge Damsite was examined to determine the cause of failure of test pieces. Bands of goethite which softened when wet were the centres of weakness.

Failure of the bitumen coat of the Ravensthorpe catchment required examination of the underlying soil. The failure was attributed to two possible causes, (1) the degree of disruptive swelling due to a high montmorillonite content and (2) channelling erosion by movement of ground waters through dispersive soil.

Buildings for which soil foundations were examined were the Ravensthorpe Police Station and the Kalgoorlie Regional Hospital. For the former, decomposed rock and clay samples were examined which represented various weathering stages of the same rock type. The clay species were smectite and minor illite. The Kalgoorlie clays were essentially nontronite and kaolin with talc, goethite, and quartz. Swelling problems could be expected of this material.

Other clays examined were proposed as potentially suitable for paper fillers or coating. Samples from Wicherina proved to be weathered shale consisting of 80 per cent kaolin with quartz and illite. The kaolin was non-dispersive as were other kaolinised rocks. Kaolin from Ottorowiri siltstone at Eneabba contained less than 10 per cent material finer than 2μm.

A deposit at Leonora was a complex mixture of montmorillonite, kaolin and halloysite. Material from Lynwood was a plastic black clay which contained 30 per cent quartz, 10 per cent microcline and 5 to 10 per cent pyrite with approximately 5 per cent organic matter.

Full firing tests were done on a clay from Roebourne.

A green clay from Forrestfield consisted of a kaolin with unusual properties. Montmorillonite was sought but not detected in the sample.

Samples in connection with a project on "pop-outs" in the road surface north of Geraldton contained smectite clays in some places and not in others.

Clay and basalt samples from Bunbury were submitted to optical, X-ray diffraction and chemical examination to assist interpretation of the origin of various clay horizons as *in situ* weathering of the basalts or transport from a separate formation. An important element in the examination was boron at the level of 1 part per million.

Diatomite

Samples of diatomite examined were largely experimental products of a Departmental project to upgrade the output quality from local deposits. The work consisted of substantially complete analysis and physical tests.

Gold

Gold assay work for the State Batteries Branch has been at its lowest volume for some years. Eight samples only were submitted for Umpire analysis where dispute had arisen between Battery and client. No check analyses were submitted from the Batteries.

Three separate submissions totalling 26 samples were submitted by private laboratories to assist in calibrating their methods.

Numerous samples of gossanous material submitted for geochemical examination were assayed for gold with no outstanding values.

The highest values recorded from public samples were as follows.

	grams per tonne
Comet Vale	25
Dumals Find	31
Kookynie	42, 51
Mt. Gibson	31
Nullagine	26, 31, 36, 46
Wiluna	98, 99

The Wiluna material contained 0.67 and 0.73 per cent antimony.

Scheelite concentrates recovered from mine dumps assayed values which indicated approximately 85 grams per tonne of dump fines.

Two groups of samples totalling approximately 100 resulted from a sampling program on mine dump material and size fractions therefrom.

An investigation was conducted to find the reason for a .5 to 10 per cent amalgamation of 20 g per tonne material from an undisclosed locality. The gold was observed to be free and therefore amalgamable but a high concentration of heavy accessory minerals prevented contact with the mercury.

Some experimental products were examined in an attempt to interpret the chemistry of a chloride extraction process for gold. The intention was to balance total gold against water soluble aurous and free gold. Amalgamation of the gold was unsuccessful because of the extremely fine product material which coated the mercury.

Iron

In addition to samples submitted for analysis for iron, several suites were collected to enable definition of the potential hazard of dusts derived from iron ores and associated overburden and wastes. A brief study of the mineralogy involved was presented to the Symposium noted under Industrial Dust Hazards.

A study associated with interpretation of the geological history of the area was made on samples of shale and banded iron formation (B.I.F.) from the Brockman Iron Formation. Each sample was examined for 43 elements representing major and trace constituents. Shale and B.I.F. results were separately subjected to statistical examination which yielded a matrix of inter-element correlations. The large volume of this data (43 x 43 entries) proved difficult to interpret and a computer programme was developed to produce a graphical representation of those correlations which were significant at various levels of probability. From these the mode of occurrence of some elements can be inferred and other suggested combinations negated.

Initial steps were taken in connection with a project to compare recognisable micro horizons in banded iron formations within and outside ore bodies. Samples were collected from core made available by a mining company together with relevant drilling information. The core selected came from three zones of matching stratigraphy near the base of BIF 12, top of BIF 5 and base of BIF 4 at Rhodes Ridge (Trendall & Blockley classification of microbanding). A total of 4.2 metres of core was selected.

A concern of the Division in relation to iron ore has been participation in Australian Standards Association (A.S.A.) efforts in support of the International Standards Organisation project to set suitable standards for analysis of iron ores in world commerce.

Investigations as part of working groups have been conducted into analysis for alkalis and hydroscopic water in iron ores, and recommendations have been channelled through A.S.A. Problems involved with the determination of metallic iron are currently being investigated.

The Laboratories have membership of the Standard Association Sub-Committee on this subject and Mr. M. B. Costello attended a meeting in September.

Limestone

Samples were examined from coastal limestone quarries in the Moore River area.

The composition varied over the following range.

	Per cent.
CaO	30 47
MgO	0.51 - 0.58
acid insolubles	45 - 14

Zircon

A large group of zircon samples examined were experimental products resulting from a project to upgrade Western Australian zircon to a premium grade to facilitate its sale. The adherent surface iron was estimated and an optical means of assessing success in cleaning was devised and a quantitative comparison given of brightness and colour.

Other

Seventeen samples of magnesite from various localities were analysed for major constituents and complete analysis of five samples was made.

Samples collected to assess the grade of a new deposit of baryte in the Pilbara Gold Field ranged from 21 to 54 per cent barium with strontium 0.12 to 0.98 per cent and fluorine below 0.01 per cent.

Environmental Examinations

Fertiliser Works Waste: Priority attention was given samples taken in connection with the build-up of a mound near docking facilities and around the disposal pipeline from a fertiliser works. A pattern of sampling was used which enabled a picture to be drawn of the constitution of the mound, together with the location in the mound of various heavy metals at the level of parts per million.

A restriction on procedure was the need to ensure that the form of occurrence of the various elements was not altered since the solubility or otherwise of elements was a point of interest.

The mound itself consisted of crystalline gypsum and sludge intermixed with shell and sediment stirred from the sea floor.

Cockburn Sound Survey: Subsequent to this work samples from a pattern covering the whole of Cockburn Sound were examined for beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, nickel, vanadium and zinc. Considerable investigation of methods was necessary due to the preponderance of calcium carbonate in the sediments and the need to reduce levels of detection to a degree which was capable of showing variation which could be considered significant.

Cadmium, cobalt, copper, lead, nickel and zinc in the range 0.1-10 parts per million were determined with a single solution by solvent extraction and atomic absorption spectroscopy. Beryllium, iron and manganese were determined by atomic absorption spectroscopy without pre-concentration. Vanadium was determined spectrophotometrically after solvent extraction. Chromium estimation in the particular matrix had special problems and it was achieved ultimately by X-ray fluorescence spectrometry. Precision and accuracy checks were made of all methods. Some difficulty was experienced with heterogeneous samples.

Arsenical Waste Disposal: Another exercise concerned with protection of the environment was related to the disposal of a limited quantity (60 kilolitres) of waste material in the form of a sludge bearing 15 per cent arsenic. Approval existed that the sludge should be incorporated in concrete and discarded underground in a suitable selected mine shaft, the selection of which was in the hands of another Department.

Tests conducted included rate of extraction of arsenic with a static leach, a continuous leach and a leach after air drying. The results of these tests, with literature information, enabled the following recommendations to be made.

(1) The bitumen coat of walls and floor of the mine should be unbroken and as thick as possible.

(2) Care should be taken to have the arsenic sludge thoroughly mixed in the concrete.

(3) The concrete should be added in one pour to avoid any joints.

(4) The arsenic free concrete topping should be of a dense impervious mix applied to the wet mass of arsenic sludge concrete.

(5) A reinforced bitumen coat should be applied to the surface concrete to prevent efflorescence.

(6) Samples from around the mine should be taken before the pour as base controls for any future checks of leaching of arsenic.

A case of suspected pollution on the foreshore at Rottnest was in the form of pink streaks which proved to be a natural organic stain.

Dust Samples

Of the 1 405 dust samples examined, 368 were concerned with hazard in various industrial situations and the remainder with general monitoring of the environment. The largest group of these was 452 samples of lead collected from the air in Perth streets. Other large groups include iron dusts and manganese iron dusts; dusts containing calcium carbonate and hydrate; copper, nickel, iron rich dusts; dusts containing alumina and graphite; and iron and aluminium. Sixteen samples were submitted individually for identification and relationship to possible sources of origin.

Industrial Hazard

Closely related to dust samples examined from the general aspect of environmental protection were those dusts and fumes examined in relation to hazard in industrial situations. These consisted very largely of samples surveying the occurrence of respirable quartz in dust from work areas in the mining industry but also in quarrying and sand blasting. The materials from which the dust was derived were silicate rocks, iron ores, beach sands and diatomite upgrading products.

Whilst the samples examined for quartz dust have come largely from the hard silicate rocks of the Kalgoorlie area, considerable interest and effort has been applied to examination of iron ores. Because of the low percentage of quartz which is significant in dusts of high overall concentration in air, and due to the absorptive affects of the heavy matrix, attention was given to preconcentration of quartz from small dust samples prior to estimation by X-ray diffractometry. This separation allows calibration against pure quartz.

Some detail of this method was given in an address by Mr. M. W. Pryce to a Symposium on Dust in the Pilbara Iron Ore Industry. Consequent on this Symposium and discussion which then took place these Laboratories have been visited by several Environment Officers of the iron ore producing companies. The object of these discussions has been to assist in the setting up of monitoring systems for testing which the companies will be required to conduct under mines regulations, so that results may be comparable.

A series of samples have been examined with respect to respirable fibres largely in relation to asbestos but including also talc. The method of examination in this instance is that defined by the Asbestosis Research Council of the United Kingdom. This is an optical microscopic method using dark field illumination. Recent reports on work with electron microscopy has indicated that as little as 0.5 per cent of fibres are visible by this method. Since standards for comparison have been produced by the same means the method has a practical use but further investigation of the electron microscopy technique is necessary both on dusts and fibres in lung tissue.

Lead dust in the air of gold assay offices and in the work area of lead accumulator battery breakers was examined. Dust being breathed by a welder of hardened steel was found to contain both manganese and chromium in excess of limit levels recommended by the National Health and Medical Research Council. Fumes from a metal refinery were also examined for arsenic.

Forensic Examinations

Forensic examinations and others designed to assist police in their investigations have been done on 28 samples. Officers of the Division have attended Courts to give evidence.

Samples in conection with a fatal hit and run case consisted *inter alia* of thin flakes of glass which were removed from the scene of the impact. These were compared with part of a headlamp glass. Refractive index and density measurements of fragments from both exhibits were very similar, but a scan of elements present indicated that they were not identical.

Materials examined to assist in the investigation of another fatal hit and run case consisted of crystalline and amorphous fragments, the previous history of which could not be established. Fragments from a paint-backed mirror were described in detail for future comparison. For the same reason mineral residues extracted from exhibits in connection with an armed hold-up were described in detail.

In connection with another armed hold-up burned cloth from two sources was compared as was soil from two sources. In the properties measured there was no significant difference between the materials from the two sources.

In a case of wilful damage to a building, soil adhering to the boots of a suspect was found to be very similar in constitution, including minor accidental constituents, to soil from the scene of the damage. Glass from the boots however, differed in a number of characteristics from glass submitted for comparison. A subsequent sample of glass had properties consistent with those of the fragments from the boots.

A similar examination of shoes and soil in an attempted assault case indicated a common origin for the two samples. Samples were submitted in connection with two cases of wilful damage involving vehicles. A suspicion existed in the first case that artificial abrasive had been added to the differential oil but none was observed. In the second case of a sample of sand of a type suspected to have been added to the transmission of a road grader was submitted together with an oil filter. Only 0.1 per cent of dust was recovered from the oil of the filter and that was finer than the submitted sand and lacked some of its mineral constituents.

In a case where a fire occurred with a vehicle pumping petrol with a diesel powered pump, a witness stated that the motor had increased in speed before the explosion and fire, indicating that petrol fumes were entering the air intake. Fuel injectors from the diesel motor were submitted for examination since lead had been reported at the injector tips by another laboratory. Five micrograms of lead were detected in an extract from an injector tip but a subsequent examination of an injector not associated with the incident showed a comparable amount. No conclusion could therefore be reached from the analysis.

White particles which had been removed from the scene of an explosion and suspected of being remnants of the explosive material proved to be quartz.

Specimens were received for examination in a case where a charred body had been found in a area which had been swept by a scrub fire. Melting tests on parts of a brass buckle and simulation tests in relation to the condition of a tobacco tin and contents set limits to the temperature to which they had previously been subjected.

Miscellaneous Examinations

A sample of langbeinite product prepared from high density brine had an analysis indicating approximately 81 per cent langbeinite $K_2SO_4.2MgSO_4$.

A fresh specimen of the mollusc "paphia crassisulca" was examined together with a fossil which had been radio-carbon dated. There was concern that some alteration may have occurred in the fossil which would invalidate the method. X-ray diffraction studies of oriented chips and powder samples showed no significant compositional or crystallographic differences which would indicate replacement of elements.

Several samples were examined for carbon associated with various stages of an ilmenite upgrading process and the method of treatment was demonstrated to a technical officer of the company concerned.

A deposit in the copper pipes of the hot water line at a District Hospital was shown to be essentially poorly crystalline serpentine (basic magnesium silicate).

Deposits blocking waste pipes from a recovery unit in an X-ray film developing area at another hospital were examined and the chemical mechanism of the build-up described. Suggestions were made regarding separation of waste streams to obviate the difficulty.

Crystals found in the bottom of an empty wine bottle were identified as the common calcium tartrate hydrate.

A porcelain insulater from a telephone line was submitted for explanation of a brown stain associated with failure of several hundred insulators. It had been suggested that high winds in the area had carried limonitic soil up into the insulator. The stain was shown to consist of wustite, magnetite and lepiochrocite which forms do not support the above explanation. Together with the observed physical shape of particles and their trace element content they indicate an electric flash possibly due to an electric storm.

Two parts from the mechanism of parking meters were submitted to examination to determine any differences in hardness and chemical composition. Significant differences were found suggesting that the specification of a uniform material had not been met.

Similarly steel for a construction was submitted for a check on conformity to specification. Failure was confirmed by analysis for a single critical element, molybdenum.

The metallic composition, both in plating and the body of a butchers' brine needle was examined and lead was shown to be present to the extent of 90 parts per million.

Concern by consumers that their purchases were not true to description caused submission of reputed silver bracelets which were a 2 to 1 alloy of copper and silver. A persian "horse brass" had been sold as being silver with agate stones. The plate was in fact tinned brass with attached chains of silver. The stones were a low melting point glass.

Samples of fluoride in lumps and polished slabs were submitted for testing of their potential as a decorative material in building and furnishing. Tests were made of lode bearing properties, uniformity and colour stability and advice regarding use was given.

Equipment

A Pye-Unicam SP 30 UV/visible Spectrophotometer and a Sharp Compet-364P-III Electronic Calculator were the major items of equipment purchased by the Division during the year.

Computing

This year the Division continued to make use of computing facilities at the W.A. Regional Computing Centre.

Work is in progress for transferring most of the Division's computing requirements from the Western Australian Regional Computing Centre (WARCC) to the Government Chemical Laboratories (GCL) system, for our recently received PDP 11/40 computer and 'in-honse' processing of silicate analysis data has begun.

Continued use of WARCC facilities may be necessary in terms of storage of large amounts of data and the use of some large X-ray diffraction programs which require facilities beyond the scope of the GCL system.

The primary function envisaged for the GCL computer system is that of 'on-line' data acquisition from various instruments in the Laboratories. For the Mineral Division this involves the X-ray fluorescence (XRF) spectrometer system.

Past experience has shown that data manipulation constitutes a significant proportion of total analysis time in XRF work. Also the several data transcriptions required when using external computing facilities increase this proportion due to data validation requirements.

Programmes are beng developed whereby the GCL computer will accept data directly from the spectrometer with no intervening transcription stages. The necessary data processing can then be carried out and analytical reports produced with greatly reduced time and staff involvement.

Computer processing of silicate analysis data together with associated trace elements continued on a routine basis.

Field Excursions

The vanadium bearing gabbro project at Coates Siding was visited and samples collected with the co-operation of the operators Agnew Clough Pty Ltd.

Current geological and airborne dust information was collected by Mr. M. Pryce with the co-operation of mine operators at the mines and port facilities of all the iron ore producers in the Pilbara area. This excursion was related to the presentation of an address to a Symposium conducted in Karratha by the Australasian Institute of Mining and Metallurgy jointly with the Institute of Engineers of Australia on the subject of Dust Control in the Pilbara Iron Ore Industry. Mr. Pryce described the mineralogy of the ores and wastes concerned and the method used for estimation of quartz in small dust samples. The ready co-operation given by all companies to this exercise was much appreciated.

Company co-operation in transport and accommodation also allowed Mr. L. Bastian to sample drill core at Rhodes Ridge.

In September Mr. D. Burns and Mr. R. M. Clarke made the Duketon—Sir Samuel excursion organised by the Geological Survey Branch to introduce the geological map of the area.

Reassessment for registration with the National Association of Testing Authorities was made of four private laboratories by Mr. M. B. Costello and two by Mr. D. Burns.

Publications

Mr. M. W. Pryce joined with Mr. M. Nottle of Department of Agriculture in preparation of a paper on the study of urinary sediments and calculi from sheep pastured on subterranean clover. The compounds studied were the calcium salt of 4-methoxyequol-B-D-glucoronide, equol and 4-methoxyequol. The data produced included crystal photographs, both powder and crystal X-ray diffraction properties and also optical properties. Some of this data was not included in the paper which was published in the journal Research in Veterinary Science entitled "Composition of some Urinary Calculi of Ruminants in Western Australia".

A paper "Urea from Wilgie Mia Cave, W.A." by P. J. Brige, was published in the *Western Australian Naturalist.*

WATER DIVISION

General

In terms of providing a technical and analytical advisory service 1975 would be considered a fruitful year. The activities of the Division, particularly in the technical advisory area have increased substantially and this technical advisory service has been used by other Government Departments and the Public alike. Areas where the increase has been marked are associated with environmental consideration, corrosion and deposition prevention, effluent treatment and swimming pool treatment.

Sample receivals of 6 400 during 1975 was an increase of 5 per cent over that of 1974. Receivals for each year since 1970 have consistently increased by up to 10 per cent and this increase is mainly the result of greater involvement in environmental studies. As mentioned in previous annual reports, this increased receival and output, without corresponding increases in staff numbers has resulted in some restriction of investigational work in other areas such as corrosion.

A definite commitment in relation to Australian Water Resources Council Network Survey samples has not eventuated because both additional staff and buildings are needed and to date finance has not been approved. New equipment being ordered is primarily selected because of its use in the present laboratory function but consideration has to be also given to probable new functions.

Table 17 shows the sample receival distribution during 1975 and there are no major changes in the various areas of activity to that of 1974. Not indicated on the chart however is the amount of consultative and advisory work undertaken, much of which does not result in the subsequent submission of a sample for analysis.

TABLE 17

WATER DIVISION

	Agriculture Department	Conservation and Environment	Department	Fisheries and Wildlife Department	Geological Survey	Leschenault Inlet Advisory Committee	Medical Department	Metropolitan Water Board	Pay—Public	Peel Inlet Advisory Committee	Public Health Department	Public Works Department	Swan River Conservation Board	Other	Total
Corrosion	....	....	....	....	....	....	4	....	1	....	1	7	....	1	14
Deposits	....	....	....	....	....	....	1	....	4	....	1	7	1	3	17
Effluents	....	....	....	....	....	....	....	....	34	....	1	9	37	....	81
Environmental Monitoring & Surveys—															
Leschenault Inlet	....	....	....	....	....	40	....	....	....	....	....	....	....	....	40
Peel Inlet & Harvey Estuary	....	....	....	....	....	....	....	....	....	87	....	....	....	....	87
Swan River—															
Depth samples	....	....	....	....	....	....	....	....	....	....	....	....	301	....	301
Monitoring	....	....	....	....	....	....	....	....	....	....	....	....	181	....	181
Investigations	....	....	....	....	....	....	....	1	2	....	....	3	....	2	8
Treatment Chemicals	....	....	....	....	....	....	....	25	....	....	....	....	....	....	25
Waters—															
Fluoridated	....	....	....	....	....	....	....	890	....	....	....	724	....	....	1 614
General	21	121	34	98	156	....	4	1 900	453	....	41	1 195	....	28	4 051
Various	....	3	4	....	....	....	....	....	1	....	2	6	....	....	16
TOTAL	21	124	38	98	156	40	9	2 816	495	87	46	1 951	520	34	6 435

Public Water Supplies

(a) Hills Source Reservoirs Salinities: Although the effect of the significantly lower than average rainfall for 1975 (682 mm versus the annual average of 881 mm) would not be expected to exert its full impact on annual average salinities in a January to December consideration, the results in Table 18 for all the major dams (not pipeheads) show that there has been no increase in salinity since 1974.

TABLE 18

SALINITY OF HILLS RESERVOIRS

1964-75 (Surface samples)

Reservoir	Salinity as NaCl Annual Mean Maximum		Minimum		1975
	mg/l	Year	mg/l	Year	mg/l
Canning	265	1972	140	1964	190
Churchmans	110	1972	100	1974/75	100
Mundaring	445	1972	120	1964	250
North Dandalup * †	140	1972	105	1974	120
Serpentine	190	1972	120	1964	140
South Dandalup †	120	1974/75	120	1974/75	120
Victoria	235	1972	170	1974	180
Wellington	490	1973	140	1964	300
Wungong *	145	1072	125	1974	135

Total dissolved solids approximates to NaCl x 1·20 for hills reservoirs.

* These are pipehead dams and mean figures represent only the flow period.

† Constructed since 1964.

(b) Fluoridated Waters: The average fluoride levels in fluoridated supplies have been slightly lower than intended for Perth Metropolitan, Mundaring and Albany. In the Metropolitan area this was mainly due to failure of the dosage equipment at the Canning tunnel. Means for the samples received from the various fluoridated supplies during 1975 are listed in Table 19.

TABLE 19

Supply	No. of Samples	Fluoride, F mg/l mean	intended
Perth Metropolitan	827	0·69	0·8±0·1
Mundaring	155	0·69	0·8±0·1
Wellington	43	0·83	0·8±0·1
Albany	136	0·70	0·9±0·1
Collie	80	0·77	0·8±0·1
Esperance	98	0·85	0·9±0·1
Geraldton	93	0·85	0·8±0·1
Manjimup	114	0·90	0·9±0·1

(c) Metropolitan Treatment Plants: The treatment plants at both Mirrabooka and Gwelup sites are subjected to periodic trials in order to assess areas where improvement in throughput, product water quality or savings in chemicals can be achieved.

At Mirrabooka, basically a colour removal plant, the present system is to aerate, add lime, alum and alginate in that order prior to entry to the upflow clarifiers. Although dosing of alum prior to aeration was calculated to effect some saving in lime quantities dosed, this savings was not effected in actual plant practice. The previously practised method of dosing lime after filtration had caused problems of insolubles deposition in the clear water tank but the lime insolubles are now conveniently removed with the slurry from the clarifiers.

The product water from the upflow clarifiers with the present method is slightly more coloured due to higher pH of operation, but the increase in colour of 1 to 2 A.P.H.A. units is nullified by the present practice of breakpoint chlorination after filtration. The colour of the water in the holding reservoir is acceptable in terms of colour and algal problems are almost non-existent. Although not confirmed in balanced plant trials the new dosage point for lime appears to be giving greater clarifier throughput.

At Gwelup, basically an iron removal plant, the use of alum has been discarded and the present practice is to chlorinate to breakpoint prior to aeration and to use alginate as a coagulant aid. This new treatment effects a greater throughput.

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Chlorination after aeration which would effect a saving in chlorine quantity due to some oxidation by the air of ferrous ion, was not effective in forming a rapid settling floc. This result was not unexpected because earlier pilot plant trials indicated such a phenomena. Chlorination at levels less than breakpoint have caused excessive consumer complaints and all chlorination practices used in the Perth metropolitan area are recommended to be at breakpoint.

(d) Denmark Town Supply: The removal of colour from a raw water, whose qualities vary seasonally, has not been readily controlled mainly due to limitations of dosing equipment at the plant. Faulty dosage has caused poor upflow clarifier performance, subsequent overloading of the sand filter leading to breakthrough of material which has subsequently coagulated and deposited in parts of the distribution system causing appearance and odour complaints.

Recommendations included maintenance repairs to feed pumps so that dosage could be optimised, adjustment of the automatic desludger so that manual operation was minimal and implementation of a daily testing procedure so that causes of unpredicted problems can be subsequently assessed and rectification carried out. Several days were spent in obtaining optimum dosage conditions by a series of short term plant trials.

(e) Kojonup Town Dam Bitument Catchment: An inspection at the site in April 75 did not completely clarify the taste problems encountered over the previous years but nevertheless allowed a reassessment of previous recommendations which had not resolved the problem. During the time of inspection light rain was falling resulting in runoff from the catchment at an estimated $50m^3$ per hour after the previous 24 hours had recorded a rainfall of 15 mm. The taste threshold of the run-off water was 5, indicating that tastes are not only associated with initial run-off water after summer and autumn rains. Because the taste had apparently not abated since the raw bitumen surface application in 1971, and because laboratory tests on the bitumen in 1974 did not give water soluble tastes, it seems unlikely that the taste is associated with a water soluble component originally present in the bitumen. Bacterial breakdown of the bitumen was considered responsible for the continuing taste. Recommendations included monitoring of the taste threshold, so that seasonal run-off taste factors could lead to a bypass system for high taste threshold water.

Environmental

(a) Swan River Depth Sampling: The twelve monthly Surveys commenced in June 74 were completed in June 75. The results of this work have been examined, collated and compared with the results obtained by Spencer of C.S.I.R.O. in 1947/54 and the preparation for publication of this work as a Report of Investigation is at an advanced state.

Characteristics of sample stations down stream of the Narrows are very similar to each other and this is also true for stations upstream of the Causeway. It would appear that the "sill" near the mouth of the Swan river and the "secondary sill" in Perth waters between the Narrows and the Causeway, are exerting "salt wedge" influences which cause oxygen depletion by two distinctly separate processes in the "upstream of Causeway" and "downstream of Narrows" stations. The oxygen depletion in upstream stations occurs in summer/autumn and that in the downstream stations in winter/spring. High nutrient levels, haloclines and thermoclines were the main contributors to the upstream situation whereas haloclines were mainly responsible for the downstream situation.

Although there were no significant changes in nitrate levels between the years 1953 and 74 (ammonia was not determined in 1953) there were significant increases in total phosphorus levels. It is considered that the phosphorus increases are not primarily due to changes in environmental factors although they could be a factor. The method of analysis for total phosphorus used by Spencer in the earlier work involved the use of limited perchloric acid which in the case of saline water would have been lost as hydrochloric acid leaving limited sodium perchlorate in a neutral condition to perform the oxidation. It has been established that the earlier digestive technique oxidises or digests only a fraction of the phosphorus present as single cell algae whereas the present technique used by these laboratories includes all the phosphorus.

(b) Metropolitan Lakes: The Water Division was represented on the committee of the "Algae Odour Control Working Group", an "ad hoc" committee formed to examine the nature and causes of odours emanating from 3 selected metropolitan lakes, namely Blue Gum and Booragoon, located in the City of Melville and Lake Monger.

Regular samples were collected at monthly intervals and analysed for temperature, pH, colour, total dissolved solids, chloride, nitrogen fraction (ammonia, nitrate, organic), phosphorus fractions (ortho phosphate, total in solution, total), dissolved oxygen, biochemical oxygen demand, potassium, chlorophyll A, algae counts and odour threshold. These laboratories were largely responsible for collecting the data obtained and preparing a final report for presentation to the Public Health Department and the Department of Conservation and Environment.

The main conclusions from the short term investigation were—

(i) odours produced were from algae blooms of anabaena and anacystis (blue green) and although the odours were similar to the mixed isomers of benzene hexachloride there was none of this pesticide present.

(ii) the natural colouring matter in Lake Booragoon of 150 to 200 A.P.H.A. units inhibited all types of algal growth despite adequate levels of nitrogen nutrient and the phosphorus being present mainly in the ortho-phosphate form at a level of 1.0 mg per litre.

(iii) lakes other than those studied produced more intense algal growths and odours and Lake Bibra was quite outstanding in this aspect. Future studies will need to include lakes such as these where the environmental factors are other than urban runoff and urban seepage.

(iv) the results and report presented would be a useful starting point for any future proposed major investigation into environmental aspects associated with these lakes, but are not adequate to base any sound recommendations.

(c) Hertha Road Rubbish Disposal: Regular water samples from this source are still being collected and analysed. Pertinent parameters which are obviously contaminating the immediate water in the aquifer include colour, bicarbonate, ammonia and its breakdown product nitrate, calcium, iron, manganese and phenols. The effect of this contamination on the adjacent series of Gwelup bores feeding the Gwelup treatment plant is of some importance. Under the worst possible conditions and assuming that all of the water from Hertha Road finds access to Bore 80 of the Gwelup series, the water from this source after chlorination and filtration treatment will with the exception of ammonia be acceptable as a drinking water supply. Although the calculated ammonia level would be well in excess of that acceptable for breakpoint chlorination it is likely to be exchanged onto the soil during its traverse. If it were all converted to nitrate some problems could also be encountered. There is at present no evidence to indicate that measurable levels are reaching Gwelup Bore 80.

(d) Muja Char plant: The production of coal char is responsible for evolution of phenols into the atmosphere which may be captured by rainfall precipitation and transported to Wellington dam. Samples of rainfall from the vicinity of the plant indicate that phenol concentrations can reach as high as 0.086 mg per litre. Regular samples from tributaries feeding Wellington dam, as well as surface and depth samples from Wellington dam are analysed for phenols. Levels in some of the tributaries have reached as high as 0.004 mg per litre but values in the dam itself rarely exceed 0.002 mg per litre. The effects of such levels are most unlikely to be exerting an influence on Wellington dam but are nevertheless very difficult to quantify because:

(1) the presence of natural phenols are of the same order of value;

(2) the rapid breakdown of industrial phenol with time e.g. 24 hours is normally adequate to reduce a level of 0.010 to 0.005 mg per litre;

(3) it is not the phenol level that is objectionable to the water supply but the chlorphenol taste produced after chlorination.

Phenols analyses are frequently requested by various departments and unfortunately some are being caught up in the same phenol frenzy that existed more than a generation ago. It is necessary to note that the standard method of phenols analysis is not specific for phenol.

(e) Laporte Effluent: Regular samples of the effluent and waters in the sand dune disposal area are analysed. Most samples collected in the neutralised zone are diluted by the fresh ground water in the aquifer and the average final diluted and neutralised effluent has the following composition:

	raw effluent	diluted neutralised effluent
pH	1·0	6·3
	mg/l	
Iron, Fe	3 400	100
Sulphate SO_4	20 000	2 800
Calcium, Ca	....	700

If it is assumed that the diluted neutralised effluent gains access to the ocean (there is no evidence of it gaining access to the estuary) and that there is no calcium sulphate deposition in the sand dunes then approximately 80 per cent of the iron in the effluent is being retained within the dune system as insoluble hydrated oxide salts. If calcium sulphate is also being deposited in the dunes, which is implied by the levels of calcium and sulphate in the neutralised effluent, then the calculated retention for iron in the dunes would be proportionately higher. If the disposal area is moved to a new site before the lime sands are exhausted and the level of iron in the diluted neutralised effluent does not exceed 100 mg per litre then the present disposal method appears an effective method for removal of most of the iron.

(f) Harvey Estuary and Peel Inlet: Regular samples are collected from sites associated with this estuarine system at staggered 3 monthly intervals. In an attempt to assess whether there has been any significant deterioration in nutrient phosphorus levels, the results for total phosphorus were compared with those obtained by C.S.I.R.O. in 1951-56. Table 20 includes a number of stations from the C.S.I.R.O. work of 1951-56 where the locations appear similar to those used by these Laboratories during 1972-75. The results are for total phosphorus P in the surface water, the summer average representing the period from December to May and the winter average the period from June to November.

Apart from the differences in analytical methods for total phosphorus over the respective periods, which makes any quantitative assessment of the total phosphorus increase impossible, the tabulated results show that the Harvey Estuary is a significantly greater contributor to the phosphorus status than the Murray River.

It is difficult to reconcile the C.S.I.R.O. phosphorus results in 1951-56 for the Murray River mouth particularly as the summer sample would have been mostly water from the Peel Inlet.

TABLE 20

HARVEY ESTUARY—PEEL INLET

Sampling Station			Season	Phosphorus, P (total) ug/l		Chloride, Cl g/l	
C.S.I.R.O. No.	G.C.L. No.	Location		1951/56	1972/75	1951/56	1972/75
9	13	Murray river, Pinjarra	Summer	10	22	1·30	0·35
			Winter	8	29	1·05	0·95
6	12	Murray river, Ravenswood	Summer	16	40	7·14	5·51
			Winter	15	35	0·67	0·81
5	15	Murray river, South Yunderup	Summer	12	50	11·7	10·3
			Winter	13	40	1·81	0·91
3	2	Murray river, Mouth	Summer	3	30	20·7	14·1
			Winter	2	51	6·36	1·60
2	4	Peel inlet, Middle	Summer	11	17	19·0	21·0
			Winter	15	69	8·40	8·62
1	8	Mandurah Bridge	Summer	11	28	18·8	19·6
			Winter	11	74	12·9	9·47
	10	Harvey river Bridge	Summer	....	215	....	0·16
			Winter	....	211	....	0·16
	7	Harvey estuary, Pt. Mealup	Summer	....	53	....	20·4
			Winter	....	170	....	5·14
7	6	Harvey estuary, Inlet	Summer	12	25	18·0	21·0
			Winter	20	93	9·18	7·62

(g) Leschenault Inlet: Samples from this source continue to be collected at six monthly intervals, each sampling date being displaced by one month each year. Because of changes in the inlet due to harbour development and deep sewering of the area near the inlet that initiated monitoring of the inlet, the sampling sites have been revised to give a better coverage of the whole inlet. There is now less intensive sampling of the area near the town of Bunbury but there are new sampling sites in the rest of the inlet.

(h) Contamination of Farm Dams: Following previous analytical work and field trials with stock on naturally polluted farm dam waters, the result of which was inconclusive, a farm dam was deliberately contaminated with sheep faeces and trials were carried out on the effect this had on sheep. The deliberate contamination was tenfold that of the highest natural contamination encountered in earlier trials; this resulted in ammonia N and dissolved phosphorus levels both in the range of 50 to 100 mg per litre over the six week period of the trials. Apart from an initial loss in weight over the first few days due to non-acceptance of this water by the sheep, after the 6 weeks period there was no statistical difference between the body weights of these sheep and a control group.

Because of possible diseases, the recommendation is still for maximum debris removal from a farm dam after a summer flash flood.

(i) Lake Argyle: 20 samples from selected depths at various locations in Lake Argyle were submitted for analyses of salinity, iron, manganese, chlorophyl A and suspended solids in an attempt to select optimum monitoring sites. None of the samples contained phosphorus in excess of 0.02 mg per litre or manganese in excess of 0.05 mg per litre and at the time of sampling, July, there was no evidence of stratification or oxygen depletion.

(j) Lead in lakes near Freeway Interchange: Ten water samples collected at the northern end of the Narrows interchange from the edges of the artificial lakes gave total lead values in the water ranging from less than 0.002 to 0.011 mg per litre. These levels show that mild contamination from lead in motor car exhaust gases may be occurring, but that the level of contamination is less than that experienced with rein water in the United Kingdom and is well below the maximum allowed in a drinking water, namely 0.05 mg per litre.

Water Treatment

(a) Reverse Osmosis: Officers are involved in analytical and consultative work associated with existing and proposed reverse osmosis units. Apart from a visitation to two pilot plants situated at Munjeno Station near the proposed site for the new township of Agnew, analysis and advice were sought for proposed installations at Denham, Eucla and Madura. Apart from the well established potential for calcium carbonate and calcium sulphate deposition and subsequent membrane fouling additional potential deposition hazards need to take into consideration the solubility of calcium fluoride and silica.

It is noteworthy that one of the plants using a raw water in the total soluble salts range of 3 to 5 000 mg per litre was discharging a reject water at 30 to 35 000 mg per litre which was supersaturated with respect to calcium sulphate, calcium fluoride and silica. Based on solubilities in pure water the degree of supersaturation was fivefold for calcium sulphate, sixteenfold for calcium fluoride, and tenfold for silica. Although the reject water remained quite clear for several hours most of the surplus silica came out of solution before the lapse of 24 hours.

Although most pretreatment recommendations are based on distilled water solubilities which leaves a reasonable margin of safety for comparatively saline waters, it is not suggested that the practice be discarded in view of the degree of supersaturation known to have been tolerated in this instance.

(b) Silicate for Iron Complexing: As an alternative to iron removal by aeration and filtration (an acceptable treatment where the iron level is less than 5 mg per litre) the formation of an iron silica complex is economically feasible but its instability at elevated temperatures is its main disadvantage. Investigational work has been carried out with waters from Wanneroo and Moora where the present iron removal practice is by aeration and filtration. The necessity for the iron to be oxidised rapidly to the ferric state prior to the silicate addition was clearly demonstrated by the ease with which the complex formed with chlorine addition but not with aeration. Holding the treated water at 70°C for several hours was generally adequate to cause some floc formation of insoluble iron compounds. Applications of this type of treatment cannot be recommended for town water supplies with hot water storage heaters but would be suitable with instantaneous types. It would seem an ideal treatment for overhead or trickle irrigation waters with low levels of iron that would otherwise cause staining or blockage problems. It could also be useful for reverse osmosis but this aspect has not been studied. A limiting factor is its cost because the level of silica to be added is between two to tenfold that of the iron level and requires to be added as the silicate.

Corrosion

(a) Geraldton Water Supply—Allanooka Mains: Allanooka water, which has been the main supply for Geraldton for the past eight years, receives no treatment prior to entry into the cement lined mains. The average carbon dioxide and dissolved oxygen levels of 100 mg per litre and 2 mg per litre respectively makes this a particularly aggressive water towards steel but the present intent was restricted to its aggressiveness towards cement linings of mains and concrete holding tanks. An inspection of the site was made during the year.

In marked contrast to the cement linings of the Mundaring Goldfields mains, which were badly leached in less than 20 years by water containing less than 5 mg per litre of free carbon dioxide, the cement linings of the mains from Allanooka were barely attacked as shown in Table 21 and its life expectancy would be in excess of 50 years. Whether the attack was prevented by the bitumen coating over the cement lining or to the superior techniques of siting a denser lining is not clear. The performance of a bitumen dipped fibro asbestos pipe at Allanooka was very similar.

The storage tanks of concrete construction were not protectively coated and the surface 3 mm of concrete in the under water section, if not already dislodged could be readily removed with a soft brush.

TABLE 21

Allanooka Water Main
Profile analysis of cement lining

Sample	Calcium, Ca per cent At Allanooka	45 km from Allanooka
Surface to 2 mm	1·7	1·5
3 mm to 6 mm	11·3	11·7
9 mm to 12 mm	13·5	15·0

Recommendations for protection of the tank included protective coatings on the inner surface areas. Although aeration to remove carbon dioxide was considered, particularly in relation to making a less aggressive water for the Geraldton Supply, it was not considered the most suitable in relation to the present problem where the cement lined mains were proving quite resistant.

(b) Corrosion and Staining of Roofing above Multistory Buildings: Staining and corrosion in two multistory Government buildings resulted in inspections and recommendations. The staining and corrosion is due to the fallout of ferrous sulphate and sulphuric acid. Hydrolysis of ferrous sulphate leads to the formation of hydrated ferric oxides and further sulphuric acid. Methods of minimisation of the problem involve the use of a low sulphur fuel, the addition of a catalytic poisoner to prevent conversion of sulphur dioxide to sulphur trioxide, maintenance of temperatures in the flue above the dew point for sulphuric acid, adoption of the correct shutting down sequence for the boiler and the installation of a corrosion resistant stack such as stainless steel.

(c) Corrosion Inhibition of Water Supply Mains: Analysis and advice were given in an experiment designed to test the inhibitive properties in a galvanised steel main of an approved inhibitor comprising 56 per cent zinc sulphate, 24 per cent sodium dihydrogen phosphate and 20 per cent sulphamic acid. The dosage level was adequate to give 1 mg per litre of zinc (Zn).

Unexpected problems were encountered. The only suitable dosing point was at a point about 30 km upstream from the galvanised main to be protected and the intervening pipeline was a cement lined mains. Approximately 90 per cent of the dosed zinc was being absorbed on the cement lining and not getting to the test section. This was in marked contrast to the phosphate where more than 90 per cent was reaching the test section. A similar phenomena had been previously observed with copper sulphate dosage in a cement lined mains in the Perth metropolitan area. Also the zinc being corroded from the initial part of the pipe section under test, was being transported downstream and this together with the phosphate present in the dosed water was, in effect, supplying the intended inhibitor to all but the initial part of the test section.

Ideally the experiment should have been carried out by direct injection into an ungalvanised main. Corrosion measurements were in approximate agreement with those cited in the literature after due allowances had been made for the occurrences within the system.

Miscellaneous

(a) Swimming Pools: Consultative and analytical involvement in this area are continually on the increase and this is not unexpected with the increasing numbers of private and public pools being built, the variety of treatment processes available and the expense associated with a correct treatment.

Most colour or deposition problems encountered have been the result of:

(i) inadequate treatment of the source water for removal of iron, manganese, alkalinity or calcium;

(ii) non-maintenance of a breakpoint chlorination condition;

(iii) uses of isocyanurate stabiliser in excess of its recommended 25 to 50 mg per litre level;

(iv) use of sulphamic acid instead of mineral acids to reduce alkalinity—this prevents the formation of a breakpoint chlorination condition;

(v) use of calcium hypochlorite instead of chlorine gas or sodium hypochlorite—unless the raw water is low in calcium and splash losses are high, pool waters adequately dosed with calcium hypochlorite ultimately become supersaturated with respect to calcium carbonate. Problems resulting from overuse of calcium hypochlorite include the formation of a milky appearance to the pool water, deposits appearing in equipment and in some extreme cases cementation of sand filters.

In some instances recommendations have required completely discarding the pool water. These included a pool water which had been excessively dosed with sulphamic acid and another where sulphamic acid had not been used, but the water required chlorine in excess of 400 mg per litre to achieve a breakpoint condition.

(b) Silver/Copper Anodes for Treatment of Swimming Pool Water: Some additional investigations were carried out on this during 1975. The nett result of these investigations is that in no instances, as theoretically predicted, has the silver level exceeded 0.01 mg per litre. Levels where silver is reputedly an effective bactericide are of the order of 0.05 to 0.10 mg per litre and even at this level its bactericidal action in comparison to that of breakpoint chlorination is debatable. Particularly because of its non-acceptance by a number of world renowned authorities, there would need to be exhaustive investigations carried out before it could be recommended as an alternative to breakpoint chlorination. Its algicidal action is excellent bcause the normal copper level in the pool water after such anodic treatment is of the order of 0.5 mg per litre.

(c) Mercury Hazards: The use of mercury manometers for testing sand filter bed pressures has caused accidental spillage of liquid mercury into some water systems and the practice has now been banned. Although liquid mercury is soluble in water at ambient temperature to the level of 0.01 mg per litre, water which had remained in contact with the spilled mercury in the sand filter for 24 hours contained only 0.0010 mg per litre of mercury, which is the recommended maximum level for a drinking water. Average levels of mercury in the water from the sand filter with normal daily practice were 0.0001 to 0.0002 mg per litre which is a normal level for total mercury in natural water.

The use of mercury thermometers for continuous measurement of oven temperatures has now been discontinued. While the effects of thermometer breakage, due to over-heating of the oven above its operable range or accidental physical contact, are not so great in an oven operating at 100°C the effect is quite significant at 200°C at which temperature the vapour pressure of mercury is 17 mm.

The equivalent of a broken thermometer in a 200°C oven, gave a mercury reading at the oven outlet of 7 600 mg per m^3 (measured at ambient temperature) and the reading in the "duct-ventilated" room one hour after the contamination source had been removed was still 15 mg per m^3. Based on a T.L.V. of 0.1 mg per m^3 for a 40 hour week the oven air should not be breathed for more than 2 seconds or the room air for more than 12 minutes. These thermometers have been replaced with the dial type.

(d) Green Hair: Green hair is normally associated with washing or swimming in a water containing levels of copper of the order of 1 mg per litre. Elderly people with white or silver hair, or others with blonde hair, particularly if the blonde hair is further bleached by the action of chlorine in a swimming pool water, are prone. In one instance the source of copper in a private swimming pool was traced to the heat exchanger used for heating the pool in winter. There appeared to be no ready remedy for the removal of the green stain although a number of complexing agents and solvents were tried.

(e) Deionised Water. Previous preference for glass distilled water for laboratory use was mainly because of costs and the known silica and suspected fluoride "slips" that reputedly occur towards the end of the run. Recent rises in electricity have caused a rise in the cost for glass distilled water and the analysis in Table 22 for deionised water from a single passage through a double resin deioniser column is purer than that from a normal still. It also has the added advantage of removing "distillable" contaminants such as ammonia. In actual practice the deionised water is further polished through an additional "in series" unit. The water used for the results obtained in the table below had a specific conductivity of 550 microsiemens per cm at 25°C and a silica content of 7 mg per litre.

TABLE 22

Deionised water from double resin bed deioniser

Fraction at rated capacity passed	Specific Conductivity microsiemens cm^{-1} at 25°C		pH		Silica, SiO_2	Fluoride, F	Ammonia, NH_3
	immediate	after standing	immediate	after standing	mg/l		
0·2	0·6	1·8	8·1	6·6	0·01	<0·02	0·02
0·4	0·6	2·2	8·1	6·1	0·01	<0·02	0·02
0·6	0·6	2·1	7·5	6·5	0·01	<0·02	0·01
0·8	0·6	2·6	7·8	6·8	0·02	<0·02	0·01
0·9	0·6	4·6	7·8	6·2	0·02	<0·02	0·01
1·0	0·6	3·7	8·5	6·4	0·03	<0·02	0·01
1·1	1.0	4·1	8·0	6·1	0·33	<0·02	0·01
1·2	3·7	3·7	5·3	5·3	7·8	<0·02	0·01
1·3	13	13	4·7	4·8	15·3	<0·02	0·01
1·4	19	19	3·5	3·7	15·1	<0·02	0·01

DIVISION VIII

Annual Report of the Chief Inspector of Explosives for the Year 1975

In accordance with Section 10 of the Explosives and Dangerous Goods Act, 1961-1974, I submit for the information of the Hon. Minister for Mines the following report on the administration of the Act for the year ended December 31, 1975.

STAFF

Mr. K. R. Price, BSc (Hons), A.R.A.C.I., Grad. Dip. Admin., was appointed Deputy Chief Inspector of Explosives as from May 21, 1975 and on April 18, Mr. W. E. Bennett, Officer in Charge, Woodman Point Explosives Reserve was appointed Sub-Inspector of Explosives.

At December 31 the staff of the Explosives Branch totalled twenty one.

LEGISLATION

The following amendments to the regulations were made throughout the year—

Explosives Regulations, 1963:—Twenty four amendments were made affecting regulations 1, 75, 76, 103, 114, 115, 116 and 116A.

Flammable Liquids Regulations, 1967:—Sixteen amendments affecting regulations 4, 5, 47, 70, 79, 96, 97, 125, 136, 140 and 141.

AUTHORISATION OF EXPLOSIVES

Five samples of explosives were submitted and examined for suitability of use in Western Australia. By the end of the year definitive tests were still being carried out on three of the explosives the other two were authorised as follows:—

'Detaprime Primers' (ZZ)
Class 3—Nitro Compounds—Division 2

'Shearcord' (ZZ)
Class 6—Ammunition—Division 2

The formulation of seven authorised explosives was altered during the year ('Molanite', 'Iregel', 'Anzomex Boosters', 'Cordtex', 'Ribcord', 'Aquaflex' and 'Geoflex') and a pumpable grade of explosives, 'Molanite P', was approved for use in operations at Bunbury Harbour.

MANUFACTURE OF EXPLOSIVES

There was no change in the number of licences issued for the manufacture of authorised explosives. These five licences allowed the production of Class 2 Nitrate explosives containing potentially hazardous components, such as powdered aluminium, and more stringent requirements were prescribed for those operations than were required for the manufacture of the simpler ammonium nitrate-fuel oil blasting agents.

One of the two licences for manufacturing fireworks was allowed to lapse during the year—perhaps as a result of more economical operations using imported fireworks. Certainly, tests conducted by the Branch staff showed that the imported firework, 'Starshells', are less of a fire hazard than locally manufactured shells in that much fewer burning embers result from their use.

IMPORTATION OF EXPLOSIVES

Seven agencies continued to hold a licence to import explosives to Western Australia and one made use of the Woodman Point Explosives Jetty for the importation of 322 tonnes of mainly dynamite type explosives from America. The majority of imported explosives came into the State by rail from Victoria and consisted mainly of the dynamite type, boosters, detonating fuse and primary initiating explosives which were imported to replenish the magazine stocks as they were used during the year. Minor quantities of explosives for specialised use, for example oil well cartridges, were imported under authority of an Entry Permit. In all, some 28 different lots of explosives were imported in this manner and after examination were issued with a Certificate of Release.

Importation of ammonium nitrate prill for explosives usage continued under Branch supervision and two shipments totalling 3 960 tonnes were imported in this manner through Western Australian Ports.

Total Consumption of Explosives for 1975

The following summary shows the quantity of explosives used throughout Western Australia during the year ended December 31, 1975:—

	Tonnes
Blasting Powder (Class 1—Gunpowder)	2.5
Nitrate Explosives (Class 2—Nitrate Mixtures) a) ANFO	67 405.0
b) A1/ANFO	10 285.0
c) Slurry	1 551.0
Dynamite Explosives (Class 3—Nitro Compounds, Div. 1)	1 277.0
Booster, Seismic Explosives, etc (Class 3—Nitro Compound Div.2)	70.5
Detonating fuse (Class 6—Ammunition, Div. 2) (5.84 x 10^6m)	131.3
Primary Initiators (Detonators, relay elements, etc) (3.3 x 10^6 units)	118.8
Total	80 841.1

The graphs (Figure 1) of the annual consumption of explosives since 1892 illustrate the increase in the use of explosives which over the past ten years has paralleled the production of iron ore from mines in Western Australia.

EXPLOSIVES RESERVES

Explosives Reserves throughout the State continued to serve the mining industry by ensuring adequate stocks of explosives were available with minimal distribution problems.

As a result of several illegal entries to the Woodman Point Explosives Reserve in the first two months of the year and the destruction by fire of an explosives agency's office and tractor shed within the area, extensive work was carried out to improve security and firebreaks within the Reserve.

Only four vessels used the shipping facilties at Woodman Point throughout the year, the bulk of explosives conveyance to and from the Reserve being by road (81%) and rail (11%). To assist with the safe storage of the 322 tonnes of explosives received by ship from America, all Government "Public" magazines were used to full capacity.

Storage at the Kalgoorlie Explosives Reserve continued to increase and a new 50 tonne capacity magazine was completed during the year. A survey of the Reserve boundaries was made and specifications prepared for the construction of more than 3 kilometres of security fencing around the area.

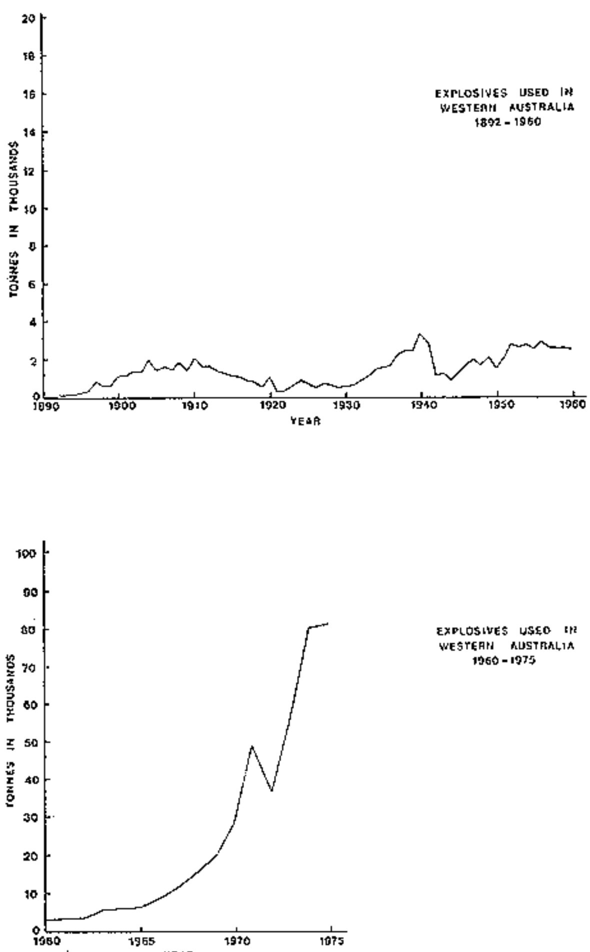


Figure 1

ANALYSIS AND TESTING

Nine samples of prilled ammonium nitrate were tested by the Laboratories for oil absorption and combustible material levels and though the results from all samples were satisfactory the Chief Inspector of Explosives made a recommendation to Westrail to alter the allowable level of combustible material in ammonium nitrate prill from 0.05% to a maximum of 0.2% in order to bring the transport requirements for Western Australia into line with international standards for this material.

Heat tests were conducted on 721 samples of nitroglycerine type explosives and all were found to be in safe condition. Similarly 20 batches of imported safety fuse were satisfactorily tested for burning characteristics. Three consignments of slurry type explosives were tested for sensitivity and one, consisting of approximately 4 tonnes of explosive, was required to be withdrawn from distribution because of failure to maintain the minimum sensitivity standard.

Three batches of distress flares were tested at the request of the Harbour and Light Department, one of which failed because of sub-standard light emission which was well below the prescribed level of 15 000 candelas for 55 seconds.

Extensive testing of electrical firing equipment was carried out through the year resulting in the addition of a modified "Nissan 30 Shot Exploder" to the list of condenser type exploders approved for use in Western Australia. The testing of a multi condenser type delay exploder was also completed but approval was withheld pending the installation of safety modifications deemed necessary for this instrument.

A total of 70 photoelectric and 50 battery operated blasting circuit testers were tested and shown to be in compliance with Australian Standard requirements for maximum current output for use on detonator circuits.

EXPLOSIVES LICENCES AND PERMITS

There was a total of 477 licences issued for explosives throughout the year, these were:—

Licence to Import	8
Licence to Manufacture Explosives	7
Licence to Manufacture Blasting Agents	119
Licence to Store, Mode A (50 kg)	33
Licence to Store, Mode B (150 kg)	17
Magazine Licence, Type One (Maximum 1 000 kg)	91
Magazine Licence, Type Two (1 001-5 000 kg)	45
Magazine Licence, Type Three (more than 5 000 kg)	63
Licence to Sell Explosives	47
Licence to Convey Explosives	47
Total Licences	477

In connection with the issue of the above licences some 256 inspections were made and considerable improvement was noted particularly in connection with explosive storage—no doubt the result of growing awareness amongst licensees that to follow the advice of an inspector will result in a more acceptable standard of safety for all concerned.

A total of 285 permits were issued throughout the year dealing with shotfiring, entry of explosives and fireworks. In connection with the latter permit, 34 fireworks displays were held for entertainment of the public with no reported injuries.

Training courses conducted by the Explosives Inspectorate for the issue of Shotfirer's Permits and to teach the safe use of explosives continued to be well attended. In all 7 courses were held and were attended by a total of 141 students of whom only eight failed to qualify for the Permit. A further 101 applicants who could not or did not wish to attend training courses were examined at Perth and in country centres for issue of the Permit and 90 of those were successful. In all, a total of 223 shotfirers were licensed throughout the year—one of whom, true to the spirit of Women's Year, was a lady spelaeologist—bringing the total number of qualified Shotfirers in Western Australia to 610.

USE OF EXPLOSIVE

Branch involvement in the use of explosives continued to increase especially since an amendment to regulation 114 deleted the exemption previously given on the use of explosives by State Departments of Works. As a result, the inspectorate were called upon frequently to advise on matters concerning explosives usage, particularly by those Shotfirers who have come to know Branch officers through explosives training courses. Also, calls from the public originated a total of eleven investigations of blasting complaints, all of which were satisfactorily concluded.

Proposals for the demolition of a gas works' chimney stack in South Fremantle were investigated by the Branch at the request of the Department of Labour and permission to use explosives was refused due to the probability of damage to surrounding dwellings. Special conditions to ensure public safety were also imposed by the Branch on proposals by an explosives demolition team intending to remove the wreck "Alkimos" by blasting. Several inspections were made of the use of explosives in deepening operations at Bunbury Harbour and these were confirmed as complying with methods previously discussed with Branch personnel. The introductory trials for a pumpable grade explosive were inspected and approval was given for its use from the drilling barges.

Practical assistance was given to the State Engineering works in an unusual case involving the removal of a 12 mm drill-bit which had seized when enlarging the centre hole in a 5 tonne steel cylindrical forging. All conventional means of removal had failed but the inspectorate after some experimentation succeeded in blowing the drill-bit from the forging using an explosive charge as propellant.

The most unusual incident to occur with the use of explosives throughout the year was a report of a hawk which swooped down to snatch a primed charge from the feet of a Shotfirer. When last seen the bird with the explosives cartridge in its talons trailing detonator lead wires was flying towards the hills. There was little the Branch could do but to arrange that the surrounding populace, particularly children, be warned of the potential danger of the charge which may have been dropped within the district.

EXPLOSIVES STOLEN, CONFISCATED OR DESTROYED

Thirteen reports were received concerning explosives found or reported stolen, totalling in all some 350 kilograms of explosives. In cases involving burglary the report was followed by immediate inspection of the premises to ensure action had been taken to reduce the possibility of further theft. Six of the incidents of theft were from quarries around the Metropolitan Area, three from Public Works Department premises and one from a magazine on the Woodman Point Explosives Reserve, as a result of which security has been significantly increased at all these premises.

In 28 inspections, usually in response to requests from licensees, some 3 750 kilograms of deteriorated explosives were destroyed in quantities ranging from four sticks (0.5 kg) to 60 cases (1 500 kg). In a further eight instances, potentially explosive deteriorated chemicals were removed from school laboratories and stores. In one instance the inspectorate was called upon by the WA Fire Brigades Board to render harmless a 50 kg drum of wetted calcium carbide. Liaison with the WA Fire Brigades Board continued at a high level throughout the year particularly in relation to dangerous goods.

DANGEROUS GOODS

The administration of the Flammable Liquids Regulations continued to occupy the greater portion of the Branch's dealings with dangerous goods, though other commodities, particularly ammonium nitrate and liquefied petroleum gases, together with the transport of dangerous goods in general, all required increasing time and attention from the inspectorate.

A total of 4 802 licences were issued for the storage of flammable liquids throughout the year for which some 3 820 inspections were made, which included the examination of 228 vehicles conveying bulk petroleum fuels, for compliance with the regulations.

The threat to petrol supplies during the year from strikes by tanker drivers precipitated many enquiries concerning the safety of fuel storages, particularly in relation to small storages of less than 220 litres capacity which though exempt from licensing requirements had to be maintained in a safe manner and the staff of the Explosives Branch was hard pressed to uphold this service to the public. In all, the staff handled some 7 600 telephone enquiries concerning various facets for conveyance, storage and handling of dangerous goods.

Several incidents within licensed premises, three involving fire which caused considerable damage to the storage depots, resulted in a more forceful administration of the regulations—one major fuel depot in Albany was refused renewal of licence and the company was instructed to cease operations involving the handling of flammable liquids until such requirements as were deemed necessary for safety had been maintained. All maintenance work on licensed premises, repairs to storage tanks, etc., involving "hot works" within flammable storage areas were conducted strictly in accordance with Branch requirements for safe working practice. These and other activities taxed the limited manpower associated with the technical and inspectorial staff of the Branch and involved all of those officers with greater work load than should be expected of them.

INCIDENTS INVOLVING EXPLOSIVES AND DANGEROUS GOODS

(a) *Explosives*

(i) Three fatalities which were directly attributable to explosives occurred during 1975. Two of the incidents were believed to be suicides and the third occurred when the deceased was attempting to set up an explosive device with malicious intent. In one of those investigations the Deputy Chief Inspector had to be recalled from annual leave to assist the police with their inquiries.

(ii) Two fatalities occurred when a private vehicle collided head on with a licensed explosives vehicle a short distance from Coolgardie. Fortunately the 12 tonne load of explosives did not detonate and the driver and co-driver escaped injury.

(iii) Four cases of injury caused by detonators were reported during the year. One case involved children playing with detonators, one of whom lost two finger joints and sustained injuries to his right eye after inserting a matchstick into the detonator. Two separate incidents within 3 months of each other occurred during the capping of safety fuse and were attributed to the discharge of static electricity buildup from the plastic outer coating of the fuse —the injuries sustained in both those cases were, fortunately, only superficial. The last case involved two youths who, following the theft of explosives and detonators, were experimentally firing charges with short lengths of safety fuse. The premature firing of a detonator resulted in one of the youths losing part of a finger.

(iv) Five instances of wilful damage by explosives were reported, one of which was perpetrated by the youth recorded injured above. Two of these outrages were on road signs and the other three were on a caravan, a mine and a house. Three of the cases have resulted in prosecutions by the police.

(b) *Flammable Liquids*

(i) Four cases of fire on licensed premises were reported throughout the year. Two occurred in bulk storage depots, one of which was completely destroyed when the pilot light of a gas refrigerator inside a caravan ignited flammable vapours, and the other caused damage to a tank truck fill stand and burnt out two bulk fuel vehicles when an explosion, believed to have been started from ignition of vapours by an exhaust spark, occurred during calibration of a tank vehicle. Only one person was injured in the latter incident. In the third case, a drum depot, Type B, was gutted by a fire believed to have been caused by irregular electrical wiring that was used contrary to the regulations prior to the installation of flameproof fittings. The fourth incident involved two youths who were both badly burnt in the service pit of a motor vehicle workshop when petrol vapour was ignited by one of the injured youths in a moment of stupid bravado.

(ii) Almost 12 kilolitres of petrol was lost as a result of a faulty expansion joint in a pipeline outside a bulk storage depot at North Fremantle during product transfer from the refinery. Prompt action by depot personnel isolated the leakage and the spilled petrol was washed away by the fire brigade and soaked into the sand without further incident.

(iii) Two fuel tank wagons were reported in rollovers throughout the year, both occurred in isolated areas of the State and, fortunately, as no fire resulted, neither of the drivers suffered major injuries. One of the drivers was later banned from driving by his company when it was discovered that he had breached the Flammable Liquids Regulations by not stopping at a rail-road level crossing—a fact which was directly attributable to the accident which occurred because evasive action had to be taken to avoid collision with a train.

(c) *Other Dangerous Goods*

(i) Ammonium nitrate was involved in only two reported incidents throughout the year. One was a train derailment which resulted in the contamination of ammonium nitrate with spilt fuel oil—fortunately the mixture was washed away without further mishap and in accordance with Branch recommendations, steps have now been taken to avoid future rail transport of these goods in close proximity to one another. The other incident involved a truck rollover in the North West in which the driver escaped injury and 20 tonnes of AN was lost without fire.

(ii) The Branch inspectorate investigated two explosions which were attributed to liquefied petroleum gas. The first, in which one man was injured, was initiated by a lighted cigarette contacting the gas-air mixture created by a leaking LPG cylinder within the house. The second also occurred as a result of gas leakage and injured three men working in a sewerage main. Work on the main ceased after the explosion until the Branch inspectorate checked the atmosphere and declared it free from flammable vapours.

(iii) Two incidents were reported concerning swimming pool chemicals when explosions occurred through contamination of the chlorinating agent. Inquiries revealed that the problem was a domestic one which may be solved by adequate labelling of the product and education of the persons concerned rather than by the imposition of regulation under the Explosives and Dangerous Goods Act.

COMMITTEES AND LECTURES

(i) The Chief Inspector attended two meetings of the SAA Committee AU/17 in Sydney during the year. This is a very active committee and in the short span of three meetings has prepared two draft standards for conveyance of flammable liquids.

(ii) SAA Committee ME/17 involved the Chief Inspector in much time consuming correspondence in relation to the proposed code for the "Storage and Handling of Flammable and Combustible Liquids", much of which is contentious in that the code, if adopted in its proposed form, would provide a lesser standard of public safety than exists in Western Australia at present under the Flammable Liquids Regulations.

(iii) The Advisory Committee on the Transport of Dangerous Goods held its 9th Meeting in Melbourne this year and Western Australia was represented by the Chief Inspector. The Model Code for the Transport of Dangerous Goods was produced by this committee and has been or is being adopted by legislation in other States of Australia. It has not yet been decided whether the Code should be implemented by legislation in Western Australia.

(iv) A lecture on "Explosive Usage" was delivered in October to the final year students of the Faculty of Engineering, University of WA.

(v) At the request of the Harbour and Light Department, a lecture was delivered to its Marine Surveyors on the hazards associated with the handling of flammable liquids and static electricity.

(vi) Two series of seventeen two-hour lectures on "Explosives for the Shotfirer" were delivered by Branch personnel throughout the year for Technical Education students.

CONCLUSION

The Explosives Branch maintained control of explosives and dangerous goods throughout the year only through the enthusiastic and unstinting attitude of its personnel towards their duties and my grateful thanks are extended to all members of the Branch staff. Appreciation is also recorded of the assistance given by members of other Departments and of other Branches of the Mines Department, in particular those of the State Mining Engineer, Survey and Mapping, Government Chemical Laboratories and Administration.

H. DOUGLAS,
Chief Inspector of Explosives.

DIVISION IX

Report of Superintendent, Mine Workers' Relief Act, and Chairman, Miners' Phthisis Board 1975

Annual Report 1975—Mine Workers Relief Act 1932 and Miners' Phthisis Act 1922.

Under Secretary for Mines:

1. This Report is submitted for the information of the Honourable Minister for Mines, on the above Acts for the year ended 31st December, 1975.

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:—

Kwinana, Herne Hill, Maddington, Gosnells, Armadale, Byford, Three Springs, Walkaway, Northampton, Useless Loop, Carnarvon, Nanutarra, Pannawonica, Robe River, Dampier, Cape Lambert, Whim Creek, Mt. Goldsworthy, Shay Gap, Finucane Island, Port Hedland, Marble Bar, Moolyella, Nullagine, Paraburdoo, Tom Price, Mt. Newman, Jigalong, Kumarina, Meekatharra, Mt. Magnet, Paynes Find, Merredin, Southern Cross, Bullfinch, Marvel Loch, Koolyanobbing, Coolgardie, Fimiston, Ora Banda, Scotia, Menzies, Leonora, Laverton, Windarra, Boulder, Kalgoorlie, Kambalda, Spargoville, Red Ross, Widgiemooltha and Norseman.

3. *Mine Workers' Relief Act*

3.1 *Total Examinations*

The examinations made under the Mine Workers' Relief Act during the year totalled 8,696 and compared with 5 164 for the previous year; an increase of 3 532. The results of examinations are as follows:—

Normal	8 394
Silicosis early, previously normal	33
Silicosis early, previously silicosis early	242
Silicosis advanced, previously normal	—
Silicosis advanced, previously silicosis early	11
Silicosis advanced, previously silicosis advanced	3
Silico-tuberculosis, previously normal	—
Silico-tuberculosis, previously silicosis early	—
Silico-tuberculosis, previously silicosis advanced	—
Silico-tuberculosis, previously tuberculosis	—
Tuberculosis, previously normal	1
Asbestosis early, previously normal	1
Asbestosis early, previously asbestosis early	—
Asbestosis advanced, previously normal	1
Asbestosis advanced, previously asbestosis early	—
Silico-asbestosis early, previously normal	3
Silico-asbestosis early, previously asbestosis early	—
Silico-asbestosis early, previously silicosis early	2
Silico-asbestosis early, previously silico-asbestosis early	5
Silico-asbestosis advanced, previously silicosis early	—
Silico-asbestosis plus tuberculosis, previously normal	—
Silico-asbestosis advanced plus tuberculosis, previously silico-asbestosis early	—
Total	8 696

The 1975 figures, together with figures for previous years are shown on the table annexed hereto. Graphs are also attached illustrating the trend of examinations since 1940.

3.2 *Analyses of Examinations*

In explanation of the examination figures, I desire to make the following comments:—

3.2.1 *Normal, etc.*

These numbered 8 394 or 96.53% of the men examined and include men having first class lives or suffering from fibrosis only. The figures for the previous year being 4 803 or 93.02% of the men examined.

3.2.2 *Early Silicosis*

These numbered 275 of which 33 were new cases and 242 had previously been reported; the figures for 1974 being 341 and 31 respectively. Early silicotics represent 3.16% of the men examined, the percentage for the previous year was 6.60%.

3.2.3 *Advanced Silicosis*

There were 14 cases reported 11 of which advanced from early silicosis. Advanced silicotics represent 0.16% of the men examined, the percentage for the previous year being 0.15%.

3.2.4 *Silicosis Plus Tuberculosis*

There were no cases reported. This compares with two for the previous year.

3.2.5 *Tuberculosis Only*

There was one new case reported in 1975 compared with none in 1974.

3.2.6 *Asbestosis*

There were four cases of early asbestosis and one case of Advanced Asbestosis reported during the year.

3.2.7 *Silicosis-Asbestosis*

Eleven cases of early silicosis-asbestosis were reported during the year, three being new cases. This category represents 0.14% of the men examined.

4. *Mines Regulation Act*

4.1 *Total Examinations*

Examinations under the Mines Regulation Act totalled 9 190. There was a decrease of 172 under this Act in 1975 as compared with 1974.

Of the total of 9 190 examined, 8 248 were new applicants and 942 were re-examinees. In addition, Provisional Certificates were issued to 832 persons in isolated country areas.

4.2 *Analyses of Examinations*

Particulars of examinations are as follows:—

4.2.1 *New Applicants*

Normal	8 246
Silicosis early	1
Silicosis early with tuberculosis	—
Tuberculosis	—
Other conditions	1
Total	8 248

4.2.2 *Re-Examinees*

Normal	942
Silicosis early	—
Silicosis early with tuberculosis	—
Tuberculosis	—
Other conditions	—
Total	942

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)	9 181
Temporary Rejection Certificates (Form 3)	—
Rejection Certificates (Form 4)	9
Re-Admission Certificates (Form 5)	—
Special Certificates (Form 9)	—
Total	9 190

5. *Miners' Phthisis Act*

The amount of compensation paid during the year was $5 273.40 compared with $6 201.88 for the previous year.

The number of beneficiaries under the Act as on 31/12/75 was 23 being 2 ex-miners and 21 widows.

V. T. FOSTER,
Superintendent, Mine Workers' Relief Act
and
Chairman, Miners' Phthisis Board.

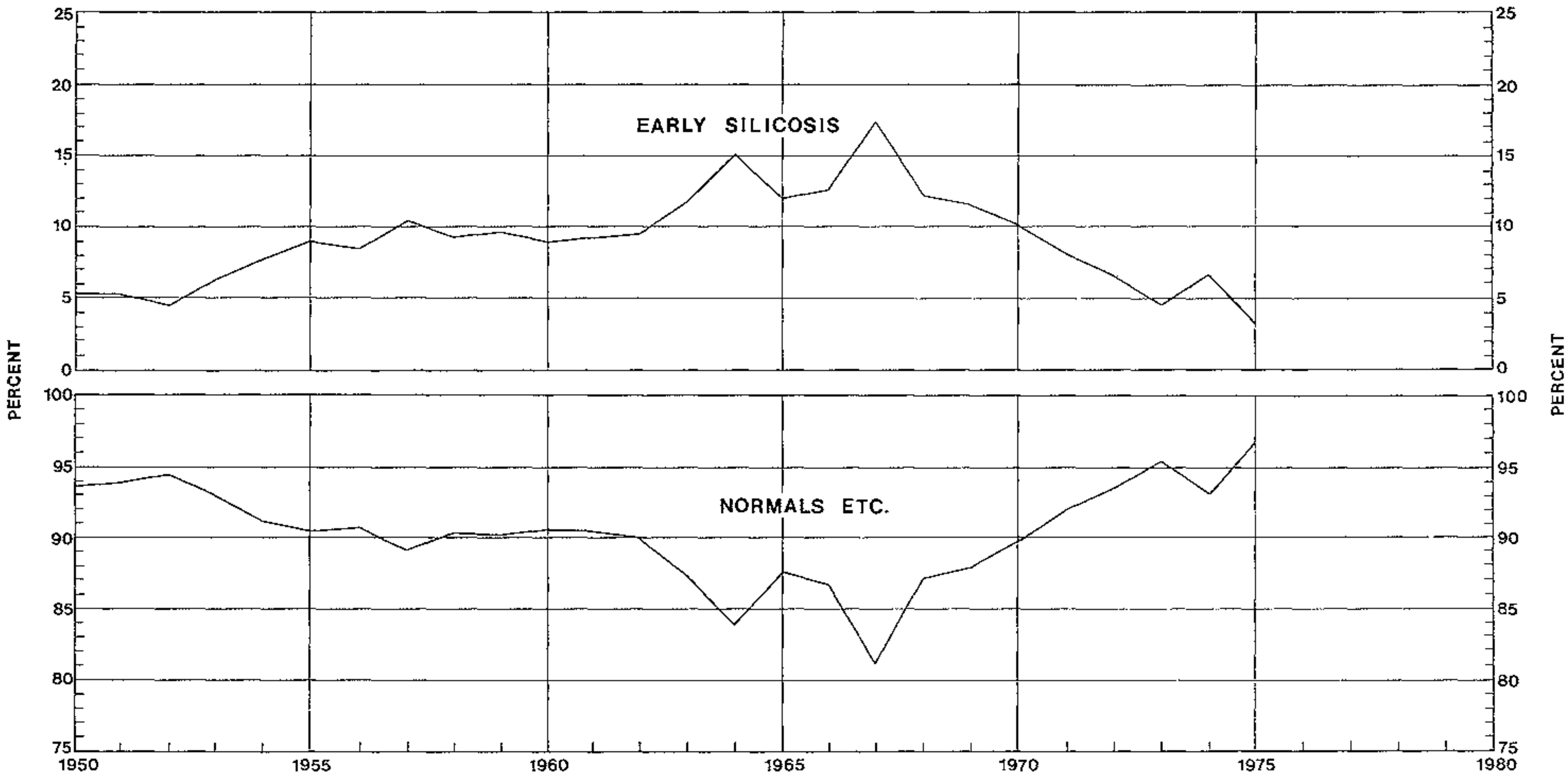
TABLE SHOWING RESULTS OF PERIODICAL EXAMINATION OF MINE WORKERS FROM INCEPTION OF EXAMINATIONS (1925)

	Normal		Silicosis Early				Silicosis Advanced					Silicosis plus Tuberculosis					Tuberculosis Only		Asbestosis									
Year	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.	Total
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	302	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	....	....	....	....	....	....	....	....	....	5 600
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	520	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	....	6 818
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	6	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	....	....	....	....	....	....	....	....	....	4 231
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	48 03	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

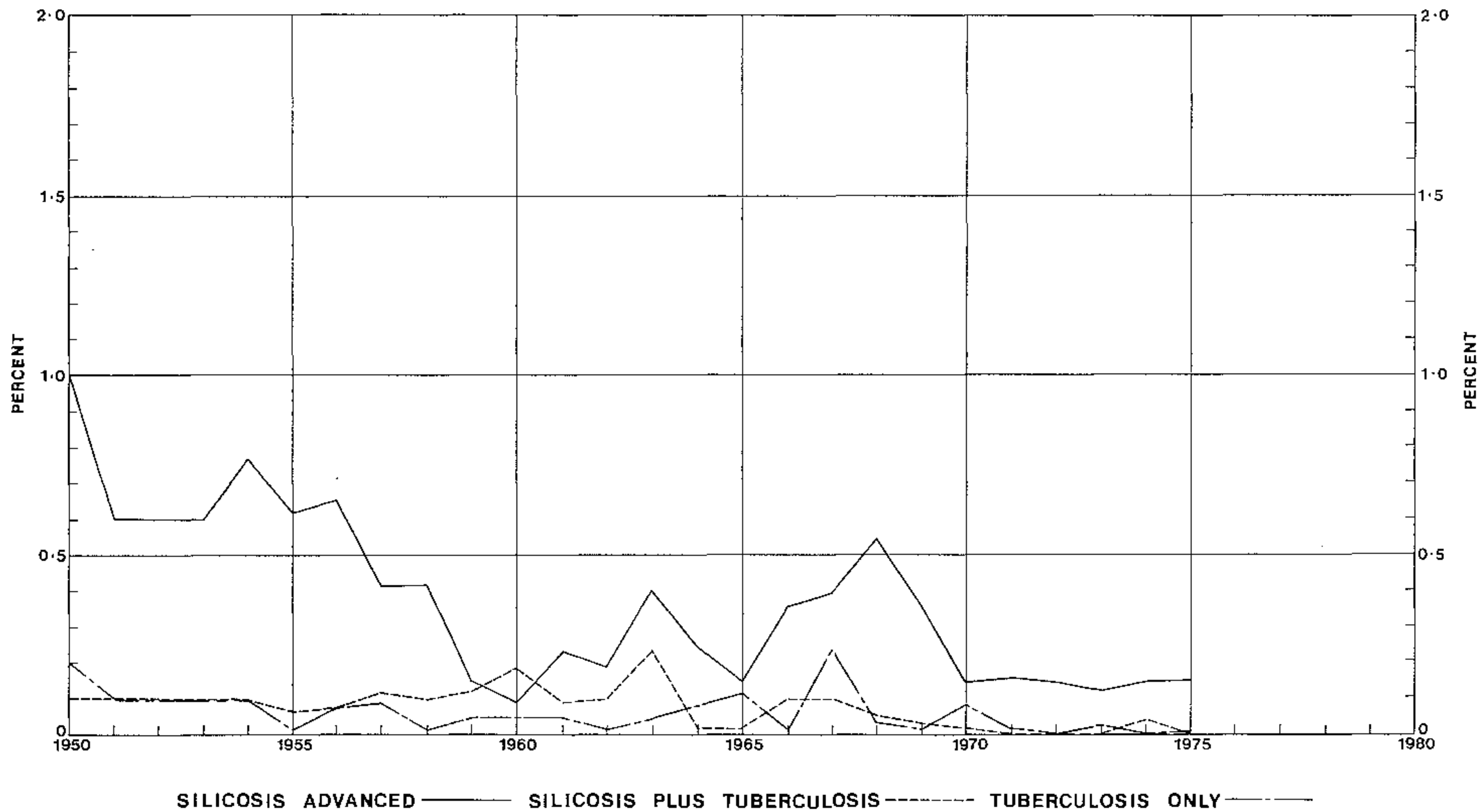
PERIODICAL EXAMINATION OF MINE WORKERS

GRAPH Nº1

SHOWING PERCENTAGES OF NORMALS AND EARLY SILICOTICS FROM 1950 ONWARDS



PERIODICAL EXAMINATION OF MINE WORKERS
GRAPH Nº 2
SHOWING PERCENTAGES OF SILICOSIS ADVANCED, SILICOSIS PLUS TUBERCULOSIS AND TUBERCULOSIS ONLY, FROM 1950 ONWARDS



MINING STATISTICS
to 31st December, 1975

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(17)—58638

TABLE I

PRODUCTION OF GOLD AND SILVER AS REPORTED TO THE MINES DEPARTMENT DURING 1975.

(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 1975					Total Production				
			Alluvial	Dollied and Specimens	Ore treated	Gold therefrom	Silver	Alluvial	Dollied and Specimens	Ore treated	Gold therefrom	Silver
			kg	kg	Tonnes	kg	kg	kg	kg	Tonnes	kg	kg
Pilbara Goldfield.												
MARBLE BAR DISTRICT.												
Bamboo Creek	G.M.L. 45/1118	Kitchener	....	....	304.00	4.553	....	....	....	3 152.22	90.340	.110
	1203	Mt. Prophecy	....	....	40.00	.284	....	....	....	5 668.76	83.204	3.536
Marble Bar	1450	Betty Boo	....	....	723.00	1.512	....	....	....	1 328.00	2.768	....
	1487	Charger	....	....	1 219.00	2.847	....	....	....	1 219.00	2.847	....
	(1456)	Elaine	....	....	338.00	.550	....	....	....	338.00	.550	....
	1331	General	....	....	398.00	.433	....	....	....	637.18	1.007	....
	927	Halleys Comet	....	....	....	15.121	1.705	....	....	6 462.06	253.684	27.507
	1209	Ironclad	....	....	404.00	.718	....	....	....	1 644.23	3.405	.006
	1332	Just in Time	3.713	....	....	....	.052	4.584	....	198.00	.179	.060
	1458	Kangaroo	....	....	265.00	2.105	....	....	....	326.99	4.712	....
Moolyella	1490	Rhondalex	....	....	193.00	.293	....	....	....	193.00	.293	....
		Sundry Claims	....	....	50.00	.070	....	....	....	50.00	.070	....
Northshaw	1468	Sponduelux	....	....	20.00	.288	....	....	....	88.00	2.143	....
	1492	Willie Woofter	....	....	403.00	.473	....	....	....	403.00	.473	....
					105.00	.295	....	....	....	209.90	3.872	....
Pilgangoora	1208	Birthday Gift	....	....								
Tambourah		Sundry Claims	....	....	13.00	.263	....	2.784	9.168	3 815.30	83.925	....
		State Battery—Marble Bar	....	....	....	*6.308	*.838	....	....	12.19	*477.339	*19.556
West Pilbara Goldfield												
Yule River	M.C. 47/305	Yule River Mining Pty. Ltd.	.701	....	....	....	....	4.082	....	....	1.439	.004
Gascoyne Goldfield.												
Mangaroon Station	G.M.L. 9/46	Star of Mangaroon	....	3.096	....	4.465	....	....	3.291	3 766.99	173.851	3.136
Peak Hill Goldfield.												
Peak Hill	G.M.L. 52/621	Atlantic North	....	.187	....	....	....	....	.813	....	....	....
	609	Morning Star	....	.594	....	....	....	....	.594	....	.038	....
	611	Mount Pleasant	....	....	30.50	.107	....	....	....	58.50	.197	....

East Murchison Goldfield.

BLACK RANGE DISTRICT.

arrambie	G.M.L. 57/1124	Barrambie Range	....	....	5.00	.086	...	....	....	73.58	4.153	.018
	1117	Scheelite Leases	....	....	50.00	.663	...	....	....	1 919.77	36.429	.610
		State Battery—Sandstone	....	....	....	*.850	...	....	....	295.16	*734.125	*1.898

Murchison Goldfield.

CUE DISTRICT.

Reedys	G.M.L. (20/2357)	Boffin	....	....	150.00	.177	....	....	....	150.00	.177	....

MEEKATHARRA DISTRICT.

Meekatharra	G.M.L. 51/2168	Commonwealth East	....	....	27.00	.676	....	....	....	27.00	.676	....
	2015	Haveluck	....	....	2 829.00	5.303	....	....	....	13 982.51	26.721	....
	(2139)	Ingliston	....	....	18.00	.283	....	....	....	18.00	.283	....
		Sundry Claims	....	....	68.00	.609	....	8.704	43.303	33 251.41	367.014	.407

DAY DAWN DISTRICT.

Day Dawn	G.M.L. 21/736	Cashel	....	....	73.00	.435	....	....	....	73.00	.435	....

MOUNT MAGNET DISTRICT.

Mt. Magnet	....	Sundry Claims	....	1.245	158.00	.445	....	4.913	83.154	63 839.70	944.038	.918
Moyagee		Sundry Claims	....	....	72.00	.099	....	.449	5.481	1 647.63	54.604	....

Yalgoo Goldfield.

Goodingnow	G.M.L. 59/1063	Ark	....	....	409.50	15.511	....	....	.388	3 650.41	107.729	....
	1242	Carnation	....	....	16.00	.091	....	....	....	508.78	5.856	....
		Sundry Claims	....	....	3.50	.074	....	4.757	5.567	11 078.97	162.906	.004
Noongal	....	Sundry Claims	....	....	3.00	.226	....	1.223	10.588	8 649.86	112.359	.036
Retaliation	1328	Julie	....	....	183.00	.766	....	....	....	183.00	.766	....

Mt. Margaret Goldfield.

MT. MORGANS DISTRICT.

Redcastle	G.M.L. 39/675	Agau	....	....	100.00	.245	....	....	....	100.00	.245	....

Table I.—*Production of Gold and Silver from all sources, etc.*—continued.

Mt. Margaret Goldfield—cont.

MOUNT MALCOLM DISTRICT.

Mining Centre	Number of Lease	Registered Name of Company or Lease	Total for 1975 Alluvial kg	Total for 1975 Dollied and Specimens kg	Total for 1975 Ore treated Tonnes	Total for 1975 Gold therefrom kg	Total for 1975 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
Leonora	G.M.L. 39/2043	Harbour Lights	....	....	405.00	.591	....	....	....	405.00	.591	....
	2015	Island	....	....	145.00	1.066	....	....	....	350.72	5.260	....
	1762	Sons of Gwalia	....	.123	416.00	.816	....	....	.336	2 724.07	6.163	....
	1860	Tower Hill	....	....	2 026.00	5.189	....	....	....	3 334.61	9.106	....
	1906	Two Glads	....	....	2 760.00	16.792	....	....	....	7 019.28	46.938	....
	2036	Victor	....	....	10.00	.079	....	....	....	10.00	.079	....
		Sundry Claims	....	....	350.00	1.240	....	1.207	12.211	25 688.52	412.487	.833
Wilsons Patch		Sundry Claims	....	....	60.00	.137	....	.145	1.694	1 888.03	45.887	.035
		State Battery—Leonora	....	....	....	*8.202	*.065	....	....	92.46	*70.112	*1.576
		(L.T.T. 37/18(2358H))—Leaver & Hadfield	....	....	485.00	*.458	....	....	....	790.00	*.723	....

MOUNT MARGARET DISTRICT.

Mining Centre	Number of Lease	Registered Name of Company or Lease	Total for 1975 Alluvial kg	Total for 1975 Dollied and Specimens kg	Total for 1975 Ore treated Tonnes	Total for 1975 Gold therefrom kg	Total for 1975 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
Laverton	G.M.L. 38/2624	Confusion	....	....	85.00	.319	....	....	....	201.85	.415	....
	2772	Golden Hill	....	....	379.00	.374	....	....	....	379.00	.374	....
		Sundry Claims	....	....	152.00	1.031	....	6.705	46.434	18 000.38	289.518	....
		L.T.T. 38/25 (2386H) McKenzie, J. A.	....	....	300.00	*.267	....	....	....	300.00	*.267	....

North Coolgardie Goldfield.

MENZIES DISTRICT.

Mining Centre	Number of Lease	Registered Name of Company or Lease	Total for 1975 Alluvial kg	Total for 1975 Dollied and Specimens kg	Total for 1975 Ore treated Tonnes	Total for 1975 Gold therefrom kg	Total for 1975 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		Sundry Claims	....	....	82.00	.752	....	1.445	66.699	3 187.84	108.127	....
Menzies	G.M.L. 29/5971	Alfia	....	....	32.00	.747	....	....	....	32.00	.747	....
	5815	Espacia	....	....	299.00	1.092	....	....	....	529.60	3.074	....
		Sundry Claims	....	.071	78.90	.723	....	1.769	19.490	43 980.69	828.269	25.311

ULARRING DISTRICT.

Mining Centre	Number of Lease	Registered Name of Company or Lease	Total for 1975 Alluvial kg	Total for 1975 Dollied and Specimens kg	Total for 1975 Ore treated Tonnes	Total for 1975 Gold therefrom kg	Total for 1975 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. 30/1326	Piano Rag	....	....	141.00	.255	....	....	....	141.00	.255	....
		Sundry Claims	....	....	69.00	.183	....	....	6.484	14 613.75	180.973	....
Morleys	1221	Emerald	....	....	61.00	.265	....	....	....	239.20	1.741	....
	1089	Paramount	....	....	90.00	.439	....	....	.046	4 787.47	19.534	....
Mulline	1107	Ajax West	....	....	79.00	.915	....	....	.043	8 568.58	207.857	....
	1173	Riverina	....	.214	....	....	....	....	.214	1 639.14	6.335	....
Mulwarrie	1113	Oakley	....	....	50.00	.244	....	....	....	5 852.05	283.280	10.387
		(L.T.T. 30/17 (2380H))—O'Brien, A.	....	....	50.00	*.043	....	....	....	50.00	*.043	....

NIAGARA DISTRICT.

Kookynie	G.M.L. 40/985	Marabella	....	....	98.00	.014	....	....	....	98.00	.014	....
		Sundry Claims	....	....	80.00	.183	....	1.895	3.370	10 374.49	219.906	.130
		(L.T.T. 40/10 (2370H)) Wanlessand Cumming	....	....	80.00	*.171	....	....	....	80.00	*.171	....

YERILLA DISTRICT.

Yarri	G.M.L. 31/1175 etc.	Porphyry (1939) G.M.N.L.	....	....	464.00	2.046	....	....	....	71 028.91	318.750	8.147
		Prior to transfer to present holders	....	....	....	....	....	....	....	30 831.44	169.477	15.785
Yerilla	....	Sundry Claims	....	....	161.00	.572	....	.027	.184	19 250.94	201.267	.043
		State Battery—Yarri	....	....	....	*4.070	*.190	....	....	280.94	*287.997	*.642

Broad Arrow Goldfield.

Bardoc	G.M.L. 24/2325	The Pride	....	....	50.00	.086	....	....	....	281.66	11.585	....
		Sundry Claims	....	....	227.00	.154	....	1.709	37.887	20 018.17	257.889	....
Broad Arrow	2346	Sunday Eve	....	....	79.00	.732	....	....	....	308.37	9.153	....
		Sundry Claims	....	....	650.00	1.414	....	31.370	98.832	42 334.87	555.897	.044
Ora Banda	2430	Dip	....	....	4.50	.129	....	....	....	4.50	.129	....
	2270 { 2290 {	Gimlet South Leases	....	....	9 584.00	6.922	....	....	....	68 789.56	203.270	5.120
	2310	New Gimblet	....	....	9.00	.203	....	....	....	2 526.76	13.702	....
		Sundry Claims	....	.163	69.10	.146	....	....	14.694	18 479.93	164.482	....
Paddington	2356	Colac	....	....	113.00	2.696	....	....	....	113.00	2.696	....
Siberia	2405	Pride of Erin	....	....	24.00	.091	....	....	....	24.00	.091	....
		L.T.T. 24/3 (1872H) Aurex Pty. Ltd.	....	....	....	*31.997	*4.066	....	.079	....	*31.997	*4.066
		(L.T.T. 24/42 (2390H)) Bizzaca, F.	....	....	31.00	*.139	....	....	....	31.00	*.139	....

North-East Coolgardie Goldfield.

KANOWNA DISTRICT.

Kanowna	....	Sundry Claims	....	....	163.00	.491	....	3.898	67.465	29 666.40	384.987	.053

KURNALPI DISTRICT.

Kurnalpi	....	Sundry Claims	....	....	14.20	.015	....	10.081	22.884	4 766.36	74.260	....
		(L.T.T. 28/3 (2433H)) McKenna, W.J....	....	*.285	....	....	....	....	*.285	....	....	....

Table I.—*Production of Gold and Silver from all sources, etc.*—continued.

Mining Centre	Number of Lease	Registered Name of Company or Lease	Total for 1975: Alluvial	Total for 1975: Dollied and Specimens	Total for 1975: Ore treated	Total for 1975: Gold therefrom	Total for 1975: Silver	Total Production: Alluvial	Total Production: Dollied and Specimens	Total Production: Ore treated	Total Production: Gold therefrom	Total Production: Silver
			kg	kg	Tonnes	kg	kg	kg	kg	Tonnes	kg	kg

East Coolgardie Goldfield.

EAST COOLGARDIE DISTRICT.

Mining Centre	Number of Lease	Registered Name of Company or Lease	Total for 1975: Alluvial (kg)	Total for 1975: Dollied and Specimens (kg)	Total for 1975: Ore treated (Tonnes)	Total for 1975: Gold therefrom (kg)	Total for 1975: 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)
Binduli	....	Sundry Claims	....	....	4.00	.021	....	....	.405	6 264.49	54.919	.010
Boorara	G.M.L. 26/6671	Waterfall North	....	.045	....	....	....	....	.045	378.75	7.196	....
Boulder	26/5780 etc.	Great Boulder Gold Mines Ltd.	....	....	14 419.00	41.699	22.263	....	.047	17 055 869.50	219 473.604	58 657.987
	5345 etc.	Kalgoorlie Lake View Pty. Ltd.	....	....	432 976.00	2 266.437	951.897	....	....	1 086 240.40	5 741.996	2 157.917
		Prior to Transfer to Present Holders	....	....	....	....	....	....	26.700	62 162 730.32	732 838.733	106 492.417
	5431 etc.	North Kalgurli Mines Ltd.	....	....	28 617.00	116.808	19.466	....	3.967	10 010 129.95	74 615.688	22 916.411
	5405 etc.	North Kalgurli (1912) Ltd. (Croesus Pty. Ltd.)	....	....	....	....	....	....	1.593	91 605.77	599.090	....
		Prior to Transfer to Present Holders	....	....	....	....	....	1.368	....	4 083 115.55	87 586.145	3 036.478
Feysville	6833	Suzanne	....	....	406.00	5.425	....	....	....	565.00	6.693	....
Hampton Plains	P.P.L. 277 Loc. 50	Kalgoorlie Lake View Pty. Ltd. (Pernatty)	....	....	923.00	6.424	....	....	....	3 431.88	21.147	....
	P.P.L. 175A Loc. 48	Shackleton, S.	....	....	433.00	1.177	....	....	.160	944.83	4.037	.008
Kalgoorlie	G.M.L. 26/6848	Golden Dream	....	....	103.00	.183	....	....	....	1 132.76	2.422	.115
	6692	Golden Pennies	....	3.275	....	....	....	....	3.275	30.48	.382	....
	6630	Golden Star	....	....	554.50	1.892	....	....	....	1 943.37	3.505	....
	6563 etc.	Kalgoorlie Lake View Pty. Ltd. (Mt. Charlotte)	....	....	610 849.00	2 657.417	....	....	....	1 584 375.38	6 204.798	....
		Prior to Transfer to Present Holders	....	....	....	....	....	....	.178	4 947 601.36	21 751.229	5.336
	6485	Maritana Hill	....	....	116.00	.028	....	....	....	6 843.95	21.008	....
	(6693)	Mary Rose	....	....	38.00	.385	....	....	....	93.10	.616	....
	6762	North Devon	....	....	47.00	.298	....	....	....	47.00	.298	....
	6639	Old Hinchcliffe	....	....	62.00	.038	....	....	....	2 361.75	7.326	....
ombola	6844 } 6845 }	Daisy Leases	....	....	893.00	16.181	....	....	.082	28 661.50	833.430	27.519
	6844	Daisy	....	....	....	....	....	....	....	6 383.06	156.511	....
	6845	Happy-Go-Lucky	....	....	....	....	....	....	....	2 108.55	52.125	....
	5689	Haoma Leases	....	....	224.00	.265	....	....	....	7 846.89	245.879	31.464
		Prior to Transfer to Present Holders	....	....	....	....	....	....	.008	61 167.00	1 801.890	25.728
	6783	Leslie South	....	....	28.00	.238	....	....	....	28.00	.238	....
	6614	Logans Gold Mine	....	....	691.00	3.957	....	....	5.227	7 987.20	46.715	.039
	6870	Sonda-Ditch	....	....	54.00	.382	....	....	....	54.00	.382	....
		Sundry Claims	....	....	618.00	1.413	....	....	22.336	29 546.31	487.250	.006
		State Battery—Kalgoorlie	....	....	....	*1.495	*.075	....	....	396.97	1 317.906	24.938

BULONG DISTRICT.

Balagundi	....	Sundry Claims	....	....	29.00	.027	....	.109	10.158	974.43	17.048	....
Bulong	G.M.L. 25/1378	Sun Rise	....	....	874.10	1.687	....	....	....	874.10	1.687	....
		Sundry Claims	....	....	9.00	.010	....	51.503	50.126	18 762.41	563.951	.010
Randalls	1356	Majestic	....	....	23.50	.024	....	....	....	796.86	1.171	....
	1364	Wanderers Find	....	....	72.00	.182	....	....	....	726.60	1.225	....

Coolgardie Goldfield.

COOLGARDIE DISTRICT.

Bonnievale	G.M.L. (15/6287)	Jenny Wren	....	....	117.00	.816	....	....	....	117.00	.816	....
	6151	Melva Maie	....	.038	61.80	.135	....	....	.084	1 129.88	3.246	....
	6289	Mystery	....	....	26.10	.104	....	....	....	26.10	.104	....
	5890	Rayjax	....	.160	651.20	2.021	....	....	1.190	1 897.09	56.050	.159
Bulla Bulling	6278	Pool Mans Wealth	....	....	119.00	.642	....	....	....	119.00	.642	....
Burbanks	6267	Grosmont	....	....	1 425.50	3.875	....	....	....	1 658.00	4.023	....
	6187	Ivanhoe	....	.088	....	....	....	....	.088	205.24	3.055	....
	6069	New Lord Bobs	....	....	397.00	.738	....	....	....	521.97	1.986	....
	6141	Warwick A. Taylor	....	....	45.00	.068	....	....	....	45.00	.068	....
		Sundry Claims	....	....	124.00	.325	....	1.712	15.475	20 118.74	299.211	.030
Coolgardie	6286	Angela	....	....	10.00	.182	....	....	....	10.00	.182	....
	6282	Doreen Rose	....	....	172.26	.832	....	....	....	172.26	.832	....
	6260	El Paso	....	....	21.00	.123	....	....	....	110.50	.268	....
	6276	Hangover Hill	....	.089	440.00	.630	....	....	.089	440.00	.719	....
	6154	Monkani	....	....	5 689.00	8.957	....	....	....	7 785.92	11.587	....
	6024	New Cock Shot	....	....	40.90	.523	....	2.054	....	259.35	1.134	.016
	6242	Paradise	....	....	97.00	4.362	....	....	....	97.00	4.362	....
	6024 etc.	Roebourne Exploration and Mining Ltd.	10.304	....	....	....	....	10.304	....	....	....	....
		Sundry Claims	.030	....	70.20	.288	....	7.375	95.544	92 899.12	941.628	.059
Gibraltar	....	Sundry Claims	....	....	62.70	.142	....	.043	1.579	3 867.37	45.406	....
Gnarlbine	6281	Emu Export	....	....	81.00	.384	....	....	....	81.00	.384	....
Hampton Plains	P.P.L. 484 Loc. 59	Baker, T. R.	....	....	424.00	.528	....	....	....	1 813.63	3.903	....
	P.P.L. 486 Loc. 59	Boucher, H.	....	....	25.00	.088	....	....	....	488.66	3.474	....
Higginsville	G.M.L. 15/5647	Fair Play Gold Mine	....	....	1 775.80	1.930	....	.137	1.950	34 008.04	106.932	.001
	6106	Liberator	....	....	167.00	1.236	....	....	....	505.34	6.031	....
	6061	Two Boys	....	....	678.40	6.393	....	....	9.074	3 979.64	35.934	....
Kambalda	M.C. 152 etc.	Western Mining Corporation	....	11.074	....	39.341	320.792	....	22.003	32.00	99.902	434.932
		Sundry Claims	....	....	59.00	.285	....	....	....	131.50	.618	....
Logan's Find	....	Sundry Claims	....	....	15.60	.075	....	.214	17.157	3 625.64	113.781	1.409
Ryans Find	G.M.L. 15/5999	Consolidated Gold Mining Areas N.L.	....	....	84.60	4.495	....	....	....	1 294.56	31.154	....
		Prior to Transfer to Present Holders	....	....	....	....	....	....	97.256	245.63	76.812	....
Widgiemooltha	....	Sundry Claims	....	....	170.10	.726	....	1.446	14.620	16 661.21	215.189	.002

Table I.—*Production of Gold and Silver from all sources, etc.*—continued.

Mining Centre	Number of Lease	Registered Name of Company or Lease	Total for 1975					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

Coolgardie Goldfield—cont.

KUNANALLING DISTRICT.

Mining Centre	Number of Lease	Registered Name of Company or Lease	Alluvial (1975)	Dollied and Specimens (1975)	Ore treated (1975)	Gold therefrom (1975)	Silver (1975)	Alluvial (Total)	Dollied and Specimens (Total)	Ore treated (Total)	Gold therefrom (Total)	Silver (Total)
Carbine	.... G.M.L. 16/1115	Emily	....	....	101.00	.186	....	....	....	101.00	.186	....
	1082	Hawkins Find	....	.131	91.00	.206	....	....	.131	91.00	.206	....
	1072	Leisa	....	6.022	176.00	2.613	....	....	6.022	509.50	3.844	....
		Sundry Claims	....	.208	....	....	....	4.238	3.487	7 127.04	75.891	....
Chadwin	....	Sundry Claims	....	....	8.00	.099	....	.444	4.253	6 592.54	96.384	.008
Dunnsville	1060	West Carolina	....	....	30.00	.083	....	....	....	40.80	.912	....
		Sundry Claims	....	....	27.00	.196	....	.653	32.163	3 260.29	66.437	....
Kintore	1059	New Haven	....	....	91.00	.495	....	....	.155	2 682.57	10.201	....
Kunanalling	1052	Catherwood	....	....	63.00	.248	....	....	....	936.30	2.411	....
	1112	Last Chance	....	....	44.00	.351	....	....	....	44.00	.351	....
		Sundry Claims	....	....	179.00	.313	....	6.735	30.928	18 373.66	322.555	.674

Yilgarn Goldfield.

Mining Centre	Number of Lease	Registered Name of Company or Lease	Alluvial (1975)	Dollied and Specimens (1975)	Ore treated (1975)	Gold therefrom (1975)	Silver (1975)	Alluvial (Total)	Dollied and Specimens (Total)	Ore treated (Total)	Gold therefrom (Total)	Silver (Total)
Bullfinch	.... G.M.L. 77/4607	Open Cut	....	....	167.00	.576	....	....	....	565.49	2.040	....
Golden Valley	4427	W.A. Gold Development N.L.	....	.173	....	....	....	....	....	9 883.15	127.272	1.400
Greenmount	4543	Devs Reward	....	....	296.00	.748	....	....	....	1 420.97	5.026	3.789
Holleton	4450	Brittania	.959	....	468.00	4.840	....	.959	....	2 703.30	58.529	....
Kennyville	4750	Battler	....	....	32.00	.038	....	....	....	32.00	.038	....
Marvel Loch	4434	Cornwall	....	....	59.00	.212	....	....	....	18 182.23	77.087	16.426
	3724	Frances Firness	....	1.700	357.00	6.901	....	....	20.110	25 663.43	335.811	9.543
	4631	Marvel Loch	....	....	1 082.00	20.808	....	....	....	1 082.00	20.808	....
	4230	May Queen	....	....	88.00	.511	....	....	....	378.59	1.861	....
		Sundry Claims	....	....	45.00	.240	....	.353	25.172	39 730.25	434.674	2.675
Mt. Jackson	4725	Numeralla	....	....	131.00	.599	....	....	....	131.00	.599	....
Parkers Range	4719	Golden Rod	....	....	108.00	.571	....	....	....	108.00	.571	....
	4626	The Australia	....	....	96.00	.380	....	....	.111	96.00	.380	....
		Sundry Claims	....	....	202.00	.558	....	.205	9.453	14 926.83	178.970	.101

Southern Cross ...	4634	Frasers	....	195.317	897.00	11.943	....	....	195.626	8 283.58	165.261	....
	4752	Holy Well	....	....	441.00	.826	....	....	....	441.00	.826	....
		Sundry Claims	....	....	42.00	.140	....	2.983	20.218	9 130.74	86.388	.298
		State Battery—Marvel Loch	....	....	....	*3.179	.177	....	....	149.36	*179.456	82.966
		L.T.T. 77/73 (1947H) Wright, L.	....	....	39.00	*.398	....	....	....	58.00	*1.599	....
		L.T.T. 77/67–70 (2123H–2126H) Weston, A. E.	....	....	....	*2.224	....	....	....	....	*2.224	....

Dundas Goldfield.

Norseman	G.M.L. 63/1936 etc.	Central Norseman Gold Corporation N.L.	....	....	129 479.00	1 436.804	676.453	....	....	5 598 170.18	76 226.352	52 184.207
		Prior to Transfer to Present Holders	....	....	....	....	....	....	51.735	70 940.22	1 489.610	513.482
	2175	Surprise	....	....	39.60	.042	....	....	....	39.60	.042	....
		State Battery—Norseman	....	....	....	*1.304	*.180	....	....	434.76	*826.274	*36.320

State Generally

		Reported by Banks and Gold Dealers	....	....	....	.287	....	37.351	38.447	....	41.668	35.487

TABLE II

Production of Gold and Silver from all Sources, showing in kilograms the output as reported to the Mines Department during the year 1975.

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	....	....	....	....	....	....	....	....	....	....	....	....	....
West Pilbara	....	....	....	....	....	....	....	.701	....	....	....	.701	....
Pilbara	Marble Bar	3.713	....	4 475.00	36.113	39.826	2.595	3.713	....	4 475.00	36.113	39.826	2.595
	Nullagine	....	....	....	....	....	....						
Ashburton	....	....	....	....	....	....	....	....	....	....	....	....	....
Gascoyne	....	....	....	....	....	....	....	....	3.096	....	4.465	7.561	....
Peak Hill	....	....	....	....	....	....	....	....	.781	30.50	.107	.888	....
East Murchison	Lawlers	....	....	....	....	....	....	....	....	55.00	1.599	1.599	....
	Wiluna	....	....	....	....	....	....						
Murchison	Black Range	....	....	55.00	1.599	1.599	....	....	1.245	3 395.00	8.027	9.272	....
	Cue	....	....	150.00	.177	.177	....						
	Meekatharra	....	....	2 942.00	6.871	6.871	....						
	Day Dawn	....	....	73.00	.435	.435	....						
	Mt. Magnet	....	1.245	230.00	.544	1.789	....						
Yalgoo	....	....	....	....	....	....	....	....	....	615.00	16.668	16.668	....
Mt. Margaret	Mt. Morgans	....	....	100.00	.245	.245	....	....	.123	7 673.00	36.806	36.929	.065
	Mt. Malcolm	....	.123	6 657.00	34.570	34.693	.065						
	Mt. Margaret	....	....	916.00	1.991	1.991	....						
North Coolgardie	Menzies	....	.071	491.90	3.314	3.385	....	....	.285	1 914.90	12.714	12.999	.190
	Ularring	....	.214	540.00	2.344	2.558	....						
	Niagara	....	....	258.00	.368	.368	....						
	Yerilla	....	....	625.00	6.688	6.688	.190						
Broad Arrow	....	....	....	....	....	....	....	....	.163	10 840.60	44.709	44.872	4.066
North-East Coolgardie	Kanowna ...	....	....	163.00	.491	.491	....	....	.285	177.20	.506	.791	....
	Kurnalpi	....	.285	14.20	.015	.300	....						
East Coolgardie	East Coolgardie	....	3.320	1 092 055.50	5 122.163	5 125.483	993.701	....	3.320	1 093 063.10	5 124.093	5 127.413	993.701
	Bulong	....	....	1 007.60	1.930	1.930	....						
Coolgardie	Coolgardie	10.334	11.449	13 050.16	80.244	102.027	320.792	10.334	17.810	13 860.16	85.034	113.178	320.792
	Kunanalling	....	6.361	810.00	4.790	11.151	....						
Yilgarn	....	....	....	....	....	....	....	.959	197.190	4 550.00	55.692	253.841	.177
Dundas	....	....	....	....	....	....	....	....	....	129 518.60	1 438.150	1 438.150	676.633
Phillips River	....	....	....	....	....	....	....	....	....	....	....	....	....
South-West Mineral Field		....	....	....	....	....	....	....	....	....	....	....	....
Northampton Mineral Field		....	....	....	....	....	....	....	....	....	....	....	....
State Generally		....	....	....	....	....	....	....	....	....	.287	.287	....
Outside Proclaimed Goldfield		....	....	....	....	....	....	....	....	....	....	....	....
Total								15.707	224.298	1 270 168.06	6 864.970	7 104.975	1 998.219

TABLE III

Return showing total production reported to the Mines Department to 31st December, 1975.

Goldfield	District	District: Alluvial	District: Dollied and Specimens	District: Ore Treated	District: Gold Therefrom	District: Total Gold	District: Silver	Goldfield: Alluvial	Goldfield: Dollied and Specimens	Goldfield: Ore Treated	Goldfield: Gold Therefrom	Goldfield: Total Gold	Goldfield: Silver
		kg	kg	Tonnes	kg	kg	kg	kg	kg	Tonnes	kg	kg	kg
West Kimberley	....	....	....	....	....	....	....	.040	.768	1.02	.077	.885	1 160.705
Kimberley	....	....	....	....	....	....	....	282.614	94.412	23 299.89	537.841	914.867	4.005
West Pilbara	....	....	....	....	....	....	....	201.871	11.655	25 300.54	759.720	973.246	59.432
Pilbara	Marble Bar	487.646	142.619	367 285.47	10 640.579	11 270.844	1 050.697	814.717	233.317	520 001.42	14 856.069	15 904.103	1 084.317
	Nullagine	327.071	90.698	152 715.95	4 215.490	4 633.259	33.620						
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	....	....	....	....	....	....	....	105.372	172.202	795 702.12	10 038.623	10 316.197	118.009
East Murchison	Lawlers	221.544	73.823	2 055 172.12	25 750.065	26 045.432	848.153	280.939	691.665	12 833 375.81	113 721.409	114 694.013	1 876.298
	Wiluna	7.355	39.007	9 016 048.65	58 235.757	58 282.119	321.060						
	Black Range	52.040	578.835	1 762 155.04	29 735.587	30 366.462	707.085						
Murchison	Cue	160.036	283.723	6 925 876.34	43 658.662	44 102.421	8 548.605	802.163	1 859.416	15 782 489.67	188 804.338	191 465.917	16 340.866
	Meekatharra	457.427	583.467	2 383 464.85	40 835.446	41 876.340	164.191						
	Day Dawn	102.381	353.886	2 070 709.73	42 787.912	43 244.179	5 270.404						
	Mt. Magnet	82.319	638.340	4 402 438.75	61 522.318	62 242.977	2 357.666						
Yalgoo	....	....	....	....	....	....	....	56.477	101.502	454 534.04	8 274.138	8 432.117	47.372
Mt. Margaret	Mt. Morgans	111.191	292.434	1 239 324.67	22 335.626	22 739.251	181.374	366.763	1 104.044	11 716 380.70	154 647.693	156 118.500	8 175.944
	Mt. Malcolm	126.552	520.656	7 905 804.88	95 791.547	96 438.755	5 935.809						
	Mt. Margaret	129.020	290.954	2 571 251.15	36 520.520	36 940.494	2 058.761						
North Coolgardie	Menzies	52.773	219.239	1 988 649.83	44 628.892	44 900.904	1 218.623	151.123	621.937	3 805 533.77	80 589.406	81 362.466	2 256.138
	Ularring	4.033	227.255	549 224.03	13 937.699	14 168.987	693.202						
	Niagara	53.451	56.717	960 611.06	16 444.745	16 554.913	177.793						
	Yerilla	40.866	118.726	307 048.85	5 578.070	5 737.662	166.520						
Broad Arrow	....	....	....	....	....	....	....	684.367	883.401	1 474 668.55	23 577.674	25 145.442	181.459
North-East Coolgardie	Kanowna	3 314.052	424.115	1 057 991.73	19 653.504	23 391.671	94.903	3 713.342	683.036	1 073 545.10	20 253.273	24 649.651	95.298
	Kurnalpi	399.290	258.921	15 553.37	599.769	1 257.980	.395						
East Coolgardie	East Coolgardie	1 049.527	1 298.565	105 588 624.18	1 227 493.679	1 229 841.771	207 233.391	1 901.934	1 798.392	105 784 039.69	1 231 663.166	1 235 363.492	207 236.494
	Bulong	852.407	499.827	195 415.51	4 169.487	5 521.721	3.103						
Coolgardie	Coolgardie	545.717	719.659	3 100 091.77	48 414.118	49 679.494	2 129.418	593.053	909.445	3 480 124.75	56 338.545	57 841.043	2 153.463
	Kunanalling	47.336	189.786	380 032.98	7 924.427	8 161.549	24.045						
Yilgarn	....	....	....	....	....	....	....	69.348	397.530	8 459 850.37	76 480.406	76 947.344	6 734.808
Dundas	....	....	....	....	....	....	....	70.176	519.883	7 678 582.26	106 497.195	107 087.254	65 186.744
Phillips River	....	....	....	....	....	....	....	18.883	25.608	133 523.68	3 916.102	3 960.593	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	....	....	....	....	....	....	....	10 470.279	10 170.135	174 057 236.73	2 091 648.478	2 112 288.892	317 760.810

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
1886	8·403	....	8·403	2 294
1887	135·592	....	135·592	37 036
1888	97·193	....	97·193	26 546
1889	431·079	....	431·079	117 742
1890	634·586	....	634·586	173 328
1891	843·406	....	843·406	230 364
1892	1 656·933	....	1 656·933	452 568
1893	3 085·543	....	3 085·543	842 770
1894	5 763·435	....	5 763·435	1 574 198
1895	6 441·847	....	6 441·847	1 759 498
1896	7 826·216	....	7 826·216	2 137 616
1897	18 781·724	....	18 781·724	5 129 954
1898	29 221·390	....	29 221·390	7 981 394
1899	39 916·966	5 823·952	45 740·918	12 493 464
1900	27 818·554	16 171·431	43 989·985	12 015 220
1901	28 729·876	24 252·300	52 982·176	14 471 308
1902	21 991·394	36 204·372	58 195·766	15 895 322
1903	25 930·526	38 291·976	64 222·502	17 541 438
1904	25 212·977	36 472·373	61 685·350	16 848 452
1905	20 375·573	40 441·549	60 817·122	16 611 308
1906	17 487·948	38 328·690	55 816·638	15 245 498
1907	13 430·579	39 369·240	52 799·819	14 421 500
1908	11 083·847	40 171·918	51 255·765	13 999 762
1909	12 017.463	37 600.957	49 618·425	13 552 548
1910	7 277·291	38 464·478	45 741·769	12 493 696
1911	4 989·691	37 649·055	42 638·746	11 646 150
1912	2 599·539	37 295·584	39 895·123	10 896 770
1913	2 682·834	38 188·480	40 871·314	11 163 402
1914	1 600·419	36 749·447	38 349·866	10 474 704
1915	539·349	37 099·332	37 638·681	10 280 456
1916	831·774	32 181·395	33 013·169	9 017 064
1917	280·631	29 899·606	30 180·237	8 243 292
1918	486·586	26 775·958	27 262·544	7 446 366
1919	200·490	22 631·509	22 831·999	7 237 016
1920	163·639	19 053·399	19 217·038	7 197 862
1921	223·035	16 999·914	17 222·949	5 895 052
1922	165·475	16 575·855	16 741·330	5 051 624
1923	184·562	15 507·496	15 692·058	4 464 372
1924	80·409	15 005·866	15 086·275	4 511 854
1925	121·633	13 602·843	13 724·476	3 748 640
1926	99·165	13 503·729	13 602·894	3 715 430
1927	104·480	12 596·703	12 701·183	3 469 144
1928	103·864	12 132·508	12 236·372	3 342 186
1929	94·465	11 637·022	11 731·487	3 204 284
1930	54·527	12 931·737	12 986·264	3 728 884
1931	53·705	15 826·860	15 880·565	5 996 274
1932	120·901	18 714·164	18 835·065	8 807 284
1933	76·109	19 743·255	19 819·364	9 772 508
1934	109·497	20 149·391	20 258·888	11 117 746
1935	306·951	19 880·732	20 187·683	11 404 208
1936	1 711·456	24 608·549	26 320·005	14 747 078
1937	2 228·468	28 895·125	31 123·593	17 487 510
1938	3 533·979	32 788·387	36 322·366	20 726 046
1939	3 071·154	34 695·859	37 767·013	23 685 928
1940	2 229·512	34 829·707	37 059·219	25 393 006
1941	2 050·526	32 453·118	34 503·644	23 702 890
1942	487·593	25 893·768	26 381·361	17 730 990
1943	199·322	16 797·964	16 997·286	11 421 338
1944	56·764	14 445·691	14 502·455	9 799 904
1945	156·431	14 417·125	14 573·556	10 021 082
1946	189·425	19 000·290	19 189·715	13 280 138
1947	162·363	21 730·951	21 893·314	15 151 148
1948	144·747	20 538·623	20 683·370	14 313 818
1949	129·799	20 038·492	20 168·291	15 925 616
1950	129·438	18 854·053	18 983·491	18 932 540
1951	173·851	19 352·261	19 526·112	19 450 686
1952	298·861	22 405·901	22 704·762	23 695 834
1953	167·844	25 458·683	25 626·527	26 598 184
1954	96·081	26 358·675	26 454·756	26 027 236
1955	127·260	26 062·030	26 189·290	26 351 118
1956	72·505	25 195·330	25 267·835	25 411 162
1957	63·522	27 826·374	27 889·896	28 076 370
1958	56·319	26 916·227	26 972·546	27 109 808
1959	72·222	26 882·327	26 954·549	27 083 868
1960	64·343	26 552·728	26 617·071	26 743 322
1961	91·524	27 025·885	27 117·409	27 413 780
1962	141·179	26 588·160	26 729·339	26 871 480
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	17 707 210
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
	361 101.039	1 799 114.432	2 160 216.371	1 190 587 627

	1974	1975
	$A	$A
Estimated Mint value of above production	1 115 914 563	1 123 284 535
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	40 607 680	62 123 888
Estimated Total	$A1 161 701 447	$A1 190 587 627
Bonus paid by Commonwealth Government under Commonwealth Bounty Act, 1930	322 896	322 896
Subsidy paid by Commonwealth Government under Gold Mining Industry Assistance Act, 1954, from 1955	29 200 611	29 200 611
Gross estimated value of gold won	$A1 191 224 954	$A1 220 111 134

TABLE V

Quantity and Value of Minerals, other than Gold, Reported during the year 1975

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonnes	Metallic Content	Value $A
		ALUMINA			
M.L. 18A	South-West	Alcoa of Australia (W.A.) Ltd.	1 108 908	....	79 993 800
M.L. 18A	South-West	Alcoa of Australia (W.A.) Ltd.	1 121 347	....	81 486 100
			2 230 255	....	(l) 161 479 900
		BARYTES			
M.C. 52/937	Peak Hill	Universal Milling Co. Pty. Ltd.	281	....	5 255
M.C.'s 8/1350, 1351	Ashburton	Lalor R. & McKenzie, R.	475	....	9 018
M.C. 70/511	South-West	Ilich, J.	22	....	415
			778	....	(a) 14 688
		BENTONITE (See Clays)			
		BUILDING STONE			
		Quartz			
M.C. 70/1921	South-West	J. E. Cutts	1 659	....	1 642
M.C. 70/2110	South-West	Snowstone, Pty. Ltd.	3 417	....	114 718
			5 076	....	(a) (b) 116 360
		Quartzite			
M.C.'s 70/1158, 1159	South-West	R. P. House	509	....	(c) 5 320
		CLAYS			
		Bentonite			
M.C. 70/1055	South-West	Scott, J. W.	253	....	2 177
M.C. 70/1042 etc.	South-West	Scott, J. W.	685	....	9 436
			938	....	(a) 11 613
		*Brick Pipe and Tile Clay			
M.C. 70/1438	South-West	Concrete Industries (Monier) Ltd.	22 410	....	(c) 22 056
		Cement Clay			
M.C. 70/798	South-West	Bell Bros. Pty. Ltd.	28 894	....	72 235
M.C. 70/483 etc.	South-West	Cockburn Cement Ltd.	30 931	....	76 090
			59 825	....	(c) 148 325
		Fireclay			
M.C. 70/304 etc.	South West	Clackline Refractories Ltd.	1 905	....	3 767
M.C. 70/1302	South-West	Bridge, J. S.	21 459	....	21 120
M.C.'s 70/522, 523	South-West	Bridge, J. S. and T. D.	30 891	....	30 403
M.C. 70/435	South-West	Midland Brick Co. Pty. Ltd.	147 873	....	36 388
M.C. 70/436, 437	South-West	Midland Brick Co. Pty. Ltd.	1 966	....	483
			204 094	....	(c) 92 161
		White Clay-Ball Clay			
M.C. 70/109	South-West	H.L. Brisbane & Wunderlich Ltd.	575	....	(c) 6 792
		Kaolin			
M.C. 70/247	South-West	Universal Milling Co. Pty. Ltd.	1 763	....	10 435
M.C. 70/2110	South-West	Snowstone Pty. Ltd.	16	....	316
			1 779	....	(c) 10 751

*Incomplete.

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonnes	Metallic Content	Value $A
		COAL			
C.M.L. 12/448 etc.	Collie	Griffin Coal Mining Co. Ltd.	973 208	....	5 506 375
C.M.L. 12/437 etc.	Collie	Western Collieries Ltd.	1 140 771	....	9 567 293
			2 113 979	....	(e) 15 073 668

TABLE V.—*Quantity and Value of Minerals, other than Gold, Reported during the Year 1975—continued*

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonnes	Metallic Content	Value $A
		COBALT (Metallic By-Product of Nickel Mining)			
M.L. 15/150 etc.	Coolgardie	Western Mining Corporation Ltd.	....	Cobalt Tonne 57·28	153 406
		COPPER (Metallic By-Product of Nickel Mining)			
M.L. 15/150 etc.	Coolgardie	Western Mining Corporation Ltd.	....	Copper Tonne 678·00	515 721
		EMERALDS			
M.L. 20/116 M.C. 20/213	Murchison	Bellairs, R. D.	Carats 1 304	....	5 250
		FELSPAR			
M.C. 59/5801 ..	Yalgoo	Chandilla Exploration & Investments Pty. Ltd.	282	....	4 215
M.C. 70/14521	South-West	O'Neil, C. K. & Watkins, A. H.	172	....	9 162
M.C. 15/80 etc.	Coolgardie	Australian Consolidated Industries	61	....	1 499
M.C. 70/111	South-West	Moore Prospecting Pty. Ltd.	186	....	2 745
			701	....	(a) 17 621
		GLASS SAND			
M.C. 70/1074	South-West	Ready Mix Group (W.A.)	11 804	....	N.A.
M.C. 70/1191	South-West	Silicon Quarries Pty. Ltd.	50 466	....	36 457
M.C. 70/417 etc.	South-West	Australian Glass Manufacturers Co.	16 539	....	21 981
M.C. 70/521	South-West	Bell Bros. Pty. Ltd.	28 457	....	46 954
M.C. 70/6056	South-West	Zaninovich, L. V.	40	....	16
			107 306	....	(c) 105 408
		GYPSUM			
M.C. 77/30 etc.	Yilgarn	Ajax Plaster Co. Pty. Ltd.	1 199	....	2 478
M.C. 77/50 etc.	Yilgarn	H. B. Brady & Co. Pty. Ltd.	18 172	....	44 714
M.C. 77/9 etc.	Yilgarn	West Australian Plaster Mills	20 073	....	41 472
M.C. 9/43 etc.	Gascoyne	Garrick Agnew Pty. Ltd.	49 293	....	169 478
M.C. 70/612 etc.	South-West	Gypsum Industries of Aust. Pty. Ltd.	20 492	....	64 042
			109 229	....	(a) 322 184
			Plaster of Paris reported as manufactured during the year 27 955 tonnes from 39 458 tonnes of Gypsum by three companies. Gypsum used in the manufacture of cement Nil.		
		IRON ORE Pig Iron			
			Ore treated Tonne	Pig Iron Recovered Tonne	
M.L. 2SA	Yilgarn	Wundowie Iron & Steel Industry	99 225	62 978	5 136 216 (c) (d)
		Ore Railed to Kwinana			
				Av. Assay Fe%	
M.L. 2SA	Yilgarn	Dampier Mining Co. Ltd.	*2 188 993	63·00	(n) 15 626 582
		Ore Shipped to Eastern States			
M.L. 4/10 etc.	West Kimberley	Dampier Mining Co. Ltd.	127 428	64·69	(n) 877 852
M.L. 4/50 etc.	West Kimberley	Dampier Mining Co. Ltd.	83 778	65·48	(n) 577 148
M.L. 244SA	Peak Hill	Mt. Newman Mining Co. Ltd.	5 980 460	64·00	(b) 37 375 613
		Ore Exported Overseas			
M.L. 4/10 etc.	West Kimberley	Dampier Mining Co. Ltd.	754 921	68·58	(b) 8 942 425
M.L. 4/50 etc.	West Kimberley	Dampier Mining Co. Ltd.	2 497 452	67·38	(b) 24 301 733
M.L. 244SA	Peak Hill	Mt. Newman Mining Co. Ltd.	23 894 369	63·00	(b) 209 523 488
T.R. 2401H	West Pilbara	Cliffs W.A. Mining Co. Pty. Ltd.	6 966 586	57·69	(b) 43 305 041
M.L. 4SA	West Pilbara	Hamersley Iron Pty. Ltd.	29 883 143	63·72	(b) 259 561 770
M.L. 235SA	Pilbara	Goldsworthy Mining Ltd.	7 260 239	63·19	(b) 65 788 575
			79 637 369	....	665 880 227

*Includes 1 114 052 wet tonnes shipped from Kwinana to Eastern States.

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonnes	Metallic Content	Value $A
		Pellets (Exported Overseas)			
T.R. 2401H	West Pilbara	Cliffs W.A. Mining Co. Pty. Ltd.	3 931 131	62·63	(b) 62 183 707
M.L. 4SA	West Pilbara	Hamersley Iron Pty. Ltd.	1 621 535	63·62	(b) 22 519 876
			5 552 666	....	84 703 583
		* LIMESTONE (For Building. Burning Purposes etc.)			
M.C. 70/1662	South-West	Bell Bros. Pty. Ltd.	6 016	....	5 295
M.C. 70/692	South-West	Bell Bros. Pty. Ltd.	54 905	....	48 316
M.C. 70/1290	South-West	Bellombra, V.	4 406	....	12 625
M.L. 70/14072	South-West	G. Korsunski Pty. Ltd.	115 921	....	57 043
M.C. 70/1227	South-West	G. Korsunski	183 602	....	90 350
M.L. 70/14211	South-West	Gibbs, C. E.	121	....	400
M.C. 70/713	South-West	General Bulldozing Co. Pty. Ltd.	1 668	....	1 086
M.L. 47/267 etc.	West Pilbara	Hamersley Iron Pty. Ltd.	29 721	....	22 293
M.C. 70/1105 etc.	South-West	Moore, F. W. and E. M.	475	....	966
M.C. 70/1298	South-West	Maffescioni, M. C.	3 245	....	3 245
M.C. 70/1093	South-West	Piper Walker Pty. Ltd.	189	....	188
M.C. 47/513	West Pilbara	Specified Services Pty. Ltd.	45 543	....	45 543
M.C. 70/709	South-West	Snader, R.	27 801	....	13 680
M.C. 70/1284	South-West	W.A. Limestone Co. Pty. Ltd.	13 841	....	20 548
M.C. 70/1660	South-West	Swan Portland Cement Ltd.	286 006	....	612 076
M.C. 70/727	South-West	Thiess Bros. Pty. Ltd.	628	....	182
M.C. 70/1237	South-West	Cooper Plant Hire Pty. Ltd.	1 016	....	406
	South-West	†Unspecified Producers	306 550	....	322 213
			1 081 654	....	(c) 1 256 455

*Incomplete. †From Private Property not held under the Mining Act.

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonnes	Metallic Content	Value $A
		MAGNESITE			
M.C. 77/76	Phillips River	Magnesite (W.A.) Pty. Ltd.	5 119	....	(b) 102 244
		MANGANESE (Metallurgical Grade)		Av. Assay Mn%	
M.C. 45/487 etc.	Pilbara	Westralian Ores Pty. Ltd.	11 140	46·06	(b) 195 938
		MICA			
M.C. 77/1309	Yilgarn	Mineral By-Products Pty. Ltd.	87	....	(a) 1 218
		MINERAL BEACH SANDS Ilmenite (g)		Av. Assay TiO2%	
Sussex Loc. 7	South-West	Cable Sands Pty. Ltd.	23 311	54·23	N.A.
M.C. 70/746	South-West	Cable Sands Pty. Ltd.	69 933	54·23	N.A.
M.C. 70/7556 etc.	South-West	Jennings Mining Ltd.	70 673	60·38	N.A.
M.C. 70/619 etc.	South-West	Westralian Sands Ltd.	116 455	55·90	N.A.
M.C. 70/399 etc.	South-West	Western Mineral Sands Pty. Ltd.	151 929	54·00	N.A.
M.C. 70/516 etc.	South-West	Western Titanium N.L.	187 663	52·91	N.A.
			619 964	54·80	(b) 14 960 955*
		Upgraded Ilmenite (g)		Av. Assay TiO 2%	
M.C. 70/516 etc.	South-West	Western Titanium N.L.	41 164	90·94	N.A.
M.C. 70/619 etc.	South-West	Westralian Sands Ltd.	5 593	68·00	N.A.
			46 757·00	88·19	N.A.

*Includes value of upgraded Ilmenite

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonnes	Metallic Content	Value $A
		RUTILE (g) (h)		TiO2 Tonne	
M.C. 70/7556 etc.	South-West	Jennings Mining Ltd.	29 804	28 510	4 051 338
M.C. 70/516 etc.	South-West	Western Titanium Ltd.	3 562	3 413	646 418
M.C. 70/9367 etc.	South-West	Western Mining Corporation	2 932	2 785	778 944
			36 298	34 708	(b) 5 476 700

TABLE V.—*Quantity and Value of Minerals, other than Gold, Reported during the Year 1975—continued*

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonnes	Metallic Content	Value $A
		LEUCOXENE (*g*) (*h*)			
				TiO2 Tonne	
M.C. 70/7556 etc.	South-West	Jennings Mining Ltd.	2 700	2 403	459 000
Sussex Loc. 7	South-West	Cable Sands Pty. Ltd.	835	733	133 399
M.C. 70/746 etc.	South-West	Cable Sands Pty. Ltd.	2 503	2 199	400 193
M.C. 70/619 etc.	South-West	Westralian Sands Ltd.	4 130	3 634	413 324
M.C. 70/516 etc.	South-West	Western Titanium Ltd.	128	113	11 520
			10 296	9 083	(*b*) 1 417 436
		MONAZITE (*g*) (*h*)			
				ThO2 Units	
Sussex Loc. 7	South-West	Cable Sands Pty. Ltd.	92	638	16 913
M.C. 70/746 etc.	South-West	Cable Sands Pty. Ltd.	274	1 910	50 735
M.C. 70/619 etc.	South-West	Westralian Sands Ltd.	936	5 616	130 508
M.C. 70/516 etc.	South-West	Western Titanium Ltd.	1 549	9 745	271 193
			2 851	17 909	(*b*) 469 349
		Zircon (*g*) (*h*)			
				ZrO2 Tonne	
M.C. 70/7556 etc.	South-West	Jennings Mining Ltd.	14 469	9 419	1 102 224
Sussex Loc. 7	South-West	Cable Sands Pty. Ltd.	1 598	1 042	255 875
M.C. 70/746 etc.	South-West	Cable Sands Pty. Ltd.	4 795	3 125	767 625
M.C. 70/516 etc.	South-West	Western Titanium Ltd.	22 969	14 834	4 394 216
M.C. 70/15565 etc.	South-West	Western Mining Corporation	379	246	97 284
M.C. 70/619 etc.	South-West	Westralian Sands Ltd.	46 141	29 580	7 385 050
			90 351	58 246	(*b*) 14 002 274
		NICKEL CONCENTRATES			
				Av. Assay Ni%	
M.L. 15/336	Coolgardie	Selcast Exploration Ltd.	8 539	14·00	4 256 772
M.C. 24/39	Broad Arrow	Great Boulder Mines Ltd.	10 968	14·82	5 814 255
M.C. 29/41	North Coolgardie	Great Boulder Mines Ltd. and North Kalgurli Mines Ltd.	4 941	9·70	1 573 900
M.C. 15/246	Coolgardie	Anaconda Australia Inc.	18 348	15·75	10 492 656
	Mt. Margaret	Windarra Nickel Mines Pty. Ltd.	68 850	11·48	25 725 337
M.L. 15/150 etc.	Coolgardie	Western Mining Corporation Ltd.	*306 379	12·03	129 965 608
			418 025	....	(*o*) 177 828 528

*Contained Silver 320·792 kg $35 404, Gold 33.782 kg $126 732. Transferred to respective items.

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonnes	Metallic Content	Value $A
		NICKEL ORE			
				Av. Assay Ni%	
M.C. 15/1288, M.L. 15/248	Coolgardie	Metals Exploration N.L.	72 360	3·42	(*c*) 5 960 114
		PALLADIUM (*h*) (Metallic By-Product Nickel Mining)			
				kg	
M.L. 15/150 etc.	Coolgardie	Western Mining Corporation Ltd.	....	108·166	267 240
		PLATINUM (*h*) (Metallic By-Product Nickel Mining)			
				kg	
M.L. 15/150 etc.	Coolgardie	Western Mining Corporation Ltd.	....	44·988	178 236
		RUTHENIUM (*h*) (Metallic By-Product Nickel Mining)			
				kg	
M.L. 15/150 etc.	Coolgardie	Western Mining Corporation Ltd.	....	5·632	8 221
		PETROLEUM			
		Crude Oils			
			Barrels		
1H	Ashburton	West Australian Petroleum Pty. Ltd.	12 833 894	....	(*m*) 28 619 583
Lic. 1	South-West	West Australian Petroleum Pty. Ltd.	33 875	....	(*m*) 75 541
			12 867 769	....	28 695 124
		Natural Gas			
			$m^3 10^3$		
Lic. 1	South-West	West Australian Petroleum Pty. Ltd.	832 171	....	(*p*) 5 337 272
		Condensate			
			tonne		
Lic. 1	South-West	West Australian Petroleum Pty. Ltd.	3 745	....	N.A.

TABLE V.—*Quantity and Value of Minerals, other than Gold, Reported during the Year 1975—continued*

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonnes	Metallic Content	Value $A
		SALT			
		State Total as Reported to Mines Dept.	3 629 328	....	(b) 17 138 054
		SEMI-PRECIOUS STONES			
		Amethyst	kg		
M.C. 9/444	Gascoyne	Soklich, F.	262	....	518
		Chalcedony			
M.C. 9/498 etc.	Gascoyne	Soklich, F.	394	....	327
		Moss Opal			
M.C. 63/60	Dundas	Soklich, F.	6 769	....	2 969
			....	....	3 814
		SILVER			
	By-Product of Gold Mining		kg 1 699·870	....	135 988
	By-Product of Nickel Mining		320·792	....	35 404
			2 020·662	....	171 392
		TALC			
M.L. 70/433	South West	Three Springs Talc Pty. Ltd.	39 604	....	N.A.
M.C. 52/190	Peak Hill	Westside Mines N.L.	8 732	....	N.A.
			48 336	....	N.A.
		TANTO-COLUMBITE ORES AND CONCENTRATES (g) (h)		Ta205 Units	
M.C. 59/5052	Yalgoo	Baker, G. S.	4·47	269	57 947
M.C. 1/647 etc.	Greenbushes	Vultan Minerals Ltd.	95·98	1 735	288 726
M.L. 1/660 etc.	Greenbushes	Greenbushes Tin N.L.	49·65	2 112	503 541
			150·10	4 116	(b) 850 214
		VERMICULITE			
M.C. 77/965	Yilgarn	Mineral By-Products Pty. Ltd.	268	....	(a) 3 350
		TIN CONCENTRATES (g) (h)		Sn Tonnes	
M.C. 1/647 etc.	Greenbushes	Vultan Minerals Ltd.	75·18	43·60	220 238
M.L. 1/660 etc.	Greenbushes	Greenbushes Tin N.L.	549·00	387·00	2 047 006
M.C. 45/1348 etc.	Pilbara	Johnston J. A. & Sons Pty. Ltd.	104·44	68·28	358 300
M.C. 45/383 etc.	Pilbara	Johnston, J. A. & Sons Pty. Ltd.	105·49	63·29	346 082
	Pilbara	Crown Lands—District Generally	1·81	1·29	6 176
M.C. 47/305	West Pilbara	Yule River Mining Pty. Ltd.	6·53	4·40	20 210
M.C. 47/3134-5	West Pilbara	Yule River Mining Pty. Ltd.	4·80	3·38	15 843
	West Pilbara	Crown Lands—Sundry Persons	·31	·22	1 040
D.C. 45/195, M.C. 384	Pilbara	Pilbara Concentrates	116·94	83·98	584 516
D.C. 45/700	Pilbara	Henderson, J. M. & Sons	2·75	1·65	7 878
			967·25	657·09	(b) 3 607 289

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-Product of Gold Mining.
(k) By-Product of Tin Mining.
(l) Value computed by the Department of Mines based on the price of Alumina F.O.B. Jamaica.
(m) Value based on the price per barrel as assessed by the Industries Assistance Commission for Barrow Island Crude Oil 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.

NOTE:—If utilised for publication please acknowledge release from the Hon. Minister for Mines.

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TABLE VI

TOTAL MINERAL OUTPUT OF WESTERN AUSTRALIA

Recorded mineral production of the State to 31st December, 1975, 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	1.52	18.00
Alumina (from Bauxite)	,,	11 806 002.00	760 990 840.00
Alunite (Crude Potash)	,,	9 218.64	431 729.44
Antimony Concentrates (*a*)	,,	9 987.42	484 994.00
Arsenic (*a*)	,,	39 294.68	1 494 410.00
Asbestos—			
Anthophyllite	,,	517.52	13 547.42
Chrysotile	,,	11 419.72	989 397.40
Crocidolite	,,	154 913.36	33 496 644.98
Tremolite	,,	1.02	50.00
Barytes	,,	9 719.44	140 239.90
Bauxite (Crude Ore) (*g*)	,,	37 330.58	187 069.50
Beryl	,,	4 098.69	1 029 757.06
Bismuth	kg	7 375.28	14 495.67
Building Stone (*g*)—			
Chrysotile-Serpentine	tonne	4.52	106.00
Granite (Facing Stone)	,,	1 058.72	38 904.00
Lepidolite	,,	84.15	713.18
Prase	,,	9.65	275.00
Quartz (Dead White)	,,	1 617.78	33 914.00
Quartz Crystal	,,	1 829.79	24 967.00
Quartz	,,	30 856.00	470 115.31
Quartzite	,,	11 142.40	55 739.00
Sandstone	,,	680.75	4 020.00
Sandstone (Donnybrook)	,,	84.33	3 486.00
Slate	,,	238.77	2 115.00
Spongolite	,,	3 893.99	42 516.00
Tripolite	,,	268.24	264.00
Calcite	,,	5.08	50.00
Chromite	,,	14 650.43	416 593.50
Clays—			
Bentonite	,,	14 773.33	110 736.52
Brick, Pipe and Tile Clays	,,	1 373 449.29	1 888 074.16
Cement Clays	,,	581 771.92	1 119 067.67
Fireclay	,,	1 785 158.49	1 702 294.09
Fullers Earth	,,	466.77	3 821.00
White Clay—			
Ball Clay	,,	31 289.99	218 238.60
Kaolin	,,	8 290.83	35 490.97
Coal	,,	48 080 393.15	174 775 476.38
Cobalt (Metallic By-Product Nickel Mining)	,,	1 241.21	4 122 789.88
Copper (Metallic By-Product Nickel Mining)	,,	6 790.04	5 953 179.00
Copper (Metallic By-Product) (*a*)	,,	194.57	65 375.10
Copper Ore and Concentrates	,,	313 398.86	10 791 660.03
Corundum	,,	64.16	1 310.00
Cupreous Ore and Concentrates (Fertiliser)	,,	88 518.55	3 311 561.30
Diamonds	....	(*e*)	48.00
Diatomaceous Earth (Calcined)	,,	528.35	15 991.00
Dolomite	,,	3 095.71	26 118.20
Emeralds (Cut and Rough)	carats	20 122.68	11 292.00
Emery	tonne	21.49	750.00
Felspar	,,	74 999.56	584 188.04
Fergusonite	kg	300.00	782.80
Gadolinite	tonne	1.02	224.00
Glass Sand	,,	1 318 618.83	1 058 207.61
Glauconite	,,	(*h*) 6 570.77	300 769.00
Gold (Mint and Export)	kg	2 160 216.37	1 190 588 627.00
Graphite	tonne	155.66	2 608.40
Gypsum	,,	1 994 287.54	4 916 000.47
Iron Ore—			
Pig Iron Recovered	,,	1 036 452.60	55 393 963.12
Ore Exported	,,	426 262 051.95	2 922 810 255.82
Pellets Exported	,,	26 905 487.37	289 168 097.33
Locally Used Ore	,,	14 875 597.43	92 505 264.60
For Flux	,,	58 996.10	74 096.00
Jarosite	,,	9.69	75.00
Kyanite	,,	4 283.34	43 562.00
Lead Ores and Concentrates	,,	489 720.00	10 636 394.41
Limestone	,,	11 675 692.00	12 286 071.52
Lithium Ores—			
Petalite	,,	8 041.97	124 123.05
Spodumene	,,	108.29	3 627.20
Magnesite	,,	36 469.76	437 666.86
Manganese—			
Metallurgical Grade	,,	1 927 082.00	41 307 545.08
Battery Grade	,,	2 253.85	90 860.20
Low Grade	,,	5 135.47	81 538.20
Mica	tonnes	135.94	9 604.78

TABLE VI.—Total Mineral Output of Western Australia—*continued*

Mineral		Quantity	Value $A
Mineral Beach Sands—			
Ilmenite Concentrates	tonne	7 701 348.87	89 722 146.20
Monazite Concentrates	,,	32 510.87	4 032 537.71
Rutile	,,	62 951.40	8 264 393.75
Leucoxene	,,	93 143.21	7 090 517.96
Zircon	,,	595 468.35	31 033 159.46
Xenotime	,,	202.30	212 889.87
Crude Concentrates (Mixed)	,,	158.45	1 553.00
Molybdenite	,,	78.74	1 730.00
Nickel Concentrates	,,	1 982 725.73	673 080 601.00
Nickel Ore	,,	420 825.16	23 570 069.62
Ochre—			
Red	,,	12 296.65	246 969.11
Yellow	,,	454.78	5 955.50
Peat	,,	4 051.54	62 633.00
Petroleum (Crude Oil)	bbls.	118 095 631.00	313 964 151.25
(Natural Gas)	$m^3 10^3$	3 175 505.94	19 119 839.37
(Condensate)	tonne	17 194.00	N.A.
Palladium (By-Product Nickel Mining)	kg	305.24	746 596.00
Platinum (By-Product Nickel Mining)	,,	171.27	621 721.00
Phosphatic Guano	tonne	12 047.32	145 420.90
Pyrites Ore and Concentrates (For Sulphur) (*b*)	,,	1 374 983.99	16 309 423.52
Quartz Grit	,,	842.81	1 400.70
Ruthenium (By Product Nickel Mining)	kg	10.91	15 521.00
Salt	tonne	17 766 650.18	63 466 700.00
Semi Precious Stones—			
Amethyst	kg	26 999.90	23 302.29
Beryl (coloured)	,,	90.72	100.00
Chalcedony	,,	75 297.59	29 956.70
Chrysoprase	,,	122 202.34	121 142.00
Dravite	,,	8 640.03	15 593.78
Green Beryl	,,	5.00	104.00
Magnesite	,,	5 072.98	2 780.00
Moss Opal	,,	89 710.92	36 089.91
Moss Agate	,,	16 256.75	4 800.00
Opal	,,	4.32	16 994.00
Opaline	,,	11.34	7.50
Opalite		1 020.00	400.00
Prase	,,	3 955.33	729.50
Quartz	,,	33 483.73	13 544.85
Tiger Eye Opal	,,	1 596.64	5 167.67
Topaz (Blue)	,,	3.17	3.50
Tourmaline	,,	1 035.10	2 123.90
Sillimanite	tonne	2.03	26.00
Silver (*c*)	kg	423 082.00	8 997 981.23
Soapstone	tonne	574.48	3 855.70
Talc	,,	369 468.28	4 719 451.65
Tanto/Columbite Ores and Concentrates	,,	2 262.77	6 043 362.41
Tin	,,	33 380.62	34 276 982.76
Tungsten Ore and Concentrates—			
Scheelite	,,	171.87	143 424.24
Wolfram	,,	309.84	125 810.16
Vermiculite	,,	3 521.03	37 730.63
Zinc (Metallic By-Product) (*d*)	,,	2 934.08	(*j*)
Zinc Ore (Fertiliser)	,,	20.32	200.00
Total Value to 31st December, 1975			6 933 371 992.05

(*a*) By-Product from Gold Mining.
(*b*) Part By-Product from Gold Mining.
(*c*) By-Product from Gold, Copper and Lead Mining.
(*d*) By-Product from Lead Mining.
(*e*) Quantity not recorded.
(*f*) Value of mineral or concentrate recovered.
(*g*) Incomplete.
(*h*) Mineral Recovered.
(*i*) Assayed Metallic Content.
(*j*) Value included in Lead Value.
(*k*) Based on the price assessed by the Industries Assistance Commission for Barrow Island crude oil at Kwinana.
(*l*) Nominal well-head value.

Footnote.—Comprehensive mineral production records maintained in the Statistical Branch of the Department of Mines show locality, producers, period, quantity, assayed or metallic content, and value of the various minerals listed above.

TABLE VII

Showing average number of men employed above and below ground in the larger mining companies operating in Western Australia during 1974 and 1975.†

Company	1974			1975		
	Above	Under	Total	Above	Under	Total
Gold*—						
Central Norseman Gold Corporation N.L.	131	87	218	147	91	238
Hill 50 Gold Mine N.L.	40	47	87	....	....	....
Kalgoorlie Lake View Pty. Ltd. (Boulder)	630	386	1 016	583	289	872
Kalgoorlie Lake View Pty. Ltd. (Mt. Charlotte)	14	131	145	9	118	127
North Kalgurli Mines Ltd.	107	28	135	114	21	135
All Other Operators	275	151	426	272	164	436
State Average	1 197	830	2 027	1 125	683	1 808
Alumina (from Bauxite)—						
Alcoa of Australia (W.A.) N.L.	1 965	....	1 965	2 072	....	2 072
Coal—						
Griffin Coal Mining Co. Ltd.	199	....	199	267	....	267
Western Collieries Ltd.	163	323	486	237	332	569
Iron Ore—						
Charcoal Iron & Steel	11	....	11	11	....	11
Cliffs Western Australian Mining Co. Pty. Ltd.	192	....	192	206	....	206
Dampier Mining Co. Ltd.	465	....	465	502	....	502
Goldsworthy Mining Ltd.	700	....	700	836	....	836
Hamersley Iron Pty. Ltd.	1 736	....	1 736	1 940	....	1 940
Mt. Newman Mining Co. Pty. Ltd.	905	....	905	1 030	....	1 030
Western Mining Corporation	41	....	41	....	....	....
Mineral Beach Sands—						
Allied Eneabba Pty. Ltd.	11	....	11	135	....	135
Cable Sands Pty. Ltd.	78	....	78	99	....	99
Jennings Mining Limited	120	....	120	169	....	169
Western Mining Corporation	....	....	....	136	....	136
Western Mineral Sands Pty. Ltd.	45	....	45	46	....	46
Western Titanium N.L.	211	....	211	200	....	200
Westralian Sands Ltd.	85	....	85	93	....	93
Nickel—						
Anaconda Australia Inc.	18	79	97	33	100	133
Great Boulder Gold Mines Limited	273	119	392	302	173	475
Metals Exploration N.L.	96	127	223	117	133	250
Selcast Exploration Ltd.	....	....	....	35	61	96
Western Mining Corporation	737	641	1 378	708	699	1 407
Windarra Nickel Mines Pty. Ltd.	....	....	....	288	118	406
Petroleum—Crude Oil—						
West Australian Petroleum Pty. Ltd.	146	....	146	110	....	110
Salt—						
Dampier Salt Limited	120	....	120	144	....	144
Lefroy Salt Co.	17	....	17	17	....	17
Leslie Salt Co.	46	....	46	37	....	37
Texada Mines Pty. Limited	314	....	314	227	....	227
All Other Minerals	258	....	258	265	....	265
State Total—Other than Gold	8 952	1 289	10 241	10 262	1 616	11 878

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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