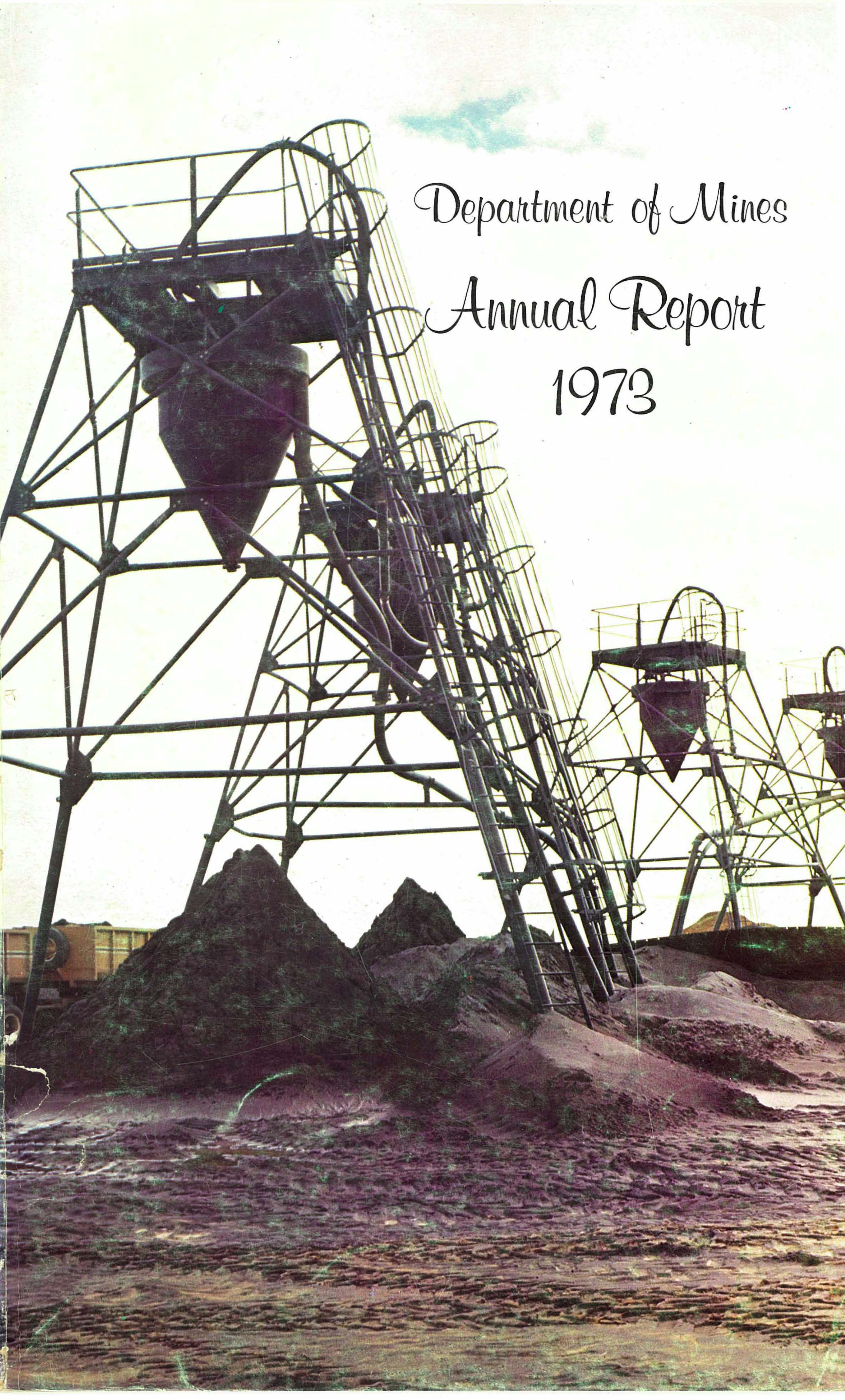
DEPARTMENT OF MINES ANNUAL REPORT 1973

Department of Mines

Annual Report

1973



REPORT OF THE

DEPARTMENT *of* MINES

WESTERN AUSTRALIA

FOR THE YEAR 1973

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

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1974

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To Hon. 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 1973, *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, 1974.

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DIVISION I

PART 1—GENERAL REMARKS

The Honourable Minister for Mines:

I have the honour to submit for your information a report on the Mining Industry for the year 1973.

The estimated value of the mineral output of Western Australia (including gold, coal and petroleum) for the year was $754 568 744, an increase of $106 024 500 compared with the figure for the preceding year. This was an all-time record and was due largely to the increase in production of iron ore, alumina, nickel, ilmenite and salt.

To the end of 1973 the progressive value of the whole mineral production of the State amounted to $4 738 million of which gold accounted for $1 169 million. Ten years ago the relevant figures were $1 202 million and $966 million respectively, when gold represented 80 per cent of the total. Today it is only 25 per cent.

ROYALTIES

Royalty revenue collected during the year amounted to $31.1 million, an increase of $6.3 million above the previous year's figure. Full details are contained in Table 2 of this part.

IRON ORE

Iron ore production for export and local use continued to grow and went from 55.4 million tonnes in 1972 to 75.8 million tonnes in 1973. This represents an increase of 36 per cent; but the value increased disproportionately rising from $384 million to $454.6 million—a rise of only 18 per cent. This was due largely to the upvaluations of the Australian dollar and to a small extent to sales of a greater proportion of fines.

ALUMINA

Production of alumina continued to increase with the further expansion of the Pinjarra refinery by Alcoa of Australia (W.A.) N.L. Output from the Kwinana and Pinjarra refineries during 1973 totalled 1.7 million tonnes having an estimated value of $108.9 million compared with 1.4 million tonnes having an estimated value of $90 million in 1972.

NICKEL

The total value of nickel in concentrates and nickel briquettes and powder amounted to an estimated $92.8 million as against $84.4 million in 1972. Sales of nickel concentrates totalled 271 632 tonnes and nickel ore 81 541 tonnes in 1973, compared with 235 360 and 73 835 tonnes respectively in 1972.

The price of $US1.53 per lb quoted by International Nickel Company Limited for four inch square electrolytic nickel cathodes F.O.B. Fort Colborne, Canada, remained constant throughout the year.

PETROLEUM
(Crude Oil and Natural Gas)

Sales of oil from Barrow Island during 1973 were down slightly from 15.4 million barrels valued at $34.3 million in 1972 to 14.6 million barrels valued at $32.5 million in 1973. Small quantities of liquid petroleum gas were shipped from Barrow Island for use in the North West.

The Dongara and Mondarra gas fields supplied a total of 28 677 million cubic feet of natural gas valued at $5.2 million to sales outlets in Perth-Fremantle-Kwinana-Pinjarra area.

Offshore exploration activity continued to be mainly centred in the North West Shelf area. New petroleum discoveries of probable commercial significance were made at the Egret, Dockrell and West Tyral Rocks wells. Appraisal wells were drilled in the previously discovered Goodwyn and Angel offshore gas/condensate fields. At the year end preliminary steps were taken by the permittee towards the application for production licences in respect of the Angel, Goodwyn and North Rankin petroleum accumulations.

On land the wells drilled gave no indication of the presence of petroleum in economic quantities. Production testing of the Barrow Island Deep well indicated that the gas accumulations penetrated are not sufficiently large to be economically recoverable at present.

GOLD

The estimated value of gold received at the Perth Mint during the year was $18 326 747, an increase of $2 284 059 compared with the figure for 1972. This increase in value was due solely to the high premiums obtained on the free market while the quantity of gold won decreased by 2 946 kg from 10 850 kg in 1972 to 7 940 kg in 1973.

Details of gold production for the year reported to the Department, as distinct from that received at the Mint, are set out in Table 1. The quantity of auriferous ore treated was 1 629 519 tonnes being 31 318 tonnes less than in 1972.

Western Australian gold included in sales on overseas premium markets by the Gold Producers' Association Ltd for the period October, 1972, to October, 1973 was 9 625.64 kg. The premium received in excess of the Mint value amounted to $10 822 740, an overall average of $1 124.3 657 per kg compared with an average of $451.2 485 per kg for the period from September, 1971, to September, 1972.

Subsidy payments by the Commonwealth Government under the Gold-Mining Industry Assistance Act totalled only $30 627 compared with $1 083 369 in the previous year. This pronounced decrease was the result of the very high prices obtained for gold sold on the free market. It is noteworthy that no subsidy has been paid since July, 1973.

Of the subsidy of $30 627 paid in 1973, $30 381 went to large producers and $246 to small producers.

COAL

Coal production from Collie during the year showed an increase of 3 529 tonnes over that for 1972 and the overall average value per tonne rose by 96 cents.

Figures for the last three years were:—

	1971	1972	1973
Tonnes	1 190 425	1 167 540	1 171 069
Total Value	$5 734 353	$5 907 162	$7 048 726
Average Value per Tonne	$4·817 1	$5·059 5	$6·019 0
Average Effective Workers	623	617	619
Proportion of Deep Mined Coal	34·86%	36·19%	36·08%

OTHER MINERALS

Other minerals to yield over a million dollars for the year were: Salt $9.8 million, Ilmenite $9.2 million, Zircon $2.7 million, Tin Concentrates $2.6 million, Limestone $1.4 million and Leucoxene $1.1 million, whilst Pig Iron valued at $3.8 million was produced by the Charcoal Iron and Steel Industry at Wundowie.

OUTLOOK

It is pleasing to record that mineral production in Western Australia continued to grow despite increased oil prices, currency fluctuations and other economic pressures.

The ability to withstand such adverse effects indicates that the industry is soundly based and is supported by an increasing consumer demand.

With expansion planning in existing mines and proposals for the opening of new ones, continued growth in the mining industry seems assured.

PART 2—COMPARATIVE STATISTICS

TABLE 1

SUMMARY

Mineral Production : Quantity, Value, Persons Engaged

	1972	1973	Variation
IRON ORE—			
Tonnes	55 538 922	75 993 300	+ 20 454 378
Value ($A)	$387 998 067	$458 518 242	+ $70 520 175
Persons Engaged	2 826	3 886	+ 1 060
ALUMINA—			
Tonnes	1 435 859	1 729 129	+ 293 270
*Value ($A)	$90 443 400	$108 916 300	+ $18 472 900
Persons Engaged	1 671	1 798	+ 127
NICKEL—			
Tonnes (ore and concentrates)	309 193	353 172	+ 43 979
Value ($A)	$84 493 697	$92 832 563	+ $8 338 866
Persons Engaged	1 804	1 981	+ 177
PETROLEUM—CRUDE OIL—			
Barrels	15 402 695	14 578 230	— 824 465
†Value ($A)	$34 346 900	$32 509 453	— $1 837 447
Persons Engaged—			
Effective Workers (excluding absentees)	133	158	+ 25
GOLD—			
Reported to Department (Mine Production)—			
Ore (Tonnes)	1 660 837	1 629 519	— 31 318
Gold (Kilograms)	10 478	8 587	— 1 890
Average Grade (Grams per tonne)	6·3	6·3	....
Persons Engaged—			
(a) Effective Workers (excluding absentees)	1 982	2 001	+ 19
(b) Total Pay Roll	2 165	2 203	+ 38
Mint and Export (Realised Production) —			
Gold (Kilograms)	10 850	7 940	— 2 910
Estimated Value ($A) (including Overseas Gold Sales Premium)	$16 042 688	$18 326 747	+ $2 284 059
COAL—			
Mine Production—			
Tonnes	1 167 540	1 171 069	+ 3 529
Value ($A)	$5 907 162	$7 048 726	+ $1 141 564
Persons Engaged—			
Effective Workers (excluding absentees)	617	619	+ 2
OTHER MINERALS—			
Value ($A)	$29 312 330	$36 386 113	+ $7 073 783
Persons Engaged—			
Effective Workers	914	1 052	+ 138
TOTAL ALL MINERALS—			
Value ($A)	$648 544 244	$754 538 144	+ $105 993 900
Persons Engaged—			
Effective Workers	9 947	11 495	+ 1 548

* 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 1972 *and* 1973
Western Australia

Mineral	1972		1973		Increase or Decrease for Year Compared with 1972	
	Quantity	Value	Quantity	Value	Quantity	Value
	Tonnes	$A	Tonnes	$A	Tonnes	$A
Alumina (from Bauxite)	1 435 859	90 443 400	**1 729 129**	**108 916 300**	+ 293 270	+ 18 472 900
Beryl	62	12 870	**162**	**29 711**	+ 100	+ 16 841
Building Stone (Quartzite)	1 108	4 410	**770**	**5 070**	— 338	+ 660
(Quartz)	3 842	37 810	**2 450**	**22 129**	— 1 392	— 15 681
(Granite—Facing Stone)	61	5 400	....	....	— 61	— 5 400
(Sandstone)	....	....	**16**	**96**	+ 16	+ 96
(Spongolite)	92	1 267	**48**	**658**	— 44	— 609
(Quartz Crystal)	213	3 192	**1 546**	**18 808**	+ 1 333	+ 15 116
Clays (Bentonite)	165	2 322	**833**	**11 708**	+ 668	+ 9 386
(Cement Clay)	32 779	89 903	**34 963**	**91 522**	+ 2 184	+ 1 619
(Fireclay)	172 058	107 180	**219 029**	**112 252**	+ 46 971	+ 5 072
(White Clay—Ball Clay)	915	10 812	**549**	**6 480**	— 366	— 4 332
(Brick Pipe and Tile Clay)	124 299	178 651	**133 312**	**174 690**	+ 9 013	— 3 961
Coal	1 167 540	5 907 162	**1 171 069**	**7 048 726**	+ 3 529	+ 1 141 564
Cobalt (Metallic By-Product Nickel Mining)	193	629 500	**131**	**477 091**	— 62	— 152 409
Copper (Metallic By-Product Nickel Mining)	725	632 400	**372**	**434 800**	— 353	— 197 600
Copper Ore and Concentrates	1 016	254 990	**35**	**8 434**	— 981	— 246 556
Felspar	569	8 408	**318**	**4 695**	— 251	— 3 713
Glass Sand	165 374	127 877	**222 670**	**139 985**	+ 57 296	+ 12 108
Gypsum	133 797	386 438	**164 255**	**503 298**	+ 30 458	+ 116 860
Iron Ore (Pig Iron Recovered)	61 805	3 987 937	**96 819**	**3 844 002**	+ 35 014	— 143 935
(Exported)	52 820 551	358 677 945	**70 045 217**	**404 330 378**	+ 17 224 666	+ 45 652 433
(Pellets)	2 618 684	25 332 185	**5 851 264**	**50 343 862**	+ 3 232 580	+ 25 011 677
Lead Ore and Concentrates	....	....	**147**	**17 513**	+ 147	+ 17 513
*Limestone	1 147 849	1 182 229	**1 353 579**	**1 426 758**	+ 205 730	+ 244 529
Lithium Ores (Petalite)	1 070	16 771	**222**	**3 466**	— 818	— 13 305
Magnesite	30	450	....	....	— 30	— 450
Manganese (Metallurgical Grade)	99 505	1 541 332	**26 306**	**428 000**	— 73 199	— 1 113 332
Mineral Beach Sands (Ilmenite)	504 970	5 936 710	**731 101**	**9 169 702**	+ 226 131	+ 3 232 992
(Monazite)	2 359	301 756	**3 016**	**394 798**	+ 657	+ 93 042
(Rutile)	3 371	345 185	**1 911**	**193 933**	— 1 460	— 151 252
(Leucoxene)	15 133	720 986	**15 396**	**1 107 188**	+ 263	+ 386 202
(Zircon)	62 596	1 608 754	**89 697**	**2 674 143**	+ 27 101	+ 1 065 389
(Xenotime)	6	6 604	**45**	**31 926**	+ 39	+ 25 322
Nickel Concentrates	235 360	81 114 200	**271 632**	**88 326 800**	+ 36 272	+ 7 212 600
Nickel Ore	73 835	3 379 497	**81 541**	**4 505 763**	+ 7 706	+ 1 126 266
Ochre (Red)	551	9 122	....	....	— 551	— 9 122
	kg		kg		kg	
Palladium (Metallic By-Product Nickel Mining)	....	....	**23**	**41 000**	+ 23	+ 41 000
Platinum (Metallic By-Product Nickel Mining)	....	....	**7**	**23 900**	+ 7	+ 23 900
	bbls		bbls		bbls	
Petroleum—Crude Oil (barrels)	75 402 695	34 346 900	**14 578 230**	**32 509 453**	— 824 465	— 1 837 447
	m.c.f.		m.c.f.		m.c.f.	
Natural Gas (1 000 cu. ft.)	23 466 978	3 176 203	**28 677 043**	**5 161 868**	+ 5 210 065	+ 1 985 665
	bbls		bbls		bbls	
Condensate (barrels)	43 269	N.A.	**30 310**	**N.A.**	— 12 959	N.A.
	Tonnes		Tonnes		Tonnes	
Salt	2 217 852	6 247 617	**3 333 937**	**9 837 959**	+ 1 116 085	+ 3 590 342
	kg		kg		kg	
Semi Precious Stones	88 240	47 074	**37 269**	**20 430**	— 50 971	— 26 644
	Tonnes		Tonnes		Tonnes	
Talc	26 013	N.A.	**37 188**	N.A.	+ 11 175	N.A.
Tanto/Columbite Ores and Concentrates	270	1 201 689	**273**	**718 167**	+ 3	— 483 522
Tin Concentrates	2 037	4 284 086	**1 216**	**2 653 423**	— 821	— 1 630 663
Vermiculite	380	2 266	**426**	**3 565**	+ 46	+ 1 299
Total	....	632 311 490	....	**735 773 950**	....	+ 103 462 460

TABLE 1 (*b*)

Quantity and Value of Gold and Silver Exported and Minted during Years 1972 *and* 1973

Mineral	1972		1973		Increase or Decrease for Year Compared with 1972	
	Quantity	Value	Quantity	Value	Quantity	Value
	kg	$A	kg	$A	kg	$A
Gold (Exported and Minted)	10 850·502	†16 042 688	**7 940·504**	**†18 326 747**	— 2 945·998	+ 2 284 059
Silver (Exported and Minted)	4 146·731	190 066	**7 919·760**	**437 447**	+ 3 773·029	+ 247 381
Total	....	16 232 754	....	**18 764 194**	+ 827·031	+ 2 531 440
Grand Total	....	648 544 244	....	**754 538 144**	....	+ 105 993 900

* Incomplete. † Including Overseas Gold Sales Premium.

TABLE 2
ROYALTIES

Mineral	Royalty Collected 1972	Royalty Collected 1973	Increase or Decrease Compared with 1972
	$	$	$
Alumina	388 480.41	396 996.34	+ 8 515.93
Amethyst	13.96	8.11	— 5.85
Bentonite	.60	9.90	+ 9.30
Beryl	22.40	28.40	+ 6.00
Building Stone	528.23	380.63	— 147.60
Chalcedony	67.22	3.67	— 63.55
Chrysophrase	75.79	15.00	— 60.79
Clay	9 755.30	14 644.89	+ 4 889.59
Coal	27 907.25	28 517.57	+ 610.32
Cobalt	580.55	766.51	+ 185.96
Felspar	24.36	11.65	— 12.71
Glass Sand	5 651.30	10 417.69	+ 4 766.39
Gypsum	7 296.56	8 222.02	+ 925.46
Ilmenite	53 982.50	67 094.14	+ 13 111.64
Iron Ore	21 984 724.69	28 030 157.31	+6 045 432.62
Leucoxene	1 839.66	1 386.70	— 452.96
Limestone	27 401.11	42 443.22	+ 15 042.11
Magnesite	16.50	5·80	— 10.70
Manganese	17 030.70	5 415.45	— 11 615.25
Monazite	947.97	1 769.05	+ 821.08
Moss Opal	40.86	26.51	— 14.35
Natural Gas	150 327.14	320 198.18	+ 169 871.04
Natural Gas Condensate	2 145.65	542.73	— 1 602.92
Nickel	581 762.19	577 935.63	— 3 826.56
Ochre	27.12	....	— 27.12
Oil (Crude)	1 452 401.99	1 362 522.06	— 89 879.93
Palladium	....	78.46	+ 78.46
Petalite	131.10	22.40	— 108.70
Platinum	....	42.54	+ 42.54
Quartz Crystal	15.96	65.85	+ 49.89
Rutile	167.62	552.30	+ 384.68
Salt	121 391.23	202 914.54	+ 81 523.31
Talc	2 774.35	3 663.27	+ 888.92
Tanto Columbite	5 469.27	2 788.79	— 2 680.48
Tin	361.11	270.94	— 90.17
Tourmaline	8.25	1.90	— 6.35
Vermiculite	8.41	31.28	+ 22.87
Zircon	3 924.73	7 994.05	+ 4 069.32
	24 847 304.04	31 087 945.48	+6 240 641.44

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 1972	Reported Yield 1973	Percentage for each Goldfield 1972	Percentage for each Goldfield 1973	* Average Yield per tonne of ore treated 1972	* Average Yield per tonne of ore treated 1973
	kg	kg	Per cent.	Per cent.	grams	grams
Kimberley	....	....	....	....	....	....
West Kimberley	....	....	....	....	....	....
Pilbara	39·017	44·483	·37	·52	21·8	24·4
West Pilbara	....	1·439	....	·02	....	....
Ashburton	....	....	....	....	....	....
Gascoyne	1·369	·050	·01	....	6·6	4·0
Peak Hill	1·485	·646	·01	·01	....	....
East Murchison	3·673	1·646	·04	·02	13·5	15·5
Murchison	794·910	532·135	7·59	6·20	10·0	8·3
Yalgoo	1·840	10·792	·02	·13	5·6	45·3
Mt. Margaret	38·322	40·380	·37	·47	12·6	5·2
North Coolgardie	30·794	8·064	·29	·09	16·7	4·3
Broad Arrow	13·711	22·963	·13	·27	2·5	1·7
North-East Coolgardie	7·542	5·127	·07	·06	5·2	4·8
East Coolgardie	7 966·937	6 540·661	76·04	76·17	5·6	4·8
Coolgardie	67·551	31·055	·64	·36	10·0	3·8
Yilgarn	41·713	204·665	·40	2·38	8·3	20·8
Dundas	1 466·479	1 140·686	14·00	13·28	9·9	7·5
Phillips River	2·516	·915	·02	·01	26·7	11·7
South-West Mineral Field	....	....	....	....	....	....
State Generally	....	1·182	....	·01	....	....
	10 477·859	8 586·889	100·00	100·00	6·3	5·3

* Averages exclude alluvial and dollied gold.

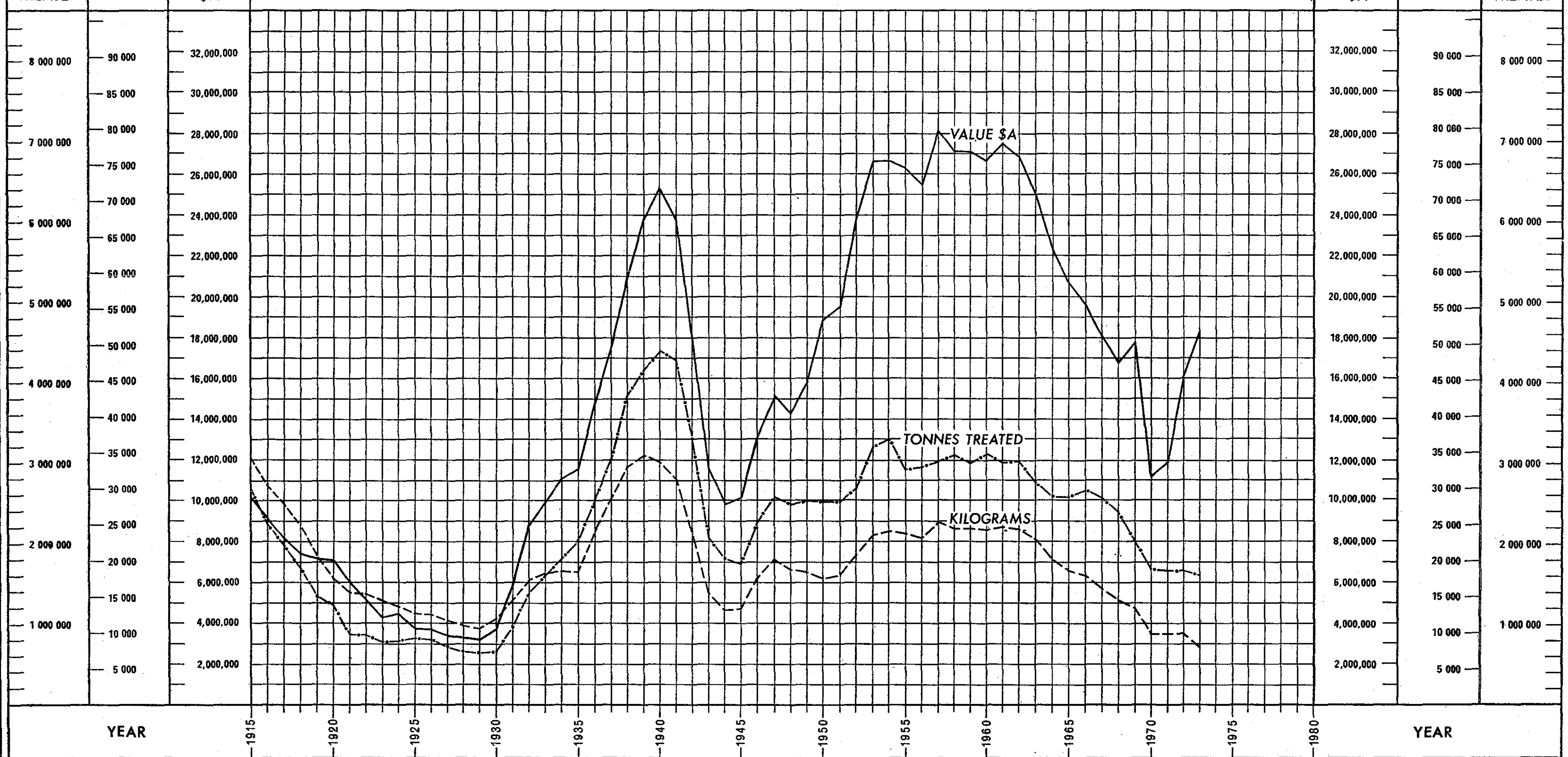
TABLE 4

Total Coal Output from Collie River Mineral Field, 1972 *and* 1973, *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
1972	422 571	3 112 225	99	311	....	....	1 359	1 031
1973	422 568	3 430 122	100	308	....	....	....	....
Open Cut Mining—								
1972	744 969	2 794 937	....	....	207	3 599	....	....
1973	748 500	3 618 604	....	....	211	....	....	....
Totals—								In All Mines
1972	1 167 540	5 907 162	99	311	207	....	....	1 892
1973	1 171 068	7 048 726	100	308	211	....	....	1 892

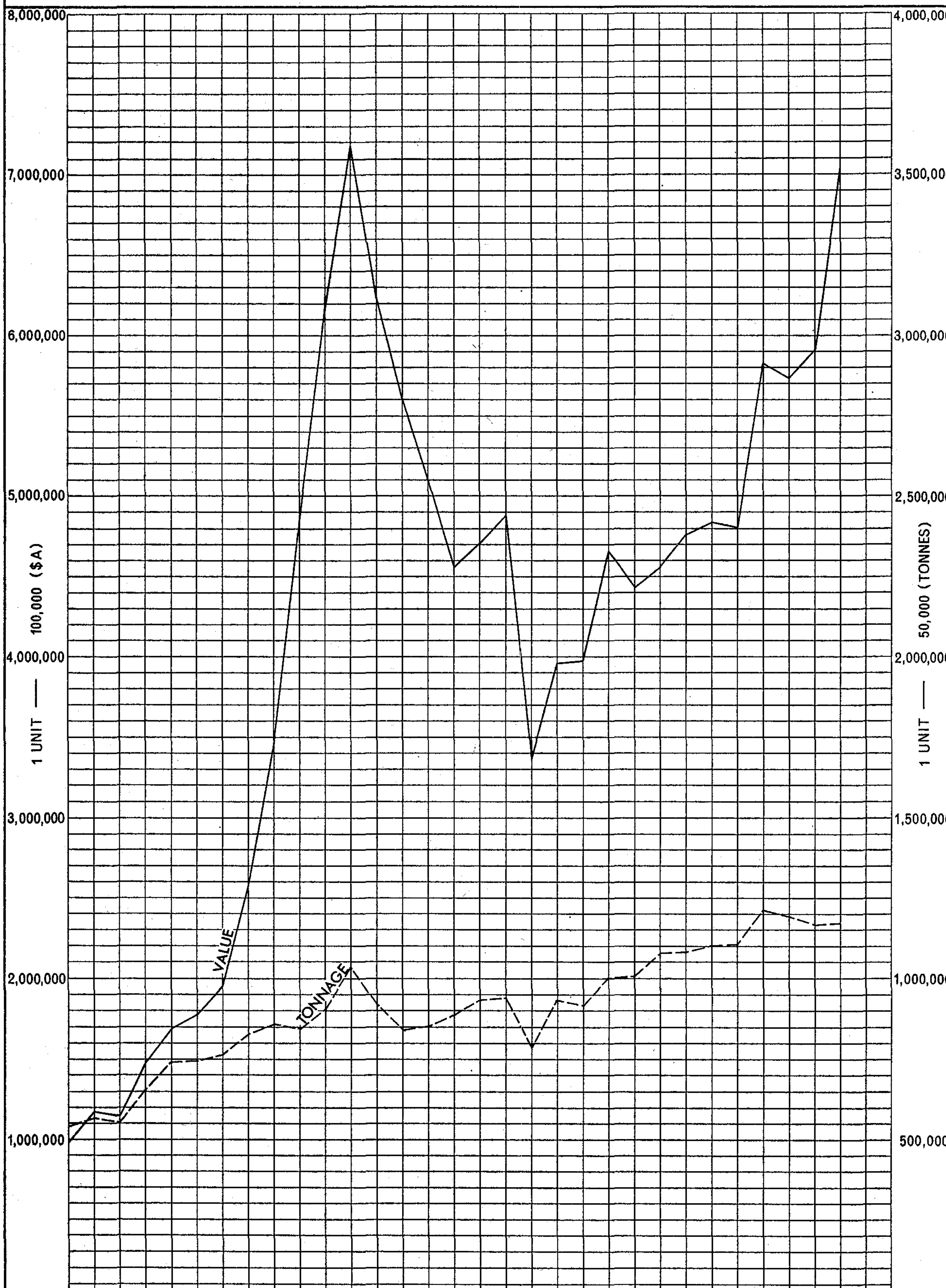
DIAGRAM OF GOLD OUTPUT

SHOWING QUANTITIES TREATED AS REPORTED TO MINES DEPT., 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 MINES DEPARTMENT



YEAR	VALUE $A	TONNES
1943	979,442	540,077
1944	1,166,150	567,283
1945	1,145,792	552,083
1946	1,460,208	652,598
1947	1,680,498	742,231
1948	1,760,472	744,702
1949	1,944,490	762,641
1950	2,575,498	827,421
1951	3,433,576	862,093
1952	4,914,592	843,790
1953	6,146,146	900,405
1954	7,177,636	1,034,687
1955	6,264,148	918,298
1956	5,595,012	843,330
1957	5,105,310	852,120
1958	4,560,398	884,860
1959	4,713,064	932,159
1960	4,878,390	937,197
1961	3,260,518	778,030
1962	3,961,556	933,864
1963	3,970,120	916,980
1964	4,678,934	1,003,268
1965	4,409,972	1,009,691
1966	4,562,087	1,078,126
1967	4,765,503	1,079,199
1968	4,816,725	1,104,831
1969	4,804,089	1,108,033
1970	5,827,291	1,216,957
1971	5,734,353	1,190,429
1972	5,907,162	1,167,544
1973	7,048,726	1,171,069
1974		
1975		

GRAPH OF TREND IN COAL OUTPUT

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

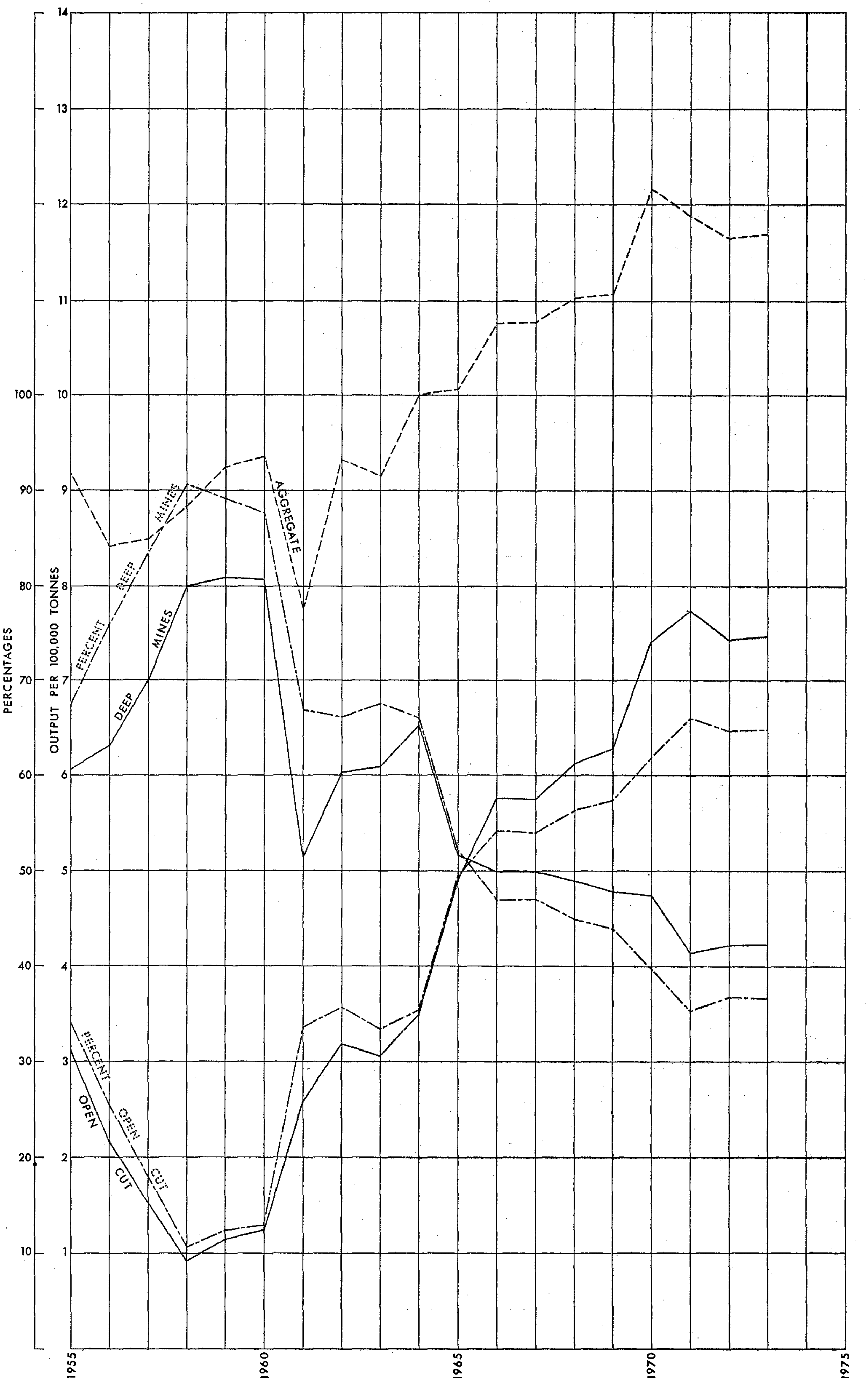


TABLE 5

MINING ACT, 1904.

LEASES AND OTHER HOLDINGS UNDER VARIOUS ACTS RELATING TO MINING.

Total Number and Area of Mining Tenements applied for during 1973 *and in force as at* 31*st December*, 1973 (*compared with* 1972)

—	Applied for				In Force			
	1972		1973		1972		1973	
	No.	Hectares	No.	Hectares	No.	Hectares	No.	Hectares
Gold—								
Gold Mining Leases	707	6 130	988	8 568	1 410	10 989	2 188	17 548
Dredging Claims	9	892	145	17 095	10	760	14	1 100
Prospecting Areas	625	4 928	418	3 423	306	2 325	367	3 206
Temporary Reserves	....	....	15	163 400	1	76	8	78 400
Totals	1 341	11 950	1 566	192 486	1 727	14 150	2 577	100 254
Coal—								
Coal Mining Leases	168	21 633	2	235	62	7 011	60	7 005
Prospecting Areas	21	23 594	....	....	....	....	9	10 037
Temporary Reserves	1	20 000	30	524 500	3	21 748	29	523 500
Totals	190	65 227	32	524 735	65	28 759	98	540 542
Other Minerals—								
Mineral Leases	47	4 411	82	7 497	412	31 287	447	38 073
Dredging Claims	46	3 562	19	287	342	14 077	284	9 586
Mineral Claims	11 270	1 282 214	6 247	689 089	15 286	1 631 757	16 610	1 729 921
Prospecting Areas	55	708	44	358	32	282	25	230
Temporary Reserves	169	1 919 101	126	1 744 400	518	7 934 844	71	958 800
Totals	11 587	3 209 996	6 518	2 441 631	16 590	9 612 247	17 437	2 736 610
Other Holdings—								
Miner's Homestead Leases	2	12	1	8	324	13 205	326	23 658
Miscellaneous Leases	20	7 247	2	41	177	7 770	186	7 863
Residence Areas	....	....	....	....	58	19	56	22
Business Areas	....	....	1	1	26	9	20	13
Machinery Areas	....	....	4	7	21	23	24	29
Tailings Areas	....	....	9	48	21	32	21	34
Garden Areas	3	8	8	16	67	97	71	109
Quarrying Areas	38	273	43	396	125	1 021	147	1 256
Water Rights	7	64	11	775	105	831	103	795
Licenses to Treat Tailings	214	....	175	....	43	....	199	....
Totals	284	7 604	254	1 292	967	23 007	1 153	33 779
Grand Totals	13 402	3 294 777	8 370	3 160 144	19 349	9 678 163	21 265	3 411 185

TABLE 5 (a)

SPECIAL ACTS

Leases applied for during 1973 *and in force at* 31*st December*, 1973 (*Compared with* 1972)

Mineral	Applied for				In Force			
	1972		1973		1972		1973	
	No.	Hectares	No.	Hectares	No.	Hectares	No.	Hectares
Bauxite	....	....	....	....	7	1 269 612·08	7	1 269 612·17
Iron	2	17 500.63	....	....	6	247 861·03	7	200 832·85
Salt	1	1 379·98	....	....	3	241 366·64	3	241 532·58
Totals	3	18 880·61	....	....	16	1 758 839·75	17	1 711 977·60

TABLE 5 (b)
PETROLEUM ACTS

Permits, Licenses and Leases applied for during 1973 *and in force as at* 31*st December*, 1973 (*Compared with* 1972)

Holding	Applied for				In Force			
	1972		**1973**		1972		**1973**	
	No.	Blocks	No.	Blocks	No.	Blocks	No.	Blocks
Onshore—								
Petroleum Act, 1967—								
Exploration Permits	11	2 164	....	....	63	8 036	**58**	**7 260**
Production Licences	....	....	....	....	3	14	**3**	**14**
Petroleum Lease (Barrow Island)	....	....	....	....	1	8	**1**	**8**
Totals	11	2 164	....	....	67	8 058	**62**	**7 282**
Petroleum Pipelines Act, 1969—		km				km		km
Pipeline Licences	2	4	....	....	5	444·8	**5**	**444·9**
Totals	2	4	....	....	5	444·8	**5**	**444·9**
Offshore—		Blocks				Blocks		Blocks
Petroleum (Submerged Lands) Act, 1969:								
Exploration Permits	3	1 200	....	....	39	10 171	**33**	**9 828**
Production Licences	....	....	....	....	....	....	....	....
Petroleum Lease (Barrow Marine)	....	....	....	....	1	12	**1**	**12**
Totals	3	1 200	....	....	40	10 183	**34**	**9 840**
Grand Totals	14	3 364	....	....	107	18 241	**96**	**17 122**

(A 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 31*st December*, 1973 *in each Goldfield, Mineral Field or District*

Goldfield, Mineral Field, or District	Gold Mining Leases		Mineral Leases		Miner's Homestead Leases		Miscellaneous Leases	
	No.	Hectares	No.	Hectares	No.	Hectares	No.	Hectares
Ashburton	....	....	13	1 010	....	....	....	....
Black Range	18	119	10	1 206	....	....	....	....
Broad Arrow	53	365	2	227	....	....	....	....
Bulong	26	232	....	....	....	....	....	....
Collie	....	....	....	....	....	....	58	6 795
(Private Property)	....	....	....	....	....	....	2	210
Coolgardie	126	956	223	24 711	22	752	7	26
Cue	38	346	....	....	4	450	1	2
Day Dawn	26	257	1	28	1	8	....	....
Dundas	435	3 894	....	....	19	378	....	....
East Coolgardie	371	2 650	2	39	61	11 319	73	562
Gascoyne	10	89	5	71	....	....	....	....
Greenbushes	....	....	65	3 643	11	238	....	....
Kanowna	49	433	3	151	12	284	....	....
Kimberley	1	10	....	....	....	....	....	....
Kunanalling	21	171	....	....	2	210	....	....
Kurnalpi	8	78	....	....	....	....	....	....
Lawlers	21	178	....	....	5	449	....	....
Marble Bar	214	1 757	1	39	....	....	17	98
Meekatharra	68	546	1	121	10	775	1	1
Menzies	61	524	....	....	7	229	1	4
Mount Magnet	100	678	4	15	....	....	....	....
Mount Malcolm	93	794	....	....	9	514	....	....
Mount Margaret	57	489	....	....	6	23	....	....
Mount Morgans	25	205	....	....	....	....	....	....
Niagara	9	60	....	....	1	8	....	....
Northampton	....	....	7	162	....	....	....	....
(Private Property)	....	....	2	13	....	....	....	....
Nullagine	39	278	....	....	2	9	2	19
Peak Hill	10	82	8	310	5	101	....	....
Phillips River	3	12	12	108	105	5 879	....	....
(Private Property)	....	....	18	2 184	....	....	....	....
South-West	5	49	....	....	....	....	....	....
(Private Property)	....	....	....	....	....	....	....	....
Ularring	26	207	....	....	1	8	....	....
West Kimberley	....	....	19	241	....	....	5	30
West Pilbara	10	91	18	383	3	14	10	92
Wiluna	8	73	27	3 156	17	1 570	3	4
Yalgoo	35	264	1	4	....	....	....	....
Yerilla	70	477	....	....	1	4	....	....
Yilgarn	141	1 092	5	251	22	366	6	20
(Private Property)	11	92	....	....	....	....	....	....
Outside Proclaimed	....	....	....	....	....	....	....	....
Totals	2 188	17 548	447	38 073	326	23 658	186	7 863

	No.	Hectares
Gold Mining Leases on Crown Land	2 177	17 456
Gold Mining Leases on Private Property	11	92
Mineral Leases on Crown Land	427	35 876
Mineral Leases on Private Property	20	2 197
Miner's Homestead Leases on Crown Land	326	23 658
Other Leases on Crown Land	184	7 653
Other Leases on Private Property	2	210

(2)—39934

TABLE 5 (d)
MINING ACT, 1904

Claims and Authorised Holdings in Force at 31st December, 1973 in each Goldfield, Mineral Field or District

Goldfield, or Mineral Field 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	2	19	....	....	393	42 440	....	....	....	....	....	....	....	....	....	....	2	19	....	....
Black Range	6	49	....	....	438	48 846	4	2	....	....	....	....	....	....	....	....	....	....	....	....
Broad Arrow	49	370	....	....	258	27 169	1	1	1	1	....	....	....	....	....	....	....	....	3	3
Bulong	23	198	....	....	194	22 615	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Collie	1	1 066	....	....	....	....	....	....	....	....	1	2	....	....	....	....	1	4	1	1
(Private Property)	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Coolgardie	46	371	....	....	1 312	138 065	3	1	....	....	1	1	....	....	4	4	20	181	5	20
Cue	14	109	....	....	471	50 202	2	1	....	....	....	....	....	....	....	....	....	....	....	....
Day Dawn	5	42	....	....	45	4 423	....	....	....	....	....	....	....	....	4	8	....	....	....	....
Dundas	9	67	....	....	364	34 719	....	....	....	....	....	....	1	2	....	....	2	19	2	5
East Coolgardie	36	303	....	....	375	40 775	32	13	....	....	1	1	10	19	10	18	5	27	11	13
Gascoyne	1	10	2	166	486	48 897	....	....	....	....	....	....	....	....	....	....	5	45	....	....
Greenbushes	....	....	....	....	1	20	1	1	....	....	....	....	....	....	9	18	....	....	2	15
Kanowna	16	136	....	....	245	27 446	....	....	....	....	....	....	....	....	....	....	....	....	1	1
Kimberley	....	....	....	....	821	97 439	....	....	....	....	....	....	....	....	1	1	6	42	....	....
Kunanalling	11	85	....	....	152	17 816	....	....	....	....	....	....	....	....	....	....	....	....	2	10
Kurnalpi	20	185	....	....	229	25 710	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Lawlers	2	15	....	....	930	105 051	....	....	....	....	2	2	1	2	....	....	....	....	1	1
Marble Bar	16	108	284	9 586	1 070	100 031	....	....	3	1	8	11	1	2	17	28	27	217	23	113
Meekatharra	1	8	....	....	376	42 893	....	....	....	....	....	....	....	....	....	....	....	....	1	2
Menzies	8	63	....	....	493	52 556	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Mount Magnet	25	222	....	....	259	30 899	....	....	....	....	....	....	....	....	6	2	....	....	4	3
Mount Malcolm	22	199	....	....	499	57 228	....	....	....	....	....	....	....	....	9	15	....	....	3	2
Mount Margaret	9	87	....	....	724	82 891	....	....	....	....	....	....	....	....	1	2	....	....	3	1
Mount Morgans	6	55	....	....	638	73 575	....	....	....	....	....	....	....	....	....	....	....	....	2	2
Niagara	4	22	....	....	128	15 337	....	....	....	....	....	....	....	....	....	....	....	....	3	2
Northampton	....	....	....	....	53	2 557	....	....	....	....	....	....	....	....	....	....	....	....	....	....
(Private Property)	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Nullagine	7	61	1	121	348	24 286	....	....	....	....	2	1	3	2	2	2	....	....	12	14
Peak Hill	2	19	....	....	460	47 660	....	....	1	1	2	3	1	2	....	....	13	155	1	4
Phillips River	9	81	....	....	231	21 652	....	....	....	....	....	....	....	....	....	....	....	....	....	....
(Private Property)	....	....	....	....	184	19 943	....	....	....	....	....	....	....	....	....	....	....	....	....	....
South West	8	8 971	8	677	327	20 642	....	....	....	....	....	....	....	....	....	....	....	....	1	3
(Private Property)	....	....	....	....	437	37 477	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Ularring	17	141	....	....	89	10 638	....	....	....	....	1	1	2	2	....	....	....	....	3	2
West Kimberley	1	10	1	121	278	28 969	....	....	....	....	2	4	....	....	....	....	17	104	2	19
West Pilbara	4	31	2	15	977	103 588	4	2	14	6	....	....	....	....	4	8	45	416	9	16
Wiluna	....	....	....	....	911	105 080	....	....	....	....	....	....	....	....	....	....	....	....	1	534
Yalgoo	12	104	....	....	439	45 460	....	....	1	2	1	2	1	2	....	....	2	12	2	4
Yerilla	8	68	....	....	106	11 759	....	....	....	....	1	1	1	1	....	....	....	....	5	5
Yilgarn	22	160	....	....	806	86 688	9	1	1	1	2	2	....	....	4	3	2	15	....	....
(Private Property)	2	12	....	....	6	562	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Outside Proclaimed	....	....	....	....	57	6 818	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Totals	424	13 447	298	10 686	16 610	1 760 820	56	22	21	12	24	31	21	34	71	107	147	1 256	103	795

TABLE 6

MEN EMPLOYED

Average number of Men employed in Mining during 1972 and 1973

Goldfield	District	Gold 1972	Gold 1973	Other Minerals 1972	Other Minerals 1973	Total 1972	Total 1973
Kimberley	....	....	....	....	4	....	4
West Kimberley	....	....	....	298	362	298	362
Pilbara	Marble Bar	18	29	530	700	548	729
	Nullagine	1	4	8	13	9	17
West Pilbara	....	....	....	1 178	1 844	1 178	1 844
Ashburton	....	....	....	306	428	306	428
Gascoyne	....	2	2	6	6	8	8
Peak Hill	....	2	2	826	1 009	828	1 011
East Murchison	Lawlers	2	....	....	....	2	....
	Wiluna	....	....	....	....	....	....
	Black Range	2	2	....	....	2	2
Murchison	Cue	....	2	....	....	....	2
	Meekatharra	13	8	....	....	13	8
	Day Dawn	2	....	....	....	2	....
	Mt. Magnet	113	123	....	....	113	123
Yalgoo	....	7	4	2	3	9	7
Mt. Margaret	Mt. Morgans	....	5	....	....	....	5
	Mt. Malcolm	28	33	....	....	28	33
	Mt. Margaret	....	8	....	....	....	8
North Coolgardie	Menzies	9	3	....	63	9	66
	Ularring	2	7	....	....	2	7
	Niagara	2	3	....	....	2	3
	Yerilla	3	9	....	....	3	9
Broad Arrow	....	20	31	331	316	351	347
North-East Coolgardie	Kanowna	9	19	....	....	9	19
	Kurnalpi	....	4	....	....	....	4
East Coolgardie	East Coolgardie	1 421	1 361	....	....	1 421	1 361
	Bulong	2	7	....	....	2	7
Coolgardie	Coolgardie	45	66	1 484	1 620	1 529	1 686
	Kunanalling	11	9	....	....	11	9
Yilgarn	....	36	47	94	115	130	162
Dundas	....	230	208	4	4	234	212
Phillips River	....	2	5	....	....	2	5
South-West Mineral Field	....	....	....	2 160	2 276	2 160	2 276
Northampton Mineral Field	....	....	....	....	8	....	8
Greenbushes Mineral Field	....	....	....	109	104	109	104
Outside Proclaimed Goldfield	....	....	....	12	....	12	....
Collie Coalfield	....	....	....	617	619	617	619
Total—All Minerals	....	1 982	2 001	7 965	9 494	9 947	11 495

	1972	1973
Minerals Other than Gold—		
Alumina (from Bauxite)	1 671	1 798
Beryl	2	3
Building Stone	7	4
Clays	11	10
Coal	617	619
Copper	22	13
Felspar	11	2
Glass Sand	8	11
Gypsum	5	5
Iron Ore	2 826	3 886
Lead Ore and Conc.	....	8
Limestone	22	30
Manganese	8	13
Mineral Beach Sands	334	337
Nickel	1 804	1 981
Petroleum (Crude Oil)	133	158
(Natural Gas)	8	7
Salt	290	436
Semi-precious Stones	20	10
Talc	10	12
Tin	154	149
Vermiculite	2	2
Total, Other Minerals	7 965	9 494

PART 3—STATE AID TO MINING

(a) State Batteries

At the end of the year there were 17 State Batteries including the Northampton Base Metal Plant.

From inception to the end of 1973, gold, silver, tin, tungsten, lead, copper and tantalite ores to the value of $42 990 329 have been treated at the State Batteries. $40 887 303 came from 3 809 485.2 tonnes of gold ore, $476 184 from 85 364.5 tonnes of tin ore, $41 087 from 4 293.6 tonnes of tungsten ore, $1 496 210 from 68 806.2 tonnes of lead ore, $11 932 from 224.0 tonnes of copper ore, $73 261 from 2 192.8 tonnes of tantalite ore, and silver valued at $4 352 recovered as a by-product from the cyaniding of gold tailings.

During the year 49 565.1 tonnes of gold ores were crushed for 484.095 kilograms Bullion, estimated to contain 410.271 kilograms fine gold equal to 8.28 grams per tonne. The average value of sands after amalgamation was 2.44 grams per tonne, making the average head value 10.72 grams per tonne. Cyanide plants produced 38.732 kilograms of fine gold, giving a total estimated production for the year of 449.003 kilograms of fine gold valued at $1 021 157.

The working expenditure for the year for all plants was $794 240 and the revenue was $64 844 giving a working loss of $729 396 which does not include depreciation, interest or superannuation. Since the inception of State Batteries, the capital expenditure has been $1 916 630 made up of $1 471 465 from General Loan Funds; $360 349 from Consolidated Revenue; $57 244 from Assistance to Gold Mining Industry; and $27 572 from Assistance to Metalliferous Mining.

Head Office expenditure including Workers Compensation Insurance and Pay Roll Tax was $109 979 compared with $89 113 for 1972.

The actual expenditure from inception to the end of 1973 exceeds revenue by $8 328 403.

(b) Prospecting Scheme

At the end of the year 9 men were in receipt of prospecting assistance as compared with 13 at the end of 1972.

Total expenditure for 1973 was $7 734.74 and refunds amounted to $898.42.

Assisted prospectors crushed 1 082 tonnes of ore during the year for 4.770 kilograms of gold.

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

Expenditure—$1 046 367.
Refunds—$202 973.
Ore Crushed—129 565 tonnes.
Gold Won—1 808.698 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 functions of this Branch are indicated by the titles of its seven Divisions:—

(1) Agriculture Division
(2) Engineering Chemistry Division
(3) Foods, Drugs, Toxicology and Industrial Hygiene Division
(4) Industrial Chemistry Division
(5) Mineralogy, Mineral Technology and Geochemistry Division
(6) Water Division
(7) Kalgoorlie Metallurgical Laboratory.

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

The number of samples received during 1973 for analysis and elucidation was 23 741 only slightly more than the 23 642 in 1972. The number of samples received gives some measure of the Laboratories' activities but far from completely describes the work. A major factor in this is the variation in the amount of work associated with different samples.

Dr L. W. Samuel, Director of the Laboratories since July 24, 1957, retired on November 14, 1973, and Mr. R. C. Gorman was appointed as the new Director.

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 requirements.

Licences held under the Explosives Act at the end of 1973 numbered 498. A total of 101 magazines, stores and premises were inspected and special attention was given to vehicles carrying explosives. Also, 4 856 licences were held under the Flammable Liquids Regulations and some 3 000 registered premises were inspected during the year.

Shotfirers' Permits are now prescribed in the Construction Safety Regulations for all blasting carried out at construction or excavation sites and 159 of such permits had been issued by the end of the year. Courses of instruction for Shotfirers under the control of the Technical Education Branch were given during the year.

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

Under arrangement with this Department the State Public Health Department continued the periodical X-Ray examination of mine workers throughout the year.

A total of 13 463 examinations were made of which 5 330 were made under the Mines Workers' Relief Act and 8 133 under the Mines Regulation Act. Of the latter, 7 609 were new applicants and 524 were re-examinees.

Compensation payments under the Miners' Phthisis Act amounted to $7 121 compared with $7 988 for the previous year. The number of beneficiaries under the Act as at 31/12/1973 was 30, being two ex-miners and 28 widows.

PART 7—SURVEYS AND MAPPING BRANCH

During the year 2 162 surveys of mining tenements were completed compared with 3 730 in 1972 and 9 813 applications for mining titles were received for processing. The value of surveys performed showed a sharp drop, being down to $400 501 as against $625 517 in 1972.

New plans prepared during the year totalled 133 at a scale of 1 : 50 000 and 6 at 1 : 100 000. In addition, four large wall plans covering 20 1 : 250 000 sheets of the Pilbara Region were prepared for the Department of Industrial Development.

PART 8—STAFF

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

In this summary I have referred only to specific items of the Department's many activities. The detailed reports of Branches are contained in Divisions II to VIII hereunder.

B. M. ROGERS,
Under Secretary for Mines.

Department of Mines,
Perth.

DIVISION II

Report of the State Mining Engineer for the Year 1973

Under Secretary for Mines:

I hereby submit the 1973 Annual Report for the State Mining Engineer's Branch, which is divided into the following sections—

Mineral and Metal Production—
by J. K. N. Lloyd, Assistant State Mining Engineer.

Mine Inspection and Accident Statistics—
by J. M. Faichney, Mining Engineer—Senior Inspector of Mines (Perth).

Petroleum Exploration and Production—
by A. J. Sharp, Senior Petroleum Engineer.

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

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

Board of Examiners—
by W. J. Cahill, Secretary, Board of Examiners.

MINERALS METALS COAL AND OIL

In Western Australia's mineral, metal, coal and oil production for the 1973 year, the value of iron ore production was again the highest at $454 674 240 followed by alumina at $108 916 300, nickel ore and concentrates at $92 832 563 and crude oil at $32 509 543.

Of the main iron ore companies Hamersley Iron Pty. Ltd. reported exports of 27 142 483 tonnes at a grade of 64.11 per cent Fe, Mt. Newman Mining Co. Pty. Ltd. 23 300 504 tonnes at 63 per cent Fe, Goldsworthy Mining Ltd. 8 294 960 tonnes at 63.22 per cent Fe and Cliffs W.A. Mining Co. Pty. Ltd. 8 162 530 tonnes at 59.92 per cent Fe.

Alumina sales by Alcoa of Australia (W.A.) Ltd. totalled 1 729 129 tonnes having an estimated value of $108 916 300 f.o.b. Kwinana. Increased production at the Pinjarra refinery is planned with the partial construction of a third digester unit this year and the construction of a fourth to follow within two years.

Nickel, nickel ore and concentrate production valued at nearly $93 million was obtained from Kambalda, Nepean, Widgiemooltha, Scotia and Carr Boyd Rocks. Operations by Poseidon Ltd. at Mt. Windarra are at the stage where ore is being stockpiled prior to going into production.

Barrow Island oilfield production in 1973 was 14.5 million barrels of crude oil—a decrease of 6 per cent on the 1972 output.

Land oil exploration drilling activity decreased from 26 rig months in 1972 to 20 rig months in 1973 whereas offshore oil drilling activity increased from 37 rig months in 1972 to 40 rig months in 1973.

DRILLING

During 1973 the Drilling Section was responsible for the drilling of 10 039 metres in 452 bores and the testing by pumping of 35 bores.

Most of the drilling programmes undertaken formed part of the State-wide ground water investigation and these were carried out at Joondalup, Eneabba, Cooya Pooya, Roebourne and the Canning Basin. Another drilling programme was carried out for the Metropolitan Water Supply Sewerage and Drainage Board to provide pressure recording points for water in the lower section of the Canning Dam wall and the underlying granite foundation.

STAFF

Appointments—	
N. J. Francis, General Assistant	21/2/73
D. Holly, Ventilation Officer	7/5/73
K. A. Wigg, Typist	15/8/73
M. J. Lucev, Secretary Stenographer	21/9/73
Promotions—	
C. H. Davidson, Drilling Supervisor	17/8/73
R. J. Griffin, Mining Engineer District Inspector of Mines	7/12/73
Resignations—	
D. Geldard, Ventilation Officer	4/1/73
D. D. Mainwaring, Ventilation Officer	2/8/73
S. M. Morris, Typist	17/8/73
L. M. Wesson, Secretary Stenographer	21/9/73
G. R. Guthrie, Mining Engineer—District Inspector of Mines	28/9/73
Deaths—	
L. C. Honey, Drilling Supervisor	26/5/73
A. N. Thompson, General Assistant	4/12/73
P. Swainston, Mining Engineer—Senior Inspector of Mines (Port Hedland)	18/12/73

A. Y. WILSON,
State Mining Engineer.

MINERAL AND METAL PRODUCTION

J. K. N. Lloyd—Assistant State Mining Engineer

Mineral production for the year 1973 is described in this report which is based on information obtained from various sources including the Statistical and Mines Inspection Sections of the Department.

Statistics relating to the mining industry are tabulated as follows:—

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

TABLE 1

Mineral and Metal Output

Mineral Product	1972		1973	
	Production	Value	Production	Value
	Tonne (t)	$A	Tonne (t)	$A
Alumina	1 435 859·19	90 443 400	1 729 128·93	108 916 300
Bentonite	164·60	2 322	833·15	11 708
Beryl	62·48	12 870	161·95	29 712
Building Stone	5 316·47	52 079	4 830·26	46 261
Clays	330 051·61	386 546	387 853·10	384 944
Coal	1 167 540·20	5 907 162	1 171 068·54	7 048 726
Cobalt	193·54	629 500	131·43	477 091
Copper—				
Ore and Concentrates	1 015·73	254 990	35·41	8 434
Metal	724·60	632 400	371·76	434 800
Felspar	569·49	8 408	318·02	4 695
Glass Sand	165 373·98	127 877	222 669·71	139 985
Gold (kg)	10 477·80	15 256 797	8 586·90	18 917 671
Gypsum	133 797·28	386 438	164 254·92	503 298
Ilmenite	504 969·88	5 936 710	731 100·69	9 169 703
Iron Ore	55 439 232·93	384 010 130	75 896 481·25	454 674 240
Iron Ore—Pig Iron	99 687·41	3 987 937	96 819·11	3 844 002
Lead Ore and Concentrates	....	....	146·77	17 513
Leucoxene	15 132·60	720 986	15 395·53	1 107 188
Limestone....	1 147 848·69	1 182 229	1 353 579·12	1 426 758
Lithium Ore—Petalite	1 070·41	16 771	221·50	3 466
Magnesite	30·48	450	....	....
Manganese	99 505·54	1 541 332	26 306·47	428 000
Monazite	2 369·45	301 756	3 015·63	394 798
Nickel Ore and Concentrates	309 192·84	84 493 697	353 172·49	92 832 563
Ochre	551·21	9 122	....	....
Palladium (kg)	....	....	23·37	41 000
Petroleum—				
Crude Oil (barrels)	15 402 695·00	34 346 900	14 578 230·00	32 509 453
Natural Gas (10^3m^3)	664 510·94	3 176 203	812 043·58	5 161 868
Condensate (barrels)	43 629·00	Not available	30 310·00	Not available
Rutile	3 370·68	345 185	1 910·57	193 933
Salt	2 217 851·56	6 247 617	3 333 937·42	9 837 959
Semi-Precious Stones	88·24	47 074	37·27	20 430
Silver (kg)	4 146·73	190 066	7 919·76	437 447
Talc	26 012·83	Not available	37 188·33	Not available
Tantalo-Columbite	269·78	1 201 689	272·59	718 167
Tin Concentrate	2 037·43	4 284 086	1 215·53	2 653 423
Vermiculite	380·37	2 266	426·10	3 565
Xenotime	6·10	6 604	45·24	31 926
Zircon	62 596·10	1 608 754	89 697·36	2 674 143
Totals	....	647 758 353	....	755 105 170

1 barrel = 42 U.S. gallons = 34·972 Imperial gallons = 158·987 litres.
1 kilogram (kg) = 32·150 75 troy ounces = 35·273 96 ounces.
1 tonne (t) = 0·984 206 5 tons.

TABLE 2

Reported Mine Development

Gold or Mineral Field	Mine	Decline and Shaft Sinking	Driving	Cross Cutting	Rising and Winzing	Exploratory Drilling	Total
Gold—		(m)	(m)	(m)	(m)	(m)	(m)
Murchison	Hill 50 Gold Mine N.L.	....	140	149	157	1 740	2 186
Dundas	Central Norseman Gold Corpn. N.L.	....	168	....	216	8 814	9 198
East Coolgardie	North Kalgurli Mines Ltd.	....	356	27	27	1 256	1 666
	Gold Mines of Kalgoorlie (Aust.) Ltd.	162	1 172	Driving	233	2 854	4 421
	Lake View and Star Ltd.....	....	1 549	and Cross	216	1 993	3 758
	Kalgoorlie Lake View Pty. Ltd.	37	3 745	Cutting	933	10 231	14 946
	Totals in Gold Mines	199	7 130	176	1 782	26 888	36 175
Nickel—							
Coolgardie	Western Mining Corpn. Ltd.	4 765	8 377	Driving	1 041	84 174	98 357
	Metals Exploration N.L.	77	1 119	and Cross	991	4 189	6 376
	Anaconda Australia Inc.	....	1 227	Cutting	303	....	1 530
	Selcast Exploration Ltd.	143	....	....	33	3 434	3 610
Broad Arrow	Scotia (Great Boulder-North Kalgurli)	21	350	267	248	678	1 564
North Coolgardie....	Carr Boyd Rocks (Great Boulder-North Kalgurli)	....	290	262	137	833	1 522
Mt. Margaret	Poseidon Ltd.	1 500	....	420	355	8 708	10 983
	Totals in Nickel Mines	6 506	11 363	949	3 108	102 016	123 942
	Totals in All Mines	6 705	18 493	1 125	4 890	128 904	160 117

ALUMINA

On behalf of *Alcoa of Australia (W.A.) Ltd.*, the Western Australian Government Railways transported 4 339 095 tonnes of bauxite from the No. 2 minesite at Jarrahdale to the company's refinery at Kwinana.

Mining operations at Jarrahdale covered 47.4 hectares with pit faces ranging from 3.5 to 5.0 metres in height. Rehabilitation of mined-out areas included the development of Langford Park, a 1.5 hectare public picnic area at the company's original minesite in the Darling Range.

The Del Park minesite was the source of 1 951 891 tonnes of bauxite treated at the Pinjarra refinery. Mining covered 19.7 hectares with pit faces ranging from 3.5 to 6.5 metres high. The mobile crusher, overland conveyors and stacker operated satisfactorily throughout the year. Expansion of the refinery has begun with the partial construction of a third digester unit and a fourth planned for construction within the next two years.

Alumina sales totalled 1 729 129 tonnes having an estimated value of $108 916 300 f.o.b. Kwinana. The average number of person employed was 1 778 which included 1 161 at the Kwinana refinery, 341 at the Pinjarra refinery, 231 at Jarrahdale and 45 at Del Park.

BENTONITE

Lake deposits near Marchagee were the source of the 833 tonne output for the year.

BERYL

Seleka Mining and Investments Ltd. mining a pegmatite at Rothsay in the Yalgoo Goldfield obtained 162 tonnes of beryl containing 1 947.25 units of beryllium oxide valued at $29 712. Three men were employed on surface mining to a depth of 9 metres along the strike of pegmatite.

BUILDING STONE

Production from mining tenements, granted under the provisions of the Mining Act, was 4 830 tonnes valued at $46 261.

Snowstone Pty. Ltd. produced 3 996 tonnes of crushed quartz from stockpiles at its Mukinbudin quarry. It is expected that mining of the deposit will recommence in 1974. Other building stone producers reported the production of 48 tonnes of spongolite from the Fitzgerald River area, 16 tonnes of sandstone from Mount Barker, and 770 tonnes of decorative quartzite from Toodyay.

CLAYS

Reported clay production from the Metropolitan Area, Bullsbrook, Byford, Goomalling and Clackline totalled 387 853 tonnes valued at $384 944. The principal users of clay were *Midland Brick Co. Pty. Ltd., Concrete Industries (Monier) Ltd., Metropolitan Brick Co. Pty. Ltd., L. Whitman Pty. Ltd., Clackline Refractories Ltd.*, and *H. L. Brisbane and Wunderlich Ltd.* Cement manufacturers obtained their supplies from Gosnells and Armadale.

COAL

The total output from all mines in the Collie Coalfield was 1 171 069 tonnes valued at $7 048 726 at the pit head. This output represented an increase of 3 529 tonnes on the previous year's figure.

The Muja open cut, operated by the *Griffin Coal Mining Co. Ltd.*, was the source of 595 856 tonnes of coal representing 50.9 per cent of the total output for the field. *Western Collieries Ltd's* output of 575 213 tonnes was obtained from the Western No. 2 mine (422 568 tonnes) and Western No. 5 open cut (152 645 tonnes). The report of the Senior Inspector of Coal Mines appears elsewhere in this Branch Report.

COBALT

Western Mining Corporation Ltd. reported that 112 tonnes of cobalt were contained in nickel concentrates from its Kambalda operations. Nineteen tonnes were contained in concentrates resulting from the operations of the *Great Boulder-North Kalgurli* partnership at Scotia. The total output of 131 tonnes was valued at $477 091.

COPPER

At Ilgarari in the Peak Hill Goldfields, *Group Explorations Pty. Ltd.* ceased production from underground early in the year and continued to treat tailings till mid-year. The output for this period amounted to 26 tonnes of concentrate containing 8.59 tonnes of copper valued at $6 980. Partial flooding of the mine has caused the walls and timbers to collapse. Halls Creek was the source of a 9 tonne parcel of ore valued at $1 454.

Western Mining Corporation Ltd. reported that nickel concentrates from its Kambalda operations contained 372 tonnes of copper having an estimated value of $434 800.

FELSPAR

Australian Glass Manufacturers Co. reported the production of 318 tonnes from its quarry at Londonderry in the Coolgardie Goldfield. 221 tonnes of petalite was obtained from the same source.

GLASS SAND

Glass sand production totalled 222 670 tonnes valued at $139 985 which value does not include the value of 58 783 tonnes obtained by *Bell Bros. Pty. Ltd.* from the Lake Gnangara deposit. Other producers included *Silicon Quarries Pty. Ltd.* at Jandakot with 149 995 tonnes, *Australian Glass Manufacturers Co.* at Lake Gnangara with 10 159 tonnes, and *Westralian Sands Ltd.* at Yoganup with 2 024 tonnes.

GOLD

The ore treated during the year amounted to 1 630 732 tonnes as compared with 1 671 272 tonnes for the previous year. Gold recovered was 8 586.90 kilograms (kg) which was 1 890.90kg less than the 1972 production of 10 477.80 kg. Grade of ore mined was lower, recovery being 5.27 grams per tonne as compared with 6.27 grams per tonne for 1972.

The calculated value of the gold produced was $18 917 671 which included $10 802 797 distributed by the Gold Producers Association from the sale of 9 625.64 kg of gold at an average premium of $1 124.37 per kilogram.

Statistics relating to the gold mining industry are tabulated in Table "3".

TABLE 3

Principal Gold Producers

Mine	1972			1973		
	Tonnes Treated	Yield Kilograms	Grams Per Tonne	Tonnes Treated	Yield Kilograms	Grams Per Tonne
Gold Mines of Kalgoorlie (Aust.) Ltd.	822 852	4 473·96	5·44	542 568	2 230·21	4·11
Kalgoorlie Lake View Pty. Ltd.	....	....	....	467 831	2 032·03	4·34
Lake View and Star Ltd.	403 875	2 538·04	6·28	224 218	1 452·80	6·48
Central Norseman Gold Corporation N.L.	147 819	1 464·41	9·91	151 903	1 135·31	7·47
North Kalgurli Mines Ltd.	161 300	823·46	5·11	131 694	735·30	5·58
Hill 50 Gold Mine N.L.	80 122	786·67	9·82	59 171	523·36	8·84
Minor Producers	55 304	391·26	7·07	53 347	477·89	8·96
Total State Production	1 671 272	10 477·80	6·27	1 630 732	8 586·90	5·27

1 gram per tonne = 0·653 3 pennyweight per ton.

As from and including the 20th June, 1973, *Lake View and Star Ltd.* and *Gold Mines of Kalgoorlie (Aust.) Ltd.* amalgamated their respective Kalgoorlie gold mining and treatment assets to form a new company *Kalgoorlie Lake View Pty. Ltd. Western Mining Corporation Ltd.* and *Westminer Investments Pty. Ltd.* also joined the operation of the new company which will be managed by *Western Mining Corporation.*

During the second half of the year the new company treated 467 831 tonnes of ore for a return of 2 032.03 kg of fine gold, average recovery being 4.34 grams per tonne. Development work completed including 3 745 metres of driving and crosscutting, 643 metres of rising, 290 metres of winzing and 37 metres of decline driving. The average of 1 226 company employees should be increased in the coming year.

Gold Mines of Kalgoorlie (Aust.) Ltd. with a six months production of 542 568 tonnes of ore for a return of 2 230.21 kg of fine gold was the State's leading producer. Production from the company's Fimiston leases was 107 339 tonnes yielding 630.34 kg of fine gold and from Mount Charlotte 435 229 tonnes yielding 1 599.87 kg. Ore reserves at the time of the merger were reported to be 424 000 tonnes at 6.69 grams per tonne for the Fimiston leases and 2 981 000 tonnes at 5.29 g/t for Mount Charlotte.

Lake View and Star Ltd. produced 1 452.80 kg of fine gold from the treatment of 224 218 tonnes of ore at an average recovery of 6.48 g/t. Ore reserves as at the end of March were estimated as 1 205 013 tonnes of positive ore at 7.59 g/t plus 322 232 tonnes of probable ore at 8.76 g/t.

North Kalgurli Mines Ltd. treated 131 694 tonnes of ore for a recovery of 735.30 kilograms of fine gold at an average recovery rate of 5.58 grams per tonne. During the previous year 823.46 kg were recovered from 161 300 tonnes. The average number of men employed during the year was 231.

The company has announced that its gold mining operations will be suspended in the coming year and have arranged for broken ore from the mine to be treated by Kalgoorlie Lake View Pty. Ltd. North Kalgurli's gold extraction plant underwent a major refit and will be used to concentrate nickel ore from Anaconda's Redross mine near Widgiemooltha. New equipment installed included 3 sets of Agitair flotation machines.

Central Norseman Gold Corporation N.L. treated 151 903 tonnes for a recovery of 1 135.31 kg of fine gold. Gold recovery was at the rate of 7.47 g/t as compared with the previous year's recovery of 9.91 g/t when 147 819 tonnes yielded 1 464.41 kilograms. Ore reserves were stated as 247 300 tonnes at 8.5 grams per tonne.

The company employing 228 men concentrated its underground mining operations on exploiting developed low grade blocks. It is planned to re-open the North Royal shaft, above the No. 4 level, early in the new year. Development work completed during the year included 216 metres of rising and 168 metres of driving and crosscutting.

Hill 50 Gold Mine N.L. at Mount Magnet treated 59 171 tonnes of ore for a return of 523.36 kilograms of fine gold, average recovery being 8.84 grams per tonne. The company has commenced a programme to develop ore between the 13 and 15 levels of the main shaft and between the 8 and 9 levels of the Morning Star. By the end of the year a rise beneath the internal shaft had been stripped to full shaft size to the 994 metre horizon. Total ore reserves estimated in June, were stated to be 660 000 tonnes at 8.42 g/t.

Smaller producers of note were *Frasers* at Southern Cross with 114.54 kg from 2 651 tonnes, *Radio* at Golden Valley in the Yilgarn with 70.11 kg from 5 125 tonnes, *Daisy* at Mount Monger with 18.02 kg from 665 tonnes, *Halley's Comet* at Marble Bar with 17.79 kg from tailings retreatment, *Mount Bellew* at Bulong with 16.33 kg from 108 tonnes, and *Logans Gold Mine* at Mount Monger with 13.36 kg from 1 176 tonnes.

GYPSUM

Plaster and cement manufacturers obtained their supplies of gypsum from Yellowdine (31 427 tonnes), Lake Brown (16 851 tonnes), Nukarni (1 065 tonnes), Norseman (224 tonnes), and Kellerberrin (41 tonnes). *Garrick Agnew Pty. Ltd.* reported the export of 114 647 tonnes from Useless Loop in the Shark Bay area.

Total gypsum production for the year was 164 255 tonnes valued at $503 298. Included in the total was 2 923 tonnes used in the manufacture of cement. Reported production of Plaster of Paris was 32 743 tonnes from 46 861 tonnes of gypsum.

ILMENITE, LEUCOXENE, MONAZITE, RUTILE, XENOTIME, ZIRCON

Sales of ilmenite totalled 731 101 tonnes valued at $9 169 703 f.o.b. Bunbury. Minerals associated with ilmenite returned $4 401 988 to the producers

Western Titanium N.L. at Capel produced 210 321 tonnes of Ilmenite assaying 54.86 per cent titanium dioxide, 13 667 tonnes of upgraded ilmenite assaying 90 per cent TiO_2, 1 135 tonnes of leucoxene, 1 367 tonnes of monazite, 1 910 tonnes of rutile, 45 tonnes of xenotime, and 27 628 tonnes of zircon. The ore bodies now being mined contain a high grade secondary ilmenite (58% + TiO_2). This material is used as a feed to the pilot upgrading plant. Construction of a 30 000 tonne per year upgrading plant, commenced in 1973 is due for completion in mid-1974.

Western Mineral Sands Pty. Ltd. at Capel sold 194 230 tonnes of ilmenite assaying 54 per cent TiO_2. Mining was confined to M.L. 421 on Wellington location 1056. The 8.5 hectare area mined was the source of 1.3 million tonnes of ore yielding 162 580 tonnes of ilmenite and 46 521 tonnes of heavy mineral residue which was sold to Westralian Sands Ltd. Construction has started on a dredge and new wet treatment plant. The change-over from dry mining to dredging is scheduled for next June.

Westralian Sands Ltd. with wet separation plants at Yoganup and a dry separation plant at Capel produced 175 483 tonnes of ilmenite assaying 57.16 per cent TiO_2, 10 106 tonnes of leucoxene, 1 265 tonnes of monazite, and 37 052 tonnes of zircon. The company is phasing out mining operations south of the Capel River and is concentrating on mining ore north of the river in an area known as Yoganup Extended. A clay scrubber was added to the wet screening plant to recover mineral trapped in clay balls. An average of 120 persons were employed throughout the year.

Ilmenite Minerals Pty Ltd. and *Cable (1956) Ltd.* wholly-owned subsidiaries of *Kathleen Investments (Aust.) Ltd.* produced 137 400 tonnes of ilmenite assaying 54 per cent TiO_2, 4 155 tonnes of leucoxene, 384 tonnes of monazite, and 25 017 tonnes of zircon. The parent company is consolidating its Western Australian operations and at the beginning of next year Ilmenite Minerals and Cable will be combined into one corporate structure operating as *Cable Sands Pty. Ltd.* Mining and wet concentration of the heavy minerals continued at Stratham and Wonnerup. Concentrates from both sites are carted to the dry treatment plant at Bunbury.

For the past 20 years ilmenite mining has been concentrated in the Bunbury-Capel-Busselton areas. In the coming year this production will be augmented by production from the Eneabba district about 130 kilometres south of Geraldton.

IRON ORE

Total iron ore production for the year was 75 993 300 tonnes valued at $458 518 242 and includes 1 203 609 tonnes used locally in the production of pig iron. This output represents a 36.8 per cent increase on the previous year's production of 55 538 920 tonnes. Iron ore exports, including pellet and sinter sales, are tabulated in Table 4.

TABLE 4

IRON ORE EXPORTS

Company	Sales Tonnes (t)	Grade % Fe
Hamersley Iron Pty. Ltd.	27 142 483	64·11
Mt. Newman Mining Co. Pty. Ltd.	23 300 504	63·00
Goldsworthy Mining Ltd.	8 294 960	63·22
Cliffs W.A. Mining Co. Pty. Ltd.	8 162 530	59·92
Dampier Mining Co. Ltd.	2 518 845	66·82
Western Mining Corporation Ltd.	788 521	59·46
Totals	70 207 843	63·19

Hamersley Iron Pty. Ltd. exported 27 142 483 tonnes of iron ore and pellets valued at $162 367 986 f.o.b. Dampier. This total included 1 732 763 tonnes of pellets shipped to Japan and 340 764 tonnes of pellets shipped to Europe.

At Tom Price 32 million tonnes of material was excavated and included about 1.6 million tonnes of low grade ore and 12 million tonnes of waste. The deposit being mined is at present divided into four pits namely Tom Price, East, West, and South Batter pits. The pit bottom has been reached in the West pit and an easterly extension of the Tom Price pit is being developed. Efficiency has been improved in the quarrying operations by introducing overall quarry spotting for truck allocation to ensure that shovels are not kept idle. This replaces the previous system where trucks were allocated to work with a particular shovel. 1 037 persons are employed at this site.

The company's Paraburdoo operations, requiring a work force of 603, were expanded in April by the introduction of continuous working on a three shift per day basis, six days per week. About half the 27.7 million tonnes mined was low grade ore and waste. The general pit dimensions are 1 100 m by 800 m with total height of faces about 70 metres.

Improvements planned for Dampier include better dust control in the pellet plant as well as increased output of uniform sized pellets. The company is carrying out further research on the production of HI-met a metallised agglomerate, containing about 93 per cent iron, which could replace scrap iron as direct feed to electric arc furnaces. There are 1 336 persons employed at Dampier which is the operational centre for the railroad, pellet plant and port facilities at East Intercourse Island and Parker Point.

Mount Newman Mining Co. Pty. Ltd. exported 23 300 504 tonnes of iron ore valued at $136 798 974 f.o.b. Port Hedland. In addition 2 754 998 tonnes, valued at $16 252 446, was shipped to the Eastern States. The company's work force of 2 175 includes 1 150 at the Mt. Whaleback mine site and 1 025 at the port and working on the 427 km railroad.

Increased production in 1974 is envisaged as the company expects to put into service three 200 tonne capacity Wabco trucks and a 17 m^3 electric shovel as well as install a third secondary crusher. Port, screening and rail facilities are to be expanded and improved.

The two pits formed by quarrying at Mt. Whaleback have quarry benches established at 15 metre intervals and have been worked over a total height of 70 metres. Ore to waste ratio was estimated as 0.83 : 1. Contractors were employed to mine a 6 million tonne scree ore deposit at the north eastern end of the deposit.

Goldsworthy Mining Ltd. reported the sale of 8 294 960 tonnes valued at $48 950 502 f.o.b. Port Hedland. Production, to be increased to 10 million tonnes per annum, was obtained from Goldsworthy, Shay Gap and Sunrise Hill. Three road haul units are being used to transport ore from Sunrise Hill to Shay Gap where the ore is crushed to 150 mm prior to railing to Finucane Island the company's stockpile area and port site at Port Hedland.

Ore production from the three mining sites was 3.3 million tonnes from Mt. Goldsworthy, 4.4 million tonnes from Shay Gap and 0.7 million tonnes from Sunrise Hill. A total of 5.6 million cubic metres of waste was removed during the period under review. The company employed and housed the work force of 1 016 and their families at the four operational centres.

Cliffs W.A. Mining Co. Pty. Ltd. exported 4 395 970 tonnes of sinter and 3 766 560 tonnes of pellets having a total value of $49 051 973 f.o.b. Cape Lambert. Over 9 million tonnes of crude iron ore (goethite-limonite) were mined from two mesas at Pannawonica near the Robe River in the West Pilbara Goldfield. It is expected that future production will be raised to 11 million tonnes per annum.

Townships at Pannawonica and Wickham have been established to house the company's 768 employees and their families.

Dampier Mining Co. Ltd. produced a total of 5 452 486 tonnes of 65 per cent Fe ore from its quarries at Koolyanobbing, Koolan and Cockatoo Islands. The nominal value of this output was $36 085 333.

Export overseas of iron ore from Koolan and Cockatoo Islands amounted to 2 518 845 tonnes (66.8% Fe) valued at $14 650 576. Shipments to the Eastern States totalled 360 510 tonnes having a nominal value of $2 483 692. The total number of persons employed on the two islands was 342 an increase of 38 on the previous year's employment figure.

Koolyanobbing production was 2 573 131 tonnes averaging 63 per cent Fe and having a nominal value of $18 951 065. Included in the production railed to Kwinana was 1 466 341 tonnes shipped from that port to the Eastern States. The remaining ore was the source of feed for the 620 000 tonne per annum capacity blast furnace. Ore reserves at the quarry are estimated as 30 million tonnes above the water table. Exploratory drilling amounting to 544 m was done to investigate the ore body at depth. One hundred men are employed at the mine.

Western Mining Corporation Ltd.. mining the Koolanooka Hills deposit near Morawa and mining small deposits at Mungada 43 miles east of Koolanooka, exported 788 521 tonnes of 59.5 per cent Fe ore valued at $5 167 026 f.o.b. Geraldton. From Mungada the ore is transported by road trains to the crushing and screening plant, at Koolanooka, at the rate of about 1 200 tonnes per day. The crushed ore mixed with previously stockpiled lower grade ore from the Koolanooka deposit is railed to Geraldton for shipment overseas. Ore breaking has ceased at Koolanooka and it is expected that the company will cease operations in this area about the middle of 1974 when all its orders have been filled. An average of 67 persons were employed at the mine sites and eight at the Geraldton stockpile.

The Charcoal Iron and Steel Industry at Wundowie obtained 96 819 tonnes of iron ore from the Koolyanobbing deposit situated about three miles east of the Dowd's Hill deposit worked by Dampier Mining. Pig iron production was 58 077 tonnes valued at $3 844 002. A work force of 11 men at the quarry site produce about 370 tonnes per day from various benches having face heights generally 6 metres high.

LEAD

Mining activity in the Northampton District was at a low ebb during 1973 but improving lead prices at the end of the year has resulted in revived interest in the field. *Tycho Mining Pty. Ltd.* continued to work the Ethel Maud and McGuire lead mines. The sale of 73.3 tonnes of concentrate containing 58.65 tonnes of lead returned $9 000 to the producer. Total production from this District was 147 tonnes containing 100 tonnes of lead valued at $17 513.

LIMESTONE

Reported production of limestone was 1 353 579 tonnes valued at $1 426 758. Quarries for this material are operated in the Wanneroo area and south of Fremantle. Country sources of supply for agricultural purposes were Lake Preston in the South West and Esperance. By arrangement with the Fremantle Port Authority, *Cockburn Cement Ltd.* is dredging limesand from Cockburn Sound.

LITHIUM

Australian Glass Manufacturers Co. obtained 221.5 tonnes of petalite from its quarry at Londonderry in the Coolgardie Goldfield. This quarry was also the source of the 318 tonnes of felspar produced during the year.

MANGANESE

Exports from Port Hedland totalled 26 306 tonnes averaging 48.31 per cent Mn and valued at $428 000 f.o.b. *Westralian Ores Pty. Ltd.* was responsible for all of this production which was exported to Japan. There is approximately 24 000 tonnes stockpiled at the company's quarry site at Woodie Woodie in the Pilbara Goldfield.

NICKEL

Nickel, nickel ore and concentrate production in 1973 had an estimated value of just under $93 million made up from production from Kambalda, Nepean, Widgiemooltha, Scotia and Carr Boyd Rocks. Operations, at Mount Windarra by Poseidon Ltd., have reached a stage where ore is being stockpiled prior to going into production.

Western Mining Corporation's nickel smelter located at Hampton about 10 km south of Boulder was brought into production early in the year. It treated 51 604 tonnes of concentrate for a production of 8 167 tonnes of nickel-copper matte. Installation of an oxygen plant is in progress so that smelter production can be increased beyond its design capacity of 200 000 tonnes per annum. The company's nickel refinery at Kwinana produced 19 813 tonnes of briquettes and powder in addition to 119 894 tonnes of ammonium sulphate, 2 845 tonnes of copper sulphide and 1 118 tonnes of mixed sulphides.

The output of *Western Mining Corporation Ltd.* was contained in 249 343 tonnes of concentrate from Kambalda averaging 13.58 per cent nickel and having an estimated value of $79 676 000. At Kambalda the company treated 1 284 273 tonnes of ore which included 80 866 tonnes of ore purchased from Metals Exploration N.L. mining at Nepean. Ore reserves were reported to be 24 051 000 tonnes averaging 3.24 per cent nickel. Development completed during the year included 48 metres of shaft sinking, 4 716 metres of decline construction, 8 377 metres of driving and crosscutting, 68 metres of winzing, and 973 metres of rising.

Sinking of the Silver Lake shaft progressed slowly and resulted in the shaft being deepened from the 12 level to the 12 loading pocket position. Scheduled final depth will be 10 m below the No. 13 level. A long crosscut on the No. 7 level has intersected the Hunt ore shoot. Another crosscut has been driven southerly on the No. 9 level to test the extension of the Lunnon ore shoot.

The Durkin haulage shaft was deepened to about 20 m below the No. 9 level. Stoping methods are gradually being changed to flat back cut and fill operations particularly for the mining of rib pillars between slots. The Otter-Juan decline was advanced to below the 10 level with decline driving continuing towards the 15 horizon. Ore is trucked to the surface using a fleet of eight Kiruna 36 tonne capacity diesel trucks. The McMahon shoot has been developed to the 4 level with most of the production from the area coming from the Nos. 2 and 3 levels. Some small stopes are being brought into production on the Fisher shoot.

During the year soil tests were carried out in readiness for the sinking of the Jan shaft which is located immediately north of the St. Ives townsite. Work was commenced on clearing and levelling the site and contracts let for the erection of the headframe, winder, workshops and store.

The *Scotia* operations, of the *Great Boulder Mines Ltd,* and *North Kalgurli Mines Ltd.* partnership, produced 18 366 tonnes of 19.18 per cent nickel concentrate valued at $7 757 400 f.o.b. Esperance. Tonneage treated at Fimiston amounted to 129 674 tonnes. Reserves at Scotia were estimated at 1 029 000 tonnes averaging 1.75 per cent nickel. Development work completed during the year included deepening the Mitchell shaft by 21 metres, driving 350 m, crosscutting 267 m, winzing 33 m and rising 215 m. Diamond drilling from the surface was also carried out west of the shaft.

At *Carr Boyd Rocks* the joint venturers completed 290 metres of driving, 261 metres of crosscutting and 137 metres of rising and winzing. The shaft has been constructed to about 190 metres below the surface. The output from this mine was 41 873 tonnes treated for a recovery of 3 922 tonnes of concentrate containing 9.93 per cent nickel and valued at $893 400. Ore reserves were calculated to be 1 536 000 tonnes averaging 1.34 per cent Ni and 0.45 per cent copper.

Metals Exploration N.L. at Nepean produced 80 666 tonnes of ore averaging 3.05 per cent Ni which ore was treated at Western Mining's concentrator at Kambalda. The nickel recovered from the ore had a market value estimated to be $4 497 263. Development work completed during the year included shaft sinking 38 m, decline driving 38 m, driving and crosscutting 1 119 m, winzing 251 m, and rising 740 m. Ore reserves at the end of June were estimated to be 490 000 tonnes averaging 4.4 per cent nickel.

Anaconda Australia Inc. re-opened its Redross mine in May and proceeded to develop six levels using trackles mining equipment. Shaft sinking was suspended last year when sinking had reached a depth of 256 metres. Production of 675 tonnes of 1.06 per cent Ni was valued at $8 500. All ore is being treated at the Croesus plant, of North Kalgurli Mines Ltd., which was converted to treat nickel ore during the latter part of the year. The company reported that ore reserves at Redross are 840 400 tonnes averaging 3.5 per cent nickel.

At Windarra, *Poseidon Ltd.* completed 1 500 metres of decline and incline driving, and 420 metres of level development as well as removing 2 793 000 cubic metres of overburden from the South Windarra open cut site.

Western Selcast continued its drilling programme at the Perseverance project at Agnew and completed the development and testing work on the 80 m level of the exploration shaft. Work ceased in December after the completion of 280 metres of driving and crosscutting and 18 493 metres of exploratory diamond drilling. Reserves are estimated as 40 million tonnes at 2.2 per cent nickel.

PALLADIUM AND PLATINUM

23.37 kilograms of palladium and 6.97 kilograms of platinum, having a total value of $64 900, were contained in nickel matte sold by *Western Mining Corporation Ltd.*

PETROLEUM

Shipments of Barrow Island crude oil totalled 14 578 230 barrels having an estimated value of 32 509 453 at the Kwinana refinery. Production of gas from Dongara was 812 million cubic metres valued at $5 161 868 at the well head. Recovered from the gas was 30 310 barrels of condensate which was sold locally and to the refinery. The report of the Senior Petroleum Engineer covers more fully the activities of companies engaged in oil search and production.

SALT

Production reported to the Department of Mines was 3 333 937 tonnes having an estimated f.o.b. value of $9 837 959.

Texada Mines Pty. Ltd. operating at Lake MacLeod exported 1 607 534 tonnes through its port at Cape Cuvier. The company's operation is based entirely on the natural brine resources, of Lake MacLeod, which lie within a 15 metre thick layer of halite. The brine is recovered through 4.5 to 6 metre deep wells sunk at appropriate locations. Approximately 1 800 hectares of evaporating pans have been constructed on the southern section of the lake. Some 1 000 hectares are used for sodium chloride production and the balance for the production of mixed salts containing potassium and magnesium sulphate. A plant to produce 200 000 tonnes of langbeinite per annum was constructed during the year. The initial output of 305 tonnes was stockpiled at the site.

Dampier Salt Ltd. exported from Mistaken Island 993 658 tonnes of salt obtained from its operations at Dampier. Concentrating and crystallizing ponds cover an area of about 1 000 hectares.

Leslie Salt Co. employing 45 men at Port Hedland exported 695 977 tonnes of salt to Japan, Korea and Taiwan.

Lefroy Salt Pty. Ltd. exported 36 748 tonnes through Esperance. The company has constructed crystallizing ponds on the bed of Lake Lefroy and the washing of the harvested salt has resulted in a higher grade product being marketed.

Although its production is not recorded by this Department, it was reported through the District Inspector that *Shark Bay Salt* exported 136 305 tonnes obtained from its operations at Useless Loop. Production figures are not available from the intermittent operations of the *W.A. Salt Supply* which produces salt for the metropolitan market.

SEMI PRECIOUS STONES

Amethyst, chalcedony, moss opal, quartz, tourmaline and tiger eye opal valued at $20 430 were obtained from deposits in the Gascoyne, Dundas, Pilbara and West Pilbara Goldfields.

SILVER

Silver production, as a by-product of gold mining, amounted to 7 919.76 kilograms valued at $437 447.

TALC

Three Springs Talc Pty. Ltd. operating an open cut near Three Springs reported the sale of 36 788 tonnes of talc. During the year 121 635 tonnes of material was mined of which 39 076 tonnes was crushed and 34 071 tonnes of saleable talc produced.

Westside Mines N.L. completed the construction of its crushing, screening and washing plant and further developed the talc deposit at Mt. Seabrook about 160 km northwest of Meekatharra. Several trial parcels totalling 400 tonnes were prepared and exported to potential buyers. Planned production for 1974 is 25 000 tonnes which will require a work force of about 15 at the site.

TANTALO-COLUMBITE

All the reported production of 272.6 tonnes of concentrate was obtained during the tin mining operations of *Greenbushes Tin N.L.* at Greenbushes. The product valued at $718 167 contained the equivalent of 9 002 units of Ta_2O_5.

TIN

Production for the year was 1 216 tonnes of concentrate containing 867.5 tonnes of tin valued at $2 653 423. Output from Greenbushes was 879 tonnes of concentrate and from the Pilbara and West Pilbara 337 tonnes.

Greenbushes Tin N.L. was the State's leading producer with an output of 780 tonnes of concentrate valued at $1 721 209. This company has constructed a new concentrating plant just south of Greenbushes in an area more central with respect to future mining operations. The only other producer in this tin field was *Vultan Minerals Ltd.* with an output of 99 tonnes valued at $206 987.

In the Pilbara the principal producers were *Pilbara Tin Pty. Ltd.* at Moolyella with 185 tonnes of concentrate valued at $397 793 and *J. A. Johnston* at Coondina with 100 tonnes valued at $220 459.

VERMICULITE

A small open cuit situated about 5 km north of Mount Palmer was the source of the 426 tonnes of vermiculite mined by *Mineral By-Products Pty. Ltd.*

MINE INSPECTION AND ACCIDENT STATISTICS

J. M. Faichney—Mining Engineer and Senior Inspector of Mines (Perth)

ACCIDENT STATISTICS

These statistics are for accidents reported to the Mines Department and cover all classes of mining and include exploration for and production of oil.

The corresponding figures for the previous year are shown in brackets.

There were 12 (18) fatal and 507 (479) serious accidents.

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

Table A gives the number of serious accidents classified according to the nature of the injury and to the mining district in which the accident occurred.

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

Table C presents fatal and serious accidents segregated according to the accident cause and to the mining district in which they occurred.

WINDING MACHINERY ACCIDENTS

Fourteen accidents involving winding machinery and associated equipment were reported during the year. They consisted of one derailment, one overwind, three involving the hanging up of a cage or skip in a shaft, and ten miscellaneous accidents.

The derailment was in the underlay Regent shaft of Central Norseman Gold Corporation N. L. whilst ore was being hoisted and occurred about 18 metres below the shaft collar. It is believed that the skip was overloaded. The skip and shaft timber were badly damaged.

The overwind occurred in the Reward shaft at the Mt. Charlotte mine when an empty kibble was being run through the shaft prior to hoisting spillage. A chain driving the depth indicator came off the sprocket when the kibble was near the end of the wind and the monkey struck the sheave wheel before the driver could stop it. There was only minor damage.

The Cage/Skip hang ups were in vertical shafts. One of these was due to the skip lying incorrectly causing it to jam in the shaft and apparently was due to a stone fouling the bridle. Another occurred during the setting of the midshaft overspeed on the controls and was due to the over reaction of the winder driver. The third accident occurred when the cage fouled a gate dislodged from the cage on an earlier trip.

Amongst the accidents classified miscellaneous were two which occurred during the lowering of equipment which was slung under the skip. The equipment jammed in the shaft. Three accidents were due to a cage gate fouling the plat cap, and were due to a gate not being securely fastened, an error in signalling, and a false signal being received. In another accident a skipman released part of a cartridge of ore before the skip had been correctly positioned. There were two accidents with kibbles. The first was due to the monkey temporarily hanging up on the skids whilst the kibble was being lowered and when it fell on to the monkey catcher minor injuries resulted to three men. In the other incident the kibble could not be raised after being check run through the shaft as due to pump failure, water had risen above the monkey stop and the kibble had floated under the wall plates. In another accident a full ore truck was not correctly secured in a cage and it moved causing considerable damage to shaft sets before the winder driver brought the cage to a stop.

The failure of the draw bar on a skip in the Chaffers shaft allowed the skip to fall from just below the tipping track at the surface to the bottom of the shaft. The grippers could not function when the draw bar failed because of the geometry of the mechanism. Considerable damage was caused to the shaft timbers but fortunately no persons were involved. All drawbars and associated gear on cages and skips have been subjected to closer scrutiny since this accident.

To ensure compliance with safety requirements the ropes involved in the above accidents were cut and recapped, and repairs or replacement effected to skips and cages.

ADIT ACCIDENTS

There was one acident in the Otter Adit of Western Mining Corporation Ltd (Kambalda Nickel Operations) when the personnel carrier ran into wheelspin holes on a bend causing the vehicle to bounce violently and the passengers to be tossed about. The holes were caused when a large truck was towed out of the Adit on the previous night shift.

PROSECUTIONS

There were no prosecutions this year.

CERTIFICATES AND PERMITS

The following were issued during the year:—

Sunday Labour Permits; Fifteen permits were issued. Nine of these were required in order that loss of time in the subsequent working of the mine would be avoided. Five permits were granted in order that normal production would not be brought to a standstill, and one permit was given in order that a Winder could be tested under load conditions after major repairs to it. Two applications for permits were refused as it was considered that, in one case, the work could be done in normal working hours, and in the other a permit was not necessary.

Permit to Fire Outside Prescribed Times: Four of these were issued and all were subject to special conditions to ensure safety in operation and included the posting of suitable warning signs, and ensuring that fumes from the firing were exhausted direct to the surface.

Certificates of Exemption (Section 46 of the Mines Regulation Act): None were issued.

Permits to Rise: Sixty eight permits were granted for the construction of rises having a total length of 2 460.4 metres. Twenty three rises (753.8 metres) were made with the conventional method whilst in forty three (1 570.6 metres) the borehole and gig method was used. Two rises (136 metres) were constructed using a Raise Climber.

Diesel Engine Equipped Units: Permits were issued for 39 units to be taken and used underground in mines.

AUTHORISED MINE SURVEYOR

Authorised Mine Surveyor Certificates were issued by the Survey Board to the following persons:—

P. J. Shedden—Certificate No. 182.

J. McGeough—Certificate No. 183.

B. G. Curran—Certificate No. 184.

D. R. Gordon—Certificate No. 185.

W. Janssen—Certificate No. 186.

R. J. Barbour—Certificate No. 187.

R. E. J. Baxter—Certificate No. 188.

W. T. Ridley—Certificate No. 190.

VENTILATION

Inspections were made of the workings of all underground metalliferous mines and most of the crushing and screening installations associated with metalliferous treatment plants, hard rock quarries, heavy mineral sands mining, and iron ore operations. Sampling of the air borne dust was undertaken at all of these operations and the quantity determined either by counting or weighing. Temperatures at underground working places were also measured.

Extensive testing of mine atmospheres and airflows were made wherever diesel engined equipment was being operated.

Assistance was given to various mines throughout the State by making primary and secondary airflow surveys and advising on ways to overcome problems of dust prevention or collection encountered underground and on the surface.

All fuming accidents were investigated and detailed reports prepared. There were no fatal accidents from fumes liberated by blasting with explosives but 18 minor accidents occurred.

The testing of the toxic fumes and dust liberated to atmosphere in the various assay laboratories and reduction plants was continued.

The total number of dust samples taken with the konimeter during the year was 1 458. The table below shows the source of the samples and the average count. The figures shown in brackets are for 1972.

Dust Samples from	Samples Giving over 1 000 + P.P.CC	Total Number of Samples	Average Count
Surface Plants	10 (55)	274 (533)	318 (388)
Assay Offices	— (—)	9 (—)	492 (—)
Stoping	4 (4)	674 (702)	174 (170)
Levels	4 (4)	218 (185)	210 (203)
Development	5 (3)	283 (212)	188 (185)
	23 (66)	1 458 (1 632)	211 (246)

Counts of 1000+p.p.cc are included in the average count.

Respirable dust sampling was also carried out with gravi-metric samplers and the results of 458 samples are shown in the following tabulation.

Dust Samples from	Less than T.L.V.	Less than 2 T.L.V.	More than 2 T.L.V.
Surface Plants	179	73	112
Surface Mining	41	12	7
Underground Mining	14	4	16
	234	89	135

T.L.V. = Threshold Limit Value.

There were no emissions of methane or hydrogen sulphide reported.

Five operating companies had 108 diesel engine equipped units in use at underground mines. This indicates an increase of 18 units on those in use in 1972 and is mainly attributed to the commencement of operations by one company and an expansion of operations by another. Regular sampling and analysing of the undiluted exhaust gas was maintained. "No load" testing of the engines was discontinued early in the year and "full load" testing substituted as investigations indicated that "full load" testing was more closely related to working conditions. A close check was kept on mine atmosphere wherever diesel engined units were operated by sampling and analysing the air flows. The summary hereunder gives the results of the sampling.

SUMMARY OF RESULTS OF SAMPLING OF CONTAMINANTS IN DIESEL EXHAUST (UNDILUTED) AND MINE ATMOSPHERE (DILUTED)

Diesel Exhaust Parts per million (P.P.M.)						Mine Atmosphere Parts per million (P.P.M.)					
Carbon Monoxide			Nitrous Fumes			Carbon Monoxide			Nitrous Fumes		
— 1 000	— 2 500	+ 2 500	— 1 000	— 2 000	+ 2 000	— 20	— 100	+ 100	— 10	— 25	+ 25
245	19	6	222	31	22	82	2	2	80	10	1

GROUND VIBRATIONS

The portable seismograph was used to record vibrations from the blasting of explosives at bauxite mines, harbour construction works, major tunnelling, minor tunnels under roads, and for the railways to determine vibration from diesel locomotives. Most of the recordings were necessary because of complaints about excessive vibrations but some were made to ensure that blasting would not give cause for complaint.

FATAL ACCIDENTS

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

Name and Occupation	Date	Mine	Details and Remarks
Whiffen, J. A. (Tallyman)	14/2/73	Aust. Iron and Steel Ltd., Kwinana	He was knocked down and run over by a truck reversing into the slag pit.
Seibel, E. (Miner)	16/2/73	Western Mining Corporation Ltd. (Kambalda Nickel Operations) Durkin Shaft	The deceased received chest injuries when crushed between a mechanical loader and the wall of the crosscut.
Hogg, W. J. (Electrician)	28/2/73	Western Mining Corporation Ltd. (Kambalda Nickel Operations) Durkin Shaft	A slab of rock fell from the back of the stope and struck the deceased as he was leaving the stope.
Leslie, J. M. (Fitter-Mechanic)	21/3/73	Western Titanium Ltd.	Whilst servicing the rams on a front end loader the " H " frame slipped from its support and crushed him against the loader.
Phillips, K. F. (Truck Driver)	30/4/73	Aust. Iron and Steel Ltd., Kwinana	He was found on a roadway used by trucks carting pig iron from the pig machine and had apparently been struck unknowingly by a truck. It occurred at night.
Emmins, T. (Loader Operator)....	4/9/73	Hamersley Iron Pty. Ltd.—Tom Price	As he was attempting to restart the stalled engine of the loader he was driving, it went down the sloping side of a hill and he was thrown from it and under a wheel.
Cravis, A. (Miner)	21/9/73	Kalgoorlie Lake View Pty. Ltd., Associated Shaft	He apparently returned to light a " pop " in the drive wall near the face already lit and was killed instantly when the face charges exploded.
Dawson, J. S. (Maintenance Foreman)	2/11/73	Cliffs Robe River Iron Associates—Cape Lambert	When an electric motor was started the external rotor of a clutch connecting to a ball mill which the deceased was examining caught and threw him causing crush injuries.
Leader, M. J. (Shift Foreman)	9/11/73	Western Titanium Ltd.	Whilst examining the intake to pumps on a pontoon in a clean water pond the pontoon overturned and he was drowned.
Fitzsimmons, S. J. (Fitter)	14/11/73 Died 2/12/73	Hamersley Iron Pty. Ltd., Tom Price	He received injuries when thrown on to a cross-member of the conveyor structure whilst attempting to release a conveyor counterweight carriage.
Seaquist, D. B. (Electrician)	17/11/73	Mt. Newman Mining Co. Pty. Ltd.—Newman	Electrocuted whilst working to instal a meter on a main switchboard.
Evans, A. (Truck Driver)	14/12/73	Mt. Newman Mining Co. Pty. Ltd.—Newman	A haulpak truck he was driving along a waste dump road swung across the road and down an embankment causing him to be thrown out and receive crush injuries.

DIAGRAM OF FATAL ACCIDENTS

SEGREGATED ACCORDING TO CLASS OF MINING

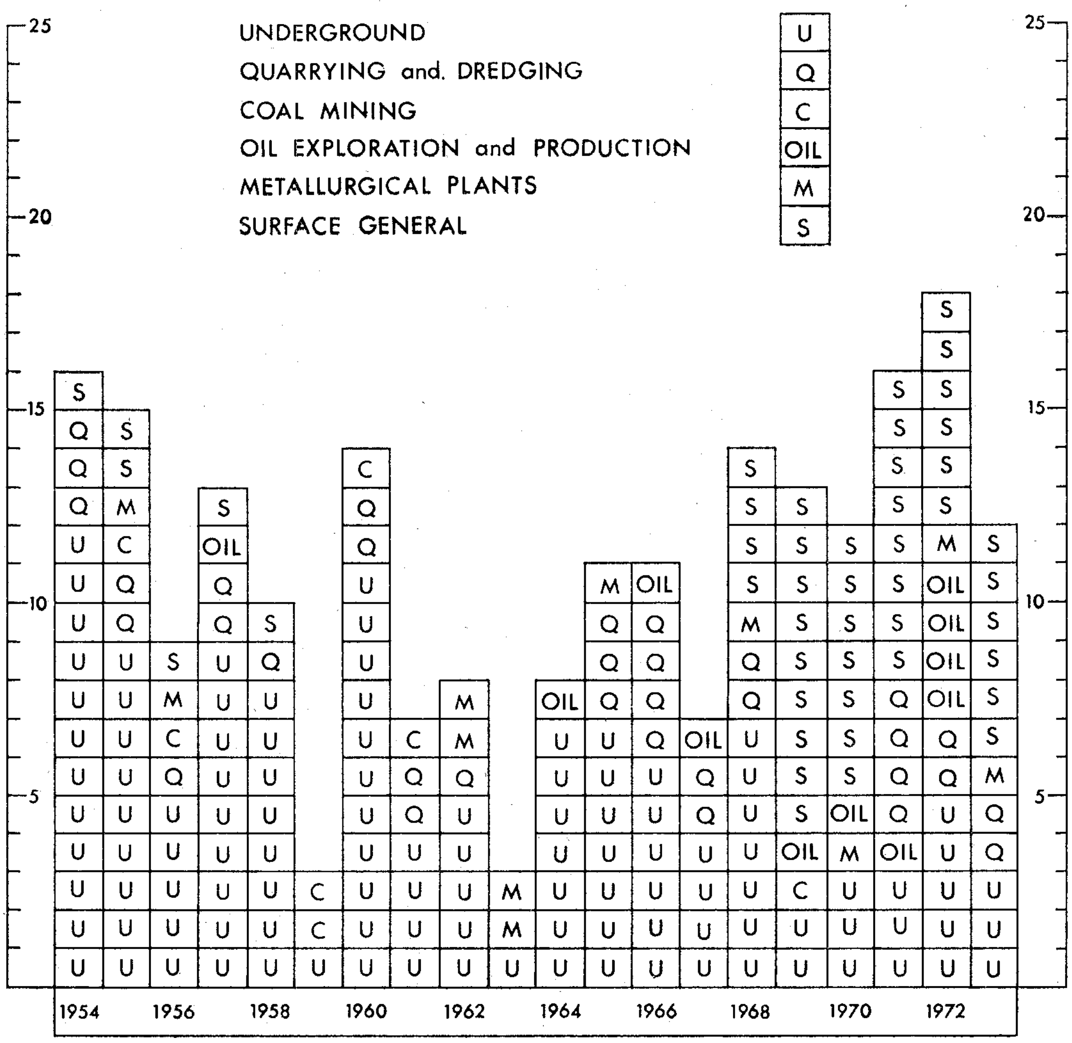


TABLE "A"

SERIOUS ACCIDENTS FOR 1973

Class of Accident	West Kim-berley	Pil-bara	West Pil-bara	Ash-burton	Peak Hill	Gas-coyne	Murchi-son	North Cool-gardie	Mount Mar-garet	Broad Arrow	East Cool-gardie	Cool-gardie	Dun-das	Yil-garn	North-ampton	South West	Green-bushes	Collie	Total
Major Injuries (exclusive of fatal)—																			
Fractures—																			
Head	....	....	....	....	....	....	....	....	....	....	1	....	....	....	....	1	....	1	3
Shoulder	1	....	2	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	3
Arm	....	1	1	....	....	....	1	1	....	....	2	5	....	....	....	5	....	....	16
Hand	....	....	2	....	....	....	....	....	....	....	1	1	....	....	....	....	....	1	5
Spine	....	....	1	....	....	....	....	....	....	....	1	1	....	....	....	....	....	....	3
Rib	....	....	2	....	....	....	....	....	....	1	2	1	....	....	....	2	....	....	8
Pelvis	....	....	1	....	....	....	....	....	....	....	1	....	....	....	....	....	....	....	2
Thigh	....	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	1
Leg	....	....	5	....	....	....	....	....	....	....	2	1	....	....	....	4	....	1	13
Ankle	....	....	1	....	1	1	1	....	....	....	1	3	....	1	....	2	....	1	12
Foot	1	1	7	....	....	....	....	....	....	1	5	2	....	....	1	3	....	1	22
Amputations—																			
Arm	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Hand	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Finger	....	....	....	....	....	....	....	....	1	....	....	1	....	....	....	....	....	1	3
Leg	....	....	....	....	....	....	....	....	....	....	....	1	1	....	....	....	....	....	2
Foot	....	....	....	....	....	....	....	....	....	....	....	1	....	....	....	....	....	....	1
Toe	....	....	....	....	....	....	....	....	....	....	....	1	....	....	....	....	1	....	2
Loss of Eye	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Serious Internal	....	....	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	1
Hernia	1	....	....	....	....	1	....	....	....	....	3	1	....	....	....	....	1	....	7
Dislocations	....	....	1	....	....	....	....	....	1	....	1	....	....	....	....	1	....	....	4
Other Major	....	....	1	....	....	....	....	....	....	....	2	....	....	....	....	....	....	....	3
Total Major	3	3	25	....	1	2	2	1	2	2	22	19	1	1	1	18	2	6	111
Minor Injuries—																			
Fractures—																			
Finger	1	....	....	....	2	....	....	1	2	....	3	10	....	....	....	4	....	1	24
Toe	....	....	....	....	....	....	....	....	....	....	....	2	....	....	....	5	....	....	7
Head	....	....	2	....	....	....	....	....	....	1	2	6	....	1	....	1	....	1	14
Eye	1	1	2	....	....	1	....	....	1	....	4	5	1	....	....	5	....	....	21
Shoulder	1	....	1	....	....	....	1	....	....	....	4	2	....	....	....	....	....	2	11
Arm	....	1	1	....	....	....	....	....	....	1	14	4	....	....	....	4	....	2	27
Hand	....	1	4	1	2	1	5	....	....	2	17	17	1	....	....	7	1	3	62
Back	....	3	8	1	1	....	1	1	....	2	19	17	4	....	....	8	....	13	78
Rib	....	....	1	....	....	....	....	....	....	....	1	2	....	....	....	....	....	....	4
Leg	1	1	3	....	1	1	1	....	1	1	25	13	3	....	....	17	1	4	73
Foot	....	....	6	1	....	2	2	....	....	....	10	8	2	....	....	5	....	4	40
Other Minor	....	....	4	1	....	1	1	1	....	1	6	9	....	....	....	9	....	2	35
Total Minor	4	7	32	4	6	6	11	3	4	8	105	95	11	1	....	65	2	32	396
Grand Total	7	10	57	4	7	8	13	4	6	10	127	114	12	2	1	83	4	38	507

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

TABLE "B"

ACCIDENTS SEGREGATED ACCORDING TO MINERAL MINED AND PROCESSED

Mineral	Men Employed	Accidents		
		Fatal	Serious	Minor
Bauxite (Alumina)	1 778	....	28	66
Coal	619	....	38	180
Gold	1 977	1	144	306
Gypsum	61	....	2	3
Ilmenite etc.	529	2	14	84
Iron	7 822	7	65	312
Nickel	3 133	2	153	478
Oil (Production and Exploration)	580	....	26	202
Salt	483	....	6	14
Tin	182	....	5	16
Other Minerals	137	....	1	....
Rock Quarries	355	....	25	39
Totals	17 656	12	507	1 700

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	....	....	....	....	....	....	....	....	....	....	....	7	....	7
Pilbara	....	....	....	....	....	....	....	....	....	....	....	10	....	10
West Pilbara	....	....	....	....	....	....	....	....	....	....	3	57	3	57
Ashburton	....	....	....	....	....	....	....	....	....	....	....	4	....	4
Peak Hill	....	....	....	....	....	....	....	....	....	....	2	7	2	7
Gascoyne	....	....	....	....	....	....	....	....	....	....	....	8	....	8
Murchison	....	....	....	1	....	1	....	....	....	6	....	5	....	13
East Murchison	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Yalgoo	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Northampton	....	....	....	....	....	1	....	....	....	....	....	....	....	1
Mount Margaret	....	....	....	1	....	....	....	....	....	2	....	3	....	6
North Coolgardie	....	....	....	....	....	....	....	....	....	4	....	....	....	4
Broad Arrow	....	....	....	....	....	....	....	....	....	8	....	2	....	10
North East Coolgardie	....	....	....	....	....	....	....	....	....	....	....	....	....	....
East Coolgardie	1	1	....	6	....	1	....	....	....	60	....	59	1	127
Coolgardie	....	2	1	7	....	1	....	....	1	75	....	29	2	114
Yilgarn	....	....	....	1	....	....	....	....	....	....	....	1	....	2
Dundas	....	....	....	....	....	1	....	....	....	9	....	2	....	12
Phillips River	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Greenbushes	....	....	....	....	....	....	....	....	....	....	....	4	....	4
South West	....	1	....	1	....	....	....	....	....	....	4	81	4	83
Collie	....	....	....	3	....	....	....	....	....	27	....	8	....	38
Nabberu	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Warburton	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Eucla	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Total for 1973	1	4	1	20	....	5	....	....	1	191	9	287	12	507
Total for 1972	....	....	1	21	2	1	1	5	1	185	13	267	18	479

PETROLEUM EXPLORATION AND PRODUCTION

A. J. Sharp—Senior Petroleum Engineer

BARROW ISLAND OILFIELD

(Operators—West Australian Petroleum Pty. Ltd.)

In 1973 the Barrow Island oilfield produced 14.5 million barrels of crude oil, a decrease of 6 per cent on the previous year's output. The average daily rate of crude oil production declined from 42 000 barrels per day in 1972 to 40 000 barrels per day in 1973.

The first shipment of L.P.G. for use in the North West was made from Barrow Island in June, 1973. L.P.G. is extracted from natural gas produced in association with the crude oil. Extraction of the L.P.G. is carried out by a low temperature separation unit.

During the year an extended production test was carried out on the Pasco No. 1 well. The Pasco No. 1 well was drilled in 1967 and penetrated hydrocarbon zones between 5 200 ft and 6 000 ft. Short production tests conducted immediately after drilling indicated that petroleum was not economically recoverable and the well was shut-in. In order to further evaluate the hydrocarbon accumulation the Pasco No. 1 well was production tested during 1973 over a seven week period. The result of the testing confirmed that production of the well is uneconomic at present.

	No. of Wells December, 1972	No. of Wells December, 1973
Producing oil wells	320	315
Part-time producing oil wells	....	....
Non-producing oil wells	16	20
Water injection wells	157	158
Water source wells	9	9
Total number of wells	502	502

SOUTH WEST GAS FIELDS AND DONGARA-PINJARRA NATURAL GAS PIPELINE

(Operators—West Australian Petroleum Pty. Ltd.)

The Dongara and Mondarra gas fields produced a total of 29 thousand million cu ft (815 x 10^6m^3) natural gas in 1973. The average daily rate of natural gas production was 77.5 million cu ft (2.2 x 10^6m^3) per day. The field facilities and pipeline operate continually throughout the year.

The depleted Walyering No. 1 well was plugged and abandoned. Steps are being taken by the Licensee to surrender the Walyering production licence area.

The remaining gas reserve of the Gingin No. 1 well was retained as a standby source of gas to be used in the event of interruption to the Dongara-Mondarra gas supply. The well remained shut-in throughout the year.

LAND EXPLORATION AND APPRAISAL DRILLING

Land exploration drilling activity decreased from 26 rig months in 1972 to 20 rig months in 1973. With the exception of Barrow Island Deep No. 1 the wells drilled on land gave no indication of the presence of petroleum in economic quantities.

The Barrow Island Deep Well (operator—West Australian Petroleum Pty. Ltd.) was drilled to a total depth of 15 256 ft (4 651 m) and penetrated gas intervals between 10 600 ft (3 232 m) and 11 400 ft (3476 m). The production testing of the gas intervals was commenced in early July. The testing indicated that the gas accumulations are not sufficiently large to be economically recoverable at present.

Land exploration drilling operations are summarised in the attached table.

OFFSHORE EXPLORATION AND APPRAISAL DRILLING

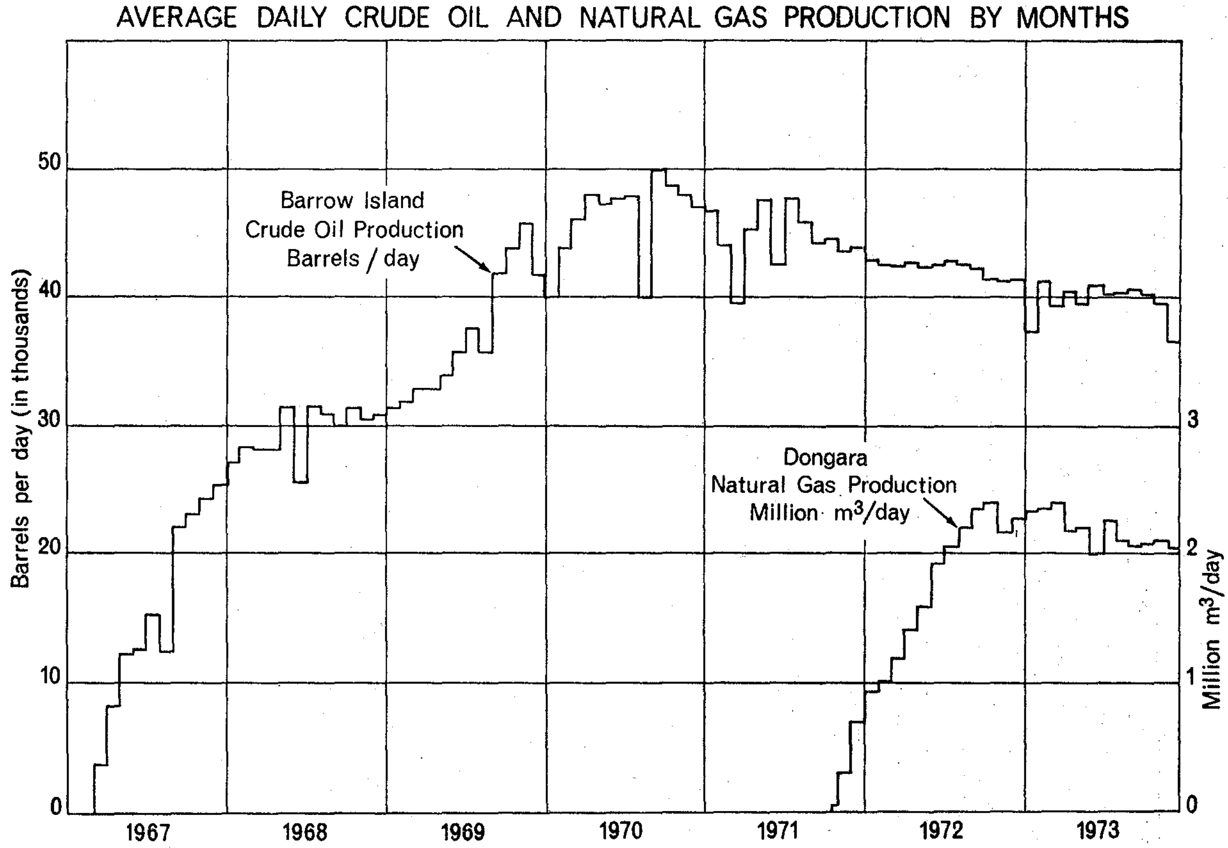
Offshore drilling activity increased from 37 rig months in 1972 to 40 rig months in 1973. The drilling ships Glomar Tasman, Navigator and Sedco 445, the semi-submersible drilling vessel Ocean Digger and the Big John drilling barge operated in the North West Shelf area during the year. Considerable delays to drilling operations were caused by the seven tropical cyclones which passed through the North West Shelf. The most intensive, Cyclone Kerry, blew the Ocean Digger and Glomar Tasman off location and damaged the Big John drilling barge. Further delays were caused by industrial disputes.

New petroleum discoveries of probable commercial significance were made at Egret No. 1 (Operator—BOCAL) and Dockrell No. 1 (Operator—BOCAL). The Egret No. 1 well produced on test at the rate of 2 729 barrels (434 m^3) per day oil with 2.9 million cu ft (82 000 m^3) per day gas on a ¾ in (19.05 mm) choke. The Dockrell No. 1 produced on test at the rate of 755 barrels (120.09 m^3) per day condensate and 13 million (371 430 m^3) per day gas on a ¾ in (19.05 mm) choke. The West Tryal Rocks No. 1 well (Operator—West Australian Petroleum Pty. Ltd.) which penetrated hydrocarbon zones of possible commercial significance was not production tested because of mechanical problems. A step out well to appraise the West Tryal Rocks structure is planned for 1974.

Three appraisal wells, Goodwyn No. 3, Goodwyn No. 4 and Angel No. 3, were drilled in order to further delineate the extent of the Goodwyn and Angel natural gas accumulations. In November, 1973 preliminary steps were taken by the permittee towards the applications for production licenses with the nomination of blocks on the Angel, North Rankin and Goodwyn structures for the purpose of declaring locations.

Offshore exploration and appraisal drilling operations are summarised in the attached table.

AVERAGE DAILY CRUDE OIL AND NATURAL GAS PRODUCTION BY MONTHS



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OFFSHORE PETROLEUM EXPLORATION/APPRAISAL DRILLING IN WESTERN AUSTRALIA

1973

OPERATOR	CONTRACTOR	RIG	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
BOCAL	Global Marine	Glomar Tasman		ROSEMARY NO. 1 12,825' (3909m) Plugged and abandoned.			ANGEL NO. 3 12,401' (3780m) Gas/Condensate. Suspended		NELSON ROCKS NO.1 7183' (2190m) Plugged and abandoned.		WAMAC NO. 1 9066' (2764m) Plugged and abandoned.	RONSARD NO. 1 9341' (2848m) Plugged and abandoned.		LAMBERT NO. 1 Drilling
BOCAL	Odeco	Ocean Digger	GOODWYN NO. 3 12,000' (3658m) Gas/condensate/oil. Suspended.			GOODWYN NO. 4 11,917' (3632m) Gas/condensate. Suspended.			DOCKRELL NO. 1 12,776' (3895m) Gas/condensate/oil. Suspended.			KERAUDREN NO. 1 12,608' (3844m) Plugged and abandoned.		POISSONNIER NO.1 Drilling
BOCAL	Atwoods Oceanics	Big John			EGRET NO. 1 12,000' (3658m) Oil. Suspended.					YAMPI NO. 1 13,697' (4176m) Plugged and abandoned.	3756'	LONDONDERRY (1145m) P & A		
WAPET	Zapata	Navigator		WEST TRYAL ROCKS NO. 1 12,685' (3867m) Gas (not production tested) Suspended.										
SHELL	Sedco	Sedco 445								EAST MERMAID NO. 1 13,345' (4067m) Plugged and abandoned.				

LAND PETROLEUM EXPLORATION/APPRAISAL DRILLING IN WESTERN AUSTRALIA

1973

OPERATOR	CONTRACTOR	RIG	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
WAPET	O.D.P.E.	Ideco Super 7-11		LAKE PRESTON NO. 1 14,977' (4566m) Plugged and abandoned.			THANGOO NO. 2 4830' (1473m) P & A		MIMOSA NO. 1 13,504' (4117m) Plugged & abandoned.			MOUNT HARDMAN NO. 1 11,021' (3360m) Plugged and abandoned.		
WAPET	Shelf	National 1320			BARROW DEEP NO. 1 15,256' (4651m) Gas completion.									
OCEANIA	O.D.P.E.	Ideco H.525				TAMALA NO. 1 4020' (1226m) Plugged and abandoned.					KALBARRI NO. 1 5051' (1540m) P & A			
AQUITANE	O.D.P.E.	Ideco H.40									CONTENTION HEIGHTS NO. 1 5874' (1791m) Plugged and abandoned.			
ROBINSON	Drilling and Prospecting Services	Longyear 44												KENDENUP NO.1 Drilling.

COAL MINING

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

The aggregate output of coal produced on the Collie Coal Field during 1973 amounted to 1 171 070 tonnes, an increase of 3 527 tonnes over the 1972 output of 1 167 644 tonnes. This represents a marginal increase of 0.30 per cent on the 1972 output.

The coal output was produced from three Collieries: Western No. 2 underground mine, Western No. 5 Open Cut and Muja Open Cut.

The Open Cut component of the total output increased by a marginal 0.12 per cent to 63.92 per cent.

The total value of the coal produced during 1973 was $7 048 725, an increase of $1 141 563 compared with the 1972 value of $5 907 162.

Western Collieries Ltd.—Western No. 2 Mine

The output of coal from this colliery was practically the same as that for 1972, the difference being an increase of only 4 tonnes for an output of 422 569 tonnes.

The widths of the working places are generally 5.5 m and 6.5 m while the working height varies from 2.2 to 3.0 metres, depending on the nature of the roof, the position of the parting on which the roof is formed, and the thickness of the coal seam. As the seam is approximately 4.0 m thick in most of the areas being worked, a band of coal varying from 1.0 m to 1.8 m in thickness is left in the roof during the first working of the seam.

The main ventilation flows are induced by two exhausting axial flow fans and an exhausting centrifugal fan located at widely separated sites on the surface.

The application of diesel equipment comprising a Wagner P.T.14 Supplies and Personnel Carrier, an Eimco L.H.D., seven Melroe Bobcat front-end-loaders and three Holder Tractors, continued satisfactorily.

Mining conditions were good in most areas of the mine.

Some pillar splitting was undertaken successfully on the retreat in No. 6 West "C" Panel.

Panel development continued in the Nos. 1, 4 and 6 West Districts and in No. 6 East District.

Development drivages continued in the No. 3 East Headings, the Cullen Headings and in the No. 3 East and No. 4 West Dips.

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

The output from this mine was 152 645 tonnes, an increase of 25 104 tonnes compared with the previous year when the output was 127 541 tonnes.

Towards the end of the year, work was commenced on excavation of the river diversion channel to enable the mine workings to be advanced to the West.

Most of the coal output was won from the Central-South area of the Cardiff Seam excavation but a small quantity was won from the North end of the Neath Seam excavation.

The Neath Seam has so far not been worked under any mined out Cardiff Seam areas. The Cardiff Seam workings have been in advance of the workings of the Neath Seam which rises to the blind outcrop to the East of the Cardiff Seam blind outcrop line.

There was some back-filling on a small scale into the neath Seam excavation. The surface overburden dumps increased significantly in the area and satisfactory profiles were achieved, particularly on the dumps formed by mobile scrapers.

Lighting arrangements and road conditions were satisfactory.

The Griffin Coal Mining Company Limited—Muja Open Cut

This mine was again the largest single producer on the coalfield. The output of 595 856 tonnes was, however, 21 574 tonnes less than the previous year's output of 617 430 tonnes.

The Hebe Seam was exposed on Block No. 5 and work continued satisfactorily on overburden removal from the widespread sites on Block No. 6.

Most of the coal output was won from the Hebe Seam on Blocks Nos. 4 and 5 but coal was also won from the Diana, Eos, Flora Galatea and Hebe Seams where these were exposed at their blind outcrop lines on Block No. 6.

Shallow overburden was removed from areas ahead of Block No. 6 where the WABCO 333 FT Mobile scraper which was purchased earlier in the year was operating on routes independent of the other vehicle traffic flows.

Overburden backfilling in accordance with the submitted design and layout procedures continued intermittently but satisfactorily. Far more overburden is being removed than can be backfilled at this stage, and it apppears that this is likely to remain the case as the faces are further advanced into the basin.

Road conditions, drainage provisions, wall and dump stability and the pit lighting were satisfactory throughout the year.

Only a minimal amount of open cut development has yet taken place down to the Hebe Seam over the abandoned underground galleries of the Hebe Mine.

The average rates of overburden removed to coal mined was 5.7 to 1.

General.

The accident record in the coal mining industry continued to be good and there were no fatalities during the year. There were 218 reported accidents of which 180 were minor and 38 were classified as serious, where an employee was absent from work for fifteen days or more.

The joint venture exploratory drilling programme of Western Collieries and Peabody Pty. Ltd. continued during most of the year until completion of the work in November. Engineering feasibility studies are continuing in relation to several areas.

The proposals to increase the generating capacity at Muja Power Station and to construct an Alumina Refinery at Worsley indicate that there will be an increasing demand for Collie coal.

At the end of the year, 618 persons were employed in the coal mining industry, approximately one-third of these in open cut mining and two-thirds in underground mining, including surface operations.

DRILLING OPERATIONS

D. A. Macpherson—Drilling Engineer

During 1973, the Drilling Section was responsible for the drilling of 10 039.1 metres in 452 bores and the development and testing of 35 bores. The drilling of 8 844.3 metres in 60 bores and the testing of all 35 bores was carried out by Departmental employees and equipment. The remaining 1 194.8 metres in 392 bores was carried out by contract.

This year, the distance bored by the Drilling Section is the second highest on record. In 1972, 9 582 metres were drilled.

A brief resume of each drilling operation 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.

ENEABBA LINE

This drilling programme 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 Eneabba Line commenced about 15 miles west of Winchester and runs west along the Carnamah/Eneabba Road, and continues west past Eneabba to within 5 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 site 7 had been completed, and the depth of site 6 was at 611 metres. During the year work was completed at site 6, site 5, site 4 and site 3, and the deep bore on site 2 had been completed.

CANNING BASIN

This drilling programme 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 will extend outwards from there.

The information is being obtained by drilling at each site one bore 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 on the same site to allow screening, developing and testing of aquifer at different depths. The bores are left in suitable condition for continuous water level measurements.

The work also involves drilling shallow shot holes for use in seismic surveys being carried out by G.S.W.A.

The work was commenced during 1972 and was suspended prior to the commencement of wet season. It was recommenced in 1973 on cessation of the wet season. The work proceeded smoothly with the exception of drilling on site 9, where high pressure shallow artesian conditions caused serious drilling problems. When work was suspended for the wet season one bore at site 9 was still flowing out of control. The work will be recommenced in 1974 on cessation of the wet season.

JOONDALUP

This programme 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 Yanchep, Muchea, Perth and the West coast. The job is required to provide information on stratigraphy and ground water conditions to a projected depth of about 76 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 on each site is left in suitable condition for continuous water level measurement.

The work was commenced in 1972, and was continued in 1973. Because of its relatively low priority the work has been carried on intermittently to suit rig availability. The job will be continued in 1974.

COOYA POOYA-ROEBOURNE

This is an investigation into the possibility of obtaining water for Roebourne and associated towns from ground water sources additional to those already being utilised. The work is being carried out for, and financed by the Public Works Department.

Initially a bore was drilled by cable tool and diamond core drilling to 244 metres. Because of the encouraging results of this bore the programme was enlarged in 1973.

During 1973, bores were drilled at selected sites by down hole hammer. Good quality water was encountered in all bores, but the individual bore yields were disappointingly low. The job was suspended late in 1973 and further work may be carried out in future years.

BROOKMAN ESTATE

This job was carried out for and financed by the Metropolitan Water Supply Sewerage and Drainage Board. The Brookmans Estate bore was an artesian bore drilled in 1899. Use had been discontinued and the bore capped off. The Metropolitan Water Board required that the bore be sealed so that there was no possibility of flow of water from one aquifer to another via the bore hole. To ensure this, it was necessary to fill the thousand foot deep bore with cement slurry. If the condition of the bore was suitable it was hoped to obtain a geophysical bore log during the course of the work.

The bore was drilled out to 266 metres, the condition of the bore did not warrant geophysical logging, due to risk of loss of equipment.

The bore was sealed by pumping in 5 cubic yards of cement slurry.

CANNING DAM

This drilling was carried out on behalf of, and was financed by the Metropolitan Water Supply Sewerage and Drainage Board. It involved drilling three vertical holes, and four angle holes from the lower gallery of the Canning Dam. The purpose of the job was to provide pressure recording points for water in the lower section of the dam wall, and the underlying granite foundation.

Bores were drilled by surface percussion drill. The work went smoothly except for the problems involved in working in confined spaces. The job was completed and all equipment and material removed.

STAFF

On 26th May, 1973 Mr. L. C. Honey, Drilling Supervisor, died of heart attack. On 4th December, 1973 Mr. A. Thompson died from heart attack.

Mr. C. H. Davidson was promoted from Assistant Drilling Supervisor to Drilling Supervisor.

PLANT

During 1973, a new heavy duty truck and a multipurpose drill rig were received. The truck was placed in service and the drill rig was being prepared for service at the end of the year.

A mindrill A2000 diamond drill rig was sold, also the GEMCO auger rig was sold.

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

TABLE SHOWING WORK CARRIED OUT DURING YEAR ENDED 31/12/73

Place	Purpose	Type of Work	Construction	No. of Bores	Metres
Eneabba Line	Groundwater Investigation	Rotary drilling	Dept. of Mines	14	5 404
		Bore Testing	....	(2)	
Canning Basin	Groundwater Investigation	Rotary Drilling	Dept. of Mines	11	1 341·8
		Bore Testing	Dept. of Mines	(9)	
		Siesmic Drilling	Contractor	392	1 194·8
Joondalup	Groundwater Investigation	Rotary and Cable	Dept. of Mines	17	1 293·5
		Tool Drilling	....	....	....
		Bore Testing	Dept. of Mines	(18)	....
Cooya Pooya	Groundwater Investigation	Down Hole Hammer....	Dept. of Mines	10	498·7
		Drilling	....	....	....
		Bore Testing	Dept. of Mines	(6)	....
Brookman Estate	Groundwater Investigation	Rotary Drilling	Dept. of Mines	1	226
Canning Dam	Foundation	Rock Drill	Dept. of Mines	7	80·3
			Totals—		
			Drilling	452	10 039·1
			Testing	(35)	

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 1973.

Mining Law Examination

An examination was held on April 9, 1973, and there were insufficient applications to warrant an examination in October. Details of the examination were:—

Entries	11
Admitted	10
Pass	9
Did not sit	1

The names of the successful candidates were:—

R. R. Brooks.
B. C. Grumitt.
J. Hylton.
R. W. Bell.
D. J. Lewis.
A. Dickson.
R. A. Nichols.
G. R. Guthrie.
A. Peck.

Underground Supervisor's Examination

At the request of Western Mining Corporation, Kambalda Nickel Operations, through the W.A. Chamber of Mines, a special examination was arranged and held on April 9, 1973. The reason given for their request was that they had approximately fifteen (15) people eligible to sit and they were short of supervisors. When applications were finally reviewed, it was found that only five (5) of the abovementioned were applicants.

Applications were received from the following centres:—

Kalgoorlie	18
Windarra	1
Norseman	1

The results were as follows:—

Passed	10
Failed	7
Repeat mining only	1

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

N. Archer.
W. L. Campbell.
J. J. Coombes.
W. J. Ferguson.
G. G. Jenkins.
H. R. Johansen.
W. Mitchell.
E. M. Moore.
K. E. Taylor.
H. H. G. Gay.

The normal annual examination was held on September 3, 1973, and applications were received from the following centres:—

Kalgoorlie	23
Norseman	3

The results were as follows:—

Passed	12
Failed	6

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

P. Brown.
T. W. Burleigh.
A. B. Duhring.
N. Fulton.
R. A. Giblett.
D. S. Harkup.
H. Korn.
W. L. Manser.
G. Reynolds.
J. Yurovich.
B. A. Bennett.
W. T. Turley.

Mine Manager's Certificates

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

R. R. Brooks.
G. F. Jenkins.
R. J. Griffin.
R. A. Nichols.
G. R. Guthrie.
A. Dickson.
J. Hylton.
W. S. Padgett.

General

Four meetings were held during the year—on March 13, May 1, July 24 and October 4, 1973.

During the year the Board visited Kalgoorlie and Norseman to examine candidates orally for the Underground Supervisor's examination.

DIVISION III

Report of the Superintendent of State Batteries—1973

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, 1973.

During the year the State Batteries changed to the metric system for production records. In this report metric measurements are used, with, in appropriate places, equivalent imperial measurements given in brackets, to allow an easy comparison with figures given in earlier reports.

Crushing Gold Ores

One 20 head, five 10 head, and nine 5 head mills crushed 49 565.1 tonnes (48 784.5 tons) of ore made up of 362 separate parcels, an average of 136.92 tonnes (134.8 tons) per parcel. The bullion produced amounted to 484.095 kilograms (15 566 oz) which is estimated to contain 410.271 kilograms (13 192 oz) of fine gold equal to 8.28 grams per tonne (5.41 dwt per ton) of ore.

The average value of the ore after amalgamation, but before cyanidation, was 2.44 grams per tonne (1.60 dwt per ton). Thus the average head value of the ore was 10.72 grams per tonne (7.0 dwt per ton) which is the same as the previous year's average.

A total of 30 tonnes of tungsten ore was also crushed at plants that crush mainly gold ores. The average cost for crushing the 49 595.1 tonnes was $13.17 per tonne ($13.38 per ton), compared with 1972 when 44 188.5 tons were crushed at a cost of $11.56 per ton.

Cyaniding

Four plants treated 10 505.7 tonnes (10 340.3 tons) of tailings from amalgamation for a production of 38.732 kilograms (1,245 oz) of fine gold. The average content was 4.9 grams (3.2 dwt) before cyanidation, while the residue after treatment averaged 1.2 grams (0.78 dwt). The theoretical extraction was, therefore, 75.1 per cent. The actual extraction was 75.2 per cent. The cost of cyaniding was $9.74 per tonne ($9.90 per ton), which was higher than the previous year, when 12 757 tons were treated at a cost of $7.17 per ton.

Silver recovered by the cyanidation of gold tailings amounted to 0.036 kg valued at $174.00.

TREATMENT OF ORES OTHER THAN GOLD

Lead Ores

During the year the Northampton State Battery crushed 2 539.6 tonnes (2 499.6 tons) of lead ore with an average content of 11.01 per cent lead. There were 11 separate parcels giving an average of 279.7 tonnes of ore per parcel.

A total of 306.0 tonnes of concentrates were produced. The concentrates averaged 74.9 per cent. lead, giving an estimated content of 229.2 tonnes of lead in concentrates.

2 233.6 tonnes of tailings were discarded. These had an average content of 2.26 per cent lead, giving a total of 50.5 tonnes of lead discarded in tailings. The recovery in the concentrates was 81.9 per cent of the lead in the ore delivered to the plant.

The cost of operating the Northampton State Battery including administration, was $38 206.24, being $15.04 per tonne ($15.28 per ton) of ore crushed. Revenue received was $5 105.83, being $2.01 per tonne. The corresponding figures for 1972 when 2 486.25 tons of ore were crushed, were operating cost $30 773.94 being $12.38 per ton, and revenue $5 009.86, being $2.02 per ton.

Tin Ore

No tin ore was crushed for the year but the Marble Bar magnetic separator plant treated 1.27 tonnes concentrates for a recovery of 1 094 kilograms of high grade tin concentrates valued at $2 250.

Tantalite-Columbite Ores

The Marble Bar magnetic separator plant recovered 24 kilograms of high grade tantalite concentrates valued at $140.

Tungsten Ore

The Norseman State Battery treated 30 tonnes of scheelite ore from which 356 kilograms of tungsten concentrates valued at $821 were recovered.

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

	1973 $	Grand Total $
Gold	1 021 157	40 887 303

OTHER ORES REALISED

Silver	174	4 352
Tin—		
Ores and Concentrates	2 250	475 04
Residues	....	1 144
Tungsten Concentrates	821	41 087
Agricultural Copper Ore	....	11 932
Lead Concentrates	64 176	1 496 210
Tantalite-Columbite Concentrates	140	73 26
Total Other Ores	$67 561	$2 103 026
Grand Total	$1 088 718	$42 990 329

FINANCIAL

	Tonnes	Expenditure	Receipts	Loss
		$	$	$
Crushing—Gold Mills	49 595·1	653 252	43 803	609 449
Magnetic Separator Plant—Marble Bar	1·27	623	80	543
Crushing Lead Mill—Northampton	2 539·6	38 206	5 106	33 100
Cyaniding	10 347·7	102 159	15 855	86 304
	62 483·67	794 240	64 844	729 396

The loss of $729 396 is an increase of $164 696 on the previous year. It does not include depreciation and interest on capital.

Capital expenditure, all from Consolidated Revenue Fund, was incurred as follows:—

		$
Boogardie	Repair Ramp and Ore Bin	14
Kalgoorlie	Repair Supports for Stamp Mills and Fine Ore Bins	26
Laverton	Repairs to Battery	9 367
Marble Bar	Changeover to A.C. Power	89
Marvel Loch	Wheel Weigher	874
Norseman	Bins and Conveyor	5 019
Yarri	Jaw Crusher and Wheel Weigher	3 135
		$18 524

Cartage Subsidies

	Tonnes	Cost
Ore Carted to State Plants	12 998.85	$20 827

Comparative figures for the last three years are:

State Plants					Private Plants		
Year	Tonnes Crushed	Tonnes Subsidised	% Subsidised	Cost	Tonnes Subsidised	Cost	Total Cost
				$			$
1971	30 020·51	15 485·36	51·58	22 321	Nil	Nil	22 321
1972	47 424·34	23 676·86	49·93	32 713	Nil	Nil	32 713
1973	52 135·97	12 998·85	24·93	20 827	Nil	Nil	20 827

Administrative

Expenditure amounted to $109 979.31 equivalent to $1.75 per tonne of ore crushed and cyanided, compared with an expenditure of $89 113.27, $1.50 per ton, for 1972.

	1972	1973
	$	$
Salaries	49 917.31	58 566.53
Payroll Tax	15 092.63	21 823.82
Workers' Compensation	17 367.96	15 920.63
Travelling and Inspection	3 089.51	5 785.96
Sundries	3 645.86	7 882.37
	$89 113.27	$109 979.31

Staff

After a long illness Manager McNamara died in January, 1973. He had given 20 years of most useful service to the State Batteries.

Manager Turner resigned to take a position in Perth, and Mechanical Supervisor Flematti resigned to go to Queensland.

Messrs. T. Edge, R. Dellar and D. Elsegood were promoted to Battery Managers at Leonora, Norseman and Ora Banda. Mr. H. Trundle was promoted to Mechanical Supervisor.

General

The price of gold continued to rise in the first half of 1973 and a big increase in the amount of gold ore crushed by the State Batteries appeared certain. However there was some reduction in the gold price after the middle of the year and this, with the Federal Government's announcement on the taxation of profits from gold mining, caused some loss of interest in gold mining by the smaller producers, so that in 1973 the gold ore crushed was only 4 723.1 tonnes (4 648.7 tons) more than in 1972.

The average grade of gold ore crushed for 1973 was 10.7 grams per tonne (7.0 dwt per ton), the same as for 1972. This grade was maintained only because of a few exceptionally high grade crushings, particularly from the Frazers Mine, Southern Cross. Actually there was a big increase in the amount of low grade ore crushed. Gold prices have risen sharply in early 1974, and a further big increase in the amount of low grade ore crushed can be expected in 1974.

Due to unusually heavy rainfall in most Goldfield Districts, the amount of tailings cyanided was less than planned. As a big proportion of the amalgamation tailings produced was too low grade for cyanide treatment there was no increase in the amount of tailings requiring treatment. The big rise in the gold price has made big increases in the payments due to prospectors when their tailings are treated and the recovered gold is sold by the Gold Producers Association. At many State Batteries, amalgamation tailings suitable for cyaniding accumulate very slowly, amounting to only a few thousands tonnes in periods of up to 20 years. As the usual State Battery cyanide leaching methods require too much initial expenditure on non-portable equipment to be used to treat these small amounts, tests using different equipment have started at the Yarri State Battery. Leaching is done in small dams with walls of old tailings, and walls and bottoms of these dams are lined with plastic sheeting. The cost of forming and lining the dams is low, so the dams will not be emptied after leaching, but new dams formed and lined as required. All equipment used is easily portable so can be readily moved when treatment at a Battery has been completed. The results so far are encouraging, indicating good recoveries and reasonable operating costs. This work will continue.

Although the price of lead was high, the Northampton State Battery treated only 2 539.6 tonnes (2 499.6 tons) of ore, practically the same as in 1972 when 2 526.0 tonnes (2 486.25 tons) were crushed. The ore was of higher grade, and contained less oxidized lead minerals, allowing a higher recovery of lead in a higher grade lead concentrate. The ore treated had a low zinc content.

One small parcel of tungsten ore was crushed of the Norseman Battery. The Marble Bar Magnetic Plant treated only a very small amount of tin concentrate.

The total of ore and tailings treated was a little higher than in 1972, but big increases in salaries, wages and supply costs caused a big increase in State Battery expenditure.

K. M. PATERSON,
Superintendent, State Batteries.

April 2, 1974.

Schedule No. 1

NUMBER OF PARCELS TREATED, TONNES CRUSHED, GOLD YIELD BY AMALGAMATION AND HEAD VALUE FOR THE YEAR ENDED 31st DECEMBER, 1973

Number of Parcels Treated	Battery	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
21	Boogardie	1 404·1	5·076	4·302	4·115	8·417	5·991
60	Coolgardie	5 129·0	22·637	19·185	8·817	28·002	5·460
72	Kalgoorlie	11 546·6	133·752	113·355	28·349	141·704	12·272
8	Lake Darlot	1 452·4	4·339	3·677	1·983	5·660	3·897
11	Laverton	1 147·2	1·560	1·323	0·943	2·266	1·975
34	Leonora	3 631·1	34·419	29·170	14·690	43·860	12·079
29	Marble Bar	1 932·4	22·360	18·950	6·195	25·145	13·012
23	Marvel Loch	3 920·4	168·077	142·445	17·774	160·219	40·868
15	Meekatharra	3 478·9	13·496	11·438	11·015	22·453	6·454
12	Menzies	1 026·4	7·439	6·305	4·330	10·635	10·361
22	Norseman	2 018·6	16·771	14·213	5·321	19·534	9·677
36	Ora Banda	10 989·8	33·453	28·352	12·018	40·370	3·673
1	Paynes Find	131·5	12·191	10·331	0·723	11·054	84·061
2	Sandstone	106·0	1·838	1·558	0·756	2·314	21·830
16	Yarri	1 650·7	6·687	5·667	4·062	9·729	5·894
362		49 565·1	484·095	410·271	121·091	531·362	10·720

Average Tonnes per Parcel .... 136·920
Average Yield by amalgamation (Fine Gold) .... 8·277 grams
Average Value of Tailings (Fine Gold) .... 2·443 grams

Schedule No. 2

DETAILS OF EXTRACTION TAILINGS TREATMENT 1973

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	3 352·8	4·5	15·139	1·1	3·823	11·316	74·7	11·202	73·9
Leonora	3 782·8	3·9	14·833	1·1	4·149	10·684	72·0	10·518	70·9
Marble Bar	1 023·5	8·6	8·828	1·4	1·468	7·360	83·4	7·746	87·7
Marvel Loch	2 346·6	5·2	12·196	1·4	3·372	8·824	72·3	8·794	72·1
Coolgardie	Slags	....	·472	....	....	·472	....	·472	....
	10 505·7	4·9	51·468	1·2	12·272	38·656	75·1	38·732	75·2

Schedule No. 3

DIRECT PURCHASE OF TAILINGS YEAR ENDED 31st DECEMBER, 1973

Battery	Tonnes of Tailings Purchased	Initial Payment to $28.00 per ·0311 kg
		$
Boogardie	371·7	396·12
Coolgardie	152·4	910·50
Kalgoorlie	1 818·0	3 386·28
Lake Darlot	45·7	41·34
Leonora	1 216·9	4 060·13
Marble Bar	464·3	2 141·46
Marvel Loch	1 792·2	1 609·60
Meekatharra	....	....
Menzies	285·5	631·60
Norseman	324·4	1 690·94
Ora Banda	97·0	272·31
Paynes Find	118·3	149·47
Sandstone	132·5	368·11
Yarri	29·8	31·50
	6 848·7	15 689·36

Schedule No. 4

STATEMENT OF RECEIPTS AND EXPENDITURE FOR THE YEAR ENDED 31st DECEMBER, 1973

Milling

Battery	Tonnes	Management and Supervision	Wages	Stores	Expenditure Total Working	Cost per Tonne	Repairs and Renewals	Sundries	Gross Expenditure	Cost per Tonne	Receipts	Receipts per Tonne	Profit	Loss
		$	$	$	$	$	$	$	$	$	$	$	$	$
Boogardie	1 404·1	12 283.50	9 105.00	2,371.42	23 759.92	16.92	1 585.74	4 965.44	30 311.10	21.59	1 413.77	1.00	....	28 897.33
Coolgardie	5 129·0	12 946.95	25 332.78	7 226.83	45 506.56	8.87	5 606.53	9 841.43	60 954.52	11.88	4 382.37	.85	....	56 572.15
Cue	....	....	....	....	....	....	....	....	....	....	1 708.50	....	1 708.50	....
Kalgoorlie	11 546·6	20 284.94	61 996.07	17 640.91	99 921.92	8.65	12 249.81	30 968.89	143 140.62	12.40	9 782.36	.85	....	133 358.26
Lake Darlot	1 452·4	10 913.16	11 910.86	1 877.57	24 701.59	17.01	2 323.96	2 473.37	29 498.92	20.31	1 335.48	.92	....	28 163.44
Laverton	1 147·2	8 347.84	4 460.04	3 355.24	16 163.12	14.09	5 838.26	3 989.07	25 990.45	22.66	867.72	.76	....	25 122.73
Leonora	3 631·1	2 923.53	22 071.78	10 370.48	35 365.79	9.74	5 702.11	9 555.01	50 622.91	13.94	3 376.95	.93	....	47 245.96
Marble Bar	1 932·4	6 926.61	9 896.70	4 239.32	21 062.63	10.90	4 462.03	4 836.01	30 360.67	15.71	2 055.07	1.06	....	28 305.60
Marvel Loch	3 920·4	11 821.32	29 241.64	7 148.14	48 211.10	12.30	1 752.00	8 081.02	58 044.12	14.81	4 045.65	1.03	....	53 998.47
Meekatharra	3 478·9	9 065.49	18 967.26	6 259.74	34 301.49	9.86	6 798.70	8 902.71	50 002.90	14.37	2 326.83	.67	....	47 676.09
Menzies	1 026·4	7 614.66	10 108.76	1 794.92	19 518.34	19.02	5 131.72	4 760.01	29 410.07	28.65	1 032 30	1.01	....	28 377.77
Norseman	2 048·6	9·070.53	15 081.38	3 685.41	27 837.32	13.59	5 867.29	5 089.86	38 794.47	18.94	2 141.83	1.05	....	36 652.64
Nullagine	....	....	685.06	49.95	735.01	....	17.69	....	752.70	....	....	....	....	752.70
Ora Banda	10 989·8	12 124.15	28 854.47	8 324.27	49 302.89	4.49	3 291.78	19 350.60	71 945.27	6.55	7 340.06	.67	....	64 605.21
Paynes Find	131·5	1 207.63	1 834.95	88.18	3 130.76	23.81	276.31	369.59	3 776.66	28.72	135.44	1.03	....	3 641.22
Sandstone	106·0	1 027.74	1 405.14	312.04	2 744.92	25.90	127.90	412.76	3 285.58	31.00	94.33	.89	....	3 191.25
Yarri	1 650·7	5 888.99	10 324.72	2 622.56	18 836.27	11.41	3 067.87	4 457.01	26 361.15	15.97	1 682.62	1.02	....	24 678.53
Head Office	....	....	....	....	....	....	....	....	....	....	81.35	....	81.35	....
Sub Total	49 595·1	132 447.04	261 285.61	77 366.98	471 099.63	9.50	64 099.70	118 052 78	653 252.11	13.17	43 802.63	.88	1 789.85	611 239.33
Marble Bar (Mag. Plant)	1·27	....	612.55	....	612.55	482.32	6.10	4.08	622.73	490.34	80.00	62.99	....	542.73
Northampton	2 539·6	14 711.31	8 061.83	4 603.13	27 376.27	10.78	4 770.19	6 059.78	38 206.24	15.04	5 105.83	2.01	....	33 100.41
Total	52 135.97	147 158.35	269 959.99	81 970.11	499 088.45	9.57	68 875.99	124 116.64	692 081.08	13 27	48 988.46	.94	1 789.85	644 882.47

Operating Loss $643 092.62

Schedule No. 5

STATEMENT OF RECEIPTS AND EXPENDITURE FOR THE YEAR ENDED 31st DECEMBER, 1973

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	....	....	....	28.00	28.00	....	....	51.19	79.19	....	448.12	....	368.93	....
Kalgoorlie	3 352.8	5 381.30	17 255.54	7 513.57	30 150.41	9.05	167.88	12 410.06	42 728.35	12.83	7 637.16	2.28	....	35 091.19
Leonora	3 622.8	1 965.20	12 791.36	6 467.55	21 224.11	5.60	152.55	5 986.50	27 363.16	7.22	3 308.12	·91	....	24 055.04
Marble Bar	1 023.5	2 099.40	4 686.03	718.26	7 503.69	7.33	275.06	2 547.73	10 326.48	10.09	3 411.06	3.33	....	6 915.42
Marvel Loch	2 346.6	659.55	7 523.27	2 397.52	10 580.34	4.51	....	5 154.27	15 734.61	6.70	5 730.64	2.44	....	10 003.97
Norseman	....	278.72	2 736.86	308.70	3 324.28	....	564.67	56.20	3 945.15	....	....	....	....	3 945.15
Yarri	....	....	940.60	933.18	1 873.78	....	107.93	....	1 981.71	....	....	....	....	1 981.71
Total	10 347.7	10 384.17	45 933.66	18 366.78	74 684.61	7.12	1 268.09	26 205.95	102 158.65	9.74	20 535.10	1.98	368.93	81 992.48
								Interest Paid to Treasury			4 680.00			4 680.00
									102 158.65		15 855.10		368.93	86 672.48

Operating Loss $86 303.55

STATE BATTERIES

TRADING AND PROFIT AND LOSS ACCOUNT FOR THE YEAR ENDED 31st DECEMBER, 1973

1972 $		$	1973 $
	Trading Costs—		
368 009	Wages	473 436	
87 610	Stores	100 337	
51 947	Repairs Renewals and Battery Spares	70 144	
130 231	General Expenses and Administration	155 003	
637 797			798 920
	Earnings—		
73 097	Milling and Cyaniding Charges		69 524
564 700	Operating Loss for the Year		729 396
	Other Charges—		
61 901	Interest on Capital	61 896	
27 206	Depreciation	25 392	
15 498	Superannuation—Employers' Share	15 566	
104 605			102 854
669 305	Total Loss for the Year		832 250

BALANCE SHEET AS AT 31st DECEMBER, 1973

Funds Employed

31st December, 1972		31st December, 1973	
	Capital—		
1 471 570	Provided from General Loan Fund	1 471 465	
341 666	Provided from Consolidated Revenue Fund	360 349	
1 813 236			1 831 814
	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—		
2 637 209	Interest on Capital		2 699 105
	Other Funds—		
7 599 005	Provided from Consolidated Revenue Fund (Excess of payments over collections)		8 328 403
12 134 266			12 944 138
	Deduct—		
	Profit and Loss :		
11 211 641	Loss at Commencement of year	11 880 946	
669 305	Loss for Year	832 250	
11 880 946	Total Loss from Inception		12 713 196
253 320			230 942

Employment of Funds

	Fixed Assets—		
1 802 053	Plant Buildings and Equipment	1 820 631	
1 568 098	Less Depreciation	1 593 490	
233 955			227 141
	Current Assets—		
26 278	Debtors	22 800	
83 484	Stores	105 174	
11 368	Battery Spares	16 744	
	Purchase of Tailings :		
20 854	Treasury Trust Account	22 971	
76 543	Tailings not Treated	74 998	
8 708	Estimated Gold Premium	4 110	
227 235			246 797
461 190	Total Assets		473 938
	Deduct—		
38 598	Current Liabilities : Creditors	62 184	
159 167	Liability to Treasurer (Superannuation—Employer's Share)	174 733	
	Purchase of Tailings :		
1 397	Creditors	1 969	
8 708	Estimated Premium Due	4 110	
207 870			242 996
253 320			230 942

DIVISION IV

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Annual Report of the Geological Survey Branch of the Mines Department for the Year 1973

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REPORTS

LIST OF FIGURES

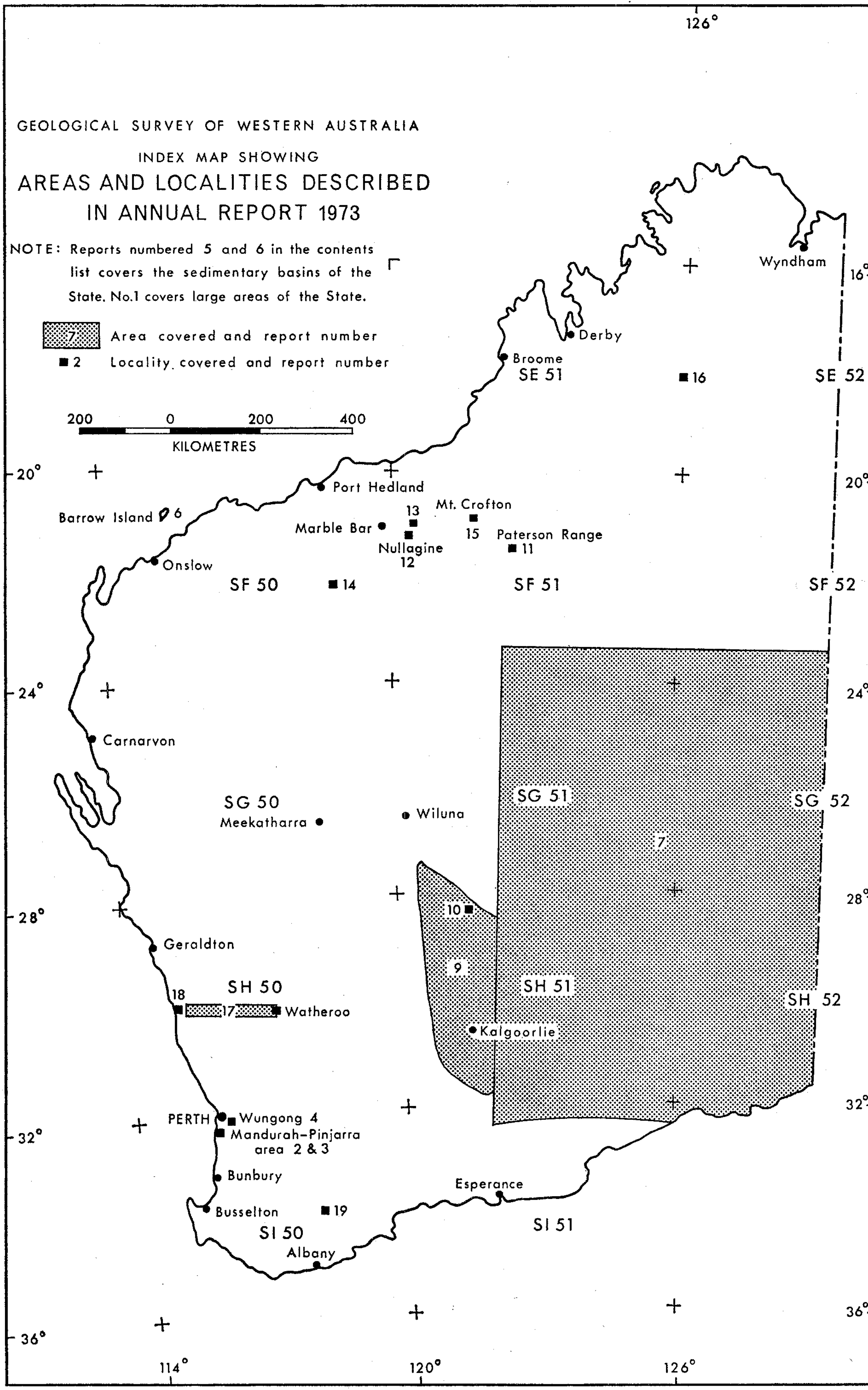

Figure 1. Index map showing areas and localities described in Annual Report for 1973.

DIVISION IV

Annual Report of the Geological Survey Branch of the Mines Department for the Year 1973

Under Secretary for Mines:

For the information of the Honourable Minister for Mines, I submit my report on the activities of the Geological Survey of Western Australia during 1973, together with some of the reports on investigations made for departmental purposes.

INTRODUCTION

In the early part of 1973 the stability which had developed towards the end of the previous year continued. This was stimulated by the availability of Temporary Reserves for exploration. During the year some 182 such reserves were approved.

In the later part of the year exploration waned for lack of a clear policy from the Commonwealth Government, and a number of companies ceased exploration.

Iron ore exploration continued but declined towards the end of the year because of the lack of new export contracts. Similarly three bauxite projects are waiting on contracts before any further work is done.

Exploration for nickel continued on a greatly reduced scale. Exploration at Agnew was nearly complete and waited on a decision with regard to development. The prospect near Forrestania was being investigated further and a decision was made to develop the mine at Redross.

There was a decline in the tempo of oil exploration. The number of test wells decreased by 30 per cent, while there was a greater decrease in seismic activity both on and off shore.

The only success in exploration was in the northwest shelf, where extensions to the Angel and Goodwyn fields were successfully tested and a discovery of gas, condensate, and oil in the Dockrell structure and oil in the Egret structure were made. The deep hole on Barrow Island was classified a gas well and the gas found on West Tryal Rocks No. 1 remains to be evaluated.

Exploration for uranium attracted more interest than any other mineral during 1973 without any significant finds being made. The search extends throughout the State, involving the sedimentary basins as well as the Precambrian areas. The only possible economic deposit found to date is at Yeelirrie. This deposit has been fully examined and waits on a Commonwealth Government's decision and a contract before development can be planned.

Due to the increase in price, gold was another mineral in which there was renewed interest. Many old prospects were being re-examined and State batteries were kept busy treating prospectors' ore. A new find, made in 1972, was reported in the Paterson Range about 250 km southwest of Marble Bar. This gold mineralization is in a new geological environment and developments should be interesting.

A nugget weighing about 1 340 grams was found a short distance southeast from Mt. Magnet by two lads following a newly graded road. The nugget was photographed (Fig. 2A) shortly before smelting.

Due to the energy crisis exploration for coal continued, particularly in the southern portion of the Perth Basin and in the Fitzroy Basin.

Exploration continued at a reduced scale for other metallic and non-metallic minerals.

Two lectures, followed by field excursions, were arranged during the year. The first was at Laverton covering the Laverton and Leonora 1 : 250 000 geological sheets. About 140 persons from private enterprise, Universities and C.S.I.R.O. attended, as illustrated in Figure 2 B, C. The second was at Dongara covering the Dongara and Hill River 1 : 250 000 geological sheets. This was entirely on sedimentary geology and about 35 persons participated (Fig. 2 D).

STAFF

Although employment opportunities for geologists were reputedly scarce, a number of geologists at Level 1 resigned during the year.

Difficulty was experienced in recruiting geologists in sedimentary geology and a senior position in this Division has not been filled for nearly two years.

Approval was received to establish a section with two geologists to deal with environmental geology and conservation.

Miss G. Solomon resigned after 8 years as a typist with the Branch when she married and moved to another State. Difficulty has been experienced in obtaining a satisfactory replacement because of the technical nature of the work involved.

PROFESSIONAL

Appointments

Name	Position	Effective Date
Brakel, A. T., B.Sc. (Hons. Ph.D.	Geologist, Level 1	3/1/73
Chin, R., B.Sc. (Hons.)	Geologist, Level 1	5/1/73
Hill, W. B., B.Sc. (Hons.)	Geologist, Level 1	5/1/73
Thompson, J. H., B.Sc. (Hons.)	Senior Geologist, Level 3	7/5/73
Barnett, J. C., B.Sc.	Geologist, Level 1	18/6/73
Wenham, M. E., B.Sc.	Geologist, Level 1	15/10/73
Green, K. H., B.Ed. (Hons.)	Geologist, Level 1	15/10/73
Klenowski, G., B.Sc. (Hons.)	Geologist, Level 1	17/12/73

Resignations

Vogwill, R.	Geologist, Level 1	2/3/73
Nicholson, J.	Geologist, Level 1	8/6/73
Commander, S. J.	Geologist, Level 1	19/7/73
Thom, J. H.	Geologist, Level 1	20/7/73
Balleau, W. P.	Geologist, Level 1	17/8/73
Gower, C. F.	Geologist, Level 1	24/8/73
Thompson, J. H.	Senior Geologist, Level 3	1/9/73
Cochrane, R. H. A.	Geochemist, Level 2	16/11/73

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CLERICAL AND GENERAL

Appointments

Name	Position	Effective Date
Mouritzen, C.	Geological Assistant	7/3/73
Spring, A. L.	Geological Assistant	12/3/73
Darby, N. D.	Geological Assistant	28/3/73
Dawson, H.	Technical Assistant	30/4/73
Formato, E.	Geophysical Assistant	10/7/73
Nolan, G. D.	Technical Assistant	12/7/73
Daly, B.	Typist	6/8/73
Larsson, G.	Typist	15/8/73
Nutt, M.	Typist	24/8/73
Blundell, C.	Geological Assistant	3/9/73
Marrell, G. W.	Technical Assistant	12/11/73

Resignations

Hadley, P.	Technical Assistant	9/2/73
McGilligan, M.	Geological Assistant	13/4/73
Branson, G.	Technical Assistant	20/7/73
Solomon, G.	Typist	26/7/73
Daly, B.	Typist	9/8/73
Larsson, G.	Typist	23/8/73
Nolan, G.	Technical Assistant	24/8/73
Spring, A. L.	Geological Assistant	16/11/73

Transfers out

Nichols, T. J.	Geological Assistant	2/3/73
Neil, J.	Geological Assistant	19/11/73

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), C. C. Sanders, J. R. Forth, G. W. A. Marcos, W. A. Davidson, A. S. Harley, R. E. J. Leech, D. P. Commander, R. G. Barnes, J. M. Campbell, J. C. Barnett, G. Klenowski.

Hydrogeology

Deep exploratory drilling continued along the cross section of the Perth Basin sediments on the Eneabba line, extending between Winchester and the coast near Beagle Island. Four sites were drilled during 1973 and potable water was obtained at each site.

Contractors to the Metropolitan Water Board also drilled ten other deep bores in the Perth Basin north of Perth, some having yielded up to 53 litres per second of water with a total salinity in the 300 to 450 ppm range.

In conjunction with the Metropolitan Water Board, investigation of shallow groundwater around Perth progressed, and separate projects at Yanchep, Gingin, Lake Thompson, Wanneroo, and Joondalup, continued. A major production bore field was also being developed at Wanneroo, on the western flank of the Gnangara mound.

In the Canning Basin further seismic work was done to delineate bedrock, and 10 exploratory bores were drilled at 8 sites along two section lines. Potable water occurs in Mezosoic sediments but the salinity increases with distance northward, and not all groundwater is suitable for public water supply. Several bores flowed strongly. More work is planned to delineate the extent of the potable water and to find the intake.

Seven exploratory bores were also drilled into the Lyre Creek Agglomerate in the catchment area of the Harding River at Cooya Pooya, south of Roebourne. The groundwater is of low salinity, and although a calculation of the water balance suggests that the area should have valuable potential, pumping results have been disappointing.

The Branch continued to provide advice in connexion with work done by groundwater consultants for mining and other companies, but activity was at a lower level than previously. Officers were also engaged in environmental studies in co-operation with other departments.

Field inspections were made and written advice given to 126 private landholders; 22 reports were written for other departments including Public Works Department, Metropolitan Water Board, Town Planning Department and the Aboriginal Affairs Planning Authority. In addition assessments of groundwater prospects were written for the Pilbara Region and the Southwest Region as a guide to the planning of future development.

Continued assistance was provided to the Public Works Department with the progressive exploration and development of groundwater supplies from the Gascoyne River bed for Carnarvon water supply and irrigation scheme.

Engineering Geology

The following investigations were carried out on proposed dam sites for the Department of Public Works:

(i) North Pole. Completion of field mapping, and geophysics. A report was written on the spillway sites and construction materials, completing that phase of investigations.

(ii) Kangan Pool. Some geophysics was done on the site itself, and on the stilling basin below a spillway proposed on the left bank.

(iii) Bullinnarwa. Geological mapping of the whole site was completed, together with drilling, geophysics, pits and costeans thus completing the geological feasibility studies. A report was commenced.

(iv) Preliminary inspections and assessments were made at Dogger's Gorge, Gregory Gorge and on the Robe River.

(v) Harvey. Two dam sites downstream of the existing weir were investigated by detailed geological mapping, drilling, and geophysics, and a report written.

(vi) Burekup. Reconnaissance mapping only; work will continue.

Investigations for the Metropolitan Water Board included:

(i) South Dandalup Dam. Geological advice was provided during construction, which is now complete. A final detailed geological report was commenced.

(ii) Lower Wungong Dam Site. A detailed geological investigation of the site and the borrow areas was made, including drilling, trenching and geophysics. The site geological investigation phase was completed.

(iii) Canning Dam tunnel. Periodic inspections were made, and a photographic record of the tunnel was compiled in conjunction with the University of Western Australia.

(iv) Carralong Brook. Geological inspections of suggested dam sites and tunnel lines were made in the Carralong Brook—Serpentine Falls area.

(v) Mullaloo Tunnel. A field reconnaissance was made and reported.

Advice was also given to other Departments such as the Government Railways and the Department of Main Roads.

SEDIMENTARY (OIL) DIVISION

P. E. Playford (Supervising Geologist), R. N. Cope (Production Geologist), G. H. Low (Senior Geologist), W. J. E. van de Graaff, J.-C. Boegli and R. W. A. Crowe.

Information received from petroleum exploration permittees and production licence-holders was evaluated and collated. Procedures for accession, storage, retrieval and distribution of data were further stream-lined and developed. The Division dealt with numerous petroleum exploration enquiries. Evaluation of coal exploration on the Collie Coalfield and on other prospective areas was continued.

A compilation report on the petroleum reserves of the entire northern Carnarvon Basin, as on 30th June, 1973 was prepared for the Pilbara Study Group. Technical advice was provided to the Fuel and Power Commission on numerous occasions.

Compilation of map sheets and explanatory notes of the Officer Basin continued throughout the year, and the preliminary editions of the Madley, Warri, Cobb, Herbert, Browne, Yowalga, Westwood, Seemore, Vernon and Mason sheets were issued. Writing of a bulletin on the Officer Basin was commenced.

Regional mapping of the northeastern Canning Basin, jointly with the Bureau of Mineral Resources, was continued, with the mapping of the Cornish, Crossland, Dummer, Helena, Mount Bannerman and Webb 1 : 250 000 sheets. In addition a drilling programme was carried out to clarify stratigraphic problems. Compilation of explanatory notes and maps for the Billiluna, Lucas and Stansmore sheets continued.

Studies of the Devonian reef complexes on the Lennard Shelf continued, with special emphasis on facies relationships in the fore-reef environment. A bulletin on "The Geology of the Perth Basin" has been completed in manuscript.

REGIONAL GEOLOGY DIVISION

R. D. Gee (Supervising Geologist), I. R. Williams (Senior Geologist), P. C. Muhling, R. Thom, J. A. Bunting, A. T. Brakel, R. J. Chin.

The programme of regional mapping of the Precambrian area of the State for publication on a scale of 1 : 250 000 continued. The progress is shown in Figure 3.

Field mapping commenced on the Nullagine, Mount Phillips and Southern Cross sheets. Field mapping of the Laverton, Duketon, Throssell and Mount Egerton sheets was completed.

Work continued on compilation of a bulletin on the geology of the southeastern part of the Yilgarn block covering the Kalgoorlie and Esperance 1 : 1 000 000 sheets.

A geological excursion of the Leonora and Laverton sheets was conducted.

MINERAL RESOURCES DIVISION

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

Field and office work continued for the production of a bulletin on the State's resources of chrome, vanadium, tungsten and molybdenum, and for the revision of the copper bulletin. Writing of the bulletin on tin and mineral sands continued.

Further tests on the application of a new geophysical technique to Western Australian conditions were made.

Compilation of the Marble Bar sheet was completed and about 75 per cent of the Nullagine sheet was mapped in conjunction with the Regional Geology Division.

Mapping of the Precambrian portion of the Perth sheet was completed and compilation commenced. A start was made on the Pinjarra sheet, and work on the Moora sheet continued.

Inspections were made of a number of kaolin deposits in the southern part of the State in order to establish the resources of this mineral. Other inspections of talc, fluorite, limestone, lead, zinc, uranium, beryl and gold deposits were made as required.

About 315 general enquiries from the public and 120 requests for data from reports on relinquished tenements received attention.

A two week field trip with a guide was arranged for Colombo Plan fellows in association with the Department of Foreign Affairs in June and July.

COMMON SERVICES DIVISION

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

The rise in demand for petrological services during 1973 increased the production of petrological reports to 92 covering 1 353 samples. Means of streamlining reporting procedures are being considered in order to handle the increased load.

A petrological and geochronological study of sills in the Weeli Wolli Formation and a petrological and field study of ultramafic lavas in the Mount Clifford area were completed. A study of the petrology of the Eastern Goldfields and a project on syenite and other alkali granitic rocks of Western Australia were continued. The computerized retrieval system for rock data was nearly ready for operation.

The capability of the section in the fields of low-grade metamorphic, fine-grained volcanic, and other fine-grained rocks was greatly increased by direct access to a new X-ray diffractometer at the Government Chemical Laboratories. Results are being reported regularly in petrological reports. Some of the more striking discoveries were that a rock from the Bangemall Beds which has been generally accepted as a chert, is in fact a K-feldspar rock and that a supposed feldspathic volcanic rock from Gregory Gorge is silicified.

The Government Chemical Laboratories continued to provide valuable chemical analyses, mineral determinations and X-ray mineral identifications.

The laboratory prepared 1873 petrological thin sections, 50 polished mounts, 35 polished slabs, 34 mineral separations, 25 sieve analyses and 120 crushings (for various analytical requirements).

The co-operative geochronological programme with the Western Australian Institute of Technology continued involving a number of projects.

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

Seventy file reports were written during the year. The table below shows that the bulk of these reports were written at the request of the Hydrology and Engineering Geology Division and dealt with palynology.

Report requested by	Field of palaeontology		
	Palynology	Micropalaeontology	Macropalaeontology
Hydrology and Engineering Geology Division	30	1	2
Sedimentary Division	5	2	7
Regional Mapping and Mineral Resources Divisions	6	2	3
Other Organizations	3	1	5

A project on Devonian brachiopods from the Lennard Shelf was completed and a start was made on the bivalves and gastropods from the same area. A preliminary study of Devonian spores from boreholes in the Gogo Formation was finished. Work continued on the Mesozoic palynology of the Perth Basin and a tentative zonation for the Upper Jurassic and Lower Cretaceous sequence in the Watheroo Line boreholes was produced. A general survey of the palaeontology of the Perth Basin was made and work started on the planktonic foraminifera from the Gingin Chalk.

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

During 1973 there was a substantial increase in the number of shallow water bores geophysically logged in the Perth Basin. However this was offset by a decrease in logging operations elsewhere and the total number of bores logged amounted to only 138 compared with 151 in 1972. Correspondingly the total logged length for all runs decreased from 31 600 to 27 000 m.

Seismic refraction surveys were carried out at the Harvey, North Pole, Bullinnarwa and Kangan Pool dam sites at the request of the Engineering Geology group. A further 40 refraction and resistivity depth soundings were made in the West Canning hydrology investigation. Exploratory drilling in the basin in 1974, whilst mainly confirming the earlier seismic bedrock depths, in one bore highlighted a velocity inversion problem and afforded the necessary control to resolve it with fair reliability.

The usual laboratory services, field salinity determinations, equipment calibration and repair, were maintained.

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

Although there were several staff changes during the year, the editorial duties connected with the items listed below and the production of twenty-eight Records indicate that the amount of material for publication passing through the Section continued to grow. In addition fourteen publications, mainly Explanatory Notes, were issued. Distribution of geological information to both public and staff continued to be a major function of the group. The preparation of a pamphlet to serve as a guide to the layout of the Geological Museum was commenced.

Requisitions raised on the Surveys and Mapping Branch for drafting services and photography for the Survey totalled 1 132. Photocopying for the public of out-of-print publications numbered 900 requisitions. Many of these contained more than one entry.

During the year 2 985 members of the public used the facilities of the library. Loans to outside organizations were 63, while loans to departmental staff totalled 4 826.

The establishment of a microfilm library was commenced and all Geological Survey publications are now available on 16 mm film in cassettes, supplemented by 35 mm aperture-card mounts for large maps. Reading and print out facilities are available at the library.

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 the 1 : 250 000 geological sheets and bulletins on the Kimberley Division as a joint project with the Survey.
(ii) Compilation of the geological mapping of the Officer Basin and preparation of a bulletin as a joint project with the Survey.
(iii) Continuation of mapping in the Canning Basin as a joint project with the Survey including stratigraphic drilling.
(iv) Continuation of the aeromagnetic survey of W.A., confined to the Officer Basin.

PROGRAMME FOR 1974

HYDROGEOLOGY AND ENGINEERING DIVISION

A. *Hydrogeology*

1. Continuation of the hydrogeological survey of the Perth Basin including deep drilling.
2. Hydrogeological investigations and/or exploratory drilling for groundwater in the following areas:
   (a) Cooya Pooya, Millstream, George River and Lower Harding.
   (b) West Canning Basin.
   (c) Murchison and East Murchison—regional assessments.
   (d) Town water supply Halls Creek.
   (e) Carnarvon Basin—Gascoyne River sands.
3. Hydrogeological investigations for Metropolitan Water Board.
   (a) Regional studies.
   (b) Deep drilling at Wanneroo, Whitfords.
   (c) Shallow drilling at Salvado, Wanneroo, Gwelup, Yanchep, Joondalup and Lake Thompson.
4. Kimberley Division—hydrogeological assistance to pastoralists as required.
5. Continuation of bore census work in selected areas.
6. Miscellaneous investigations and inspections as requested by Government departments and the public.

B. *Engineering*

1. Kimberley Area—investigation for the raising of the Moochalabra dam.
2. Pilbara area—further investigations at the following dam sites: Kangan Pool, Robe River, Gregory Gorge and Dogger's Gorge—completion of work at Bullinnarwa and North Pole (spillway).
3. Darling Range area—completion of work at South Dandalup dam site—continuation of work at Lower Wungong dam site—Burekup dam site, South Canning and North Dandalup dam site—commencement of work on the proposed tunnels at Lower Wungong and Mullaloo and aqueduct route from Collie River to Harvey Dam.

SEDIMENTARY (OIL) DIVISION

1. Maintain an active interest in the progress and assessment of oil exploration in Western Australia.
2. Evaluate oil and gas discoveries and assess the resources of the State.
3. Completion of the Bulletin on the Perth Basin.
4. Preparation of the Bulletin on the Officer Basin.
5. Mapping of the Canning Basin in conjunction with the Bureau of Mineral Resources.
6. Commence surface and sub-surface study of the Carnarvon Basin.

REGIONAL GEOLOGY DIVISION

1. Completion of Throssell, Duketon, Nullagine, Mount Egerton 1 : 250 000 sheets.
2. Continuation of mapping of the Bangemall Basin on the Collier and Robinson Range 1: 250 000 sheets.
3. Commencement of mapping on the Sir Samuel, Paterson Range and Yarrie sheets.
4. Continuation of mapping on the Southern Cross and Mount Bannerman sheets.
5. Continuation of the re-assessment of the regional geology of the Eastern Goldfields.

MINERAL RESOURCES DIVISION

1. Maintain records and assess mineral exploration in Western Australia.
2. Completion of mineral resources bulletins on tin, mineral sands, copper and vanadium, chromium, tungsten and molydbenum deposits of Western Australia.
3. Completion of re-mapping of the Nullagine 1 : 250 000 sheet.
4. Regional mapping of the Darling Range on 1 : 250 000 scale and study of the bauxite occurrences.
5. Miscellaneous mineral investigations as required.

PUBLICATIONS AND RECORDS

Issued during 1973

Annual Report, 1972.

Publications Catalogue, 1973.

Report 2:

A reappraisal of the Yule River area:
Port Hedland Town water supply, and
An appraisal of the effects of longterm pumping in the Lake Allanooka area.

Mineral Resources Bulletin 9: The lead, zinc and silver deposits of Western Australia.

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

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

Geological map of Forrest 1 : 250 000 Sheet (SH/52-10 International Grid) with explanatory notes.

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

Geological map of Jubilee 1 : 250 000 Sheet (SH/52-5 International Grid) with explanatory notes.

Geological map of Kurnalpi 1 : 250 000 Sheet (SH/51-10 International Grid) with explanatory notes.

Geological map of Lennard River 1 : 250 000 Sheet (SE/58-8 International Grid) with explanatory notes.

Geological map of Madura-Burnabbie 1 : 250 000 Sheet (SI/52-1 International Grid) with explanatory notes.

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

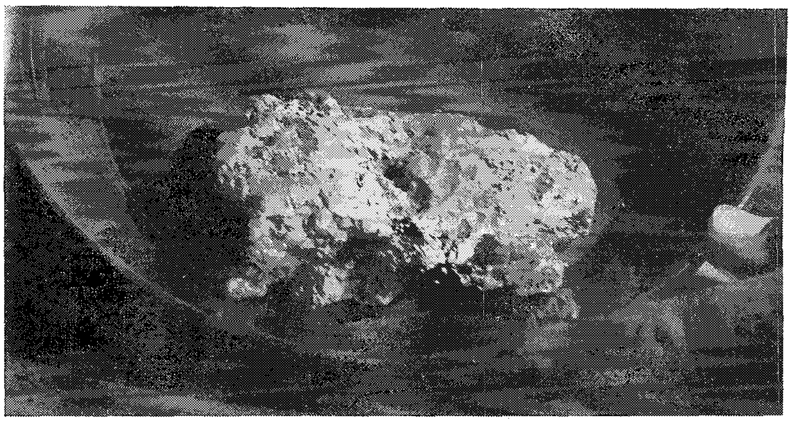
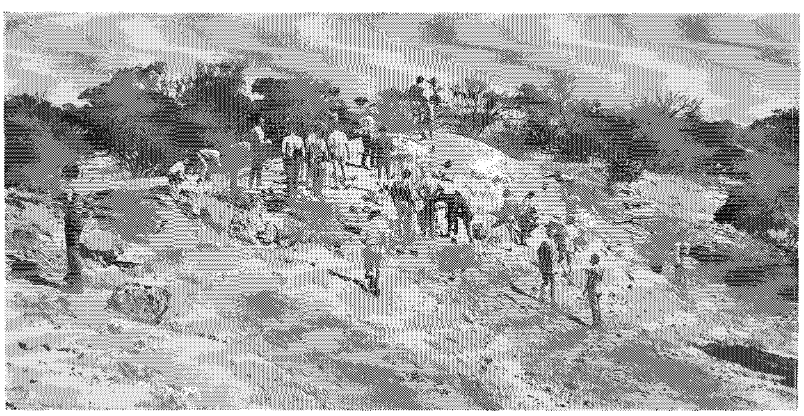


Figure 2. Photographs of field excursions held during 1973.

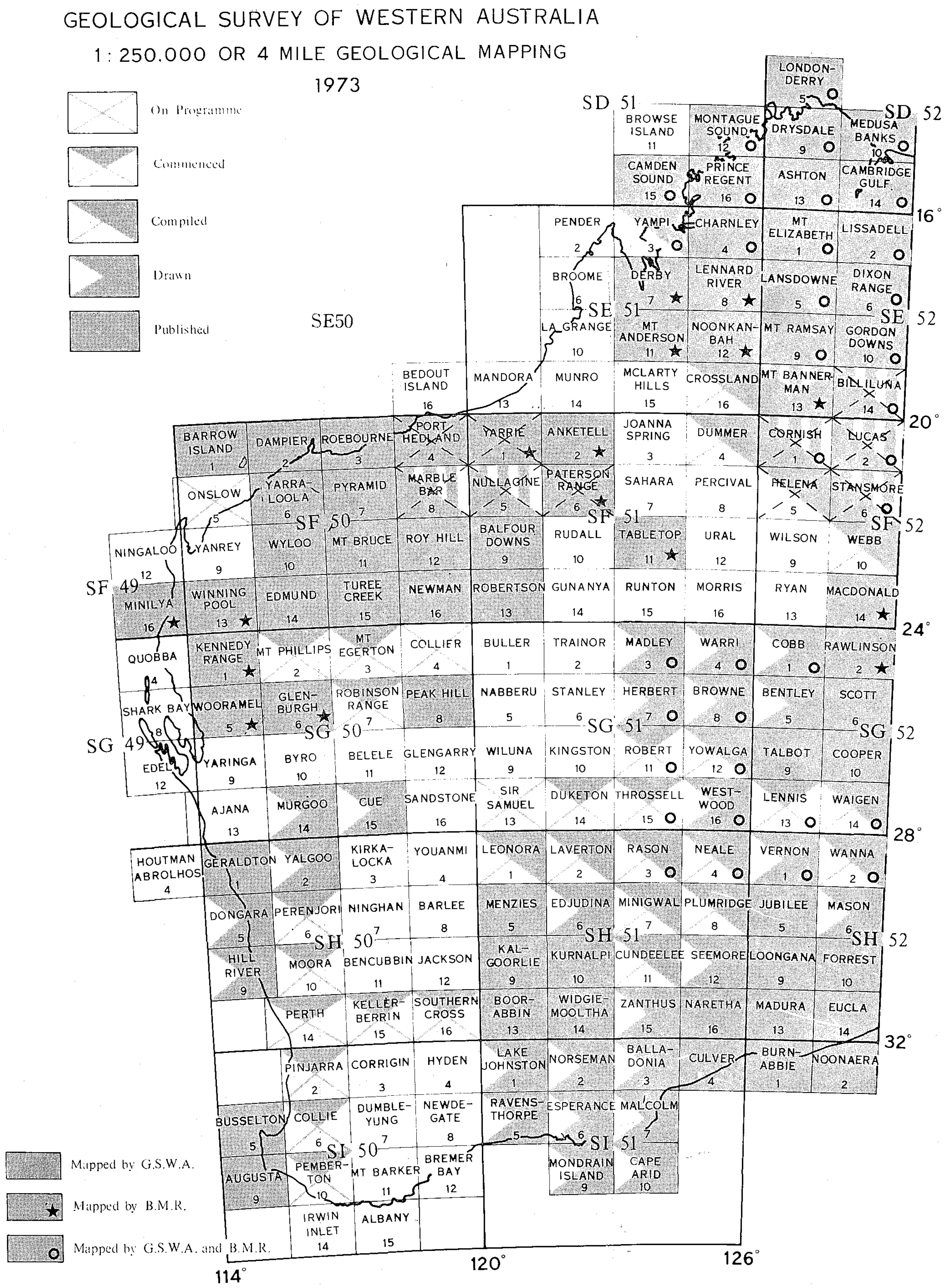
A. Photograph of a gold nugget found within a few kilometres of Mt. Magnet on 24th November, 1973.

B. Photograph of vehicles assembled at the start of the Leonora-Laverton geological field excursion.

C Photograph of part of the 140 strong group that attended the Leonora-Laverton excursion on 1st November, 1973.



D Photograph of group examining the type section of the Yarragadee Formation, 8 km north of Mingenew on the Dongara-Hill River geological excursion.



Broken lines or shading indicates remapping

Figure 3

Geological map of Peak Hill 1 : 250 000 Sheet (SG/50-8 International Grid) with explanatory notes.

In Press

Bulletin 123: The geology of the Blackstone Region, Western Australia.
Geological map of Balladonia 1 : 250 000 Sheet (SI/51-3 International Grid) with explanatory notes.
Geological map of Bentley 1 : 250 000 Sheet (SG/52-5 International Grid) with explanatory notes.
Geological map of Cue 1 : 250 000 Sheet (SG/50-15 International Grid) with explanatory notes.
Geological map of Edjudina 1 : 250 000 Sheet (SH/51-6 International Grid) with explanatory notes.
Geological map of Esperance-Mondrain Island 1 : 250 000 Sheet (SH/51-6 and 10 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 Lake Johnston 1 : 250 000 Sheet (SI/51-1 International Grid) with explanatory notes.
Geological map of Malcolm-Cape Arid 1 : 250 000 Sheet (SI/51-7 and 11 International Grid) with explanatory notes.
Geological map of Murgoo 1 : 250 000 Sheet (SG/50-14 International Grid) with explanatory notes.
Geological map of Norseman 1 : 250 000 Sheet (SI/51-2 International Grid) with explanatory notes.
Geological map of Ravensthorpe 1 : 250 000 Sheet (SI/51-5 International Grid) with explanatory notes.
Geological map of Seemore 1 : 250 000 Sheet (SH/51-12 International Grid) with explanatory notes.
Geological map of Yalgoo 1 : 250 000 Sheet (SH/50-2 International Grid) with explanatory notes.
Geological map of Yampi 1 : 250 000 Sheet (SE/51-3 International Grid) with explanatory notes.
Geological map of Zanthus 1 : 250 000 Sheet (SH/51-15 International Grid) with explanatory notes.

In Preparation

Bulletin 124: The geology of the Perth Basin.
Mineral Resources Bulletin: Tin.
Mineral Resources Bulletin: Heavy mineral sands.
Geological maps 1 : 250 000 with explanatory notes, the field work having been completed:

Billiluna, Browne, Cobb, Cundeelee, Duketon, Herbert, Laverton, Lennis, Leonora, Lucas, Madley, Marble Bar, Mason, Minigwal, Neale, Perth, Rason, Robert, Stansmore, Throssell, Vernon, Waigen, Wanna, Warri, Westwood, Yowalga.

Geological map 1 : 2 500 000 Western Australia.
Geological map 1 . 1 000 000 Kalgoorlie.
Geological map 1 : 1 000 000 Esperance.

Records Produced

1966/6 Geology of the Darling Scarp between latitudes 32° and 33° South, W.A., by J. L. Baxter and J. J. G. Doepel.
1973/1 Lalla Rookh proposed dam site and spillway, Shaw River—foundation geology, by J. Nicholson (restricted).
1973/2 The geology of the peninsula west of Leschenault Inlet, by R. W. A. Crowe (restricted).
1973/3 Report on the geology of the Fitzgerald River lignite, by A. E. Cockbain and W. J. E. van de Graaff (restricted).
1973/4 Kangan Pool dam site, Sherlock River, geological investigation—progress report, by J. M. Campbell (restricted).
1973/5 Wells drilled for petroleum exploration in W.A. to the end of 1972, by G. H. Low.
1973/6 Explanatory notes on the Yalgoo 1 : 250 000 geological sheet, W.A., by P. C. Muhling and G. H. Low.
1973/7 West Canning Basin hydrology investigation, geophysics 1972—progress report, by D. L. Rowston (restricted).
1973/8 A proposed structural subdivision for the Eastern Goldfields Province of the Archaean Yilgarn Block, Western Australia, by I. R. Williams.
1973/9 Explanatory notes on the Ravensthorpe 1 : 250 000 geological sheet, W.A., by R. Thom and S. Lipple.
1973/10 Lower Wungong proposed dam site: brief geological report of investigations March 1973, by G. Marcos.
1973/11 A review of the geological investigations of the Eastern Goldfields Province including bibliography to December 1972, by I. R. Williams.
1973/12 Summary of progress on the Precambrian stratigraphy of W.A., by R. D. Gee.
1973/13 B.M.R. Billiluna No. 1 stratigraphic test bore, by R. W. A. Crowe.
1973/14 Explanatory notes on the Rason 1 : 250 000 geological sheet, W.A., by C. F. Gower and J.-C. Boegli.
1973/15 Carnarvon water supply. Gascoyne River 18-mile bore by J. R. Forth.
1973/16 Petroleum reserves of the Goodwyn Field, W.A., as at 30/6/73, by R. N. Cope (restricted).
1973/17 Harvey proposed dam sites, seismic refraction survey, by I. R. Nowak.
1973/18 Explanatory notes on the Warri 1 : 250 000 geological sheet, W.A., by W. J. E. van de Graaff.
1973/19 The petroleum reserves of the northern Carnarvon Basin, W.A., as at 30th June, 1973, by R. N. Cope (confidential).
1973/20 Hydrogeology of the Werillup, Sand Patch and Snake Hill areas, near Albany, by J. R. Forth (restricted).
1973/21 Pilbara region—outline of groundwater resources, 1973, by W. P. Balleau.
1973/22 North Pole proposed dam site—eastern spillway—seismic refraction survey, by I. R. Nowak (restricted).
1973/23 Explanatory notes on the Mason 1 : 250 000 geological sheet, W.A., by W. J. E. van de Graaff.
1973/24 Analysis of coal from the Sue Coal Measures, Southern Perth Basin, Western Australia, by A. E. Cockbain.
1973/25 Bullinnarwa Pool proposed dam site, seismic refraction survey, by I. R. Nowak (restricted).
1973/26 Harvey proposed dam sites—geological report, by J. Nicholson.
1973/27 De Grey River groundwater investigation, by W.A. Davidson.
1973/28 Explanatory notes on the Laverton 1 : 250 000 geological sheet, W.A., by C. F. Gower.

Reports in other Publications

Blockley, J. G., 1973, Geology of Western Australian tin deposits, *in* Papers presented at the Western Australian Conference 1973: Australasian Inst. Mining Metall., p. 131-140.
Playford, P. E., 1973, Petroleum exploratory in Western Australia, *in* Papers presented at the Western Australian Conference 1973: Australasian Inst. Mining Metall., p. 183-191.
Trendall, A. F., 1973, Geology of Western Australia iron ore, *in* Papers presented at the Western Australian Conference 1973: Australasian Inst. Mining Metall., p. 129-130.
—— 1973, Iron-formations of the Hamersley Group of Western Australia: type examples of varved Precambrian evaporites, *in* Genesis of Precambrian iron and manganese deposits: Proc. Kiev Symp., 1970 (Earth Sciences, 9), Unesco, p. 257-270.
—— Precambrian iron-formations of Australia: Econ. Geol., v. 68, p. 1023-1034.
—— Time-distribution and type-distribution of Precambrian iron-formations in Australia, *in* Genesis of Precambrian iron and manganese deposits: Proc. Kiev, Symp., 1970 (Earth Sciences, 9), Unesco, p. 49-57.
—— Varve cycles in the Weeli Wolli Formation of the Precambrian Hamersley Group, Western Australia: Econ. Geol., v. 68, p. 1089-1097.

1st February, 1974. J. H. LORD,
Director.

CALCRETE IN WESTERN AUSTRALIA

by C. C. Sanders

ABSTRACT

Calcrete is a carbonate rock occurring in association with fluvial sediments in the ancestral river valleys of arid regions in Western Australia. It has formed by the *in situ* replacement of valley-fill debris by carbonate precipitated from percolating carbonate-saturated ground and soil water. In Australia it frequently attains a thickness of 10 m, but may rarely be as much as 30 m thick.

Calcrete has a well developed secondary porosity and high permeability, and in places it forms excellent aquifers. Some calcretes close to Archaean granites are selectively mineralized by uranium.

In the arid zone there are also widespread soil carbonates which are termed kankar, but these are superficial and unlike calcrete are not valley controlled.

INTRODUCTION

Calcretes have been shown to be the most productive aquifers in the arid zone of Western Australia, because of the shallow depth to water in the deposits and their high permeability. Commonly the groundwater is potable, but where the water is brackish to saline it can usually be extracted in sufficient quantities to be suitable for industrial uses, e.g. the beneficiation of minerals. Furthermore, some calcretes, because of their closeness to uranium-bearing provenance rocks, have become hosts for uranium mineralization. The established and potential economic importance of these carbonate rocks makes necessary a better understanding of the nature of calcrete and prompts comparison with other arid zone carbonate rocks such as travertine, kankar, and calcareous paleosols.

Exploration of calcretes both for groundwater supplies and possible uranium mineralization is at present taking place in the Pilbara region in the northwest, and the East Murchison District in the central part of the State (Fig. 4).

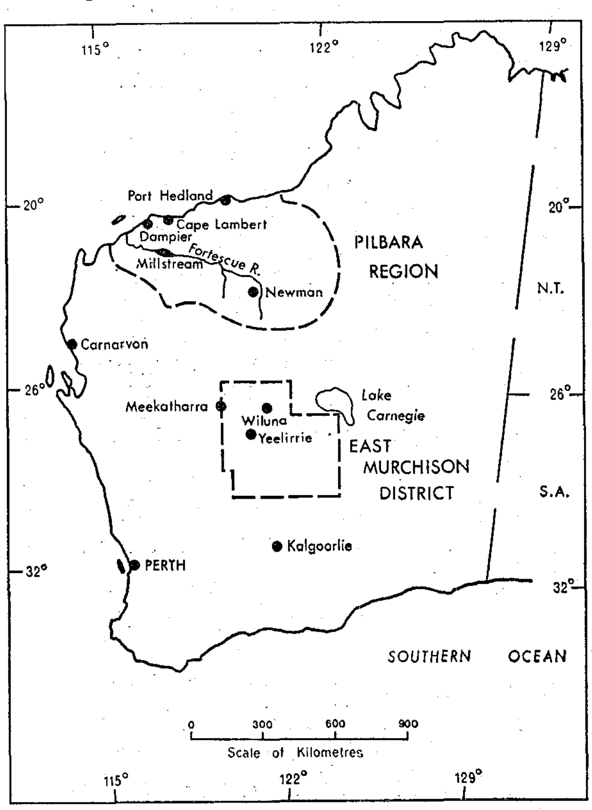


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Figure 4. Areas of intensive calcrete exploration.

CALCRETE

OCCURRENCE AND DESCRIPTION

The main rivers of the inland follow ancestral courses with alluvial, and in places calcrete infilled valleys, up to 30 m thick. The topography is mainly subdued with gentle gradients averaging 1 : 1 000, the water courses generally being poorly defined. Some of the valleys in the Pilbara Region, where drainage is to the coast from the Hamersley Range, have been subjected to rejuvenation and consequent renewed erosion. In the East Murchison drainage is internal towards large salt lakes, which now occupy parts of an extensive Tertiary river system that flowed southeastward to the Eucla Basin (Mabbutt and others, 1963; Morgan 1966). Other writers have presented reconstructions of the palaeodrainages of the region based on photo-interpretation, soils and vegetation evidence; Bunting and others (1974) have used altimetric data.

Calcrete crops out along the valley floors mainly as low mounds of nodular calcium carbonate dispersed in a brown calcareous soil, the mounds being separated by a network of narrow alluvial channels. In places it forms indurated sheets of calcium carbonate, frequently having karstic features such as sink holes (Fig. 5), cavities and solution pipes. Calcrete is restricted to ancestral or existing water courses, although these may not be apparent at ground level because of the low relief and a lack of indentifiable trunk drainage tracts. Air-photographs, however, usually show a distinctive residual dendritic drainage pattern, the calcrete being visible as whitish crenulated platforms ("brain pattern" Fig. 6). Furthermore, in some places the calcrete is overlain by thin alluvial wash and eolian sand, but its presence may be discerned on air-photographs from a conspicuous pock-mark pattern (gilgai), caused by carbonate solution and soil collapse. Colluvial debris also tends to mask any surface radioactivity associated with uranium within the calcrete.

Calcrete most commonly occurs along flat reaches of the drainage and around salt lakes (Morgan, 1966; Sanders 1969). The water table is usually at a depth of 3 to 6 m below ground level, except in areas where the base level of valleys has been lowered by renewed erosion, as along the Oakover River in the Pilbara region. Here the water table rests between 20 and 30 m below the calcrete surface.

Subsurface calcrete is of nodular and blocky limestone, which is friable and permeable in places, elsewhere it may occur as massive impermeable sheets a square metre or so in area. The level of the water table is marked by horizontal layers of brown pebbly detrital debris. Where the groundwater has a salinity generally less than about 5 000 mg/l massive opaline silica (chert) bands up to 0.5 m thick may occur. Past higher or lower elevations of the water table are often marked by various levels of opaline silica, but these are rarely more than a metre above or below the present water table. Often the opaline rock is fractured and fissured, the joints being encrusted with concretionary secondary carbonate. Some of the larger fissures have become avenues for groundwater movement and have been enlarged by water action to 0.3 m or more in width. Occasionally large caverns have formed, and these may connect with the surface (de la Hunty, 1958). Calcrete has a high secondary porosity, and in zones of uranium mineralization carnotite and some other exotic radioactive minerals may occupy pores and fractures mainly at the water table.

Beneath the silica layer the calcrete has variable lithology, from hard limestone to fine calcareous sand, with occasional brown detrital silt, sand and gravel layers cemented by ferroan carbonate. Where calcreted valleys occur in granite

Figure 5. Cavernous calcrete surface at Paroo Station, Wiluna. The sink hole at left of centre is 0·8 m deep and 3·2 m wide. Note the mound development.

Figure 6. Air-photograph of typical calcrete area—white area interspersed by dendritic streams leading to a trunk drainage (Weeli Wolli Creek, Pilbara Region). Lands Department of W.A. photo 373 Roy Hill run 18. No. S123. Scale 10 mm=400 m.

terrains white kaolinitic clays are commonly dispersed in the limestone profile. The materials are usually sufficiently well cemented to permit bores to remain uncased. The permeability of the deposit varies greatly depending on the degree of cementation, the amount of residual clay and fine debris, and the development of conduits by solution.

The full calcrete sequence may range in thickness from 5 to 30 m, but is usually of the order of 5 to 10 m. Its origin has been discussed in a number of papers, the general concensus being that the limestone was formed by the slow replacement of fluviatile silt, sand and gravel by carbonate, mainly in the calcitic form, precipitated from high pH, carbonate-saturated ground and soil water. Neither the mineralogy of the limestone nor the replacement mechanism are as yet fully documented. However calcrete groundwaters have a positive Langelier index (see Hem, 1970), indicating supersaturation with respect to calcite. Silica carried in solution is presumably reconstituted into chert at the water table, where oxidization and consequently a reduction in pH occurs.

NOMENCLATURE PROBLEMS

Elsewhere in the semi-arid and arid areas of Australia and other continents there are widespread superficial calcium carbonate deposits that are usually in the form of fine-grained unconsolidated material, nodules, and indurated sheets and commonly contain varying amounts of terrigenous materials and chert. They are known by various local terms, such as caliche, croûte calcaire, nari, kankar or kunkar, etc. Goudie (1971, 1972) gives a bibliography of such deposits, and argues that an acceptable international term for them all would be "calcrete". Generally they bear no relationship to distinct drainages, and are often found in the unsaturated zone well above the water table, where they are formed by cementation and/or *in situ* replacement of pre-existing soil material, mainly by calcium carbonate. In Western Australia these limestone soils are very extensive, especially in the Kalgoorlie region, where they are termed kankar. Heath (1966) points out that this is a more acceptable spelling than kunkar.

It seems that these pedogenic carbonates deserve a standard term of their own that is universally applicable. Thus if a rational term is chosen for kankar, caliche, etc., it should be chosen from the more common synonyms, and not from a term that possibly implies something quite different. "Calcrete" as coined by Lamplugh (1902) is poorly described, but appears to refer to the carbonate cement. Further, Lamplugh (1907) used calcrete to describe carbonate deposits occurring along part of the Zambesi River, and these are probably similar to the Australian valley-controlled calcretes.

The Geological Survey of Western Australia intends to retain both the terms calcrete and kankar for the time being.

AGE

The age of calcrete development in Western Australia is given in the literature as being late Tertiary to Holocene (Traves and others, 1956, Sofoulis, 1963, Sanders, 1973).

There are no reports of isotope age dating having been done, and no datable fossil remains have been found. Calcrete chronology is based on stratigraphic evidence, for instance in the East Murchison, calcrete is part of the uppermost sequence in valley-filled drainages which demonstrably lead southeastward to the Tertiary Eucla Basin. Moreover, calcrete development is enhanced under arid climatic conditions, which from geomorphological evidence, such as peneplanation and alluviation of trunk drainages and development of salt lakes (Mabbutt and others, 1963), commenced in the late Tertiary and have persisted to the present.

ECONOMIC IMPORTANCE

A calcrete at Millstream on the Fortescue River is described by Davidson (1969), and is reported by Collett and Sadler (1973) as yielding 22.5 megalitres ($22.5 \times 10^3 m^3$*) per day of potable water suitable for developing towns in the Pilbara. At least $350 \times 10^6 m^3$ is estimated to be in storage. Further, these authors predict for Dampier-Cape Lambert a daily water requirement by 1990 of 450 megalitres ($450 \times 10^3 m^3$) if the concept of an integrated industrial complex becomes a reality; much of this water must come from underground sources.

Balleau (1973) examined the hydraulics of many of the Pilbara river basins. He concluded that calcreted aquifers in association with local alluvial reservoirs along river valleys are recharged from intermittent rainfall and catchment runoff at an average overall rate of $300 \times 10^3 m^3$ per day. If the rate of abstraction is made equal to the recharge rate any alteration of the water balance will be minimized and the prospect exists of meeting much of the projected 1990 water demand from groundwater sources.

In the East Murchison District, north of Kalgoorlie, a number of calcretes are being investigated for their groundwater resources. One, at Paroo Station near Wiluna, could yield at least $12.3 \times 10^3 m^3$ per day of potable water (Sanders, 1973). Other calcretes should provide industrial quality water at salinities greater than 1 500 milligrams per litre total dissolved solids. The predicted combined daily demand of companies in this region is given by Collett and Sadler (1973) as upward of 160 megalitres ($160 \times 10^3 m^3$), but 75 per cent of the water may be of industrial quality at salinities ranging from 3 000 to 100 000 mg/l TDS, depending on company requirements.

Intensive uranium prospecting of calcrete followed the January 1972 announcement by Western Mining Corporation of a significant discovery at Yeelirrie 90 km south of Wiluna. The Corporations 1973 Annual Report records the proven ore resources for the explored area at Yeelirrie as 32×10^6 tonnes containing 0.15 per cent uranium oxide (3.3 lbs. per long ton). Discoveries by other exploration companies working in the region have also been announced in the press.

REFERENCES

Balleau, W. P., 1973, Pilbara Region—outline of groundwater resources, 1973: West. Australia Geol. Survey Rec. 1973/21 (unpublished).

Bunting, J. A., van de Graaff, W. J. E., and Jackson, M. J., 1974, Palaeodrainages and Cainozoic Palaeogeography of the Eastern Goldfields, Gibson Desert and Great Victoria Desert: West. Australia Geol. Survey Ann. Rept. 1973, p. 45-50.

Collett, D. B., and Sadler, B. S., 1973, Water Supplies for Mining Developments in Arid Regions of Western Australia: The Institution of Engineers, Australia, Annual Engineering Conference, Perth 1973, Proceedings.

Davidson, W. A., 1969, Millstream hydrogeological investigation: West. Australia Geol. Survey Ann. Rept. 1968, p. 17-22.

de la Hunty, L. E., 1958, Report on water supply problem at Lorna Glen Station, 86 miles E. N. E. of Wiluna: West. Australia Geol. Survey Bull. No. 113.

Goudie, A. S., 1971, A regional bibliography of calcrete: *in* W. J. McGinnies, B. J. Goldman and P. Paylore, (eds.), Food, Fiber and Arid Lands: Tucson, Univ. Arizona Press. p. 421-437.

——— 1972, The chemistry of world calcrete deposits: Jour. Geol. v. 80, p. 449-463.

Heath, G. R., 1966, Carbonate nodules formed in soil profiles: The nomenclature problem: Aust. Jour. Sci. v. 28, No. 10 p. 395-396.

Hem, J. D., 1970, Study and interpretation of the chemical characteristics of natural water: U.S. Geol. Survey Water Supply pap. 1473 (2nd. ed.).

Lamplugh, G. W., 1902, Calcrete: Geol. Mag. (United Kingdom) v. 9, p. 575.

* The Metric Conversion Board recommends that cubic metre be used for volume and integrated volumetric flows, water distribution, irrigation diversions, storage capacity and underground basins.

——— 1907, Geology of the Zambesi Basin around Batoka Gorge: Geol. Soc. London Quart. Jour., v. 63, p. 162-216.

Mabbutt, J. A., Litchfield, W. H., Speck, N. H., Sofoulis, J., Wilcox, D. G., Arnold, J. M., Brookfield, M., and Wright, R. L., 1963, General report on lands of the Wiluna—Meekatharra area, Western Australia, 1958: C.S.I.R.O. Land Research Series No. 7.

Morgan, K. H., 1966, Hydrogeology of the East Murchison and North Coolgardie Goldfields: West. Australia Geol. Survey Ann. Rept. 1968, p. 14-17.

Sanders, C. C., 1969, Hydrogeological reconnaissance of calcrete areas in the East Murchison and Mt. Margaret Goldfields: West. Australia Geol. Survey Ann. Rept. 1968, p. 14-17.

——— 1973, Hydrogeology of a calcrete deposit on Paroo Station, Wiluna, and surrounding areas: West. Australia Geol. Survey Ann. Rept. 1972, p. 15-26.

Sanders, C. C., and Harley, A. S., 1971, Hydrogeological reconnaissance of parts of Nabberu and East Murchison Mining Fields 1970: West. Australia Geol. Survey Ann. Rept. 1970, p. 23-27.

Sofoulis, J., 1963, The occurrence and hydrological significance of calcrete deposits in Western Australia: West. Australia Geol. Survey Ann. Rept. 1962, p. 38-42.

Traves, D. M., Casey, J. N., and Wells, A. T., 1956, The Geology of the south western Canning Basin, Western Australia: Australia Bur. Mineral Resources Rept. 29.

RECHARGE TO THE JURASSIC AQUIFER OF PINJARRA

by J. R. Forth

ABSTRACT

The term "Jurassic aquifer" is informally applied to a thickness of water-producing sands contained within a greater thickness of saturated clays, silts and sands of Jurassic, Cretaceous and Quaternary age at Pinjarra (70 km south of Perth, Western Australia).

Pinjarra is on the coastal plain westward of the Darling Fault. The land surface slopes gently westward to the sea and is drained by minor streams.

Drilling has shown that the coastal plain deposits consist of interfingering layers and lenses of sand, silts and clays. The block-faulted Jurassic sediments are unconformably overlain at the surface by westward-dipping Cretaceous strata and up to 15 m of Quaternary sands and silts.

Groundwater flow in the confined Jurassic aquifer is westward from an impermeable fault boundary towards the sea 20 km distant.

The aquifer is about 150 m below the ground surface and is 25 m thick. Its transmissivity is shown to be in the range 150 to 180 m^2/d, and aquifer recharge, prior to pumpage, is shown to be about 2 640 m^3/d.

When head changes in the cone of depression, resulting from long term abstraction, are analysed, then it is clear that leakage to the aquifer is not by vertical percolation from the water table, but is mined from water stored in sediments above and below the aquifer.

Aquifer recharge is apparently restricted to a very small part of the total potential recharge area of 8.2 x 10^6 m^2, and abstraction from the Jurassic aquifer can only lead to small increases in recharge by capture.

INTRODUCTION

The alumina refinery site at Pinjarra (70 km south of Perth) is underlain by a thick sequence of fine sediments. Present water production is from bores (the locations of which are given in Commander, 1974) whose screens have been emplaced in sands of Jurassic age, loosely referred to as the "Jurassic aquifer".

There has been extensive testing of the main producing aquifer, and a substantial body of information has been derived from the many observation bores sited within the cone of influence. In the ensuing discussion data collected during long term abstraction are applied to the problem of describing the locus of the water pumped, and the possible effect of pumping of the recharge regime.

SYMBOLS

Symbols used are those of Hantush, 1964.

A	=	area
B	=	leakage factor = $\sqrt{Kb/(K'/b')}$
b	=	uniform thickness of an aquifer
b'	=	uniform thickness of a semipervious layer
d	=	day
H (u,β)	=	an indefinite integral
H	=	head
i	=	hydraulic gradient
K	=	hydraulic conductivity of an aquifer
K'	=	hydraulic conductivity of a semipervious layer
Ko(x)	=	zero-order modified Bessel function of the second kind
m	=	metres
Q	=	discharge
r	=	radial distance
r_w	=	effective radius of a well
S	=	storage coefficient of an aquifer
S'	=	storage coefficient of a semipervious layer
s	=	drawdown
T	=	transmissivity
t	=	time
u	=	$r^2/4vt$
W(u)	=	well function for a non-leaky aquifer
β	=	$(r/4B)\sqrt{S'/S}$ = a parameter in formulae pertaining to leaky aquifers with storage in the semipervious layer
δ	=	$1 + S'/3S$
v	=	T/S
Δh	=	head difference

HYDROGEOLOGICAL SETTING

The principal aquifer systems are in Jurassic and Cretaceous sediments consisting of interfingering layers and lenses of sand, sandy clay and clay, which are covered by a relatively thin layer of more recent sandy and clayey sediments. The detailed stratigraphy and structure of the area has been described by Commander, 1974. The Jurassic sands tapped for production are typically 150 to 200 m below the ground surface, which is about 20 m above sea level.

Water in the Jurassic and Cretaceous sediments has a pressure head, while in the uppermost surficial sediments there is a water table. Recharge to the generally confined Jurassic aquifer is restricted to a small area bounded on one side by an unnamed fault parallel to and westward of the Darling Fault, and on the other, approximately by the 24 m potentiometric contour (Figs. 7 and 8).

The potential recharge area is limited to the zone in which potentiometric levels in the Jurassic aquifer are lower than the elevation of the water table. Hence there appears to be a possibility of increasing the area of recharge by pumping water from the Jurassic and Cretaceous sediments, thereby reducing their potentiometric levels.

Production from 1970 to 1974 has been from bores whose screens are set in Jurassic sands, selected because of their potential for supporting sustained production at high rates. The screened intervals have been chosen as the best that exist within an economic depth range. Water could be pumped from other depth intervals at the production bore sites, though yields might not necessarily be as great as those presently obtained. All the sediments are fully saturated, including those that are classified as aquifers and those that are not. This is important when considering the likely behaviour of bores in this area.

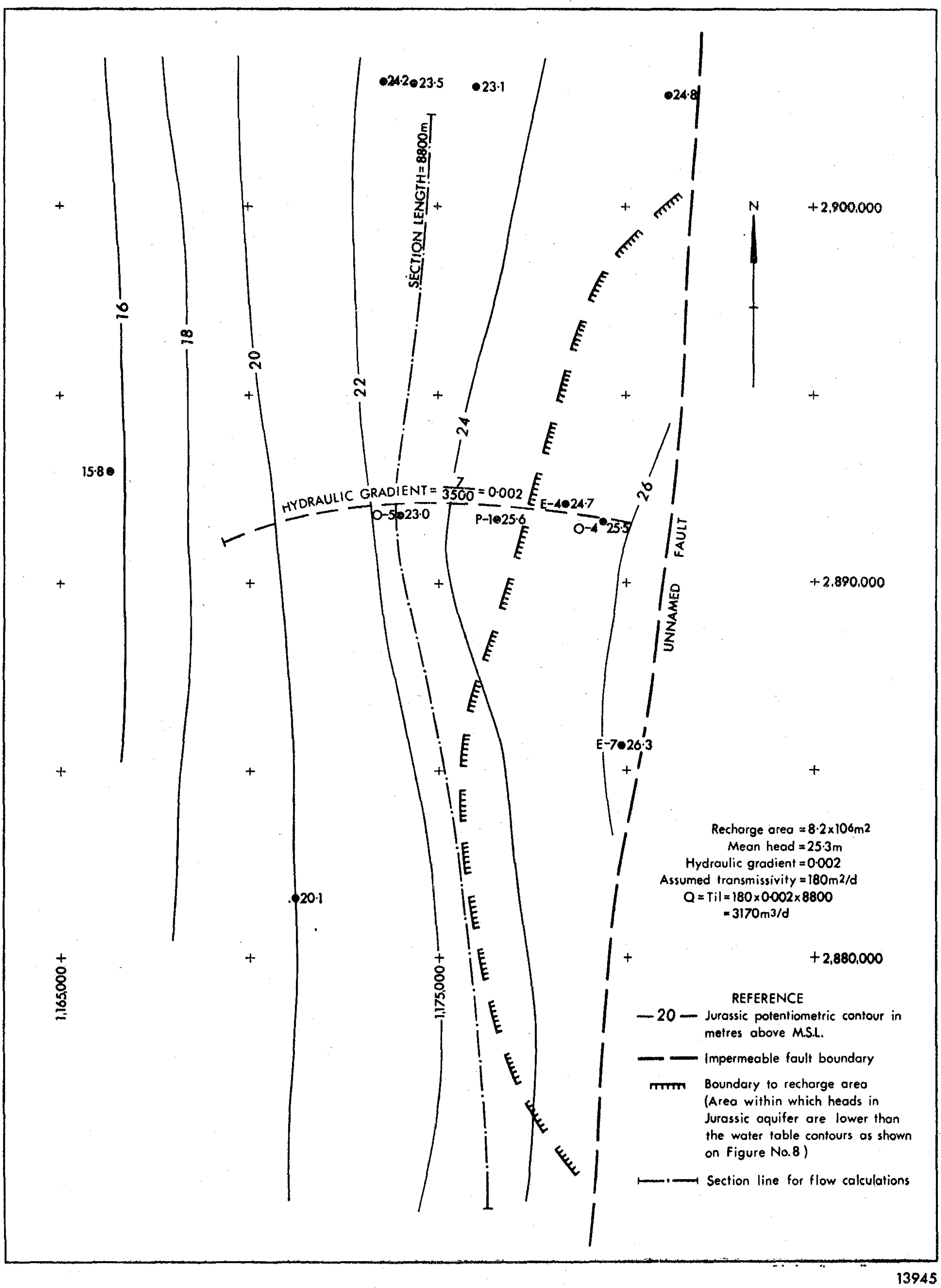

Figure 7. Potentiometric map for Jurassic aquifer prior to long term pump test.

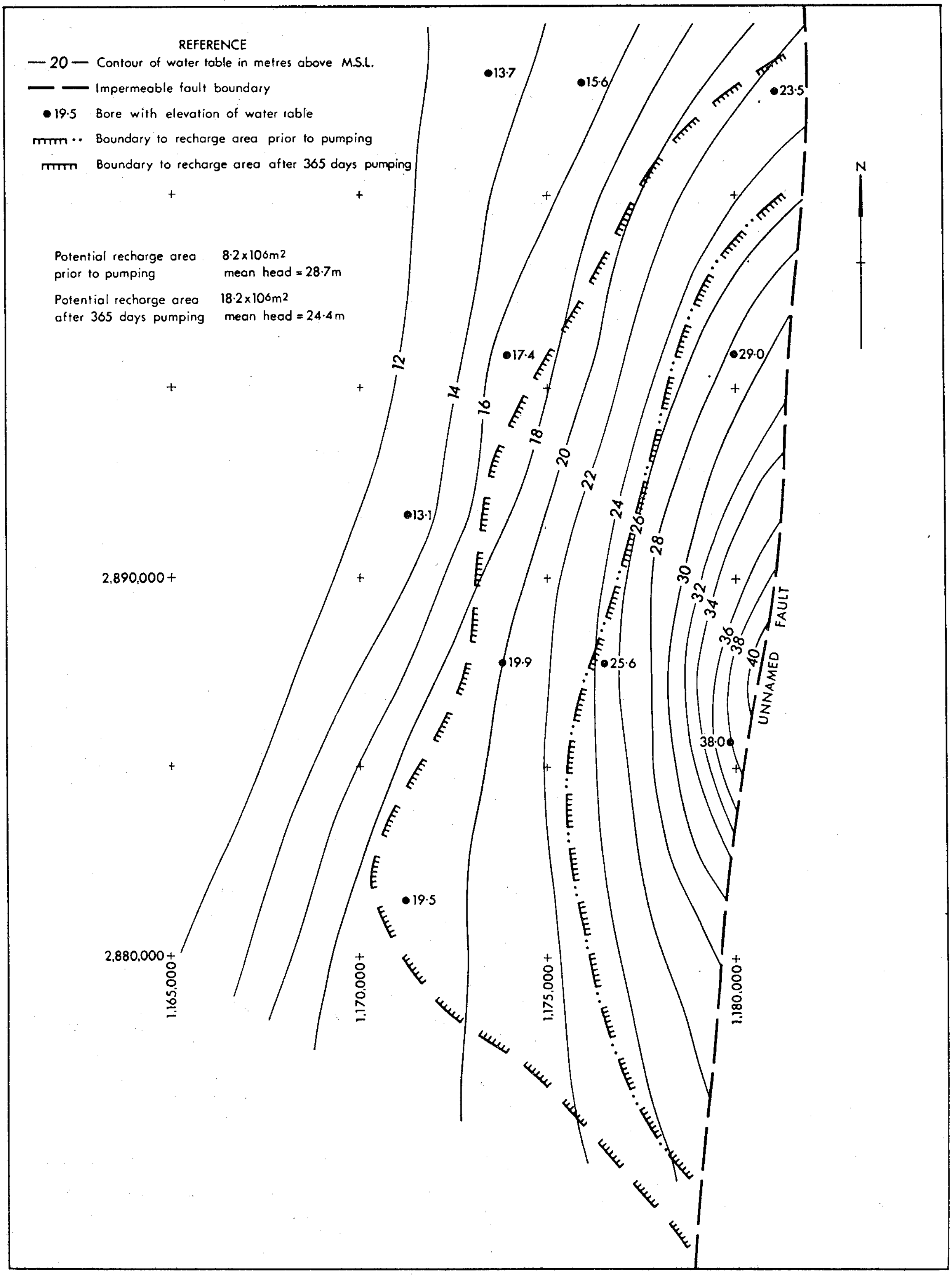

Figure 8. Contours of elevation of water table.

THEORETICAL AQUIFER RESPONSE.

With a knowledge of the hydrological setting it is possible to discuss the behaviour of a pumping bore having screens set in the Jurassic or Cretaceous aquifers. Hantush (1964) has given the mathematical theory of flow under conditions similar to those pertaining at Pinjarra. The following equations are all taken from his work and are not individually acknowledged.

The aquifers being pumped are confined, and from what is known of the geology of the area it can be said that they are "leaky".

Hantush, (1964) states, that for pumping bores in such systems "the discharge . . . is supplied from local storage in the main artesian aquifer, as well as leakage, if any, originating in and/or passing through the semipervious confining beds. The confining beds of an artesian aquifer are rarely completely impermeable. Frequently, the artesian sand is confined above and/or below by a semipervious elastic clay or silt that yields significant amounts of water from storage. In certain instances, the water released from storage in these semipervious layers is much more significant than that released from storage in the artesian sand they confine. These semipervious layers may . . . be over/or underlain by aquifers whose capacity for lateral flow is sufficient that the head distribution therein is not affected by flow conditions in the main artesian aquifer in spite of the leakage from or into them".

The flow equations for wells discharging from confined aquifers have been detailed by Hantush and are summarized here. For a short time interval

($t < \frac{S'b'}{10K'}$) and with steady flow, the general flow equation for confined aquifers is:

$$S = (Q/4\pi T)\ H(u,\beta) \quad .... \quad .... \quad .... \quad .... \quad (1)$$

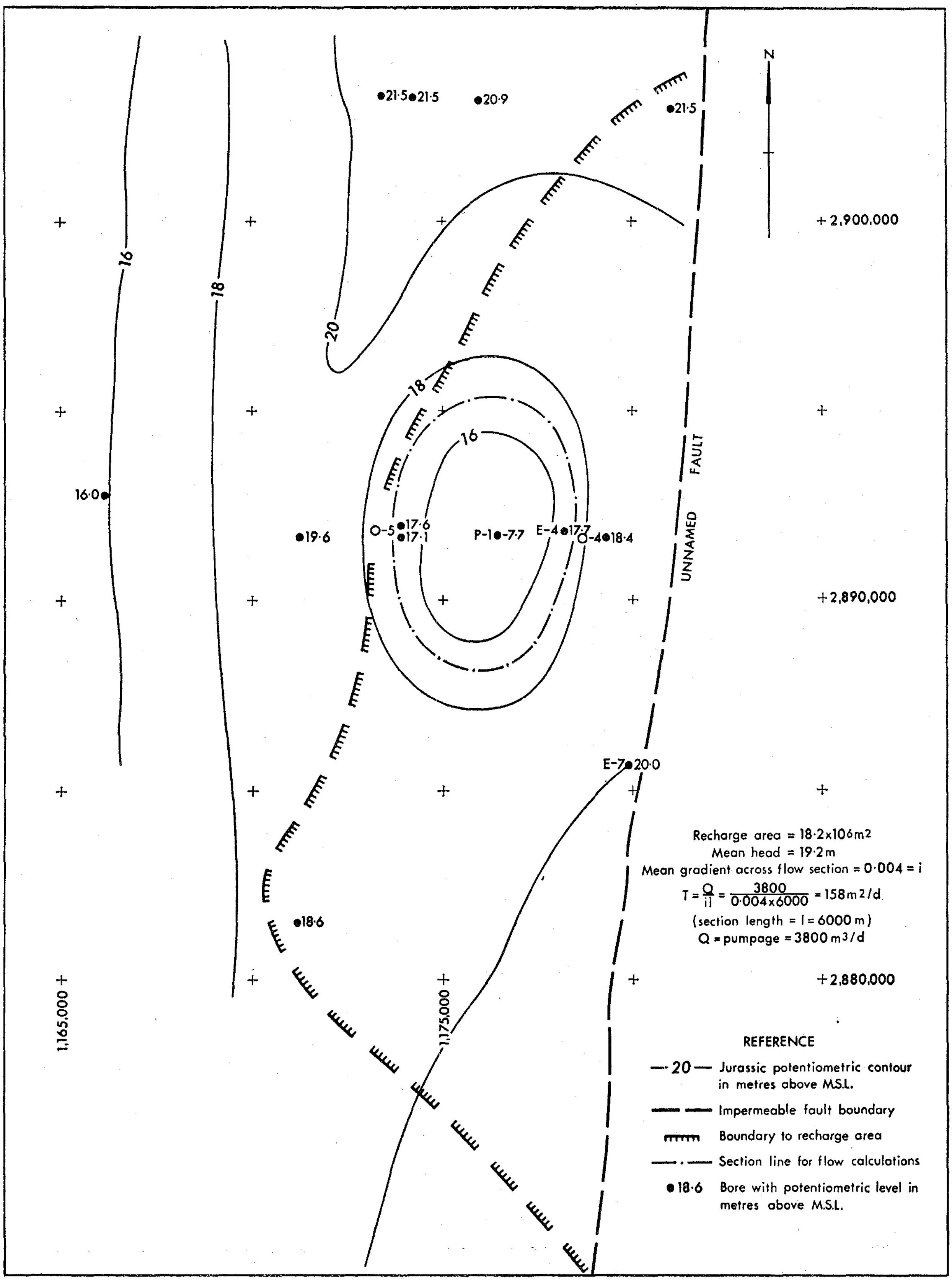

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Figure 9. Potentiometric map for Jurassic aquifer after 365 days pumping.

The equation holds whether leakage is from elastic storage in overlying or underlying beds, or if the leakage is by flow through semipervious confining beds without a contribution from elastic storage. If there is no leakage then $\beta = O$ and the function of $H(u,\beta)$ is identical with the Theis well function $W(u)$.

Hantush has also provided solutions for long times:

(i) Leakage with storage in the semipervious layer

where $r_w/b < 0.1$

and $t > 2b'S'/K'$

and $t > 30\ \delta_1 r^2_w/\nu \left\{1 - (10r_w/B)^2\right\}$

$$s = (Q/4\pi T)\ W\ (\delta_1 u, r/B) \quad .... \quad .... \quad (2)$$

(ii) Leakage without storage in the semipervious layer

$$s = (Q/4\pi T)\ W(u, r/\beta) \quad .... \quad .... \quad (3)$$

For both long time solutions (equations 2 and 3), as time becomes effectively long the yield of the well is sustained almost entirely by leakage through the semipervious layer (a steady state of flow will be essentially realized) and the steady drawdown is given by

$$s = (Q/2\pi T)\ K_o(r/B) \quad .... \quad .... \quad .... \quad (4)$$

which is the Jacob (1946) steady state leaky artesian equation.

This very brief summary of the principal radial flow equations for confined aquifers is given to point out some of the problems that must be faced before pump test data from confined aquifers can be analysed. At Pinjarra it is almost certain that there is leakage to the Jurassic aquifer. It follows then that aquifer behaviour cannot be analysed by the Theis equation or the Jacob straight line modification. If very early time data are available then equation 1 could be used, or if late time steady state data are available, analysis by equation 4 could be used. There are some difficulties in applying equations 2 and 3 (mainly in establishing which is applicable) and their use would not be strongly recommended at Pinjarra. In those cases where the Theis or Jacob modifications have been used for analysis, the resultant calculated transmissivites will be too large.

JURASSIC AQUIFER TRANSMISSIVITY

An estimate of aquifer transmissivity can be made by flow net analysis of the mapped cone of depression (Fig. 9). The resultant value (158 m^2/d) should be slightly too high because of leakage to that portion of the aquifer between the section line used for the calculation, and the pumping bore, P-1.

Data collected during a long term pump testing have also been analysed using standard type curves. The time-drawdown observations have the apparent form of the Theis curve and if so matched, as demonstrated in Figure 10, yield a resultant transmissivity of 348 m^2/d and a storage coefficient of 3.48×10^{-4}. The data show that after 365 days pumping the aquifer had not reached an equilibrium state and that drawdowns were still increasing.

Curve matching to the Theis non-leaky curve obviously implies that there is no leakage and as long as drawdowns continue, the pumped water is being derived from storage in the induced cone of depression. The volume of the cone of depression (Fig. 9) is approximately 170×10^6 m^3 after 365 days pumping. The derived storage coefficient is 3.48×10^{-4}, so the volume of water abstracted from the cone of depression in the pumped aquifer should be $3.48 \times 10^{-4} \times 170 \times 10^6 = 5.92 \times 10^4 m^3$ of water. Pumpage during the same period was $3\,800 \times 365 + 1.39 \times 10^6 m^3$. The proportion of pumped water taken from the cone of depression is $5.92 \times 10^4/1.39 \times 10^6$ or approximately 4 per cent of the total pumpage. Therefore, 95 per cent of the pumped water must have come from sources other than that cone. This can only be by leakage from water bearing beds above or below those pumped. In this case the drawdown pattern cannot be described by the Theis curve and another form of analysis must be used.

On Figure 11, observed drawdowns from four observation bores are shown matched to the $H(u,\beta)$ "leakage from storage" curves (equation 1 of previous section). A reasonable match can be made, and the resultant transmissivity is 180 m^2/d which is in fair accordance wth the flow net result of 158m^2/d. The 180 m^2/d result has been used in subsequent calculations to illustrate some features of the aquifer's response to long term pumping.

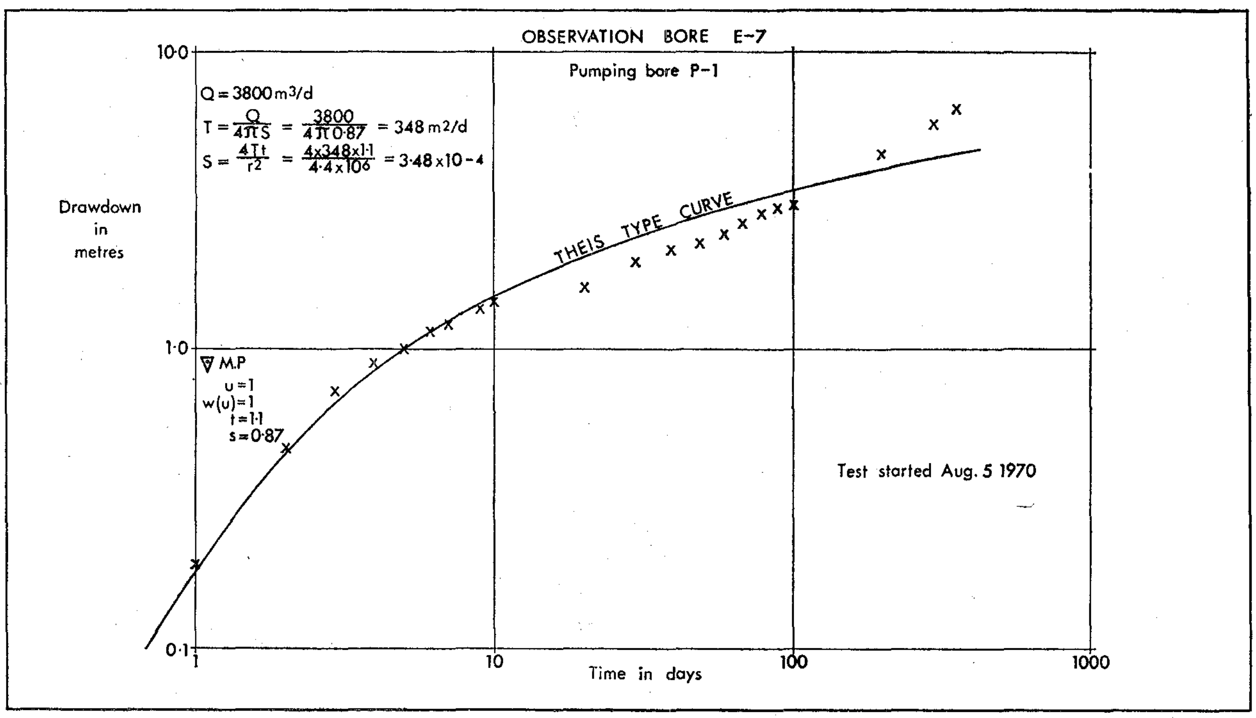

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Figure 10. Pump test analysis of observation bore E-7 by Theis Curve.

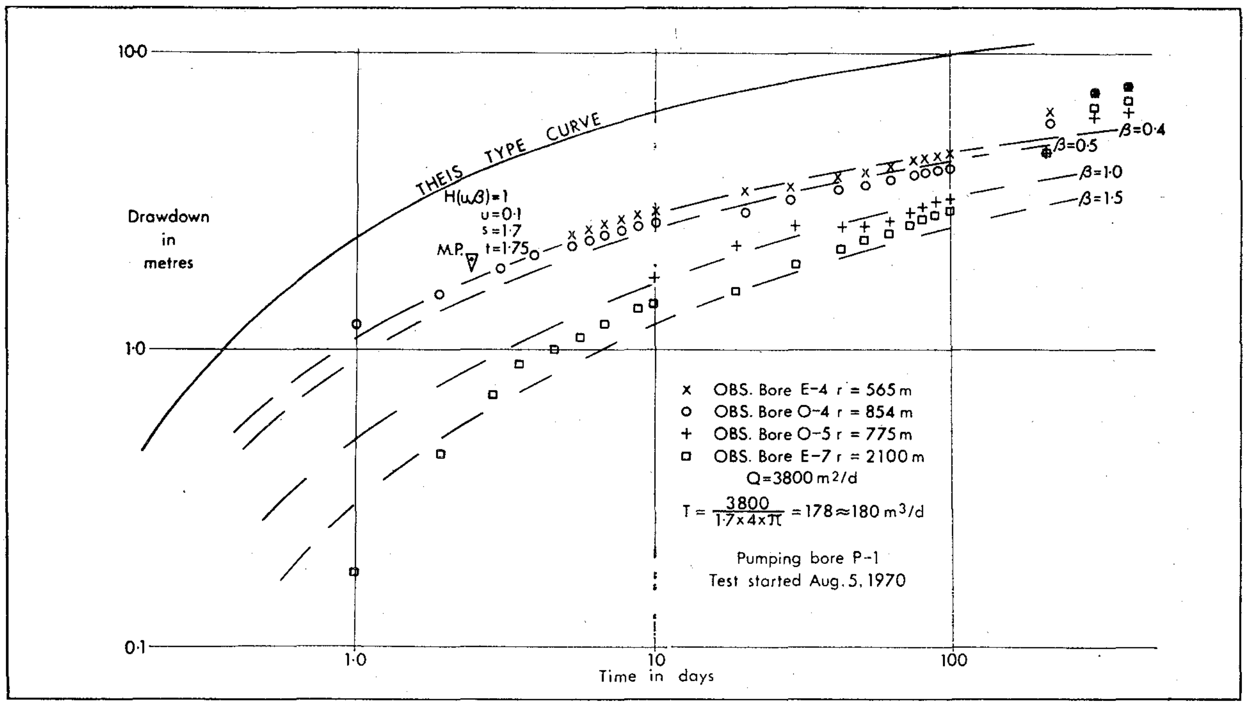

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Figure 11. Pump test analysis of observation bores E-4, 0-4, 0-5 and E-7, by Hantush H(u,β) " leakage from storage " curves.

BOUNDARY EFFECTS

At Pinjarra, faults and lithological variations impose an extremely complex set of boundary conditions upon the aquifer's response to pumping. In a previous section the theoretical aquifer response has been discussed. As the period of pumping increases, the complex boundary conditions will steadily cause a divergence between the theoretical and actual response; the net effect being that actual drawdowns will be larger than those calculated. There is no possibility of calculating such effects by using the presently available data. Instead, in these notes, some observed changes in the aquifer's status are presented and an attempt is made to provide some meaning to these observed changes.

SOURCE OF PUMPED WATER

Production Bore P1 (Fig. 7) was pumped at a rate of 3 800 m^3/d for 415 days from 5 August 1970. These notes relate to the observation bore data collected during the first 365 days of that prolonged pumping test. The bore is screened in Jurassic sands from 132.5 to 137.7 and from 166.4 to 187.1 m below the natural surface.

During the early stages of pumping, the water moving to the bore is from elastic storage in the screened aquifer. As heads reduce and a cone of pressure reduction develops, leakage is induced from underlying and overlying beds. If the confining beds (both above and below, it must be stressed) have hydraulic conductivities very much lower than that of the pumped aquifer, then a widespread cone of depression with large changes in head will develop in the screened aquifer. It has already been shown that the reduction of storage in the main aquifer is small, most of the pumped water being taken from storage in the overlying and underlying beds. At the end of 365 days pumping, the cone of depression was still growing. This shows that the aquifer had not reached equilibrium with vertical percolation, but was still drawing upon elastic storage.

Pressure heads in the sediments overlying and underlying the main aquifer will progressively change, as water is given up from elastic storage. If the vertically changing heads intercept a zone with sufficiently high lateral transmissivity, then lateral flows in that zone may be sufficient to satisfy the vertical leakage and the system will stabilize in an equilibrium condition. This zone may or may not be the water table aquifer in the surficial sediments.

Since the induced cone of depression was still growing after 365 days pumping, the vertical permeabilities were likely to be small. The pumped water was therefore being mined from storage, and during that period there had been no direct capture from the water table.

JURASSIC AQUIFER RECHARGE

By comparing the Jurassic aquifer potentiometric map with the water table contour map (Figs. 7 and 8) the potential area of recharge prior to pumpage from the Jurassic aquifer can be delimited. Only where heads in the Jurassic aquifer are lower than the water table can there be recharge to the lower aquifer.

Lateral flow, in the Jurassic aquifer, from the area which can be recharged by the water table can be computed by application of Darcy's Law. With a transmissivity of 180 m^2/d, lateral flow is 3 170 m^3/d (Fig. 7). This flow must come from the water table and is the total recharge to the Jurassic aquifer in the investigated area under natural conditions.

The potential area of recharge is defined on Figures 7 and 8, and for these areas the mean heads have been calculated by planimetry:

	Recharge area prior to pumpage	Mean head
Water table aquifer	8.2 x 10^6 m^2	28.7 m
Jurassic aquifer	8.2 x 10^6 m^2	25.3 m

Thus, the lateral flow of 3 170 m^3/d is from an area of no more than 8.2 x 10^6 m^2 and is in response to a head difference of 28.7—25.3 = 3.4 m. The Jurassic aquifer is about 150 m below the water table. The average vertical permeability through this thickness is therefore:

$$K' = Qb/\Delta hA$$
$$= (3\,170 \times 150) / (3.4 \times 8.2 \times 10^6)$$
$$K' = 1.7 \times 10^{-2}\ m/d$$

Figure 9 shows the potentiometric map for the Jurassic aquifer after 365 days pumping. By comparison with the water table potentiometric map (Fig. 8) the new increased area of potential recharge can be defined (Fig. 8 and 9). The new area is 18.2 x 10^6 m^2 and the new mean head difference between the Jurassic aquifer and the water table is 24.4—19.2 = 5.2 m.

If leakage is directly proportional to the area and head difference between the aquifers, then the potential increase in recharge is: $A_2 H_2/A_1 H_1 = 18.2 \times 5.2 \times 10^6/8.2 \times 3.4 \times 10^6 = 3.4$ where the subscripts 1 and 2 refer to time 1, and time 2. Therefore the potential recharge after 365 days pumping would be $3.4 \times 3\,170 = 10\,760$ m³/d, a value which is unrealistic because it is impossible for the induced leakage to be greater than the pumped rate of 3 800 m³/d. Hence, there must be an error in the data used, or in the assumptions made in the argument.

The estimate of 180 m²/d transmissivity could be too high, but would have to be reduced to about 50 m²/d to account for the above discrepancy. This implies that the Jurassic aquifer has a hydraulic conductivity of less than 2 m/d. It is hardly likely that the sands described as the Jurassic aquifer could have such a low hydraulic conductivity. The calculation of transmissivity for the cone of depression on Figure 9 indicated that the aquifer transmissivity might be slightly less than 158 m²/d. This is equivalent to a hydraulic conductivity of about 6 m/d which seems reasonable.

The most likely explanation would be that at Pinjarra, vertical leakage is not uniform and is not linearly proportional to development of a cone of depression in the Jurassic aquifer. It is possible that leakage is restricted to one or several very small localised areas; unless a pumping bore is sited in or very near that area it will be difficult to substantially increase the rate of leakage unless an extremely large cone of depression is developed in the Jurassic aquifer.

If a transmissivity of 150 m²/d is accepted as being more suitable for the Jurassic aquifer then:

$$\text{throughflow} = \text{recharge} = 150 \times 0.002 \times 8\,800 = 2\,640 \text{ m}^3/\text{d}.$$

If it is further assumed that the area of vertical recharge to the Jurassic aquifer is fixed by some geological control, then the mean head differences can be found for the original potential recharge area, prior to and after 365 days pumping.

Recharge area	Mean head for potential recharge area
Water Table	28.7 m (Fig. 8)
Jurassic aquifer prior to pumping	25.3 m (Fig. 7)
Jurassic aquifer after 365 days pumping	19.2 m

The increased head differential created by pumping is therefore:

$$\frac{28.7 - 19.2}{28.7 - 25.3} = \frac{9.5}{3.4} = 2.79 \text{ times the initial}$$

one.

If the transmissivity were as low as 150 m²/d (see above) then recharge was 2 640 m³/d. With an increased head differential of 2.79 times the initial one, recharge should rise to 7 400 m³/d i.e. 2.74 x x 2 640 m³/d. This is well in excess of pumpage and must therefore be incorrect. The area in which recharge takes place, must therefore be smaller than the potential recharge area of 8.2×10^6 m² shown on Figures 7 and 8.

The Jurassic aquifer potentiometric contours show that recharge may originate from the vicinity of bore E-7, near the unnamed fault boundary (Fig. 7). If it is assumed that head changes at that bore are representative of the actual recharge area, then prior to the onset of pumping the head differential between the water table and the Jurassic aquifer was $38.0 - 26.3 = 11.7$ m. After 365 days pumping the head differential was increased to $38.0 - 20.0 = 18.0$ m. This is equivalent to potential increases in recharge of (18.0/11.7) 2 640 = 3 980 m³/d, which is only slightly greater than the pumpage. The head differential used would be applicable to a very small area (approximately that bounded by the 36 m water table contour and the unnamed fault on Fig. 8). The calculated increase in leakage is sufficiently close to the pumpage rate to show that recharge to the Jurassic aquifer must be limited to a small area in the vicinity of bore E-7. If recharge is assumed to take place over an area larger than that bounded by the 36 m water table contour, then it will be found that the cone of depression should have reached equilibrium before the end of the 365 day pumping period.

CONCLUSIONS

The Jurassic aquifer has a transmissivity of about 150 to 180 m²/d in the vicinity of the pumping bore. Elsewhere it may be lower.

Aquifer recharge and throughflow is estimated to be about 2 640 m³/d.

Recharge to the Jurassic aquifer is limited to an area much smaller than the potential recharge area of 8.2×10^6 m².

During the prolonged pumping test, production bore P-1 drew most of its water from storage in sediments overlying and underlying the aquifer. There is no evidence to show that there has been any significant capture of additional recharge from the water table.

REFERENCES

Commander, D. P., 1974, Hydrogeology of the Mandurah-Pinjarra area: West. Australia Geol. Survey Ann. Rept. 1973, p. 20-25.

Hantush, Mahdi S., 1964, Hydraulics of wells: Advances in Hydroscience, v. 1, Academic Press, p. 281-432.

Jacob, C. E., 1946, Radial flow in a leaky artesian aquifer: Trans. A. Geophys. Union, v. 27, p. 198-205.

HYDROGEOLOGY OF THE MANDURAH – PINJARRA AREA

by D. P. Commander

ABSTRACT

Eighteen exploratory water bores were drilled in the Mandurah-Pinjarra area under Government drilling programmes between 1962 and 1969, and a further twenty-three were drilled for industry east of Pinjarra between 1969 and 1972. These bores have provided information on local stratigraphy, water quality, yield and movement. Two major geological formations are present in the area, the Lower Jurassic Cockleshell Gully Formation, and the Lower Cretaceous Warnbro Group. A threefold division of the latter correlates broadly with the Gage Sandstone, the South Perth Shale, and the Leederville Formation of the metropolitan area. The dip of those beds and the slope of the basal Cretaceous unconformity are generally westwards.

A deep sand-filled Quaternary channel, that cuts through the Leederville Formation, has been recognized in one bore and may have a considerable effect on local hydrology.

Variable quantities of potable water containing less than 1 000 ppm TDS have been located under much of the area, and large supplies of brackish water, from 2 000 to 4 000 ppm TDS, are also present. Generally better supplies and lower salinity waters are available in the east of the area.

One intake area has been found to the east of Pinjarra and another is believed to exist in the North Dandalup area. Water movement is in a general westerly direction from these intakes.

INTRODUCTION

The Mandurah-Pinjarra area is about 70 km south of Perth, on the low lying coastal plain. Farming is the dominant land use, and most of the land has been cleared for pasture. The alumina refinery east of Pinjarra is the only heavy industry.

Numerous shallow bores and wells are used by private landholders for domestic, stock and irrigation purposes, and a few deeper bores (to 150 m) have been drilled where larger supplies are required. Mandurah receives water from the Yunderup bores near Ravenswood, and groundwater is also utilised by the alumina refinery.

Until 1962 there was little information on the subsurface geology and hydrology of the area. The nearest deep bores were in the metropolitan area, until drilling by the Geological Survey between Byford and Rockingham commenced in 1961 (Berliat, 1964). Seismic surveys by West Australian Petroleum Pty. Ltd. culminated in the deep oil exploratory well Pinjarra No. 1 (Jones and Nicholls, 1966).

Exploratory drilling for town supply water was commenced in 1962 near the coast at Mandurah. Domestic quality water was first located near Ravenswood (Emmenegger, 1964) and by 1969 a total of eighteen bores had been drilled with an aggregate depth of nearly 4 000 m. These bores range in depth from 610 m (Mandurah No. 1 or M-1) to 96 m (M-15); eleven bores were cased for observation and the remaining seven abandoned.

Detailed correlations between the bores have been made on the basis of lithology, age (by palynology) and the gamma-ray logs. Water samples were collected and static water levels measured wherever possible and resistivity logs run in the rotary drilled holes. Nearly 100 water samples have been chemically analysed.

A further twenty-three deep bores (Pinjarra E-, O-, OW- and P- series) with an aggregate depth of over 5 000 m were drilled to the east of Pinjarra as part of a detailed study of the groundwater being used for the alumina refinery (Fig. 12).

PHYSIOGRAPHY AND CLIMATE

The Swan Coastal Plain has been divided into a number of geomorphic elements which parallel the present coastline (Woolnough, 1920; McArthur and Bettenay, 1960). The Ridge Hill Shelf forms a narrow belt up to 4 km wide at the base of the Darling Scarp and consists of leached and ferruginized beach sands of the Yoganup Formation and Ridge Hill Sandstone. The Pinjarra Plain west of the Ridge Hill Shelf is essentially flat lying, underlain by alluvial sands and clays of the Guildford Formation. To the west of, and overlying the Pinjarra Plain, are three sand dune systems; from east to west the Bassendean Sand, the Coastal Limestone and Safety Bay Sand. The Coastal Limestone is a leached and lithified calcarenite that forms a ridge up to 60 m high.

The average rainfall is about 800 mm per annum, falling mainly in the winter months, April to September. There is no surface drainage in the sand dune systems, but a number of lakes represent the water table. The soils of the Pinjarra Plain become waterlogged and swampy in the winter. The Murray River is the only major river in the area, having its headwaters in the Wheat Belt and an average salinity in excess of 2 000 ppm TDS. Three smaller freshwater rivers, the Serpentine, North and South Dandalup Rivers have their headwaters in the Darling Ranges, but have very low flows in the summer. Several small ephemeral streams drain the Darling Scarp, and all streams reach the sea through Peel Inlet which truncates the Coastal Limestone.

GEOLOGY

The Perth Basin is an elongated sedimentary trough 1 000 km long, bounded by the Darling Fault along the western edge of the Precambrian Shield. The Mandurah-Pinjarra area lies in the southern part of the basin where the thickness of Mesozoic sediments is in excess of 10 000 m.

There are no surface outcrops of Mesozoic sediments in the Mandurah-Pinjarra area as they are generally covered by Quaternary deposits. Early

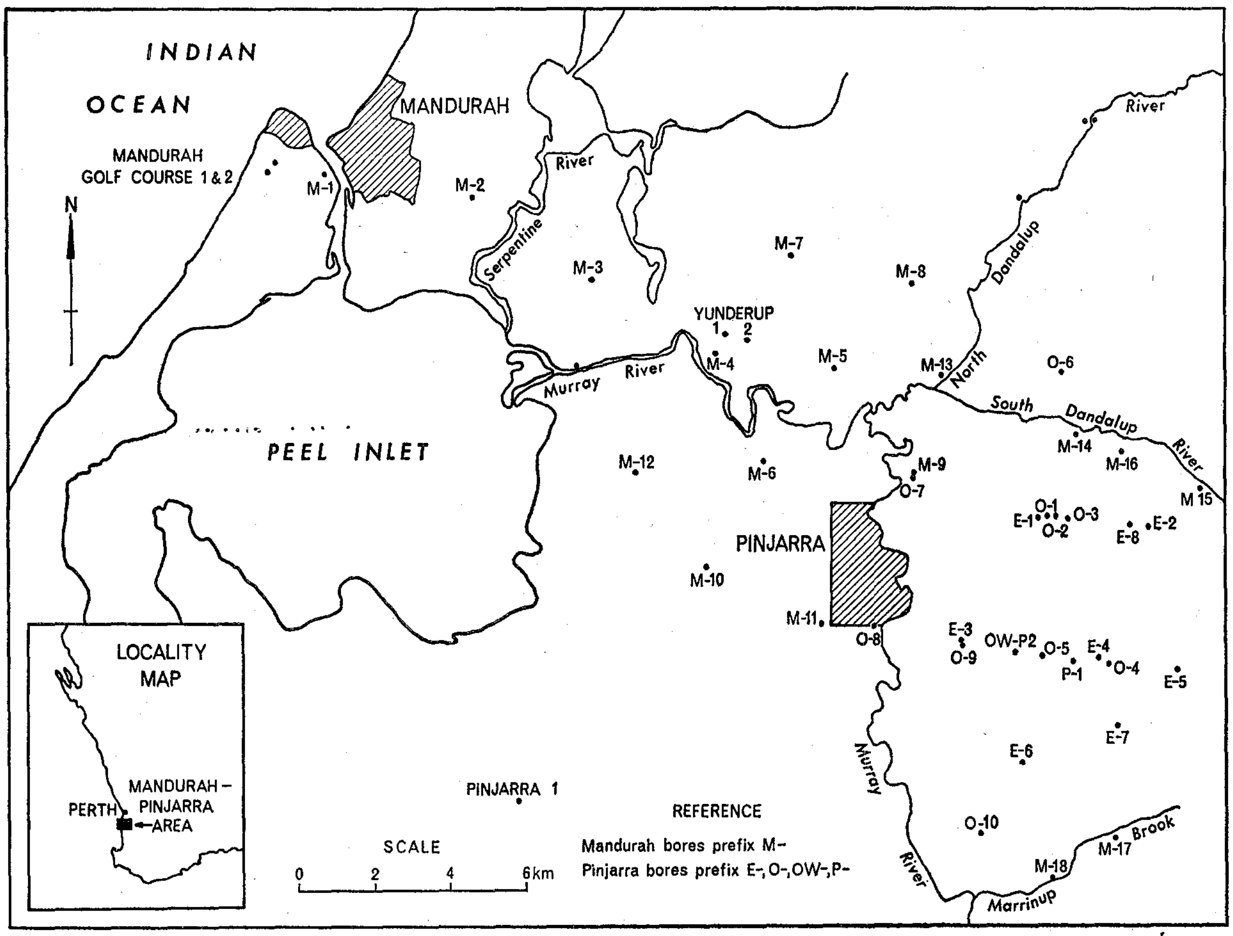

Figure 12. Mandurah–Pinjarra area—bore location map.

Cretaceous and early Jurassic sediments have been encountered in water bores, and Pinjarra No. 1 exploratory oil well bottomed in Triassic after penetrating 2 200 m of early Jurassic sediments. The intra-Neocomian unconformity cuts out the Upper Jurassic so that the Lower Cretaceous Warnbro Group lies directly on the Lower Jurassic Cockleshell Gully Formation. A simplified stratigraphic succession is given in Table 1.

TABLE 1. STRATIGRAPHY OF THE MANDURAH-PINJARRA AREA

Age	Group/Formation/Member
Quaternary	Safety Bay Sand Coastal Limestone Bassendean Sand Guildford Formation Yoganup Formation Ridge Hill Sandstone Un-named sand (deep channel filling)
UNCONFORMITY	
Lower Cretaceous	Warnbro Group: Leederville Formation South Perth Shale Gage Sandstone Member
UNCONFORMITY	
Lower Jurassic	Cockleshell Gully Formation
Middle to Upper Triassic	Lesueur Sandstone

Seismic surveys indicate substantial faulting in the Cockleshell Gully Formation and various dip directions. By contrast the Warnbro Group has a gentle westerly dip, although steeper dips occur near the Darling Fault where Lower Jurassic sediments are upfaulted.

The geology has been described by Lowry (1965), Low (1971) and Playford and others (in press).

COCKLESHELL GULLY FORMATION

Sediments of Lower Jurassic age encountered in the area are correlated with Cattamarra Coal Measures Member of the Cockleshell Gully Formation in the Northern Perth Basin.

The formation is an unconsolidated continental sand-shale succession, the sands being mostly well sorted coarse-grained quartz with minor feldspar and accessory garnet and pyrite. Thin coal seams are often present. The shale units vary from unlaminated siltstone-mudstones to fissile micaceous shales. The colour is usually dark grey, but near the unconformity there appears to be a weathered zone where mottled red-brown to yellow colours are common. The bedding is very well differentiated and the gamma-ray logs have a distinct character. The shale units do not exceed 50 m in thickness except in the upfaulted block adjacent to the Darling Fault where a shaley sequence over 150 m thick was encountered. The sand and shale units tend to be lens shaped and detailed correlations are not possible except in very closely spaced bores.

WARNBRO GROUP

The Warnbro Group can be subdivided into three distinct units on the basis of lithology, facies and age (Emmenegger, 1964). The lower unit is equivalent to the Gage Sandstone Member of the South Perth Shale, and the middle and upper units are equivalent to the rest of the South Perth Shale and the Leederville Formation respectively. The South Perth Shale equivalent has a different lithology to the type section in the metropolitan area.

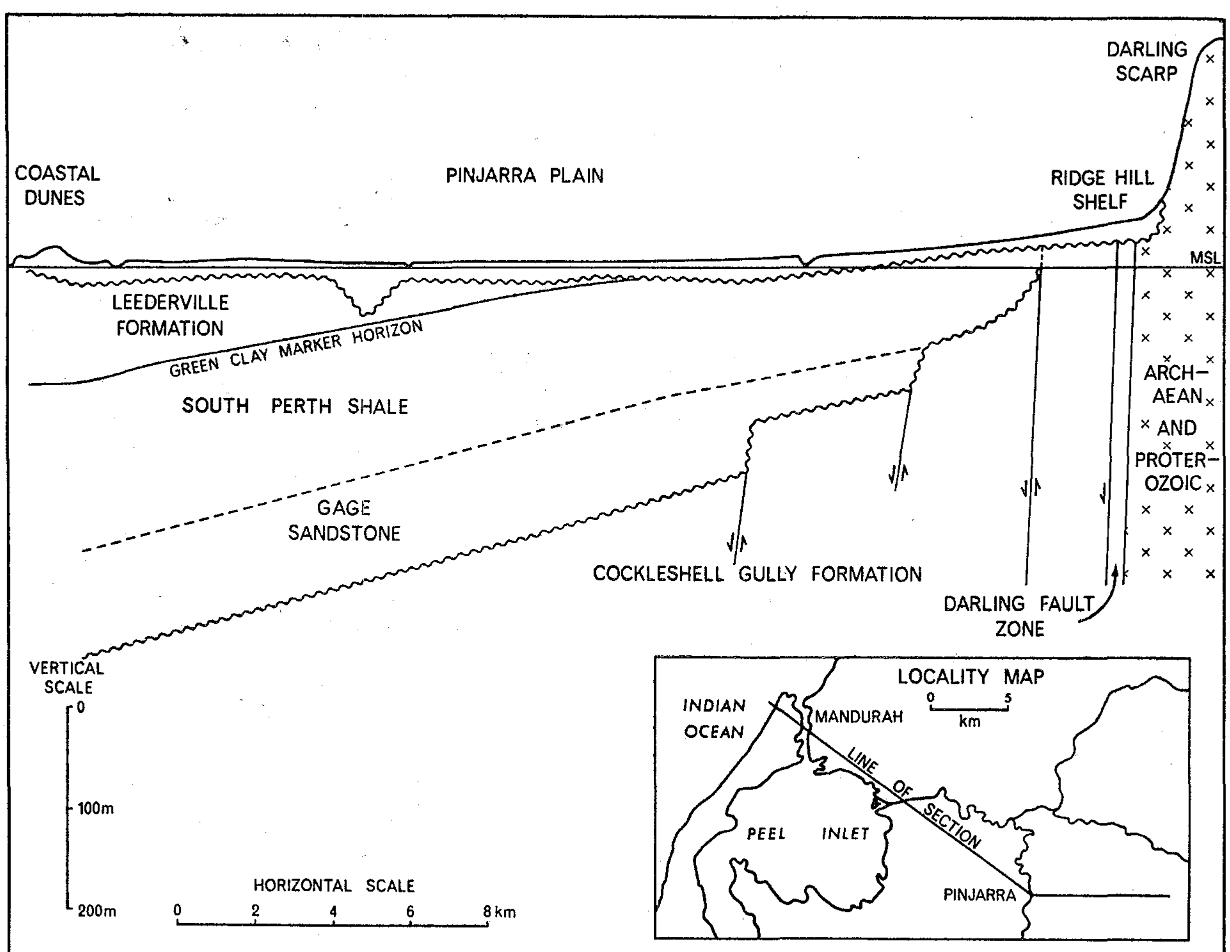

Figure 13. Mandurah-Pinjarra area—geological cross section.

Gage Sandstone

This is an alternating sand-shale succession, continental or near shore, very similar in lithology to the underlying Cockleshell Gully Formation. It is difficult to distinguish between the two on the gamma-ray logs. The age of the Gage Sandstone, however, is Neocomian, and it was deposited in depressions on an uneven surface eroded across Lower Jurassic sediments (Fig. 13). The thickness of the member varies from over 100 m at Mandurah to 40 m at Pinjarra, and it wedges out 3 km east of Pinjarra.

South Perth Shale equivalent

The South Perth Shale equivalent in the Mandurah-Pinjarra area is a succession of interbedded thin sands and silts, contrasting with the predominantly shaley type section in the metropolitan area. The thickness decreases from 170 m at the coast (M-1) to 140 m near Pinjarra. East of Pinjarra the top of the formation has been eroded and Quaternary sediments rest directly on it.

This formation can be further subdivided into a lower part, mainly siltstone, mudstone and minor sandstone, and an upper part characterised by a high concentration of calcareous material, shells, pebble beds (igneous rocks) and glauconite. The top of the formation is marked by a bright green glauconitic clay which is readily identifiable in boreholes. Individual beds are generally laterally continuous, although to the east of Pinjarra correlations are difficult.

The South Perth Shale was laid down in a predominantly marine environment with littoral intervals; beach sands were recorded at 160 m in Mandurah No. 5 bore.

Leederville Formation

The Leederville Formation occurs mainly west of Pinjarra and has been eroded to the east. The thickest section was encountered in the most westerly bore at Mandurah Golf Course, where the thickness is 117 m. The lithology is a sequence of interbedded siltstones, shales and sandstones which are grey, dark grey to brown in colour. The bedding is well differentiated in M-2 but becomes more silty in M-1; individual beds can be correlated between the two bores. In M-3 the whole section of the Leederville Formation has been eroded by a deep Quaternary channel.

QUATERNARY

Sediments of Quaternary age lie unconformably on the Warnbro Group and directly on the early Jurassic and Precambrian rocks in the extreme east. These deposits are colluvium, alluvium, littoral and eolian sands, the lithology and relationship of which have been described in Low (1971) and Morgan (1969). Mandurah No. 3 bore encountered an exceptional thickness of Quaternary sediments to a depth of 65 m below sea level (Emmenegger, 1964). These coarse well sorted sands probably represent an infilling of a river channel cut during a period of very low sea level.

HYDROGEOLOGY

EASTERN FAULT BLOCK

The narrow fault block of Lower Jurassic sediments immediately west of the Darling Fault (Fig. 13) appears to be a very shaley part of the Cockleshell Gully Formation, and no aquifers of appreciable extent were encountered in Mandurah 15 and Pinjarra E-2. The water in these bores is unconfined, and the potentiometric head declines with depth. The water level in M-15 is about 19.5 m above sea level, with a seasonal range of 1 m, and in E-2 the water level is 18 m. M-15 is slotted from 15 m above to 55 m below sea level and E-2 is screened at a depth of 100-130 m below sea level.

The western faulted boundary acts as a hydraulic barrier, and the potentiometric surface on the west side of the fault is more than 7 m higher (Fig. 14). This contrast in potentiometric levels is associated with a complementary salinity contrast as water in M-15 and E-2 has 2 400-4 000 ppm TDS while in E-8, to the west of the fault, it is only 420 ppm TDS.

Water movement within this fault block is probably very slow, the salinity is fairly high, and only small supplies are available from the limited aquifers. E-5 was drilled to a depth of 148 m and did not encounter any productive aquifers. Further details are given in Commander (in prep.)

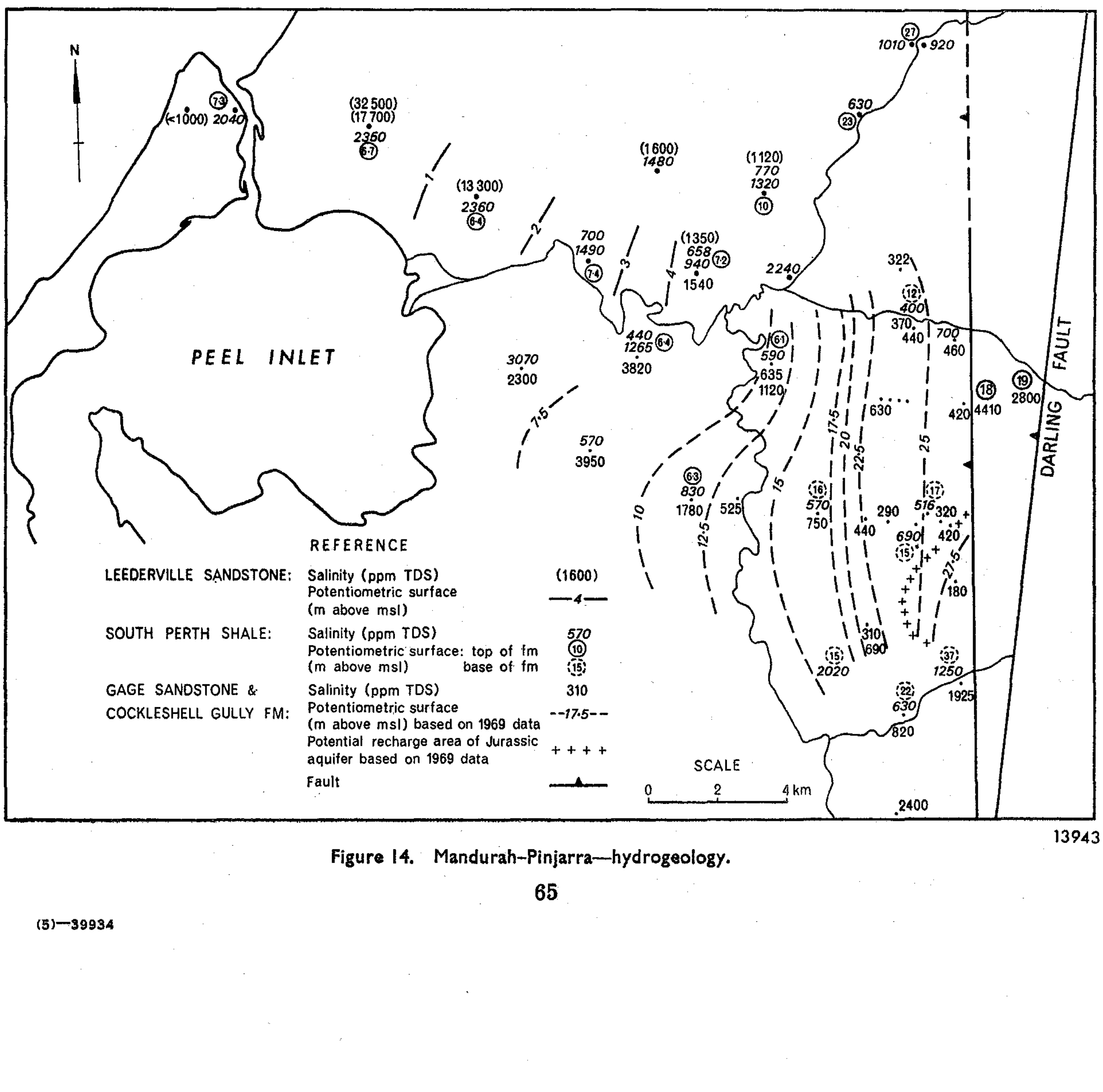

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Figure 14. Mandurah-Pinjarra—hydrogeology.

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COCKLESHELL GULLY FORMATION AND GAGE SANDSTONE

The similarity of lithology in both the Cockleshell Gully Formation and the Gage Sandstone is reflected in a similarity in hydrological characteristics.

An intake area to these aquifers has been identified around Pinjarra E-7 where the potentiometric surface in the Cockleshell Gully aquifers is 27 m above sea level (Fig. 14) and 8 to 13 m lower than the water table. The salinity of less than 200 ppm TDS in E-7 is the lowest encountered in any of the Mesozoic aquifers in the Mandurah-Pinjarra area. Movement of water takes place from E-7 in a westerly direction. The salinity increases with increasing distance from the recharge area, becoming 500 ppm just east of Pinjarra and climbing steeply to 3 950 ppm in M-10 4 km west of Pinjarra. Over a large area the potentiometric surface is above ground; M-14 has an artesian head of 11 m. A region of steep groundwater gradients exists at the eastern margin of the Gage Sandstone.

In all the bores, except E-7 and E-6, the potentiometric head increases with depth and gradients of 1 m per 10 m depth are maintained across the shale units. The salinity also tends to increase with depth and in general the best quality water is encountered at the top of the formation, just below the unconformity.

The amount of fresh water, less than 500 ppm, is large in the aquifers to the east of Pinjarra, and individual bores are capable of producing 4 000 m^3 per day. However, the amount of recharge to the Mesozoic aquifers each year from rainfall is small compared with the total amount of water in storage. Forth (1974) discussed the recharge to these aquifers.

SOUTH PERTH SHALE

The sand beds in the South Perth Shale are fairly thin compared with the Cockleshell Gully and Gage Sandstone aquifers, and are interbedded with silts and shales. These thin sand beds, however, are laterally continuous and are the most important sources of underground water for domestic and farm purposes.

The potentiometric head increases with depth and a head difference of 4 m between the top and the bottom of the formation was encountered in M-9. Aquifers in the formation are confined by the green clay and other shale beds immediately below. The salinity increases westwards and is highly variable with depth. Water of less than 1 000 ppm TDS is generally available east of M-8, M-4 and M-10, and probably the cleaner the sands the better quality. In M-5 there is a sharp increase in salinity at the contact with the Gage Sandstone, the quality deteriorating from 1 200 ppm to 3 500 ppm TDS over a depth of 15 m.

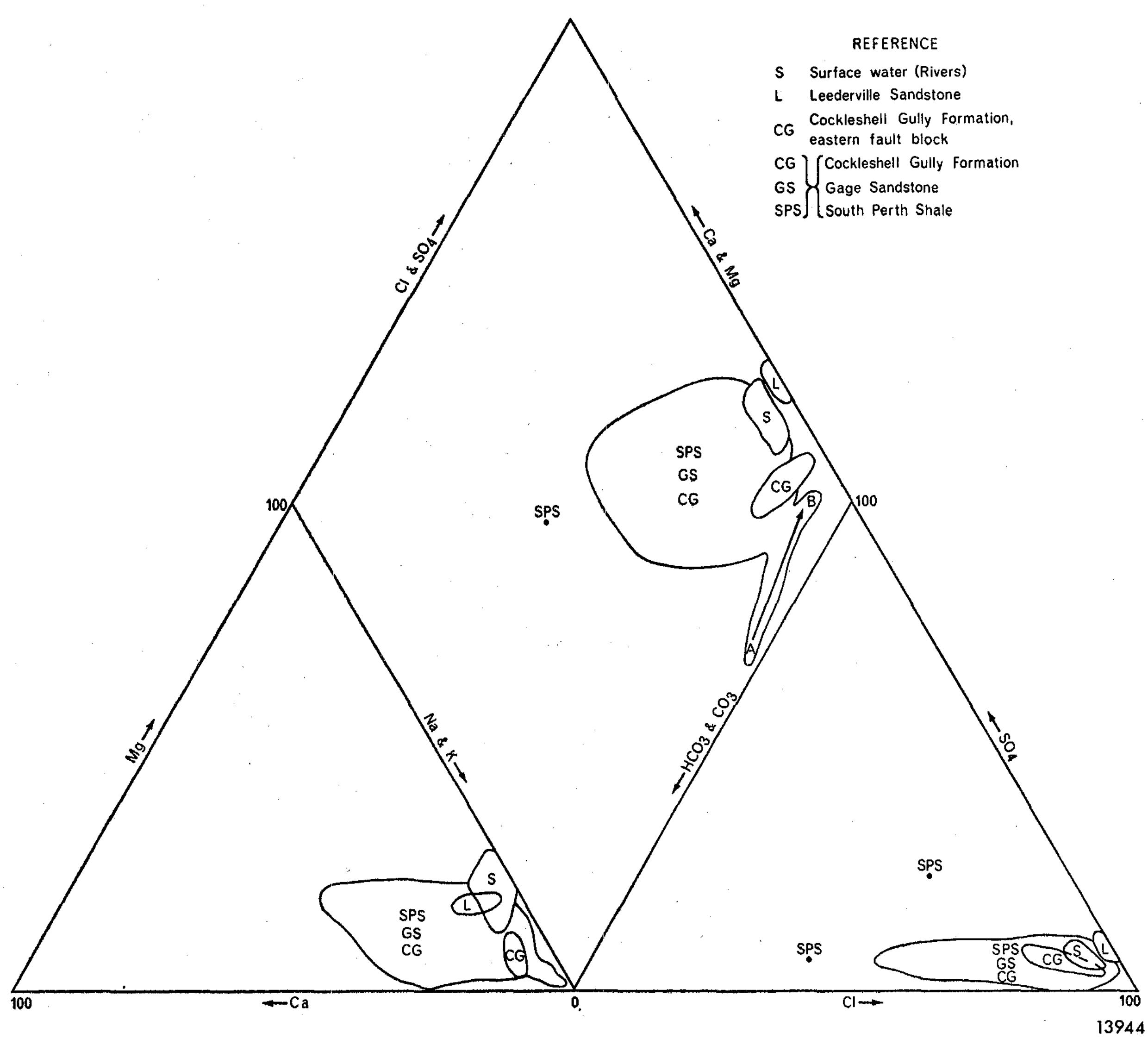

Figure 15. Trilinear plot of chemical analyses,f rom the Mandurah–Pinjarra area.

Recharge to these aquifers takes place in the North Dandalup district, where the potentiometric surface is over 25 m above sea level, and also by upward movement from the Cockleshell Gully Formation east of Pinjarra. Groundwater gradients in these districts are as steep as 5×10^{-3}, but west of Pinjarra the gradient is very slight, the potentiometric levels for the top of the formation in both M-5 and M-1 being just over 7 m above sea level although they are 14 km apart.

LEEDERVILLE FORMATION

The Leederville Formation has not been thoroughly explored in the Mandurah area. The thick sand units form good aquifers but the salinity is very variable. At the coast, water of 1 200 ppm TDS has been obtained from the Mandurah Golf Course borehole No. 2. Farther inland at Mandurah No. 2 the water quality obtained was 17 000-32 000 ppm; this was probably due to the Quaternary channel in M-3 which also contains saline water. The extent of this saline water intrusion is not known. The potentiometric surface falls from 4 m at M-5 to near sea level at M-2, the gradient being in the region of 5×10^{-4}. Data collected from M-2 indicate that the potentiometric head declines with depth. Recharge probably takes place directly from the water table, and inflow to the Leederville Formation aquifers can occur both from the Quaternary channel and upwards from the South Perth Shale, especially if the Quaternary channel cuts through the green clay aquiclude at any point.

QUATERNARY

Small supplies of fresh water are generally available from the dune sands and coastal limestone (Morgan, 1969). Shallow groundwater near Peel Inlet and the Serpentine River is probably brackish or saline. The Quaternary channel which contains saline water at M-3 may contain fresher water inland. Further exploration would be necessary to determine the course of this channel.

HYDROCHEMISTRY

Over ninety chemical analyses have been made on bore waters and surface waters in the area, and percentages of the main ions present are plotted on a trilinear diagram (Fig. 15). These have been grouped together in the same aquifer classes described above.

All waters are predominantly sodium chloride, with lesser amounts of calcium, magnesium, potassium, sulphate and bicarbonate ions being present. Minor amounts of nitrate were found in M-10 and O-5, but only in an analysis from M-10 was any significant quantity present (51 ppm).

The trend shown from A to B on Figure 15 represents the changes in composition from analyses lower down in E-3 and E-6 through M-11 to M-10 and M-12. This difference in composition from the aquifers higher up in E-3 and E-6 and in the other bores in the Cockleshell Gully Formation probably indicates a different flow regime and recharge area. Also water from these bores has a significantly lower hardness than water of the same TDS content in the rest of the Cockleshell Gully Formation aquifers.

Water analyses from the upper part of the South Perth Shale show higher calcium/magnesium to sodium ratios than those from the lower part; this probably reflects the more calcareous nature of the upper part of the formation.

The analyses of saline water from the Leederville Formation and the Quaternary channel have a similar composition to that of sea water indicating a connection with the sea.

CONCLUSION

Four major groups of aquifers exist in the Mandurah-Pinjarra area. The narrow fault block of Lower Jurassic rocks adjacent to the Darling Fault contains limited aquifers with a water quality in excess of 2 400 ppm TDS.

The thick sands of the Cockleshell Gully Formation, just to the west of the fault block, contain a large quantity of pressure water, less than 500 ppm TDS, with an artesian head of up to 11 m. West of Pinjarra the quality of water in the Cockleshell Gully Formation and Gage Sandstone deteriorates to over 2 000 ppm TDS.

The South Perth Shale consists of thin aquifers which contain fresh water (less than 1 000 ppm) over most of the area, and is the major supplier for domestic, farm, and town supply purposes. The top of the South Perth Shale can be recognized by the green clay bed, and bores drilled below this are often artesian.

The Leederville Formation aquifers have not yet been fully explored, and so far only water of over 1 000 ppm TDS has been located. A region of saline water intrusion into the Leederville Formation is associated with the Quaternary channel.

REFERENCES

Berliat, K., 1964, Report on exploratory drilling for underground water in the Perth Basin west of Byford: West. Australia Geol. Survey Ann. Rept., 1963, p. 9-14.

Commander, D. P., in prep., Hydrogeology of the Mandurah-Pinjarra area: West. Australia Geol. Survey Rec.

Emmenegger, C., 1964, Report on exploratory drilling for underground water at Mandurah-Perth Basin, W.A.: West. Australia Geol. Survey Rec. 1964/15 (unpublished).

Forth, J. R., 1974, Recharge to the Jurassic Aquifer of Pinjarra: West. Australia Geol. Survey Ann. Rept., 1973, p. 14-20.

Jones, D. K., and Nicholls, J., 1966, Pinjarra No. 1 Well completion report: West Australian Petroleum Pty. Ltd., P.S.S.A. Rept. 65/4176 (unpublished).

Low, G. H., 1971, Explanatory notes on the Phanerozoic rocks of the Pinjarra 1 : 250 000 Geological Sheet, Western Australia: West. Australia Geol. Survey Rec. 1971/25 (unpublished).

Lowry, D. C., 1965, Geology of the Southern Perth Basin: West. Australian Geol. Survey Rec., 1965/17 (unpublished).

McArthur, W. M., and Bettenay, E., 1960, The development and distribution of the soils of the Swan Coastal Plain, W.A.: C.S.I.R.O. Soil Publication No. 16.

Morgan, K. H., 1969, Hydrogeology of the Swan Coastal Plain, Kwinana-Pinjarra area: West. Australia Geol. Survey Rec. 1969/11 (unpublished).

Playford, P. E., Cope, R. N., Low, G. H., Lowry, D. C., and Cockbain, A. E., in press, Phanerozoic: *in* Geology of Western Australia: West. Australia Geol. Survey Mem. No. 2.

Piper, A. M., 1944, A graphic procedure in the geochemical interpretation of water analyses: Am. Geophys. Union. Trans., v. 25, p. 914-23.

Woolnough, W. C., 1920, The Physiographic elements of the Swan Coastal Plain: Royal Soc. West. Australia Jour. and Proc. v. 5, p. 15-20.

WEATHERING PROFILE OF GRANITIC ROCKS IN THE BORROW AREA OF THE PROPOSED LOWER WUNGONG DAM

by G. W. Marcos

ABSTRACT

Granitic rocks at Lower Wungong are leucocratic, medium-grained gneissic tonalities and granodiorites, probably of igneous origin. Their weathering profile is more than 17 m thick, mostly represented by laterites and a completely weathered kaolin horizon. This represents an advanced stage of weathering. Local deviations which are common both in sequence and thickness, can be attributed to geomorphological history, geological structures, underground water movements and dykes acting as barriers. The weathering profile mostly represents zones I, IIa and IIb of Ruxton and Berry (1957) grades VI and V of Little (1969), zones IVa and IVb of Chandler (1969), or grades VI and V of Fookes and Horswill (1969). The weathering profile follows the normal sequence for granitic terrain, and the kaolin horizon can be subdivided into upper, middle and lower divisions.

INTRODUCTION

More than 120 hollow augerholes were drilled and sampled in the proposed borrow area at Lower Wungong (Fig. 16). Samples were taken at 3 m intervals for soil testing. Soil samples from 81 holes were examined to (1) differentiate soils derived from granitic rocks from those derived from dolerite dykes, (2) determine the general weathering sequence of each rock type present in the area, and the vertical distribution in each hole thus enabling an approximate volume distribution to be made, (3) correlate between each soil type and its engineering behaviour. The latter data are to be used for embankment soil zoning, if needed.

The results of (1) confirmed the presence of dolerite dykes previously mapped (Fig. 16), and helped in their delineation. The results of (2) showed that the granitic weathering profile is represented by an old profile where the laterite and kaolin horizons are well developed, while the highly and moderately weathered horizons are rather thin. Table 2 could be regarded as an approximate volume percentage distribution of horizons in the granitic weathering profile.

TABLE 2. PERCENTAGE DISTRIBUTION OF HORIZONS IN THE GRANITIC WEATHERING PROFILE.

(Excludes massive laterite and shear zones)

Horizon	Percentage of weathered granitic profile	Horizon subdivisions	Percentage distribution of horizons
Laterite	17·5	gravel massive pisolitic gibbsitic	40·5 excluded 15·5 44·0
Completely weathered	69·5	upper kaolin middle kaolin lower kaolin	50 16 34
Highly weathered	13·0		

The results of (3) demonstrated lithological and mineralogical differences in the upper and lower parts of the kaolin horizon with a middle transitional division. Many differences are reflected in the corresponding engineering properties given in Table 3.

WEATHERING PROFILE

I. LATERITE

The laterite horizon can be subdivided into:

(a) Gravelly
(b) Massive
(c) Pisolitic
(d) Gibbsitic

(a) *Gravelly laterite* consists of ferruginous gravels in a sand, silt and clay matrix, and when transportation has occurred, it also contains humus. It is *in situ* on high ground, from which it has been transported to the depressions. The dry material is firm and crumbles under pressure, but in the wet state it is friable. It has poor to moderate grading, high permeability and a high dry density. As the gravelly laterite is essentially a transported soil in the borrow area, it has unpredictable variable and sometime undesirable engineering properties for use as embankment borrow material.

(b) *Massive laterite* occupies high ground on both sides of the Wungong river and at the top and east side of the "island". It is composed of well cemented ferruginous nodules and concentrations, that are subangular at the base and rounded on top. The cement is mostly siliceous ferruginous gibbsitic clay. Jointing is poor and excavation normally involves the use of explosives. Its dry density is high.

(c) *Pisolitic laterite* is composed mostly of plastic gibbsitic clay and silt, with lenticular ferruginous concretions. Quartz is present only as an accessory. The *in situ* material is friable when slightly moist, but the dry material is firm and strong. Normally it has a high plasticity index although instances of moderate plasticity may occur. It is slightly permeable *in situ* but when compacted is impervious. The dry density is moderate. The main Unified Soil Classifications (Earth Manual U.S.B.R.) to be expected are CH and MH, also CI and MI to a lesser extent.

(d) *Gibbsitic laterite in situ* is granular or silty. Quartz grains are rare, and if present are mostly medum or fine grained. *In situ* it has a moderate to high void ratio and fair permeability, but when compacted is impermeable. The dry density is moderate, and the U.S.C. laboratory classifications to be expected are mostly CH, CI and MH.

II. COMPLETELY WEATHERED GRANITIC ROCKS

These are represented by the kaolin horizon, the three divisions being established on the basis of clay, silt and platy-micaceous mineral content. The last is of an indefinite mineralogy. It is possibly kaolinite and illite, and has been derived from the decomposition of feldspars.

(a) *Upper kaolin* is mainly clay and silt in the finer than –200 B.S. sieve fraction, but the clay size is predominant, while platy-micaceous minerals are rare. X-ray diffraction patterns show that the silt clay fraction is mainly kaolin (85 per cent); illite and montmorillonite being accessories (5 per cent). Electron micrographs show that kaolin is mostly kaolinite plates covered with halloysite in a flocculated state (Fig. 17 A, B).

In situ permeability is low and after compaction the material is impermeable. Its dry density is moderate. U.S.C. classifications to be expected are CH, MH, CI and MI.

(b) *Middle kaolin* represents a transitional stage between the upper and lower divisions. The ratio of clay to larger sized material decreases with depth, while the proportion of silt and platy-micaceous minerals increases. X-ray diffraction patterns are not yet available, but electron micrographs show that the material is mostly kaolinite and halloysite (Fig. 17C,D). Halloysite tubes are

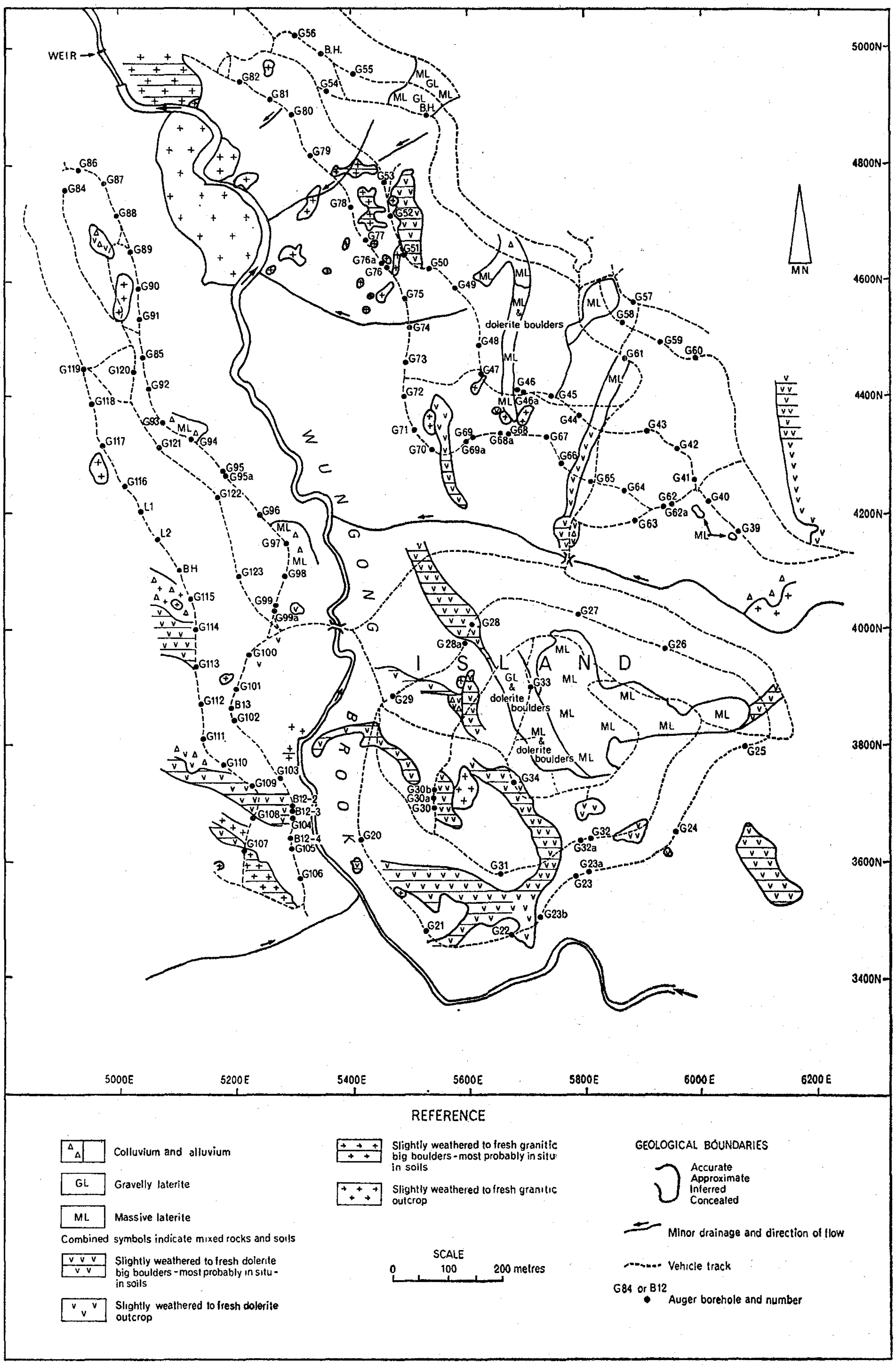

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Figure 16. Lower Wungong proposed dam site, geological map and borehole locations.

less abundant than in the upper kaolin. Kaolinite is well ordered having angular to subangular plates with occasional slight bending at the edges and a fairly open structure. Illite is present as elongated books with angular edges. U.S.C. classes to be expected are MH, CH and MI in the upper part, and MI, CI and SF_{silty} in the lower parts. *In situ* permeability is generally low except in the SF_{silty} and ML classes.

(c) *Lower kaolin* is a silty sand (of quartz and partially decomposed feldspars) with a moderate to low clay content and abundant platy-micaceous minerals. X-ray diffraction patterns show that the silt-clay fraction is predominently kaolin (85 per cent) illite (10 per cent) and montmorillonite ($\leqslant 5$ per cent). Electron micrographs show that the kaolin is predominently kaolinite plates covered with halloysite tubes ranging from perfect to distorted cylinders (Fig. 17 E, F).

In both middle and lower kaolin divisions another unidentified mineral appears as cylinders composed of rounded plates (which could be tubes) with basal cleavage (Fig. 17D). The rounded plates are linked together on the outside by lateral elongated tube-like crystals. Electron micrographs also show that samples rich in iron oxides have a lesser percentage of halloysite than samples which are deficient in iron oxides.

The *in situ* permeability of this division is greater than in the upper or middle kaolin, but low permeability values are expected after compaction except in soils of low plasticity, e.g. SF_{silty}. The dry density is moderate.

Because of the abundance of platy-micaceous minerals in the lower kaolin, compacting methods should be carefully selected. This will avoid stratified fill of low strength. Laboratory U.S.C. classes to be expected are MI, MH and SF_{silty}.

III. *HIGHLY WEATHERED GRANITIC ROCKS*

Below the completely weathered rock is a thin highly weathered horizon of gritty clay and/or silty sands, quartz, and partially decomposed feldspar. In places it can be more than 5 m thick, but is usually one metre or less. There are partially decomposed micas in proportion to that of the parent rock.

Although it is harder than the kaolin horizon, it can be easily excavated by light equipment. *In situ* permeability is high to moderate, and varies considerably when compacted depending on the silt and clay content. Low liquid limits and plasticity are common, and high values are rare. Laboratory U.S.C. classes to be expected are MI in the upper sections and ML or SF_{silty} in the lower section.

LIQUID LIMIT VALUES

TABLE 3. PERCENTAGE DISTRIBUTION OF LIQUID LIMITS AND LINEAR SHRINKAGE IN EACH HORIZON.

Horizon	Sub-division	Percentage of total sample	L.L. Category	Percentage distribution of L.S. <5	5–9	9–10	>10
		36	<50	20	20	20	40
	Gravel	50	50–70	0	0	14	86
		14	>70	0	0	0	100
		43	<50	0	33	67	0
	Pisolitic	28·5	50–70	0	0	0	100
		28·5	>70	0	50	0	50
Laterite		44	<50	0	28	44	28
	Gibbsitic	25	50–70	0	0	25	75
		31	>70	0	0	0	100
	Upper Kaolin	32	<50	20	70	0	10
		43	50–70	0	20	36	44
		25	>70	0	8	25	67
Completely Weathered	Middle Kaolin	19	<50	20	60	0	20
		73	50–70	5	45	40	10
		8	>70	0	0	0	100
	Lower Kaolin	58	<50	8·5	80	8·5	3
		32	50–70	0	53	16	31
		10	>70	0	0	25	75
Highly Weathered		66	<50	37	49	14	0
		25	50–70	16	17	17	50
		9	>70	0	50	50	0

When liquid limits (L.L.) of the different soils of the weathered profile are grouped into three categories namely < 50, 50-70, and > 70 (Table 3), the following is apparent.

The first category (L.L. < 50), is occasionally found in soils overlying the kaolin horizon in locations where soils are believed to be transported, and in shallow laterites containing subordinate amounts of small pisolites. It is mainly found in soils (i) which are excessively silty with or without small amounts of clay, (ii) containing an appreciable to high amount of platy-micaceous minerals, (iii) of excessively high fine-grained sand content with little silt-clay size fraction.

Soils (i) and (ii) are well represented in the lower kaolin division as well as in the soils derived from sheared granitic rocks, while (iii) is well represented in the highly weathered horizon.

The second category (L.L. 50-70) is moderately represented in the laterite horizon. It is also mainly found in soils containing a high to intermediate percentage of clay and low to moderate silt and fine-grained sand with little or no platy-micaceous mineral content. The category is represented in both upper and middle kaolin divisions.

The third category (L.L. > 70) represents a moderate percentage of the soils in the laterite horizon and upper kaolin division, but a low percentage of those of middle and lower kaolin division and the highly weathered horizon.

LINEAR SHRINKAGE VALUES

Linear shrinkage (L.S.) values of more than 10 (Table 3) are well represented in soils of L.L. third category (> 70), and in the top 3 m of the weathered profile in some of the soils above the kaolin horizon which are of doubtful origin. These values are also found in weathered structurally weak zones, e.g. shear zones and in shallow permeable soils affected by leaching and precipitation.

In general the main two factors influencing L.S. values in the soils of the area are the silt-clay percentage, and the mineralogical composition of silty-clay fraction, particularly the montmorillonite percentage.

OBSERVATIONS FROM PLASTICITY CHART

The Casagrande plasticity classification chart shows that Id soils lie above the A-line, and that the IIa soils are nearly equally distributed both above and below the A-line. Further IIc soils lie below the A-line and have a lower plasticity index than the Id and IIa. Soils of II, having a negligible or very low content retained on the –200 B.S. mesh lie below the A-line (Fig. 18).

The mineralogical composition of the passing –200 B.S. mesh, particularly montmorillonite and halloysite species, influences the sample's location in the plasticity chart.

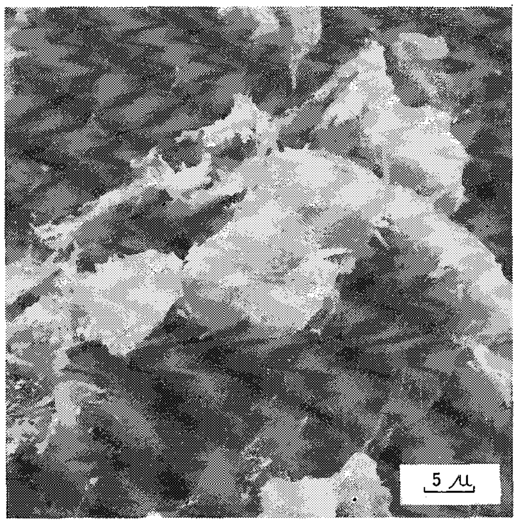
Figure 17 (opposite)

Electron micrographs of granitic soils.

A and B Augerhole G58 at 3 m depth. Brown-yellow mottled white, damp, cleaved silty clay; upper kaolin of kaolin horizon. Kaolinite domains covered with halloysite tubes.

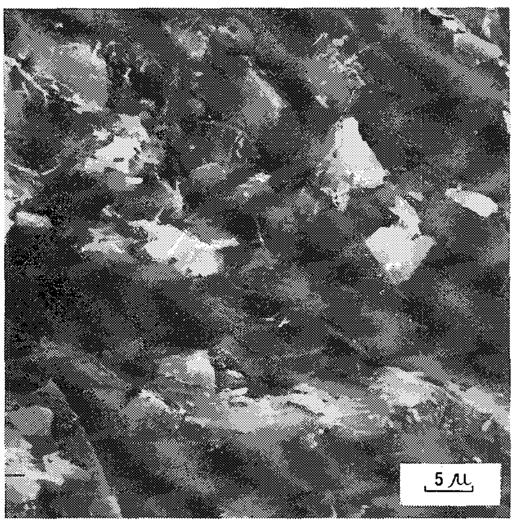
C and D Augerhole G58 at 6 m depth. White with brown-orange stains on cleavage planes, slightly micaceous, damp, silty clay; middle kaolin of kaolin horizon. View on cleavage, mostly kaolinite covered with halloysite tubes.

E and F Augerhole G44 at 10 m depth. Brown, wet, coarse micaceous sandy silt; lower kaolin of kaolin horizon. Kaolinite plates (K), mica laths (M), and a few halloysite tubes (H).



A

B



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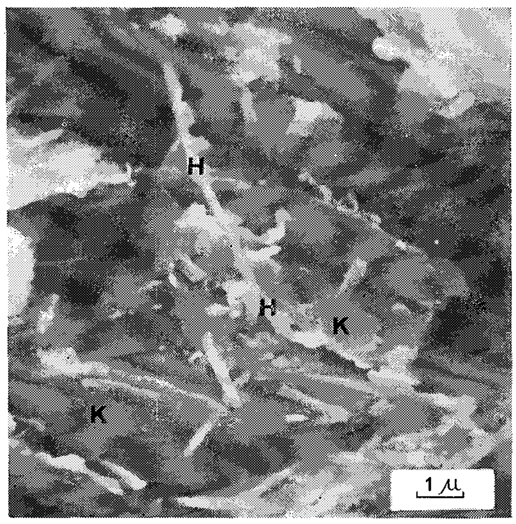
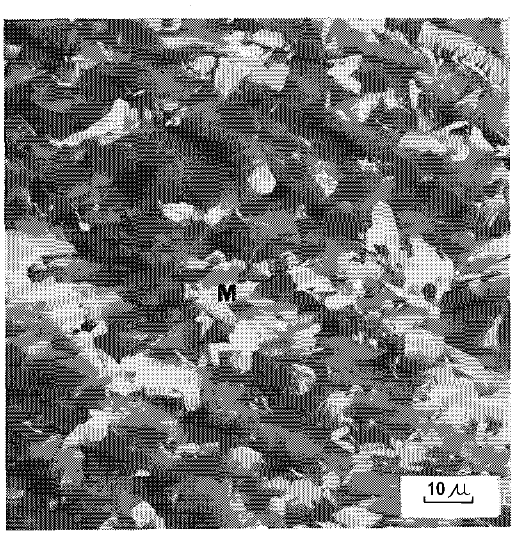


D



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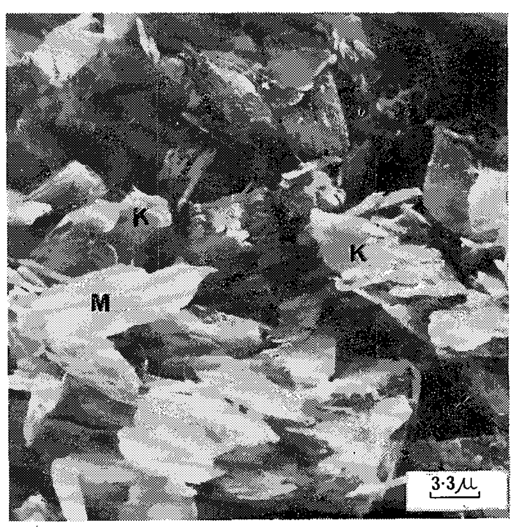

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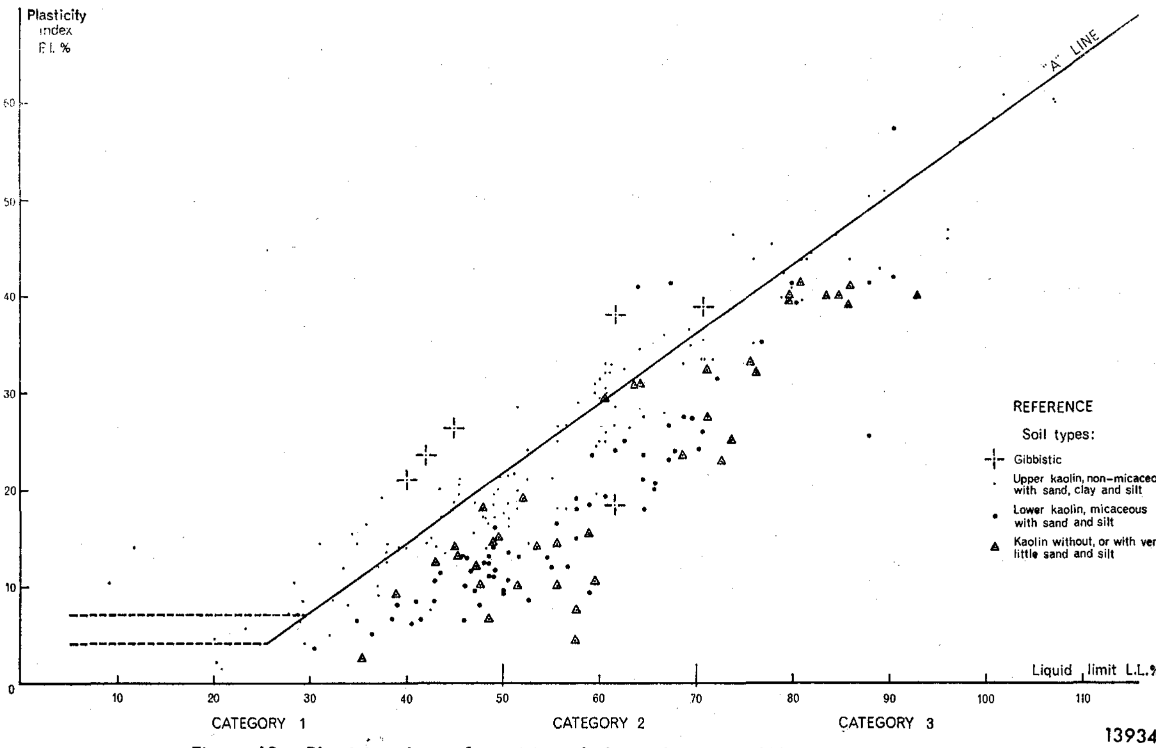

Figure 18. Plasticity chart of granitic soils from the Lower Wungong borrow area.

CONCLUSIONS

The weathering profile in the borrow area has reached an advanced stage of development.

Deviations from both sequence and thickness are common. These can be attributed to geomorphological history, geological structures, underground water movements and dykes acting as barriers to such movement.

The completely weathered granitic rocks are represented mainly by the kaolin horizon, which has been subdivided into upper, middle and lower divisions based on clay, silt and indeterminate platy-micaceous minerals.

The X-ray diffraction results for the kaolin horizon showed that: (i) kaolin is the main constituent, while illite and montmorillonite are subordinate; (ii) illite percentage increases from upper to lower kaolin divisions.

The scanning electron microscope results for the kaolin horizon showed that: (i) kaolin is mainly kaolinite plates covered with halloysite tubes (the latter is well represented in the lower kaolin division and least represented in the middle kaolin division); (ii) illite percentage increases from upper to lower kaolin divisions; (iii) the soil is characterized by a fluocculated bookhouse microstructure; (iv) there are marked variations in individual mineral sizes and shapes, as well as in the degree of packing within domains.

There is some relationship between the engineering properties of soils and their position in the weathering profile. This in turn could be related to similarities in mineralogical composition.

ACKNOWLEDGEMENTS

The author is grateful to the Metropolitan Water Board for facilities granted and for permission to publish information about soil testing in this report. The Civil Engineering Department, University of W.A. kindly supplied the electron micrographs of Figure 17.

REFERENCES

Casagrande, A., 1948, Classification and identification of soils: Proc. Am. Soc. Civil Engrs. 133 p. 783-810.

Chandler, R. J., 1969, The effect of weathering on the shear strength properties of Keuper Marl: Geotechinque, v. 19 pt. 3, p. 321-334.

Earth Manual; U.S.A. 1968, Dep. of Interior, Bureau of Reclamation, Denver, Colorado.

Fookes, P. G. and Horswill, P., 1969, Discussion on engineering grade zones; Proc. Conf. In Situ Testing Soils and Rocks: Inst Civ. Eng., London 1969, p. 53-57.

Little, A. L., 1969, The engineering classification of residual tropical soils: Proc. International Conf. Soil Mech. Found Eng. 7th, Mexico, 1, p. 1-10.

Ruxton, B. P., and Berry, L., 1957, Weathering of granite and associated erosional features in Hong Kong: Bull. Geol. Soc. Am. 68, p. 1263.

PETROLEUM EXPLORATION IN WESTERN AUSTRALIA IN 1973

by G. H. Low

ABSTRACT

The tempo of oil exploration activity in Western Australia showed a marked decline during 1973 compared to the previous year. The number of test wells completed was 30 per cent less, and land seismic and marine seismic activity was 46 per cent and 65 per cent respectively less than the 1972 figure.

Drilling activity was largely confined to the northern Carnarvon, Canning and Browse Basins. The B.O.C. group successfully tested extensions to the Angel and Goodwyn fields and discovered gas, condensate, and oil in the Dockrell structure, and oil in the Egret structure. West Australian Petroleum Pty. Ltd.'s West Tryal Rocks No. 1 well found significant gas and condensate-bearing sands and has been suspended pending further tests, while the Company's Barrow Deep No. 1 is classified as a gas well.

Twenty-two wells were completed during the year and three were drilling at 31st December for a total of 63 612 m. Geophysical activity consisted

of marine seismic, in some cases with associated gravity and magnetic work, in the Perth, Carnarvon, Canning, Browse and Bonaparte Gulf Basins, land seismic in the Perth, Carnarvon, Canning and Eucla Basins, and land gravity in the Perth and Eucla Basins.

During the year several onshore tenements were relinquished in the Carnarvon and Canning Basins, and offshore tenements were relinquished in the Bremer and Eucla Basins.

INTRODUCTION

Petroleum exploration activity in Western Australia showed a marked downward trend in 1973 compared with 1972. Exploratory drilling over the past two years is shown in the following tabulation:

	Wells completed		Wells drilling on 31st December	
	1972	1973	1972	1973
New field wildcat wells	22	16	4	2
Extension test wells	6	3	1	....
Deeper pool test wells	0	1	1	....
Stratigraphic wells	16	2	0	1

Total drilling : 1972—102 876m
1973—63 612m

Three of the 1973 new-field wildcat wells are regarded as successful tests and have been suspended. West Tryal Rocks No. 1 is classified as a gas/condensate discovery, Dockrell No. 1 is a gas/condensate/oil discovery, and Egret No. 1 is an oil discovery. Successful extension tests of fields discovered earlier were made in Angel No. 3, and Goodwyn No. 3 and No. 4. The deeper pool test Barrow Deep No. 1 is classified as a suspended gas well.

Test figures for gas given in the text are quoted in thousands of cubic metres per day ($x\,10^3\,m^3/d$). Oil and condensate test figures are quoted in barrels per day (b/d).

Geophysical survey and surface geological survey activity also declined compared with 1972. The totals for 1973 are as follows (with the 1972 figures in brackets):

Type of Survey	Line Km		Party months or Geologist months	
Land seismic	1 776	(3 266)	—	
Marine seismic	14 904	(43 218)	—	
Gravity (land)	—		7·0	(10·5)
Gravity (ship-board)	3	(4 362)	—	
Aeromagnetic	—	(26 445)	—	
Magnetic (ship-board)	1 117	(5 019)	—	
Geological	—		3·5	(13·0)

PETROLEUM TENEMENTS

During the year offshore tenements in the Bremer and Eucla Basins and onshore tenements in the southwestern Canning Basin and in the Carnarvon Basin were surrendered. Large areas in the sedimentary basins are currently available for application.

Petroleum tenements current on December 31st 1973 are shown in Figure 21, 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	364	14-11-74	Woodside Oil N.L., Shell Development (Aust.) Pty. Ltd., B.O.C. of Australia Ltd.
WA- 2-P	381	14-11-74	West Australian Petroleum Pty. Ltd.
WA- 7-P	135	10-7-75	Continental Oil Co. of Aust. Ltd.
WA-13-P	387	29-8-74	West Australian Petroleum Pty. Ltd.
WA-14-P	396	29-8-74	,, ,, ,, ,,
WA-15-P	352	20-3-75	Arco Aust. Ltd., Australian Aquitaine Petroleum Pty. Ltd., Esso Exploration and Production Aust. Inc.
WA-16-P	354	16-4-75	,, ,, ,, ,,
WA-17-P	378	22-4-75	,, ,, ,, ,,
WA-18-P	322	16-4-75	,, ,, ,, ,,
WA-19-P	142	20-3-75	Alliance Oil Development Aust. Ltd.
WA-20-P	34	10-10-74	West Australian Petroleum Pty. Ltd.
WA-21-P	241	14-11-74	,, ,, ,, ,,
WA-23-P	398	3-10-74	,, ,, ,, ,,
WA-24-P	208	17-10-74	,, ,, ,, ,,
WA-25-P	256	16-10-74	,, ,, ,, ,,
WA-26-P	400	22-12-74	Canadian Superior Oil (Aust.) Pty. Ltd. Australian Superior Oil Co. Ltd., Phillips Australian Oil Co., Sunray Australian Oil Co. Inc., Genoa Oil N.L., Pexa Oil N.L., Hartog Oil N.L., Flinders Petroleum N.L., Crusader Oil N.L.
WA-27-P	294	18-5-75	,, ,,
WA-28-P	375	24-3-75	Woodside Oil N.L., Shell Development (Aust.) Pty. Ltd., B.O.C. of Australia Ltd.
WA-29-P	400	18-5-75	,, ,, ,,
WA-30-P	400	2-7-75	,, ,, ,,
WA-31-P	400	18-5-75	,, ,, ,,
WA-32-P	395	2-7-75	,, ,, ,,
WA-33-P	389	18-5-75	,, ,, ,,
WA-34-P	397	2-7-75	,, ,, ,,
WA-35-P	400	2-7-75	,, ,, ,,
WA-36-P	57	18-5-75	,, ,, ,,
WA-37-P	118	2-6-75	,, ,, ,,
WA-39-P	104	12-3-75	BP Petroleum Development Aust. Pty. Ltd. Abrolhos Oil N.L.
WA-40-P	102	12-3-75	,, ,, ,,
WA-43-P	241	17-9-78	Planet Exploration Co. Pty. Ltd.
WA-44-P	400	17-9-78	,, ,, ,, ,, ,,
WA-50-P	330	23-7-78	Esso Exploration and Production Aust. Inc.
WA-51-P	278	25-7-78	,, ,, ,, ,,

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 5	132	26-7-75	West Australian Petroleum Pty. Ltd.
EP 6	199	27-8-75	,, ,, ,,
EP 7	200	27-8-75	,, ,, ,,
EP 8	200	8-8-77	,, ,, ,,
EP 9	200	27-8-75	,, ,, ,,
EP 13	200	27-8-75	,, ,, ,,
EP 17	200	27-8-75	,, ,, ,,
EP 18	200	27-8-75	,, ,, ,,
EP 19	200	27-8-75	,, ,, ,,
EP 20	200	8-8-77	Australian Aquitaine Petroleum Pty. Ltd.
EP 21	90	26-7-75	West Australian Petroleum Pty. Ltd.
EP 23	163	6-8-75	,, ,, ,,
EP 24	167	6-8-75	,, ,, ,,
EP 25	96	6-8-75	,, ,, ,,
EP 26	1	27-8-75	BP Petroleum Development (Aust.) Pty. Ltd., Abrolhos Oil N.L.
EP 27	2	19-8-75	,, ,, ,,
EP 28	4	19-8-75	,, ,, ,,
EP 29	7	19-8-75	,, ,, ,,
EP 31	200	6-10-75	Beach-General Exlporation Pty. Ltd., Australian Aquitaine Petroleum Pty. Ltd.
EP 32	200	15-4-76	,, ,, ,,
EP 33	123	15-4-76	,, ,, ,,
EP 34	1	15-4-76	Woodside Oil N.L., Shell Development (Aust.) Pty. Ltd., B.O.C. of Australia Ltd.
EP 35	1	15-4-76	,, ,, ,,
EP 36	1	15-4-76	,, ,, ,,
EP 37	149	22-9-75	West Australian Petroleum Pty. Ltd.
EP 38	130	22-9-75	,, ,, ,,
EP 40	67	26-7-76	,, ,, ,,
EP 41	180	18-7-76	,, ,, ,,
EP 42	200	1-9-75	,, ,, ,,
EP 43	163	1-9-75	,, ,, ,,
EP 44	113	1-9-75	,, ,, ,,
EP 45	197	19-11-75	Continental Oil Co. of Aust. Ltd., Australian Sun Oil Co. Ltd.
EP 46	199	1-9-75	,, ,, ,,
EP 47	199	19-11-75	,, ,, ,,
EP 48	199	19-11-75	,, ,, ,,
EP 50	110	1-9-75	West Australian Petroleum Pty. Ltd.
EP 51	17	8-9-75	Lennard Oil N.L.
EP 52	18	8-9-75	,, ,, ,,
EP 54	123	22-9-75	Alliance Oil Development Aust. N.L.
EP 58	200	20-7-76	Associated Australian Oilfields 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 59	186	18-7-76	,, ,, ,,
EP 60	2	....	West Australian Petroleum Pty. Ltd.
EP 61	4	19-9-76	,, ,, ,,
EP 62	8	19-9-76	,, ,, ,,
EP 63	4	19-9-76	,, ,, ,,
EP 64	1	....	,, ,, ,,
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 69	82	5-4-77	Sunningdale Oils Pty. Ltd.
EP 70	71	25-9-77	Associated Australian Oilfields 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.

Number	No. of graticular sections	Expiry date of current term	Registered holder or applicant
EP 71	81	6–7–77	Coastal Petroleum N.L.
EP 72	198	21–8–77	Planet Exploration Company Pty. Ltd.
EP 73	198	21–8–77	" " "
EP 75	198	21–8–77	" " "
EP 76	188	23–7–77	Genoa Oil N.L., Hartog Oil N.L., Olympus Petroleum N.L., Pexa Oil N.L., Omega Oil N.L., Kambalda Petroleum N.L.

Production Licences

Number	No. of graticular sections	Expiry date of current term	Registered holder or applicant
PL 1	5	24–10–92	West Australian Petroleum Pty. Ltd.
PL 2	4	24–10–92	" " "
PL 3	5	24–10–92	" " "

PETROLEUM TENEMENTS UNDER THE PETROLEUM PIPELINES ACT, 1969

Pipeline Licences

Number	Expiry date 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 1973 are shown in Figures 19 and 20. Details relating to the wells drilled during the year are given in Table 4. All the petroleum exploration wells drilled in Western Australia up to the end of 1973 are listed in Geological Survey Record 1974/2.

A summary of the principal results of the drilling in each basin during the year is as follows:

PERTH BASIN

The Lake Preston No. 1 new field wildcat was the only well drilled in the Perth Basin during 1973. It was plugged and abandoned after reaching a total depth of 4 565 m, in the Lower Permian section. No significant shows of hydrocarbons were recorded, and the shows obtained were confined to coal gas. However, the well indicated that the Sue Coal Measures is a good generative unit.

CARNARVON BASIN

Seven wells were completed by the B.O.C. group in the Carnarvon Basin during 1973, and Lambert No. 1 was drilling at the end of the year. Four of the completed wells were new field wildcat tests and of these Dockrell No. 1 was a successful gas/condensate/oil discovery and Egret No. 1 was a successful oil discovery. Extensions to the Angel and Goodwyn fields were successfully tested in Angel No. 3 and Goodwyn No. 3 and 4. All the successful tests were on the Nelson Rocks and Rosemary structures.

West Australian Petroleum Pty. Ltd. completed two wells in the Carnarvon Basin, West Tryal Rocks No. 1 and Barrow Deep No. 1, both of which were spudded in 1972.

West Tryal Rocks No. 1, a new field wildcat well, was a successful gas/condensate discovery. It has been suspended until a new rig is available for further testing. Barrow Deep No. 1 was a deeper-pool test on Barrow Island. The well yielded significant quantities of gas but serious drilling difficulties were experienced with supernormal formation pressures.

The only onshore wells in the Carnarvon Basin were Tamala No. 1 and Kalbarri No. 1 drilled for stratigraphic information by Oceania Petroleum Pty. Ltd.

The results obtained in the extension test wells in the Angel and Goodwyn fields are discussed in a separate report on petroleum development and production in 1973 (p. 37). Some details of the discovery wells are as follows:

Dockrell No. 1

The testing programme indicated a main hydrocarbon reservoir of approximately 105 m of gross pay with an oil leg approximately 12 m thick. Two separate thin gas/condensate zones were also located below the main reservoir. The following is a summary of the results of two drill-stem tests run in the hole:

D.S.T. No.	Interval (metres)	Surface choke	Oil b/d	Gas x 10^3 m^3/d	Condensate b/d
1.	2 987–2 995	¾ inch	....	371·4	755
2.	3 004–3 008	⅜ inch	1 869	53·8	....

The gas and condensate in D.S.T. No. 1 was accompanied by water at the rate of 7.4 barrels per day.

Egret No. 1

The Egret No. 1 well is located approximately 8 km southeast of the Eaglehawk oil discovery well. The results of a drill-stem test are summarized as follows:

D.S.T. No.	Interval (metres)	Surface choke	Oil b/d	Gas x 10^3 m^3/d	Water b/d
1.	3 119–3 128	¾ inch	2 729	81·2	20–30

The oil was 39° A.P.I. gravity and it was recovered from the top sand of the Tithonian section.

West Tryal Rocks No. 1

This well is currently suspended until a new drill rig is available for testing a significant hydrocarbon accumulation identified in Late Triassic to Early Jurassic sands of the Mungaroo Formation. Wireline log evaluation indicates the presence of 90 m of possible hydrocarbon pay in a column which extends over a gross interval of 265 m with a transitional hydrocarbon water contact from 3 489-3 501 m.

Barrow Deep No. 1

This well was drilled as a deep exploratory test on Barrow Island and is currently classified as a gas well after the discovery and testing of significant hydrocarbon accumulations in Middle Jurassic sands. The well did not reach the planned total depth of 4 877 m because of supernormal formation pressures and the primary objective of testing possible Late Triassic sands of the Mungaroo Formation was not achieved. Six drill stem tests were conducted to evaluate three sands between 3 242-3 254 m, 3 329-3 363 m, and 3 424-3 500 m. Because of the necessity to maintain pressure control these tests were of limited duration and none of the zones was flowed to the surface. The lowermost zone, with a proven net gas pay of 9.4 m between 3 424 and 3 500 m, gave the best results during later production tests and it has a calculated open-flow potential of 5 660 x 10^3 m^3 gas per day.

CANNING BASIN

Three offshore new field wildcat wells, East Mermaid No. 1 drilled in 389 m of water for Shell Development (Australia) Pty. Ltd., Wamac No. 1 drilled for Amax Petroleum (Australia) Inc., and Ronsard No. 1 drilled for the B.O.C. group, were completed during 1973. The B.O.C. Poissonnier No. 1 wildcat was drilling at the end of the year. Onshore West Australian Petroleum Pty. Ltd. completed three new field wildcats in the northern Canning Basin and one of them, Mimosa No. 1, encountered a minor gas and oil show, the remainder of the completed wells were dry, and all were abandoned. Contention Heights No. 1 new field wildcat well, drilled for Australian Aquitaine Petroleum Pty. Ltd. in the southeastern Canning Basin, was also dry and was abandoned after reaching a total depth of 1 791 m in Early Ordovician sediments.

BROWSE BASIN

The B.O.C. group drilled two new field wildcat wells, Londonderry No. 1 and Yampi No. 1, in the Browse Basin during 1973. In Yampi No. 1 log analysis indicates that several thin hydrocarbon-bearing sands are present but reservoir characteristics are poor. Both wells were abandoned.

BREMER BASIN

An onshore stratigraphic well, Kendenup No. 1, was being drilled for Silfar Pty. Ltd. at the end of the year.

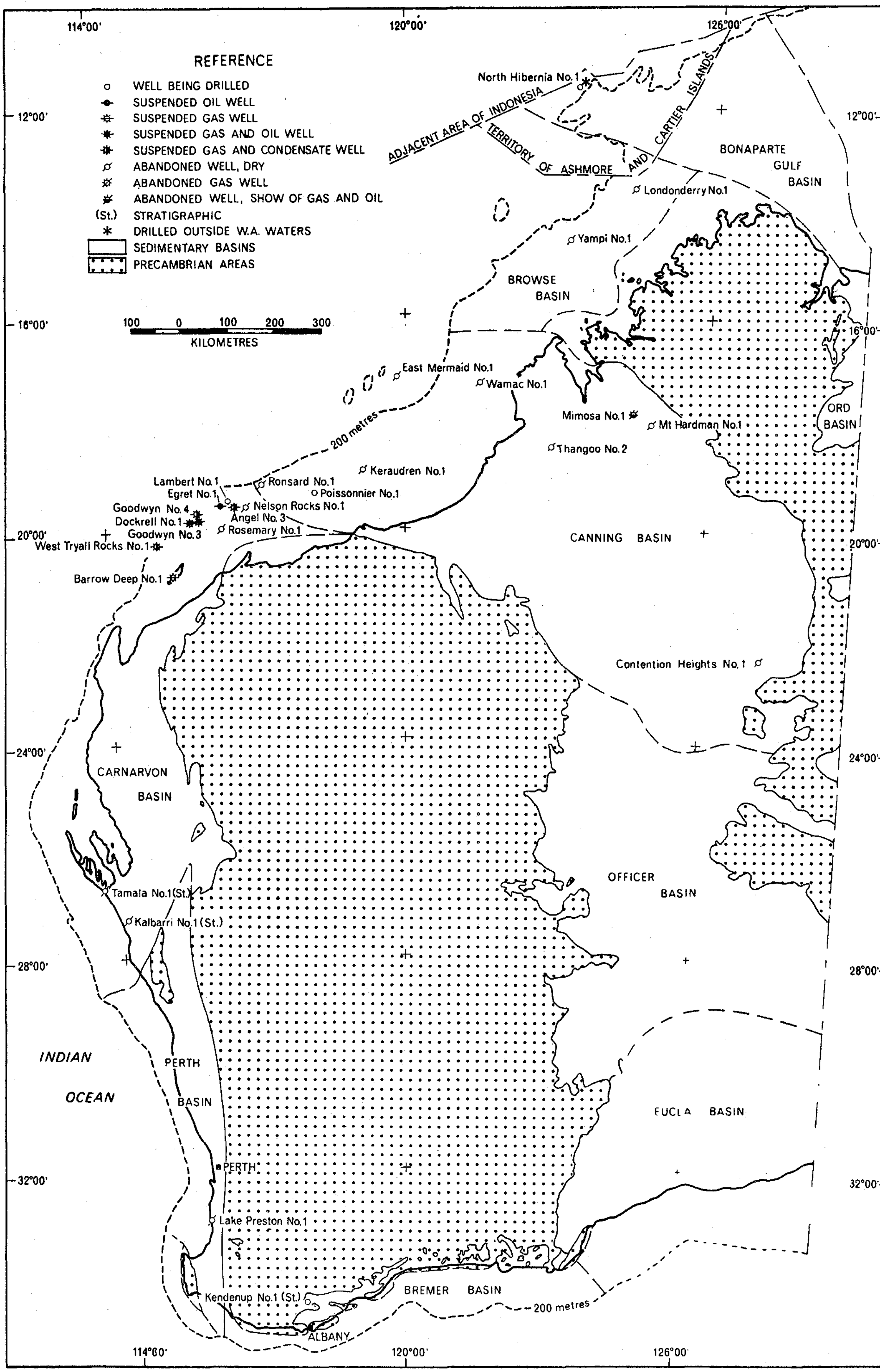

Figure 19. Wells drilled for petroleum exploration in W.A. during 1973.

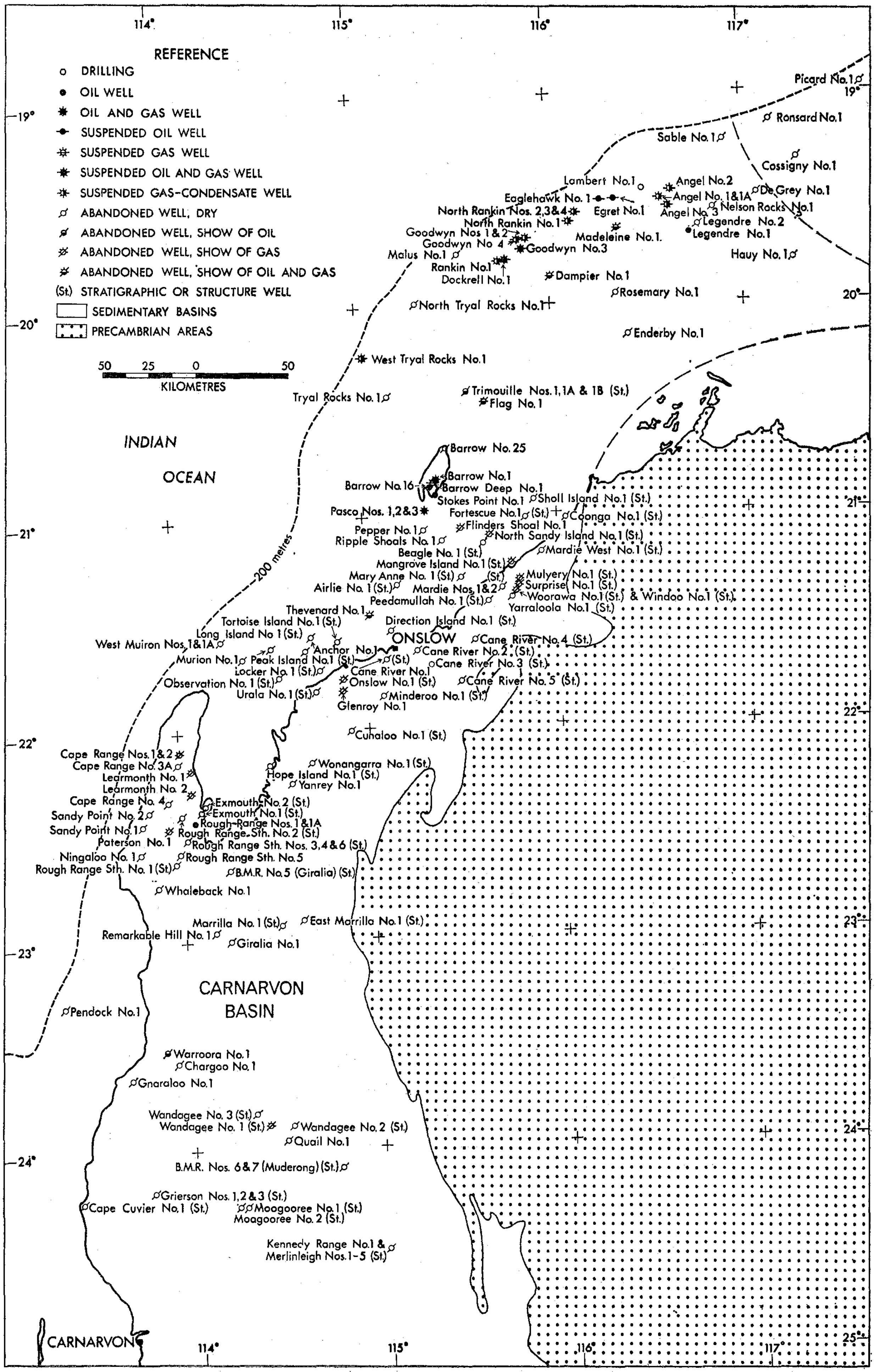

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Figure 20. Northern Carnarvon and southwestern Canning Basins showing wells drilled for petroleum to 31st December, 1973.

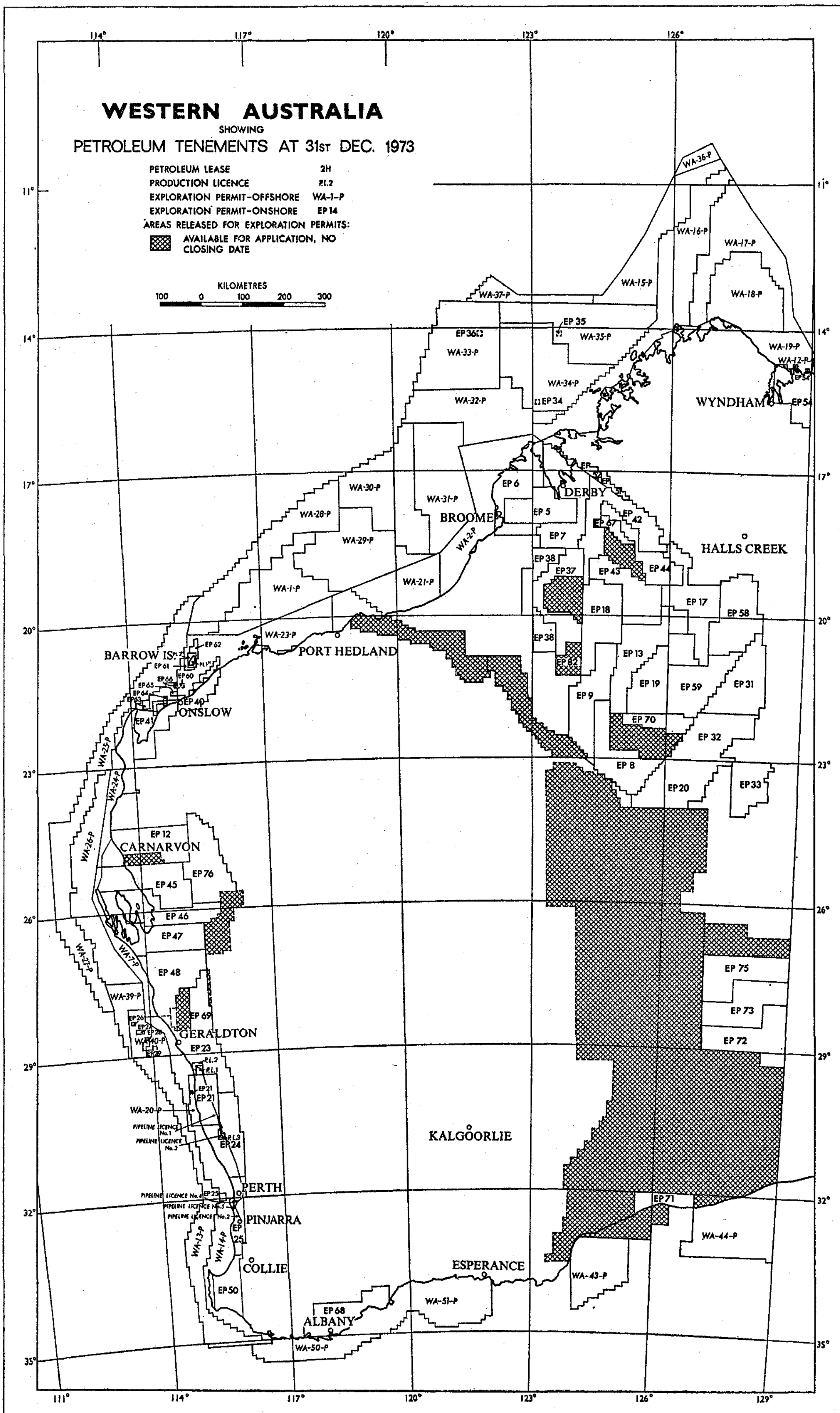

Figure 21. Petroleum tenements at 31st December, 1973.

TABLE 4. WELLS DRILLED FOR PETROLEUM EXPLORATION IN WESTERN AUSTRALIA DURING 1973

Basin	Well	* = subsidized	Concession	Operating Company	Type	Position: Latitude South °	′	″	Position: Longitude East °	′	″	Elevation and water depth (metres) G.L.	R.T.	W.D.	Dates: Commenced	Reached T.D.	Rig released	Total depth (or depth reached) in metres	Bottomed in	Status on 31 Dec., 1973
Perth	Lake Preston No. 1	*	EP–25	Wapet	NFW	32	55	13	115	39	39	10·1	14·6	....	20/12/72	7/3/73	9/3/73	4 565	L. Permian	Dry, P. & A.
Carnarvon	Angel No. 3	....	WA–1–P	B.O.C.	EXT	19	32	30	116	37	46	....	9·4	66·4	27/4/73	15/6/73	28/6/73	3 780	....	G & C well suspended
	Barrow Deep No. 1	*	PL–1H	Wapet	DPT	20	50	07	115	22	57	38·7	46·6	....	16/9/72	20/6/73	21/7/73	4 650	M. Jurassic	Gas well suspended
	Dockrell No. 1	....	WA–28–P	B.O.C.	NFW	19	47	16	115	46	49	....	30·0	110·0	30/6/73	17/8/73	28/8/73	3 895	....	G, C & O well suspended
	Egret No. 1	*	WA–28–P	B.O.C.	NFW	19	30	24	116	20	52	....	12·5	118·2	24/12/72	12/5/73	28/5/73	3 658	Triassic	Oil well suspended
	Goodwyn No. 3	....	WA–28–P	B.O.C.	EXT	19	44	09	115	52	43	....	30·2	118·8	14/12/72	9/2/73	22/2/73	3 657	....	G & O well suspended
	Goodwyn No. 4	....	WA–28–P	B.O.C.	EXT	19	41	38	115	50	54	....	30·2	128·0	24/2/73	6/6/73	28/6/73	3 633	....	G & C well suspended
	Kalbarri No. 1	*	EP–47	O.P.P.L.	STR	87	16	00	114	06	26	129·2	132·8	....	11/9/73	3/10/73	4/10/73	1 539	Silurian	Dry, P & A
	Lambert No. 1	....	WA–28–P	B.O.C.	NFW	19	27	24	116	29	23	....	10·0	125·0	13/11/73	....	....	3 476	....	Drilling
	Nelson Rocks No. 1	....	WA–1–P	B.O.C.	NFW	19	33	37	116	51	19	....	10·0	75·0	30/6/73	30/7/73	1/8/73	2 190	....	Dry, P & A
	Rosemary No. 1	*	WA–1–P	B.O.C.	NFW	19	57	14	116	20	40	....	9·5	64·9	13/11/72	26/3/73	26/4/73	3 909	L. Jurassic	Dry, P & A
	Tamala No. 1	*	EP–47	O.P.P.L.	STR	26	38	42	113	38	04	2·7	7·0	....	4/4/73	7/5/73	8/5/73	1 225	Silurian	Dry, P & A
	West Tryal Rocks No. 1	*	WA–25–P	Wapet	NFW	20	13	45	115	02	04	....	12·2	137·8	23/10/73	4/3/73	31/3/73	3 866	M-U. Triassic	G & C well suspended
Canning	Contention Heights No. 1	*	EP–32	A.A.P.	NFW	22	25	36	127	13	31	418·4	4·6	....	16/8/73	24/9/73	6/10/73	1 791	L. Ordovician	Dry, P & A
	East Mermaid No. 1 RDR 2	....	WA–30–P	Shell	NFW	17	10	01	119	49	21	....	9·7	389·2	30/6/73	9/10/73	15/10/73	4 067	....	Dry, P & A
	Keraudren No. 1	....	WA–29–P	Hemat	NFW	18	54	28	119	09	15	....	30·0	95·0	31/8/73	13/12/73	19/12/73	3 844	....	Dry, P & A
	Mimosa No. 1	*	EP–44	Wapet	NFW	17	51	00	124	35	00	57·0	61·6	....	17/6/73	17/8/73	23/8/73	4 117	M-U. Devonian	Gas & oil show
	Mt. Hardman No. 1	*	EP–67	Wapet	NFW	18	00	38	124	54	48	57·0	61·6	....	6/9/73	6/11/73	10/11/73	3 360	U. Devonian	Dry, P & A
	Poissonnier No. 1	....	WA–1–P	B.O.C.	NFW	19	18	31	118	09	20	....	28·9	82·0	20/12/73	....	....	1 042	....	Drilling
	Ronsard No. 1	*	WA–1–P	B.O.C.	NFW	19	08	32	117	09	34	....	9·7	154·0	12/10/73	9/11/73	12/11/73	2 843	....	Dry, P & A
	Thangoo No. 2	*	EP–14	Wapet	NFW	18	26	33	122	54	35	118·0	192·8	....	9/5/73	31/5/73	2/6/73	4 830	Precambrian	Dry, P & A
	Wamac No. 1	*	WA–31–P	Amax	NFW	17	14	26	121	29	28	....	19·5	76·0	6/8/73	22/9/73	11/10/73	2 764	....	Dry, P &A
Browse	Londonderry 1	....	WA–35–P	B.O.C.	NFW	13	36	53	124	30	40	....	12·5	90·8	28/9/73	7/10/73	8/10/73	1 145	....	Dry, P & A
	Yampi No. 1	*	WA–34–P	B.O.C.	NFW	14	33	21	123	16	21	....	13·4	97·8	3/6/73	17/9/73	27/9/73	4 176	....	Dry, P & A
Bremer	Kendenup No. 1	....	EP–68	Silfar	STR	34	29	36	117	45	22	159·0	....	....	19/12/73	....	....	31	....	Drilling

Total	78 053
Less drilling done in 1972	14 441
Total drilling done in 1973	63 612

A.A.P. = Australian Aquitaine Petroleum Pty. Ltd.
Amax = Amax Petroleum (Australia) Inc.
B.O.C. = B.O.C. of Australia Ltd.
Hemat = Hematite Petroleum Pty. Ltd.
O.P.P.L. = Oceania Petroleum Pty. Ltd.
Shell = Shell Development (Australia) Pty. Ltd

Silfar = Silfar Pty. Ltd.
Wapet = West Australian Petroleum Pty. Ltd.
DPT = Deeper pool test well
EXT = Extension test well
G & C = Gas and Condensate
G, C & O = Gas, condensate and oil

G & O = Gas and oil
NFW = New field wildcat well
P & A = Plugged and abandoned
STR = Stratigraphic well

GEOPHYSICAL SURVEYS

SEISMIC

During 1973 seismic surveys were conducted in the Perth, Carnarvon, Canning, Browse, Bonaparte Gulf and Eucla Basins. Details are as follows:

SEISMIC SURVEYS

Basin	Permit No.	Company	Line kilometres	
			Marine	Land
Perth	EP-21	West Australian Petroleum Pty. Ltd.	....	55
"	EP-23	" " "	....	27
"	EP-24	" " "	....	194
"	EP-25	" " "	....	123
"	WA-20-P	" " "	2 000	....
Carnarvon	PL-1H	West Australian Petroleum Pty. Ltd.	....	15
"	WA-23-P	" " "	126	....
"	WA-24-P	" " "	360	....
"	WA-25-P	" " "	2 753	....
"	WA-41-P	" " "	....	48
"	WA-27-P	Canadian Superior Oil (Aust.) Pty. Ltd.	981	....
Carnarvon/ Canning	WA-1-P	B.O.C. of Australia Ltd	1 125	....
	WA-28-P	" " "	975	....
Canning	EP-5	West Australian Petroleum Pty. Ltd.	....	31
"	EP-7	" " "	....	75
"	EP-13	" " "	....	75
"	EP-15	" " "	....	64
"	EP-18	" " "	....	109
"	EP-19	" " "	....	77
"	EP-37	" " "	....	56
"	EP-43	" " "	....	139
"	EP-44	" " "	....	15
"	WA-2-P	" " "	1 508	....
"	WA-21-P	" " "	376	....
"	EP-58	Associated Australian Resources N.L.	....	257
"	EP-59	" " "	....	398
"	WA-29-P	B.O.C. of Australia Ltd.	127	....
"	WA-30-P	" " "	571	....
"	WA-31-P	" " "	584	....
"	WA-31-P	Amax Petroleum (Aust) Inc.	98	....
"	WA-29-P	Hematite Petroleum Pty. Ltd.	191	....
Browse	WA-32-P	B.O.C. of Australia	314	....
"	WA-33-P	" " "	893	....
"	WA-34-P	" " "	581	....
"	WA-35-P	" " "	531	....
"	WA-37-P	" " "	402	....
Bonaparte Gulf	WA-15-P	Arco Australia Ltd.	428	....
"	WA-16-P	" "	942	....
"	WA-17-P	" "	229	....
"	WA-18-P	" "	361	....
"	WA-19-P	" "	105	....
"	WA-36-P	B.O.C. of Australia Ltd.	143	....
Eucla	EP-71	Coastal Petroleum N.L.	....	18
		Totals	14 904	1 776

GRAVITY

Gravity surveys were carried out during the year in the Perth and Eucla Basins. Details are as follows:

GRAVITY SURVEYS

Basin	Permit No.	Company	Party	Ship-board line kilometres
Perth	EP-69	Sunningdale Oils Pty. Ltd.	5·0	....
Eucla	EP 71	Coastal Petroleum N.L.	0·4	....
		Totals	5·4	....

In addition West Australian Petroleum Pty. Ltd. carried out a total of 47 work days of gravity survey in association with land seismic, and 2-5 km of gravity survey associated with marine seismic, in the Perth, Carnarvon and Canning Basins.

MAGNETOMETER

Ship-board magnetic surveys were conducted in the Carnarvon and Canning Basins. Details are as follows:

MAGNETIC SURVEYS.

Basin	Permit No.	Company	Line kilometres	
			Aero-magnetic	Ship-board
Canning	WA-31-P	Amax Petroleum (Aust.) Inc.	....	98
"	WA-29-P	Hematite Petroleum Pty. Ltd.	....	191
Carnarvon	WA-27-P	Canadian Superior Oil (Aust.) Pty. Ltd.	....	825
		Totals		1 114

GEOLOGICAL SURVEYS

A surface geological survey amounting to 3.5 geologist months was carried out by Associated Australian Resources N.L. in EP 59 and EP 70 in the Canning Basin.

OTHER SURVEYS

West Australian Petroleum Pty. Ltd. carried out 576 square kilometres of hydrographic survey, 148 km of bathymetric sparker, and 39 km of bathymetric sonar in the Perth and Carnarvon Basins.

PETROLEUM DEVELOPMENT AND PRODUCTION IN WESTERN AUSTRALIA IN 1973

by R .N. Cope

ABSTRACT

During 1973 the Barrow Island Field produced 2 295 467 m^3 of crude oil. Sales totalled 2 314 043 m^3 on which royalty of A$1 362 522 was paid. Remaining oil reserves are estimated to be about 27×10^6 m^3. Production testing of Pasco Island No. 1 (near Barrow Island) showed that the Pasco Field is subeconomic.

In the Rankin area, three additional appraisal wells were drilled in 1973; Goodwyn No. 3, No. 4 and Angel No. 3. The combined proved plus probable gas reserves of the North Rankin, Goodwyn and Angel Fields have been estimated at 380×10^9 m^3. Additional possible gas reserves are put at 130×10^9 m^3. The North Rankin Field alone is estimated to hold about 223×10^9 m^3 of recoverable gas in the proved plus probable categories.

Gas production from the Dongara and Mondarra Fields in the northern Perth Basin during 1973 totalled 815 487 000 m^3; sales were 809 629 000 m^3 and royalty paid was A$320 741. Remaining gas reserves are about 11 090 000 000 m^3. Wapet's options to apply for the secondary entitlement blocks in Locations 1 and 2 (Dongara-Mondarra) and 3 (Walyering) were not exercised. Seven blocks were therefore excised from EP-23 and four blocks from EP-24. An application was received from Wapet to surrender Production Licence No. 3 (Walyering).

INTRODUCTION

There are three petroleum fields in the course of long-term planned production in Western Australia; the Barrow Island Field, in the northern Carnarvon Basin, and the Dongara and Mondarra Fields in the northern Perth Basin.

The Barrow Island Field, sited about 60 km off the northwest coast near Onslow, produces oil with some liquid petroleum gas and condensate. The solution gas is nearly all flared as its utilization is non-commercial, apart from about 9.4 per cent of the gas produced which is currently used as field fuel.

The Dongara Field, south of Geraldton, and the nearby small Mondarra Field, produce gas, which is piped south to Perth, Kwinana, and Pinjarra. A small quantity of condensate is separated from the gas and sold. The small Yardarino Field, also near Dongara, has not so far been developed to the production stage.

Implementation of the national policy of metrication is proceeding fairly smoothly with respect to petroleum development and production. "Soft" metrication (conversion to metric units after recording in imperial units) is being adopted by both West Australian Petroleum Pty. Ltd. (referred to here as Wapet) and B.O.C. of Australia Ltd. "Hard" metrication (recording in metric units) presents special instrumentation problems. These problems hinge largely on the fact that the regulatory bodies of the petroleum industry in the United States of America (the home, and supply base, of much of the industry) have no plans for metrication, as they consider that it would be prohibitively expensive.

In this report volumes of both liquids and gas are expressed in cubic metres at Australian metric standard conditions; these conditions were decided in 1973 as 15 degrees Celsius (°C) and 101.325 kilopascals (kPa). Liquid volumes are also stated (between parentheses after the metric quantities) in barrels at imperial standard conditions (60 degrees Fahrenheit and 14.73 pounds per square inch in air), as the barrel (34.972 6 imperial gallons) is an internationally accepted unit in crude oil production.

The conversion factors used to prepare the tables of this report are: 1 cubic metre at metric standard conditions = 35.42 cubic feet at imperial standard conditions; 1 barrel at imperial standard conditions = 0.158 91 cubic metres at metric standard conditions; 1 volume unit at imperial standard conditions = 1.005 0 volume units at metric standard conditions.

NORTHERN CARNARVON BASIN

GENERAL

The northern Carnarvon Basin is the most petroleum-productive area of the State to date, and it is also the most prospective. In addition to the producing Barrow Island Field, three offshore fields are thought to contain commercial reserves of gas, namely, North Rankin, Goodwyn and Angel (Fig. 22). For detailed information on the petroleum geology of this area see Martison and others (1973).

The 1973 half-yearly report of Woodside-Burmah Oil N.L. gave the estimated proved plus probable natural gas reserves of the "Rankin Trend" as 380×10^9 m^3 (13.5×10^{12} CF). Additional possible reserves were put at 130×10^9 m^3 (4.5×10^{12} CF). These figures cover the North Rankin, Goodwyn and Angel Fields, although the Angel Field is not on the "Rankin Trend" (the southern margin of the Rankin Platform).

BARROW ISLAND FIELD

Petroleum is produced from the Barrow Island Field under Petroleum Lease 1H.

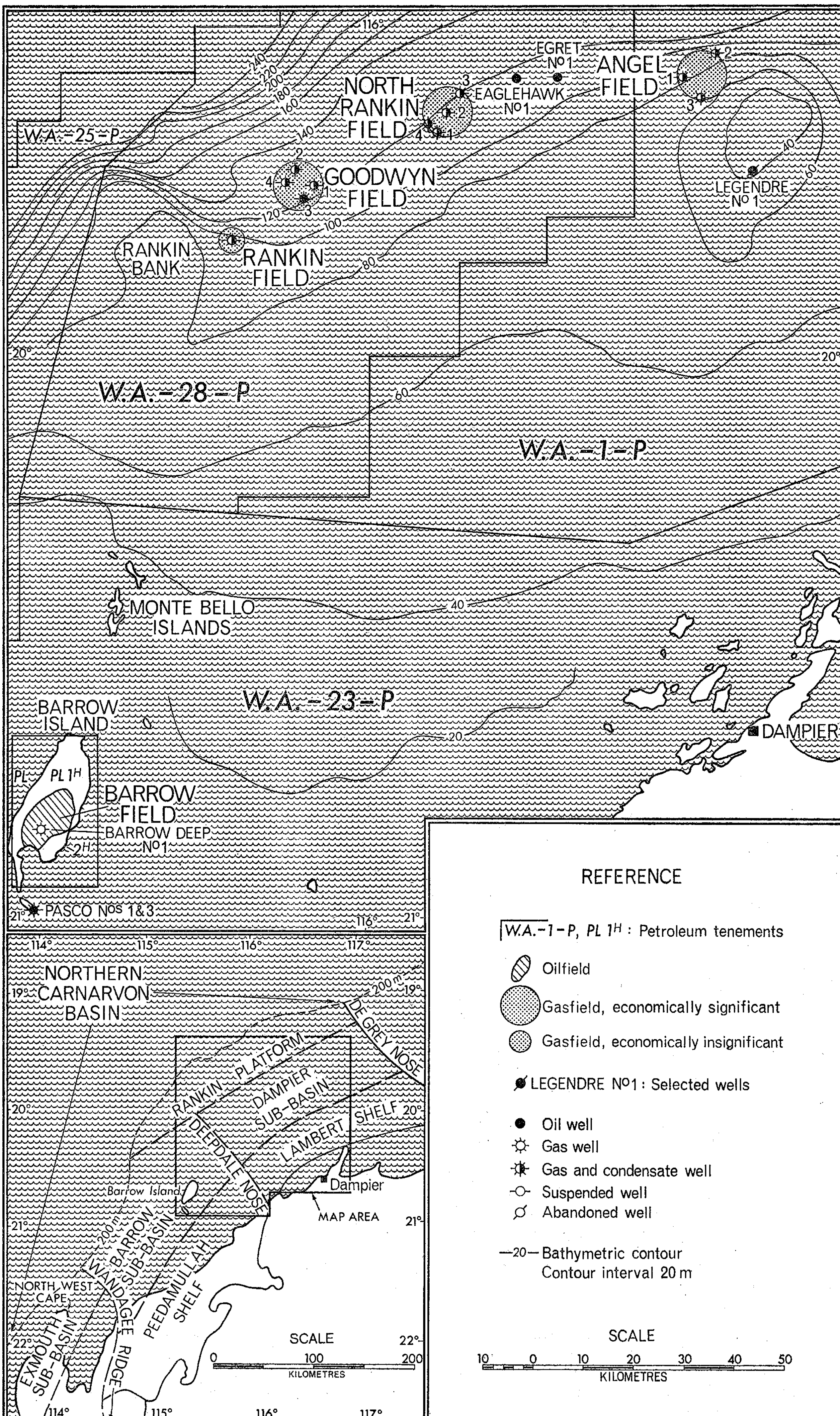

Figure 22. Northern Carnarvon Basin. Bathymetry and petroleum development. Inset map shows area of main map in relation to structural sub-divisions.

(6)—39934

TABLE 5. BARROW ISLAND FIELD. PRODUCTION DURING 1973

Reservoir	Average daily prod. oil in m^3 (bbls) during December, 1973	Production for year 1973					Cumulative production				
		Oil in m^3 (bbls)	L.P.G. in m^3 (bbls)	N.G. in m^3 (bbls)	Water in m^3 (bbls)	Gas 10^3 m^3	Oil in m^3 (bbls)	L.P.G. in m^3 (bbls)	N.G. in m^3 (bbls)	Water in m^3 (bbls)	Gas 10^3 m^3
Windalia	5 681 (35 754)	2 252 980 (14 177 711)	4,794 (30 169)	5 082 (31 978)	958 631 (6 032 540)	163 829	14 213 722 (89 445 107)	4 794 (30 169)	5 082 (31 978)	2 757 753 (17 354 182)	1 494 014
Muderong	51 (318)	20 237 (127 350)	....	....	9 210 (57 958)	3 423	154 597 (972 862)	....	....	34 942 (219 884)	23 392
Jurassic, 5 500′	....	....	....	....	....	....	2 476 (15 580)	....	....	16 150 (101 628)	14 577
Jurassic, 6 200′	....	....	....	....	....	....	9 136 (57 489)	....	....	19 697 (123 952)	80 563
Jurassic, 6 600′	36 (224)	10 911 (68 664)	....	....	28 311 (178 160)	2 587	47 522 (299 053)	....	....	84 846 (533 923)	20 606
Jurassic, 6 700′	30 (187)	11 339 (71 357)	....	....	7 673 (48 284)	11 023	177 682 (1 118 128)	....	....	50 341 (316 792)	94 636
Total Field	5 798 (36 483)	2 295 467 (14 445 082)	4,794 (30 169)	5 082 (31 978)	1 003 825 (6 316 942)	180 862	14 605 135 (91 908 218)	4 794 (30 169)	5,082 (31 978)	2 963 729 (18 650 361)	1 727 878

Water injected during 1973 : 5 895 243 m^3 (37 098 000 bbls).   Cumulative water injected : 28 081 914 m^3 (176 715 839 bbls).

Table 5 gives the statistics of production by reservoir and product during 1973 and the cumulative production including that of 1973. Figure 23 shows the status of wells with respect to the main ("Windalia Sand") reservoir at the end of 1973. The various categories are shown in Table 6. Stripping of the solution gas was initiated in January 1973 and the products sold. Apart from limited demand for field-fuel and gas-lift in production operations, no commercially viable outlet for the unused gas can be found and 90.6 per cent was flared.

TABLE 6. BARROW ISLAND FIELD. WELL STATUS BY RESERVOIRS AT 31st DECEMBER, 1973.

Reservoir	Flowing	Pumping	Gas lift	Closed in	Water injection	Water source	Water disposal	Total
Windalia	16	177	110	15	158	9*	7†	492
Muderong..	2	3	3	....	....	....	....	8
Jurassic, 5 500′	....	....	....	·1	....	....	....	1
Jurassic, 6 200′	....	....	....	2	....	....	....	2
Jurassic, 6 600′	1	....	....	....	....	....	....	1
Jurassic, 6 700′	2	1	....	2	....	....	....	5
Total	21	181	113	20	158	9	7	509

*Completed in Barrow Formation.
† Completed in Cape Range Group.

The statistics relating to field-fuel gas, crude-oil disposal and royalty paid are shown in Table 7. Details of the development of the Barrow Island Field have been given in previous Annual Reports (e.g. Cope, 1972, 1973).

TABLE 7. BARROW ISLAND FIELD. OIL AND GAS DISPOSAL DURING 1973

	Oil m^3 (bbls)	Gas $m^3 \times 10^3$
Total Production	2 295 467 (14 445 082)	180 862
Field fuel	....	17 013
Oil shipments	2 314 043 (14 561 971)	....

Royalty paid : $1 362 522.

The subsurface geology of Barrow Island has recently been made public (Crank, 1973). Geochemical studies have revealed that in the Barrow Island Field, and in the Barrow Basin generally, the crude oils fall into two families. "Those occurring in Cretaceous reservoirs are naphthenic to aromatic in composition, while those in the Jurassic are paraffinic-naphthenic and have a high wax content" (Powell and McKirdy, 1973, p. 84).

Remaining reserves of crude oil in the Barrow Island Field in the proved and probable categories at the end of 1973 were 27.4 million m^3 (172 million barrels).

PASCO ISLAND FIELD

In 1967 three wells, Pasco Nos. 1, 2 and 3, were drilled on a then unnamed island (subsequently named Boodie Island), southwest of Pasco Island (Fig. 23). Wells 1 and 3 encountered oil and gas in Upper Jurassic sands of the Barrow Formation, but due to problems of logistics and product disposal they could not be tested adequately at the time of discovery. However, after suitable arragements had been made in 1973, Pasco No. 1 was production-tested between 26th January and 12th May. The results demonstrated that the field is sub-economic.

NORTH RANKIN FIELD

No further appraisal wells were drilled during 1973 in the North Rankin Field (No. 22). For the development of this important field to date, previous reports should be consulted (e.g. Cope, 1973).

On 29th March 1973, Woodside-Burmah Oil N.L. announced that it had received the independent assessment of reserves of the North Rankin Field which it had commissioned in the latter part of 1972. The press release added that the report of the consulting geologists (DeGolyer and MacNaughton) estimates proved and probable recoverable gas reserves was 223×10^9 m^3 (7.9×10^{12} CF). This represents a substantial reduction from the company's own preliminary estimate (in the combined proved plus probable categories) of 287×10^9 m^3 (10.17×10^{12} CF), released on 14th December, 1972. The 20th March, 1973 release attributed this reduction to further reservoir studies and seismic reinterpretation.

GOODWYN FIELD

At the start of 1973 Goodwyn No. 3 was being drilled. A further extension test well, Goodwyn No. 4, was drilled directly after No. 3 was finished (Low, 1974, Table 4). Test results were as follows:

Well No.	DST No.	Perforated interval m	Choke sizes (inches) bottom	Choke sizes (inches) surface	Gas flow 10^3 m^3/d	Liquid recovery type	Liquid recovery rate m^3/d	Liquid recovery gravity API
3	1	3 017–3 028	3/4	1/2	76	oil	434	41·7
....	2	2 988–2 996	3/4	3/4	....	water	394	....
....	3	2 881–2 893	3/4	3/4	487	condensate	187	50·9
4	1	2 900–2 901	3/4	5/8	306	,,	89	not released
....	2	2 858–2 905	3/4	3/4	483	,,	131	,,

The water depth over the Goodwyn Field is about 120 m. Substantial reserves will therefore be necessary for viable development. No reserves figure has so far been released for his field. However, subtraction of North Rankin reserves from those of the total for the three main fields results in a proved plus probable gas reserves estimate for the Goodwyn and Angel Fields of 158×10^9 m^3 (5.6×10^{12} CF).

ANGEL FIELD

The area around the Angel Field is one of poor seismic resolution, presumably owing to the absence of acoustic reflectors in the critical interval of the stratigraphic column.

Angel No. 3 was drilled during 1973 (see Low, 1974, Table 4). A drill-stem test over the interval 2 741-2 750 m yielded 220 000 m^3 per day of gas accompanied by 45 m^3 per day of condensate, using a ⅜ inch bottom choke and a ½ inch surface choke.

NORTHERN PERTH BASIN

GENERAL

Petroleum tenements in the northern Perth Basin are illustrated in Figures 24 and 25, and also in Low, 1974, Figure 21. Important developments affecting the tenements over the past 10 years may be summarized as follows.

The discovery of oil and gas in Yardarino during 1964 was followed by gas discoveries in Gingin No. 1 (1965), Dongara No. 1 (1966), Mondarra No. 1 (1968), and Walyering No. 1 (1971). Locations 1 and 2 were declared on 29th January 1971 and 26th March 1971 respectively, to cover the Yardarino, Dongara and Mondarra Fields. Location 3 was declared on 17th September 1971 to cover the Walyering Field.

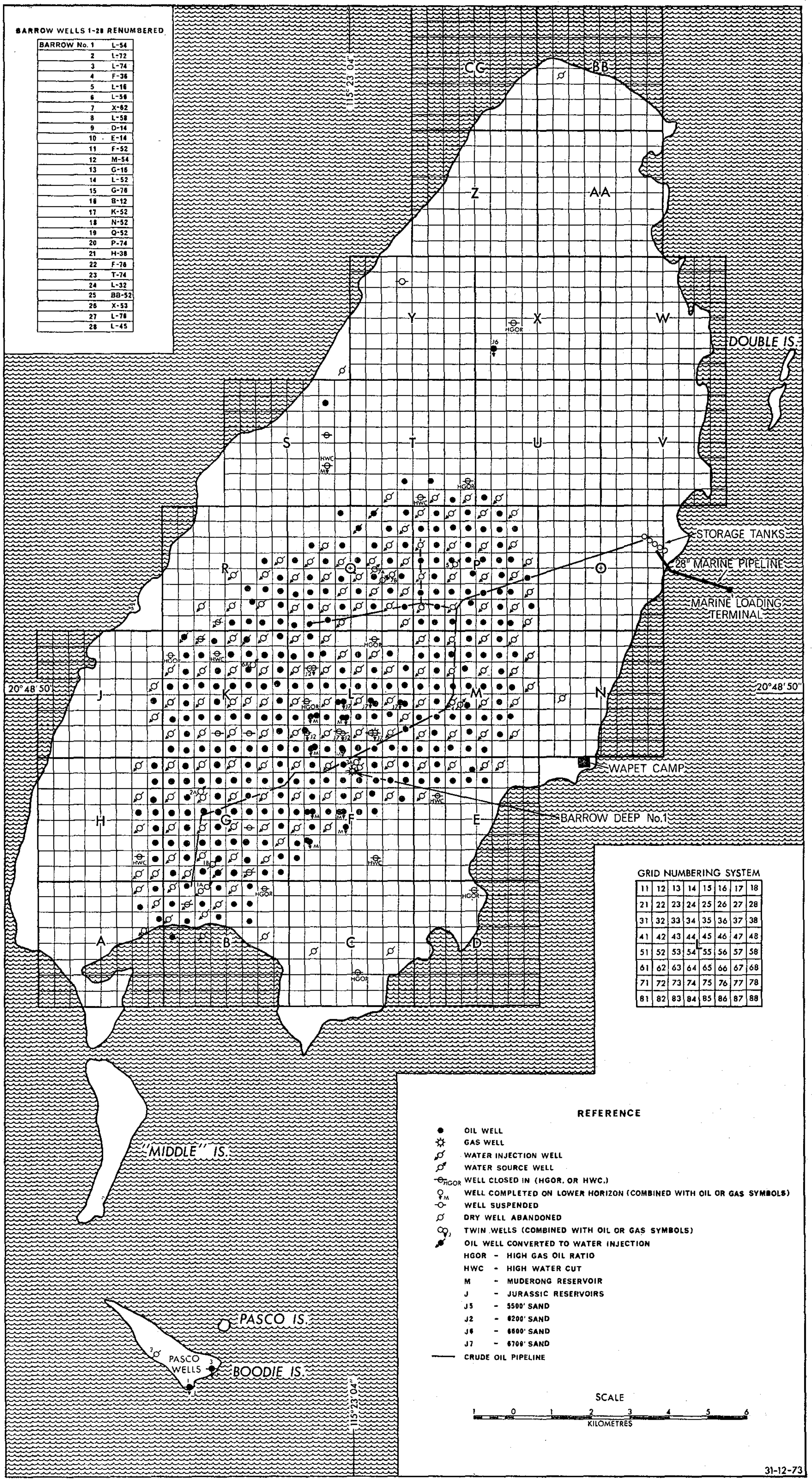

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Figure 23. Barrow Island Field, northern Carnarvon Basin. Status of wells with respect to the "Windalia Sand" reservoir.

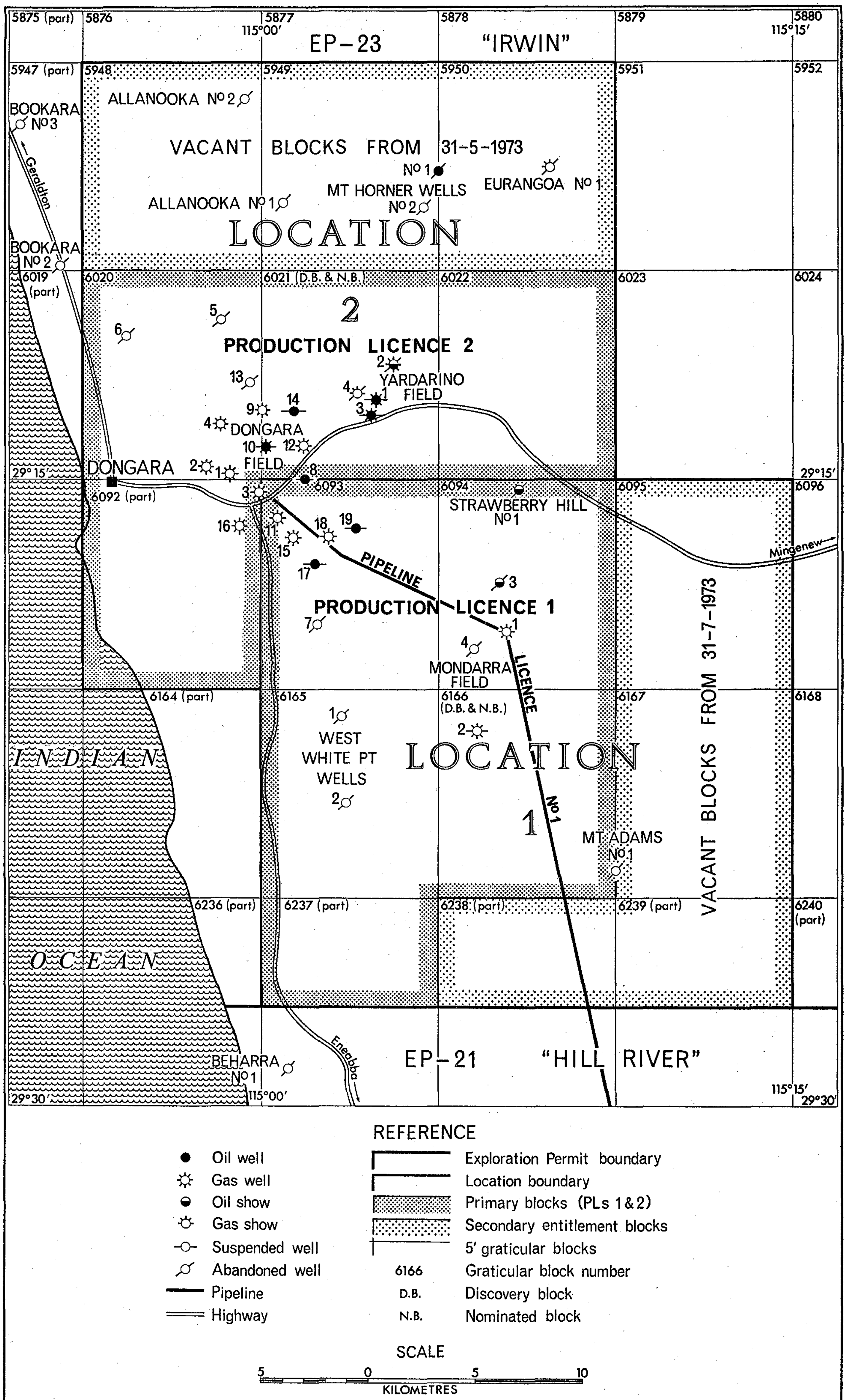

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Figure 24. Dongara area, northern Perth Basin. Status of petroleum tenements and wells (Perth Sheet; 1 : 1 000 000 Map Series).

Appraisal drilling of the Dongara and Mondarra Fields was carried out between 1966 and 1970. Gas reserves have been put at about 12 600 x 10^6 m^3 (450 x 10^9 CF). After market studies in the Perth area a 415 km long 36 cm pipeline was laid (see Cope, 1972, Fig. 16). Production was started on the same day that the Wapet applications for Production Licences 1 and 2 were approved, i.e. 25th October, 1971. Monthly gas production from the Mondarra and Dongara Felds to the end of 1973 is illustrated in Figure 26.

The originally planned pipeline route was diverted to take in the Walyering No. 1 well and Production Licence 3 was approved, also on 25th October, 1971, covering the Walyering Field (Fig. 25). For the details of production testing of Walyering No. 1 and Gingin No. 1 during 1972 see Cope (1973), p. 42 and 43 and Figure 17.

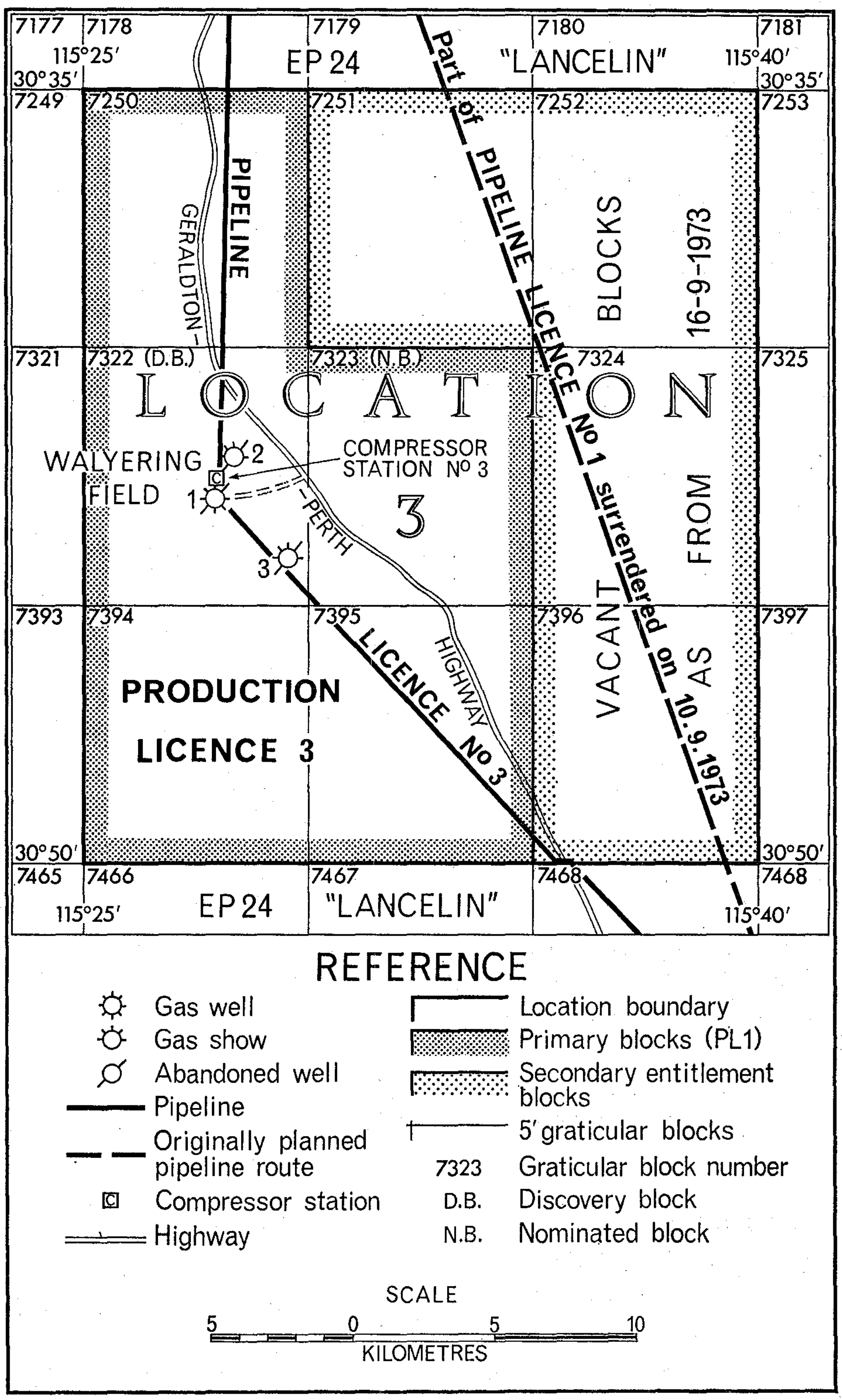

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Figure 25. Walyering Field, northern Perth Basin. Status of petroleum tenements and wells.

TABLE 8. DONGARA AND MONDARRA FIELDS. PRODUCTION DURING 1973

Field	Number of producing wells at 31–12–73	Average daily production during December, 1973		Production for year 1973			Cumulative production		
		Gas 10^3 m^3	Condensate m^3 (bbls)	Gas 10^3 m^3	Condensate m^3 (bbls)	water m^3 (bbls)	Gas 10^3 m^3	Condensate m^3 (bbls)	Water m^3 (bbls)
Dongara	10	1 920·7	9·0 (56·7)	756 206	3 731 (23 481)	3 031 (19 074)	1 360 734	7 601 (47 834)	5 640 (35 491)
Mondarra	1	125·8	2·6 (16·4)	59 281	1 195 (7 517)	247 (1 553)	102 475	2 152 (13 541)	482 (3 034)
Total	11	2 046·5	11·6 (73·1)	815 487	4 926 (30 998)	3 278 (20 627)	1 463 209	9 753 (61 375)	6 122 (38 525)

Total gas sold in 1973 = 809 629 x 10^3 m^3. Total royalties paid = $A320 741.

DONGARA, MONDARRA AND YARDARINO FIELDS

Production from the Dongara and Mondarra Fields during 1973 is given in Table 8. The status of the petroleum tenements and the wells at the end of the year is shown in Figure 24. Using the approximate initial gas reserves figure of 12 600 x 10^6 m^3 the remaining reserves at the end of 1973 were 11 090 x 10^6 m^3 (about 400 x 10^9 CF).

Upon declaration of Production Licences 1 and 2 the balance of the total number of blocks in Locations 1 and 2 were available for application by Wapet within the prescribed time limit. In neither case was the option exercised. The three-block secondary entitlement of Location 2 was excised from EP-23 on 31st May and the four-block secondary entitlement of Location 1 also from EP-23 on 31st July, 1973 (W.A. *Government Gazette* of 25th January, 1974). At the end of 1973 all the excised blocks were vacant.

WALYERING FIELD

As with Locations 1 and 2 Wapet did not exercise its option to apply for the four secondary entitlement blocks in Location 3 (Fig. 25). On 16th September, 1973, the four blocks were excised from EP-24 and at the end of 1973 they remained vacant. In the fourth quarter, an application from Wapet to surrender Production Licence 3 was registered. The application was dated 26th October, 1973.

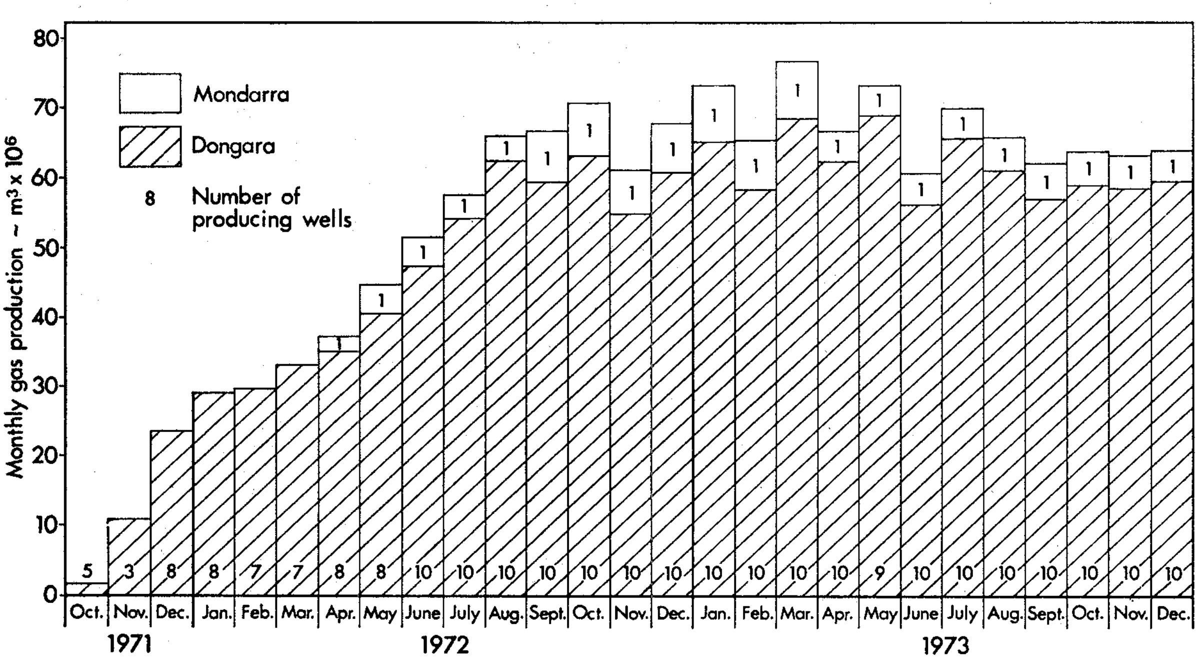

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Figure 26. Mondarra and Dongara Fields (Production Licences 1 and 2), northern Perth Basin. Monthly gas production between 25th October, 1971 and 31st December, 1973.

REFERENCES

Cope, R. N., 1972, Petroleum development and production in Western Australia in 1971: West. Australia Geol. Survey Ann. Rept. 1971, p. 43, 44.

——— 1973, Petroleum development and production in Western Australia in 1972: West Australia Geol. Survey Ann. Report 1972, p. 40-44.

Crank, K., 1973, Geology of Barrow Island Oil Field: Australian Petroleum Explor. Assoc. Jour. v. 13, pt. 1, p. 49-57.

Low, G. H., 1974, Petroleum exploration in Western Australia in 1973: West. Australia Geol. Survey Ann. Rept. 1973, p. 29-36.

Martison, N. W., McDonald, D. R., and Kaye, P., 1973, Exploration on continental shelf off northwest Australia: Am. Assoc. Petroleum Geologists, Bull. v. 57/6, p. 972-989.

Powell, T. G., and McKirdy, D. M., 1973, Crude oil correlations in the Perth and Carnarvon Basins: Australian Petroleum Explor. Assoc. Jour. v. 13, pt. 1, p. 81-85.

PALAEODRAINAGES AND CAINOZOIC PALAEOGEOGRAPHY OF THE EASTERN GOLDFIELDS, GIBSON DESERT AND GREAT VICTORIA DESERT

by J. A. Bunting, W. J. E. van de Graaff and M. J. Jackson*

ABSTRACT

The salt-lake chains of the arid interior of Western Australia are the remnants of ancient river courses. Based on topographic contour maps a reconstruction of these palaeodrainages has been made. The river systems formed between the Early Cretaceous and the Late Eocene, and have been inactive since the Middle Miocene.

The rivers in the southern part of the area studied once flowed to the Southern Ocean via the Eucla Basin, while those in the north flowed to the Indian Ocean via the Canning Basin. Extensive river capture of some southerly flowing streams has taken place by rivers that flowed to the north.

The uplift of Western Australia since the Eocene has been very uniform, and only minor tilting has occurred.

INTRODUCTION

As part of the geological mapping projects of the Officer Basin and the Eastern Goldfields topographic contour maps of the area, shown in Figure 27, were produced. These maps are of great importance for the reconstruction of palaeodrainages as marked by the present day salt-lake systems, and generally for the unravelling of the Cainozoic history of the area. The contour maps were drawn using spot-height data obtained by the Bureau of Mineral Resources during regional gravity surveys of Western Australia. Most of the State has now been covered by these surveys and the results are available as maps on 1 : 250 000 scale. The elevations of the gravity stations, which are spaced at intervals of approximately 11 km, have been determined barometrically. As a result, altimetric information for large areas of the State is available for the first time.

The aim of this paper is to present some ideas generated by the new topographic maps and information gained during the current regional mapping programme.

Gibson (1909, 1912) and Gregory (1914, 1916) were the first to interpret the numerous salt lakes in the arid interior of Western Australia as remnants of ancient river courses. Jutson (1934), on the other hand, argued that the present-day salt lakes cannot be considered as damned portions of dismembered rivers.

However, the new evidence shows that the lakes occur in broad interconnected valley systems. Some continue into relatively deep valleys with strings of small, partly interconnected lakes and are very clearly old river courses, for example those of Ponton Creek and Salt Creek (which occasionally flow today) and Serpentine Lakes. The evidence, therefore, favours the interpretation that the salt-lake systems mark old drainage lines developed during a period of considerably higher precipitation than that of today.

Since Gregory (1916) made a first attempt, a number of writers (Jackson, 1966; Morgan, 1966; Lowry, 1970; Mulcahy and Bettenay, 1972; Beard, 1973; Sullivan, 1973 among others) have presented reconstructions of parts or all of the palaeodrainage systems in Australia. These reconstructions were based on the general distribution of the salt lakes, soil mapping (Mulcahy and Bettenay, 1972), vegetation mapping (Beard, 1973), information on flows of water, and scant altimetric information. In the areas underlain by Precambrian rocks the old drainage lines are relatively well defined and easy to recognise. In the Gibson and Great Victoria Deserts, however, a thick sand dune cover in many areas makes it difficult or impossible to trace the old drainage lines directly between clay pans and salt lakes. Nevertheless, it is locally feasible to reconstruct large parts of the ancient drainage systems by tracing soil and vegetation patterns on aerial photographs. Because of the very gentle relief in most of the desert areas it is, however, difficult to take topography into account when tracing the old drainages. This has unavoidably led to serious errors in earlier reconstuctions. In the lower reaches of the major trunk valleys, where topographic relief is often nearly imperceptible, it is essential to have reliable altimetric information in order to trace the older river courses. The upper reaches of a drainage system are fairly easy to reconstruct. For example Figure 28, which was produced before the spot-height data were available, shows the palaeodrainages on the Warri Sheet area (SG/51-4).

METHOD OF CONTOURING

The barometric spot-height data are sufficiently accurate and reliable to permit topographic contouring on a regional scale, although some heights and/or positions can be shown to be inaccurate. An attempt was made to prepare computer-drawn contour maps, but this was not satisfactory, owing to the wide spacing of the data. In order to draw realistic contours all topographic information visible on air-photographs must be taken into account. This means that much of the contouring is necessarily subjective. Moreover, the data have been contoured on the assumption that the palaeodrainages form an integrated valley system, and it has been further assumed that the infilling of the valleys, which dismembered the ancient rivers, did not produce topographic irregularities of sufficient magnitude to completely obscure the valley forms. That the drainage systems were indeed integrated can be easily observed in parts of the Gibson Desert, where a dendritic dry valley system is present over Cretaceous claystones and siltstones (Fig. 28). Because of the absence of sand-dune cover even very small valleys can be recognized on air-photographs. The variations in the density of the drainage system in this area are mainly due to subsequent erosion which has obliterated some parts of the valley system.

Apart from the gravity-survey data there is also altimetric information in the form of accurately levelled benchmark traverses (only the heights shown on the maps are accurate, the plotting of the benchmark positions is often inaccurate) and other spot-height data. However, these various sets of data show systematic differences. Therefore, only the gravity-survey data have been used to determine the course and location of the contours whereas the other data have only been used to differentiate low and high areas. At a few locations a single inconsistent spot-height elevation has been disregarded but the discrepancy rarely exceeds a few metres.

Although the contours are partly interpretative, the fact that they can be drawn in the shape of integrated valley systems is very significant.

* Bureau of Mineral Resources.

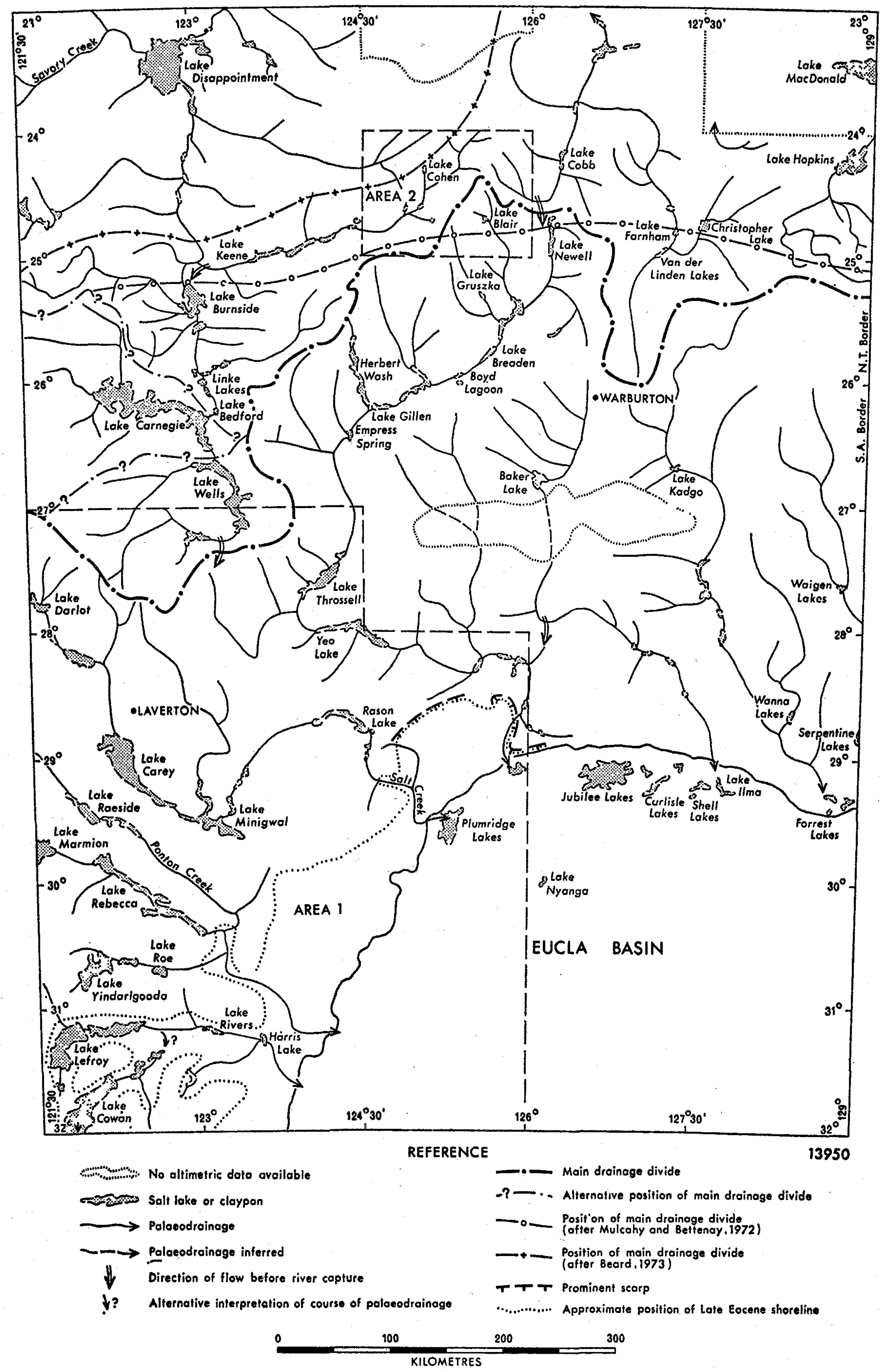

Figure 27. Palaeodrainage of part of the arid interior of Western Australia. (Inset 1, see Fig. 29; inset 2, see Fig. 28).

Figure 28. Palaeodrainage on the Warri Sheet (SG/51–4).

GENERAL ASPECTS OF PALAEODRAINAGE SYSTEMS

One important conclusion is that the major drainage divide between ancient drainage systems which once flowed to the Indian Ocean via the Canning Basin, and those systems which flowed to the Southern Ocean, generally has a more southerly position than that suggested by previous authors (Fig. 27). Another important conclusion is that the configuration of some of the drainage systems is strongly suggestive of large-scale river capture. The capture was mainly by the rivers that drained towards the northwest. The first example of river capture is the Lake Cobb system, which has captured the southeast-flowing headwaters of the Lake Throssell system (to the north of the mapped area the Lake Cobb-Lake Farnham system enters an enclosed depression which may be of relatively recent tectonic origin). The Lake Disappointment system has captured a very substantial number of streams. The northernmost of these is probably the Lake Keene system. The west-southwest orientation of the Lake Keene system strongly suggests that it originally formed part of a southwardly discharging system. As far south as Lake Bedford all originally south-flowing palaeodrainages have been captured by the north-flowing Lake Disappointment system. Though the data are not conclusive it seems very likely that Lake Carnegie and Lake Wells were also captured by the Lake Disappointment system. A third example of probable river capture is present in the Baker Lake system. From the map configuration it is inferred that the Baker Lake system was originally a tributary of the lower reaches of the Lake Throssell system. Other cases of river capture probably occur in the southwestern part of the study area, and are discussed below.

The orientation and texture of the various parts of the drainage system is determined to a large extent by bedrock geology. The finely-textured drainage pattern (Fig. 28) is characteristic of the relatively impermeable claystones and siltstones, which are mostly Cretaceous. On the predominantly sandy bedrock in the remainder of the Gibson and Great Victoria Deserts a much more coarsely textured drainage pattern is present. On the sedimentary rocks the drainage pattern is dendritic at an areal scale (Fig. 28), but at a regional scale it has a somewhat parallel aspect. The pronounced parallelism of the tributaries of the upper parts of the Lake Throssell and Baker Lake systems, that have their tributaries occurring to the northwest of the main valley, is suggestive of an extremely gentle cuesta-type topography.

Another instance where bedrock geology obviously determines the course of the palaeodrainage is that of the Lake Disappointment system, which runs almost due north-south along the contact between the Proterozoic and Phanerozoic sediments.

In the Precambrian basement areas, bedrock geology only locally affects the orientation of the palaeodrainages. In part of Lake Raeside, where it follows the eastern flank of the Edjudina Range, and parts of Lake Rebecca, there is an obvious relationship between lake orientation and basement strike.

EASTERN GOLDFIELDS, EUCLA BASIN, AND WESTERN GREAT VICTORIA DESERT

The area depicted in Figure 29 exemplifies most of the important aspects of the palaeodrainage systems in the study area.

Age of the palaeodrainages

No precise age of the palaeodrainages can be established, and it is likely that the age varies from district to district. There is, however, a concensus of opinion that since the Miocene little flow of water occurred in the rivers draining towards the Eucla Basin (Jackson, 1966; Morgan, 1966; Lowry, 1970; Beard, 1973). This contention is based on the observation that none of the major valleys which are recognizable in the Eastern Goldfields or in the Great Victoria Desert continue across the Eucla Basin, which is surfaced by

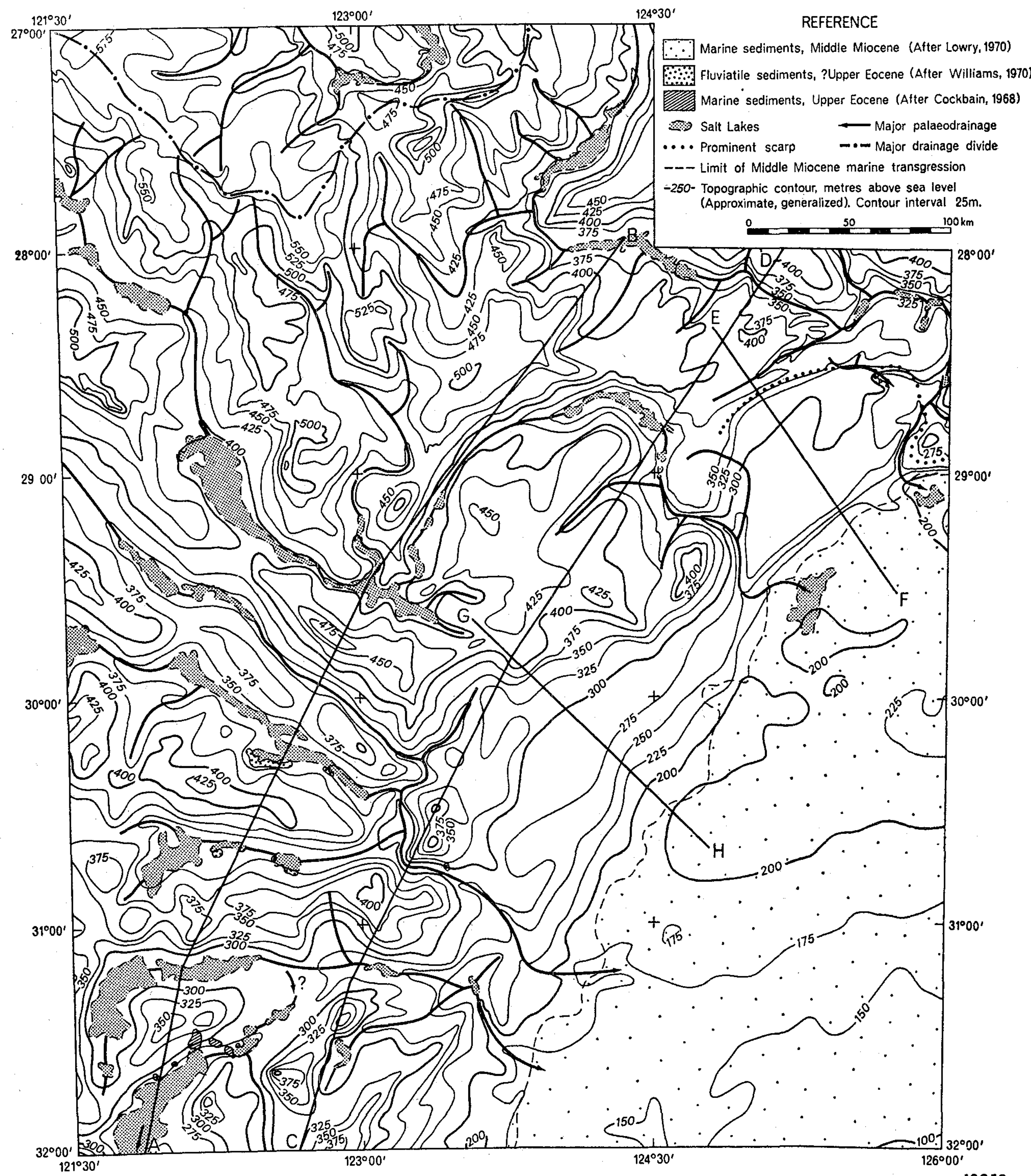

Figure 29. Topographic contour map of parts of the Eastern Goldfields, Great Victoria Desert and Eucla Basin.

Miocene limestone. At the discharge points of some of the valleys along the basin margin, groups of salt lakes have formed, e.g. Forrest Lakes, Plumridge Lakes. Other palaeodrainages have not given rise to any major salt lake at the discharge point, e.g. Ponton Creek. Also there are some salt lakes on the northern part of the Eucla Basin area which have no obvious relationship with a palaeodrainage discharge point (Jubilee Lakes). Though Lowry (1970) has mapped a number of ancient drainage lines in the Eucla Basin area, these do not appear to be related to the integrated systems farther north. The inference is that although some rivers which flowed across part or all of the Eucla Basin did exist in Late Miocene or more recent times, they were of relatively minor importance. The valley systems in the adjoining areas must have formed before the sea finally retreated from the Eucla Basin. As the youngest sediments in the Eucla Basin are of Middle Miocene age, the palaeodrainages are of pre-Middle Miocene age.

The distribution of laterite also points to a pre-Middle Miocene age for the palaeodrainages. A laterite duricrust is widespread in the area, except in the Eucla Basin where it is conspicuously absent. The lateritic crust follows the shape of the valley (cf. Mulcahy and Bettenay, 1972, p. 353) and therefore must have formed while valley formation was still taking place. Under the present arid to semi-arid climate laterite cannot form; substantially higher precipitation is necessary for the formation of a lateritic profile. It is obvious that for the formation of a well-developed river system, such as depicted in the accompanying illustrations, a high humidity climate is required. Jennings (1967 a, b) and Lowry (1970) argue, mainly on the basis of geomorphological evidence, that for long periods, since the Miocene, the climate of the Eucla Basin has never been much more humid than at present.

Geomorphological evidence on the Neale Sheet area permits palaeodrainages in the Great Victoria Desert to be more accurately dated. Across the Neale Sheet area runs a scarp (Fig. 29, also Lowry, 1970, Fig. 52), which separates a plain of very gentle relief in the south from the undulating laterite surface in the north (N.B. only the approximate position of the crest of the scarp is shown on the maps). The maximum height of the scarp is of the same order as the contour interval, and therefore it does not stand out very clearly on the contour map (Fig. 29). In the field, however, it is quite conspicuous and it is expressed very clearly on aerial photographs.

The scarp and the plain to the south have been modified only slightly by the palaeodrainages. Even where the Lake Throssell river system crossed the scarp there is no incised valley. Some palaeodrainages can be traced across the plain, but topographic relief is much more gentle and subdued than the adjoining parts of the Great Victoria Desert. Thus it is probable that the palaeodrainages system formed before the development of the scarp and plain, but that some flow continued afterwards.

The scarp and the rather featureless plain to the south are interpreted as a marine erosion scarp and platform. They occur at considerably higher elevations than the northernmost marine sediments of Middle Miocene age (29°S, 126°E). The scarp has been lateritized and is therefore older than the unlateritized Miocene sediments. It seems most likely that the scarp and plain formed during the Late Eocene transgression, represented in the Eucla Basin by the Wilson Bluff and Toolinna Limestones and in the Eastern Goldfields by the Eundynie Group. In the Gibson Desert the palaeodrainage systems developed on Lower Cretaceous strata and therefore the main period of major valley formation in the Gibson and Great Victoria Deserts was between the Early Cretaceous and Late Eocene. On those areas of the Precambrian shield not covered by the Early Cretaceous transgression the palaeodrainage features may, in part, be much older.

The Late Eocene Marine Transgression

Marine sediments consisting of spongolite, dolomite and limestone, collectively called the Eundynie Group outcrop along the shores of Lake Cowan. These have been dated on fossil evidence as Late Eocene (Cockbain, 1968). Similar spongolite crops out on the northern side of Ponton Creek 3 km south of Cundeelee Mission. The Lake Cowan sediments range in elevation from 270 to 300 m and the Ponton Creek outcrop is at 300 m. The range in elevation of the base of the possible Late Eocene scarp mentioned above is about 270 to 320 m. This range may be due to minor tilting, but erosion and sand migration subsequent to its formation are equally likely interpretations. It has to be stressed however, that only the crest of the scarp has been mapped. The position and elevation of its base are unknown as it is covered by recent sediments. The approximate limit of the Late Eocene transgression can therefore be drawn at about the 320 m contour in the Neale-Plumridge area, gradually falling to 280 m at Lake Cowan. The change in elevation is similar in magnitude to that shown by the Middle Miocene shoreline (see Fig. 29) and is probably due to slight warping of the shield. The position of the Late Eocene shoreline is also illustrated by profiles E-F and G-H (Fig. 30). Profile E-F shows two distinct steps, a lower one with the western limit of Miocene sediments at its base, and an upper one, between 325 and 375 m marking the prominent scarp. Two similar, if more subdued steps occur along line G-H.

Lowry (1970, p. 156-157) suggests that the 1 000 ft (305 m) contour is the limit of the Late Eocene transgression and shows an arm of sea extending inland to include the whole of Lake Rebecca. It is probable that this arm extended no farther than the lowermost reaches of Lake Rebecca. Pre-laterite fluviatile sediments of possible Late Eocene age (Williams, 1970) occur along the shores of Lake Rebecca and Lake Roe indicating that these areas may have been continental at that time.

Topographic Profiles

Two profiles, A-B and C-D are shown in Figure 30. These are approximately 180 and 100 km respectively from the line marking the western limit of Miocene marine sediments. Profile A-B shows a steady rise in elevation from SW to NE. This is best illustrated by the successive steps of the salt lake floors from Lake Cowan (265 m) to Lake Minigwal (395 m). The trend continues south of Lake Cowan with a further fall of 20 m to Lake Dundas. The magnitude of the steps is generally greater than the gradual falls along the lengths of the individual lakes (e.g., the Lake Carey-Minigwal system drops only 10 m in 200 km). It is suggested that these features could be due to a gentle upwarp of the shield after the development of the river system but before the Late Eocene marine transgression. The same warping could account for the capture of Lake Minigwal by the Lake Rason system.

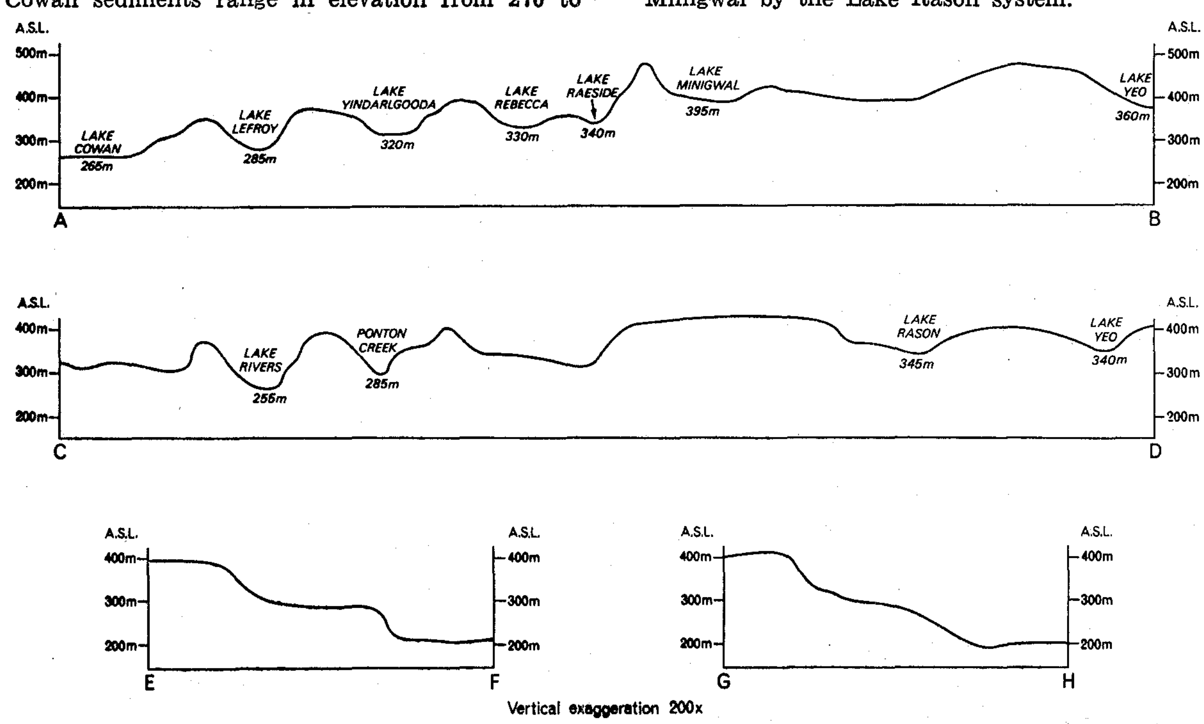

Figure 30. Topographic profiles (for location of section lines see Fig. 29).

INDIVIDUAL DRAINAGE SYSTEMS

Some of the features of the area shown on Figure 29 will now be discussed from the viewpoint of the individual drainage systems.

Lake Throssell System

One of the most conspicuous features of the Lake Throssell system is the sharp change in direction between Lake Throssell and Lake Yeo. The southwest flowing Lake Throssell drainage turns abruptly on approaching the Archaean Yilgarn Block, and continues east-southeast, roughly parallel with the edge of the shield, through Lake Yeo. Minor uplift and tilting of the shield margin early in the development of the drainage system may have contributed to the sharp change in direction.

Lake Carey—Minigwal system

Most major lake systems draining the eastern Yilgarn Block discharge southeastward into relatively narrow, deep valleys (e.g., Ponton Creek, Salt Creek). These disappear at the westernmost limit of the Miocene marine sediments. The Lake Carey-Minigwal system is unusual in having no such valley. It appears not to have reached even the Eocene coastline, although it may at some stage have flowed into the northern reaches of Ponton Creek. It is suggested that at some time before the Late Eocene, the Lake Carey-Minigwal system was captured by the Lake Rason system possibly due to crustal uplift, and subsequently flowed to the Eucla Basin via the Salt Creek system.

Lake Raeside system

The Lake Raeside system and its tributaries, the Lake Rebecca and Lake Yindarlgooda systems, discharged through the deeply incised Ponton Creek. The distinctly parallel Lakes Raeside and Rebecca make an angle of about 30 degrees with the general strike direction of the Archaean basement rocks.

Lake Lefroy system

The Lake Lefroy system probably discharged through Harris Lake into the Eucla Basin. The topographic data, however, are inconclusive and it is possible that Lake Lefroy drained through Lake Cowan. It is more likely that when the palaeodrainages ceased regular flow the Lake Cowan system was on the point of capturing the upper reaches of the Lake Lefroy system. That the Lake Cowan system was actively capturing streams at that time is indicated by the presence of a northwestward-trending tributary which logically would have formed part of the Lake Lefroy system.

CONCLUSIONS

The uplift of the central parts of Western Australia since the Miocene has been remarkably uniform with only minor warping. This is clearly demonstrated by the fact that palaeodrainages which formed before the Late Eocene and which stopped flowing during or soon after the Middle Miocene, can be reconstructed by drawing topographic contours of the present land surface. The same very gentle uplift is demonstrated by the gentle slope to the south of the Middle Miocene shoreline. The position of this shoreline corresponds approximately with the present extent of the Eucla Basin. The general evidence of the Late Eocene transgression around the 300 m contour also indicates uplift with very little tilting (Johnstone and others, 1973), although there was probably some upwarping in pre-Late Eocene times centred on Lake Minigwal.

REFERENCES

Australia Bur. Mineral Resources, Reconnaissance 1 : 250 000 gravity maps of W.A., 1962-1972.

Beard, J. S., 1973, The elucidation of palaeodrainage patterns in Western Australia through vegetation mapping; Vegetation Survey of Western Australia: Vegmap Publications, Occasional Paper No. 1.

Cockbain, A. E., 1968, Eocene foraminifera from the Norseman Limestone of Lake Cowan, Western Australia: West. Australia Geol. Survey Ann. Rept. 1967, p. 59-60.

Gibson, C. G., 1909, The geological features of the country lying along the route of the proposed Transcontinental Railway in Western Australia: West. Australia Geol. Survey Bull. 37.

——— 1912, Geology of Kalgoorlie and Boulder, *in* Contributions to the study of the geology and ore deposits of Kalgoorlie, East Coolgardie Goldfield, by E. S. Simpson and C. G. Gibson: West. Australia Geol. Survey Bull. 42, p. 11-56.

Gregory, J. W., 1914, The lake system of Westralia: Geographical Jour. v. 43, p. 656-664.

——— 1916, The central lakes of Westralia and the Westralian peneplain: Geographical Jour. v. 48, p. 326-331.

Jackson, P. R., 1966, Geology and review of exploration, Officer Basin, Western Australia: Hunt Oil-Hunt Petroleum-Placid Oil Rept. (unpublished).

Jennings, J. N., 1967a, Some karst areas of Australia, *in* Jennings, J. N.. and Mabbut. J. A., Eds., Landform studies from Australia and New Guinea: Canberra, Australia Nat. Univ. Press, p. 256-292.

——— 1967b The surface and underground geomorphology, *in* Dunkley, J. R., and Wigley, T. M., Eds., Caves of the Nullarbor: Sydney, Speleol. Research Council, p. 13-31.

Johnstone, M. H., Lowry, D. C., and Quilty, P. G., 1973, The Geology of south-western Australia —a review: Jour. Royal Soc. West Australia, v. 56, p. 5-15.

Jutson, J. T., 1934, The physiography (geomorphology) of Western Australia: West. Australia Geol. Survey Bull. 95.

Lowry, D. C., 1970, Geology of the Western Australian part of the Eucla Basin: West. Australia Geol. Survey Bull. 122.

Morgan, K. H., 1966, Hydrogeology of the East Murchison and North Coolgardie Goldfields: West. Australia Geol. Survey Ann. Rept. 1965, p. 14-19.

Mulcahy, M. J., and Bettenay, E., 1972, Soil and landscape studies in Western Australia: The major drainage divisons: Geol. Soc. Australia Jour., v. 18, p. 349-358.

Sullivan, M. E., 1973, Drainage disorganisation of the Western Australian river-lakes: Australian New Zealand Assoc. Adv. Sci. (ANZAAS), Abstracts, 45th Congress, Perth; section 21, p. 105.

Williams, I. R., 1970, Kurnalpi, W.A.: West. Australia Geol. Survey 1 : 250 000 Geol. Series Explan. Notes.

RECENT PROGRESS ON THE PRECAMBRIAN STRATIGRAPHY OF WESTERN AUSTRALIA

by R.D. Gee

INTRODUCTION

The accompanying chart summarizes recent progress on the Precambrian stratigraphy of Western Australia (Fig. 31). It updates the summary of Horwitz (1968), and is presented within the framework of the Precambrian tectonic units after Daniels and Horwitz (1969). The subdivision of the Yilgarn Block is after "The Geology of Western Australia" (G.S.W.A., in press).

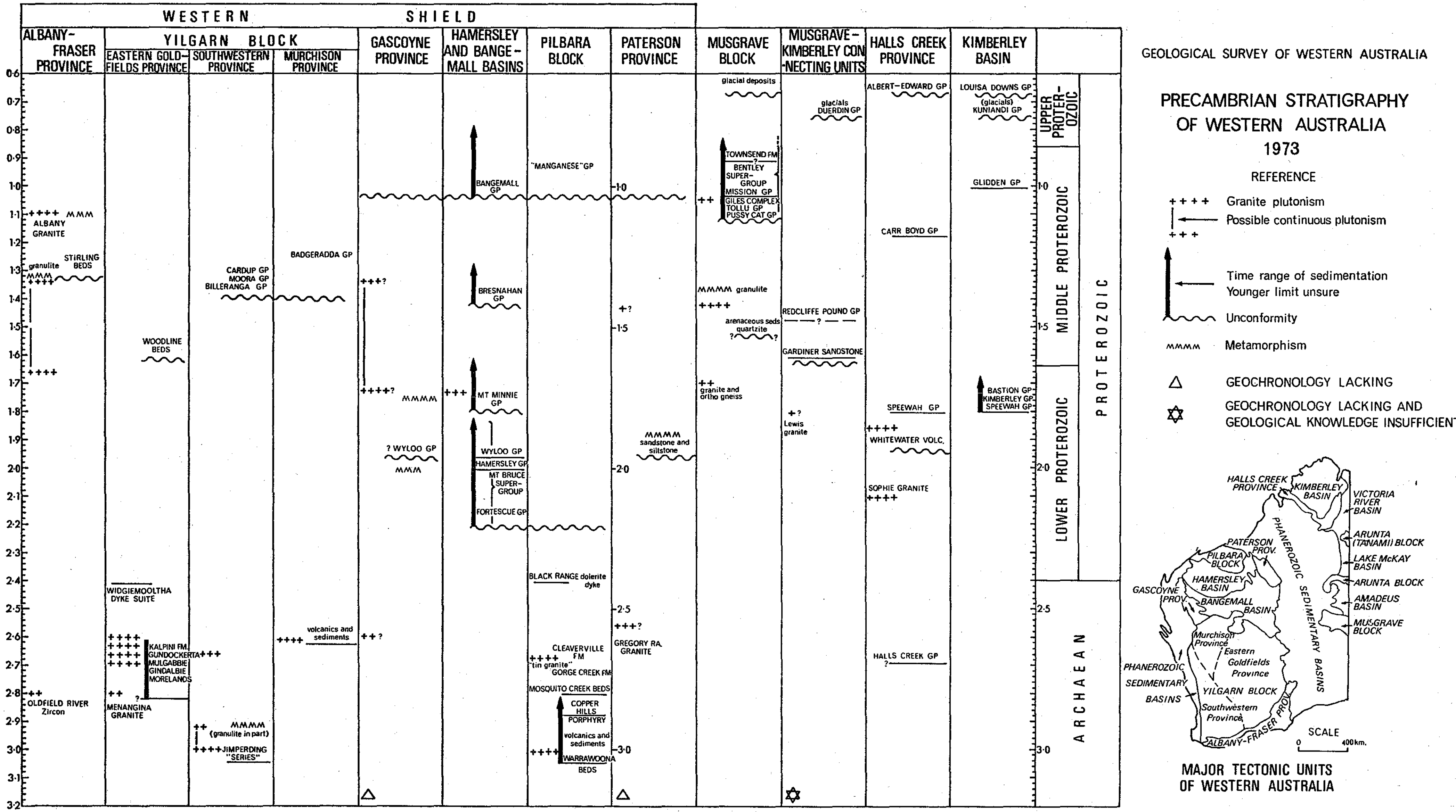

Figure 31. Precambrian stratigraphy of Western Australia.

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RECENT GEOCHRONOLOGY

A joint geochronology programme between the Geological Survey of Western Australia and the Western Australian Institute of Technology has been operating since 1968. The more notable results include a younger limit of 2 200 m.y. for the base of the Mount Bruce Supergroup (de Laeter and Trendall, 1971), and the confirmation of two episodes of granite intrusion of 3 120 m.y. and 2 670 m.y. in the Pilbara Block (de Laeter and Blockley 1972). Geochronology studies at the Australian National University have documented a period of widespread granitic activity in the Yilgarn Block at 2 600-2 700 m.y., and an earlier period of plutonism and high-grade metamorphism at 2 900-3 100 m.y. that was confined to the Southwestern Province (Arriens, 1971). Finally, there is an age of 1 630 m.y. on the glauconitic Gardiner Sandstone that unconformably overlies the basement rocks of the Tanami Block (Blake, Hodgson and Muhling, 1973).

SUBDIVISION OF THE PRECAMBRIAN

The Geological Survey of Western Australia uses a two-fold subdivision of the Precambrian. The Western Shield contains two roughly equant cratonic blocks of mostly granitic and volcanogenic rocks that record ages (whole-rock Rb/Sr) older than 2 600 m.y. These blocks are surrounded by either thick basins of continental-type sediments, or wide belts of metamorphism and plutonism that record ages younger than 2 200 m.y. This forms the basis of two divisions which are conveniently called Archaean and Proterozoic. On geological grounds the natural position of the boundary in Western Australia lies somewhere between 2 600 m.y. and 2 200 m.y. although it should be noted that the base of the Mount Bruce Supergroup may be older than that shown on the chart. The boundary at present is set at 2 400 m.y. by a date on the Widgiemooltha Dyke Suite. This allocation is justified on the premise that the mafic dykes, that cut both the Yilgarn and Pilbara Blocks, indicate stabilization of the Archaean terrains. The current application of this figure (2 400 m.y.) does not preclude the possibility that the boundary may be diachronous. It will be noted that there is a tendency here to use the term Archaean in a tectonic sense rather in a strict time sense.

For descriptive regional geology, the Survey does not use a time-stratigraphic subdivision of the Proterozoic. Such studies are fitted to a framework of rock-term stratigraphy, magmatism, metamorphism and isotopic ages. However, for convenience in communication, especially with the limited number of isotopic dates available at present, the terms Lower, Middle and Upper Proterozoic are used. The boundaries (1 640 m.y. and 880 m.y.) although taken from the Canadian Shield (Stockwell, 1964), are arbitrary, and bear no implied relationship to major tectonic and magmatic cycles in the Western Shield of Australia. There are no present intentions to vary these figures to follow the changes in the boundaries in Canada (for example, Stockwell, 1970, p. 51; Stockwell, 1972), or to bend the boundaries to fit major geological events in the Western Shield. The status of the terms Lower, Middle and Upper may well decline and become informal adjectives.

The outline of a single sedimentary-magmatic cycle is emerging for the entire Western Shield. This involves long and continued sedimentation commencing no later than 2 200 m.y., followed by widespread metamorphism and plutonism peaking at about 1 400 m.y., and terminating at about 1 100 m.y. The resultant terrains are unconformably overlain by gently folded and unmetamorphosed sedimentary rocks of an age about 800-1 000 m.y. It is considered premature to erect a time-stratigraphic sub-division punctuated by major events of the above nature. In view of the possibility of diachronous tectonic events on a continental or global scale, it is questionable whether such an approach is even desirable. As an example of the possible difficulties that this approach may encounter, it is notable that the base of the Carpentarian (Dunn, Plumb and Roberts, 1966) in the Kimberley area, has no counterpart in the Western Shield.

ARCHAEAN STRATIGRAPHY

Recent geological mapping has concentrated on the Archaean terrains of the Yilgarn Block, of which 40 per cent are now mapped. Data are presented on lithological maps, but stratigraphic analyses have employed the concept of the association (Williams, 1973). The Archaean succession is composed of consanguineous lithological groups, for example mafic volcanic, felsic volcanogenic, arenaceous groups. The individual lithologies may be complex, but are related by a consistent spatial association, and a common volcanic or sedimentary regime. The associations are formalized and generally given formational status. The association is related to the formal term "group" (Australian Code of Stratigraphic Nomenclature, 1964), although this latter term has not been used because the constituent units of the association are generally not established.

Superposition of associations has been demonstrated in several places, especially in the Eastern Goldfields Province, where the multicycling of several mafic and felsic associations is recognized. Within the Archaean succession consistent stratigraphical relationships between associations can be deduced from facing evidence and established regional fold structures. A regional, composite stratigraphic succession can then be postulated. However, where discrete volcanic centres or piles are identified and lateral variation occurs between volcanic rocks and volcanoclastic sedimentary rocks, the correlations can be tenuous.

The search for a sialic basement to the Archaean granite-volcanogenic terrains has not been successful. Current concepts of mantle-derived granite and "primitive" oceanic basaltic crust, which derive support from geochemical, petrological and isotopic studies, are not inconsistent with the data of regional mapping. However, there is evidence of a protonucleus of highly metamorphosed pelitic, psammitic and calcareous sedimentary rocks in the Southwestern Province of the Yilgarn Block.

REFERENCES

Arriens, P. A., 1971, The Archaean geochronology of Australia: Geol. Soc. Australia, Special Publication No. 3, p. 11-23.

Australian Code of Stratigraphic Nomenclature, (Fourth Edition) 1964: Geol. Soc. Australia Jour. v. 11, pt. 1, p. 165-171.

Blake, D. H., Hodgson, I. M., Muhling, P. C., 1973, The Geology of the Granites and Precambrian areas of the Lucas, Billiluna and Stansmore 1 : 250 000 Sheet areas, W.A.: Australia Bur. Mineral Resources, Rec. 1973-171 (unpublished).

Daniels, J. L., and Horwitz, R. C., 1969, Precambrian tectonic units of Western Australia: West. Australia Geol. Survey Ann. Rept. 1968, p. 37-38.

de Laeter, J. R., and Blockley, J. G., 1972, Granite ages within the Archaean Pilbara Block, Western Australia: Geol. Soc. Australia Jour. v. 19, pt. 3, p. 363-370.

de Laeter, J. R., and Trendall, A. F., 1971, The age of the Gidley Granophyre: West. Australia Geol. Survey Ann. Rept. 1970, p. 62.

Dunn, R. R., Plumb, K. A., and Roberts, H. G., 1966, A proposal for time-stratigraphic subdivision of the Australian Precambrian: Geol. Soc. Australia Jour. v. 13, pt. 2, p. 593-608.

Horwitz, R. C., 1968, Provisional subdivisions of the Precambrian in Western Australia: West. Australia Geol. Survey Ann. Rept. 1967, p. 44.

Stockwell, C. H., 1964, Fourth report on structural provinces, orogenies and time-classification of rocks of the Canadian Shield: Canada Geol. Survey Paper 64-17.

——— 1970, Introduction, Geology of the Canadian Shield: *in* Geology and Economic Minerals of Canada, Economic Geology Report No. 1: Canada Geol. Survey, Paper 72-52.

——— 1972, Revised Precambrian time scale for the Canadian Shield; Canada Geol. Survey, Paper 72-52.

West. Australia Geol. Survey, in press, The Geology of Western Australia, Mem. No. 2.

Williams, I. R., 1973, Kurnalpi, W. A.: West Australia Geol. Survey 1 : 250 000 Geol. Series Explan. Notes.

STRUCTURAL SUBDIVISION OF THE EASTERN GOLDFIELDS PROVINCE, YILGARN BLOCK

by I. R. Williams

ABSTRACT

The Eastern Goldfields Province of the Archaean Yilgarn Block is divided into three units, called from west to east, the Southern Cross, Kalgoorlie and Laverton Subprovinces. The subprovinces have distinctive structural, lithological and geochemical characteristics. However, the Southern Cross and Laverton Subprovinces show petrogenetic and structural similarities which can be interpreted in terms of a broadly analogous origin. In contrast the central Kalgoorlie Subprovince contains many unique structural and lithological elements. Structural and stratigraphic discontinuities occur at the junctions between the subprovinces.

The Kalgoorlie Subprovince has been the locus of long-term instability. It is postulated that instability is related to incipient development of a trough, graben or rift-like structure within earlier-formed Archaean crustal material. The uniqueness of the Kalgoorlie Subprovince is further expressed by its economic wealth. The subprovince has produced 75 per cent of the gold and contains over 96 per cent of known nickel reserves in Western Australia.

INTRODUCTION

The subdivision of the Eastern Goldfields Province is largely based on 1 : 250 000 scale regional mapping by the Geological Survey over the last ten years. More than fifty per cent of the province has now been mapped and the results published in an Explanatory Note Series. Photogeological interpretation has now been used in the unmapped adjoining areas of the province. Geophysical data, particularly total magnetic intensity maps, issued by the Bureau of Mineral Resources, Canberra, and geochemical and petrological information from publications and theses of the C.S.I.R.O. and University of Western Australia, have also been taken into account. All sources of information are gratefully acknowledged.

The subdivision of the Eastern Goldfields Province is provisional and stems from an attempt to explain the regional distribution of the major lithologies. This distribution supports the concept of structural, petrological and probable geochemical domains within the province. All three aspects are in some way related to puzzling north to north-northwest trending major tectonic lineaments, recently found in the Archaean terrain (Williams and others, 1971; Gower and Bunting, 1972).

This subdivision also attempts to place in perspective the mineralized zone that extends from Norseman to Wiluna, a zone colloquially called the "nickel belt".

REGIONAL SETTING

The Eastern Goldfields Province (G.S.W.A., The Geology of Western Australia, in press) occupies an area of about 325 000 km^2 and roughly constitutes the eastern half of the Archaean Yilgarn Block (Daniels and Horwitz, 1969). The boundaries of the province are loosely defined, pending the completion of regional mapping, and in many cases mark the erosional rather than the real extent of the Archaean rocks. The northern and eastern boundaries and south-western corner of the province are irregular erosional boundaries. In these areas the Archaean terrain is unconformably overlain by the Proterozoic Bangemall Basin sediments (c. 1 000 m.y.), Permian Officer Basin sediments and the Proterozoic Barren Beds (more than 1 150 m.y.), respectively. The southeastern and southern extension of the Eastern Goldfields Province is terminated by a linear tectonic, high-grade, polymetamorphic and magmatic belt (mobile zone) called the Albany-Fraser Province (less than 1 660 m.y.) The western boundary is an arbitrary line which separates structural disparities within the Yilgarn Block. It is gently arcuate, with convexity westwards. The boundary occurs over granitic rocks and it does not cross linear or arcuate greenstone belts (metamorphosed volcanic and sedimentary assemblages). However, the boundary passes over an immense layered mafic body, the Windimurra Complex (de la Hunty, 1970), which is situated 50 km east of Mount Magnet.

The western boundary separates the north-northwesterly trends of the Eastern Goldfields greenstone belts from the northeasterly trending belts of the Murchison Province and from the high-grade metamorphic terrain (granulite) and greenstone-deficient region of the older (about 3 000 m.y.) Southwestern Province (Fig. 32 A).

STRUCTURAL AND STRATIGRAPHIC ELEMENTS OF THE EASTERN GOLDFIELDS PROVINCE

The Archaean terrain of the province can be divided into two major components; the intrusive granite-migmatite-gneiss areas and the greenstone belts. Although the former occupies about 70 per cent of the area, it is petrologically, chemically and structurally the lesser known entity. The contents of the greenstone belts, on the other hand, have been studied in detail for at least 60 years, particularly in the southeastern portion of the province (MacLaren and Thompson, 1913; Woodall, 1965; Prider, 1965; Horwitz and Sofoulis, 1965; Williams, 1969; Glikson, 1971; Hallberg, 1972). Although most lithologies are now well documented, proposed stratigraphic, structural and genetic models remain controversial.

STRUCTURAL ELEMENTS OF THE GREENSTONE BELTS

The regional shape of the greenstone belts (the present visual extent and not the presumed original extent) is attributed to a complex interplay of tectonic, igneous and erosional events (see Fig. 32 B). The shapes vary from narrow arcuate belts, sometimes linked by "bow-tie" structures (see Barlee Sheet, total magnetic intensity map, Bureau of Mineral Resources) in the Southern Cross-Sandstone region to large irregular (vermiform) regions with linear appendages in the Norseman-Kalgoorlie-Wiluna region. Smaller isolated linear metamorphic belts occur along the eastern margin of the province.

The internal structure of the narrow (less than 50 km in width) greenstone belts is mostly synclinal, the thickest accumulation of volcanic and sedimentary rocks occurs towards the central axis. In some cases homoclinal sequences and major anticlinal structures may dominate individual greenstone belts of this type, e.g. Bremer Range area, Lake Johnston Sheet area (Gower and Bunting, 1972). Such structures suggest a wider distribution of volcanic and sedimentary assemblages than is now preserved. The linkages have been disrupted and removed by later granitic intrusion. The major fold axes are roughly parallel to the elongation of the greenstone belt. The arcuate greenstone belts are draped around concordant domal granite-migmatite complexes. In detail the complexes are intrusive, have contact metamorphic aureoles and xenolith-rich margins. Shearing and normal faulting at the margins suggests diapiric emplacement. The configuration of the greenstone belts in the Southern Cross-Sandstone region, and to a lesser extent in the eastern margin of the province. is attributed to the emplacement of granitic bodies. There appears to be a close connection between rising granitic domes and concomitant downsagging of the greenstone belts.

Various structural relationships are present in the large complex greenstone belt of the central part of the province. The Archaean layered succession can be traced continuously (allowing for superficial cover) for over 800 km from south of Norseman to the Wiluna area. The greenstone terrain reaches a maximum width of about 200 km. Thick stratigraphic sequences are common, and the maximum known thickness of about 27 km occurs in the Kalgoorlie-Norseman region (McCall, 1969; Doepel, in press; Williams, 1970).

Major fold axes, trending north-northwest, dominate the central region. They are linear rather than arcuate, and are commonly truncated by discordant composite granitic bodies. North-northwest-trending anticlinal structures are commonly intruded by small granitic plutons, e.g. Edjudina Anticline (Williams and others, 1971). This structural-magmatic relationship is different from that in the Southern Cross-Sandstone region where the granitic rocks are coeval rather than subsequent to major structures.

The differing styles of greenstone belts can be emphasized by simplifying their gross shape (Fig. 32C). The narrow linear and arcuate belts can be represented by a single line which is the elongation direction of the belt (this trend direction is also roughly parallel to the major fold axes). In complex belts the regional foliation, magnetic trends, fold axes and gross outline of the granite-greenstone contact have all been taken into account. This simplification may require several representative trend lines.

The arcuate style and northerly pre-granite trend of the greenstone belts in the western third (Southern Cross-Sandstone region) contrasts with the style of other areas which are more linear and have a dominant north-northwest trend. This latter style is evident in the central Norseman-Wiluna region of the province. Remnants of the arcuate style are possibly present in the northeast corner of the province.

LINEAR DISRUPTION ZONES

The pattern of the simplified trends suggests that there are a number of major, linear disruption zones along which lithological and structural trends terminate or change direction (Fig. 32D). The zones diverge south-southeasterly across the province from Wiluna region towards the southern boundary. The more westerly zones extend from west of Wiluna to the vicinity of Ravensthorpe. They lie between the arcuate greenstone belts of the Southern Cross-Sandstone region and the extensive linear belts of the Norseman-Wiluna region. Sections of the western zones correspond to established faults, shear zones and air-photograph and aeromagnetic lineaments. However, the continuity of these zones has been disrupted by granitic intrusions. The plutons form part of a continuous north-trending zone of coelesced bodies, commonly porphyritic, which are roughly coincident with the western zone. Consequently there is no physical connection between the greenstone belts on either side of this zone. Geological mapping of the Lake Johnston 1 : 250 000 Sheet area has shown that these granitic bodies may be dilational (Gower and Bunting, 1972). The movement along the western zone is not conclusive but an east-block-down movement is present along some sections.

The easterly disruption zones occur mainly within the greenstone belts and are rarely intruded by later granitic bodies. A prominent lineament in this zone extends from the Mount Keith area southeast past Leonora, to the Mulgabbie area. It corresponds with the Mount Kilkenny Fault (Williams and others, 1971), and is here called the Keith-Kilkenny Lineament. A parallel lineament that extends through Mount Celia has been called the Mount Celia Fault (Williams and others, 1971). In places the easterly zones appear to be intruded by dykes of ultramafic material, for example in the Mount Keith area. Truncation of regional magnetic trends and splay "faults" are characteristic features of the eastern zones. In contrast to the western zone, the stratigraphy can be correlated across the eastern zones and a consistent west-block-down movement can be deduced. The regional setting for the zones is given in Figure 32D.

Regional mapping has revealed numerous less continuous strike faults and lineaments in the layered succession. (The term "strike-fault" is used for a fault whose strike is parallel with the regional strike of the surrounding rocks, and does not necessarily imply strike slip movement.) These faults are concentrated in the central part of the province between the major western and eastern linear disruption zones. The Boulder Fault (Woodall, 1965), Hampton, Mount Monger and Claypans Faults (Williams, 1970) and Yilmia dislocation (McCall, 1969) belong to this category. The faults appear to decrease in frequency away from this region and although parallel faults and lineaments persist in the Laverton region they are not common in the Southern Cross-Sandstone region (see Fig. 33A).

STRATIGRAPHIC STRUCTURAL RELATIONSHIPS

The stratigraphy of the southwestern portion of the province is reasonably well documented (McCall, 1969; Doepel, in press; Williams, 1970; Glikson, 1971; Williams and others, 1971; Gower and Bunting, 1972). Although a wide variety of lithologies is present, a natural two-fold subdivision, formulated on the dominant volcanic rock type can be established. These groupings were called by Williams (1969) basic volcanic and acid volcanic-clastic associations. More recently, the terms mafic-ultramafic and felsic-clastic associations have been favoured (Williams and others, 1971). Williams (1969) noted the cyclical repetition of the associations and suggested that volcanic cycles may principally be responsible. Formalized stratigraphy and numbered volcanic cycles were adopted for the Kurnalpi and Edjudina Sheet areas (Williams, 1970; Williams and others, 1971).

Stratigraphic review has shown that the youngest Archaean rocks (2 600 m.y.), belonging to cycles 2 and 3, predominate in the Norseman-Wiluna region that lies between the eastern and western disruption zones. Outside this region the equivalent stratigraphic levels are confined to major synclinal structures. In contrast, stratigraphically older rocks are confined to the cores of large anticlinal structures within the Norseman-Wiluna region (e.g. Bulong Anticline, Williams, 1970). However, they constitute the major part of the succession in the Laverton region which lies northeast of the eastern zone (Keith-Kilkenny Lineament). It is not possible, at this stage, to define the relative stratigraphic position of the rocks in the Southern Cross-Sandstone region. Lithological associations suggest that the rocks are probably slightly older than the cycles 2 and 3 of the Norseman-Wiluna region. The Bremer Range belt, lying midway between the Norseman area and the southern extension of the Southern Cross belt, consists mainly of cycle 1 rocks (Gower and Bunting, 1972).

The distribution of cycle 2 and 3 in the Kurnalpi Sheet area is controlled by north-northwest fold axes (Williams, 1970). Cycle 1 rocks are confined to cores of the larger north-northwest-trending anticlinal structures and are independently folded about north-trending, variably plunging, axes. Hence the older fold generation is oblique to the younger north-northwest-trending fold period and the cycle 2 rest unconformably on cycle 1 rocks. Local unconformities are also present within individual cycles. Many of the large granitic bodies in this region are concordant with the younger fold trends but truncate the older fold trend.

Regional mapping has indicated that cycle 1 rocks predominate in the Laverton region and both north and north-northwest fold trends occur in this region. Cycle 2 rocks are preserved only in long, sinuous north-northwest-trending synclines which are in most cases closely connected to regional strike faults (Williams and others, 1971). These faults have a consistent west-block-down movement and are thought to be genetically related to the eastern linear disruption zone (see Fig.

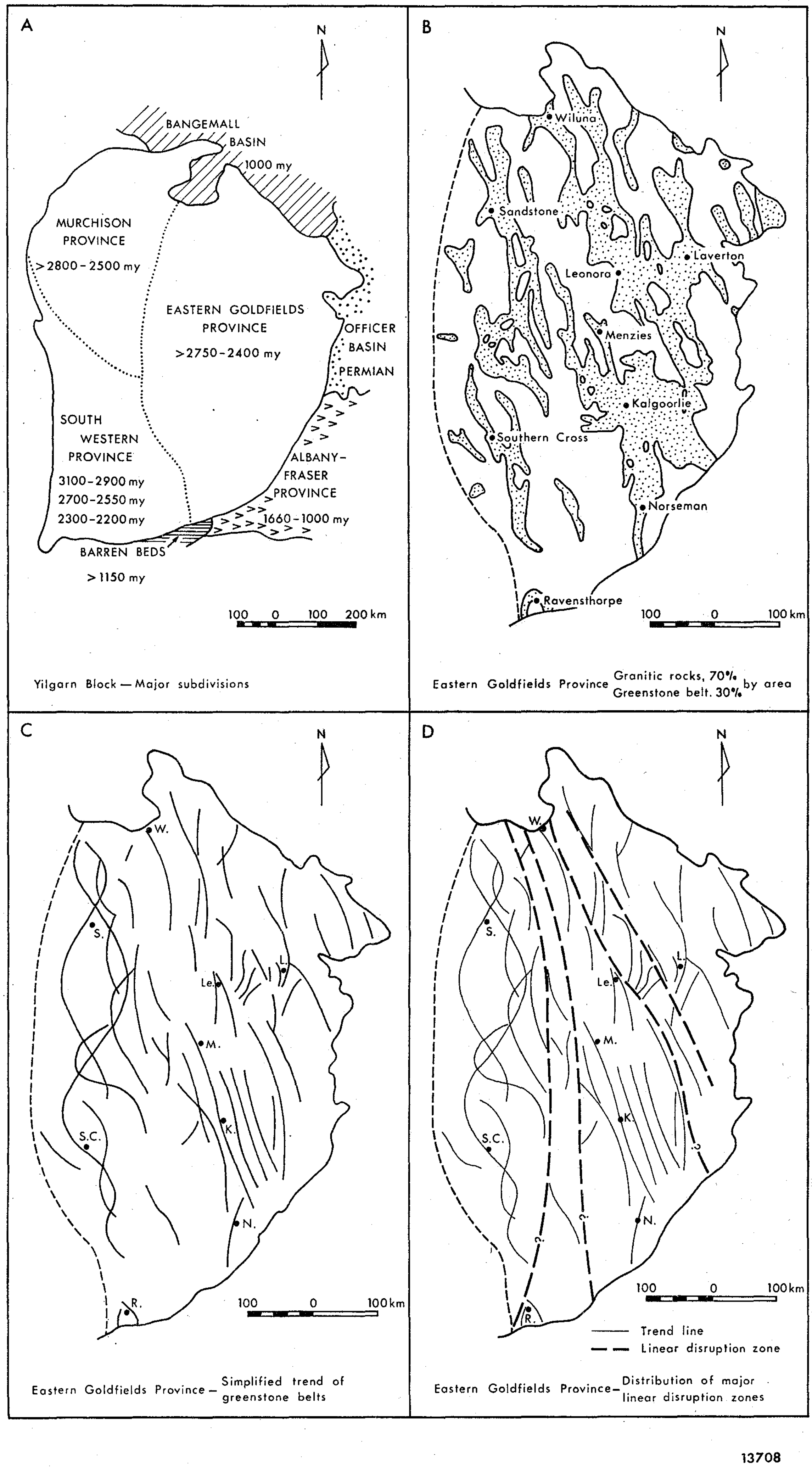

Figure 32. Structural subdivisions of the Eastern Goldfields Province, Yilgarn Block.

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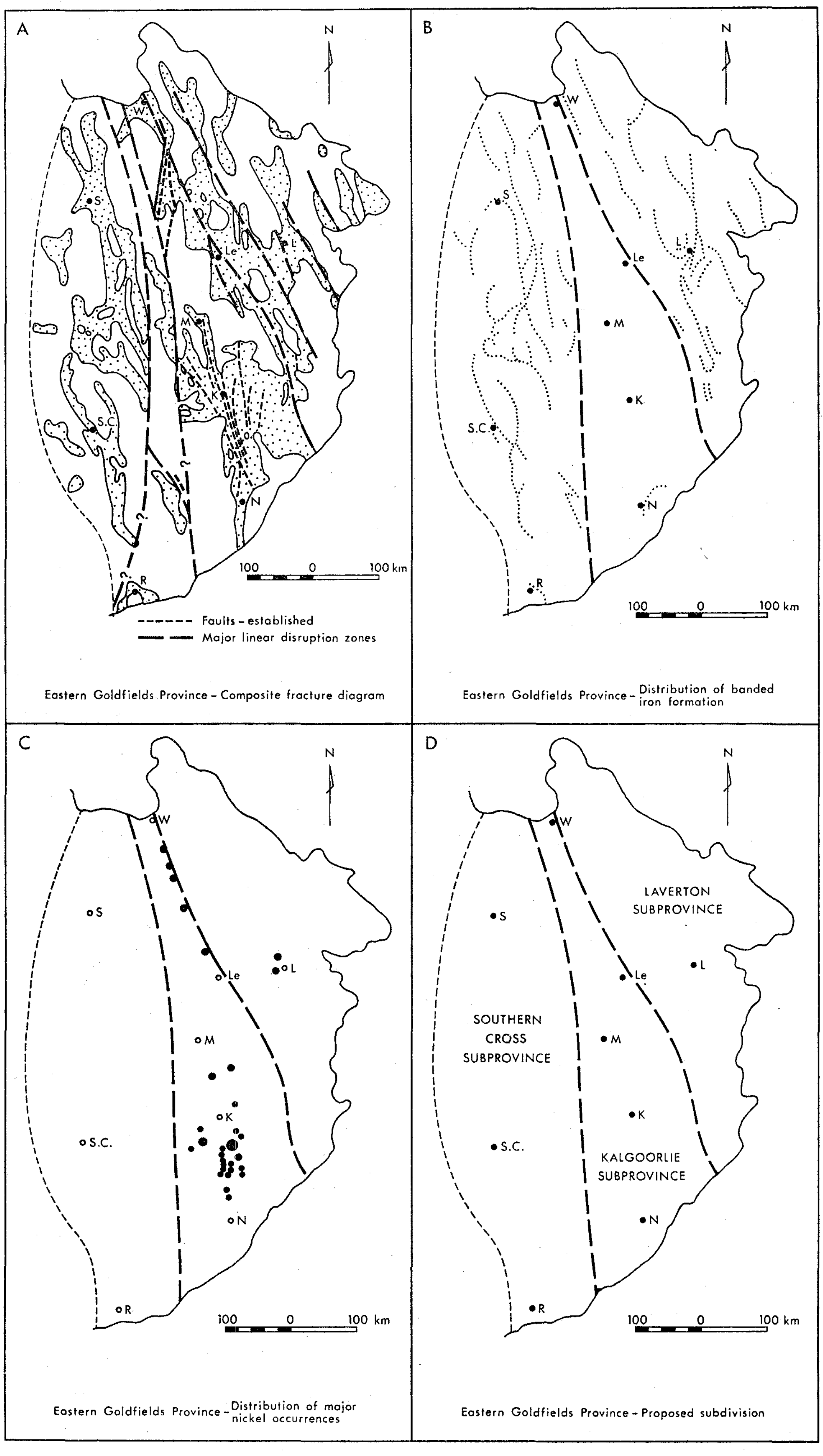

Figure 33. Structural subdivisions of the Eastern Goldfields Province, Yilgarn Block.

33A). Grantic rocks show affiliations with both structural episodes.

Detailed stratigraphic data are not yet available for the Southern Cross-Sandstone region. However, the distinctive regional configuration of the greenstone belts and the resolved northerly trend (the older trend of the Norseman-Wiluna region?) distinguishes the region from the remainder of the province.

LITHOLOGY DISTRIBUTION IN THE EASTERN GOLDFIELDS PROVINCE

The spatial distribution of the individual lithologies within the greenstone belts is well documented for the southeastern quarter but is incompletely known in the remainder of the province. However, collation of available data has revealed distribution patterns which are believed to reflect significant palaeogeographical conditions.

BANDED IRON FORMATION

The distribution of banded iron formation (BIF) is perhaps the most significant. BIF, in this case, refers to rocks (mainly chemical sediments) which have distinct colour and compositional banding and which exhibit varying degrees of magnetism that can be detected on regional total magnetic intensity maps. They are closely associated with, but not as widespread as, the non-magnetic cherts. The magnetic BIF occurs in the Southern Cross-Sandstone and Laverton regions but is almost entirely absent from the central Norseman-Wiluna region (see Fig. 33B). The chert occurs throughout the province and in some areas appears to be a facies equivalent of the magnetic BIF (Williams, 1970; Williams and others 1971). Major BIF and chert horizons occupy particular levels in the Archaean succession. The main horizons in the Laverton and Norseman-Wiluna regions lie between successive volcanic cycles. Regionally they overlie felsic volcanic rocks and associated clastic rocks and underlie mafic and ultramafic rocks. They may be interbedded with tuffaceous, sedimentary or mafic rocks.

BIF and chert horizons are particularly prominent between cycles 1 and 2 in the Kurnalpi and Edjudina Sheet areas. They are well exposed in the Edjudina Range (Williams and others, 1971). This same stratigraphic level can be traced westwards from the Laverton region to the Norseman-Wiluna region. However, a progressive change has been documented from BIF and chert in the Laverton region, to chert on the eastern margin of the Norseman-Wiluna region. This horizon is expressed by an angular unconformity in the Kalgoorlie area (central part of the Norseman-Wiluna region, Williams, 1970).

The stratigraphic position of the prominent BIF and chert horizons in the Southern Cross-Sandstone region has not yet been determined. However, structural correlation across the Norseman-Wiluna region suggests that the BIF of the Mount Ida-Davyhurst belt, on the eastern margin of the Southern Cross-Sandstone region, may also lie between cycles 1 and 2.

Banded iron formation and chert horizons may have been deposited during periods of quiescence between successive volcanic cycles. The paucity of these rocks in the Norseman-Wiluna region may then be attributed to continuous tectonic activity which inhibited BIF formation. The boundaries of the BIF-free central zone coincide with the inner margins of the major western and eastern linear disruption zones.

ULTRAMAFIC ROCKS

Broadly the ultramafic rocks show a reverse distribution pattern to that of the BIF in the province. They are concentrated within the Norseman-Wiluna region and are less frequent and more isolated in the Laverton and the Southern Cross-Sandstone regions.

The ultramafic rock group comprises discrete, podiform extrusive and intrusive, serpentinized bodies after peridotite and dunite (D. A. C. Williams, 1972), layered mafic-ultramafic bodies (Williams and Hallberg, 1973), and high-magnesian basalts. The discrete podiform and layered mafic-ultramafic bodies and to a lesser extent the high-Mg basalts are concentrated in the Norseman-Wiluna region. The discrete peridotitic and dunitic bodies may carry segregated nickel-sulphide deposits (Hudson, 1972). The distribution of existing nickel mines and potential deposits clearly indicates a concentration of this nickel mineralization in the Norseman-Wiluna region (see Fig. 33C). The mineralization in turn is largely restricted to the mafic-ultramafic association of cycle 2 (Mulgabbie Formation, Williams, 1970) within this region.

The disposition of nickel-bearing and other ultramafic rocks in the Norseman-Wiluna region also corresponds to the greatest concentration of the strike faults in the province (see Fig. 33A). The major linear disruption zones and associated faults control the emplacement of ultramafic dykes in the Mount Keith, Kathleen Valley and Agnew districts and pass near or truncate thick ultramafic complexes such as those at Mount Clifford, Murrin, Yundamindra and Linden. Several ages of ultramafic emplacement are evident although the present fracture pattern is, in most cases, not the obvious feeder system for the bulk of the ultramafic material. However, it is still tempting to postulate that these lines of weakness reflect fundamental fractures or mantle-tapping structures in the Archaean crust which, at an earlier stage, acted as conduits for the rapid transfer of ultramafic material from depth to a surface or near-surface environment. There appears little doubt that a direct relationship exists between the intensity of fracturing and the distribution of the ultramafic rocks. The paucity of nickel-bearing ultramafic rocks in the Southern Cross-Sandstone region could possibly be attributed to the apparent lack of north-trending fracture zones.

MAFIC ROCKS

Mafic rocks are widespread in the province. Tholeiitic basaltic rocks are the most common, but their associated lithologies suggest a varied environment. Hallberg (1972) studied pillowed tholeiitic basalts in the Kalgoorlie-Norseman areas and found them to be a uniform sequence of quartz-normative tholeiites which showed little differentiation throughout a pile greater than 8 000 m in thickness. Major and minor element chemistry resembles that of present day abyssal tholeiites. The tholeiitic basalts are associated with ultramafic rocks but are chemically and texturally separate (D.A.C. Williams, 1972). The mafic-ultramafic assemblage is abruptly overlain by a felsic-clastic sequence. Andesitic rocks are absent and there is no evidence of calc-alkaline differentiation. The tholeiitic basalts described by Hallberg (1972) belong to cycles 2 and 3.

In contrast, tholeiitic rocks in the Laverton region and those found in cycle 1 within the Norseman-Wiluna region are associated with mafic to felsic cyclicity. The mafic assemblages pass gradually upwards to predominantly felsic assemblages. Andesitic rocks have been recorded from these piles (Williams and others, 1971). Internal small-scale cyclicity, represented by the mafic rock, felsic rock, BIF triplet, is common (these may also be tuffaceous rocks). The tholeiites are generally massive and pillow lavas are not common. The ultramafic rocks in cycle 1 tend to form separate complexes and are spatially separate from the mafic to felsic cycles.

Andesitic rocks have also been found in the Southern Cross-Sandstone region at Marda (Bye, 1970) and Diemals. They occur in small calc-alkaline complexes. Basaltic rocks are common in areas away from the calc-alkaline centres and are closely associated with BIF, gabbro, mafic tuff and high-Mg basalt. This assemblage differs from the mafic-ultramafic association of the Norseman-Wiluna region in respect of high BIF and low peridotitic ultramafic content.

A characteristic lithology of the Southern Cross-Sandstone region is a layered gabbro with poorly developed ultramafic layers and thick gabbroic and anorthositic layers. The bodies contain segregated, titaniferous, vanadiferous, magnetite deposits. The Windimurra Gabbro and layered intrusions at Barrambie, Montague Range, Youanmi and near Lake Medcalf belong to this category. The magma stem is believed to be tholeiitic.

FELSIC ROCKS

Felsic rocks have several modes of occurrence in the province. They may form thick extremely restricted piles of mixed flows, breccias, intrusive and pyroclastic rocks, bordered by extensive coarse to fine-grained volcanoclastic deposits. The composition varies from dacite to potash rhyolite with occasional andesitic types. The felsic complexes show no genetic or chemical affinities with underlying or overlying mafic volcanic rocks (Larking, 1969; Hallberg, 1970). This type of felsic complex is common in cycles 2 and 3. It also occurs in cycle 1 which crops out in the Norseman-Wiluna region.

Other felsic complexes are related to mafic rocks. The association constitutes a mafic to felsic cycle, where lithologies progress from basalt upwards through andesite to dacite and rhyodacite. The upward progression is accompanied by increased pyroclastic content. BIF and chert cap the mafic to felsic cycles. The ratio of basic, intermediate and acid components in the mafic to felsic piles varies considerably. Some centres have a large basalt and andesitic component and only minor felsic material; others resemble calc-alkaline sequences and are dominated by andesitic rocks ($\leqslant$ 60 per cent). Mafic to felsic volcanic piles are confined to cycle 1 and are typically found in the Southern Cross-Sandstone and Laverton regions.

CLASTIC SEDIMENTARY ROCKS

Clastic sedimentary rocks that exhibit a mixed provenance are generally deposited in areas devoid of coeval volcanism. These sedimentary rocks are characteristic of higher levels of the Archaean succession in the province and constitute the clastic part of the felsic-clastic associations of cycles 2 and 3. Although sequences of clastic rocks are found in older felsic-clastic associations they are not the major lithology. They tend to be oligomictic and the major components are volcanoclastic and chemical sedimentary rocks.

Polymictic conglomerate is a major component of the younger clastic sequences. The Kurrawang Beds, situated between Kalgoorlie and Coolgardie, contain a high proportion of conglomerate horizons (Glikson, 1971). Similar conglomerate horizons occur in the Merougil Creek area west of Kambalda, the Penny, White Gate and Gundockerta districts of the Kurnalpi Sheet area, the Yilgangi area near Edjudina and the Butcher Bore area northeast of Malcolm. The conglomerates occur in the upper horizons of felsic-clastic associations at or near the top of the Archaean succession.

The Kurrawang Beds, which lie near the western margin of the Norseman-Wiluna region, contain a high proportion of BIF, jaspilite and chert clasts. Likewise, but to a lesser degree, the conglomerate horizons at Yilgangi and Butcher Bore on the eastern margin of the Norseman-Wiluna region contain chert and jaspilite clasts. The remaining conglomerate horizons, situated centrally within the Norseman-Wiluna region contain no BIF and only very small percentages of chert clasts. The provenance of the BIF and probably the greater portion of the chert and jaspilite clasts lies outside the Norseman-Wiluna region. The nearest BIF occurrence to the Kurrawang Beds lies 70 km to the southwest near Queen Victoria Rocks.

The general immaturity and poor sorting of the conglomeratic assemblages would suggest the fairly rapid filling of a basin or trough structure. Significantly, the majority of thick polymictic conglomerate beds lie within or adjacent to the Norseman-Wiluna region. This region is bordered by the major linear disruption zones that appear to define a trough or graben-like structure.

TABLE 9. CHARACTERISTICS OF THE MAJOR REGIONAL SUBDIVISIONS OF THE EASTERN GOLDFIELDS PROVINCE

Southern Cross-Sandstone region	Norseman-Wiluna region	Laverton region
1. Individual or single greenstone belts ; arcuate trends.	Compound greenstone belts, irregular shape with linear appendages, linear trends.	Compound and individual greenstone belts, linear and gently arcuate trends.
2. Resolved northerly regional trend.	Dominant younger north-northwesterly fold trend, older northerly trend unconformably beneath.	Dominant older northerly trend, younger north-northwesterly trend.
3. Domal granites and arcuate greenstone belts genetically related.	Large granitic bodies related to north-northwest fold ; trend truncates north fold trend. Granitic rocks intrude pre-existing structures.	Granitic rocks are probably related to both the north and north-northwest fold trends.
4. Bordered by gently arcuate linear disruption zone on eastern side. Relative movement east-block-down. Strike faults in layered succession uncommon.	Bordered by eastern and western linear disruption zones. Numerous strike faults in layered succession. Concentrated in centre of region (Kalgoorlie), decrease east and west from central region.	Bordered by linear disruption zone on western side. Relative movement west-block-down Strike faults in layered succession occur throughout but decrease eastwards.
5. Archaean stratigraphy not well known. Attempted correlation suggests rocks may be equivalent to cycle 1 and older.	Youngest Archaean rocks in province, 2 600 m.y. Predominantly cycle 2 and 3 rocks, cycle 1 rocks in cores of regional anticlines.	Predominantly cycle 1 rocks, some older cycle 2 rocks occur in keels or regional synclines.
6. BIF and chert prominent, local disconformities and unconformities between cycles.	Chert, very minor BIF between cycle 1 and 2, major unconformity between cycles 1 and 2 ; and cycles 2 and 3.	BIF and chert prominent, disconformities and unconformities between cycles.
7. Intermittent tectonic activity, periods of quiescence denoted by BIF.	Continuous tectonic activity, interval of time lasting from cycle 1 to 3.	Intermittent tectonic activity, periods of quiescence between succeeding volcanic cycles, as denoted by BIF.
8. Ultramafic rocks not common, mainly high-Mg basalts, periodotitic ultramafic concentrated in southern half of region, traces of nickel mineralization.	Ultramafic rocks very common, form ultramafic-mafic assemblages ; region contains 80 per cent known ultramafic rocks of province. Contains 96 per cent proven nickel reserves in W.A.	Ultramafic rock content variable, decreases eastwards across the region, concentrated in ultramafic complexes separate from cyclic mafic to felsic assemblages. Scattered nickel mineralization.
9. Rare occurrences of ultramafic-mafic bodies derived from high-Mg basalt magma.	Contains numerous layered ultramafic-mafic bodies derived from high-Mg basalt magma.	Not found.
10. Contains large layered gabbros, characterized by anorthosites, poor ultramafic development, segregated titaniferous vanadiferous magnetite bands.	Not found.	Not found.
11. Gabbro-basalt, high-Mg basalt, mafic tuff-BIF assemblages, minor calc-alkaline sequences, andesites. Pillow lavas not common.	Mafic-ultramafic assemblages. Tholeiitic basalts resemble recent abyssal tholeiites, calc-alkaline sequences absent, andesites very rare or absent. Pillow lavas common.	Cyclic volcanic mafic to felsic assemblages, BIF, minor calc-alkaline sequences ? andesites. Pillow lavas not common, ultramafic complexes.
12. ?Cyclic felsic rocks associated with mafic rocks, felsic complexes rare.	Felsic complexes common ; felsic rocks unrelated to underlying mafic rocks.	Cyclic mafic to felsic assemblages. Felsic complexes rare.
13. Polymictic and oliogomictic conglomerates are present but not common. Stratigraphic relationship not known.	Polymictic conglomerates form thick sequences near and at the top of Archaean succession. Source of clasts commonly from adjoining regions. Oligomictic conglomerates common with felsic complexes.	Polymictic and oligomictic conglomerates are present but occur at base of sequences, possibly related to unconformities.
14. Relatively stable area may be shelf or platform environment.	Unstable region, indications suggest a trough, rift or graben-like environment within older Archaean crustal material.	Relative stable area, may be shelf/platform with possible terrestrial environments.

CONCLUSIONS

The significant structural and lithological variations of the Eastern Goldfields Province are listed in Table 9.

The data reveal three natural divisions of the Eastern Goldfields Province which are separated by linear disruption zones. The divisions have been designated subprovinces and are called, from west to east, the Southern Cross, Kalgoorlie and Laverton Subprovinces (Table 10).

TABLE 10. SUBDIVISIONS OF THE EASTERN GOLDFIELDS PROVINCE, YILGARN BLOCK

Region	Subprovince
Southern Cross-Sandstone	Southern Cross
Norseman-Wiluna	Kalgoorlie
Laverton	Laverton

A structural-palaeogeographic reconstruction of the Archaean environment, before the closing tectonic magmatic events, would possibly reveal a tensional pattern represented by an incipient graben or rift-like structure corresponding to the Kalgoorlie Subprovince. By far the greater proportion of Younger Archaean rocks, namely cycles 2 and 3, occur within this region together with the bulk of the nickel-bearing ultramafic rocks. In consequence the Kalgoorlie Subprovince forms a unique and economically important component of the Eastern Goldfields Province.

REFERENCES

Bye, S. M., 1970, The acid volcanic rocks of the Marda area, Yilgarn Golfield, Western Australia: Geol. Soc. Australia Special Publication No. 3, p. 32.

Daniels, J. L., and Horwitz, R. C., 1969, Precambrian tectonic units of Western Australia: West. Australia Geol. Survey Ann. Rept. 1968, p. 37-38.

de la Hunty, L. E., 1970, Cue, W. A.: West Australia Geol. Survey 1 : 250 000 Geol. Series Explan. Notes.

Doepel, J. J. G., in press, Explanatory notes on the Norseman 1 : 250 000 Sheet, West. Australia Geol. Survey.

Glikson, A. Y., 1971, Archaean geosynclinal sedimentation near Kalgoorlie, Western Australia: Geol. Soc. Australia Special Publication No. 3, p. 443-460.

Gower, C. F. and Bunting, J. A., 1972, Explanatory Notes on the Lake Johnston 1 : 250 000 Geological Sheet: West. Australia Geol. Survey Rec. 1972/12 (unpublished).

Hallberg, J. A., 1970, The petrology and geochemistry of metamorphosed Archaean basic volcanic and related rocks between Coolgardie and Norseman, Western Australia: Univ. West. Australia Ph. D. thesis (unpublished).

——— 1972, Geochemistry of Archaean volcanic belts in the Eastern Goldfields Region of Western Australia: Jour. Petrology v. 13. No. 1, p. 45-56.

Horwitz, R. C., and Sofoulis, J., 1965, Igneous activity and sedimentation in the Precambrian between Kalgoorlie and Norseman, Western Australia: Australasian Inst. Mining Metall. Proc. 214, p. 45-59.

Hudson, D. R., 1972, Evolution of genetic models for Australian sulphide nickel deposits: Australasian Inst. Mining Metall. Ann. Conf. Newcastle, May-June 1972, p. 59-68.

Larking, A. N., 1969, Acid rocks and their relationships to the gold mineralization, Norseman, Western Australia: Univ. Adelaide Hons. thesis (unpublished).

McCall, G. J. H., 1969, The Archaean succession to the west of Lake Lefroy: Royal Soc. West. Australia Jour., v. 52, Pt. 4, p. 119-128.

MacLaren, J. M., and Thompson, J. A., 1913, Geology of the Kalgoorlie Goldfields: Mining Sci. Press, parts 1-5, p. 45-48, 95-99, 187-190, 228-232, 374-379.

Prider, R. T., 1965, Geology and mineralization of the Western Australian Shield: *in* Geology of Australian Ore Deposits, 2nd edn. Commonwealth Mining Metall., Australia and New Zealand Cong. 8th Pub., v. 1, p. 56-65.

West. Australia Geol. Survey, in press, The Geology of Western Australia, Mem. No. 2.

Williams, D. A. C., 1972, Archaean ultramafic, mafic and associated rocks, Mt. Monger, Western Australia: Geol. Soc. Australia Jour. v. 19, pt. 2, p. 163-188.

Williams, D. A. C. and Hallberg, J. A., 1973, Archaean layered intrusions of the Eastern Goldfields region, Western Australia: Contributions to Mineralogy and Petrology, v. 38, p. 45-70.

Williams, I. R., 1969, Structural layering in the Archaean of the Kurnalpi 1 : 250 000 Sheet area, Kalgoorlie region: West. Australia Geol. Survey Ann. Rept. 1968, p. 40-41.

——— 1970, Kurnalpi, W.A.: West Australia Geol. Survey 1 : 250 000 Geol. Series Explan. Notes.

Williams, I. R., Gower, C. F. and Thom. R., 1971, Explanatory notes on the Edjudina 1 : 250 000 Geological Sheet, W.A.: West. Australia Geol. Survey Rec. 1972/26 (unpublished).

Woodall, R. W., 1965, Structure of the Kalgoorlie goldfield: *in* Geology Australian Ore Deposits, Commonwealth Mining Metall. Australia and New Zealand Cong. 8th Pub., v. 1, p. 71-79.

ARCHAEAN ULTRAMAFIC LAVAS FROM MOUNT CLIFFORD

by R. G. Barnes, J. D. Lewis, and R. D. Gee

ABSTRACT

A thick pile of Archaean ultramafic volcanic rocks at Mount Clifford, 260 km north of Kalgoorlie has accumulated on a platform of tholeiitic pillow basalts adjacent to a major tectonic feature, the Keith-Kilkenny lineament. The complex consists of a multitude of thin serpentinized peridotite flows, together with other highly magnesian rock types.

The lavas display distinctive features of morphology and petrology indicating an extrusive origin. These include thin chilled margins, an upper spinifex-textured zone of pyroxene peridotite and a lower porphyritic zone of olivine peridotite. This textural asymmetry provides a primary facing indicator.

Eleven chemical analyses from a core sample of a flow 1.24 m thick are presented. Chemical and modal variations within the flow indicate that the chilled margins are undifferentiated. The olivine peridotite was formed by crystal settling from a highly fluid magma containing about 12 per cent phenocrysts.

INTRODUCTION

The existence of magmatic ultramafic rocks as a characteristic component of Archaean volcanogenic belts is now widely accepted. Such rocks have been described from Canada by Naldrett and Mason (1968) and Pyke and others (1973), from South Africa by Viljoen and Viljoen (1969a), and from Western Australia by Nesbitt (1971), McCall and Leishman (1971), D.A.C. Williams (1971) and Lewis and I. R. Williams (1973).

The occurrence of peculiar quench or "spinifex" textures in these rocks has been fully described by Nesbitt (1971) who, with Lewis (1971), interprets the texture as indicating the rapid cooling of a crystal-free ultramafic liquid.

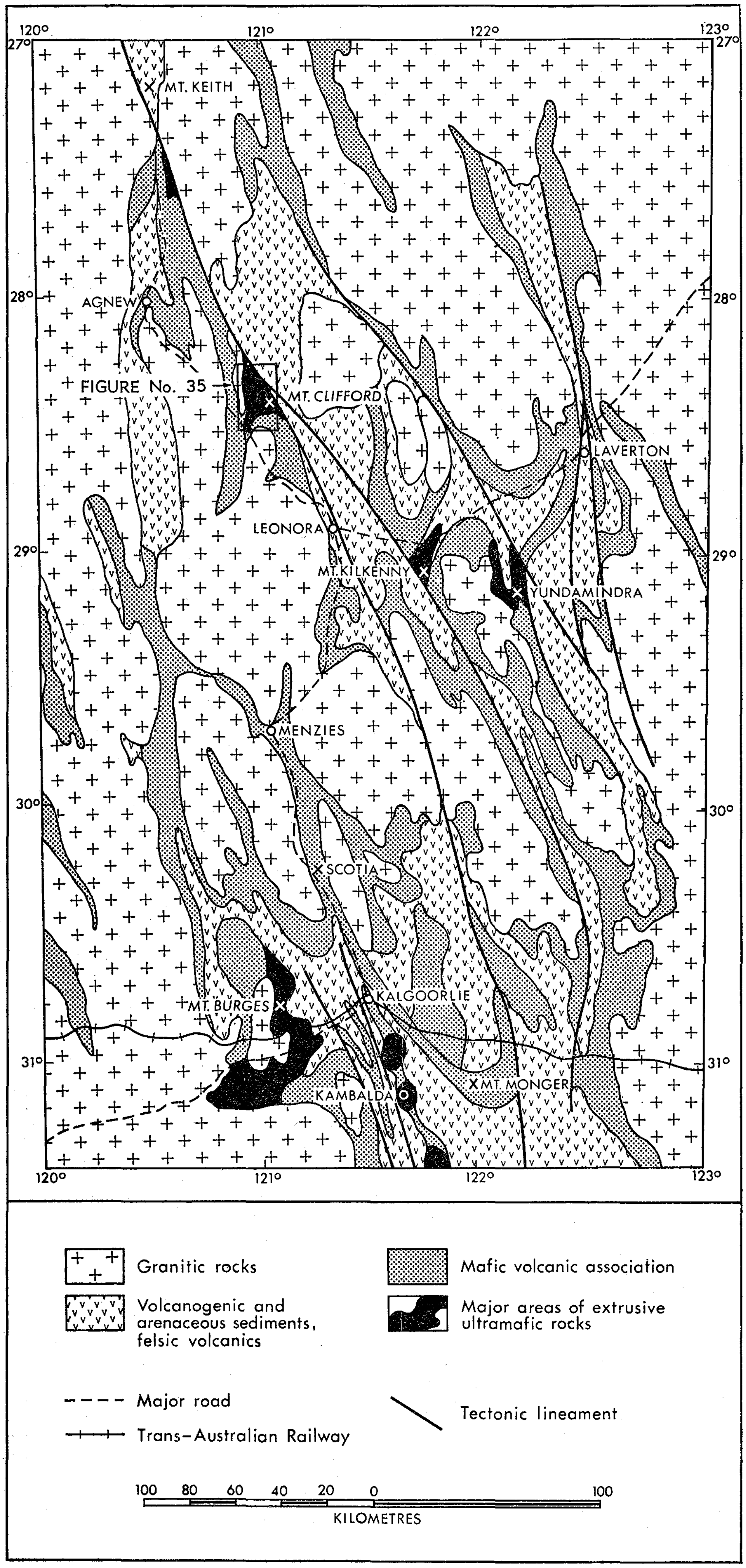

Figure 34. **Mount Clifford-Kalgoorlie regional map (see Fig. 35 for Mount Clifford enlargement).**

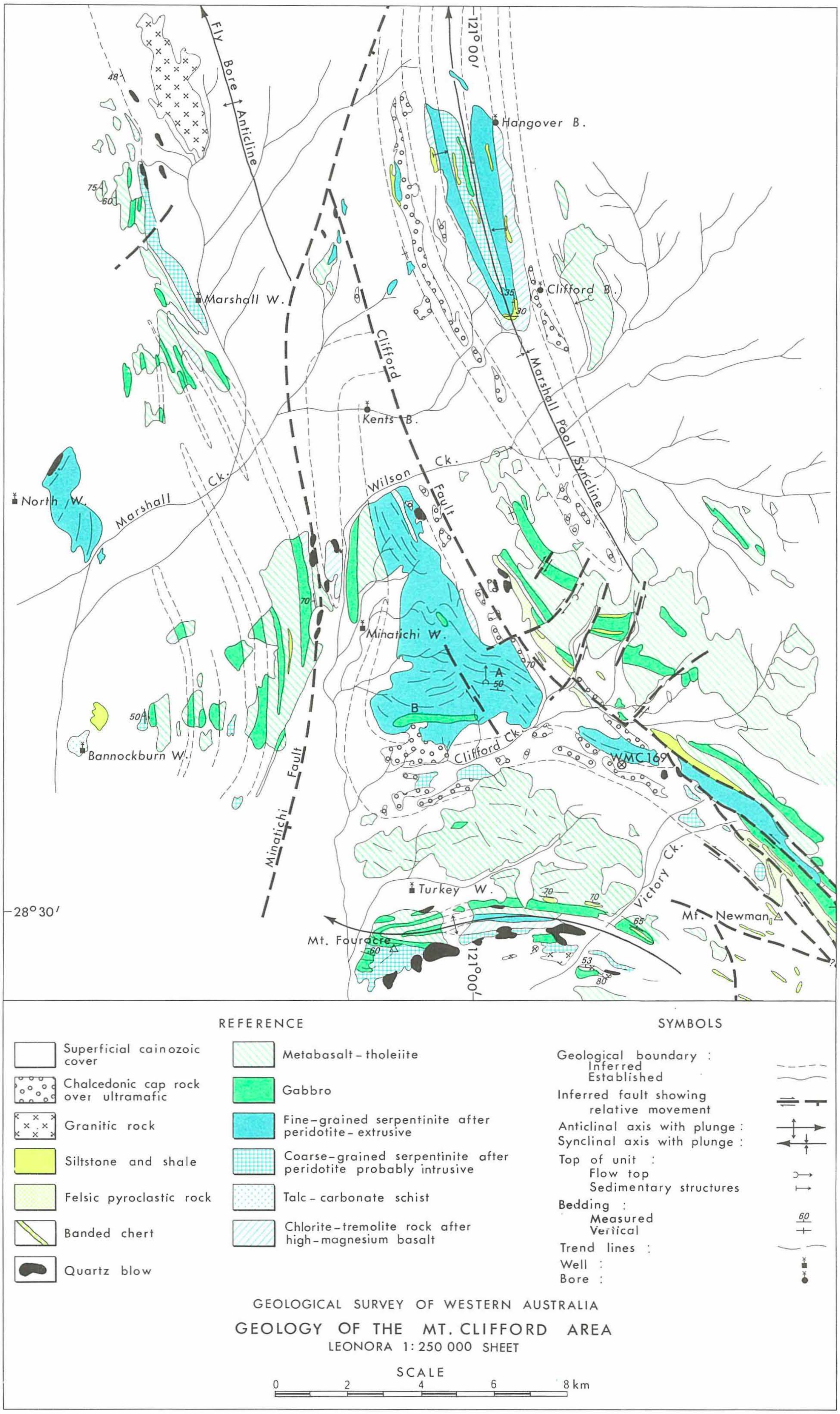

Figure 35.

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However, the presence of spinifex texture alone does not provide unequivocal evidence for an ultramafic lava, as such textures are often developed at the margins of obviously intrusive bodies. At present three localities of undoubted peridotite lavas have been described (Viljoen and Viljoen, 1969a; Pyke and others, 1973; Lewis and I. R. Williams, 1973). In each case there are distinctive features of morphology and petrography indicative of extrusion of a mobile peridotitic magma. These include pillow forms, from the South African examples, and a marked textural asymmetry and slaggy vesicular flow top from Canadian and Western Australian examples.

The purpose of this paper is to describe the field occurrence, flow morphology, petrography and chemistry of Archaean ultramafic lava flows at Mount Clifford, 53 km north-northwest of Leonora township in the Mount Malcolm Goldfield. This area contains one of the best exposed outcrops of extrusive, serpentinized peridotite in Western Australia. The recognition of extrusive morphological features is of value to the field geologist in interpreting facing and environment. Further, the chemistry of the serpentinized periodotite closely reflects that of the original rock.

The authors believe the lavas of the Mount Clifford area are broadly similar to the ultramafic lavas of Munro Township, Ontario (Pyke and others, 1973) with which they are compared.

REGIONAL SETTING

The Mount Clifford area lies in the northern part of the Norseman-Wiluna greenstone belt, which is characterized by elongate, domal, granitic plutons and batholiths. The latter intrude and deform an Archaean volcanogenic succession which consists of tholeiitic basalts, intrusive and extrusive rocks of the high magnesia (ultramafic) rock suite, felsic volcanics, volcanogenic sediments, arenaceous and conglomeratic sediments and banded iron formations. The belt is further characterized by north-northwest trending tectonic lineaments that have been active throughout the deposition of the volcanogenic succession.

Mount Clifford lies on the western side of the most conspicuous and perhaps most important of these lineaments, named informally the Keith-Kilkenny lineament (Williams, 1974, p. 54). This lineament forms a major boundary in the subdivision of the Eastern Goldfields Province. Williams has further postulated that this structure is the expression of a fundamental mantle-tapping fracture that initiated and controlled the subsequent development of the Archaean crust.

Regionally the Keith-Kilkenny lineament marks a thick accumulation of volcanogenic rocks, including extrusive peridotite. It is also the regional locus of a high level conglomerate and intrusive ultramafic lenses, and appears to have controlled the intrusion of adjacent granite plutons. There is evidence that splay faults and folds are related to the lineament, thus demonstrating progressive deformation related to plutonic activity.

Periodotite lavas also occur in association with thick mafic sequences in other parts of the Eastern Goldfields (Fig. 34). Those at Sir Samuel, Mount Kilkenny and Yundamindra bear a regional spatial relationship to tectonic lineaments but this relationship is more tenuous in the Mount Burges and Kambalda areas. The regional stratigraphic position of the peridotite lavas at these localities is uncertain, however, it appears to be variable and is by no means confined to the lowest part of the Archaean succession. This contrasts with occurrences in the Kaapvaal Shield, South Africa, where peridotite lavas occur only in the lower half of the Onverwacht Group (Anhaeusser, 1971, a,b).

LOCAL GEOLOGICAL SETTING

An interpretive geological map of the area after Thom and Barnes (in press) is presented in Figure 35. The Keith-Kilkenny lineament passes along the eastern edge of the geological map but is not marked as it is ill-defined on the ground in the Mount Clifford area. Faulting in the area is defined by prominent quartz ridges and zones of sheared rock. These, together with aeromagnetic data delineate two major faults in the Mount Clifford area called the Clifford and Minatichi faults.

East of the Keith-Kilkenny lineament, in the Mount Clifford area, is a thick sequence of felsic volcanic and related sedimentary rocks, whereas to the west there is a mafic suite that includes the ultramafic rocks in question. The mafic rocks are exposed in a series of north-northeast plunging folds, therefore the more southerly outcrops are stratigraphically lower, the youngest rocks in the area being preserved in the core of the Marshall Pool syncline.

Two major structural zones are present in the area:

Western area. This contains a mafic association consisting predominantly of tholeiitic basalt and intrusive gabbros. Ultramafic rocks, including both intrusive and extrusive types are also found. The sequence is presumed to face west and is confined to the area west of the Minatichi fault.

Central and Eastern area. These areas contain a mafic-ultramafic association exposed in the trough of the Marshall Pool syncline and on the western side of the Clifford fault.

The Marshall Pool syncline contains a sequence of high-Mg basalts and serpentinized peridotite, interbedded with thin sedimentary horizons and rare intrusive rodingite (Ca-metasomatized gabbro). The syncline is nearly isoclinal, plunges gently north, and is bounded by the Keith-Kilkenny lineament to the east and the Clifford fault to the west. To the south, within this fault slice and underlying the ultramafic rocks, is a lower sequence of strongly carbonated and pillowed tholeiitic basalt.

West of the Clifford fault, in the central area, the mafic-ultramafic association is again exposed in an elbow shaped, north-east facing pile of intrusive and extrusive serpentinized peridotite with minor high-Mg basalt and thin sedimentary horizons. A minimum thickness of 1 200 m is exposed. The elbow shape outlines a rather angular asymmetrical syncline, that plunges 45° northeast. The peridotite mass is underlain to the south by tholeiitic basalt. The western boundary of this succession is formed by either the Minatichi fault, or a thin elongate dome of granitic rock extending southwards from the core of the Fly Bore anticline. Alternatively the granite may have been intruded along the Minatichi fault. Farther south the tholeiitic basalt is underlain by a chert, sediment, layered gabbro sequence which is exposed in the Mount Fouracre anticline. This anticline is isoclinal and has an arcuate trace around a lobe of granite on its southern side. Several strike faults or dislocations can be identified immediately south of Mount Fouracre between the gabbro and the granite, and also at Mount Newman where a series of faults slice a chert horizon. These faults are parallel or slightly acute to the strike of the surrounding rocks and swing to the west in sympathy with the regional structure. They appear to be folded splay faults related to the Clifford fault.

The favoured structural interpretation for the Mount Clifford area is that a single succession, consisting of a basal chert, sediment, gabbro sequence passing up through tholeiitic basalt into a mafic-ultramafic sequence, was folded and dislocated by a splay fault system related to the Keith-Kilkenny lineament. A lobe of granite, that stems from the main batholith to the south, appears to have ruptured the isoclinally folded sequence causing strike-slip movement along the Clifford and related faults. Thus the succession on the western side of the Clifford fault is repeated on the eastern side.

THE ULTRAMAFIC SUITE

The ultramafic suite comprises four rock types:

Extrusive serpentinized peridotite

This peridotite displays a primary flow zonation that includes glassy peridotite, fine and coarse-grained bladed spinifex peridotite, fine and medium-grained granular to porphyritic peridotite, with skeletal olivine and acicular clinopyroxene. The variety of textures and structures are shown in Figures 37A, B, C, D and E.

High-Mg basalt

This is characteristically a fine-grained grey-green, tremolite-chlorite, or carbonate-tremolite serpentine rock and may contain pseudomorphs after olivine phenocrysts. Acicular pyroxene gives the rock a distinctive texture (Fig. 37E) and in places a characteristic hackly fracture. Chemically (Table 12, Column 10; and McCall and Leishman, 1972) they are of pyroxenitic composition and contain about 10 or 12 per cent MgO. They compare favourably with the average high-Mg basalt of Hallberg and D. A. C. Williams (1972), (Table 14, Column 5 this paper), and are considered to be genetically related to the peridotite as shown in Figure 44.

In the Marshall Pool Syncline the high-Mg basalt outcrops as a unit stratigraphically below the extrusive peridotite; it also occurs to a lesser extent within the extrusive peridotite pile in the central Mount Clifford area.

Coarse-grained serpentinized peridotite

This type is not well exposed due to a chalcedonic cap-rock covering. It consists of coarse euhedral olivine up to 5 mm in diameter, and lacks the flow zones of the other peridotite. It is found primarily at the base of the extrusive peridotite pile in the central Mount Clifford area, and is considered an intrusive sill. It is probably genetically related to the extrusive peridotite, and may represent a high level intrusion during the early part of the extrusive phases.

Talc-carbonate schist

This represents highly altered serpentinite or talc-tremolite-chlorite rock. It is typically found in thin bodies close to major faults.

It is not clear whether the ultramafic complex, as now exposed, is an entire lava pile, or a remnant wedge of a once more continuous ultramafic layer folded into the adjacent rocks by movements related to the Keith-Kilkenny lineament. However, the lensoid nature of the outcrop, and its lateral continuity are evidence of a primary feature. It can be postulated that the ultramafic complex formed close to the primeval Keith-Kilkenny lineament and developed on a platform of tholeiitic pillow basalt. This platform also contained layered gabbroic sills and thin but persistent horizons of banded chert. The lavas developed as an outward-thinning pile on the platform. In this respect, it is not unlike an oceanic ophiolite complex.

ULTRAMAFIC LAVAS

There are two main occurrences of peridotite lavas in the Mount Clifford area:

(1.) Within the Marshall Pool syncline, where the lavas are associated with coarse-grained intrusive ultramafic rock and high-Mg basalt, and are interbedded with numerous thin sedimentary horizons.

(2.) A large elbow-shaped flow complex, with associated coarse-grained intrusive ultramafic rock, trending north-northwest from Mount Clifford, is treated in detail in this paper.

The peridotite lavas extend north-northwest from Mount Clifford for 12.9 km along the strike and the outcrop is 3.2 km across at its widest point. Topographically the outcrop forms an area of rolling hills with steep sided valleys which are strike controlled. Parallel micro-lineaments (see Fig. 36A) represent the surface expression of individual lava flows but over much of the area they are absent due either to poor exposure or to lack of a distinctive flow morphology.

Throughout the Mount Clifford area the thicker flows occur at the base of the pile and become thinner towards the top. This suggests that the magma issued from a single vent which gradually became choked causing the lava to issue from numerous smaller vents and fissures. On the eastern side, the lavas dip steeply east, but to the west they are folded into a shallow northeast plunging syncline. Dips on the northern and southern limbs of this syncline range from 40° to 60°. The lavas lens out to the north-northwest and south-southeast and are right-side-up.

Like the ultramafic lavas described by Pyke and others (1973) from Munro Township, Ontario, there are two basic morphologies for the Mount Clifford lavas. Most noteworthy and easily recognized are the flows in which the upper half consists of a coarse-grained spinifex-textured pyroxene peridotite and the lower half of a medium to fine-grained porphyritic olivine peridotite. Less easily delineated are the flows, similar to those described by Viljoen and Viljoen (1969) from the Barberton area of South Africa, in which the only variation is a greater concentration of porphyritic olivine in the lower half of the flow.

In the area designated A in Figure 35 the features of the spinifex type flow are easily recognized. The upper spinifex zones weather in positive relief, whereas the massive porphyritic peridotite is poorly exposed. However, weathering may also produce a spinifex zone that is very broken. Rubble strewn exposures prevent detailed mapping of individual flows but the positive relief ridges outline flows several hundred metres long. A traverse of 130 m across strike revealed a total of 26 flows ranging from 0.85 m to 7.7 m thick, and averaging 5 m thick. A nearby stream section exposed a complete flow unit only 0.5 m thick.

In the area designated B in Figure 35, the spinifex zones are thin whilst the flows appear to be of considerable thickness. Thin beds of carbonaceous siltstone, interspersed within the lavas, are the loci of thin gabbroic sills.

Unlike the Canadian and South African examples, Mount Clifford contains a number of flows with a distinctly vesicular top. Such flows were noted in the southeastern extension of the lavas, a little to the west of Western Mining Corporation DDH 169 (Fig. 35), where although the outcrop is poor, thinly layered northwest trending rocks are evident. Several narrow zones, about 1 m thick, of vesicular peridotite are separated by 10 m thick zones of coarse porphyritic peridotite. A gradation in grain size suggests a northeasterly facing.

MORPHOLOGY OF THE FLOW UNITS

Throughout the Mount Clifford and Marshall Pool areas a regular textural and mineralogical zonation of the flows is evident. A core section from W.M.C. DDH 169, 1.8 km northwest of Mount Clifford, that passed through a flow 1.24 m thick, allows us to identify precisely several zones that are typical of the flows in general. This zonation is illustrated in Figure 38, and their description is:

Zone:

A_1—Chilled and fractured flow top.

A_2—Fine-grained, spinifex-textured pyroxene peridotite.

A_3—Spinifex-textured pyroxene peridotite.

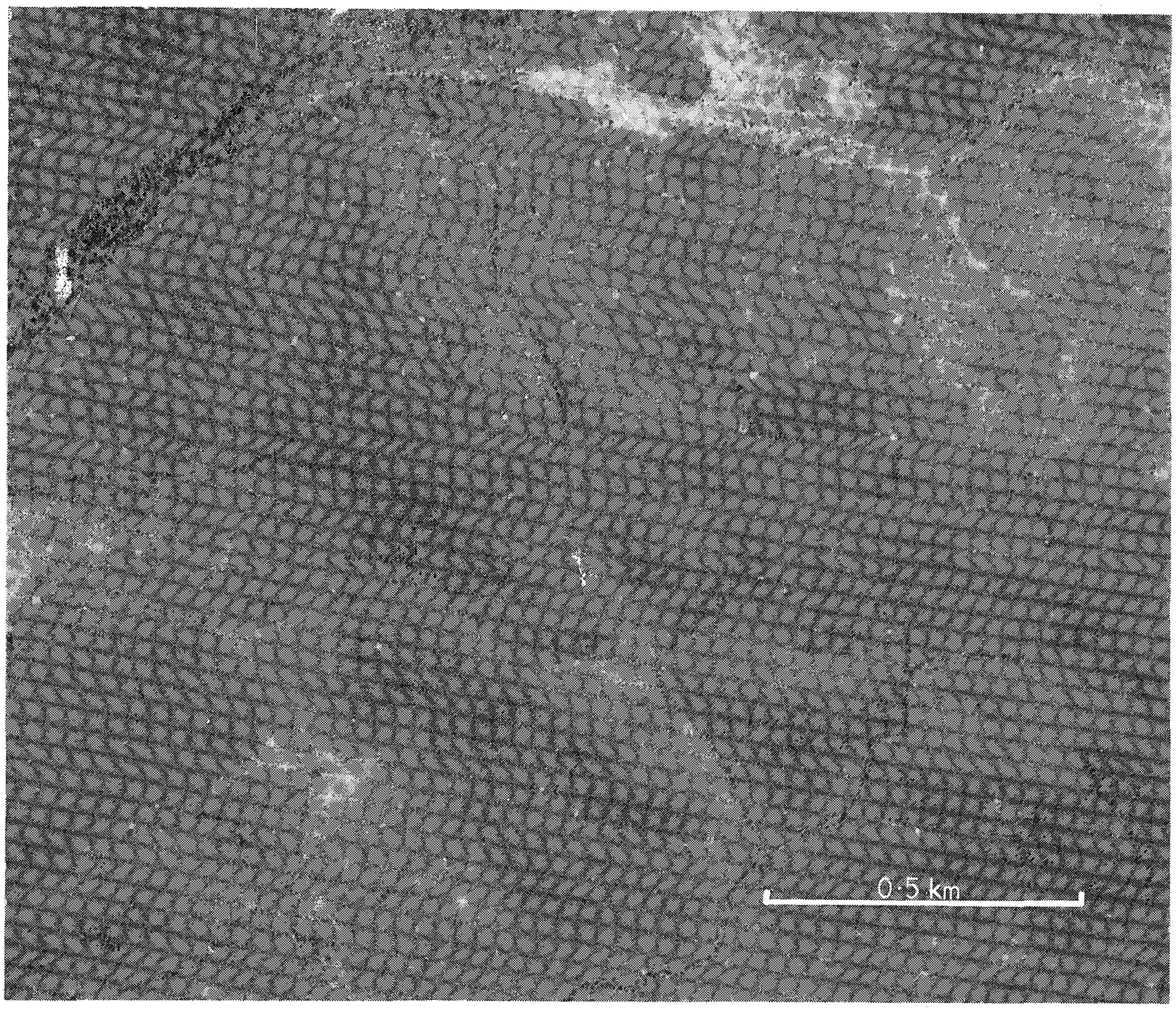
B_1—Foliated olivine peridotite.

B_2—Porphyritic olivine peridotite.

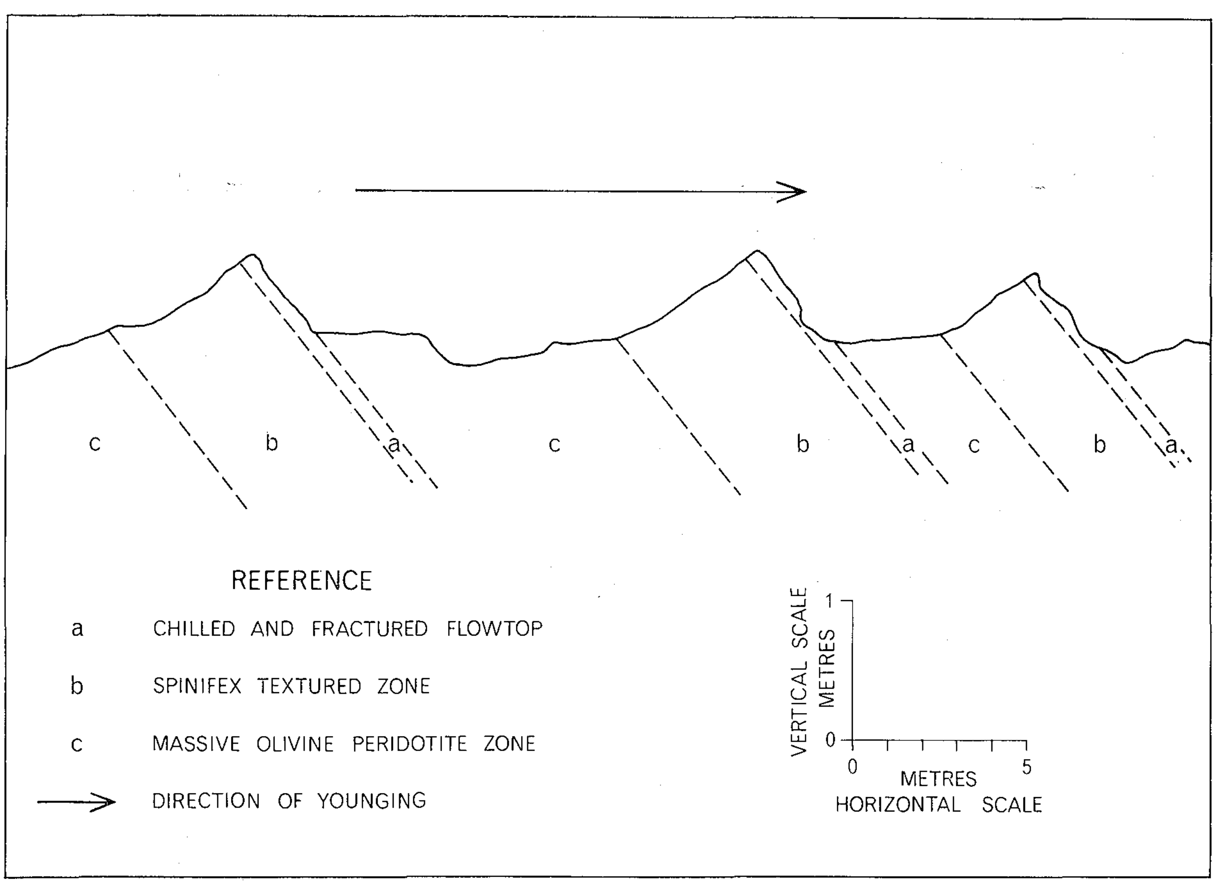
B_3—Lower chilled zone.

Where zones A_2 and A_3 outcrop as a ridge the flow top, A_1, is distinctive due to its pale weathering colour. The A_1 zone is usually less than 20 cm thick and consists of a dense blue-black serpentinite with many irregular fractures. The surface expression of these fractures gives the appearance of spheroidal weathered dolerite on a small scale (Fig. 37A).

Zones A_2 and A_3 are easily distinguished in the field from the structureless, chilled flow top. In weathered specimens the A_2 zones show coarse bladed spinifex texture in which the large olivine blades stand out in positive relief. The blades



A



B

Figure 36.

A. Air-photograph of area ' A ' (Fig. 35) showing micro-strike photo-lineaments representing individual lava flows.

B. Diagrammatic cross-section parallel to dip, through surface outcrop of the peridotite lavas.

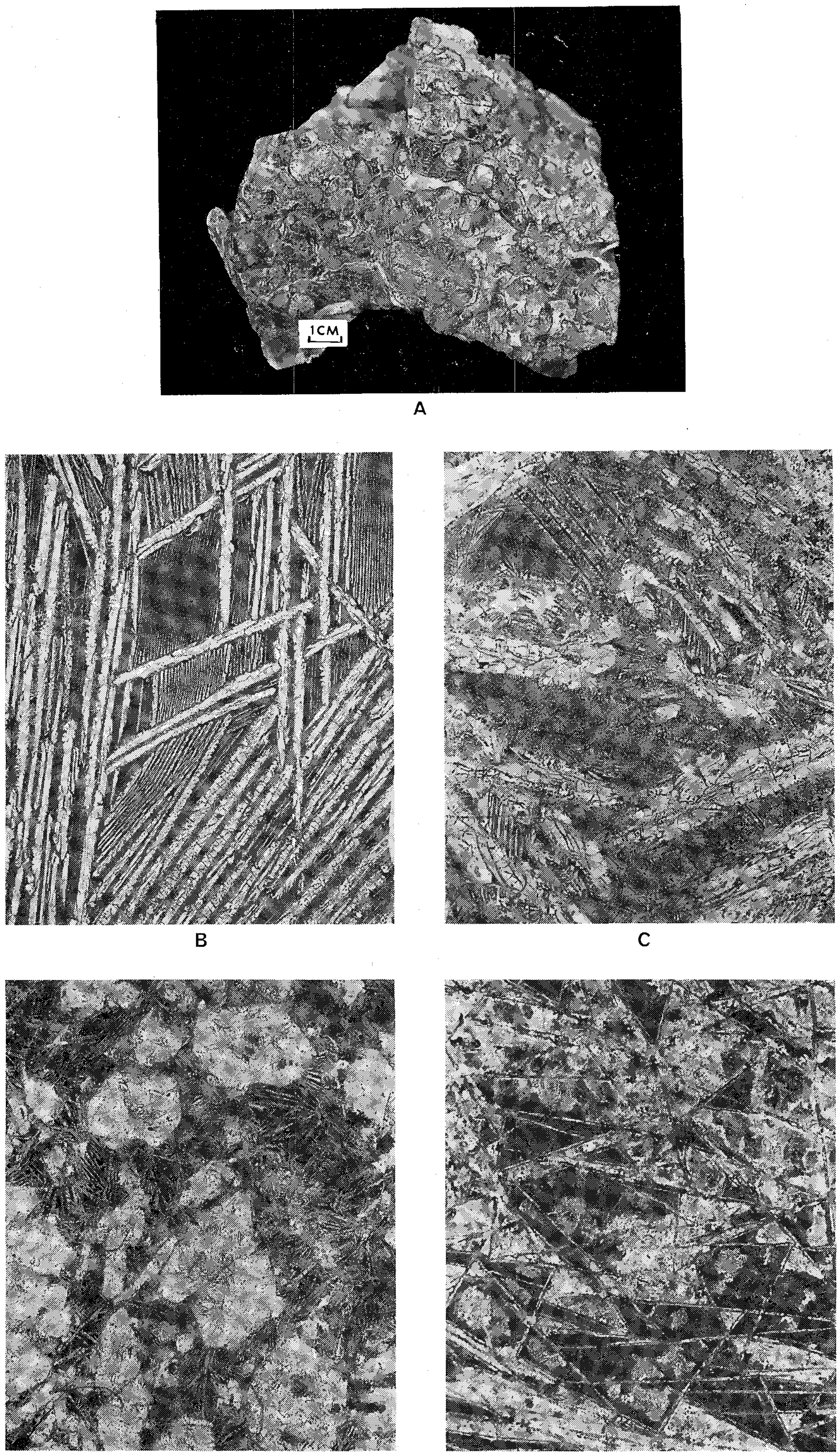


Figure 37.

Photographs of typical textures of Mount Clifford ultramafic rocks.

A. Chilled and fractured flow top.
B. 32773, x 4. Pyroxene peridotite of zone A_3, showing plate spinifex textures. A second generation of olivine lamellae has formed in the polyhedral areas enclosed by the large olivine plates.
C. 38224, x 6. Random spinifex texture from zone A_2. This sample is from a thick flow and shows the skeletal development of olivine and interstitial clinopyroxene.
D. 32775, x 15. Porphyritic peridotite of zone B_2. Note the development of interstitial clinopyroxene.
E. 32772, x 20. High-Mg basalt. Elongate blades of olivine with interstitial clinopyroxene and minor plagioclase.

Note : all specimens are completely altered, olivine to serpentine or chlorite, and clinopyroxene to tremolite.

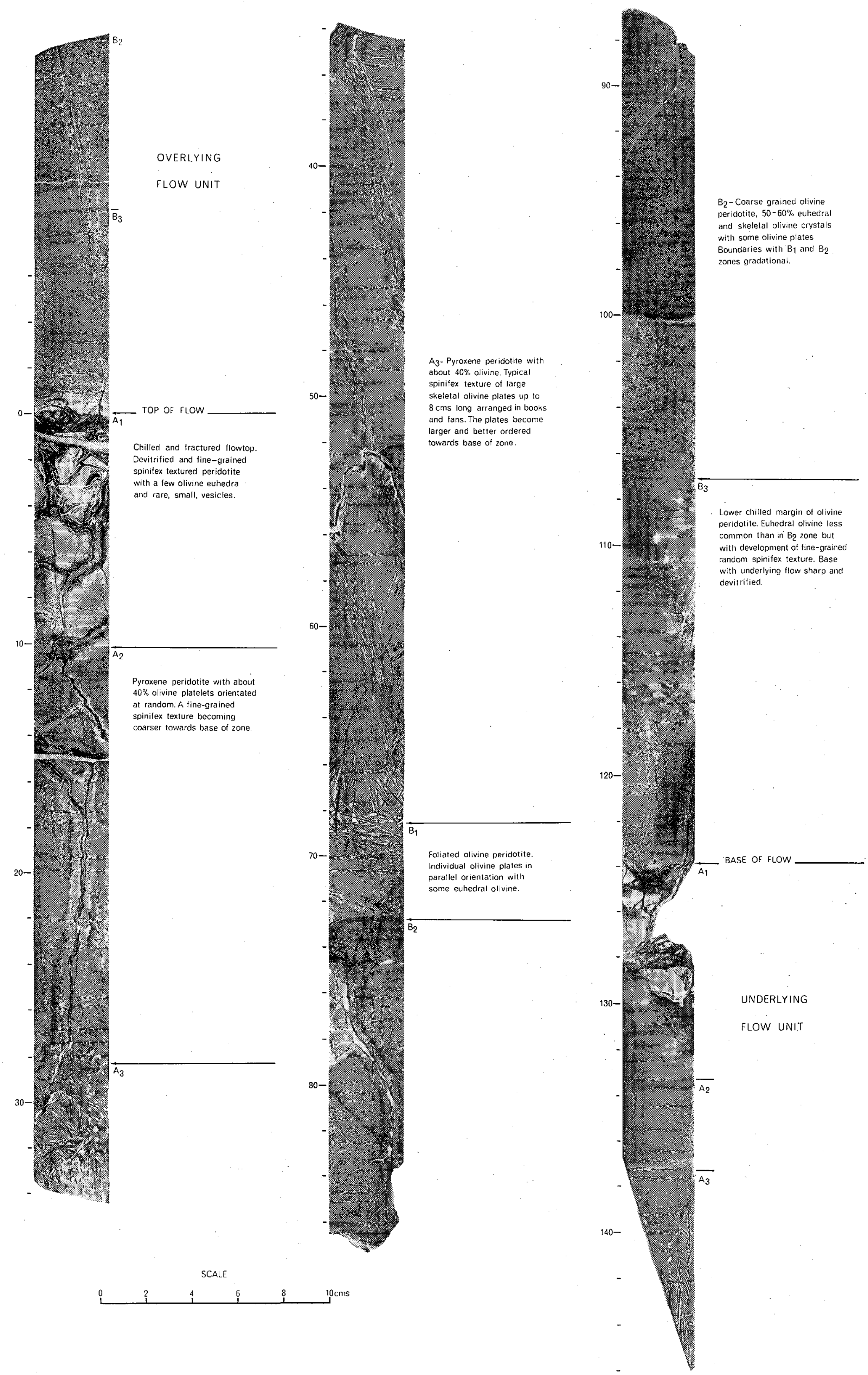


Figure 38. Polished core section from W.M.C. DDH 169, showing the textural variation through a thin ultramafic flow.

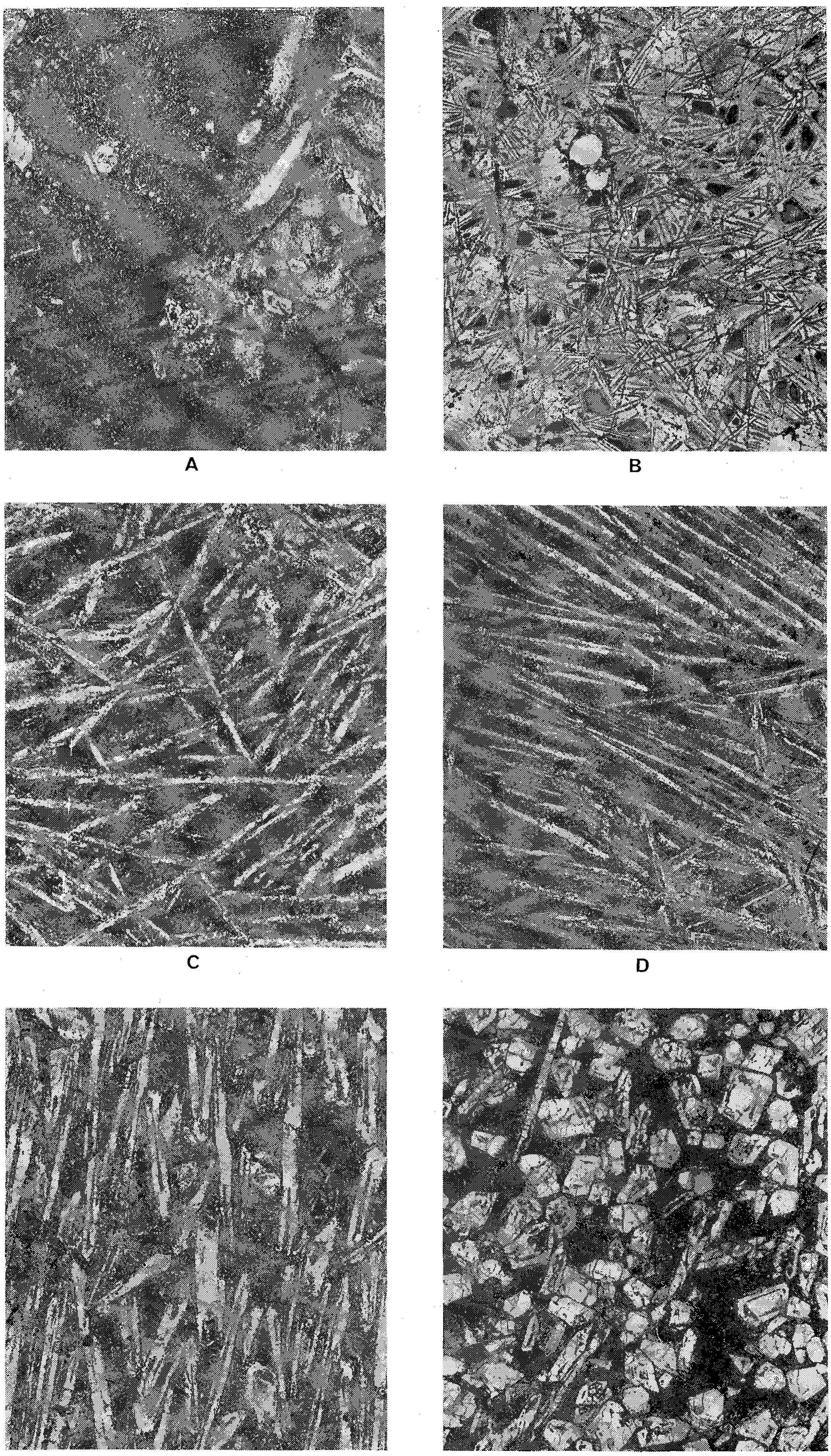


Figure 39

Photomicrographs of drill core specimens from W.M.C. DDH 169, Mount Clifford.

A. 15156F, x 10. B_3 and A_1 zones. Base of overlying flow (to the left of photo) and top of underlying flow. Note devitrified glassy nature of both chilled margins, the presence of small phenocrysts and a streaked out chlorite filled vesicle in the underlying flow.
B. 15157B, x 20. A_1 zone. Small scale random spinifex texture in the upper chilled margin of the flow. Note small spherical vesicles and rare phenocrysts. Compare with texture of high-Mg basalt Fig. 37E.
C. 15158C, x 23. A_2 zone. Pyroxene peridotite with randomly orientated olivine plates.
D. 15159B, x 10. A_3 zone. Spinifex textured pyroxene peridotite. Olivine plates are larger and more ordered than in C.
E. 15160G, x 20. B_1 zone of foliated olivine peridotite. Skeletal and doubly terminated olivine plates in sub-parallel orientation.
F. 1516D, x 20. B_2 zone of porphyritic olivine peridotite. Note the skeletal nature of many olivine crystals and the small proportion of platy olivine present.

Note : All specimens are totally altered, A-D are now chlorite-tremolite rocks ; E and F are serpentine-tremolite rocks.

show a gradation in size, from large at the base to small at the top, and thus provide a primary facing indicator.

The zone of foliated olivine peridotite, B_1, is narrow and rarely visible in the field. However, it is prominent in core sections where it provides the most conspicuous internal boundary within the flow. The zone is not always present and varies in width up to about 10 cm.

The porphyritic olivine peridotite zone, B_2, is the major zone in the lower half of the flow. It is a medium to fine-grained green-black serpentinite. On weathered surfaces small euhedral olivine crytals are seen.

The lower chilled zone, B_3, is not often seen in the exposures. Where visible it is similar in appearance to the upper chilled zone, but lacks the fractures.

PETROGRAPHY OF THE ULTRAMAFIC FLOWS

A common feature of all ultramafic rocks from the Mount Clifford area is the extensive alteration of primary minerals to serpentine, chlorite and tremolite. The metamorphism is essentially isochemical except for the introduction of a small amount of CO_2. That metamorphism did not involve large-scale transfer of components is indicated by the preservation of original igneous textures, and that iron, expelled from olivine during serpentinization, has not been distributed throughout the rock but forms a fringe of granules of magnetite around the pseudomorph. The scheme of alteration is not constant, but commonly olivine is altered to serpentine or chlorite and clinopyroxene to tremolite. In the drill core example the upper chilled margin and the spinifex-textured zones have been altered to chlorite-tremolite rocks. Towards the base of the A_3 zone, chlorite, after olivine, becomes more highly coloured and strongly pleochroic from green to pale orange and is probably the calcium-rich variety, xanthophyllite. Throughout the B_1, B_2, and much of the B_3 zones in which porphyritic olivine is dominant, serpentine replaces chlorite and the rock becomes a serpentine-tremolite rock. In the lowermost 10 cm of the flow, the alteration scheme is again chlorite-tremolite. It is tempting to suggest that the different alteration schemes in the lower and upper parts of the flow give rise to the different resistances to the weathering. Surface specimens collected from all zones, however, were found to be serpentine-tremolite rocks. None of the Mount Clifford specimens contained original olivine or pyroxene. However, despite complete replacement, the original igneous textures of the rocks are often beautifully preserved (Figs. 37 and 39) so that descriptions will be based on the original rather than the metamorphic mineralogy.

The following descriptions refer mainly to the drill-core sample of a single flow unit.

A_1 Chilled and fractured flow top

The upper half of the flow top is variable and in thin section has an agglomeratic appearance. Some patches are of devitrified glass containing about 14 per cent small euhedral olivine phenocrysts up to 0.5 mm across (Fig. 39A), while others, with fewer phenocrysts, are made up of small matted plates of olivine up to 0.4 mm long (Fig. 39B). The glassy patches often merge into the spinfex-textured parts and fractures pass indiscriminately through the rock. These fractures probably indicate cracking on cooling as there is no evidence of brecciation. The fractures in the flow top are filled with fibrous tremolite and green and brown chlorite. The marginal glassy peridotite is strongly dusted with anhedral grains of oxide and sulphide. A few small vesicles about 0.5 mm across are seen in this part of the flow (thin sections 15157A, B and Fig. 39B).

The lower half of the flow top grades into the random spinifex texture of zone A_2. Fractures, vesicles and euhedral olivine become less common and the olivine plates grow to a maximum length of about 1.5 mm. The interstitial material is a devitrified glass with no crystalline clinopyroxene, whilst the overall texture of the altered rock is similar to a high-Mg basalt (Compare Figs. 37E and 39B). The chilled margin is also noteworthy for its lack of dendritic opaque minerals which, in this zone, are distributed as a "dust" throughout the rock.

A_2 Pyroxene peridotite with random spinifex texture

The boundary between the A_1 and A_2 zones is gradational, and less obvious in thin section than in the polished core (Fig. 38). Small-scale spinifex texture becomes progressively coarser and more organized towards the base. The zone is characterized by dendritic chromite and feathery clinopyroxene as the interstitial material, rather than glass. Blades of olivine make up about 35-40 per cent of the rock (Fig. 39C) and range in length from 1.5 mm near the top (15157D) to 8 mm near the boundary with the underlying A_3 zone. The length : breadth ratio of the plates varies from about 20 : 1 to 10 : 1, and for the most part, the plates are randomly orientated about triangular and rhomboidal areas of feathery to acicular clinopyroxene and dendritic chromite. Near the base of the zone (15158D) the large olivine plates occasionally form small fans, and although the interstitial clinopyroxene forms acicular crystals up to 1 mm long, the chromite remains as dendritic crystals about 0.5 mm across.

A_3 Pyroxene peridotite with large-scale spinifex texture

This, the largest zone in each flow, is distinctive both in the field and microscopically. It is characterized by large books and fans of olivine plates

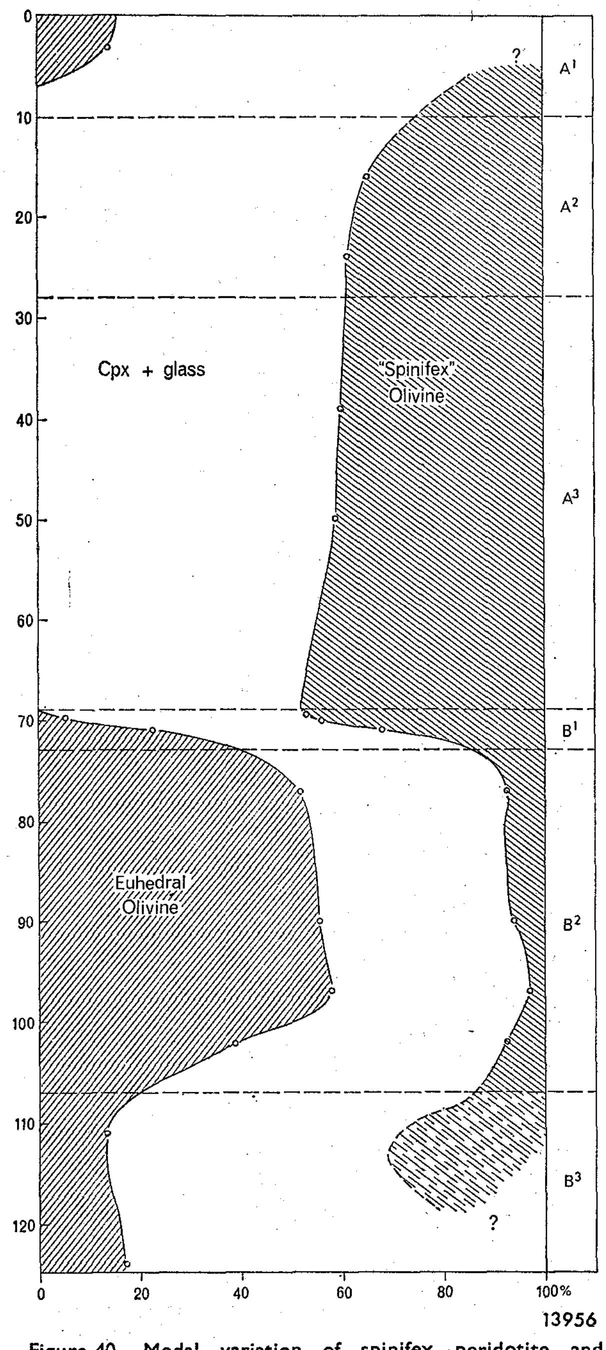


Figure 40. Modal variation of spinifex peridotite and euhedral peridotite with depth in flow. Left hand scale in cm below flow top. Right hand scale gives zones within the flow.

with their long axes sub-vertical and the apices of the fans pointing towards the top of the flow (Figs. 37B, 38, 39D). This type of spinifex texture has been fully described by Nesbitt (1971) and Pyke and others (1973).

Modal analyses (Fig. 40) show that the zone consists of 40 per cent bladed olivine and 60 per cent interstitial material. The latter consists of acicular clinopyroxene and dendritic chromite similar to that in the A_2 zone. The length of the olivine plates in the core section varies from about 2 cm near the top to about 8 cm at the base, and in thicker flows, seen in the field, may be up to 30 cm long. In thin section the blades are rarely more than 0.5 mm thick, show an internal skeletal structure and have a length : breadth ratio of up to 50 : 1.

B_1 *Foliated olivine peridotite*

Between the spinifex zone, A_3, and the underlying porphyritic peridotite zone, B_2, a narrow zone of foliated peridotite is usual. The B_1 zone is generally poorly exposed but is well represented in the W.M.C. DDH 169 core, where such zones vary in thickness from 3 to 10 cm. As noted by Pyke and others (1973) the junction between the spinifex zone and the foliated zone is the most distinctive zone boundary in the flow (Fig. 38). The foliated peridotite is characterized by elongate skeletal olivine plates (Fig. 39E) in sub-parallel orientation. Interstitial acicular clinopyroxene and dendritic chromite, similar to that in higher zones, are present. In addition there are euhedral olivine crystals whose abundance increases rapidly downward. The base of the zone is taken where euhedral olivine becomes dominant over platy olivine. This transition is illustrated in Figure 40 where modal analyses show that over a distance of 2 cm olivine plates cease to be the dominant mode of crystallization. The plates themselves are unlike those of the overlying spinifex zone in that they are rarely longer than 3 mm, have a length : breadth ratio of 10 : 1 or less, and are more skeletal than the plates for the A_3 zone. Also the plates are often doubly terminated indicating growth at both ends, whereas spinifex fans develop in one direction only.

B_2 *Olivine peridotite*

This zone is characterized by the presence of about 55 per cent modal euhedral olivine and 5 per cent platy olivine (Fig. 40). The olivine is set in a matrix of fine-grained feathery clinopyroxene, glass and a few small euhedra of chromite (Fig. 39F, see also Figs. 37C and D). The olivine euhedra are between 0.7 and 1.0 mm long and somewhat skeletal. A few larger euhedra, up to 1.5 mm across, are markedly skeletal. The platy olivine forms skeletal crystals up to 3 mm long and 0.3 mm thick, similar to those of the B_1 zone but without preferred orientation (Fig. 39F). The chromite euhedra are about 0.1 mm across and much less plentiful than the dendritic chromite of the spinifex zones.

The development of both olivine and interstitial pyroxene appears to depend, in part, on the thickness of the flow. In surface specimens (20543-4), from a flow 3 m thick, not only are the olivine crystals larger (up to 2 mm across) but the clinopyroxene shows the skeletal and acicular development typical of the spinifex zones of the core sample.

Towards the base of the B_2 zone (15164 A, B) the olivine euhedra become smaller and less numerous. In interstitial areas small spinifex-style plates of olivine begin to develop and over a distance of a few centimetres the olivine peridotite grades into the basal chilled zone.

B_3 *Lower chilled zone*

The lowermost part of the core section is similar to the uppermost zone. However, fractures are absent. Throughout this lower zone there are small olivine phenocrysts, but the dominant texture is a fine-grained irregular spinifex with interstitial feathery clinopyroxene which grades downward into a glassy material with hair-like olivine blades. The lowermost centimetre, or so, seems to have been completely glass and the contact with the underlying flow is sharp (Fig. 39A). The larger spinifex plates are up to 1.5 mm long and are randomly orientated, but the smaller plates nearer the base are matted and foliated parallel to the base. Olivine phenocrysts in the glassy parts of the chilled zone are smaller and less skeletal than those in the overlying B_2 zone. In one slide (15165D) there is a crop of very small euhedral olivine crystals (0.1 mm or less) which appear to have formed in preference to spinifex-type plates. Chromite is present throughout most of the chilled zone as small dendritic crystals but in the lowermost glassy portions it is present only as a dusting of minute opaque grains.

Vesicular flow units

Surface specimens of two vesicular flow units southeast of the Mount Clifford area are so thoroughly serpentinized that little remains of their original textures. Specimens obtained from the centres of the flows (20549-51) appear to have been composed of coarse-grained peridotite with subhedral olivine crystals 3-4 mm across making up at least 70 per cent of the rock. Specimens from a narrow vesicular zone (20547, 8) appear to be a similar rock with slightly smaller olivine and large chlorite-filled vesicles up to 1 cm across. Textures similar to the dendritic olivine displayed in the Murphy Well ultramafite (Lewis and I. R. Williams, 1973) are not present, but the vesicles often have a pyroxene-rich "tail" identical to those associated with vesicles in the Murphy Well rocks. The "tail" marks the upward path of the vesicle and is filled by acicular skeletal clinopyroxene up to 1 mm long, and glass. Some vesicles were evidently trapped by the olivine crystals and failed to produce a tail, but others have irregular tails up to 8 mm long with a small circular vesicle 2 mm across at the upper end. Although most vesicles are spherical to sub-spherical some of the larger ones are irregular in shape.

CHEMISTRY

Bulk chemical analyses and C.I.P.W. norms of 13 samples from the core section are presented in Table 11. Some of the chemical variations exhibited by these samples are shown in Figures 41 and 42. Analyses of additional rocks from the Mount Clifford area, including a high-Mg basalt from the Marshall Pool syncline, are given in Table 12. For comparison analyses of peridotitic lavas and high-Mg magma types from various Archaean terrains are given in Tables 13 and 14.

If analyses 4 and 5 of Table 11 are taken to be typical of the upper spinifex zones of the flow, and analysis 9 to be typical of the lower porphyritic zone, then it will be seen that there are significant chemical differences. The porphyritic olivine peridotite is rich in MgO but is comparatively poor in Al_2O_3, CaO and total Fe, and this is reflected in the greater amount of olivine in the mode of the olivine peridotite (60 per cent) than in the spinifex-textured rocks (40 per cent). This difference is further emphasized by the olivine occuring in different forms (Fig. 40).

Chemical variations throughout the flow are shown in Figure 41. Nickel and sulphur follow the MgO curve and are concentrated in the porphyritic zone whereas chromium and titania follow the total Fe curve and are concentrated in the spinifex zones. Nickel is present in the ultramafic rocks of the Yilgarn Block both as sulphides and in small amounts in olivine (see e.g. Lewis and I. R. Williams, 1973). Except in the chilled margins Ni follows the MgO curve faithfully, indicating that in these low-sulphur ultramafics from

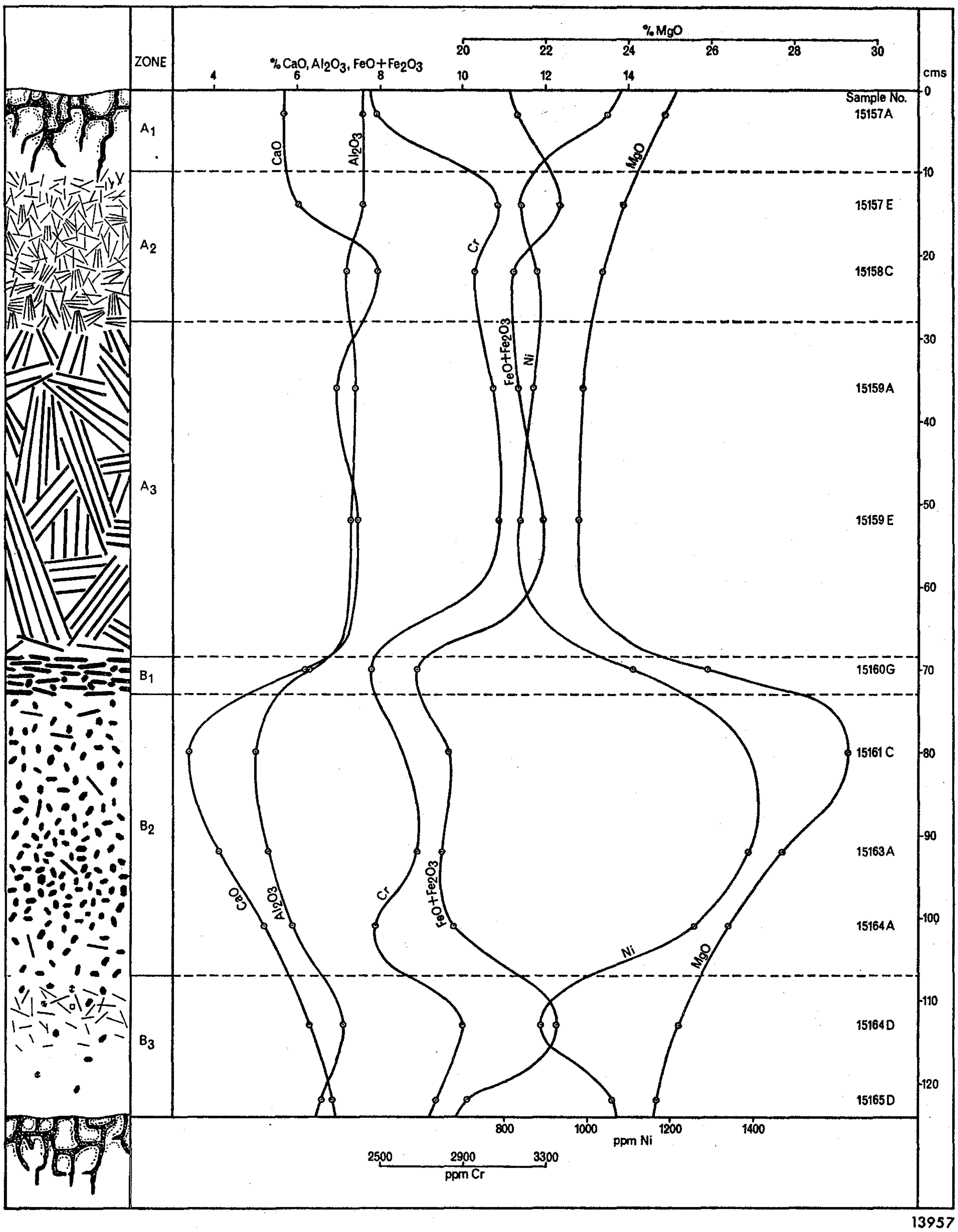


Figure 41. Chemical variation within a single flow unit.

TABLE 11. ANALYSES OF ULTRAMAFIC LAVA FROM MT. CLIFFORD

	1	2	3	4	5	6	7	8	9	10	11	12	13	
	15156E	15157A	15157E	15158C	15159A	15159E	15160G	15161C	15163A	15164A	15164D	15165D	15165E	A
SiO_2	45·1	41·6	41·8	42·3	43·2	42·8	44·6	43·3	43·5	43·3	42·5	44·2	42·1	42·89
Al_2O_3	6·4	7·6	7·6	7·2	7·4	7·3	6·3	5·0	5·3	5·9	7·1	6·6	7·6	6·76
Fe_2O_3	2·1	3·4	3·8	2·9	2·6	3·3	2·8	2·7	2·9	3·4	4·5	3·1	4·1	3·20
FeO	6·87	7·96	8·56	8·35	8·73	8·66	6·11	6·95	6·58	6·38	7·73	7·00	7·52	7·78
MgO	24·6	24·9	23·9	23·4	22·9	22·8	25·9	29·3	27·7	26·4	25·2	24·7	24·9	24·95
CaO	7·49	5·70	6·03	7·96	6·99	7·43	6·24	3·40	4·09	5·20	6·28	6·82	5·63	6·11
Na_2O	0·49	0·49	0·46	0·63	0·49	0·45	0·40	0·40	0·46	0·38	0·51	0·65	0·38	0·48
K_2O	0·1	0·1	0·0	0·0	0·1	0·1	0·1	0·2	0·2	0·1	0·0	0·0	0·0	0·09
TiO_2	0·32	0·28	0·38	0·36	0·37	0·37	0·28	0·22	0·26	0·27	0·34	0·32	0·36	0·32
MnO	0·17	0·16	0·19	0·20	0·20	0·20	0·15	0·17	0·16	0·15	0·17	0·17	0·15	0·18
H_2O^+	6·50	7·65	7·24	6·51	6·63	6·56	6·81	8·90	8·24	7·67	6·92	6·76	7·59	7·01
H_2O^-	0·43	0·46	0·38	0·22	0·30	0·34	0·68	0·93	1·02	0·93	0·29	0·33	0·40	0·49
CO_2	0·62	0·51	0·27	1·51	0·26	0·91	0·25	0·20	0·11	0·27	0·28	0·36	0·27	0·52
P_2O_5	0·03	0·04	0·04	0·05	0·02	0·06	0·03	0·01	0·01	0·03	0·05	0·04	0·04	0·03
Total	101·2	100·8	100·6	101·6	100·3	101·2	100·7	101·7	100·5	100·3	101·9	101·1	101·1	100·8
Trace Elements (ppm)														
Cr	2 680	2 490	3 070	2 960	3 050	3 070	2 460	....	2 680	2 480	2 900	2 770	3 000	....
Co	85	90	90	85	90	90	75	....	100	90	85	90	95	....
Ni	980	1 050	840	880	870	840	1 110	....	1 390	1 260	890	1 060	930	....
Cu	35	350	30	25	20	60	30	....	20	45	30	45	80	....
Zn	80	60	70	60	60	60	90	....	70	60	50	70	50	....
S	250	460	80	80	70	100	290	....	480	410	70	230	150	....
Ba	5	5	5	5	5	5	5	....	5	5	5	5	5	....
Sr	50	30	30	80	50	60	20	....	20	20	30	30	20	....
Zr	60	40	10	50	20	40	20	....	30	10	30	10	50	....
C.I.P.W. Norm														
Or	0·59	0·59	0·00	0·00	0·59	0·59	0·59	1·18	1·18	0·59	0·00	0·00	0·00	0·59
Ab	4·48	4·57	4·23	5·84	4·48	4·15	3·64	3·72	4·32	3·55	4·65	5·92	3·47	4·40
An	16·15	19·93	20·13	18·19	19·16	19·06	16·33	12·44	12·95	15·56	18·54	16·23	20·81	17·56
Ap	0·07	0·09	0·09	0·12	0·05	0·17	0·07	0·02	0·02	0·07	0·12	0·09	0·09	0·07
Di	18·90	8·55	9·64	19·53	14·45	16·34	13·50	4·92	7·43	10·00	11·80	15·94	7·46	12·11
Wo	9·93	4·47	5·03	10·21	7·55	8·53	7·10	2·59	3·91	5·25	6·17	8·36	3·90	6·34
En	7·36	3·20	3·52	7·23	5·31	5·94	5·31	1·94	2·92	3·88	4·36	6·09	2·79	4·56
Fs	1·61	0·88	1·09	2·09	1·59	1·88	1·09	0·39	0·60	0·86	1·28	1·49	0·77	1·20
Hy	25·94	18·96	21·35	10·66	22·33	19·46	30·11	32·98	32·29	30·12	18·08	22·93	24·86	22·35
En	21·28	14·86	16·29	8·27	17·20	14·78	24·99	24·47	26·77	24·65	13·98	18·43	19·47	17·69
Fs	4·66	4·09	5·06	2·39	5·14	4·67	5·13	5·52	5·51	5·47	4·10	4·50	5·39	4·66
Ol	32·70	45·38	42·04	44·38	36·33	38·53	34·10	44·10	39·99	38·10	45·80	37·32	41·37	41·14
Fo	26·35	34·81	31·32	33·64	27·33	28·58	27·81	36·11	32·59	30·61	34·62	29·41	31·70	31·88
Fa	6·35	10·57	10·72	10·74	9·00	9·95	6·29	7·99	7·40	7·49	11·19	7·91	9·67	9·26
Mt	1·59	1·88	2·03	1·88	1·88	2·03	1·59	1·59	1·59	1·59	1·88	1·74	2·03	1·88
Il	0·66	0·59	0·78	0·74	0·76	0·76	0·57	0·46	0·55	0·57	0·70	0·66	0·74	0·66
Salic%	21·1	25·0	24·4	23·8	24·3	23·7	20·5	17·1	18·4	19·7	22·9	22·1	24·2	22·4
Femic %	78·9	75·0	75·6	76·2	75·7	76·3	79·5	82·9	81·6	80·3	77·1	77·9	75·8	77·[illegible]

NOTE : Norms calculated on volatile free basis and after adjusting Fe^{3+} : Fe^{2+} ratio to 1:9 (see text). *Analysts:* Govt. Chemical Laboratories, FeO, Na_2O, and H_2O by chemical methods, remainder by X.R.F. 1. Base of overlying flow. 2. Chilled and fractured flow top, A_1 zone. 3 and 4. Pyroxene peridotite A_2 zone. 5 and 6. Pyroxene peridotite, A_3 zone. 7. Foliated olivine peridotite, B_1 zone. 8, 9 and 10. Olivine peridotite, B_2 zone. 11 and 12. Basal chilled, B_3 zone. 13. Top of underlying flow. A. Weighted average of analysis 2–12. For location of samples on core section see Fig. 38.

TABLE 12. ADDITIONAL ANALYSES FROM THE MT. CLIFFORD AREA

	1	2	3	4	5	6	7	8	9	10
	32773	32775	38280	32778	38282	32771	35962	38281	35960	32772
SiO_2	42·3	44·6	42·2	40·9	40·5	40·5	42·9	41·9	43·4	49·8
Al_2O_3	6·1	7·3	5·8	2·9	2·9	3·8	1·8	2·1	6·8	12·4
Fe_2O_3	5·8	2·2	5·7	3·3	3·9	3·6	2·9	2·8	6·6	2·4
FeO	3·49	7·38	4·22	4·65	4·10	4·54	4·00	1·99	5·73	8·55
MgO	29·5	25·2	29·2	36·3	36·5	36·6	38·00	39·9	26·9	11·8
CaO	5·59	6·84	5·05	0·11	0·17	0·73	0·08	0·14	4·29	7·23
Na_2O	0·30	0·22	0·24	0·00	0·01	0·05	0·03	0·02	0·21	4·09
K_2O	0·00	0·00	0·00	0·00	0·00	0·00	0·00	0·00	0·00	0·00
TiO_2	0·28	0·44	0·28	0·18	0·17	0·18	0·07	0·09	0·54	0·81
MnO	0·17	0·20	0·18	0·16	0·15	0·17	0·09	0·08	0·20	0·21
H_2O^+	7·68	6·50	7·54	11·57	11·53	11·00	11·70	11·91	6·89	2·86
H_2O^-	0·54	0·36	0·36	0·70	0·85	0·37	0·44	0·70	0·40	0·31
CO_2	0·05	0·04	0·03	0·02	0·02	0·03	0·02	0·04	0·06	0·06
P_2O_5	0·04	0·06	0·02	0·00	0·00	0·01	0·02	0·00	0·06	0·10
Total	101·8	101·3	100·8	100·7	100·7	101·6	101·4	100·7	102·1	100·6
Trace Elements (ppm)										
Cr	2 570	1 780	1 030	1 860	1 530	1 290	1 440	1 720	2 280	1 090
Cu	10	10	10	10	10	10	10	10	50	60
Ni	1 400	1 240	1 420	1 850	1 910	1 840	1 670	2 190	1 400	350
Zn	50	80	90	50	200	50	60	90	60	90
S	60	50	40	40	80	30	50	180	70	60

Analysts: Government Chemical Laboratories ; FeO, H_2O and CO_2 by chemical method, all other elements by X.R.F.

1. Spinifex-textured pyroxene periodtite, Mt. Clifford.
2, 3. Olivine peridotite, Marriot Prospect, Mt. Clifford (Area B Fig. 35).
4, 5, 6. Olivine peridotite, Mt. Clifford North extension.
7. Olivine peridotite, near Bannockburn Well, Mt. Clifford.
8. Olivine peridotite, near W.M.C. DDH 169, Mt. Clifford.
9. Intrusive peridotite, Mt. Fouracre.
10. High-Mg basalt, Mt. Clifford North extension.

Mount Clifford the partitioning of Ni between a sulphide phase and the olivine lattice is in equilibrium. A similar equilibrium exists between Cr in chromite and in the clinopyroxene lattice.

A significant feature of the chemistry of the Mount Clifford rocks is that the weighted average of the 11 analyses from the flow (Table 11, Column A) is in good agreement with the analysis of the basal chilled zone (Table 11, Column 12) and fair agreement with the upper chilled zone and the foliated B_1 zone (Table 11, Columns 1 and 2). This suggests that these zones represent essentially undifferentiated portions of the flow. The high Al_2O_3 in the upper chilled margin may be due to chlorite which fills the fracture veins.

The norms in Table 11 were calculated after exclusion of volatiles and adjustment of the Fe^{3+} : Fe^{2+} ratio to 1 : 9 in order to compensate for oxidation of iron during serpentinization. Normatively the rocks contain from 12 per cent to 21 per cent anorthite, and up to 33 per cent orthopyroxene, minerals which have not been observed in the mode. Orthopyroxene and plagioclase are not present in the interstitial glass of the Mount Clifford rocks because wherever the glass is sufficiently devitrified to determine it is replaced by feathery tremolite after an original clinopyroxene. In other studies where fresh pyroxene was available for analysis (Nesbitt, 1971; Pyke and others, 1973; Lewis and I. R. Williams, 1973) it has been shown that the clinopyroxene of these ultramafic rocks is a high alumina augite containing 6 per cent to 9 per cent Al_2O_3 in the molecule. The result of incorporating Al_2O_3 into the clinopyroxene rather than the anorthite molecule is to release the CaO of the anorthite to form more clinopyroxene thus also absorbing the orthopyroxene calculated in the norm. It is probable that the clinopyroxne of the Mount Clifford rocks would also have been a high alumina variety. The norms indicate that under different cooling conditions none of the Mount Clifford rocks would be strictly ulramafic but would be classified as picrites. The rapid cooling of the magma, however, has given rise only to olivine, clinopyroxene and an iron-rich residual glass so that mineralogically the rocks are ultramafic.

TABLE 13. ULTRAMAFIC LAVAS FROM W. AUSTRALIA, CANADA, SOUTH AFRICA AND CYPRUS

	1	2	3	4	5	6	7	8
SiO	40·37	40·8	39·3	41·0	41·58	42·06	40·36	43·00
Al_2O_3	4·66	10·0	5·91	5·54	3·44	2·21	1·97	4·64
Fe_2O_3	5·41	2·94	3·68	3·46	5·20	4·73	5·84	2·42
FeO	4·03	6·49	3·31	6·16	6·01	5·23	3·75	6·47
MgO	31·06	23·3	33·9	32·0	26·71	29·93	35·17	33·45
CaO	4·17	6·86	2·58	4·21	5·99	5·18	3·45	3·99
Na_2O	0·11	0·23	0·20	0·28	0·12	0·16	0·05	0·25
K_2O	0·03	0·07	0·12	0·07	0·03	0·02	0·00	0·05
TiO_2	0·22	0·25	0·17	0·21	0·38	0·31	0·41	0·18
MnO	0·17	0·16	0·10	0·13	0·19	0·16	n.d.	0·15
H_2O^+	9·05	5·91	9·23	5·47	9·03	8·62	7·76	3·83
H_2O^-	0·34	0·86	1·06	0·73	0·18	0·15	0·21	1·22
CO_2	0·11	0·28	0·31	0·42	n.d.	n.d.	n.d.	n.d.
P_2O_5	0·08	0·02	0·03	0·01	n.d.	0·02	n.d.	....
Cr_2O_3	0·17	0·45	0·29	0·38	0·30	0·31	n.d.	0·51
NiO	0·18	n.d.	n.d.	n.d.	0·15	0·18	0·25	....
Total	100·16	98·62	100·19	100·07	99·70	99·76	99·22	100·16

n.d.—no data.

1. Peridotite average of 7 analyses from Murphy Well (Lewis and Williams 1971, p. 64, Nos. 3–10).
2–4. Ultramafic flow, Munro Township, Ontario. 2. A_2 zone ; 3. B_2 zone ; 4. B_3 zone (Pyke and others 1973).
5–7. Peridotite flow, Barberton, South Africa. 5. AU5. pillowed peridotite from top of flow ; 6. V_2peridotite, centre of flow ; 7. VU32A, peridotite, base of flow (Viljoen and Viljoen 1969).
8. Ultrabasic pillow lava, vitrophyric types, Cyprus(Gass 1958).

TABLE 14. REPRESENTATIVE ANALYSES OF PERIDOTITES, HIGH–MG BASALTS AND THOLEIITES

	1	2	3	4	5	6	7	8	9
SiO_2	43·70	42·10	48·4	46·2	49·9	51·4	43·54	47·90	50·83
Al_2O_3	6·10	4·35	7·4	5·3	10·6	14·8	3·99	11·84	14·07
Fe_2O_3	2·94	4·45	9·8	9·6	1·9	1·5	2·51	2·32	2·88
FeO	5·27	5·69	....	....	8·0	9·1	9·84	9·80	0·06
MgO	27·85	30·77	24·9	33·3	14·1	6·7	34·02	14·07	6·34
CaO	6·25	3·74	8·0	3·6	9·5	10·7	3·46	9·29	10·42
Na_2O	0·19	0·17	0·24	0·17	1·54	2·7	0·56	1·66	2·23
K_2O	0·02	0·03	0·05	0·02	0·13	0·18	0·25	0·34	0·82
TiO_2	0·28	0·18	0·33	0·24	0·51	0·92	0·05	1·65	2·03
MnO	0·20	0·20	0·18	0·15	0·17	0·21	0·21	0·15	0·18
H_2O^+	....	....	....	....	3·1	1·0	} 0·76	0·59	0·91
H_2O^-	6·92*	8·48*	5·3*	9·7*	....	....			
CO_2	....	....	....	....	0·1	0·1	....	....	....
P_2O_5	....	....	0·04	0·03	0·07	0·13	....	0·19	0·23
Cr_2O_3	n.d.	n.d.	0·43	0·44	0·24	....	....	....	....
NiO	n.d.	n.d.	0·18	0·25	n.d.	....	....	....	....
Total	99·72	....	....	....	....	99·44	100·00	....	....

* Loss on ignition

1. Plate spinifex peridotite, Scotia W.A. SD3/266 (Nesbitt 1971).
2. Olivine peridotite adjacent to 1. Scotia W.A. (Nesbitt 1971).
3. Average of 11 olivine-poor peridotites from Mt. Hogan ultramafic lenses (D. A. C. Williams 1973).
4. Average of 14 peridotites from cores of Mt. Hogan ultramafic lenses (D. A. C. Williams 1973).
5. Average of 35 high-Mg basalts. Eastern Goldfields W.A. (Hallberg and Williams 1972).
6. Average of 123 tholeiitic basalts from Kalgoorlie-Norseman W.A. (Hallberg 1972).
7. Average peridotite (Nockolds 1954).
8. Average tholeiitic olivine basalt (Nockolds 1954).
9. Average tholeiitic basalt (Nockolds 1954).

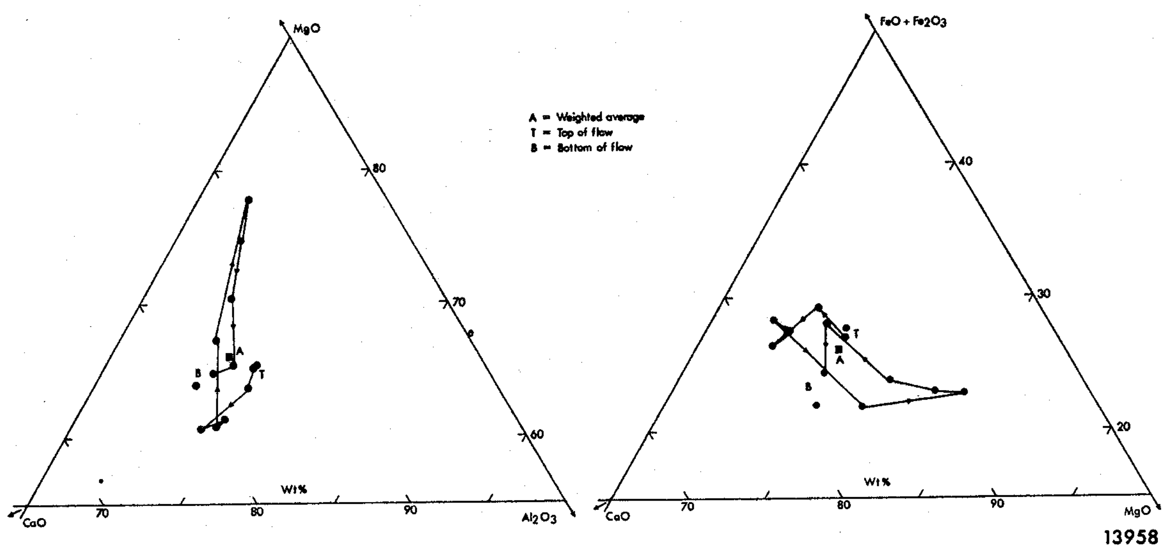


Figure 42. MgO–CaO–Al_2O_3 and total Fe–CaO–MgO variation diagrams of the Mount Clifford ultramafic rocks.

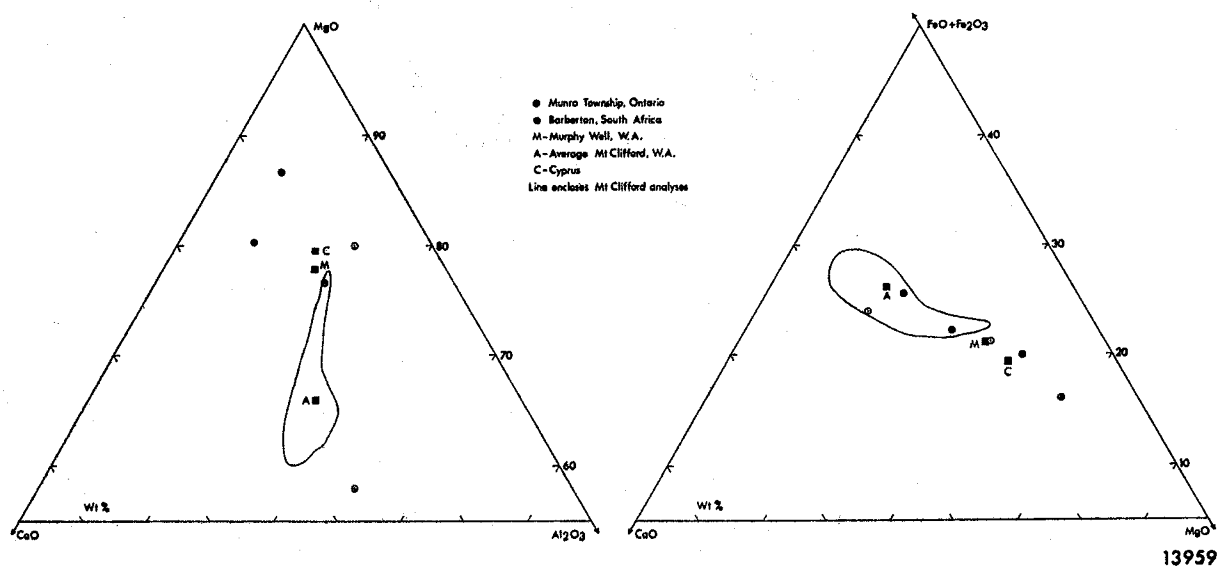


Figure 43. Comparison of ultramafic lavas.

Comparison of the Mount Clifford analyses with those from the Munro Township ultramafic flows (Table 13, Columns 2-4) shows that the spinifex zone at Mount Clifford is slightly more siliceous and less aluminous than the Canadian example but otherwise the analyses are in good agreement. The considerably lower MgO content of the porphyritic zone of the Mount Clifford lavas (Table 11, Column 9) compared with the Munro Township flows indicates a lower concentration of olivine. Nevertheless Figure 43 shows that the Munro lavas are similar to the Mount Clifford flows whereas peridotite lavas from the Barberton Mountainland of South Africa (Table 13, Columns 5-7; Viljoen and Viljoen, 1969a) fall in a different field. The South African rocks are high in MgO but lower in CaO and especially in Al_2O_3 with the result that the CaO : Al_2O_3 ration is consistently greater than unity. Although some of the Mount Clifford analyses show a ratio slightly greater than 1.0 the majority range down to 0.68. With respect to the Murphy Well ultramafic lava (Lewis and I. R. Williams, 1973) and the ultrabasic pillow lava from Cyprus (Gass, 1958, and this paper Table 13, Columns 1, 8) the Mount Clifford lavas are less peridotitic but fall on the same compositional trend.

Comparison of the Mount Clifford lavas with other peridotite and high-Mg basalt from Western Australia (Table 14 and Fig. 44) reveals a general similarity in the magma type that these analyses represent.

DISCUSSION

That rocks similar to the Mount Clifford ultramafites are true peridotitic lavas is now widely accepted, as is the hypothesis that they crystallized from a liquid magma with only a small proportion of phenocrysts. Both upper and lower chilled margins show that the units are complete and the marked asymmetry of the flow zones, coupled with the regularity of such features across strike, supports the hypothesis that the flows were laid down one after the other.

The very fluid nature of an ultramafic magma would allow it to spread rapidly over a wide area with the result that a lava pile would be built up of many thin flows. The remarkable lateral persistence of flows only a few metres thick has been documented by Pyke and others (1973). In the Mount Clifford area this feature is emphasized by the persistence of strike ridges of spinifex-textured peridotite several hundred metres long (Fig. 36). In the Munro Township exposures of small bulbous flows about a metre long were also mapped. The Mount Clifford lavas are not so well exposed, however, small discontinuous flows are found among the thicker flows. These may represent tongues of liquid advancing in front of a major lava flow rather than pillows as found by Viljoen and Viljoen (1969a) in South Africa. There is no clear indication of pillows in the Mount Clifford peridotites.

After extrusion the chilled upper surface of the lava must have formed rapidly. The formation and preservation of this thin zone and the maintenance of still conditions, in order that spinifex texture might develop within the liquid interior, suggests that the lava poured into a basin which effectively ponded the flow. The presence of thin shale horizons between the flows indicates that the eruptions were submarine.

Spinifex texture has been shown to form by the quenching of an ultramafic liquid which was free of phenocrysts or other potential nucleii (Nesbitt, 1971; Lewis, 1971). In contrast the lower porphyritic and more olivine-rich layer (B_2 zone) is probably derived from an accumulation of olivine phenocrysts which formed nucleii around which further crystallization could take place. The mechanism by which this differentiation of olivine phenocrysts took place is not clear but at least two processes are possible, namely flow differentiation, and crystal settling. Viljoen and Viljoen (1969a, p. 98) maintain that the small size of the olivine nucleii would inhibit crystal settling. Therefore they favour the flow differentiation model in which crystals will tend to migrate away from the margins of a flowing body of liquid. If the flow rate was low (Bhattacharji, 1967) phenocrysts would concentrate at, or just below, the centre of the flow. This process appears to be confirmed by the shape of the graph for modal euhedral olivine in Figure 40. However, if the liquid fraction of the magma, as represented by the spinifex zones A_2 and A_3, was capable of crystallizing 40 per cent olivine then it can be calculated that the B_2 zone contained only 33.7 per cent phenocrysts before the magma finally crystallized. If these phenocrysts are then distributed throughout the magma their proportion falls to 12.2 per cent which is in fair agreement with the 15 per cent phenocrysts observed in the chilled margins. It has been noted above that the chemical composition of the chilled zones approximates to the average composition of the flow, and it seems probable that differentiation did not take place until after the lava had erupted and the chilled margins formed.

The crystal settling model imposes limitations on the cooling history of the magma. Principally it implies that the magma remained liquid for some time after extrusion, enabling the olivine phenocrysts to grow and settle. A magma as low in silica as the Mount Clifford ultramafic flows would have a low viscosity and a high melting point. Viljoen and Viljoen (1969a) have shown that an ultramafic liquid can exist at about 1 400° C. The fluidity of an ultramafic magma has been demonstrated by Lewis and I. R. Williams (1973) from studies of the morphology of vesicles in such a flow. Vesicles observed in some flows at Mount Clifford exhibit similar features and testify to a highly mobile magma. However, the presence of spinifex texture and interstitial glass even in the centre of the flow shows that crystallization, when it finally occurred, was very rapid. The paradox which requires that the magma remain fluid while olivine crystals settle, yet requires rapid chilling to produce glass, may be resolved if a suggestion of Wyllie (1960) is accepted. From consideration of experimental data on the system CaO-MgO-Fe-SiO_2, Wyllie suggests that the slope of the liquidus surface in the peridotite range is rather flat. The effect of such a plateau would be that the major part of a peridotite magma would crystallize over a small temperature range. Therefore, if a magma is extruded at temperatures above this "plateau"—with highly forsteritic olivine phenocrysts in equilibrium with the liquid fraction—there will be a temperature, and time interval, during which settling can occur with little additional crystallization. This interval will be followed by a short period during which the remainder of the magma will "freeze".

The composition of olivine found by microprobe in ultramafic flows falls within the narrow range of Fo_{89} to Fo_{93}. This probably represents the upper end of the plateau in the liquidus surface.

Nesbitt (1971) invoked a degree of superheating to clear the upper spinifex zones of potential nucleii before final crystallization. However, if extrusion at temperatures above the level of the liquidus "plateau" is accepted, then the nucleii could be cleared simply by crystal-settling through a magma of low viscosity.

Under this interpretation, which is favoured by the authors, the chilled margins represent a skin of rock of about the same composition as the original magma, which sufficiently slowed heat loss from the main part of the flow to allow crystal settling to accomplish the zonation now observed in the flows. Variations in the temperature of extrusion and the rate of heat loss would (Pyke and others 1973, p. 974) be sufficient to arrest differentiation, so forming the type of flow which does not have an upper spinifex zone.

The final crystallization of the magma after extrusion illustrates several points of interest. The foliated B_1 zone contains a concentration of short olivine plates which are also found in the porphyritic B_2 zone. Such plates probably represent early-formed, free floating crystals, which nucleated after extrusion but before the spinifex type plates, governed by cooling from the upper surface, finally predominated. The small plates, their long axes parallel to the top of the underlying olivine-liquid mush, would settle more slowly than euhedral olivines. In the thin (1.24 m thick) flow studied the time interval for final crystallization would be short and it is apparent that olivine crystallized simultaneously in two entirely different habits. In the upper zone, free of phenocrysts, the olivine formed large plates, whereas in the lower zone skeletal over-growths on existing euhedral olivines were forming. This supports the conclusion of Drever and Johnston (1957) that the habit of olivine is dependent upon small variations in the physical environment of crystallization.

Early formed chromite euhedra also settled during differentiation, and are only found in the porphyritic zone. From the chemistry of the flow, however, (Fig. 41) it is seen that chromium is concentrated in the upper zones either as part of the pyroxene lattice or as dendritic chromite. This suggests that under the conditions of extrusion, the bulk of the chromium was held in solution until the last stages of crystallization. This is in contrast to the layered sills of high-Mg basalt composition where chromium is concentrated near the base of the sills (Hallberg and D. A. C. Williams, 1972).

MAGMA TYPE

In Figure 44 the Mount Clifford rocks are plotted on F-M-C and A-M-C diagrams along with other peridotites, high-Mg basalts and tholeiites from the Eastern Goldfields. Nockolds' (1954) average peridotite, olivine tholeiite and tholeiite are also plotted on the same diagrams for comparison. Analyses with greater than 10 per cent combined water have not been used following a suggestion by Viljoen and Viljoen (1969b) that in such rocks complete serpentinization has expelled much of the CaO and Al_2O_3. This is confirmed by reference to Table 12 analyses 4-8 which show that high water content correlates with low CaO in rocks which are otherwise similar to those of Table 11.

The triangular diagrams show that the peridotite, pyroxene peridotite and high-Mg bassalt, lie on a well-defined trend which, as Nesbitt (1971, p. 336) states, may be a fractionation trend away from the MgO pole. The A-M-C trend is clearly defined, and it is of interest that the average tholeiite of Nockolds and the average Archaean tholeiite of Hallberg (1972) lie on the end of this trend. Although major element chemistry of Archaean ultramafic rocks indicates a differentiation trend which ends with the tholeiite basalts, Hallberg and D. A. C. Williams (1972) suggest that these rocks are not derived from a single magma source. Trace element trends within the peridotite to high-Mg basalt range do not continue into the tholeiites. In addition, while the ultramafic rocks show a wide variation in composition, tholeiites from the Yilgarn Block cluster within a very narrow composition range.

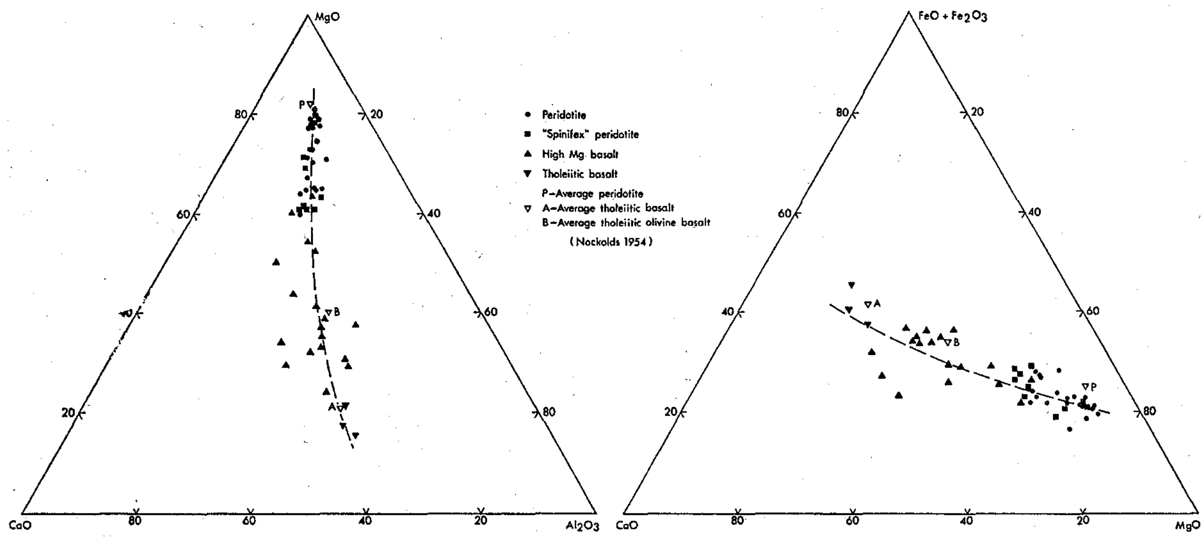


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Figure 44. MgO–CaO–Al_2O_3, and total Fe–CaO–MgO variation diagrams of the high-Mg rock suite from the Archaean of Western Australia.
Data from this study and Nesbitt (1971), McCall and Leishman (1971), D. A. C. Williams (1972), Hallberg (1972), Hallberg and D. A. C. Williams (1972).

The Mount Clifford rocks are representative of a highly magnesian magma, that because of a thin crust and consequently steep temperature gradient in Archaean times was able to reach the surface and erupt as a lava. The relationship of this magma with the tholeiite magma of Archaean and Phanerozoic times remains uncertain.

ACKNOWLEDGEMENTS

The authors would like to thank Dr. R. Woodall of Western Mining Corporation for presenting the core section from drill hole W.M.C. 169, Mr D. Reid also of W.M.C., for helpful discussion in the field, and Dr. J. A. Hallberg of C.S.I.R.O. Perth. Dr. A. J. Naldrett of the University of Toronto gave helpful suggestions during various stages of this study.

REFERENCES

Anhaeusser, C. R., 1971a, Cyclic Volcanicity and Sedimentation in the Evolutionary Development of Archaean Greenstone Belts of Shield Areas: Geol. Soc. Australia, Spec. Pub. No. 3 p. 57-70.

——— 1971b, The Barberton Mountainland, South Africa, A Guide to the Understanding of the Archaean Geology of Western Australia: Geol. Soc. Australia, Spec. Pub. No. 3, p. 103-119.

Bhattacharji, S., 1967, Scale Model Experiments on Flowage Differentiation in Sills, *in* P. J. Wyllie (Ed.), Ultramafic and Related Rocks: New York, John Wiley, p. 69-70.

Bowen, N. L., 1928, The Evolution of the Igneous Rocks: New York, Dover.

Drever, H. I. and Johnston, R., 1957, Crystal growth of forsteritic olivine in magmas and melts: Roy. Soc. Edinburgh Transactions v. 63, p. 289-315.

Gass, I. G., 1958, Ultrabasic pillow lavas from Cyprus: Geol. Mag. v. 95, p. 241-251.

Hallberg J. A., 1972, Geochemistry of Archaean Volcanic Belts in the Eastern Goldfields Region of Western Australia: Jour. of Petrology v. 13, p. 45-56.

——— and Williams, D. A. C., 1972, Archaean mafic and ultramafic rock associations in the Eastern Goldfields Region, Western Australia: Earth and Plan. Sci. Letters v. 15, p. 191-200.

Lewis, J. D., 1971, "Spinifex Texture" in a slag, as evidence for its origin in rocks: West. Australia Geol. Survey Ann. Rept. 1970, p. 45-49.

Lewis, J. D., and Williams, I. R., 1973, The petrology of an ultramafic lava near Murphy Well, Eastern Goldfields, Western Australia: West. Australia Geol. Survey Ann. Rept. 1972, p. 60-68.

McCall, G. J. H., and Leishman, J., 1971, Clues to the origin of Archaean eugeosynclinal peridotites and the nature of serpentinization: Geol. Soc. Australia Spec. Pub. No. 3, p. 281-299.

Naldrett, A. J., and Mason, G. D., 1968, Contrasting Archaean ultramafic igneous bodies in Dundonald and Clergue townships, Ontario: Canadian Jour. of Earth Sciences v. 5, p. 118-143.

Nesbitt, R. W., 1971, Skeletal crystal forms in ultramafic rocks of the Yilgarn Block, Western Australia: evidence for an Archaean ultramafic liquid: Geol. Soc. Australia Spec. Pub. No. 3, p. 331-347.

Nockolds, S. R., 1954, Average chemical compositions of some igneous rocks: Geol. Soc. America Bull. v. 65, p. 1007-1032.

Pyke, D. R., Naldrett, A. J., and Eckstrand, O. R., 1973, Archaean ultramafic flows in Munro township, Ontario: Geol. Soc. America Bull. v. 84, p. 955-978.

Thom, R., and Barnes, R. G., in press, Explanatory notes on the Leonora 1 : 250 000 Geological Sheet, West. Australia Geol. Survey.

Viljoen, M. R., and Viljoen, R. P., 1969a, Evidence for the existence of a mobile extrusive peridotite magma from the Komati Formation of the Onverwacht Group: Geol. Soc. South Africa Spec. Pub. No. 2, p. 87-112.

Viljoen, R. P., and Viljoen, M. R., 1969b, The effects of metamorphism and serpentinization on the volcanic and associated rocks of the Barberton Region: Geol. Soc. South Africa Spec. Pub. No. 2, p. 29-53.

Williams, D. A. C., 1971, Determination of primary mineralogy and textures in ultramafic rocks from Mt. Monger, Western Australia: Geol. Soc. Australia Spec. Pub. No. 3, p. 259-268.

——— 1972, Archaean ultramafic, mafic and associated rocks, Mt. Monger, Western Australia: Geol. Soc. Australia Jour. v. 19, p. 163-188.

Williams, I. R., 1974, Structural subdivisions of the Eastern Goldfields Province, Yilgarn Block: West. Australia Geol. Survey Ann. Rept. 1973, p. 53-59.

Wyllie, R. J., 1960, The System CaO-MgO-FeO-SiO_2 and its bearing on the origin of ultrabasic and basic rocks: Miner. Mag. v. 32, p. 459-470.

NOTES ON THE PATERSON RANGE GOLD PROSPECTS

by J. G. Blockley

ABSTRACT

The recently discovered Paterson Range gold prospects lie in a little prospected part of the Great Sandy Desert. They consist of quartz and quartz-limonite reefs, with pyrite boxworks and free gold, intruded concordantly into a sequence of sandstone, siltstone, shale and dolomite provisionally correlated with the Middle Proterozoic Bangemall Group. Granite, dated at 600 m.y., intrudes the sediments 25 km west of the prospects.

Most deposits occur in domes or anticlines, and many have a saddle-reef form. The principal prospect, with indicated reserves of 2 million tonnes averaging about 14 g of gold per tonne, follows a shale horizon around the outcrop of a well-formed dome.

The prospects differ from most other gold deposits in Western Australia in being Middle Proterozoic and in having as host rocks, sediments laid down on a stable shelf. Most other deposits are Archaean or Lower Proterozoic, and occur in greenstones belts or geosynclinal sequences. The saddle-reef form is also unusual. The only other gold deposits of comparable age, setting, and form, are at Bangemall on the southern edge of the Bangemall Basin. Further prospecting seems warranted in the Precambrian rocks of the western part of the Great Sandy Desert, and elsewhere in the folded margins of the Bangemall Group.

INTRODUCTION

The Paterson Range gold prospects lie near the northern end of the Paterson Range between latitudes 21° 35′ and 21° 47′ S and longitudes 122° 05′ and 122° 15′ E. The area is in the western edge of the Great Sandy Desert. The prospects occur in low rocky hills that protrude through the desert sand.

Newmont Pty. Ltd., which has tenure over the deposits has established a base known as Telfer Camp at lat. 21° 42′ S, long. 122° 12′ E. Access to the area is by a bulldozed dirt track which joins the Port Hedland to Woodie Woodie road near the Ragged Hills lead mine. Travelling time from the camp to Marble Bar, the closest town, is about 8 hours. Most personnel and light supplies are brought in by charter aircraft landing at a newly constructed strip near the camp.

Gold and copper concentrations were found in the Paterson Range area by Mr. Ronald Thomson, Geological Consultant to Day Dawn Minerals N.L. in 1971. At about the same time a private prospector, Mr. J. P. Turcaud, attempted to interest a number of companies in gossans with anomalous copper, lead and zinc values that he had located in the area. In following up the earlier work of Day Dawn Minerals N.L., Newmont Pty. Ltd. discovered free gold in a number of gossans in localities known as Main Dome and West Dome, within a larger structure called the Telfer Dome. It covered the more prospective ground with Mineral Claims, and more recently, with Gold Mining Leases and T.R.s for gold.

The prospects were inspected by J. H. Lord and the writer on the 23rd and 24th of August, 1973.

REGIONAL GEOLOGY

The gold prospects occur in a sequence of folded, slightly metamorphosed, cross-bedded sandstone, siltstone, shale, dolomite and calcarenite typical of sediments deposited in a stable shelf environment (Krumbein and Sloss, 1953). They closely resemble rocks of the Middle Proterozoic Bangemall Group, and are here tentatively assigned to this unit, although final correlation will depend on the results of proposed regional remapping programme in the area. Previous mapping by the Bureau of Mineral Resources (Wells, 1959) placed these sediments in the Lower Proterozoic at a time when the age relationships of the rock units in the Pilbara region were poorly understood (Fig. 45).

About 100 km south of the prospects, the Bangemall Group sediments overlie unconformable gneiss and schist dated by J. R. de Laeter at about 1 500 m.y. About 25 km west of the prospects, the sediments are intruded (Wells, 1959) by alkali-feldspar granite dated at about 600 m.y. (Trendall, 1974). Much of the area shown as granite on the B.M.R. reconnaissance map is in fact occupied by limestone or dolomite.

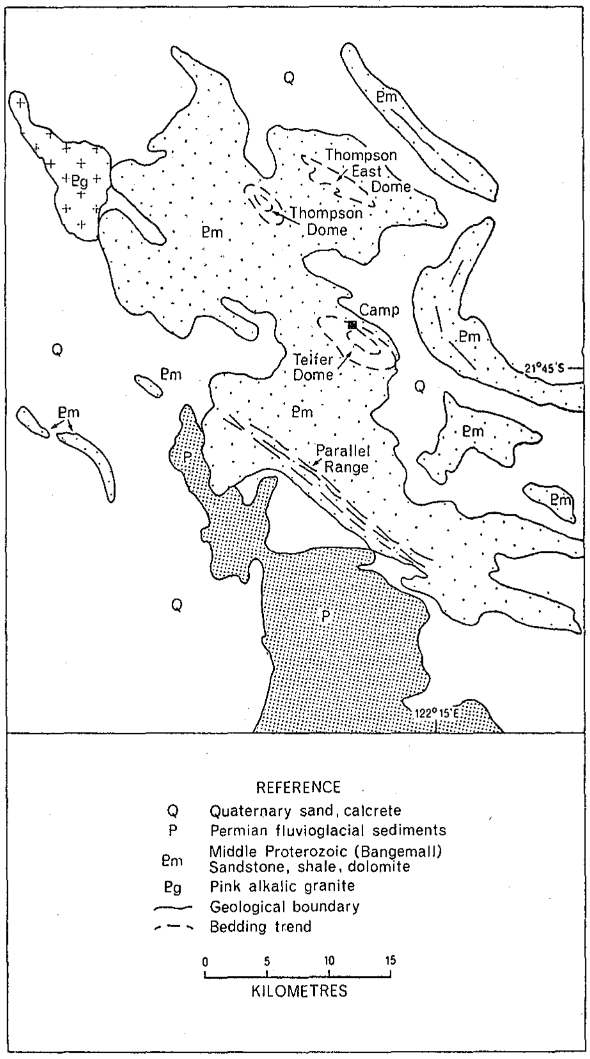

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Figure 45. Paterson Range gold prospects—regional geology (after Wells, 1959).

MINERALIZATION

Gold occurs in reefs ranging in composition from almost pure vitreous quartz, through limonitic quartz with pyrite boxworks, to limonitic gossan. Most reefs are conformable, following thin horizons of shale or siltstone within sandstone units, although some are intruded along faults or cleavage planes and cut the bedding. The richer reefs are found in domes and anticlines, and many are conformable or saddle form. Free gold is visible in the outcrops of several reefs, surface assays are typically 10-60 g per tonne ranging up to 245 g per tonne. It is usually in the limonite, pointing to a secondary origin from primary gold contents in pyrite. The wall rocks of many of the veins also contain pyrite boxworks and are reported to carry low gold values.

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Company geologists have put forward two possible modes of origin of the gold. One is that the gold was syngenetic being concentrated into the reefs during folding and metamorphism. The other is that the mineralization is related to granite intrusions such as that at Mount Crofton. There are objections to both of these hypotheses. Syngenetic gold deposits are usually found in conglomerate beds (e.g. Witwatersrand, Nullagine), but no conglomerates are known in the sequence near the prospects. Experience in Western Australia and elsewhere (e.g. Klominsky and Groves, 1970) indicates that gold is related to granodiorites or adamellites rather than to alkali granite. Further work will be required to determine the origin of the gold.

MAIN DOME PROSPECT

The principal gold prospect, and the one on which most work has been done, occurs in the Main dome (Fig. 46). This is a prominent well formed dome of sandstone, siltstone and shale having a prominent exposure which stands out well on air-photographs. It is about 2.7km long and 1.0 km wide, with its long axis striking at 300°. The stratigraphic succession seen in the dome is, from youngest to oldest:

Unit	Thickness (m)
Outer shale	+30
Rim sandstone	30-40
Upper Vale shale	4
Median sandstone	25
Footwall sandstone	50
Middle Vale shale	10-12
Lower Vale shale	1
Core sandstone	+60

(All names are informal)

The most prospective reefs are in the Middle Vale shale. They form lenses, mainly on the footwall side of the shale, around the entire outcrop of the unit. However, the thickest development is on the south-eastern flank of the dome. In the northern and southern closures of the dome, the Middle Vale reef straddles the main anticlinal axis in true saddle-reef form.

Drilling done by Newmont Pty. Ltd. along the Middle Vale reef has so far indicated about 2 million tonnes of ore averaging about 14 g per tonne of gold.

Several small gossans have been found in the Upper Vale and Lower Vale shales, but most seem unimportant. The Eastern reefs, on the north-east side of the domes in the Outer shale, consist of gossan and grey quartz containing some gold.

West Dome

Another dome with an en echelon relationship to the Main dome is situated about 1.2 km farther west. It contains a number of gossans and limonitic quartz reefs with gold contents of generally less than 3 g per tonne. The gossans inspected occur on the crest of the fold and appear to have formed as saddle reefs. Other gossans on the south-west side of the dome are shown on the Newmont maps, but were not examined.

Thomson Dome

About 15 km northwest of the base camp is the Thomson dome in which stratiform gossans occur at two horizons within pyritic sandstone on the southern flank. Gold contents in the gossans range up to 3.4 g per tonne.

Comparisons with other gold deposits in Western Australia

Most gold won from Western Australia has come from deposits within the greenstone belts of the Archaean nuclei, usually in volcanic rocks or in sediments of volcanic origin. They consist of sulphide or telluride lodes (e.g. Wiluna and Kalgoorlie respectively), tensional quartz veins (e.g. Coolgardie and Cue), or fracture fillings and replacements of banded iron formation (e.g. Mount Magnet and Laverton). Other deposits, with a much smaller total production, lie in late Archaean or Lower Proterozoic rocks and consist mainly of auriferous quartz veins injected along the cleavage planes of folded geosynclinal sediments. Examples are the gold deposits of Mosquito Creek, the Ashburton Valley and Halls Creek. The saddle-reef form is

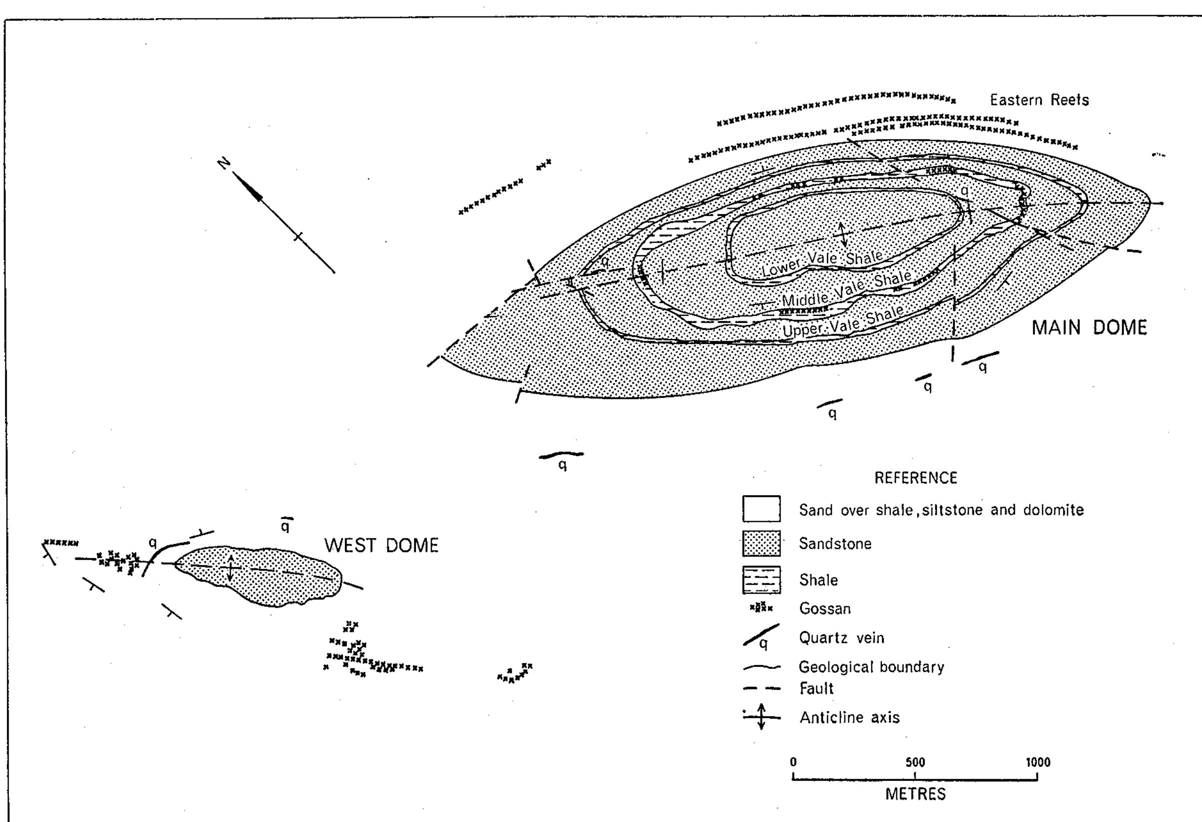

Figure 46. Telfer Dome gold prospects—geological map (after Newmont Pty. Ltd.).

rare in Archaean and Lower Proterozoic deposits, the only other example is at Breens Camp, 50 km west of Marble Bar (Blatchford, 1913).

The Paterson Range gold prospects differ from most others in the State in three respects: they are much younger probably 600 to 1 000 m.y.; many of them are saddle reefs; and their host rocks are sediments typical of a stable shelf rather than a geosyncline, and lack any appreciable volcanic component.

The only other gold deposists in the Bangemall Group are at Bangemall, near the southern edge of the Bangemall Basin. The veins here occur in an anticline of sandstone and shale, overlain by chert, and intruded by dolerite sills. Maitland (1909) notes that the most important feature of the field is the saddle-reef form of the goldbearing quartz veins. These grade from white vitreous quartz, through cavernous ferruginous quartz into limonite with pyrite kernels. Except for the dolerite sills and the nearby chert, the geological setting and the form of the deposits are very similar to those in the Paterson Range area.

CONCLUSIONS

The Paterson Range gold deposits are only the second recorded occurrence of gold within rocks of the Bangemall Group. Their discovery in this little prospected area should lead to further exploration within the Middle and Lower Proterozoic rocks of the Paterson Range, Rudall and Gunyana 1 : 250 000 Sheets.

The similarity of the deposits in the Paterson Range to those at Bangemall indicates that all the folded margins of the basin should be examined more closely for gold, and possibly other minerals.

There seems to be a reasonable chance that the Paterson Range gold prospects will eventually support a mining operation.

ACKNOWLEDGEMENTS

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REFERENCES

Blatchford, T., 1913, Mineral resources of the North-West Division, investigations in 1912: West. Australia Geol. Survey Bull. 52, p. 29.

Klominsky, J., and Groves, D. I., 1970, The contrast in granitic rock types associated with tin and gold mineralization in Tasmania: Proc. Australia Inst. Min. Metall. No. 234, p. 71-81.

Krumbein, W. C., and Sloss, L. L., 1953, Stratigraphy and Sedimentation: W. H. Freeman and Co., San Francisco, p. 388.

Maitland, A. G., 1909, Geological investigations in the country lying between 21° 30' and 25°30' S latitude, 113° and 118° 30' E longitude embracing parts of the Gascoyne, Ashburton and West Pilbara Goldfields: West. Australia Geol. Survey Bull. 33, p. 34.

Trendall, A. F., 1974, The age of a granite near Mount Crofton, Paterson Range Sheet: West. Australia Geol. Survey Ann. Rept. 1973, p. 92-96.

Wells, A. T., 1959, Paterson Range 4-mile Geological Series: Australia Bur. Mineral Resources Explan. Notes 17.

DIAMOND EXPLORATION IN WESTERN AUSTRALIA

by J. D. Carter

ABSTRACT

Diamond exploration in Western Australia as reported to the Mines Department is reviewed. Exploration has been carried out in the Nullagine district of the Pilbara Block, in the Northern Canning Basin principally between the Lennard and Fitzroy Rivers, and near the Serpentine River about 50 km southeast of Perth.

At Nullagine some 70 diamonds have been recovered since the first discoveries in 1895. Subsequent exploration has not disclosed kimberlite or kimberlitic minerals, and commercial occurrences of diamonds have not been located.

In the Northern Canning Basin attention has been centred on lamproite intrusions of Miocene age. A report that kimberlitic material underlies Mount Abbott was not confirmed by follow-up investigations. Although nine small diamonds were reported as having been found in the Lennard River, later exploration failed to find further diamond or kimberlitic minerals.

Kimberlitic pyrope garnet has been reported from the Serpentine River, but kimberlites themselves have not been found.

INTRODUCTION

Exploration for diamond in Western Australia has been carried out by companies holding Temporary Reserves (T.Rs.—Crown Land reserved for mineral exploration). There is little published information on these investigations apart from a brief reference by Lawrence (1971). The account now given has the purpose of bringing together the principal results of exploration operations as reported to the Mines Department.

Since the first discovery of diamonds in 1895 near Nullagine in the Pilbara Goldfield, the potential of the State for diamond has been a subject of speculation. Some prominence has been given to the likelihood that India, an important producer of diamonds, was connected to the northwestern part of Australia until the break-up of Gondwanaland in the Early Cretaceous. Results of diamond exploration, however, have not been encouraging. Altogether only about 70 diamonds have been recovered near Nullagine and although the Lennard River in the Northern Canning Basin is reported to have yielded nine diamonds, intensive follow-up investigations failed to disclose further gems. At one other locality, near the Serpentine River about 50 km southeast of Perth, there is an indication that kimberlite* or a secondary source rock of diamond may be exposed in the district. Here garnets considered to have been derived from kimberlite have been recovered from a stream draining the western margin of the Yilgarn Block.

Exploration for diamond usually involves a search for indicator minerals (I.M.). The diagnostic suite includes pyrope garnet, which is often chromium-bearing, magnesian ilmenite, and chromium-bearing diopside. According to Mannard (1968) at least three-quarters of the known kimberlite pipes have been traced by I.M.. In Australia the only proved kimberlites are those near Terowie 230 km north of Adelaide, and in describing these Colchester (1972) remarks that chrome diopsides "are always present as accessory phenocrysts in the kimberlite matrix". In Western Australia the search for I.M., particularly pyrope and magnesian ilmenite, has been the principal means of exploration.

* Kimberlite is an ultrabasic rock which is the primary source of diamond. It is defined in Dawson (1967).

The review is compiled from reports of operations chiefly on T.Rs. provided by individuals and companies, namely J. F. B. Jeppe, R. C. Horwitz, Conzinc Riotinto Australia Exploration Pty. Ltd. (C.R.A.E.), Mining Advisers Pty. Ltd. (M.A. Pty. Ltd), the group Exoil N.L., Transoil N.L. and Petromin N.L., and The Stellar Minerals Pty. Ltd. A number of principal reports are included in the reference list at the end of this paper.

NULLAGINE

GENERAL

Nullagine, in the Pilbara Goldfield, about 240 km south-southeast of Port Hedland, was the scene of Western Australia's first diamond discovery, in 1895. Since then occasional diamonds have been found there, principally during the search for gold. It was not until 1965 that systematic exploration for diamonds was begun. As a result 20 gems were recovered during ventures conducted by J. F. B. Jeppe, C.R.A.E. and M.A. Pty. Ltd.

Prior to 1965 records of finds are vague, but at least 70 diamonds have been recovered, as shown below:

NULLAGINE DIAMOND DISCOVERIES

1895*	F. R. Groom described 17 diamonds
1900	230 t conglomerate yielded 25 diamonds
1915	C. Frazer reported a 3¾ carat† diamond
1922	E. S. Simpson reported three diamonds
1924	H. Bowley examined two diamonds presumed to be of Nullagine origin
1933	A. Aiken found two diamonds
1965	J. F. B. Jeppe found five diamonds
1969	C.R.A.E. found one diamond
1970	M.A. Pty. Ltd. found 14 diamonds

* Records of finds from 1895 to 1933 are compiled from Simpson (1951).

† One carat equals 200 mg.

None of the Nullagine diamonds are known to have been assessed by an expert valuer though certain descriptions suggest diamonds of gem quality. An example is the diamond reported by C. Frazer and referred in Simpson (1951) as "This stone was a complete crystal and was said to have made a valuable gem."

The precise locations of the early finds are uncertain. Sites of discoveries referred to by Simpson (1951) are Brooks Hill lying about 2 km northwest of Nullagine, and Grants Flat, 1 km west of the town, where the large stone reported by C. Frazer was recovered (Fig. 47). Noldart and Wyatt (1962) state that the immediate source of the diamonds is an auriferous conglomerate, termed the Beatons Creek Conglomerate, found at the base of the Lower Proterozoic Fortescue Group at various localities near Nullagine.

Recent exploration at Nullagine has shown that diamonds are contained in conglomerate younger than the Beatons Creek Conglomerate. The younger conglomerate and associated sediments are termed informally the "Brooks Hill beds" and attributed provisionally to the Tertiary.

GEOLOGY

The stratigraphy of the Nullagine region is currently under review. This description is compiled from reports of C.R.A.E., M.A. Pty. Ltd. and the Geological Survey of Western Australia. The geology, illustrated by Figure 47, is subdivided as follows:

Age	Deposits	Intrusions
Quaternary	Alluvium—Recent: fluviatile sands and gravels Alluvium—intermediate levels: fluviatile sands and gravels with basalt detritus; fluviatile sands and gravels derived from Beatons Creek Conglomerate Alluvium—high level: fluviatile sands and gravels derived from Beatons Creek Conglomerate	
Tertiary	"Brooks Hill beds": fluviatile sands, gravels and conglomerates variably ferruginized	
Lower Proterozoic	Fortescue Group: undifferentiated lavas; undifferentiated sedimentary rocks with Beatons Creek Conglomerate at base	Dolerite, quartz-feldspar porphyry
Archaean	Mosquito Creek Beds*: metamorphosed rocks including conglomerates	

* The status of the Mosquito Creek Beds is under review

The Mosquito Creek Beds of the Archaean underlie the undulating country around Nullagine and east of the town. About 2 km west of Nullagine the lowest part of the Proterozoic Fortescue Group forms an escarpment marking the eastern limit of the group. Locally the base of the group is formed by the Beatons Creek Conglomerate, an auriferous formation which is reportedly diamondiferous. Sofoulis (1958) describes the conglomerate:

> Boulders present in the basal horizon are derivative of older fine grained sandstones, quartzites, slates, grits, conglomerates, jaspilitic rocks, identical in character with the metamorphosed sediments of the Mosquito Creek Formations and in conjunction with the shape and size of such, there is little doubt that these boulders were furnished from a Mosquito Creek land surface and in close proximity to the present position of the conglomerate.

The origin of the Cainozoic strata at Nullagine is similar to that of deposits of the same age in the Hamersley Iron Province to the west and the description of the latter given by MacLeod (1966) serves to illustrate these strata:

> On geomorphological grounds they can be broadly divided into two age groups. The older deposits had accumulated prior to the commencement of a rejuvenated cycle of stream erosion and have been much dissected during this younger cycle. The younger deposits represent the more recent products of this erosion and redistribution following the rejuvenation of the drainage systems.

The "Brooks Hill beds" represent the older deposits, while fluviatile sands and gravels found at varying levels represent the younger sediments.

"Brooks Hill Beds"

Elongate limonite-capped mesas formed by "Brooks Hill beds" stand up to 45 m above the valley floors of the Nullagine River and its tributaries such as Bonnie Creek. They are flat lying. A summary of the lithology of the beds is provided by Lovett (1971):

> Generally, an upper and lower unit with sometimes an intermediate one can be discerned. The basal unit usually consists of sands and conglomerates varying in lithology and thickness. Sometimes, however, this unit is absent and instead the intermediate or upper unit overlies the bedrock. The upper unit is typified by limonite-cemented clay, sand, and grit, commonly with a high proportion of fossilised wood fragments. The thickness of the unit appears to be greatest in the mesas upstream at Garden Pool.

Variations in lithologies and thicknesses of the units are shown in Table 15.

TABLE 15. "BROOKS HILL BEDS"—SECTIONS.
(after Lovett, 1971)

Nullagine River—Bonnie Creek confluence	Brooks Hill N.W. extension	Banana Hill
upper unit—		
Limonitic pisolites and wood fragments in a limonitic clay cement.	Cemented limonitic clay and sand, wood fragments.	Cemented limonitic sand and clay.
15 to 24 m	3 m	7·5 m
intermediate unit—		
Iron pisolites, basalt fragments and clay matrix.	Bleached and kaolinized clay and sand; minor conglomerate lenses.	Clay and sand.
3 to 6 m	15 m	1·8 m
lower unit—		
Ill-sorted boulder conglomerate in a bleached clay matrix.	Interbedded conglomerates, sand and clay (diamondiferous)	Pebble conglomerate and sand (diamondiferous)
1·8 to 3·6 m	3 m	3·7 m
	Kaolinized basalt	Mosquito Creek Beds

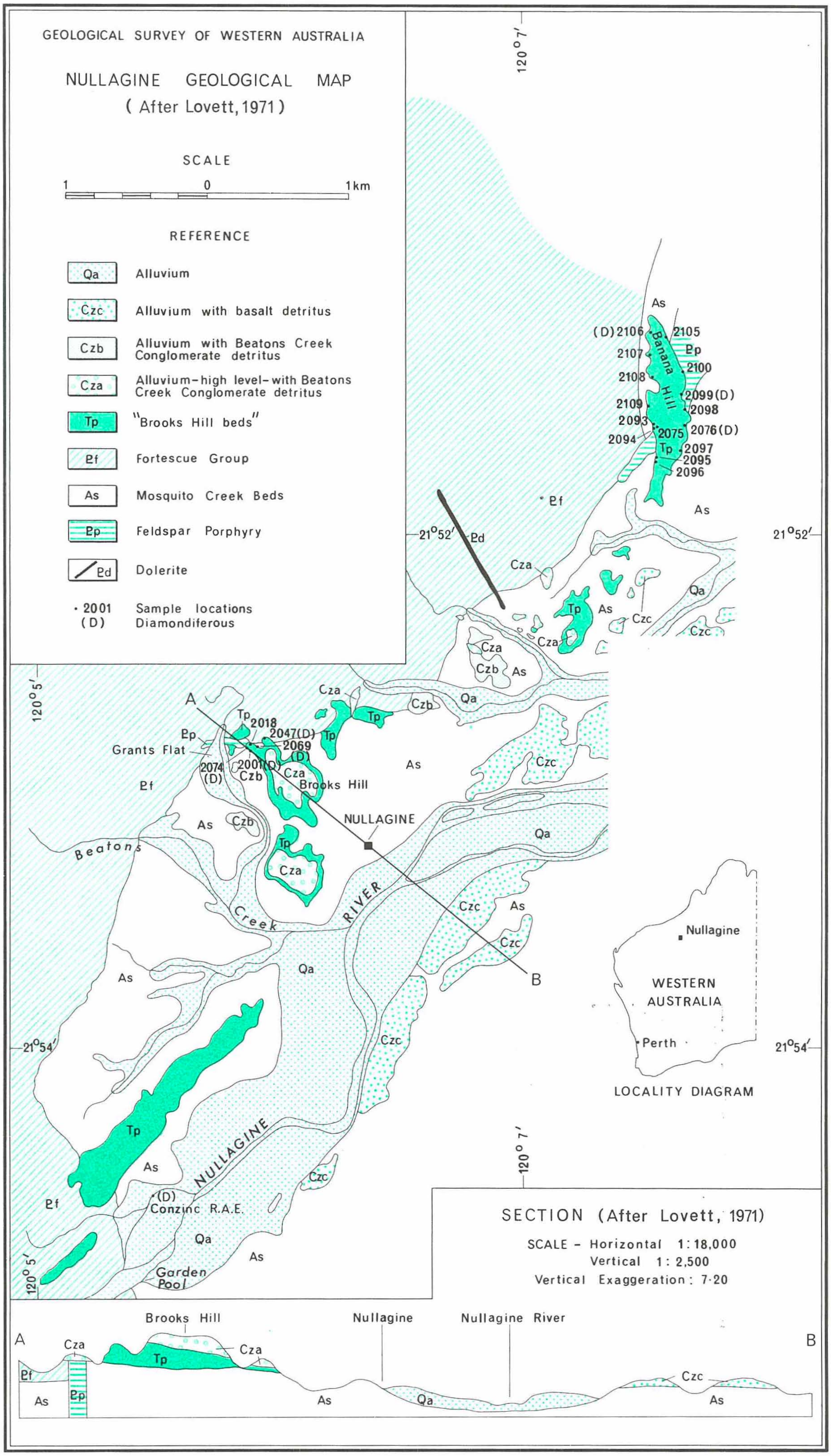

Figure 47.

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Fluviatile Deposits

Four categories of fluviatile deposits are present as illustrated on Figure 47: high-level channel deposits overlying the lateritic capping of some of the mesas, fluviatile sediments of two varieties forming terraces at lower levels but above the valley floor and fluviation of the Nullagine River.

Igneous Intrusions

Igneous intrusions are represented by dolerite dykes and feldspar porphyry bodies.

EXPLORATION

Prior to 1965 two very brief investigations of the diamond occurrences were made. Groom (1896) during a short visit to Nullagine confirmed the diamond find, observing that the gems were recovered at or near Brooks Hill and were enclosed in conglomerate. Nearly 60 years later Sofoulis (1958) described an examination of T.Rs. Nos. 1393H to 1398H and some 390 km^2 of country in the vicinity of Nullagine. In this report there is mention of diamonds occurring in the basal conglomerate of the Proterozoic rocks though no example of a diamond being recovered from these rocks *in situ* is cited.

In 1965 and 1967 respectively, systematic exploration for diamonds was begun during interconnected operations over T.Rs. No. 3582H (J. F. B. Jeppe) and 4175H (C.R.A.E.). In September 1967 these were substituted by T.R. No. 4508H occupied by C.R.A.E. Rights of Occupancy were transferred to J. F. B. Jeppe in December 1970 when exploration was continued by M.A. Pty. Ltd. The T.R. was relinquished in April 1971.

T.R. No. 3582H

Operations over the T.R. of 840 km^2 apparently were small in scale. There are reports that numerous small samples and bulk samples amounting to more than 39 t were taken, but there is no record of sample locations. It is not clear whether samples were tested for I.M. There are references in reports of C.R.A.E. and M.A. Pty. Ltd. to the recovery of five small diamonds including a stone found *in situ* at Brooks Hill but information on only three diamonds is available (Table 16).

T.Rs. Nos. 4175H and 4508H

Exploration by C.R.A.E. over an area of some 4 000 km^2 included photogeology, which produced no positive results. Some sampling of Tertiary sediments and stream deposits was also carried out.

Stream samples are described as being taken from suitable points such as behind rock bars; the samples after sieving yielding fractions weighing 14 kg. Forty-six samples were examined. Heavy mineral residues obtained by gravity concentration and heavy-fluid separation were inspected optically. One small diamond (15 microns in size) was discovered in alluvium of a tributary of the Nullagine River. Although garnet and ilmenite were identified, these minerals apparently were not tested to determine whether they were kimberlitic in origin. Drainage examined during the stream-sediment sampling programme is shown on Figure 48.

No diamond or I.M. were recovered from the "Brooks Hill beds", although these were tested by sampling the basal unit at six localities. Three were mesas near Nullagine (including the northwest extremity of Brooks Hill where J.F.B. Jeppe had previously discovered a diamond *in situ*), and the remainder at mesas lying south of Nullagine. Farther to the south, mesas in Bonnie Creek (shown on the Roy Hill 1 : 250 000 Geological Sheet as Robe Pisolite) were examined with the conclusions that "The prospects for finding extensive gravel deposits in the Bonnie Creek Valley mesas, which could be the sources of alluvial diamonds, are very low" (Lishmund, 1967).

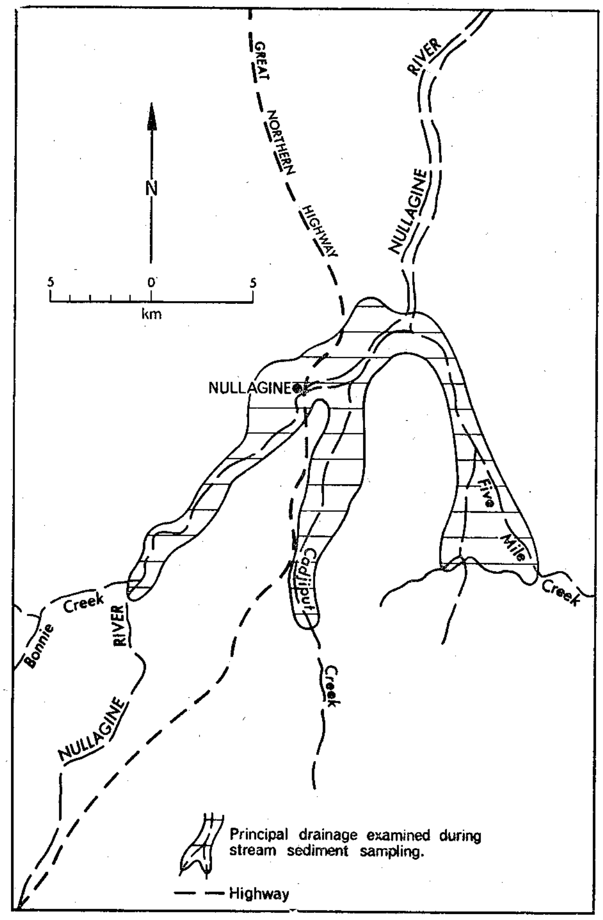

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Figure 48. Nullagine area, showing stream-sediment sampling (after Conzinc Riotinto Australia Pty. Ltd. and Mining Advisers Pty. Ltd.).

In addition, an examination of deposits ascribed to the Oakover Formation in the vicinity of Carawine Pool, on the Oakover River, recorded that these strata composed of "dirty buff-coloured gravels" should be searched for I.M. (Lishmund, 1967). Gravels in the Oakover Formation have not been recorded by the Geological Survey of Western Australia.

T.R. No. 4508H was also explored by M.A. Pty. Ltd. This exploration had dual objectives. Firstly, to find a pre-Cainozoic diamond source rock by means of stream-sediment sampling. Secondly, to test the diamond potential of Cainozoic sediments near Nullagine, principally the "Brooks Hill beds". Fourteen diamonds were recovered by gravity concentration from the base of the "Brooks Hill beds" although none were found in the stream sediments. Heavy-mineral residues were obtained by gravity concentration. Garnet and ilmenite were both identified in stream sediments, and the "Brooks Hill beds" were examined optically for garnet and by electron-probe microanalysis for ilmenite, but no grain was considered to be of kimberlitic origin.

A bulldozer and back-hoe were used to sample the base of the "Brooks Hill beds" at Brooks Hill and at Banana Hill to the north (Fig. 47). Twenty samples totalling 42 m^3 were taken. Each consisted of between 1 and 2 m^3 of basal unit and, except at two localities, 0.3 m^3 of bedrock. Jigging and optical examination of residues led to the recovery in the field of fourteen diamonds from six samples. Some features of the finds, shown in Table 16, are a stone weighing 1.03 carats, with two tiny stones (Sample No. 2001), and two stones with a combined weight of 0.6 carat (Sample No. 2106), and six small stones of combined weight less than one carat from a palaeochannel at the northwest extremity of Brooks Hill (Sample No. 2074).

TABLE 16.

DIAMONDS FOUND AT NULLAGINE 1965-1970.

(after Lovett, 1971)

Sample* Number	Date	Weight (carats)	Quality†	Remarks
J1	1965	0·18	Gem	Found by J. F. B. Jeppe
J2	1965	0·15	Gem	Found by J. F. B. Jeppe
J3	1965	0·96	Industrial	Found by J. F. B. Jeppe
27	1969	(size 15 microns)	....	Recovered by C. R. A. E. Pty. Ltd. from stream alluvium
2001/A	1970	0·08	Gem	"Brooks Hill beds"
2001/B	1970	0·09	Industrial	Brooks Hill
2001/C	1970	1·03	Gem	Brooks Hill
2069	1970	0·14	Industrial	Brooks Hill
2074A	1970	0·28	Gem	Brooks Hill
2074B	1970	0·21	Gem	Brooks Hill
2074C	1970	0·17	?Gem	Brooks Hill
2074D	1970	0·13	Industrial	Brooks Hill
2074E	1970	0·11	?Gem	Brooks Hill
2074F	1970	0·05	Gem	Brooks Hill
2076	1970	0·12	Gem	"Brooks Hill beds" Banana Hill
2099	1970	0·13	Gem	"Brooks Hill beds" Banana Hill
2106A	1970	0·48	Gem	"Brooks Hill beds" Banana Hill
2106B	1970	0·12	?Gem	"Brooks Hill beds" Banana Hill

* Nos. 2001/A to 2106/B were found during investigations by Mining Advisers Pty. Ltd.

† None of the stones is known to have been appraised by an expert valuer.

Note: Basal portions of the older alluvium were sampled at three points and various features elsewhere were tested, all without result.

In the search for kimberlite or a secondary distribution source, 79 stream sediment samples were collected from watercourses draining the Proterozoic. Samples ranged from 0.4 to 2.3 m^3 in volume and at all but two points were obtained from the base of the alluvium. No I.M. or diamond were recovered. Drainage examined during the stream-sediment sampling programmes is shown on Figure 48.

NORTHERN CANNING BASIN

GENERAL

A description of the geology of the Northern Canning Basin, situated in the West Kimberley Goldfield in the northern part of the State, is given by Guppy and others (1958). The principal features referred to here are shown on Figure 49.

There has been some speculation that the Kimberley region is favourable for the occurrence of diamond, with interest focused on a small group of minor leucite-bearing intrusions of lamproite forming plugs and craters, described by Wade and Prider (1940). Prider (1960) includes a scheme suggesting a genetic relation between the lamproitic rocks and kimberlite. Wellmann (1973) gives age determinations indicating a Miocene age for the lamproites.

EXPLORATION

There have been three exploration ventures since 1967: one conducted by the group Exoil N.L., Transoil N.L. and Petromin N.L. when nine diamonds were recovered from alluvium of the Lennard River; a second by The Stellar Minerals N.L. and a third by the Bureau de Recherches Geologiques et Minieres Australia the results of which are described briefly by Lawrence (1971).

Exoil N.L., Transoil N.L. and Petromin N.L.

Operations were conducted over **T.R. No. 4665H** of about 670 km^2, and its severance T.R. No. 5184H, between 1967 and 1970. The T.Rs. were cancelled in 1971. Investigations took place in four phases.

In 1967 grab samples of lamproite, lamproitic debris and alluvium were collected and examined for I.M. and diamond. Lamproitic material was collected from the following plugs:

- Wolgidee Hills
- Hills Cone
- White Rocks
- Noonkanbah Hill
- Moulamen Hill
- P Hill
- Fishery Hill
- Machells Pyramid
- Mount Cedric
- Djada Hill
- Mount North

Alluvium was also sampled in the Fitzroy River channel west of Mount Abbott. No diamond or I.M. were identified.

In 1968 a combined aeromagnetic and radiometric survey of 1 770 line-kilometres was flown at a height of 150 m above mean ground level, with flight lines spaced 422 m apart. Results were not encouraging and there was no ground follow-up.

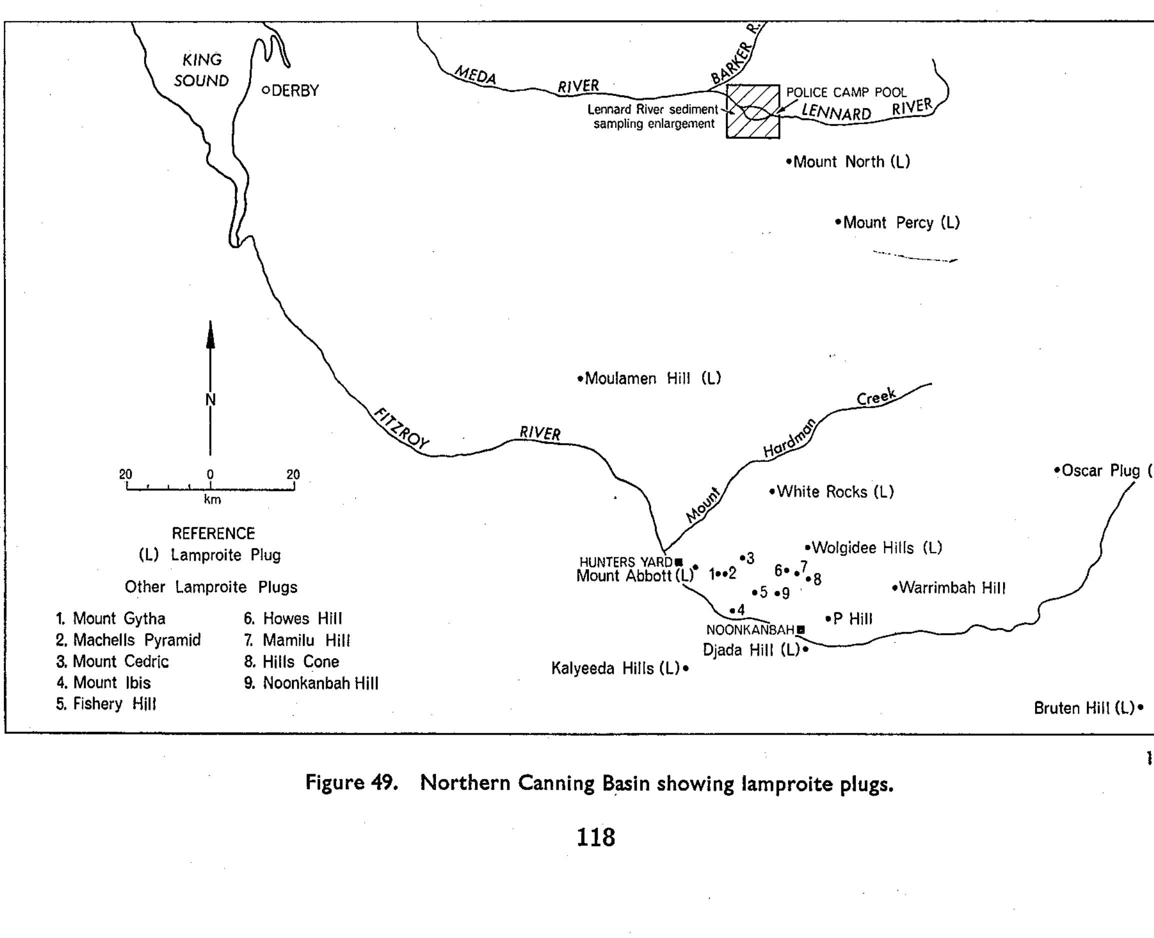

Figure 49. Northern Canning Basin showing lamproite plugs.

In October, 1969, alluvium in the beds of the Lennard River and adjoining tributaries was sampled for I.M. At each of the 37 positions numbered on Figure 50, two samples were taken. After sieving individual samples weighed between 11 and 22 kg; the total sample weight amounted to about a tonne. Heavy-mineral suites were examined for pyrope and chromium-bearing diopside but neither mineral was found. Ilmenite, the dominant opaque mineral, was not tested for a possible kimberlitic origin.

Four diamonds were recovered during the I.M. search and the entire one tonne sample was then examined for diamond. A total of nine gems were said to have been found, with a combined weight of 1.65 carats. Descriptions of these are given in Table 17 and the reported locations of the finds are shown on Figure 50.

TABLE 17. DIAMONDS REPORTED FROM THE LENNARD RIVER, 1969.

Sample Number	Weight (carats)	Quality	Remarks
20	0·25	?Industrial	One whole stone and two cleavage fragments
22	0·25	?Industrial	Whole stone
25	0·33	?Industrial	Two whole stones
31	0·32	?Industrial	One whole stone
37	0·5	?Industrial	One almost whole stone and a cleavage fragment

In 1970, follow-up investigations consisted of regional soil sampling for I.M. in the Lennard River area and large-scale sampling of the Lennard and Fitzroy Rivers for diamond. During the soil survey several hundred samples were collected from the general area shown on Figure 50. Sampling procedure consisted of excavating samples of approximately a cubic metre from which heavy minerals were extracted by gravity concentration. No diamond or I.M. were found.

Alluvium in the Lennard River was tested for diamond and I.M. in the vicinity of sites from which diamonds had been recovered. Sample points were selected where natural concentrations of heavy minerals were to be expected and sites were excavated to bedrock, potholes and natural barriers being cleaned out. (Sites A to Q, Fig. 50). At each of 15 locations approximately one tonne of sieved material was treated by machine jigging, the heavy minerals being sorted by hand. None of the samples yielded diamond or I.M. Duplicate samples treated and examined by a second laboratory confirmed the field result. Ilmenite was identified but not tested for kimberlitic origin.

Alluvium in the Fitzroy River at 25 localities between Noonkanbah Yard and Hunters Yard was similarly sampled and treated. No diamonds or I.M. were found. Ilmenite was recovered but was not tested for a kimberlitic origin.

The report concludes "despite all efforts by a South African leading authority in diamond exploration no further diamonds were found and no minerals normally associated with diamonds were observed . . . In view of these conclusions it can only be assumed that results of the early sampling were not representative of the area from which the samples were taken" (Haynes, 1971).

The Stellar Minerals Pty. Ltd.

From 1968 to 1971 The Stellar Minerals N.L. explored the Fitzroy Trough for diamond with emphasis on the investigation of the lamproite plugs in the Noonkanbah district. Eleven T.Rs.

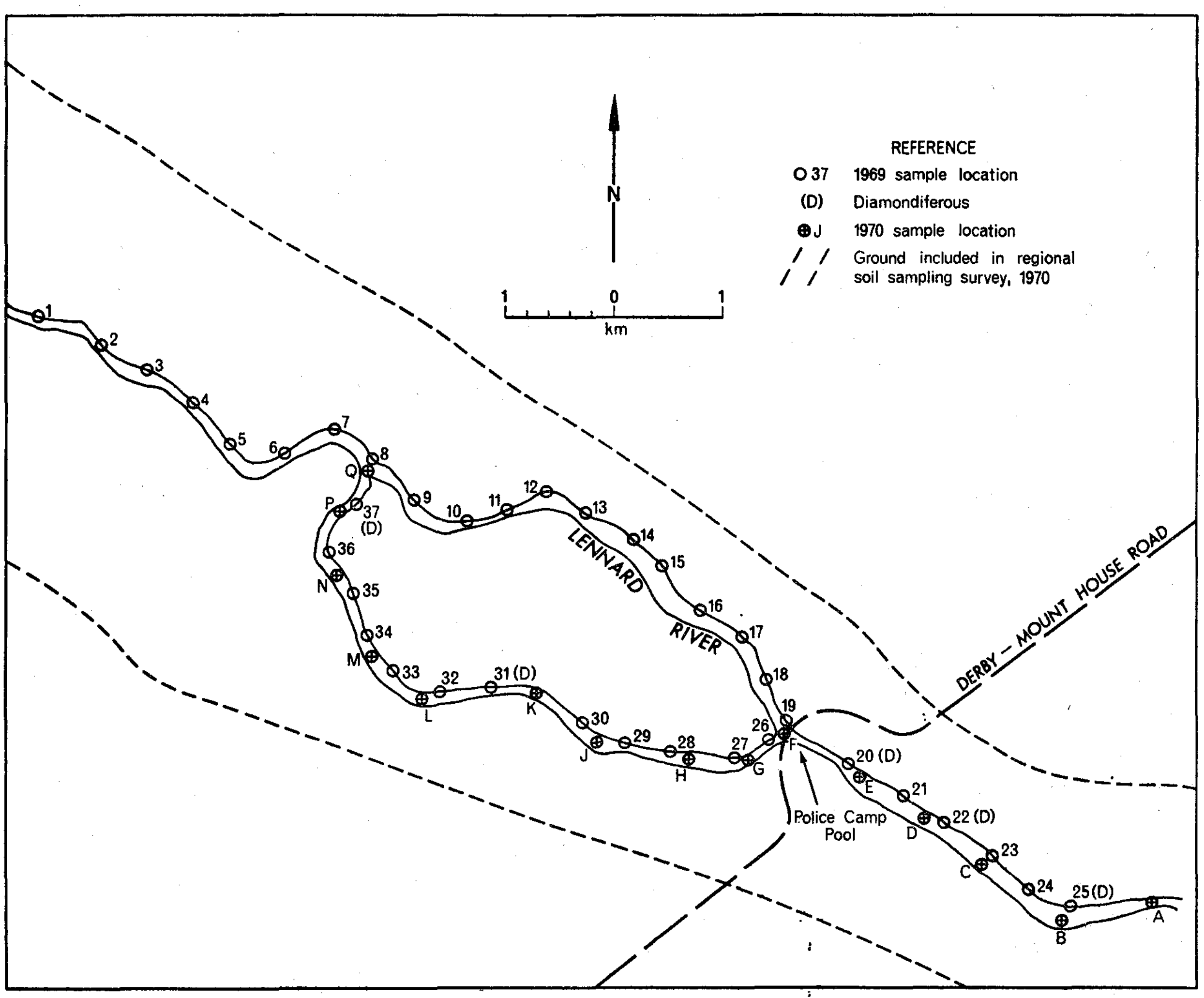

Figure 50. Lennard River sediment sampling (after Exoil N.L., Transoil N.L. and Petromin N.L.)

were occupied embracing lamproites, a cryptovolcanic structure (Mount Abbott) and Cainozoic sedimentary deposits:

T.R. No. 4630H Wolgidee Hills and lamproites to the south and west lying between P Hill and Mount Gytha[1]
T.R. No. 4631H Mount Abbott[2]
T.R. No. 4632H White Rocks[1]
T.R. No. 4633H The Sisters (Kalyeeda Hills)[1]
T.R. No. 4634H Warrimbah Hill[3]
T.R. No. 4635H Moulamen Hill[1]
T.R. No. 4636H Mount North[1]
T.R. No. 4637H Mount Percy[1]
T.R. No. 4643H Oscar Plug[1]
T.R. No. 4644H Mount Hardman Creek[3]
T.R. No. 4659H Bruten Hill[1]

1. = Lamproites
2. = Cryptovolcanic structure
3. = Cainozoic sediments

Four of the T.Rs. exceeded 150 km^2: 4630H (746), 4644H (259), 4634H (233) and 4631H (155); the remainder varied between 15 and 93 km^2. Exploration techniques included rock, soil and stream-sediment sampling, shallow drilling, and ground magnetic and radiometric surveys. Geophysical surveys were discontinued when initial tests failed to give useful results at selected localities.

Although the T.Rs. were the subject of considerable exploration there were no encouraging results. Diamond was not found. In early stages of operations it was reported that kimberlite had been located near Mount Abbott and that pyrope occurred near The Sisters (Kalyeeda Hills). Extensive follow-up at both localities failed to confirm these results.

Principal operations on T.Rs. are summarized below. Except where stated samples were treated and examined for diamond or I.M. Heavy minerals were extracted by gravity concentration and examined optically. Some garnet and ilmenite were investigated by electron-probe microanalysis.

T.R. No. 4630H: Wolgidee Hills. A two tonne sample was taken from the centre of the Hills; about a tonne of lamproite detritus was obtained from twelve pits on a line extending westwards from the centre of the body. One hundred and seventy five soil samples of volume 7.6 m^3 were collected. A Gemco auger drill was used to sink 105 holes with total depth of 547 m. Also 13 auger holes were drilled on a lineament between Wolgidee Hills and Mamilu Hill.

P Hill. Six bulk samples and six soil samples were taken from around the lamproite. Total drilling from 22 auger holes, near the plug and on the surrounding plain, amounted to 406 m.

Hills Cone. Four samples totalling 0.2 t were obtained from pits and seven soil samples were collected. Twenty three auger holes were sunk for a total depth of 142 m, and 11 holes for 111 m along a line joining Hills Cone and Mamilu Hill.

Mamilu Hill. Four pits were sunk into lamproite and seven soil samples collected. Drilling consisted of 29 auger holes for 178 m. Holes were drilled on the lineament between Mamilu Hill and Howes Hill.

Howes Hill. Seven soil samples were collected and 30 auger holes totalling 130 m sunk. Holes were drilled along a line to Mount Cedric.

Mount Cedric. Eight bulk samples and 22 soil samples were obtained. Drilling consisted of 27 auger holes for 181 m and further holes were put down along a line to Mount Abbott.

Machels Pyramid and Mount Gytha. Eleven bulk samples and 15 soil samples were collected. Drilling included 37 auger holes for 148 m as well as holes drilled along a line between Mount Gytha and Mount Abbott.

T.R No. 4631H, Mount Abbott. This feature is described by Prider (1960) as a cryptovolcanic structure with no igneous rock exposed. Kimberlite minerals were reported to have been found at Mount Abbott, specifically from a pit nearly two metres deep (two pyrope grains), and from a second pit and trenches all less than a metre in depth exposing weathered bedrock with pyrope, ilmenite and green diopside. Further trenches were dug to an average depth of about two to three metres, together with 24 drill holes averaging 15 m in depth. It was reported that tuffisite and tuffisite breccia containing kimberlite minerals were present in at least five localities. Minerals said to have been recovered included garnet, within the range of kimberlite pyrope, picroilmenite (magnesian ilmenite) and picrochromite (magnesian chromite).

Further work, including drilling 100 auger holes for a total of 479 m in 1970-71, however, led to the conclusion that no kimberlites, diamonds or kimberlitic indicator minerals were present in the area.

T.R. No. 4632H, White Rocks. Exploration included trenching, the collecting of 7 soil samples and the sinking of 46 auger holes for a combined depth of 213 m. There is no information on results of treatment of cuttings from drillholes.

T.R. No. 4633H, The Sisters (Kalyeeda Hills). Pyrope was recovered from a shallow pit sunk near lamproite in 1968. Follow-up work included 75 auger holes drilled for 506 m and 13 soil samples. None of this material contained minerals of kimberlitic origin.

T.R. No. 4634H, Warrimbah Hill. This T.R. covered scattered outcrops of Warrimbah Conglomerate, a deposit of massive well rounded water-worn pebbles and boulders which may be of Pleistocene age (Veevers and Wells, 1961). The conglomerate was tested at Warrimbah Hill by trenching and sampling. A bulk sample of 17 m^3 was also collected but there is no information on any results of treatment.

T.R. No. 4635H, Moulamen Hill. About 2 m^3 of conglomerate, described as Tertiary age, from the western end of the Erskine Range was treated without result.

T.R. No. 4636H, Mount North. Two shallow pits and a trench were sunk in watercourses draining the feature, and sampled material comprising at least 1.5 m^3 was treated without result.

T.R. No. 4637H, Mount Percy. A pit about 3 metres deep was sunk in decomposed lamproite and sampled without result.

T.R. No. 4643H, Oscar Plug. Three grab samples taken from the small plug and associated dyke were collected and treated without result. Three soil samples did not contain kimberlitic material.

T.R. No. 4644H, Mount Hardman Creek. Alluvium (1.5 m^3) was collected from a pit and 14 trenches and treated without result. A further bulk sample of 9.3 m^3 failed to yield kimberlitic material.

T.R. No. 4659H, Bruten Hill. Two grab samples from the lamproite, 5 soil samples from the base of the plug and 4 alluvial samples from nearby Christmas Creek were tested without result.

"Kimberley Region" exploration by Bureau de Recherches Geologiques et Minieres

Lawrence (1971) refers briefly to exploration for diamond in the "Kimberley Region" but does not give specific locations or any results of exploration. The ground covered was some 100 000 km^2 and embraced approximately 2 500 km length of the larger rivers. To obtain a sample density of one sample per 1 000 km^2, samples were taken every 25 km, usually down to riverine bedrock and ranged in size from 2 to 20 m^3. A total of some 1 000 m^3 of alluvium may have been treated in this manner.

SERPENTINE RIVER AREA

In an address to the Western Australia Division of the Geological Society of Australia in 1972 R. C. Horwitz described exploration for I.M. in the south-west of the State. The region was selected because of the highly dissected nature of the Archaean terrain. This study was not extended into the Eastern Goldfields since considerable exploration for placer gold had not located diamond.

Pyrope was recovered from heavy-mineral residues panned from sands and gravels of the Serpentine River bed between the South-West Highway crossing and the Darling Scarp, approximately 50 km southeast of Perth. A single pyrope garnet was also found in a residue obtained from the Medulla Brook just east of the Darling Fault and south of the road to Jarrahdale (Horwitz, R. C., pers. comm.).

The garnets, pin-head in size, are considered to form a characteristic grouping by reason of size, brown colour, densities and refractive indices which range between 1.735 and 1.77. An opinion has been expressed that these garnets belong to a small titanium-rich, brown garnet group, which is known and diagnostic of kimberlites, but is not described in the literature.

No other exploration for diamond is known to have been carried out in this area.

CONCLUSIONS

NULLAGINE

At Nullagine diamonds occur in the basal portion of the "Brooks Hill beds" and in recent stream sediments. However, the volumes and grades of both categories of diamondiferous gravels have not been assessed. So far as is known no parcel of Nullagine diamonds has been the subject of expert valuation, a prior requisite to assessment of the grade of the diamondiferous deposits. Although no I.M. have been identified, it appears that the volumes of heavy mineral residues examined have been insufficient to allow a firm conclusion to be reached on whether I.M. are present or not.

On the problem of an immediate source of the Nullagine diamonds there is some evidence pointing to the Beatons Creek Conglomerate. The diamondiferous basal unit of the "Brooks Hill beds" contains material similar to rocks composing the Beatons Creek Conglomerate (Lovett, 1971). Diamonds have been found only near Nullagine where the conglomerate is well developed and have not been found where this formation does not occur. There is no record of an examination of the Beatons Creek Conglomerate for diamond by the systematic sampling and large volume (100 t) treatment of this rock.

NORTHERN CANNING BASIN

In the Northern Canning Basin, despite conflicting results of operations at Mount Abbott and along that portion of the Lennard River shown on Figure 50, the scales of operations have been such that the prospects of these areas yielding diamond are slight.

SERPENTINE RIVER AREA

No useful conclusion can be drawn from current knowledge of diamond prospects along the western margin of the Yilgarn Block immediately south of Perth.

REFERENCES

Colchester, D. M., 1972, A preliminary note on kimberlite occurrences in South Australia: Geol. Soc. Australia Jour., v. 19, p. 383-386.

Dawson, J. B., 1967, A review of the geology of kimberlite *in* Wyllie, P. J. (Ed.) Ultramafic and Related Rocks: Wiley, New York, p. 241-251.

Groom, F. F., 1896, Report of a visit to Nullagine, Pilbara District, to examine the country reported to be diamond yielding: West. Australia Dept. Mines Ann. Rept. 1895, Appendix 4, p. 27.

Guppy, D. J., Lindner, A. W., Rattigan, J. H., and Casey, J. N., 1958, The geology of the Fitzroy Basin, Western Australia: Australia Bur. Mineral Resources Bull. 36.

Haynes, R. W., 1971, Completion report on Temporary Reserves Nos. 4665H, 5184H and 5423H Lennard River Area, Western Australia: Exoil N.L., Transoil N.L. and Petromin N.L. (unpublished).

Lawrence, M. J., 1971, The diamond search in Australia: Applications of a mobile prospection unit and the concept of mineral-geochemistry: Australasian Inst. Mining Metall. Proc. Ann. Conference 1971, v. 4, p. 24, 1-33.

Lishmund, S., 1967, Report on preliminary indicator mineral sampling, Nullagine area, Project 403: Conzinc Riotinto Australia Exploration Pty. Ltd. (unpublished).

Lovett, D., 1971, Report on Nullagine diamond project, Nullagine, Western Australia: Mining Advisers Pty. Ltd. (unpublished).

MacLeod, W. N., 1966, The geology and iron deposits of the Hamersley Range area, Western Australia: West. Australia Geol. Survey Bull. 117.

Mannard, G. W., 1968, The surface expression of kimberlite pipes: Geol. Assoc. Canada Proc. v. 19, p. 15-21.

Noldart, A. J., and Wyatt, J. D., 1962, The geology of portion of the Pilbara Goldfields: West Australia Geol. Survey Bull. 115.

Prider, R. T., 1960, The leucite lamproites of the Fitzroy Basin, Western Australia: Geol. Soc. Australia Jour., v. 6, p. 71-118.

Simpson, E. S., 1951, Minerals of Western Australia, v. 2, p. 136-140.

Sofoulis, J., 1958, Report on reconnaissance of the diamondiferous country in the vicinity of Nullagine, Pilbara Goldfield, W.A.: West Australia Geol. Survey Bull. 109.

Thomas, W. N., 1968, Report on investigations for 1967: Temporary Reserve 4508H Nullagine area, W.A.: Conzinc Riotinto Australia Exploration Pty. Ltd. (unpublished).

Veevers, J. J., and Wells, A. T., 1961, The geology of the Canning Basin, Western Australia: Australia Bur. Mineral Resources Bull. 60.

Wade, A., and Prider, R., 1940, The leucite-bearing rocks of the West Kimberley area, Western Australia: Geol. Soc. London Quart. Jour., v. 96, p. 39-98.

Wellman, P., 1973, Early Miocene potassium-argon age for the Fitzroy Lamproites of Western Australia: Geol. Soc. Australia Jour., v. 19, p. 471-474.

THE MEENTHEENA FLUORITE DEPOSITS, PILBARA GOLDFIELD

by A. H. Hickman

ABSTRACT

Some of the largest known fluorite deposits in Western Australia occur at Meentheena, 75 km east of Marble Bar. The fluorite, which has intruded a Lower Proterozoic sequence of basalt, andesite and agglomerate, is a hydrothermal deposit formed during Proterozoic deformation. The areal distribution of the mineral is controlled by a conjugate fracture system established during this period of movement. As yet it is uncertain whether the fluorite is primary, originating from a deep-seated alkalic magma, or if it represents remobilized Archaean fluorite from the underlying basement.

The Meentheena fluorite deposits are well situated to supply any future steel industry in the Pilbara region.

INTRODUCTION

The presence of fluorite in the Meentheena area was discovered in 1971. Subsequent pegging of the area by Barakee Mining and Exploration Pty. Ltd. was followed by geological mapping, costeaning and open-cut mining. At present Meentheena Fluorite Pty. Ltd., the operating company, is conducting a drilling programme to determine the depth of mineralization and to obtain a more detailed estimate of ore reserves.

LOCATION, ACCESS AND FACILITIES

Meentheena is situated on the Nullagine River 220 km east-southeast of Port Hedland and 75 km east of Marble Bar. Road access from Port Hedland is by way of Great Northern Highway for 240 km to Mount Edgar Station and thence by graded track eastwards for a further 50 km. An airstrip has been constructed 1 km north of the exploration camp and a bore has been drilled to provide a permanent water supply. Water is also available from the nearby Tumbiana Pool on the Nullagine River.

GEOLOGY OF THE MEENTHEENA AREA

The regional geology of the area around Meentheena is shown on the Nullagine sheet of the 1 : 250 000 Geological Series (Noldart and Wyatt, 1962; Thom and Hickman, in prep.) and on Figure 51.

The fluorite deposits occur as fissure veins within folded and faulted Lower Proterozoic volcanic rocks. No large igneous intrusions are exposed close to the prospects but quartz veining is extensive and several narrow rhyolitic dykes intrude the area.

STRATIGRAPHY

The rock succession of the Meentheena area belongs to the lower part of the Lower Proterozoic Fortescue Group, as shown below:

STRATIGRAPHY OF FORTESCUE GROUP IN THE MEENTHEENA AREA

Formation	Lithology	Thickness
Kuruna Siltstone	sandstone, siltstone and pisolitic tuff	20 m
Nymerina Basalt	dark grey mottled basalt, some vesicular flows	300 m
Tumbiana Formation:	sedimentary rocks:	
carbonate member	ripple bedded siliceous limestone	30 m
tuff member	pisolitic tuff with minor siltstone and shale	100–200 m
Kylena Basalt	massive, often vesicular basalt and andesite	500–800 m
Hardey Sandstone	sandstone, conglomerate, tuff and shale (includes grey felsic porphyry, partly amygdaloidal)	50–200 m
Mt. Roe Basalt (Oldest)	basaltic and andesitic amygdaloidal lava with thick agglomerate and lapilli tuff (includes some felsic lava)	300+ m
	UNCONFORMITY	
	Archaean granite and greenstones.	

Although the deposits are situated close to the centre of the large Proterozoic outcrop shown on Figure 51 they occur on a structural high, all of them being within the Mount Roe Basalt the lowest formation of the Fortescue Group. It seems certain from information gained through regional mapping that unless the Mount Roe Basalt is exceptionally thick in this area the underlying Archaean basement cannot lie far beneath the present erosion surface, probably no more than 100-200 m.

West of the Nullagine River a thick sequence of agglomerate, lapilli tuff and gritty tuff forms a large part of the Mount Roe Basalt, whereas to the east the formation consists primarily of massive vesicular basalt and andesite. Amygdales and vugs within the lavas are filled with quartz, calcite and phyllosilicate minerals. Porphyritic basalt is predominant toward the base of the unit.

The agglomerate and tuff west of the river is composed of well rounded to very angular fragments (up to 10 cm in diameter) of quartz, quartzite, chert, granite, basalt and schist. Most of these rocks were derived from the underlying Archaean basement and were ejected from a nearby early Proterozoic vent. The agglomerate represents an explosive phase of volcanicity which deposited pyroclastic rocks over most of the Pilbara. Isolated wedge-shaped bodies of a similar lithology and age also occur in the Marble Bar, Pyramid, Mount Bruce and Roebourne Sheet areas.

STRUCTURE

The Meentheena fluorite deposits are situated on the faulted culmination of a broadly domal structure (Fig. 52). This structural high is truncated sharply to the west of the prospects by the Meentheena Fault, a high-angle fracture striking almost due north at Meentheena. Regional mapping has shown the fault to be essentially a dextral wrench with a horizontal displacement of approximately 4 km. Vertical movement is also present, but less pronounced, and probably only amounts to a few hundred metres (western block downthrown). The Meentheena Fault is an important regional structure extending 100 km from Cookes Creek in the south to the Little de Grey River in the north. Meentheena is situated close to the middle of its course.

The structural complexity in the area of the fluorite deposits is far greater than is normally encountered in Proterozoic terrain of the eastern Pilbara. Between the larger faults depicted on Figure 51 there is a well developed conjugate system of minor fractures. These reach a maximum density in the area of the prospects where they are mineralized not only by quartz, as is common elsewhere, but also by fluorite. The presence of slickensides, belts of crush breccia and intensely sheared vein quartz all testify to considerable movement along many of these fissures.

Figure 51 indicates that the fold pattern of the Meentheena area is not simple. It forms essentially a dome-and-basin pattern with predominantly north to northwest-trending axes. Fold geometry in the immediate area of the prospects has not been investigated in detail, but in general the fluorite occurs high on the northwest flank of an open and irregularly shaped elongate dome.

FLUORITE DEPOSITS

The areal distribution of the main fluorite-bearing veins is shown on Figure 52. Two sets of veins striking respectively at 60° and 135° are present. A typical vein consists of an outer zone of quartz with a wide central zone of interlayered quartz and coarse-grained massive anhedral fluorite. The fluorite sometimes exhibits a banded texture parallel to the vein walls. This phenomenon is common in many other fluorite deposits of the world and has been variously ascribed to rhythmic introduction, or rhythmic variations in the concentration of the mineralizing solutions.

Fluorite bodies within individual veins are rarely tabular but tend to outcrop as pinch-and-swell structures. An absence of drilling data precludes any reliable statement on the three-dimensional geometry of the ore bodies.

The walls of the fissure veins are generally composed of silicified and brecciated country rock. This siliceous breccia contains angular fragments of quartz, chert and bleached country rock in a matrix of white fluorite. Purple fluorite appears to have been introduced at a relatively late stage and veins the rock intricately. Fragmentation of the early quartz and fluorite reflects some degree of disturbance and collapse during mineralization. More than one generation of quartz is present. Some of the veins contain sheared (platy) quartz intruded by later undeformed quartz and fluorite.

Thick veins of calcite are present on the periphery of the mineralized area but no barite, a mineral frequently associated with fluorite, has been detected anywhere in the area. Small occurrences of galena, malachite and goethite have been noted east of the Nullagine River where brochantite and atacamite are also present.

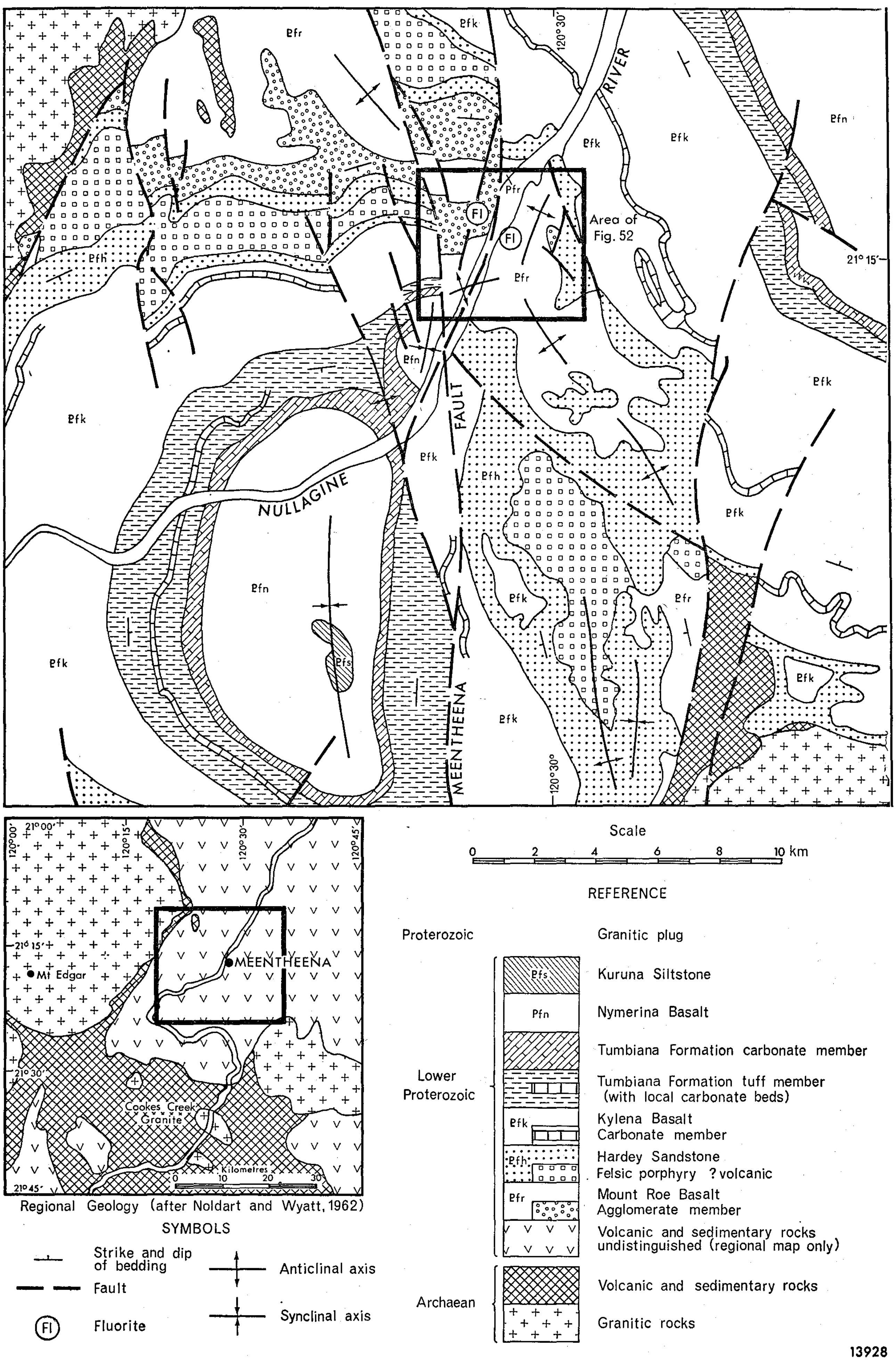

Figure 51. Meentheena area geological map.

Veins of rhyolitic breccia containing fluorite have been noted at various localities within the prospects. Rhyolitic dykes devoid of fluorite are also present (Fig. 52).

ORIGIN

The structural environment of the Meentheena fluorite deposits is similar to that of many other fluorite mining areas in the world. The fluorite is epigenetic and was deposited in a fracture system from ascending hydrothermal solutions. Two sources may be envisaged for the fluorite:

(1) A deep-seated Proterozoic alkalic magma beneath the Meentheena area.

(2) A fluorite-rich Archaean granite underlying the prospects.

The mineralogy of the deposits suggests that they are epithermal. The absence of tin, tungsten and molybdenum minerals indicates this (Peters, 1958). There is little evidence to suggest that the area is underlain by a large Proterozoic alkalic intrusion. The presence of rare rhyolitic dykes does not in itself substantiate this interpretation especially as these dykes contain no fluorite. Granitic plugs approximately 10 km west of the deposits are of granodiorite composition and contain only minor traces of fluorite.

A late Archaean fluorite-rich granite occurs 35 km south of Meentheena at Cookes Creek. This rock contains about 2 per cent accessory fluorite (J. Lewis, pers. comm.) and is extensively veined by quartz, fluorite and barite. Should such a granite form part of the Archaean basement beneath the Meentheena area it is possible that local severe deformation during Proterozoic folding and fracturing might have mobilized the mineral. Under such conditions fluorite veins could be formed in the lower levels of the Proterozoic succession.

Until more detailed drilling results are available each of the above interpretations is tenable.

GRADE AND ORE RESERVES

The total reserves of the larger veins are estimated at 13 000 tonnes per vertical metre of 50 per cent CaF_2 ore. Total reserves of the entire Meentheena area exceed 30 000 tonnes per vertical metre but most of this material is of low grade. Open-cut mining of the deposits and flotation separation of the fluorite from its only significant impurity, quartz, is probably feasible.

A total of 8 000 tonnes of ore has now been extracted and is stockpiled 3 km north of the company's exploration camp (lat. 21° 16′ S, long. 120° 27′ E).

The ore reserves indicated by this investigation are comparable with those of the State's only other known major fluorite occurrence at Speewah, 110 km south of Wyndham.

CONCLUSIONS

The Meentheena fluorite deposits are structurally controlled by a Proterozoic fracture system and were formed by precipitation from ascending hydrothermal solutions.

The deposits are well situated to supply any future steel industry located in the Pilbara region.

REFERENCES

Noldart, A. J., and Wyatt, J. D., 1962, The geology of portion of the Pilbara Goldfield: West. Australia Geol. Survey Bull. 115 .

Peters, W. C., 1958, Geologic characteristics of fluorspar deposits in the Western United States: Econ. Geol. v. 53, p. 663-688.

Thom, R., and Hickman, A. H., in prep., Explanatory notes on the Nullagine 1 : 250 000 Geological Sheet, W.A.: West. Australia Geol. Survey Rec.

PETROGRAPHY, CHEMICAL COMPOSITION, AND GEOCHRONOLOGY OF TWO DOLERITE SILLS FROM THE PRECAMBRIAN WEELI WOLLI FORMATION, HAMERSLEY GROUP.

by J. R. de Laeter*, R. Peers, and A. F. Trendall.

ABSTRACT

The intracratonic Hamersley Basin had a maximum extent of about 150 000 km² over what is now the northwest part of Western Australia, between latitudes 20°-24° South, and longitudes 116°-122° East. Deposition probably started no later than 2 300 m.y. ago and terminated about 1 800 m.y. The 2 400 m thick Hamersley Group is the middle group of three deposited in the basin, and is characterized by abundant banded iron formation (BIF). The Weeli Wolli Formation occupies the middle fifth of the Hamersley group, and consists of BIF, shale, and dolerite in the approximate proportions 3 : 1 : 6. The lower part of a diamond corehole that passed through 118 m of the formation transected two dolerite sills, 33 m and 76 m thick, separated by 44 m of BIF and shale. The dolerite is neither macroscopically nor microscopically unusual, and appears to have had typical primary mineralogy although this is now modified by both deuteric and metamorphic effects. However, twenty complete analyses show high average K_2O (2.7 per cent) and low CaO (5.56 per cent). Vertical chemical variation through both sills shows that differentiation was negligible, and that the high average K_2O is due to marginal samples which have very high (up to 7.1 per cent) K_2O probably derived from assimilation of adjacent shale. The anomalously low CaO is probably accounted for by cross-cutting veins of carbonate and axinite. Twelve representative dolerite samples taken through both sills for Rb-Sr isotope analysis are widely scattered on an isochron diagram. It is possible to interpret the scatter in terms of four separate ages: a young (900-1 200 m.y.) up-dating expressed by one sample; an earlier up-dating (1 689 ± 222 m.y.) expressed by four samples; an age of dolerite intrusion (c. 2 100 m.y.) expressed by three samples; and an age of shale deposition (c. 2 200 m.y.) acquired by four marginal dolerite samples by digestion of adjacent shale.

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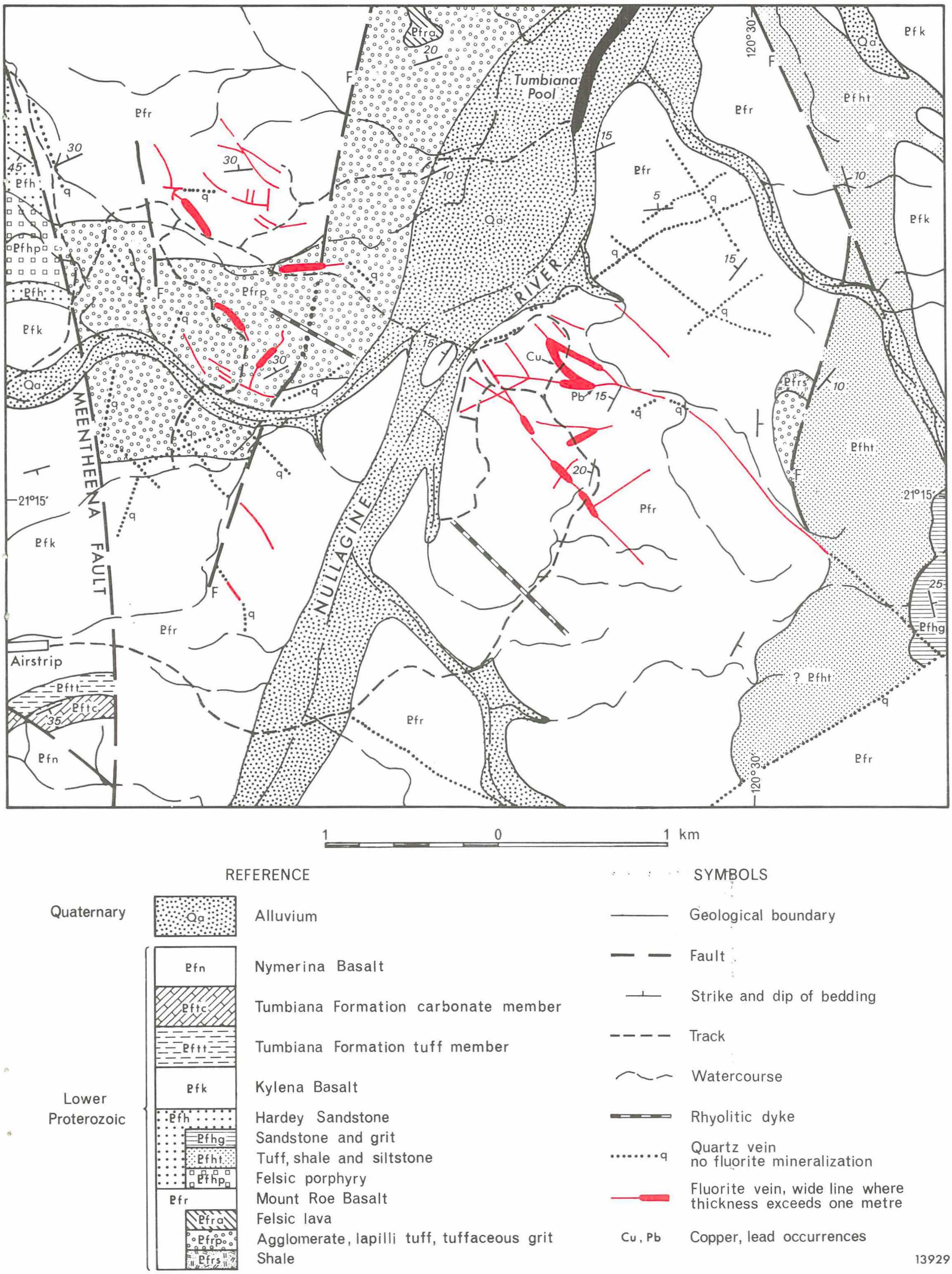

Figure 52. Meentheena fluorite deposits—geological map.

INTRODUCTION

The Weeli Wolli Formation is one of eight constituent formations of the Hamersley Group, a major depositional unit of the intracratonic Hamersley Basin, which extended over some 150 000 km^2 of the northwestern part of Western Australia during the early Proterozoic. The development of the Hamersley Basin, and the present geology of the area, have been described in detail by Trendall and Blockley (1970), and shorter summaries are also available (Trendall, 1968, 1972, 1973a).

The 2 400 m thick Hamersley Group is characterized by an abundance of banded iron formation (BIF), and the Weeli Wolli Formation, which forms roughly the central fifth of the thickness of the group, itself consists of BIF, shale, and dolerite, in the approximate proportions 3 : 1 : 6; its usual thickness is about 450 m. By comparison with other units of the Hamersley Group the Weeli Wolli Formation is poorly exposed. For this reason a continuously cored diamond drillhole, referred to as DDH WW1, was drilled at 22° 17′ 30″ S, and 118° 24′ 00″ E, about 44 km south of Wittenoom, in the Hamersley Range area, in 1970. It passed through 272 m of the Weeli Wolli Formation, of which 154 m was dolerite, in four separate sills. A graphic log showing these, forms Figure 53. The hole was inclined northward at an angle of 60° through the north limb of a gentle anticline, so that it transected the stratification perpendicularly.

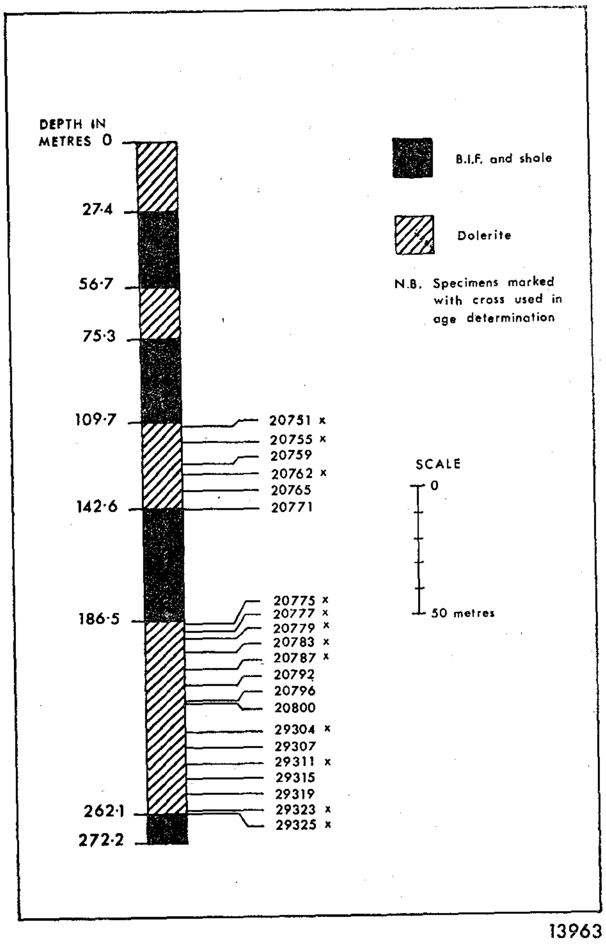

Figure 53. Graphic log of the part of the Weeli Wolli Formation encountered in DDH WW1, showing sample positions.

Although DDH WW1 was drilled to obtain a fresh representative sample of the BIF, on which a preliminary note has been published (Trendall, 1973b), the recovery of complete core sections through the sills made it desirable to place an account of these on record. Twenty samples, which appeared to be completely free of surface weathering effects, were therefore selected from the lowest two sills (referred to informally as the lower and upper sills in this paper), for petrographic examination and chemical analysis. The remarkably high potassium contents revealed by these analyses, and by the visible abundance of potassic feldspar, suggested that the rocks might be chemically suitable for whole-rock Rb-Sr isotopic analysis.

The Rb-Sr ratios of ten of these twenty samples showing a wide range of values were measured accurately by X.R.F.S., and the unspiked Sr^{87}/Sr^{86} ratios were also determined separately. Two further samples were added later to resolve ambiguities; one of these was not one of the twenty analysed samples (20777). Although the Rb-Sr results remain equivocal, all the data obtained merit publication, especially since substantial further work, which cannot be given high priority, would be needed to resolve the remaining problems. The purposes of this paper are therefore to present the petrographic, chemical and geochronological data so far available, and to discuss their significance in the light of previously existing knowledge of Hamersley Basin development, including some unpublished information.

The Rb-Sr isotopic and X.R.F.S. analyses reported here were carried out by J. R. de Laeter in the Physic Department of the Western Australian Institute of Technology. This paper is the sixth report of results of the joint geochronology programme initiated between the Institute and the Geological Survey in 1968.

PETROGRAPHY

The photomicrographs of Figure 54 and 55 show typical examples of the dolerite types present in both of the sampled sills. The mineral composition of the 21 thin sections cut appears in Table 18. A generalised description of these sections follows, with comment on significant variations within them.

Most of the dolerites have a relict subophitic to intergranular texture, and are composed essentially of plagioclase, pyroxene and opaque minerals; all of these constituents are replaced by secondary minerals to a greater or lesser extent. Although the form of the primary plagioclase is well preserved, no plagioclase more calcic than albite remains. Abundant saussurite, and the presence of calcic secondary minerals such as carbonate, epidote, and axinite, indicate that the primary feldspar was a calcic plagioclase. In addition to this "albitization", all of the plagioclase from the lower sill and some from the upper sill appears to have been replaced by K-feldspar. The K-feldspar is evenly kaolinized, and readily distinguished from the plagioclase. However, its presence was confirmed by staining.

About half of the specimens examined retain some relict pyroxene which, without exception, is a clinopyroxene. Typically it occurs as ragged cores which are dark pink in plane polarised light due to included hematite "dust". Replacement of the pyroxene evidently took place along cleavage and fracture planes and at the grain margins. The principal alteration products are amphibole, chlorite and ferrostilpnomelane, with amphibole predominating. Amphibole occurs as aggregates of ragged blades which partly or wholly pseudomorph pyroxene. It is pleochroic with X = pale green, Y = apple green, and Z = pale blue green, but the colour is commonly more intense at the margins indicating a slight variation in chemical composition. Most of the secondary amphibole is actinolite, but the more strongly coloured amphibole may be ferroactinolite or hornblende. A small amount of a primary brown hornblende is present in several specimens. Chlorite is abundant both as a secondary mineral after pyroxene and as an interstitial mineral. Its most common form is a fibrous, radiating aggregate, that has yellow green to pale emerald green pleochroism, and striking anomalous blue birefringence. The co-existence of two chlorites in some samples from the lower sill was confirmed using X-ray methods. The second chlorite forms extremely fine-grained aggregates which are difficult to resolve, and it is variously coloured pale yellow green and olive green. Ferrostilpnomelane is absent from the upper sill, but abundant in the lower, although its abundance in individual samples is extremely variable. Typically it occurs as radiating fibrous aggregates pseudomorphous after pyroxene, but where it is really abundant it is present throughout the rock. It is pleochroic, either colourless to pale green or pale yellow green to olive green but is easily distinguished from chlorite by its birefringence, and from amphibole on the basis of its extinction angle.

The interstitial pockets between the relict plagioclase and pyroxene grains are variously infilled. Most commonly the infilling is a fine-grained granophyric intergrowth of quartz and K-feldspar with included acicular apatite crystals. Less commonly, quartz and chlorite occur interstitially and in the most altered samples the infilling is carbonate or axinite.

Opaque grains are present throughout both sills, but are more abundant in the lower sill. Two varieties were recognized, small grains of fresh pyrite which are yellow in reflected light, and large skeletal grains of a black mineral partly replaced by a mixture of leucoxene and sphene. In a few specimens none of the original mineral remains.

Perhaps the most striking feature of these dolerites is the abundance of the secondary calcium-rich minerals carbonate, epidote and axinite. All three of these tend to be coarsely crystalline, with the appearance of having invaded the rock, and on textural evidence alone do not appear to be primary. Axinite is a particularly characteristic mineral if the section is a little thick and its distinctive lilac pleochroism can be observed. The epidote of these dolerites occurs both as a constituent of saussurite, and as large subhedral pistachio-green grains. Both axinite and carbonate are abundant as coarse veins which cut the dolerite core at intervals along its length.

The specimens that vary from the above descriptions are amygdaloidal, xenolithic or chilled. Specimens 20751, 20759 and 20771 from the upper sill are amygdaloidal. The amygdales are roughly spherical and vary in diameter up to 5 mm. They are variously infilled with epidote, chlorite, quartz, sphene, axinite and pyrite (Fig. 55A). In specimen 20759 the amygdales are imperfectly rimmed by devitrified material. Specimen 20771 from the base of the upper sill is extremely fine grained and includes undoubted, though now recrystallized, xenolithic material (Fig. 55B). The matrix is a poorly crystallized mixture of plagioclase, epidote, actinolite, sphene and chlorite with some porphyroblastic axinite. The xenolith illustrated measures 4 mm by 1 mm, has well-defined layering which is probably relict sedimentary, and is composed of cherty quartz, chlorite, epidote, axinite, a yellowish garnet (probably grossular), pyrite and amphibole.

Several other structures included in this rock, one composed of a K-feldspar mosaic with minor epidote, chlorite and pyrite, and the other rich in axinite, could also be interpreted as xenoliths. Similarly, in specimen 20775 from the top of the lower sill, there are irregular patches of coarse-grained carbonate, epidote and axinite with subordinate ferrostilpnomelane and K-feldspar which may represent recrystallized xenoliths or imperfect amygdales.

CHEMICAL COMPOSITION

The compositions of the 20 samples analysed are set out in Table 19, together with the computed C.I.P.W. norms. In Figure 56 the variation with depth of selected elements is displayed. All the analyses were carried out by the Government Chemical Laboratories; all determinations except FeO, Na_2O, H_2O^+, H_2O^- and CO_2 were by X.R.F.S.

TABLE 18. SUMMARY OF COMPOSITIONAL VARIATION WITHIN THE DOLERITES OF DDH WW1

		Primary Minerals			Secondary Minerals								Accessory Minerals				
Sill	Sample	Plagioclase (albite)	Clinopyroxene	Interstitial quartz/K-feldspar	Amphibole (actinolite)	Chlorite	Ferrostilpnomelane	Epidote	Axinite	Carbonate	Sphene and leucoxene	K-feldspar	Black opaque	Pyrite	Apatite	Amygdales	Comments
Upper Sill	20751	x		x	x	x		x			x	x	x			x	Vesicles infilled with epidote, chlorite, quartz and sphene.
	20755	x		x	x	x		x			x		x		x		Plagioclase rimmed by radiating quartz-alkali feldspar intergrowth.
	20759		x	x	x	x		x			x			x	x	x	Epidote and chlorite infill vesicles which are rimmed by devitrified glass. One amygdale has partial rim of pyrite.
	20765	x	x	x	x	x		x			x			x	x		Amphibole zoned to brown hornblende.
	20771	x			x	x		x	x		x			x		x	Chlorite, epidote, quartz, pyrite and axinite infill vesicles. Rock is chilled and includes xenoliths.
Lower Sill	20775	x	x		x	x	x	x			x	x	x		x	?	Possible xenoliths or amygdales, now carbonate, epidote, axinite, ferrostilpnomelane and K-feldspar.
	20777	x	x		x	x	x	x			x	x	x		x		
	20779	x	x		x	x	x	x	x	x	x	x	x		x		
	20783	x		x	x	x	x	x	x	x	x	x	x	x			Primary brown hornblende zoning to actinolite.
	20787	x	x	x	x	x	x	x	x		x	x	x	x	x		
	20792	x	x	x	x	x	x	x	x	x	x	x	x	x	x		Includes some brown hornblende.
	20796	x	x	x	x	x	x	x	x	x	x	x	x	x	x		Includes some interstitial quartz and axinite,
	20800	x	x	x	x	x		x	x	x	x	x	x	x	x		
	29304	x			x	x		x			x	x		x	x		Interstitial quartz and chlorite. Two chlorites present.
	29307	x			x	x			x		x	x		x	x		Two chlorites present.
	29311	x		x	x	x	x	x	x		x	x	x	x	x		Two chlorites present.
	29315	x		x	x	x	x	x	x	x	x	x	x	x	x		
	29319	x	x	x	x	x	x			x	x	x	x	x	x		
	29323	x		x	x	x	x	x	x	x	x	x	x	x	x		
	29325	x			x	x	x			x	x	x	x		x		

x = present

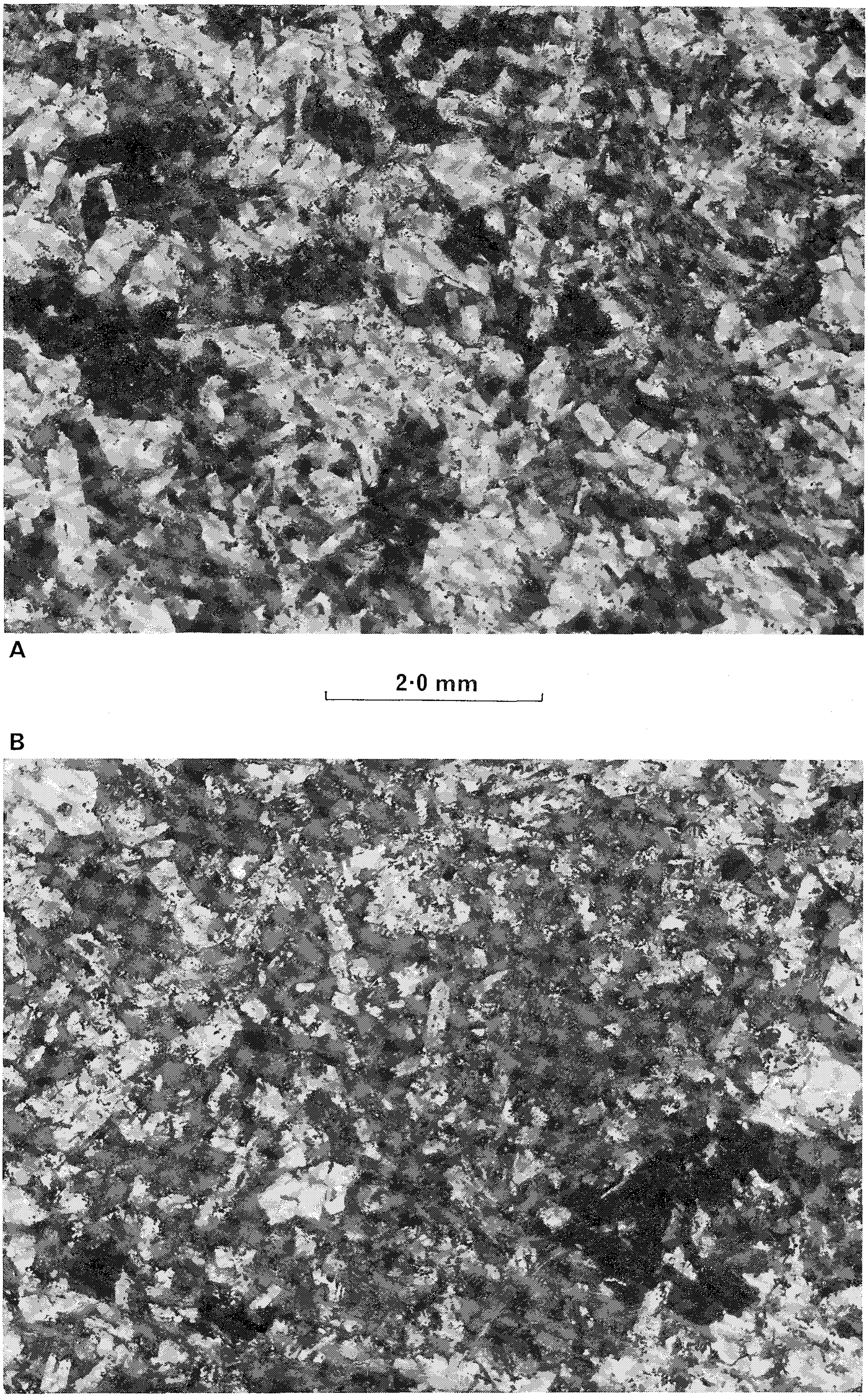

FIGURE 54

Photomicrographs of two samples from the lower sill of DDH WWI

A. 20779. Plane polarised light. Altered dolerite from 194 m, composed of plagioclase (pale grey laths), clinopyroxene (dark grey), amphibole and ferrostilpnomelane (fibrous laths), epidote (grey with moderate relief) and an opaque mineral (black, skeletal form).

B. 29315. Plane polarised light. Altered dolerite from 248 m, composed of plagioclase (pale grey laths), chorite and amphibole pseudomorphous after pyroxene (fibrous grey), interstitial quartz (clear, white), an opaque mineral being replaced by sphene (black skeletal) and epidote (grey with relief).

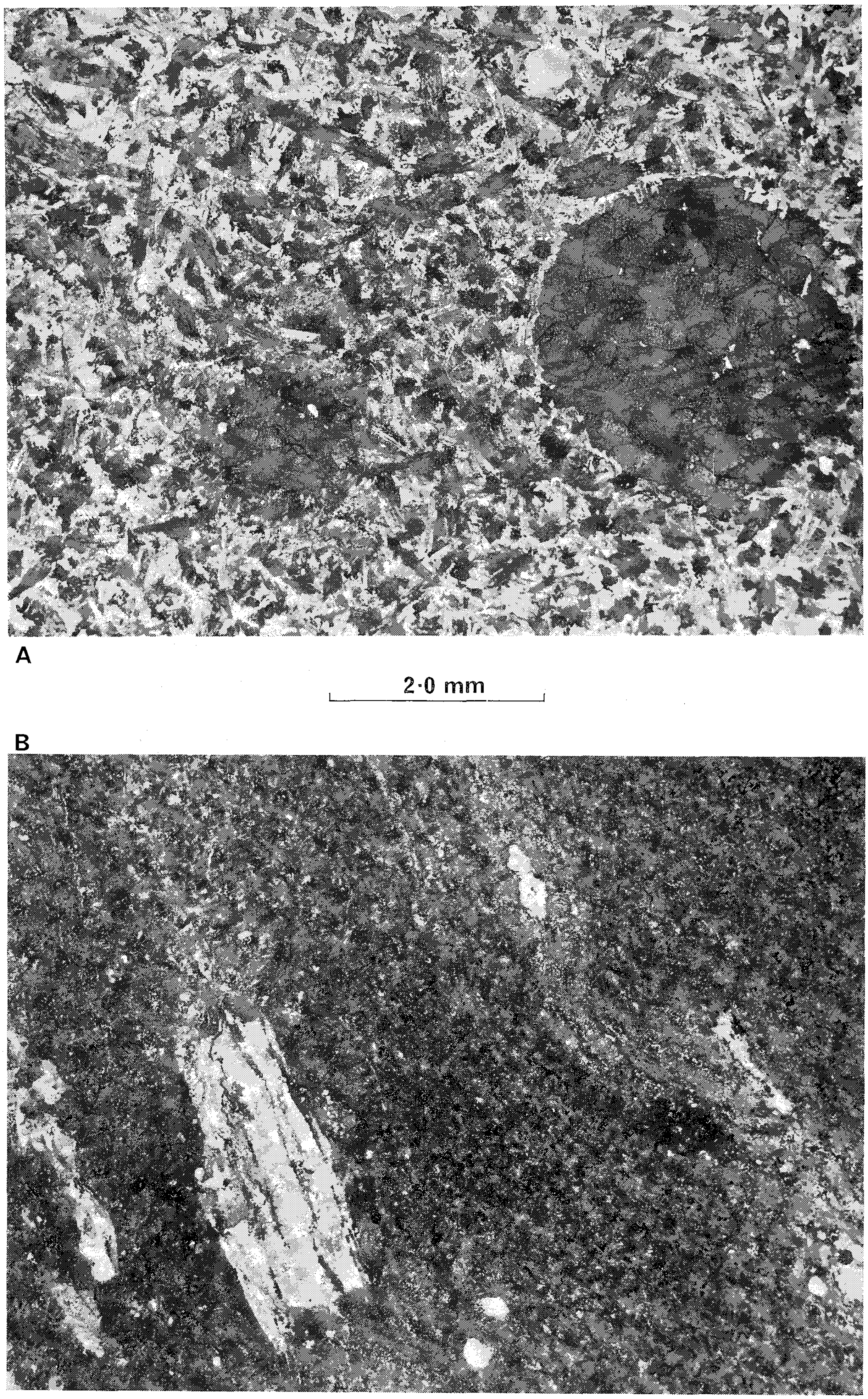

FIGURE 55

Photomicrographs of two samples from the upper sill of DDH WWI.

A. 20751. Plane polarised light. Altered amygdaloidal dolerite from the chilled upper surface of the upper sill (at 111·25 ,). Amygdales infilled with epidote (grey, cleaved, with moderate relief) and chlorite (grey with fibrous structure). Groundmass is composed of plagioclase (light grey laths), amphibole pseudomorphous after pyroxene (grey, fibrous laths), epidote (small dark grey grains with moderate relief). Interstitial mottled grey areas are quartz-K-feldspar intergrowth. The clear white patch at the centre top of the photomicrograph is a hole in the thin section.

B. 20771. Plane polarised light. Altered xenolithic dolerite from the base of the upper sill (at 143 m). Recrystallized xenolith at left is composed of cherty quartz (clear, white), chlorite and amphibole (pale, grey, mottled), epidote (grey with moderate relief, also dark grey and finely granular), axinite (clear pale grey), garnet (dark grey, moderate relief cluster top centre of xenolith and pyrite (black). Other xenolithic fragments are composed of cherty quartz and chlorite. The matrix is a poorly crystallized mixture of feldspar, epidote, amphibole, chlorite and sphene with some axinite.

TABLE 19. COMPOSITIONS AND C.I.P.W. NORMS OF TWENTY DOLERITE SAMPLES FROM THE WEELI WOLLI FORMATION

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
	20751	20755	20759	20762	20765	20771	20775	20779	20783	20787	20792	20796	20800	29304	29307	29311	29315	29319	29323	29325	Average of Column 1–20
SiO_2	56·1	60·6	52·7	55·1	54·3	49·6	51·1	50·6	57·5	50·7	51·0	50·2	50·2	48·1	49·1	51·3	50·1	50·9	50·5	50·5	52·3
Al_2O_3	14·6	13·6	15·7	14·6	14·8	13·8	12·2	12·8	10·8	14·3	14·1	13·9	14·6	16·3	14·8	14·2	14·5	13·6	13·2	13·4	14·0
Fe_2O_3	3·1	3·0	3·5	2·8	3·6	7·6	3·4	5·5	5·3	3·7	4·3	3·5	4·1	7·1	5·1	4·3	4·8	3·6	4·1	2·8	4·3
FeO*	6·19	4·99	7·10	6·70	6·63	10·46	9·62	9·40	8·72	10·09	8·68	9·29	7·41	7·35	9·01	9·39	9·15	9·06	10·03	10·18	8·47
MgO	3·6	3·0	5·0	5·4	4·8	5·0	4·2	3·6	1·9	4·3	4·6	4·6	5·0	3·7	5·1	4·6	4·6	4·6	5·2	5·2	4·4
CaO	4·74	4·28	5·28	5·16	4·46	3·31	7·08	7·16	3·57	5·05	6·98	7·04	9·12	6·49	4·21	5·61	5·36	6·78	5·17	4·37	5·56
Na_2O*	3·25	2·92	4·25	3·23	2·90	3·56	1·46	2·59	2·89	3·12	3·55	3·26	2·22	3·10	3·81	2·68	3·35	3·02	1·78	0·35	2·86
K_2O	3·9	4·2	2·3	2·9	3·5	1·4	5·4	3·0	2·2	2·5	1·1	1·1	2·6	0·7	0·9	1·7	0·9	2·2	3·3	7·1	2·7
H_2O^+*	2·59	1·96	3·37	3·21	3·46	3·93	3·21	3·45	3·33	4·05	3·54	3·71	3·21	4·60	4·57	4·04	4·08	2·55	3·91	3·69	3·72
H_2O^-*	0·08	0·13	0·12	0·08	0·11	0·11	0·15	0·26	0·35	0·06	0·05	0·06	0·11	0·72	0·86	0·26	0·61	0·16	0·31	0·21	0·24
CO_2*	0·00	0·00	0·00	0·32	0·23	0·00	0·46	0·30	0·92	0·14	0·20	0·54	0·08	0·00	0·00	0·00	0·17	0·23	0·26	0·00	0·32
TiO_2	0·58	0·55	0·56	0·49	0·49	0·45	1·26	1·50	1·45	1·25	1·08	1·10	0·93	1·18	1·22	1·29	1·30	1·25	1·25	0·16	0·97
P_2O_5	0·10	0·09	0·06	0·06	0·06	0·11	0·14	0·18	0·17	0·13	0·13	0·10	0·12	0·13	0·11	0·16	0·11	0·16	0·15	0·21	0·12
MnO	0·15	0·12	0·17	0·16	0·17	0·18	0·20	0·24	0·27	0·22	0·19	0·28	0·46	0·11	0·10	0·19	0·14	0·20	0·22	0·21	0·20
Total	98·9	99·5	100·2	100·2	99·5	99·5	99·9	100·5	99·5	99·7	99·5	98·6	100·2	99·6	98·9	99·7	99·3	100·0	99·3	99·4	99·6

C.I.P.W. Norms

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Q	5·36	13·42	....	4·28	4·90	3·74	0·45	3·58	20·40	1·47	3·19	3·31	1·14	6·25	2·51	6·61	5·17	1·76	4·91	....
C	....	....	....	....	....	0·70	....	....	....	....	....	....	....	....	0·21	....	....	....	....	....
Or	23·03	24·78	13·84	17·12	20·72	8·14	32·11	17·73	13·12	14·72	6·35	6·60	15·41	4·27	5·23	9·89	5·45	12·94	19·27	41·88
Ab	27·48	24·67	36·00	27·31	24·51	30·09	12·33	21·94	24·45	26·38	30·02	27·57	18·76	26·21	32·21	22·70	28·34	25·51	15·10	2·96
An	13·71	11·75	16·76	16·79	16·94	15·68	10·59	14·51	10·05	17·70	19·38	19·87	22·26	28·36	20·15	21·63	21·85	17·14	18·33	13·98
Di	7·56	7·31	7·40	5·23	2·72	....	17·25	14·94	0·61	4·69	10·86	9·09	17·79	2·42	....	4·31	2·41	11·66	3·91	5·54
Wo	3·83	3·72	3·77	2·67	1·39	....	8·64	7·50	0·30	2·35	5·49	4·57	9·06	1·24	....	2·17	1·22	5·86	1·97	2·78
En	1·95	1·99	2·06	1·50	0·77	....	3·84	3·39	0·10	1·03	2·75	2·12	4·95	0·72	....	1·05	0·61	2·72	0·95	1·29
Fs	1·78	1·60	1·57	1·06	0·56	....	4·77	4·05	0·21	1·31	2·62	2·40	3·78	0·46	....	1·09	0·58	3·08	0·99	1·47
Hy	13·32	9·79	10·90	20·37	19·27	24·97	15·10	12·28	14·26	22·24	17·12	19·76	13·38	23·93	23·22	21·12	21·30	18·75	24·23	22·80
En	6·97	5·43	6·20	11·93	11·15	12·47	6·73	5·60	4·74	9·77	8·76	9·27	7·59	18·49	12·68	10·34	10·93	8·79	11·88	10·67
Fs	6·35	4·36	4·70	8·44	8·12	12·50	8·37	6·68	9·52	12·47	8·36	10·49	5·79	5·44	10·54	10·78	10·37	9·96	12·35	12·13
Ol	....	....	5·53	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	1·46
Fo	....	....	3·01	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	0·68
Fa	....	....	2·52	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	0·78
Mt	4·46	4·41	5·11	4·04	5·26	11·08	4·95	7·91	7·73	5·41	6·18	5·06	5·90	10·30	7·35	6·31	6·99	5·28	6·01	4·07
Il	1·11	1·05	1·06	0·93	0·94	0·85	2·39	2·84	2·75	2·37	2·06	2·09	1·77	2·23	2·31	2·54	2·46	2·38	2·38	2·48
Ap	0·23	0·22	0·14	0·14	0·15	0·26	0·34	0·43	0·41	0·30	0·31	0·24	0·28	0·31	0·26	0·37	0·27	0·37	0·36	0·38
Cc	....	....	....	0·73	0·52	....	1·03	0·68	2·09	0·32	0·45	1·23	0·18	....	....	....	0·39	0·52	0·59	....

* Analysis by chemical methods, remainder by X.R.F.
Analysts : Government Chemical Laboratories : N. March (X.R.F. analyses), G. Bialecki and R. Hogg (analyses by chemical methods).

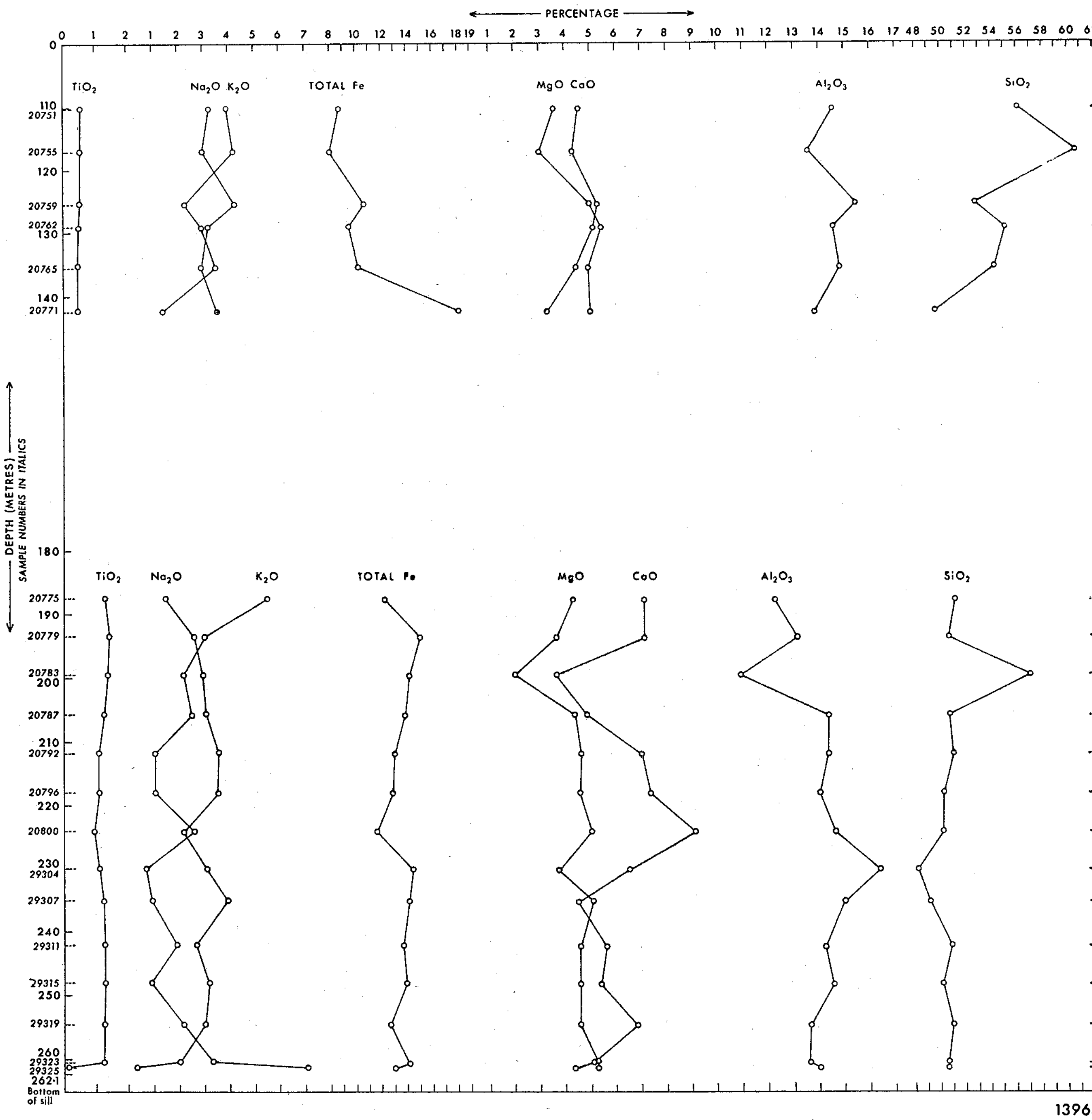

Figure 56. Variation of selected elements with position in sill : lower two dolerite sills intersected in DDH WW1.

RUBIDIUM-STRONTIUM DATA

Experimental procedures

About 100 g of each sample was reduced to –200 mesh using a jaw crusher and a Tema mill. Approximately 0.2 g of powder was then accurately weighed and taken into solution in a $HF\text{-}HC10_4$ mixture in a teflon dish. This solution was converted to the chloride form with 2.5M HC1. After again taking to dryness the residue was redissolved in 1M HC1 and centrifuged. The supernate was transferred to a quartz ion-exchange column contraining 2 g of Dowex 50W-X8, 200-400 mesh cation-exchange resin. Strontium was eluted using 2.5M HC1 and, after being taken to near dryness, each sample was loaded on the side filaments of a conventional rhenium triple filament assembly, ready for mass spectrometric analysis.

Blank determinations using the isotope dilution technique showed that the Rb and Sr contamination introduced by the chemical processing was less than 10^{-9} g and 10^{-8} g respectively. Full details of the isotope dilution technique used in this laboratory are given by de Laeter and Abercrombie (1970).

Isotopic analyses were carried out on a 30.5 cm radius, 90° magnetic sector, solid source mass spectrometer equipped with an electron multiplier. Previously outgassed rhenium filaments were used throughout the analyses. No evidence of Sr contamination from the ion source or filaments was ever observed.

A 1μg sample of $SrCl_2$ produced an ion-beam of approximate strength 10^{-11} amps for many hours of operation. The resulting signals were amplified in a vibrating reed electrometer with a 10^8 ohm input resistor. A voltage to frequency converter, followed by an electronic counter, allowed digital presentation of the data, which was fed on-line to a small digital computer. The amplifying system was periodically checked for linearity and speed of response.

Mass 85 was monitored on a sensitive scale at intervals during the analysis in order to correct the measured 87 peak for Rb contribution. The isobaric contribution of Rb^{87} to the Sr^{87} ion-beam was always less than 0.01 per cent before data were collected.

The isotopic peaks were scanned magnetically from mass 86 to 88 and then back again, this operation constituting one sweep. Approximately 40 sweeps were taken for each sample.

Replicate analyses of the NBS 987 Sr standard were made to give a mean value of Sr^{87}/Sr^{86} of 0.7105 normalised to a Sr^{88}/Sr^{86} value of 8.3752. The Sr^{87}/Sr^{86} values listed in Table 20 have been normalised to a Sr^{88}/Sr^{86} value of 8.3752. A value of 1.39×10^{-11}/year was used for the decay constant of Rb^{87}.

X-ray fluorescence was used to select rocks with favourable Rb/Sr ratios for mass spectrometric analyses, and also to determine precise values of the Rb/Sr ratio for the selected samples. A Siemen's SRS-1 fluorescence spectrometer equipped with a molybdenum tube, a lithium fluoride (200) crystal and a scintillation detector was used. The method of Norrish and Chappell (1967) was used to determine the Rb/Sr ratio in the samples.

Results

The measured Rb/Sr and Sr^{87}/Sr^{86} ratios, as well as the Rb^{87}/Sr^{86} ratios calculated from these, are given in Table 20. The errors accompanying the ratios are given at the 95 per cent confidence level. The data are also plotted in Figure 57, together with the isochrons the status of which is discussed below.

TABLE 20. RUBIDIUM-STRONTIUM DATA FOR 12 DOLERITE SAMPLES.

Sample No. *	Rb/Sr	Rb^{87}/Sr^{86}	Sr^{87}/Sr^{86}
[1]29304	0·107 ± 0·002	0·31 ± 0·006	0·7305 ± 0·0007
[1]29311	0·439 ± 0·007	1·27 ± 0·02	0·7588 ± 0·0007
[2]29323	0·72 ± 0·01	2·10 ± 0·03	0·7697 ± 0·0007
[2]20787	0·89 ± 0·01	2·59 ± 0·03	0·7767 ± 0·0007
[1]20779	0·94 ± 0·01	2·75 ± 0·04	0·8086 ± 0·0008
[1]20751	1·01 ± 0·01	2·94 ± 0·04	0·8208 ± 0·0007
[1]20762	1·14 ± 0·02	3·33 ± 0·05	0·8186 ± 0·0007
[1]20755	1·68 ± 0·03	4·95 ± 0·09	0·8842 ± 0·0008
[3]20783	1·91 ± 0·02	5·57 ± 0·06	0·8162 ± 0·0007
[2]29325	4·0 ± 0·07	11·9 ± 0·2	1·0075 ± 0·0010
[1]20775	4·06 ± 0·04	12·2 ± 0·12	1·1023 ± 0·0007
[2]20777	4·2 ± 0·07	12·5 ± 0·2	1·0084 ± 0·0009

*Note: Superscript 1 before Sample Number indicates inclusion in older isochron. Superscript 2 indicates inclusion in younger isochron. Superscript 3 indicates sample not used for isochron computation.

DISCUSSION

Bulk composition and vertical compositional variation of the sills

The rocks of the two sills with which this paper deals have the typically dark green granular macroscopic appearance of dolerites. In thin section they appear to have crystallised originally as clinopyroxene-feldspar-opaque rocks with the usual texture of dolerites; and finally, the apparent replacement relationship of the K-feldspar and the abundance of secondary Ca-rich minerals associated with the existing albite, jointly suggest that the original feldspar was largely the calcic plagioclase to be expected in normal dolerites.

TABLE 21. SELECTED AVERAGE ANALYSES REFERRED TO IN DISCUSSION.

	1	2	3	4	5	6	7
SiO_2	52·5	50·6	51·2	47·0	54·7	50·0	50·8
Al_2O_3	14·1	15·3	15·1	15·8	14·2	14·7	12·8
Fe_2O_3	4·3	2·4	2·3	3·3	4·7	4·7	3·1
FeO	8·5	8·9	8·9	7·9	9·2	8·5	9·9
MgO	4·4	6·4	6·4	7·1	3·7	4·6	4·7
CaO	5·6	10·1	10·1	10·1	0·1	6·6	5·7
Na_2O	2·9	2·4	2·2	3·2	0·1	3·1	0·9
K_2O	2·7	0·9	0·9	1·4	10·0	1·4	6·3
H_2O^+	3·7	1·0	0·9	1·0	2·6	4·0	3·5
TiO_2	1·0	1·5	1·5	2·5	0·5	0·1	0·7
P_2O_5	0·1	0·26	0·20	0·50	0·1	1·1	0·2
MnO	0·2	0·18	0·19	0·16	0·1	0·1	0·2
Total Fe	9·6	8·6	8·5	8·4	10·4	9·9	9·9

1. Average of 20 analyses reported in Table 19 of this paper (recalculated to 100 per cent on dry basis).
2. Average of 417 dolerites (Manson, 1967).
3. Average of 331 tholeiitic dolerites (Manson, 1967).
4. Average of 84 alkalic dolerites (Manson, 1967).
5. Potassic shales of Brockman Iron Formation (average of columns 1 and 3 of Table 15 in Trendall and Blockley 1970).
6. Average of 6 innermost samples of lower sill (columns 11–16 of Table 19).
7. Average of 2 outermost samples of lower sill (columns 7 and 20 of Table 19).

Despite these features, columns 1-4 of Table 21 leave no doubt that the average composition of both sills differs markedly from that of average dolerite. Notably it has excess K_2O and deficient CaO, but shows significant enrichments in SiO_2, Fe_2O_3 and Na_2O and a deficiency in MgO. We accept the circumstantial evidence already given

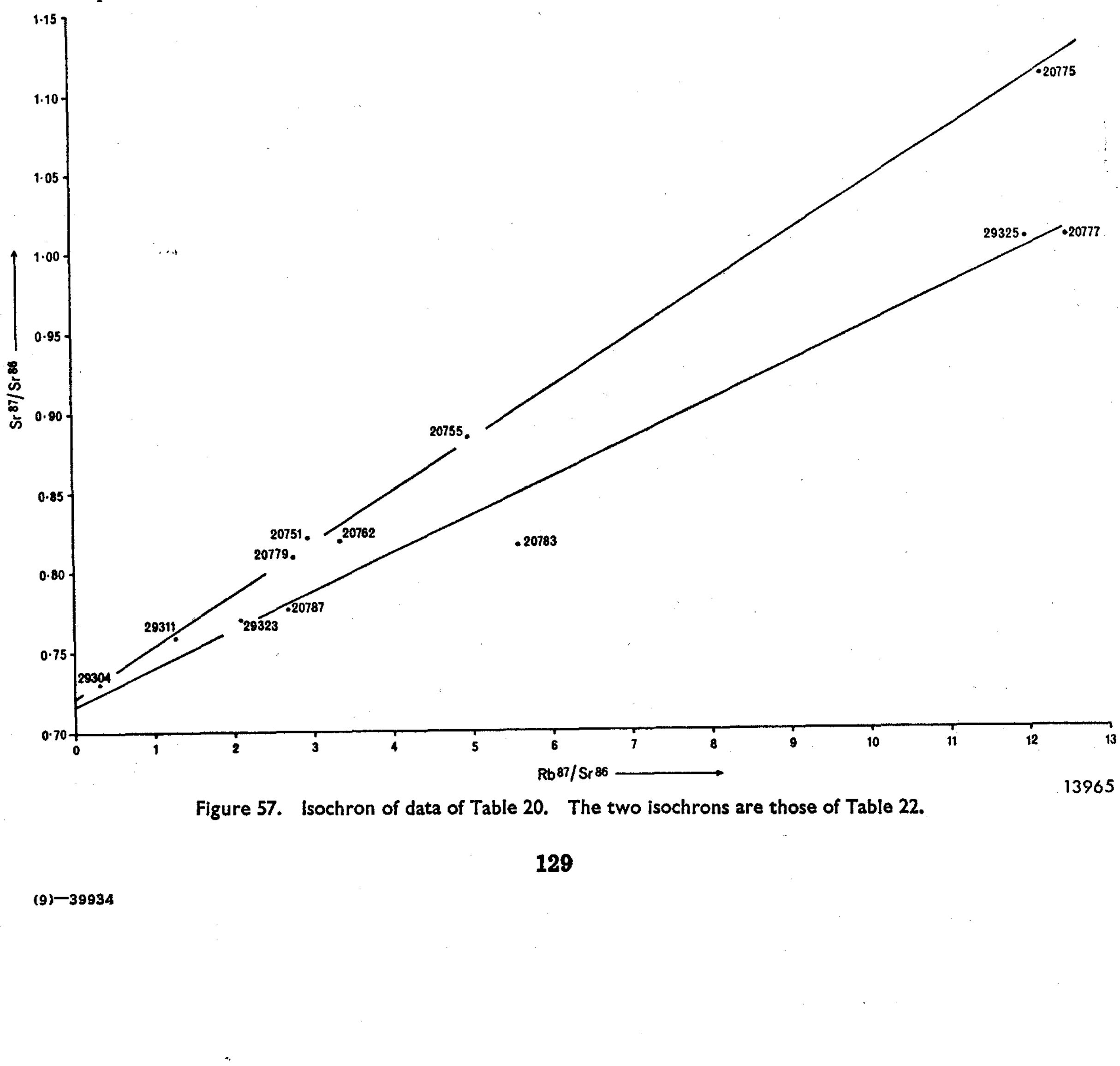

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Figure 57. Isochron of data of Table 20. The two isochrons are those of Table 22.

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that the magma was essentially doleritic, and attribute at least part of these chemical disparities to contamination.

The Weeli Wolli Formation parted preferentially along shale horizons to receive these sills. Although none of these shales have yet been analysed some shales of the immediately underlying Brockman Iron Formation are known to have an unusually high K_2O content. Reference to Table 21 indicates firstly that, provided the oxidation state of the iron is disregarded, all major components except Al_2O_3 of the marginal dolerite of the lower sill (column 7) are intermediate between such shale (column 5) and average alkalic dolerite (column 4); and secondly that, in respect to both alkali content and proportions, the inner, and presumably less contaminated part of the same sill (column 6) has a very different composition, close to that of average alkalic dolerite. This inner material remains deficient in both CaO and MgO compared with alkalic dolerite, and we suggest, but cannot quantitatively demonstrate, that the carbonate axinite in veins which transect the core may account for the bulk of this deficiency. The occurrence of axinite appears to support the possibility of assimilation of shale; some shales of the Brockman Iron Formation have abundant tourmaline as a source of boron (Trendall and Blockley, 1970, p. 115). The inner dolerite of the sill is also somewhat richer in total Fe and SiO_2, and this may well be due to a smaller proportion of digested BIF.

Marginal contamination by BIF may also be the explanation for the high Fe and SiO_2 contents of sample 20771, the lowest sample from the upper sill. If this is accepted then the only asymmetry suggestive of consistent vertical compositional zoning in either sill is otherwise explained. Figure 56 clearly indicates the general lack of compositional layering in both sills, and this is consistent with the homogeneity of both mineral composition and texture.

We conclude that both sills probably result from the intrusion of rather alkali-rich basic magma which was at least marginally contaminated by the adjacent sediments, and which crystallized sufficiently quickly for negligible differentiation to take place. One interpretation of the Rb-Sr data, referred to later, suggests that even the internal dolerite of the sills is contaminated, but it does not seem that this can be argued from the major element compositions alone.

Post-emplacement alteration

We have already suggested that pre-emplacement modification of the magma took place by digestion of material from the intruded sedimentary rocks. We have further noted that the principal primary minerals have been altered to a greater or lesser extent after crystallization: the pyroxene mainly to amphibole, and the calcic plagioclase to albite and epidote. If the potassium in K_2O-rich samples is derived by assimilation of shale we must assume that both this initial breakdown of calcic plagioclase and the further replacement of albite by K-feldspar followed the initial crystallization almost instantaneously. It may be that in the replacement of albite by K-feldspar the additional potassium was concentrated in interstitial glass so that it was available during a late stage of the first cooling of the sills.

Although these dolerites are thus assumed to have acquired much of their present mineral composition by early deuteric processes, the ferrostilpnomelane seems likely to have a different status. Stilpnomelane is a common constituent of much of the BIF of the Hamersley Group. Trendall and Blockley (1970, p. 294) summarised the evidence for the thermal history of the group and concluded from evidence then available that no part of the Brockman Iron Formation immediately below the Weeli Wolli Formation had reached a temperature above 160°C. But Becker's (1971) later oxygen isotope work led him to conclude that the lowest member of the Brockman Iron Formation had experienced a temperature between 250° and 300°C. Since ferrostilpnomelane has not been reported as a result of deuteric processes, but is a common product of low-grade regional metamorphism, it seems more likely that this mineral in the dolerites was produced by a later low-grade pervasive metamorphism, as suggested by Ayres (1972) for the Brockman Iron Formation. This is consistent with its textural occurrence.

Interpretation of Rb-Sr data

It is immediately clear that the data of Table 20 and Figure 57 have a sufficiently wide scatter to make the calculation of a single meaningful isochron completely impossible; nor can this be achieved by the arbitrary omission of one or two points.

In the fourteen years since the isochron concept for whole-rock Rb-Sr geochronology was conceived, a wide range of refined statistical techniques has been evolved for the evaluation of the value and error limits of both the slope, and Y intercept of an isochron defined by a set of approximately colinear points (analyses) to which the concept applies. However, in the treatment of an array of widely scattered points from a group of samples collected from a single rock body, a good deal of judgement must be applied if the best working hypothesis to explain the scatter is to be developed. In dealing with such an array, the first step is subjective visual construction of the fewest straight lines that pass as close as possible to as many points as possible; the second step is assessment of the geological credibility of the ages represented by these lines; and the final stage is intuitive integration of these two steps until least internal conflict within the total evidence is achieved. The succeeding discussion presents the product of such a process.

The five points of Figure 57 with Rb^{87}/Sr^{86} greater than 4 are so disposed that a minimum of three lines is needed to include all of them. A line of greatest slope is required by samples 20755 and 20775; and samples 20762, 20751, 20779, 29311 and 29304 fall fairly close to this line. Samples 29325 and 20777 may be assumed to lie reasonably close to a single line of less steep slope passing between them and extending down to include at least 20787 and 29323, and possibly also 29304 and 29311. Sample 20783 cannot be accommodated by either of these lines, and can only lie on a line of least slope which may again include 29304, or 29311, 29323 and 20787, or all of these latter four analyses. The possible significance of each of these lines is examined in reverse order.

Lines of least slope including 20783, and any combination of the four possible points suggested above, would represent ages between approximately 900 and 1200 m.y. It is true that the samples 20783, 20787, 29323, 29311 and 29304 are a sequential set of five samples through the greater part of the thickness of the lower sill (Fig. 53); however, these five points are by no means precisely colinear, and we appeal to the evident departure of 20783 from the consistent compositional trends expressed by samples above and below (Fig. 56) to support the alternative view that it has genuinely been affected by a late event, possibly related to the development of the Bangemall Basin farther south. We do not suggest that the anomalous composition was acquired at the time of this event, but that it possibly caused a distinctive mineralogy, not evident optically, which was selectively sensitive to thermal up-dating. We thus regard sample 20783 as unique and anomalous and can offer no satisfactory explanation for its isotopic composition.

Of the remaining points of Figure 57, the two which appear to have equal potential for contributing to either of the two steeper lines were arbitrarily allocated to the older isochron, and both were computed using the programme of McIntyre and others (1966). The first (older) set thus included 29304, 29311, 20779, 20751, 20762, 20755 and 20775; the second (younger) set included 29323, 20787, 29325 and 20777. The results appear in Table 22.

TABLE 22. ISOCHRONS COMPUTED FROM SELECTED DATA OF TABLE 20.

Samples	Age	Initial Ratio Sr^{87}/Sr^{86}
Older Group : 20775, 20755, 20762, 20751, 20779, 29311, 29304	2222 ± 116	0·7219 ± 0·0084
Younger group : 29325, 20777, 20787, 29323	1689 ± 222	0·7174 ± 0·0140

For both isochrons the mean square of the weighted deviates was 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 Sr^{87}/Sr^{86} ratio of each set was homogeneous, and that all the samples of that set were subsequently closed to Rb and Sr, therefore do not hold. The programme has then examined each set of data for geological variation and indicated that the distribution of the residuals suggests that the rocks within the older isochron have the same age but different initial Sr^{87}/Sr^{86} ratios. The programme also suggests that the distribution of the residuals for the younger set of data is a combination of experimental and geological variation proportional to and independent of the Rb^{87}/Sr^{86} ratios.

Although we accept the two ages of Table 22 as useful for the purposes of discussion, the arbitrary allocation of the two samples with lowest Rb^{87}/Sr^{86} to the upper isochron means that no genetic significance can be attached to the computed initial Sr^{87}/Sr^{86} values.

Trendall and de Laeter (1972) reported an age of 1 720 ± 25 m.y. from beds of porcelanite, believed to represent tuff, within the Joffre Member of the Brockman Iron Formation, which lies immediately and conformably below the Weeli Wolli Formation. In the discussion of that result they summarised (ibid, Table 4) the Rb-Sr data then available from rock units for whose time relationship to the Joffre Member there was geological evidence. They concluded that acceptance of 1 720 m.y. as the time of an event which terminated free isotope mobility within the Joffre Member, some 300-400 m.y. after its deposition, led to a satisfactory integration of all available geological and geochronological evidence.

We see the younger isochron of Table 22 as supporting evidence for a significant regional event in the Hamersley Basin area at about 1 700 m.y. which strengthens part of Trendall and de Laeter's (1972) conclusions. This event we now envisage to have involved local igneous activity (the Boolaloo Granodiorite), tectonism, de-watering of Hamersley Group sediments, and probably the general low-grade metamorphism of the Hamersley Group already referred to in this discussion. Three of the four points contributing to this isochron are close to the margin of the lower sill, so that the implied up-dating could credibly be related to the likely zone of high stress between the more competent dolerite and less competent shale during folding. However 20787 lies well within the sill, and is separated from the margin by samples (20775, 20779) which preserve an older age. Acceptance of our present explanation of this isochron thus involves acceptance of irregular distribution of up-dating within the sill.

The older of the two isochrons appears to be capable of two explanations, which may most clearly be separated by initially restating the isochron hypothesis in its most commonly applied form: colinearity of a set of points is consistent with the hypothesis that, at a time represented by the slope of the line (isochron) the Sr^{87}/Sr^{86} ratio throughout the rock body from which the analysed samples were collected had the uniform value represented by the ordinate intercept. The existence of a uniform Sr^{87}/Sr^{86} value is normally taken to be possible, in rock bodies with inhomogenous Rb/Sr, only in a small number of special situations in their life. Such situations are usually conceived of as their existence as magma in the case of igneous rocks; equilibration with ambiant water, in the case of sedimentary rocks; and for metamorphic rocks, their metamorphism. In the sills under discussion a standard interpretation of the oldest isochron would suppose it to represent the age of intrusion and crystallization of the dolerite.

This interpretation requires that, at that time, strontium was isotopically equilibrated throughout each sill. However we have supposed, earlier in this discussion, that potassium now present in the marginal dolerite was substantially contributed by assimilated shale, and the interpretation would therefore require that while radiogenic strontium from the shale diffused to equilibrium throughout the sill, potassium remained locally restricted. The alternative concept is to suppose that radiogenic strontium derived from ingested potassic shale had not greater mobility than potassium, and this supposition forms the basis for the second explanation of the older isochron.

If the uncontaminated doleritic magma had, as would be expected, a low (say < 0.5) Rb/Sr ratio, and it intruded slightly older potassic shales of much higher Rb/Sr, then individually isochemical mixtures of dolerite and shale would fall within a very narrow zone approximating a depositional age isochron of the shale. We believe this to be the best interpretation of the status of the older isochron of Figure 57 and Table 22; it represents a depositional age of about 2 200 m.y. for the invaded shale. With the exception only of 20762, all the points which contribute to it with Rb^{87}/Sr^{86} above 1.5 are of samples close to sill margins, whose K_2O contents (Table 19) additionally lead to suspicion of contamination.

It follows that the age of dolerite intrusion must be sought in uncontaminated dolerite. Samples 29304 and 29311 come from the inner part of the lower sill, and have K_2O contents of only 0.7 and 1.7 per cent respectively. A line joining them represents an age of 2 090 m.y. but, perhaps more significantly, these two points are very closely colinear with 20762, whose position in the sill has already been noted as anomalous if it is to be interpreted as a contaminated rock. Although these data are admitted to be inadequate, we conclude that they suggest an age of about 2 100 m.y. as the intrusive age of the dolerite.

More data are nevertheless required before these suggestions can be accepted as other than tentative. A serious problem remaining from them, for example, is that if samples 29304, 29311 and 20762 are accepted as inner uncontaminated samples which define an age of intrusion, then the initial Sr^{87}/Sr^{86} ratio involved, in excess of 0.72, certainly cannot be that of a magma derived directly from the mantle. The petrogenetic problems involved cannot be effectively pursued until more data are available.

Integration of Rb-Sr interpretation with regional geochronology

In their earlier summary Trendall and de Laeter (1972) were able to achieve a satisfactory integration of all available geochronological and geological evidence from the Hamersley Basin. The interpretations discussed above, although tentative, introduce new difficulties which now make this impossible.

The relevant data are displayed in summary in Figure 58. In that Figure the stratigraphic positions of samples used in published Rb-Sr age determinations are shown in the central column, while the equivalent numbers appear, with vertical error bars where appropriate, to the right of the column in relation to a time scale in millions of years. The numbers of the 14 determinations are arranged, as far as possible, in the time sequence suggested by the geological evidence, so that any departure from upward numbered sequence on the time scale represents an anomaly to be explained; in most instances of non-sequence there is a simple explanation, but in some there is not.

Working upwards through the numbered determinations, No. 4 is out of sequence because the 2 940 m.y. age is that of detrital muscovite from the underlying Archaean rocks rather than that

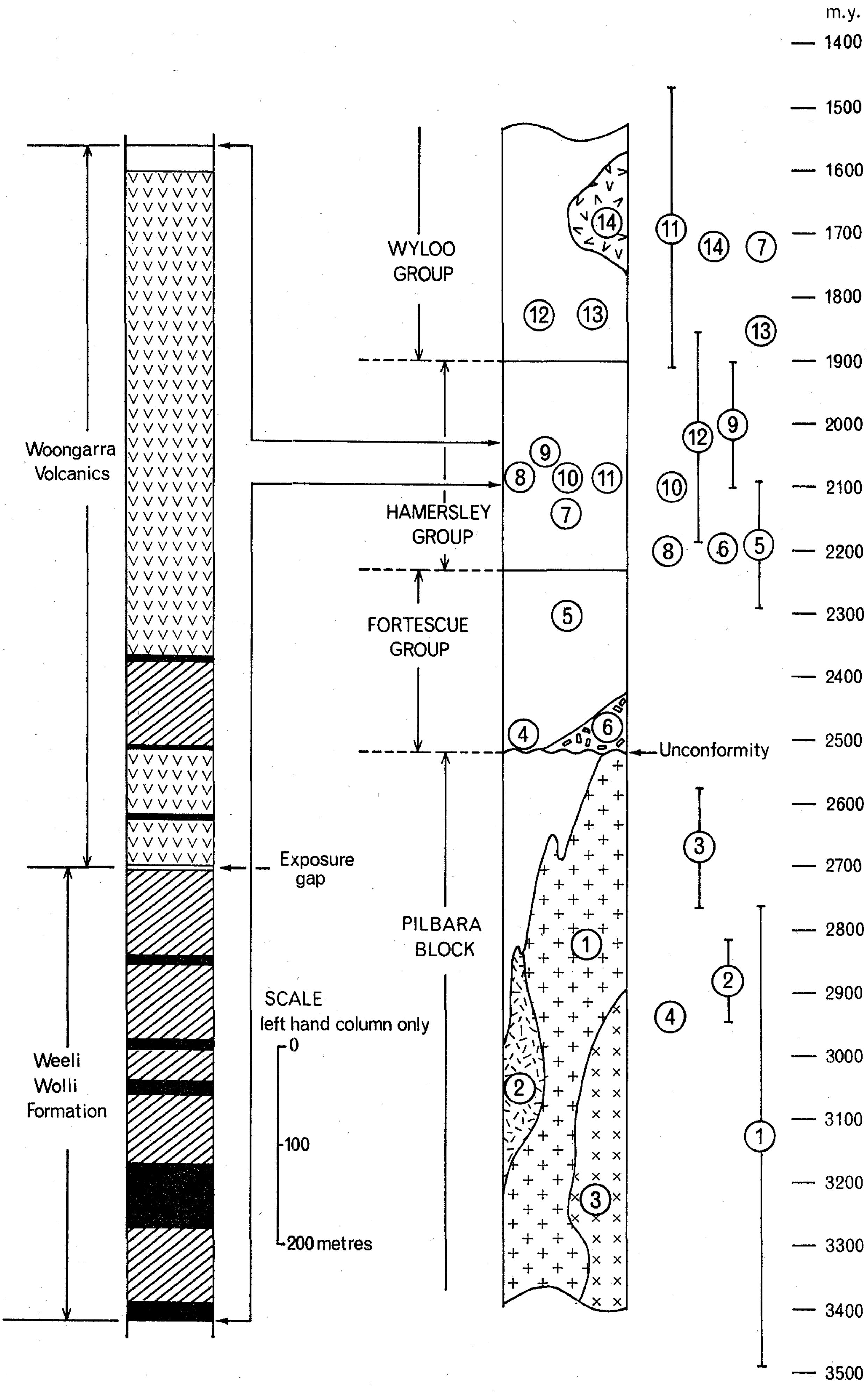
m.y.
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
2600
2700
2800
2900
3000
3100
3200
3300
3400
3500
Woongarra Volcanics
Weeli Wolli Formation
Exposure gap
SCALE left hand column only
0
100
200 metres
WYLOO GROUP
HAMERSLEY GROUP
FORTESCUE GROUP
PILBARA BLOCK
Unconformity
13966

Figure 58.

of deposition of the Cliff Springs Formation. Nos. 5, 6 and 8 appear coeval. There is no difficulty in explaining this, because No. 6 certainly represents an intrusive age, and No. 5 probably, also does. No. 7 appears much later than any of these three, and is believed to represent a late up-dating, as already discussed; No. 11 appears out of sequence because of the same up-dating event. So far all non-sequences can be simply accounted for, and the first real difficulty occurs in the reverse order of Nos. 9 and 10. Before discussing this fully it is necessary to record briefly some results of continuing work by one of us (A.F.T.) on the Hamersley Group which are not yet published.

There are three main points to note:

(1) The dolerite sill which Trendall and Blockley (1970 p. 92) thought to occur within the Woongarra Volcanics is now known to be present consistently over much of the outcrop area; it is believed to be, in effect, a representative, in the overlying formation, of the dolerite sills of the Weeli Wolli Formation.

(2) The occurrence reported by Trendall and Blockley (1970, p. 91) of a xenolith of the overlying Woongarra Volcanics in dolerite of the Weeli Wolli Formation has been closely re-examined, and found to be in error.

(3) Careful study of the upper margin of the Woongarra Volcanics indicates that its acid igneous rocks are, on the balance of evidence, more likely to be intrusive than extrusive.

The third point destroys what has come to be accepted as the most reliable internal evidence for the depositional age of the rocks of the Hamersley Basin (No. 9): instead, this age of $2\,000 \pm 100$ m.y. sets only a minimum age for the sediments into which the acid sills were intruded. Taken together the three points place the acid igneous sills of the Woongarra Volcanics and the dolerite sills of the Weeli Wolli Formation as spatially overlapping sets of intrusions for whose relative age there is no present evidence. Nos. 9 and 10 of Figure 58 are thus no longer anomalous, and the age (No. 8—2 200 m.y.) here interpreted by us as the depositional age of the Weeli Wolli Formation becomes the most reliable, and the only direct determination of depositional age in either the Fortescue Group or the Hamersley Group.

Clearly this situation is unsatisfactory, and further work is planned to place more definite time constraints on Hamersley Basin evolution.

FIGURE 58 (opposite)

Summary of selected geochronological data from the Hamersley Group and unconformably underlying Archaean rocks.

The circled numbers in the central diagrammatic stratigraphic column correspond with those placed against a scale of years to the right. A key to numbers follows in which the information relevant to each number is given in the sequence : age (m.y.) ; points on isochron (WR = whole rock, L = leached or residual fraction, M = separated mineral, n.a. = information not available) ; rock body ; reference. All the listed ages were obtained by the Rb-Sr method.

1. 3 125 ± 366 ; 7 WR ; older granite of Pilbara Block ; de Laeter and Blockley, 1972.
2. 2 880 ± 66 ; 6 WR ; Copper Hills Porphyry ; de Laeter and Trendall, 1970.
3. 2 670 ± 95 ; 6 WR ; younger (tin) granite of Pilbara Block ; de Laeter and Blockley, 1972.
4. 2 940 ; 1 M ; muscovite from basal Cliffs Springs Formation of Fortescue Group ; Compston and Arriens, 1968.
5. 2 190 ± 100 ; n.a. ; interbedded layers of acid igneous rocks in Fortescue Group ; Compston and Arriens, 1968.
6. 2 196 ± 26 ; 6 WR ; granophyre intruded along basal unconformity of Fortescue Group ; de Laeter and Trendall, 1971.
7. 1 720 ± 25 ; 5 WR, 2 L ; porcelanite (tuff) of Joffre Member of Brockman Iron Formation in Hamersley Group ; Trendall and de Laeter, 1972.
8. 2 200 ; 4 WR ; marginally contaminated dolerite of Weeli Wolli Formation to give inherited depositional age of shale ; this paper.
9. 2 000 ± 100 ; 48 WR ; Woongarra Volcanics ; Compston and Arriens, 1968.
10. 2 100 ; 3 WR ; central uncontaminated part of dolerite of Weeli Wolli Formation, thought to give age of intrusion ; this paper.
11. 1 689 ± 222 ; 4 WR ; up-dating of some parts of dolerite of Weeli Wolli Formation ; this paper.
12. 2 020 ± 165 ; n.a. ; layered acid igneous rocks interbedded in the Wyloo Group ; Compston and Arriens, 1968.
13. 1 850 ; 1 WR ; Wyloo Group tuffaceous siltstone ; Leggo and others, 1965.
14. 1 720 ; 2 WR, 2 M ; Boolaloo Granodiorite (intrudes Wyloo Group) ; Leggo and others, 1965.

The different forms of ornamentation in the central column distinguish different bodies of igneous rock which are clearly identified by the numbers. All sedimentary and metasedimentary rocks are left blank. In the left-hand column, which is a scale summary of the lithology of the Weeli Wolli Formation and the Woongarra Volcanics near Woongarra Pool (Trendall and Blockley, 1970) the ornamentation follows that of Figure 53, with the addition of v = fine-grained rhyolite or dacite, formerly believed to be extrusive, but now more likely to be intrusive ; solid black includes tuff as well as BIF and shale. See text for further discussion.

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REFERENCES

Ayers, D. E., 1972, Genesis of Iron-bearing Minerals in Banded Iron Formation Mesobands in the Dales Gorge Members, Hamersley Group, W.A.: Econ. Geol. v. 67 no. 8, p. 1214-1233.

Becker, R. E., 1971, Carbon and oxygen isotope ratios in iron formation and associated rocks from the Hamersley Range of Western Australia and their implications: Unpublished Ph.D. thesis, Univ. of Chicago, 238p.

Compston, W., and Arriens, P. A., 1968, The Precambrian geochronology of Australia: Canadian Jour. of Earth Sciences, v. 5, p. 561-583.

de Laeter, J. R., and Abercrombie, I. D., 1970, Mass spectrometric isotope dilution analyses of rubidium and strontium in standard rocks: Earth and Planetary Science Letters, v. 9, p. 327-330.

de Laeter, J. R., and Blockley, J. G., 1972, Granite ages within the Archaean Pilbara Block, Western Australia: Geol. Soc. of Australia Jour., v. 19, p. 363-370.

de Laeter, J. R., and Trendall, A. F., 1970, The age of the Copper Hills Porphyry: West. Australia Geol. Survey Ann. Rept. 1969, p. 54-59.

——— 1971, The age of the Gidley Granophyre: West. Australia Geol. Survey Ann. Rept. 1970, p. 62-67.

Leggo, P. J., Compston, W., and Trendall, A. F., 1965, Radiometric ages of some Precambrian rocks from the Northwest Division of Western Australia: Geol. Soc. Australia Jour., v. 12, pt. 1, p. 53-65.

Manson, V., 1967, Geochemistry of basaltic rocks: major elements; *in* Basalts: the Poldervaart treatise on rocks of basaltic composition, v. 1, p. 215-269, New York, Interscience Publishers, 495pp.

McIntyre, G. A., Brooks, C., Compston, W., and Turek, A., 1966, The statistical assessment of Rb-Sr isochrons: J. Geophys. Res., v. 71, p. 5459-5468.

Norrish, K., and Chappell, B., 1967, X-ray fluorescence spectrography; *in* Zussmann, J. (Ed.) Physical Methods in Determinative Mineralogy: London, Academic Press.

Trendall, A. F., 1968, Three great basins of Precambrian banded iron formation deposition: a systematic comparison: Geol. Soc. Am. Bull v. 79, p. 1527-1544.

——— 1972, Revolution in Earth History: Geol. Soc. Australia Jour. v. 19, p. 287-311.

——— 1973a, Iron-formations of the Hamersley Group of Western Australia: type examples of varved Precambrian evaporites: Genesis of Precambrian iron and manganese deposits. Proc. Kiev Symp., 1970.

——— 1973b, Varve Cycles in the Weeli Wolli Formation of the Precambrian Hamersley group, Western Australia: Econ. Geol. v. 68, p. 1089-1097.

Trendall, A. F., and Blockley, J. G., 1970, The iron formations of the Precambrian Hamersley Group, Western Australia, with special reference to the associated crocidolite: West. Australia Geol. Survey Bull. 119.

Trendall, A. F., and de Laeter, J. R., 1972, Apparent age, and origin, of black porcelanite of the Joffre Member: West. Australia Geol. Survey Ann. Rept. 1971, p. 112-118.

THE AGE OF A GRANITE NEAR MOUNT CROFTON, PATERSON RANGE SHEET

by A. F. Trendall

ABSTRACT

Eight Rb-Sr isotopic analyses were carried out on whole-rock samples from a small granitic body that intrudes gently folded low-grade metasedimentary rocks, possibly correlative with the Bangemall Group, near Mount Crofton (21° 33′ S; 121° 27′ E). Seven analyses of six samples of coarse biotite granite, and one of a finer vein, define a 614 ± 42 m.y. isochron with R_i = 0.709 3 ± 0.007 3. With the addition of data from the eighth sample, a cross-cutting low-strontium aplite with a much higher Rb-Sr ratio, the resultant isochron becomes 594 ± 2 m.y., with R_i = 0.712 2 ± 0.002 5. This slight apparent difference may be genuine. The age of crystallization of the granite is in any case close to 600 m.y. This age, at about the Precambrian-Cambrian boundary, is consistent with it geological relationships. Unpublished data of Compston from two previous whole-rock analyses of granite unconformably overlain by Lower Ordovician sandstone at a depth of 2 015 m in a petroleum exploration well 240 km north-northwest of Mount Crofton lie on the same isochron; it seems likely that an extensive igneous province of this age developed along the western edge of the Canning Basin immediately before initial deposition. This may have a direct tectonic relationship with igneous and metamorphic activity in the south-western part of the Yilgarn Block.

INTRODUCTION

The most recent published account of the geology of the Paterson Range 1 : 250 000 Sheet area is that of Wells (1959). Although Blockley (1974) notes that much of the granite outcrop shown by Wells is in fact occupied by sedimentary rocks, granite does crop out east and southeast of Mount Crofton (21° 33′ S, 121° 27′ E). Coarse biotite granite is well exposed in several bare rounded hills rising a few tens of metres above the sandy plain over an area of about 40 km². Wells (1959, p. 5 and map) described this granite as cutting Lower Proterozoic rocks, which Blockley (1974) likens to the Bangemall Group.

In November, 1973, Newmont Pty. Ltd. supplied seven large unweathered samples from this granite for isotopic age determination. This paper reports Rb-Sr isotopic results from these samples, provides a brief description of the material, and discusses the geological significance of the results.

MATERIAL USED

Six of the seven samples received (30557-58-59-60-61-62) were collected from a low granite hill centred 1.5 km east of Mount Crofton. The sampling points form an irregular array with an average separation distance of about 30 m, and a maximum distance of 130 m. The location coordinates for the group are 21° 33′ S , 121° 58′ E. The seventh sample (30555-56) was taken from a separate hill, 6.5 km east-southeast of Mount Crofton, at 21° 35′ S , 122° 00′ 30″ E; it bears two numbers because the granite forming the bulk of the sample (30555) was cut by a vein 2 cm wide which was analysed separately (30556).

The granite in the vicinity of the sample locations is remarkably uniform in appearance. On broken surfaces vaguely defined elongate areas of rather patchily coloured pink to red feldspar up to 20 mm long are randomly arranged within an interstitial mixture of similar feldspar, equant grains of dark glassy quartz 2-5 mm across, and random black biotite flakes whose longest dimensions are of the same order. Although the feldspar areas give the rock a coarse appearance it is only rarely that a cleavage face of feldspar wider than 10 mm can be seen, and most feldspar cleavage faces on broken surfaces of the granite are less than 5 mm across. No macroscopically defined planar or linear direction, defined either by variations of mineral content or by mineral orientation, was observed; the rock appears quite massive and homogeneous.

The following generalised description of the petrography of the coarse granite applies to thin sections cut from samples 30555 and 30558-30562 inclusive.

Quartz and feldspar are the main constituents of the rock, and form approximately 30 and 60 per cent by volume respectively, with biotite and other constituents making up the remainder. The main feldspar is an alkali variety with highly irregular extinction, probably a cryptoperthite. The irregularity is expressed in a variety of ways ranging from vague general strain, through various microperthitic textures, to annealed crack networks of cataclastic appearance. Several optically distinct individuals up to 5 mm across make each of the feldspar areas macroscopically apparent, and it appears that these areas are relics of large early ternary feldspar phenocrysts which were extensively modified during cooling. Optically imperfect simple twinning is often present. Most individuals are cloudy with undetermined "dust", and this cloudiness usually has an irregular distribution which follows the irregularities of the extinction pattern. Much clearer subhedral oligoclase grains, up to 2 mm across but mostly much smaller, occur either singly or in aggregates, and may be enclosed within or marginal to the alkali feldspar. The oligoclase is distinguished by its strain-free extinction, lamellar twinning, and often by albite rims which are occasionally myrmekitic.

Quartz forms an irregular continuous mosaic of clear and intensely strained anhedral grains up to 5 mm across. Biotite forms subhedral flakes, scattered in clusters. It is conspicuously pleochroic, from pale straw to very dark brown. Chloritisation is rare, but thin goethitic veinlets in and around the biotite may reflect weathering. Very minor amounts of sphene, green amphibole, apatite, and opaque minerals are usually associated with the biotite.

The 2 cm thick vein of 30556 consists in thin section of separate grains, or clusters of grains, of all the minerals of the adjacent granite, up to 5 mm across, set in an even-grained polyhedral mosaic of quartz, albite, and microcline, in which most grains are between 0.05 and 0.1 mm in diameter. The edges are quite sharply defined, and the marginal textures imply that the vein originated by fracturing and small-scale stoping from the granite constituents.

The aplite sample received, 30557, consisted of a compact pale pinkish brown sugary-textured rock in which more coarsely crystalline bands show feldspar cleavage faces up to about 4 mm across. In thin section the finer parts closely resemble the matrix part of the vein 30556. An even-grained polyhedral mosaic of average grain diameter of about 0.1 mm is composed of quartz, albite, and an alkali feldspar which resembles a cryptoperthite rather than microcline. Fluorite is also present. In one part of the thin section these same constituents form a coarser aggregate resembling the granite, except that a bladed texture and an abundance of vermiform quartz in both feldspars combine to give a pegmatoid appearance. This is consistent with the field occurrence of the aplite. Subsequent observation showed that the sample was collected from a vein about 60 cm thick striking approximately north and dipping westward at about 15 degrees. While the lower part of the vein is of aplitic appearance the uppermost 5-10 cm consists of a coarse pegmatoid edge in which each crystal is several centimetres across. The vein thus resembles closely the layered aplite dykes from the Yilgarn Block described by Doepel (1970).

EXPERIMENTAL PROCEDURES

All instruments and methods used are the same as those described by de Laeter and others (1974), except as noted below.

The Sr^{87}/Sr^{86} values of Table 23 were normalised to a Sr^{88}/Sr^{86} value of 8.365 to give a mean value of 0.710 3 for replicate analyses of NBS 987 standard. The resultant age difference of about 0.13 per cent is not large enough to affect comparison with other ages reported from the Western Australian Institute of Technology laboratory where the more usual 8.375 2 normalising value has now been adopted. Most Sr^{87}/Sr^{86} values of Table 23 result from three runs each made up of ten sweeps; errors quoted for these values relate to reproducibility between runs, and do not derive from within-run variation.

For accurate X.R.F.S. determination of the Rb/Sr ratio a pre-set count of 2×10^5 was used for each peak and two associated background values, and for all samples except 30557 the peak-to-background ratio was such that better than ± 1 per cent precision was obtained. For 30557 the low Sr peak necessitated a total of five passes in each of which the Sr values (peak and two backgrounds) were measured twice.

RESULTS

The measured Rb/Sr (X.R.F.S.) and Sr^{87}/Sr^{86} ratios appear in Table 23, together with the calculated Rb^{87}/Sr^{86} values. All errors are at the 95 per cent confidence level. The data are also plotted in Figure 59 together with a theoretical 600 m.y. isochron with an R_i of 0.70, as an aid to visual assessment.

TABLE 24. COMPUTED ISOCHRONS FROM DIFFERENT COMBINATIONS OF ANALYTICAL RESULTS

Combination	Age (m.y.)	R_i (Sr^{87}/Sr^{86})	Model*
1	614 ± 47	0·7093 ± 0·0073	3
2	611 ± 24	0·7105 ± 0·0037	4
3	594 ± 2	0·7122 ± 0·0025	3
4	594 ± 1	0·7131 ± 0·0016	3

* Except for Combination 4, this column shows the preferred Model of the programme of McIntyre and others (1966). In summary, a programme choice of Model 3 means that a smaller increase to the assigned experimental errors is involved by an assumption that departure from a perfect fit is due to variations of R_i between coeval samples than by an assumption that it is due to variations in age between samples of the same R_i (Model 2). Model 4 is a compromise between Models 2 and 3. For Combination 4 the programme found no preference between a Model 2 and a Model 3 isochron, and the Model 3 result is here inserted for ease of comparison with Combination 3.

Combination 3 includes all the analyses; that is, it represents Combination 1 with the addition of the aplite 30557. Combination 4 includes all the analyses except the visually anomalous 30561; it represents Combination 2 plus the aplite 30557.

INTERPRETATION OF RESULTS

Age of the granite

From Table 23 it is clear that the 2 cm thick cross-cutting vein 30556 does not differ significantly in its Rb and Sr data from its enclosing granite 30555, whereas the thicker cross-cutting aplite 30557 differs substantially. The geological and chronological relationship between granite and aplite are critical to the interpretation of the results. If, for reasons of geological judgement, it is postulated that the emplacement of both the parent granite body and the aplite (30557) took place over a geologically very short interval (less than a million years) then the figure of 594 m.y. of Table 24 may be accepted as a point more closely fixed within the wider age ranges of Combinations 1 and 2, and thus as a highly accurate date for this essentially single event. But the data presented do not invalidate the alternative hypothesis that the main granite was emplaced at about 612 m.y., about the mean of Combinations 1 and 2, and that the aplite was intruded substantially later. In this latter case the pooling of 30557 with the granite analyses would not be valid

TABLE 23. ANALYTICAL DATA FOR EIGHT WHOLE-ROCK SAMPLES FROM THE GRANITE NEAR MOUNT CROFTON

Sample No.	Rb (ppm)	Sr (ppm)	Rb/Sr	Rb^{87}/Sr^{86}	Sr^{87}/Sr^{86}
30560	247	108	2·27 ± 0·02	6·59 ± 0·07	0·766 6 ± 0·001 3
30559	239	99	2·34 ± 0·02	6·80 ± 0·07	0·767 4 ± 0·002 7
30558	295	95	3·10 ± 0·03	9·02 ± 0·09	0·789 1 ± 0·000 4
30562	279	86	3·15 ± 0·03	9·17 ± 0·09	0·788 9 ± 0·000 2
30561	276	80	3·35 ± 0·03	9·74 ± 0·1	0·788 1 ± 0·001 7
30555	276	50	5·39 ± 0·05	15·8 ± 0·2	0·844 3 ± 0·000 6
30556	276	50	5·63 ± 0·06	16·5 ± 0·2	0·851 8 ± 0·001 1
30557	414	9	63·4 ± 1·8	215 ± 6	2·495 ± 0·003

Note: The Rb and Sr concentrations are preliminary results from loose powder samples, and have an accuracy of about ± 5 per cent. The Rb/Sr ratios are from accurate measurements of these ratios on compressed pellets; they do not correspond exactly with the ratios that would be derived from the separate Rb and Sr values shown.

The ages and intial ratios computed using the programme of McIntyre and others (1966) for various combinations of data appear in Table 24. Combination 1 of that Table includes all the analyses except 30557: that is, it includes all the massive granite samples and the thin vein 30556, but excludes the cross-cutting aplite 30557. Combination 2 is similar, but excludes also 30561 purely on the grounds that, from the plot of Figure 59 and from the computed results of Combination 1, it appears to depart farther than the remaining samples from a more closely colinear set of points; such anomalous departures below Rb-Sr isochrons are commonly and credibly attributed to weathering effects, but in this instance the granite of 30561 shows neither more nor less evidence of these than other samples. The result for Combination 2 confirms this impression, but does not greatly affect the preferred age.

for the computation of an isochron and the 594 m.y. so derived would be meaningless, since it would become necessary to assume an R_i to derive an age from the single analysis of 30557. If the aplitic liquid differentiated from the crystallizing granite magma at 612 m.y. with its present ratio of Rb to common Sr, and with its Sr^{87}/Sr^{86} equal to that of the granite (as would be expected), then the analytical data provide no criterion for the selection of an R_i related to the age of aplite intrusion. Provided that the aplitic liquid remained chemically closed and undifferentiated after its formation, the isochron hypothesis does not distinguish between its intrusion and crystallization at any time between 612 m.y. and the present; in fact, under the postulated conditions, the aplite analysis should reinforce the 612 m.y. isochron, whatever its time of emplacement. It follows that any interpretation involving a real younger age for the aplite must suppose that the aplite acquired

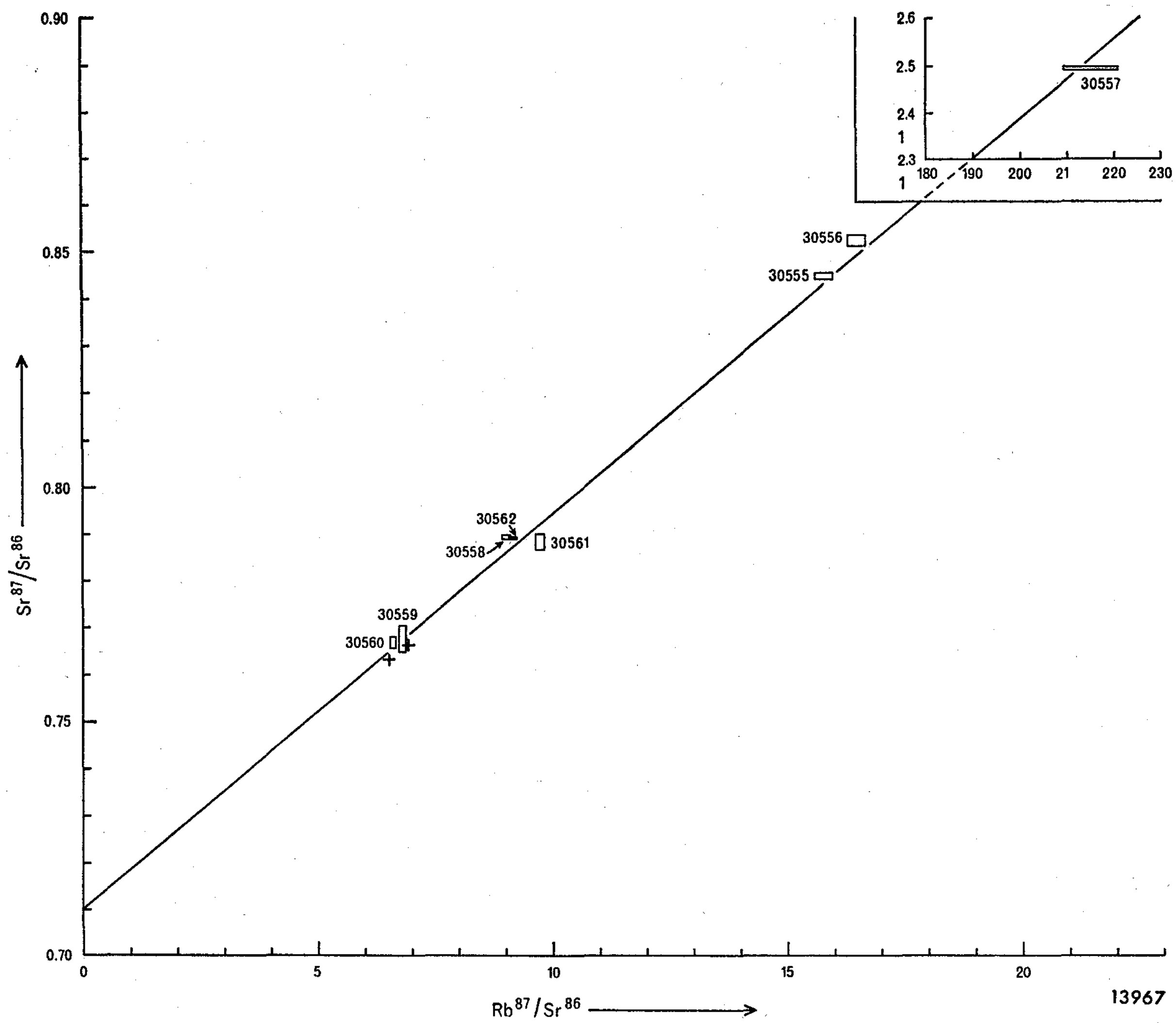

Figure 59. Isochron diagram including eight samples from the granite near Mount Crofton (rectangles with sides proportional to analytical error) and two granite samples from Samphire Marsh No.1 (crosses: analyses by Compston). See Tables 24 and 25 for data. The line plotted is a reference isochron representing an age of 600 m.y. with an initial Sr^{87}/Sr^{86} ratio of 0·71.

its chemical identity, and in particular its high Rb/Sr ratio, significantly later than the emplacement of the analysed granite which it cuts. It is difficult in this case to suggest any mechanism not involving differentiation from granite close to the same, later, crystallization age. It is possible that such a granite existed (and exists) at some lower level from which the aplite ascended transgressively, and that the granite sampled at the level of the present land surface represents an earlier product of a "front" of crystallization which descended through the (unknown) vertical extent of the magma over a short period. For an estimate of the duration of this period let:

- A^A = age of aplite differentiation, intrusion, and crystallization
- R_i^A = initial Sr^{87}/Sr^{86} ratio of the aplite
- t = interval between the crystallization of the upper (analysed) part of the granite, and that of the lower part from which the aplite differentiated
- $\frac{Rb^{87}}{Sr^{86}}$ = the mean Rb^{87}/Sr^{86} ratio of the entire granite body
- λ = decay constant of Rb^{87}

and accept the following data and approximations from Tables 23 and 24:

Age of crystallization of analysed part of granite = 612 m.y.

Initial Sr^{87}/Sr^{86} (at 612 m.y.) of granite = 0.71

Present Sr^{87}/Sr^{86} ratio of aplite (30557) = 2.495

Present Rb^{87}/Sr^{86} of aplite = 215

$$\text{Then } R_i^A = 0.71 + \frac{Rb^{87}}{Sr^{86}} \lambda t \quad \text{.... .... (1)}$$

and also $t = 612 - A^A$

$$= 612 - \frac{\mathrm{Ln}\left\{\frac{2.495 - R_i^A}{215} + 1\right\}}{\lambda} \quad (2)$$

If, for present purposes, Rb^{87}/Sr^{86} be taken as the mean of all samples of Table 23 except 30557 (10.5), and also as time-invariant, then solution of equations 1 and 2 gives values for t of 18 m.y. and $R_i^A = 0.7126$, so that $A^A = 594$ m.y. It is thus not surprising, in this model, that the aplite sample regresses convincingly with the granite samples, in spite of the invalidity of the process, since its real but different age lies within the uncertainty limits of the granite isochron.

In summary, the data presented in Tables 23 and 24 are consistent with either of two separate geological models. In the first of these the granite and the aplite are both 594 m.y. old; in the second the granite is about 612 m.y. old and the aplite about 594 m.y. old. Additional data from separated minerals may discriminate between these two models; meanwhile the likely age of the granite from whole-rock analyses is best expressed as "about 600 m.y".

Origin of the granite

The age and initial Sr^{87}/Sr^{86} of the granite, accepted for the purpose of further discussion as 600 m.y. and 0.71 respectively, together indicate, firstly, that the granite was not emplaced as a direct isochemical mantle differentiate, and secondly, that if the whole of the granite is material with a prior crustal history then that history was quite short. If 10.5 is again accepted as a mean Rb^{87}/Sr^{86} value for the whole granite, then an interval of the order of only 30-60 m.y. is derived for wide assumed limits of 0.702-0.706 for possible mantle Sr^{87}/Sr^{86} at about that time (Faure and Powell, 1972, p. 132).

An isochemical anatectic derivation from an underlying eastward extension of the Archaean Pilbara Block cannot be invoked for this granite; neither can such a derivation be convincingly contrived by reasonable models involving open chemistry. An anatectic origin from lower levels of the adjacent metasediments is also excluded if:

(1) melting is envisaged as isochemical as far as Rb and Sr are concerned, and

(2) the sediments are taken to have the same age of the Bangemall Group, and this is accepted as 1 000 m.y. (Compston and Arriens, 1968; but see also Jackson, 1973), and

(3) the sediments were in isotopic equilibrium with sea water at that time, and this is accepted to have had an Sr^{87}/Sr^{86} ratio of 0.708 3 (Faure and Powell, 1972, p. 134).

Although all these assumptions are reasonable, some may be invalid.

The simplest and most credible genetic model which accommodates the reported data is that the granite magma differentiated from a mantle source with Sr^{87}/Sr^{86} of about 0.704, no more than about 20 m.y. before its emplacement. In addition, the elevation of its initial Sr^{87}/Sr^{86} prior to crystallization was achieved jointly by internal radiogenic increase of Sr^{87} and partly by assimilation of older crustal material of high Sr^{87}/Sr^{86} ratio during the course of its ascent.

REGIONAL GEOLOGICAL SIGNIFICANCE

The granite age reported here indicates igneous activity at the western margin of the Phanerozoic Canning Basin a comparatively short time before its initiation during the Ordovician. In the Paterson Range area no sedimentary rocks older than Permian overlie granite unconformably. However, granite encountered at a depth of 2 015 m in a stratigraphic petroleum exploration well, Samphire Marsh No. 1 (19° 31′ 08″ S, 121° 10′ 51″ E), 240 km north-northwest of Mount Crofton is overlain unconformably by Lower Ordovician sandstone (Johnstone, 1961). Two whole-rock Rb-Sr analyses of this granite were carried out by Compston, and the results were reported, in a personal communication to Johnstone (1961) to indicate "an age not older than 700 million years and not younger than 500 million years".

Although Compston's result was published by Johnstone (1961, footnote p. 8), it was not included in a subsequent compilation of geochronological data by White (1962), a review of Precambrian rocks encountered in deep Phanerozoic basin drilling by Peers and Trendall (1968), or a review of Australian Precambrian geochronology by Compston and Arriens (1968); Peers and Trendall (1968) even suggested the desirability of such work being done. It seems possible that the results created little interest partly because they did not relate clearly to other geochronological data available; and partly because a K-Ar age of 580 m.y. from the same granite, reported in the same footnote by Johnstone (1961), was mentioned both by White (1962) and by Peers and Trendall (1968) and was accepted as the reflection of Ordovician weathering. It seems to have become tacitly accepted that Compston's Rb-Sr results were also probably related to weathering, rather than that they represented a true age for the granite.

TABLE 25. ANALYTICAL DATA FROM CORE 12, SAMPHIRE MARSH No. 1*

Sample	Rb (ppm)	common Sr (ppm)	Rb^{87}/Sr^{86}	Sr^{87}/Sr^{86}
A	197	87·6	6·51	0·763
B	202	84·7	6·91	0·766

* Data of W. Compston, A.N.U. No. G.A. 198.

The analytical results obtained by Compston appear in Table 25, and are plotted in Figure 59, from which it is apparent that their regression with the Mount Crofton samples would have little effect on the computed age. The data of Figure 59 could be explained as the result of weathering only if radiogenic strontium had been completely extracted from these rocks 600 m.y. ago; the samples appear completely fresh, and so far as is known weathering is an ineffective mechanism for the up-dating of granite (Worden and Compston, 1973). A re-examination of the granite from Samphire Marsh No. 1 shows it to be closely similar to that at Mount Crofton in both macroscopic and microscopic appearance, although a highly altered amphibole is more abundant than biotite in the thin section used by Peers and Trendall (1968). It is concluded that co-genetic granite magma may have been generated during a late Precambrian or early Cambrian period of igneous activity over a wide area along the western side of the Canning Basin.

There is insufficient evidence to assess the likely thickness of overlying cover when these granites were intruded, but it seems unlikely that this could have been less than a kilometre. Vertical uplift and erosion of at least this magnitude is therefore indicated during the 120 m.y. between intrusion and the Early Ordovician. Possibly the eroded material was transported to the (present) south-east, where continuous deposition through uppermost Precambrian into the Cambrian took place in the subsiding Amadeus Basin (Wells and others, 1970).

It is not possible to allocate an exact stratigraphic age to the granite at Mount Crofton at present. Firstly, because separate mineral analyses are needed to reduce the limits of uncertainty; secondly, because there is no international agreement on a biostratigraphic definition of the base of the Cambrian (Daily, 1972); and thirdly, because isotopic dating of any lowest Cambrian strata leaves substantial doubt concerning the possible error in the approximate 600 m.y. age currently accepted for the base (Lambert, 1971).

The igneous activity reported here at about 600 m.y. at the northeast extremity of the Western Australia Precambrian Shield, may well correspond in regional tectonic terms with the long-known up-dating and metamorphism in the southwestern part. Extensive areas of Archaean rocks along the western margin of the Yilgarn Block had their radiogenic strontium redistributed between their constituent minerals at about this time, and granulites of the Leeuwin Block register a 670 m.y. metamorphism (Compston and Arriens, 1968). A metamorphic event at about 600 m.y. has also been detected by P. J. Leggo in central Australia (Harding, 1966). It may be that igneous and metamorphic events of about this age are more widely distributed along the borders of the Phanerozoic basins than has so far been appreciated, and that they may provide a clue to the geological events which preceded the initiation of the basins. This is an area of ignorance to which Peers and Trendall (1968) drew attention.

ACKNOWLEDGEMENTS

The results reported here were obtained during the tenure of an Honorary Visiting Fellowship in the Physics Department, Western Australian Institute of Technology. I wish to thank Dr. J. R. de Laeter, former Head of that Department and now Dean of Applied Science, for his patient instruction in the instrumental techniques employed, and also to the following members of the Department for additional guidance and advice whenever it was needed: Mr. I. D. Abercrombie, Mr. M. T. McCulloch and Dr. K. J. R. Rosman in mass spectrometry, and Mr. W. W. Thomas in X.R.F.S. procedures. Dr. de Laeter also made suggestions for improvement of the manuscript. To staff of Newmont Pty. Ltd. thanks are due for providing the material, and for arranging an inspection of the sample localities at short notice. Finally, I should like to thank Dr. W. Compston, Research School of Earth Sciences, Australian National University, both for drawing my attention to his previous analyses of the Samphire Marsh No. 1 samples and for permitting publication of his data.

REFERENCES

Blockley, J. G., 1974, Notes on the Paterson Range gold prospects: West. Australia Geol. Survey Ann. Rept. 1973, p. 71-73.

Compston, W., and Arriens, P. A., 1968, The Precambrian geochronology of Australia: Canadian Jour. of Earth Sciences, v. 5 p. 561-583.

Daily, B., 1972, The base of the Cambrian and the first Cambrian faunas *in* Stratigraphic Problems of the Later Precambrian and Early Cambrian: University of Adelaide, Centre for Precambrian Research, Spec. Pub. No. 1, p. 13-37.

de Laeter, J. R., Peers, R., and Trendall, A. F., 1974, Petrography, chemical composition and geochronology of two dolerite sills from the Precambrian Weeli Wolli Formation, Hamersley Group: West Australia Geol. Survey Ann. Rept. 1973, p. 82-91.

Doepel, J. J. G., 1970, Layered aplite dykes near Merredin and Meckering, Western Australia: West Australia Geol. Survey Ann. Rept. 1969, p. 23-25.

Faure, G., and Powell, J. L., 1972, Strontium Isotope Geology: Berlin, Springer-Verlag.

Harding, R. R., 1966, Catalogue of age determinations carried out by the K-Ar, Rb-Sr, Re-Os, and Pb-α methods on Australian rocks between June 1962 and December 1965: Australia Bur. Mineral Resources Rec. 1966/22 (unpublished).

Jackson, M. J., 1973, Officer Basin Project *in* Australia Bur. Mineral Resources Geological Branch Summary of Activities 1973.

Johnstone, M. H., 1961, Samphire Marsh No. 1 well Western Australia: Australia Bur. Mineral Resources Petroleum Search Subsidy Acts Pub. 5.

Lambert, R. St. J., 1971, The pre-Pleistocene Phanerozoic time-scale, a review *in* Part 1 of the Phanerozoic time-scale, a supplement: Special Publication of the Geological Society, No. 5, London, p. 9-31.

McIntyre, G. A., Brooks, C., Compston, W. and Turek, A., 1966, The statistical assessment of Rb-Sr isochrons; J. Geophys. Res. v. 71, p. 5459-5468.

Peers, R., and Trendall, A. F., 1968, Precambrian rocks encountered during drilling in the main Phanerozoic sedimentary basins of Western Australia: West. Australia Geol. Survey Ann. Rept. 1967, p. 69-77.

Wells, A. T., 1959, Explanatory Notes on the Paterson Range 1: 250 000 Sheet: Australia Bur. Mineral Resources.

Wells, A. T., Forman, D. J., Ranford, L. C., and Cook, P. J., 1970, Geology of the Amadeus Basin, central Australia: Australia Bur. Mineral Resources, Bull. 100.

White, D. A., 1962, Review of the age determination programme of the Bureau of Mineral Resources, Australia, 1956-1962: Australia Bur. Mineral Resources Rec. 1962/129 (unpublished).

Worden, J. M., and Compston, W., 1973, A Rb-Sr isotopic study of weathering in the Mertonvale Granite, Western Australia: Geochim. Cosmoch. Acta, v. 37 p. 2567-2576.

DEVONIAN SPORES FROM THE GOGO FORMATION, CANNING BASIN

by K. Grey

ABSTRACT

Cuttings from Noonkanbah No. 1 borehole, drilled in the Gogo Formation of the Canning Basin, yielded spores of a late Middle to early Late Devonian age. Identifications to generic level are listed, and a comparison made with Devonian assemblages known from other areas in Australia.

INTRODUCTION.

The Gogo Formation was described by Playford and Lowry (1966) as an inter-reef deposit which inter-tongues with the fore-reef facies repesented by the Sadler Limestone. It comprises a sequence of shale and siltstone with thin beds of limestone and abundant calcareous nodules. Exposures of the Gogo Formation are poor, but it is present in the Bugle Gap, Emanuel Range and Pillara Range areas. Drilling by the B.M.R. West Canning Basin Field Party in 1972 penetrated sediments of this formation in Nookanbah No. 1 borehole. Cuttings from this borehole have yielded a diverse microflora containing several new species. This is the first published record of spores from the Gogo Formation.

LOCATION AND BOREHOLE DATA

The B.M.R. Noonkanbah No. 1 borehole was sited near Sadler Ridge and Longs Well Creek; Noonkanbah 1 : 250 000 sheet, SE/51-12; 18° 34′ 13″ S, 125° 58′ 16″ E (Fig. 60). The hole reached a total depth of 155.4 m, and five cores were cut at approximately 30 m intervals. Cuttings and one quarter of all cores are stored at the Geological Survey of Western Australia. The hole was drilled entirely within the Gogo Formation and penetrated calcareous mudstone and interlaminated limestone of the inter-reef sediments. Further details are given by Druce and Radke (1973).

PREVIOUS PALAEONTOLOGICAL STUDIES

A diverse fauna has been described from the Gogo Formation. This includes ammonoids (Glenister, 1958), conodonts (Glenister and Klapper, 1966; Seddon, 1970), brachiopods (Veevers, 1959), and radiolaria, siliceous sponge spicules and ostracods (Glenister and Crespin, 1959). Crustacean and fish remains are also common (Playford and Lowry, 1966; Brunton and others, 1969; Rolfe, 1966). Of these, ammonoids, conodonts and crustaceans have proved most useful for age determination, and they indicate an early Late Devonian age (Frasnian do 1 α to do 1 β). Roberts and others (1972) stated that there was no palaeontological evidence to support an extension of the Gogo Formation into the Givetian, although both Playford and Lowry (1966), and Glenister and Klapper (1966), had considered this a possibility on stratigraphic grounds.

PALYNOLOGY

Cuttings from depths of 33 m, 96 m, 130 m and 147 m were examined for palynomorphs. Specimens from 33 m and 96 m showed a poor degree of preservation. Spores from 130 m were slightly less corroded and those from 147 m were fairly well preserved. All four samples contained similar palynormorphs; the absence of certain forms in the shallower samples is probably a result of weathering. Investigation of the microflora has so far been of a preliminary nature, and no attempt is made in this report to deal with the

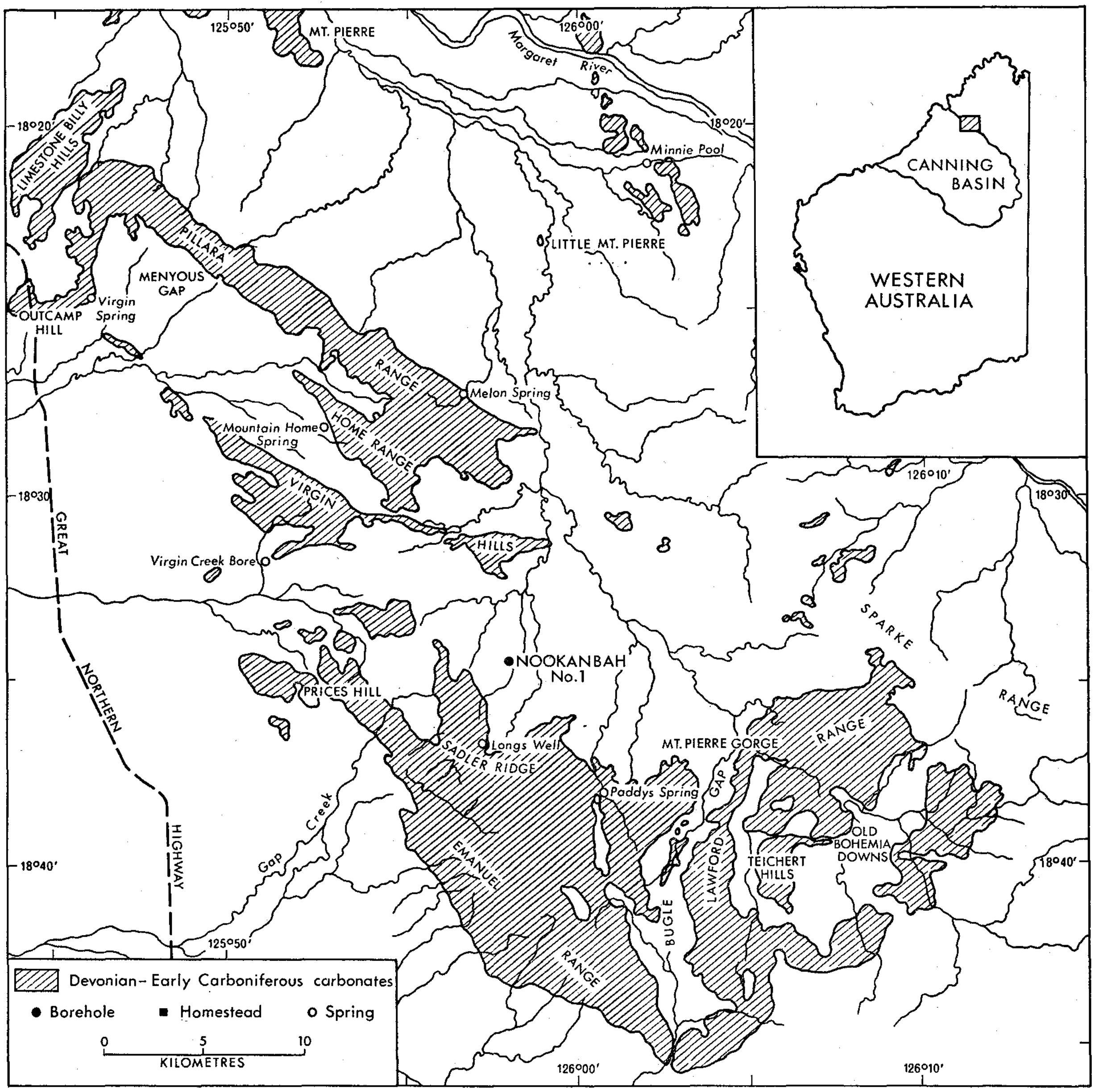

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Figure 60. Emanuel Range area, showing location of Noonkanbah No. I borehole.

detailed systematics of the assemblage. The list of genera given below (Table 26) is incomplete, as some specimens still have to be identified. Some of the more important forms are shown in Figure 61.

TABLE 26. DISTRIBUTION OF SPORE GENERA NOONKANBAH No. 1 BOREHOLE

Genera	Depth in metres 147 m *F8481	130 m *F8480	96 m *F8479	33 m *F8478
Acinosporites sp.	x			x
Ancyrospora sp. A	x	x		x
Ancyrospora spp.	x			x
Apiculatasporites sp.	x			x
Apiculiretusispora sp.	x			
?*Archaeoperrisaccus* sp.	x			
Auroraspora sp.	x	x		x
Calamospora spp.	x	x	x	x
Convolutispora sp.	x	x	x	x
Cyclogranisporites sp.	x			x
Cymbosporites sp.	x	x	x	x
Dibolisporites sp.	x	x		x
?*Grandispora* sp.	x			x
Geminospora sp.	x			
Hymenozonotriletes sp.	x			
Hystricosporites sp.	x	x		
Latosporites sp.	x			
Leiotriletes spp.	x			
Lophozonotriletes sp.	x		x	x
?*Perotriletes* sp.	x			x
Punctatisporites sp.	x			
Reticulatisporites sp.	x			
Retusotriletes spp.	x			
Rhabdosporites sp.	x	x		x
Samarisporites spp.	x	x	x	x
Stenozonotriletes sp.	x	x		
Verrucosisporites sp.	x	x		x

* G.S.W.A. registered fossil number. x = present.

The assemblage is characterized by the presence of large camerate spores, and by forms with either grapnel-tipped spines or biform ornament. Spores with radial ribbing, usually common in Devonian assemblages, were not observed. *Cymbosporites* sp. is abundant in all four samples and shows a wide variation in ornament. *Ancyrospora* and *Samarisporites* are common throughout the assemblage, but are more abundant in the two lower samples. Specimens of *Verrucosisporites* and *Convolutispora* are present in fairly large numbers in the sample from 147 m, but are less frequent in the other samples. *Dibolisporites*, a significant form in three of the samples, was not observed in the sample from 96 m, although it may be present as a corroded form.

AGE OF THE ASSEMBLAGE

Only generalized assertions can be made about the age of the assemblage at this time. Examination of core material, and a detailed study of the systematics will probably enable a more precise dating to be made. The general aspect of the microflora suggests a Middle to Late Devonian age. Grapnel-tipped ornament is a common feature of Middle Devonian spores, and is less frequent in the Late Devonian. Other groups, such as the verrucate spores, range into the Carboniferous. It is therefore very difficult to be precise with regard to age, using only generic information. *Ancyrospora* sp. A shows close affinities to, and is probably conspecific with *Ancyrospora parva* de Jersey which is regarded as ranging through the Givetian and the Frasnian (de Jersey, 1966). It thus seems likely that the assemblage from the Gogo Formation is of Givetian or Frasnian age.

COMPARISON WITH OTHER DEVONIAN ASSEMBLAGES FROM AUSTRALIA

Very few papers dealing with Devonian assemblages from Australia have been published. Balme and Hassell (1962) described Famennian spores from the Fairfield Formation of the Canning Basin. Several genera are common to both the Fairfield Formation and to the older Gogo Formation although differences occur at specific level. This similarity suggests that a diverse, but evolving flora was well established in the Canning Basin during Middle to Late Devonian times. The single Frasnian assemblage from the Sadler Limestone examined by Balme and Hassell contained a restricted microflora composed of spores of the *Punctatisporites* type and is probably facies controlled.

Balme (1960) described two Frasnian, possibly Givetian, assemblages from the Gneudna Formation of the Carnarvon Basin. The Gneudna Formation occupies a similar stratigraphic position to the Gogo Formation, but the spore assemblages from the two formations show surprisingly little similarity. The Gneudna assemblages, unlike the assemblage from the Gogo Formation, are poor in species. The specimens of *Radiaspora* and *Chomotriletes*, figured by Balme, are absent from the Gogo assemblage. *Geminospora lemurata* Balme, the most abundant species in the Gneudna assemblages, was not observed in material from the Gogo Formation. Balme commented on the dissimilarity between the assemblages from the Gneudna Formation and those from the Fairfield Formation (Balme and Hassell, 1962), and suggested that the marked diffence between the two had a genuine biostratigraphical significance. In view of the wide differences between the Gneudna and the Gogo microfloras, it now seems possible that a biogeographical factor may have caused some of the differences between the floras of the two basins during Middle and Late Devonian times.

Middle Devonian assemblages from the Etonvale Formation in the Adavale Basin of Queensland have been described by de Jersey (1966). He compared the Adavale material with the assemblages described by Balme (1960), Balme and Hassell (1962) and the then unpublished work of Hodgson on the Amadeus Basin. He concluded that the Adavale assemblages were older than those from Western Australia and the Amadeus Basin. The material from the Gogo Formation has several genera in common with the Adavale assemblages, particularly in the presence of *Ancyrospora* sp. A, which is probably equivalent to *Ancyrospora parva* de Jersey. *Geminospora lemurata*, occurring only in the higher part of the Adavale assemblages, was not recorded from the Gogo Formation. This suggests that a detailed comparison of species present may reveal a correlation between the Gogo Formation and part of the Etonvale Formation of the Adavale Basin.

Hodgson (1968) described an assemblage from the Pertnjara Formation of the Amadeus Basin of late Middle or early Late Devonian age. This assemblage also contains the genus *Ancyrospora*. Hodgson referred some of his specimens to *Ancyrospora* cf. *A. simplex* Guennel, but de Jersey (1966) regarded Hodgson's specimens as conspecific with *A. parva*. The samples from the Pertnjara Formation of the Amadeus Basin contain *Geminospora lemurata* and *Radiaspora darensis*, neither of which has been observed in the Gogo assemblage.

CONCLUSIONS

Until further work is done on the Gogo microfloras comparison with other Australian assemblages remains uncertain, but would tend to suggest that the assemblage is slightly older than those from the Gneudna Formation and Pertnjara Formation and younger than assemblages from the lower part of the Etonvale Formation in the Adavale Basin. A correlation between the Gogo assemblage and the upper part of the Etonvale Formation may be possible after detailed identification of core material. Comparison with overseas assemblages has also been deferred until more information has been obtained on the species present in the Gogo Formation.

REFERENCES

Balme, B. E., 1960, Upper Devonian (Frasnian) spores from the Carnarvon Basin, Western Australia: The Palaeobotanist v. 9, p. 1-10.

——— and Hassell, C. W., 1962, Upper Devonian spores from the Canning Basin, Western Australia: Micropaleontology, v. 8, p. 1-28.

Brunton, C. H., Miles, R. S., and Rolfe, W. D. I., 1969, Gogo Expedition 1967: Geol. Soc. London Proceedings No. 1655, p. 79-83.

de Jersey, N. J., 1966, Devonian spores from the Adavale Basin: Queensland Geol. Survey, Pub. 334.

Druce, E. C., and Radke, B. M., 1973, B.M.R. stratigraphic drilling in the Noonkanbah and Lennard River 1 : 250 000 sheet areas, Western Australia, 1972: Australia Bur. Mineral Resources, Rec. 1973/26 (unpublished).

Glenister, B. F., 1958, Upper Devonian ammonoids from the *Manticoceras* Zone, Fitzroy Basin, Western Australia: Jour. Paleontology, v. 32, p. 58-96.

——— and Crespin I., 1959, Upper Devonian microfaunas from the Fitzroy Basin, Western Australia: Australian Jour. Sci., v. 21, p.222-223.

——— and Klapper, G., 1966, Upper Devonian conodonts from the Canning Basin, Western Australia: Jour. Paleontology, v. 40, p. 776-842.

Hodgson, E. A., 1968, Devonian spores from the Pertnjara Formation, Amadeus Basin, Northern Territory: Australia Bur. Mineral Resources Bull. 80, p. 65-83.

Playford, P. E., and Lowry, D. C., 1966, Devonian reef complexes in the northern Canning Basin, Western Australia: West. Australia Geol. Survey Bull. 118.

FIGURE 61 (opposite)

Photomicrographs of Devonian spores.

Magnification of all specimens x 500. G.S.W.A. Fossil registration numbers follow figure descriptions. Coordinates on Leitz Ortholux microscope number 587962 are given in brackets.

a. *Acinosporites* sp., F8481/1 (30·3 x 96·9)
b. *Ancyrospora* sp. A., F8481/1 (31·0 x 103·2)
c. *Ancyrospora* sp., F8481/1 (37·1 x 100·9)
d. *Auroraspora* sp., F8481/1 (39·4 x 111·9)
e. *Convolutispora* sp., F8481/1 (42·3 x 110·8)
f. *Cyclogranisporites* sp., F8481/1 (35·2 x 110·1)
g. *Cymbosporites* sp., F8481/1 (34·3 x 110·9)
h. *Dibolisporites* sp., F8481/1 (32·3 x 110·0)
i. *Hystricosporites* sp., F8481/2 (34·7 x 109·3)
j. *Latosporites* sp., F8481/1 (33·5 x 106·0)
k. *Lophozonotriletes* sp., F8481/1 (39·4 x 106·0)
l. *Retusotriletes* sp., F8481/2 (28·8 x 102·5)
m. *Rhabdosporites* sp., F8481/1 (33·7 x 110·0)
n. *Stenozonotriletes* sp., F8481/1 (43·2 x 98·4)
o. *Verrucosisporites* sp., F8481/1 (43·3 x 108·8)
p. *Samarisporites* sp., F8481/1 (35·2 x 100·7) proximal view
q. *Samarisporites* sp., F8481/1 (35·2 x 100·7) distal view

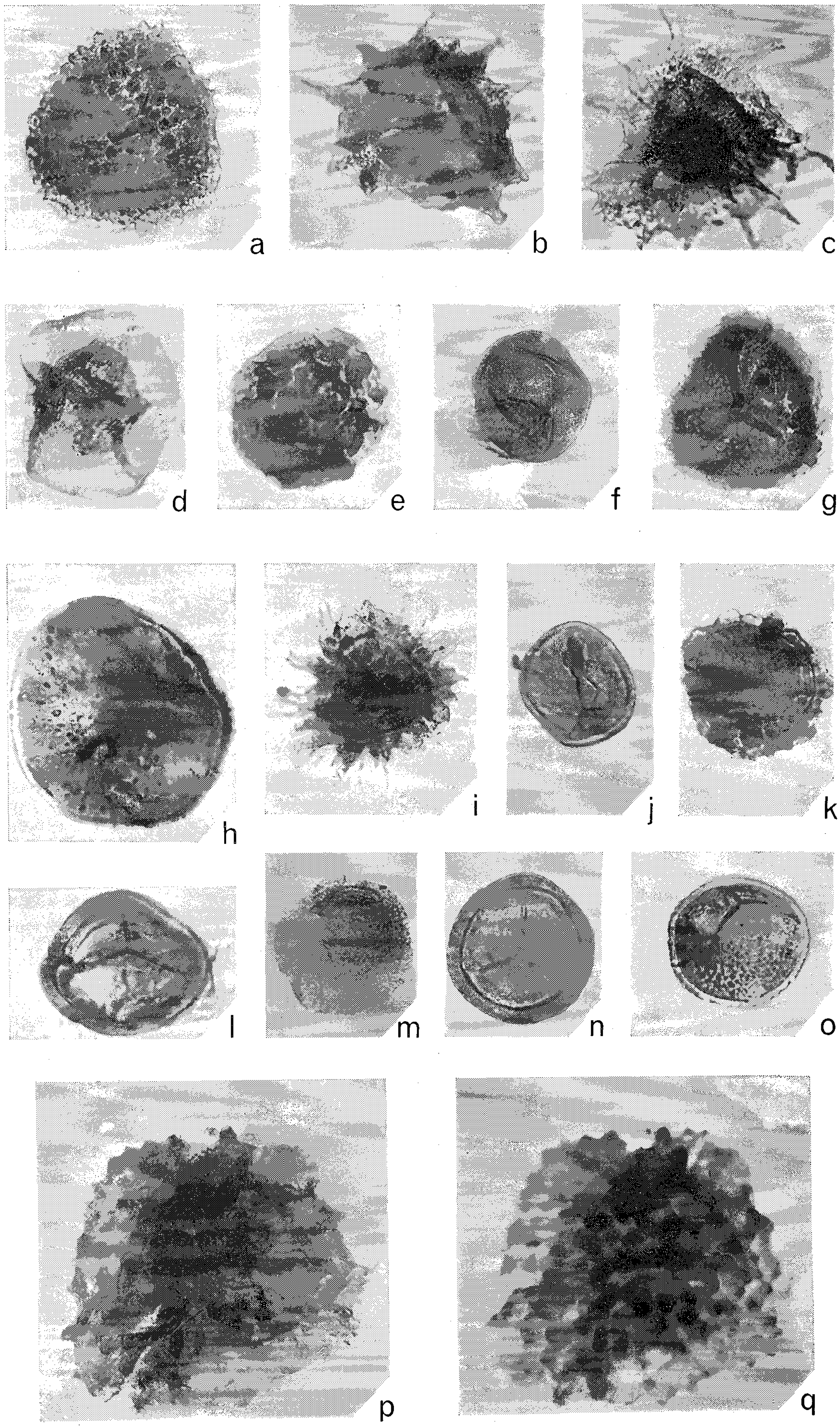

Figure 61.

Roberts, J., Jones, P. J., Jell, J. S., Jenkins, T. B. H., Marsden, M. A. H., McKellar, R. G., McKelvey, B. C., and Seddon, G., 1972, Correlation of the Upper Devonian Rocks of Australia: Geol. Soc. of Australia Jour., v. 18, p. 467-490.

Rolfe, W. D. I., 1966, Phyllocarid crustacean fauna of European aspect from the Devonian of Western Australia: Nature 209, No. 5019, p. 192.

Seddon, G., 1970, Frasnian conodonts from the Sadler Ridge—Bugle Gap area, Canning Basin, Western Australia: Geol. Soc. of Australia Jour., v. 16, p. 723-753.

Veevers, J. J., 1959, Devonian brachiopods from the Fitzroy Basin, Western Australia: Australia Bur. Mineral Resources Bull. 45.

STRATIGRAPHIC PALYNOLGY OF THE WATHEROO LINE BOREHOLES, PERTH BASIN

by J. Backhouse

ABSTRACT

Four biostratigraphic zones are recognized in the Upper Jurassic and Lower Cretaceous of the Yarragadee Formation in the Watheroo Line boreholes in the Perth Basin, some 210 km north of Perth, Western Australia. These are in ascending order, the *Dampieri, Baculatisporites, Cicatricosisporites* and *Concavus* Zones. The zonation is compared with the zonations of Balme (1964) and Ingram (1967a), and also with zonations proposed in Eastern Australia.

INTRODUCTION

The Watheroo Line boreholes (referred to as W.L. boreholes in this report) are located between Watheroo and Jurien Bay in the Perth Basin, approximately 210 km north of Perth. Drilling started in 1967 and by 1968 boreholes W.L. 1 to W.L. 4 and the Agaton boreholes 7 and 19 were completed. Drilling recommenced in 1971 and by the end of 1972 W.L. 5 to W.L. 12 had been drilled (Fig. 62).

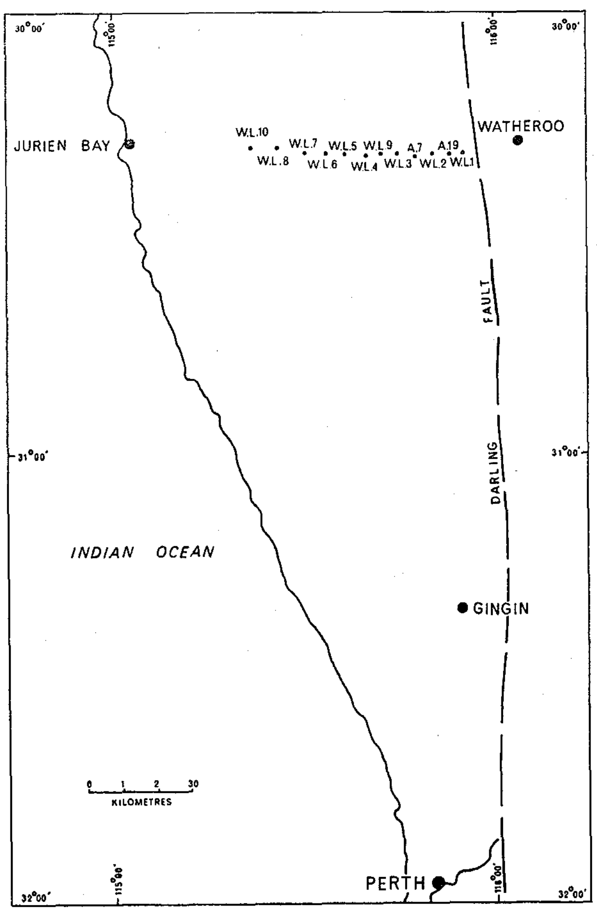

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Figure 62. Location of Watheroo Line boreholes.

This report is concerned with the palynology of samples taken in the Yarragadee Formation in boreholes W.L. 1 to W.L. 10 and Agaton 7 and 19, as shown in Figure 63. The Yarragadee Formation was not encountered in the boreholes W.L. 11 and W.L. 12 which intersected Lower Jurassic and Triassic sediments respectively. Very poor assemblages of spores and pollen were obtained after preparing samples from W.L. 8 and results from this borehole are excluded.

Samples were taken from conventional cores except those from W.L. 7, 8 and 10 which were from sidewall cores.

All samples were originally prepared by a procedure which involved maceration in Schultze solution. Later the samples were processed again by a method which did not use a strong oxidizing agent, although some samples were treated with concentrated nitric acid for up to ten minutes. It was noticed that the number of *Baculatisporites* spp. was much higher in preparations where Schultze solution was not used. It was concluded that Schultze solution selectively destroys these forms and this results in a biased spore count. The data given in Table 27 are from preparations made without using Schultze solution.

Data for two samples prepared using Schultze solution are included in Table 27 for comparison.

PREVIOUS WORK

In 1957 Balme subdivided the Jurassic and Lower Cretaceous of Western Australia into broad zones which he called Microfloras I, IIa and IIb. In 1969 he renamed the microfloras after the most characteristic component of each assemblage. Microflora IIa was renamed the *Dampieri* Assemblage and Microflora IIb was called the *Microcachryidites* Assemblage.

Ingram (1967a) recognized three zones in the Yarragadee Formation in the Gingin Brook boreholes, which he named Zones A, B and C.

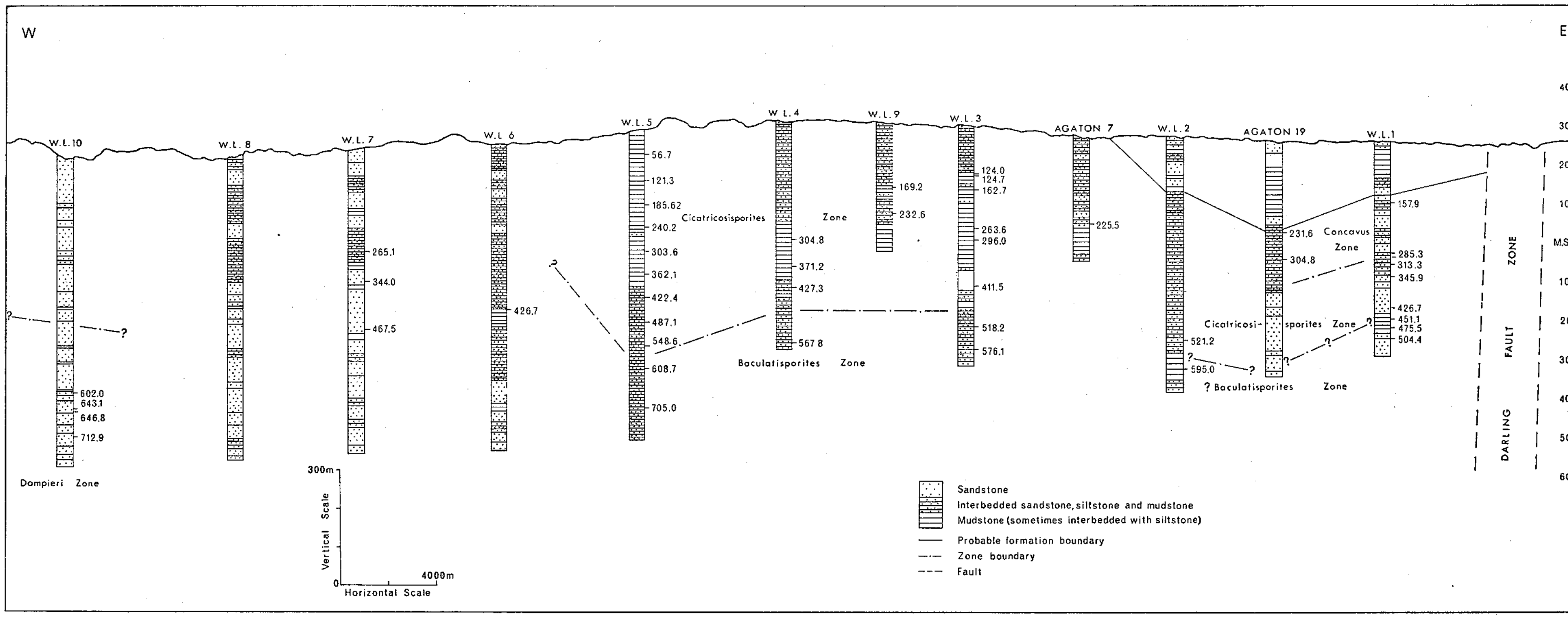

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Figure 63. Palynological correlation of Watheroo Line boreholes.

TABLE 27. DISTRIBUTION OF PALYNOMORPHS IN SAMPLES FROM WATHEROO LINE BOREHOLES 1 TO 10 AND AGATON 7 AND 19

PALYNOMORPHS	W.L.10				W.L.7			W.L.6	W.L.5											W.L.4				W.L.9		W.L.3									A.7	W.L.2		A.19		W.L.1								
	712.9	646.8	643.1	602.0	467.5	344.0	265.1	426.7	705.0	608.7	548.6	487.1	422.4	362.1	303.6	240.2	185.6	121.3	56.7	567.8	427.3	371.2	304.8	232.6	169.2	576.1	518.2	411.5	296.0	263.6	162.7	124.7	124.0	124.0*	225.6	595.0	521.2	304.8	231.6	504.4	475.5	475.5*	451.1	426.7	345.9	313.3	285.3	157.9
Aequitriradites acusus									1					1			2									4															1							
A. hispidus								p				1		9	3	1	3		3		2					5	1				1				1	1					4			1				
A. sp. cf. *A. verrucosus*																	1			1						2		3			2									1	3							
Araucariacites australis	94	88	65	74	7	12	11	13	21	16	21	27	34	26	17	15	14	8	8	13	17	10	17	2	7	27	16	23	21	3	3	7	9	5	16	10	13	14	10	11	6	19	17	24	32	20	23	16
Baculatisporites comaumensis	10	12	4	4	3	36	39	2	41	53	53	87	77	62	25	71	62	37	96	68	69	31	37	11	40	95	43	74	65	30	64	21	31		20	19	66	28	25	80	87	5	24	51	19	75	8	5
Ceratosporites equalis						1	10	6	5	2	2					3	4		2	2			1	2				4	2			p					1		6	2	2					1	1	
Cicatricosisporites australiensis													p		p						1		1		p			p	p		1						p							1				p
C. sp. cf. *C. ludbrooki*											p														1										1		p									p		
Classopollis classoides	10	9	18	20	1	4	4	7	1	2	2	3	2	1	4			1	1		1				1	1		1		3	2					1	1	31	41	1	3	3	21	1	54	10	13	27
Clavatipollenites hughesii											p																																					
Concavisporites infirmus																		2	1	1												1						p				1					p	1
C. jurienensis								1				1		3																2		5	p	3	1				1	p	1	1	1	1		p	p	
Contignisporites cooksonii					2				7			3	1	3	5	3		1	2	2	2	2	1		1	2	3	7	8	2	1	2	2	1	1	2	4			2	6	4	5	2			p	
C. multimuratus								2	8	1	3	3	5	4	3	1	2	1			1	3	1	3	1	3	1		6		1	p	2		4	2	2	1		1	3		2	3		6	p	
Cooksonites sp. cf. *C. variabilis*										1						1									1	1																						1
Coronatispora perforata								p	1						1			1											1										1	3								
C. telata					1					2												1			1							p	1		1	1	1			2	2	1	p		p		1	p
Cyathidites australis			1	3	1	2	3	4	7	5	3	8	8	13	1	6	9	3			6	4	1		5	6	3	8	3	1	7	1	7	16	11	1	11	4	p	3	11	3	2	3		15	1	2
C. concavus																		p					p									p	p	1	2		p	2	1				p	1			p	7
C. minor	4	10	17	14	1	14	21	12	16	13	17	14	8	16	9	16	20	20	13	19	16	17	17	9	13	12	14	26	10	17	14	17	19	19	22	7	16	20	17	36	30	21	20	31	20	33	13	8
Cycadopites nitidus		2	2	2			3	1	2	1				3	1			15	3				1			1	1		3	2	p	1			1	3		1	2	2	1	5	3	5	2		3	1
Densoisporites velatus										1					1							1															1				p	1	p					1
Dictyophyllidites sp.					1					p	3			1		1					1				2	1	1	3							6			p									p	
Dictyotosporites complex										1										1		1	1		p				p				3			1			p		p	1	p					1
Foveosporites canalis	1					1	1					2	2										2			1			1			1				1								2		1		
Foveotriletes parviretus						2	1		1														1										2						1							1		2
Gleicheniidites senonicus				p			1	3		2				1	p			2	1		1	1	1	2	p			1	2	3	1	1					3	3	1	p	1	2	1		2		1	5
Inaperturopollenites limbatus																																							p				p		p	p		5
I. turbatus								p																																								
Ischyosporites crateris								3	2		1	1			2	1		3	2	4		3		1	4	2	3			1		3	2		18	1	3	1			p	9	p	p		7	1	
Klukisporites scaberis		2		p				3	2	1			1				3	1			1	1			2	2	1	2	1	1	1		1		2	2					p	1	1	1		1		
Kuylisporites lunaris																																	p															
Laevigatosporites sp.															p												1				1				1								p	p			p	
Leptolepidites major								p	1	1								2			1				1																p	1	p		1			
L. verrucatus				3			1	3	1	1		1		1		1		1		3	1	1				1		1												3	3							
Lycopodiacidites sp.	1							1				1						p			1	2					3	1			p	1							p		p	3	p					p
Lycopodiumsporites austroclavatidites	1	8	6	6	1	9	11	13	12	7	8	7	7	5	6	1	2	5	4	6	4	5	3		2	1	6	5	3		1	p	1			1		1		8	2	3	7	2				1
L. circolumenus	2				2	2	1	3	1					2	p	1	2	p	3		6	1			4		1	3	2		p						2		1	2	1		1				p	
L. sp. cf. *L. eminulus*						1		p	1				1	2	1		1	3			1					1	1	1	2	2	1	1				2					2			2		1		
L. sp. cf. *L. nodosus*																																						p										p
Matonisporites crassiangulatus									1	2												1					1				p							p						1		p	p	1
M. cooksoni										1																																						p
M. sp.									1				1	p																											p	1	p					
Microcachryidites antarcticus					1	3	3	18	5	15	12	2	1	5	14	14	13	14	2	8	7	22	22	11	31		12	2	13	8	6	23	14	42	18	18	12	35	35	p	3	22	21	8	15	3	44	50
Microfoveolatosporis canaliculatus							1								1			1												1			p	1	2		3		1	p		3		1				p
Murospora florida				1			1	4	2		p						1				1	1			p														1				p	1		2	p	p
Neoraistrickia truncatus	1			6		5	2	2		2		2	3	1	3	8	3	13	12	3	10	8	1					2	2	3		3	4		1	1	3		3	10	2		3	2		1	2	
Nevesisporites vallatus							p				p																1								2	1								p				
N. sp.								p		1					1							4		4	p		1	1		1	p	9	2	23	4	6	3	p			1		p	p	1		2	
Pilosisporites notensis																												1		1	p				3													
Podocarpites sp.	1	2		2											1			1																														
Reticulatisporites pudens						p																															p		2		2		1					
Reticuloidosporites arcus																						1	1	1											1		5						3					
R. sp.											1				2							1		1							p		p	2									1				p	
Staplinisporites caminus	1			1			p							p																		1																
Stereisporites antiquasporites		2	4					p				1									2	1																1	6						1			
Trilobosporites purverulentus											p											p																						p				
Tripartina sp. cf. *T. variabilis*								p		1							1					1											p	1	3			1					p				p	
Zonalapollenites dampieri	20	16	20	9	2	1	4	5	7	3	4	4	4	2	3	3	3	3		3	3	1	1		3	6	5	7	2		p	p	4	2	2		2		1	2	1	12	4	6	2	3	2	p
Z. segmentatus																									1	1					p		4		1								1				p	
remanie forms					2		2	1	1				1	1	2	4	2	p	1	1	2					2	9		p												1	1	p	1				
bisaccate forms	50	39	48	44	14	22	59	83	36	32	28	17	33	17	46	24	32	39	17	15	18	38	44	12	37	6	41	6	23	24	8	67	36	53	30	21	20	36	36	1	8	46	45	22	34	10	65	54
Acritarchs																																																
Leiosphaeridia spp.			2			3		1	2	6	14		3		24		3	2	17	15	11	25	24		12			5		6	1	21	23	21	4	2	3	3	p			7	4	3	1		5	1
Veryhachium spp.										1	1				1								p																				p					
Incertae sedis																																																
Horologinella sp.															2																p	p						p									p	p
Other	4	10	13	11	4	6	21	9	14	26		15	8	21	22	24	17	18	12	36	14	12	22	12	27	17	29	12	29	10	17	20	28		20	12	24	18	8	30	13	23	12	23	16	9	15	10
Total	200	200	200	200	43	124	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	71	200	200	200	200	200	111	133	200	200	200	200	116	200	200	200	200	200	200	200	200	200	200	200	200

p Observed but not in actual count.

* Count of palynomorphs in a sample prepared using Shultze solution.

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ZONATION

Four biostratigraphic units named, in ascending order, *Dampieri* Zone, *Baculatisporites* Zone, *Cicatricosisporites* Zone and *Concavus* Zone can be recognized in the Yarragadee Formation in the Watheroo Line boreholes. The *Dampieri* Zone corresponds to Balme's (1964) *Dampieri* Assemblage and Ingram's (1967a) Zone A. The remaining three zones are new.

Table 28 shows the distribution of key species within the zones. Spore and pollen counts from each sample are set out in Table 27. Some of the important forms are shown in Figures 64 and 65.

TABLE 28. DISTRIBUTION OF KEY FORMS IN THE WATHEROO LINE ZONATION

Palynomorph	*Dampieri* Zone	*Baculatisporites* Zone	*Cicatricosisporites* Zone	*Concavus* Zone
Foveosporites canalis	—	—	—	
Klukisporites scaberis	—	—	—	
Leptolepidites verrucatus	—	—	—	
Staplinisporites caminus	—	—	—	
Araucariacites australis	—	—	—	—
Baculatisporites spp.	—	—	—	—
Classopollis classoides	—	—	—	—
Lycopodiumsporites austroclavatidites	—	—	—	—
L. circolumenus	—	—	—	—
Murospora florida	—	—	—	—
Zonalapollenites dampieri	—	—	—	—
Aequitriradites spp.		—	—	
Contignisporites spp.		—	—	—
Microcachryidites antarcticus		—	—	—
Nevesisporites spp.		—	—	—
Pilosisporites notensis			—	
Cicatricosisporites spp.			—	—
Cyathidites concavus			—	—
Inaperturopollenites limbatus			—	—

Dampieri Zone

The stratigraphically lowest zone, the *Dampieri* Zone, occurs only in W.L. 10. Only four samples from W.L. 10 yielded good assemblages of spores and pollen. The remaining samples had very sparse assemblages or were barren of palynomorphs.

Assemblages from this zone show high counts of *Araucariacites australis* Cookson and bisaccate forms, and relatively high counts of *Zonalapollenites dampieri* Balme and *Classopollis classoides* Pflug. Absent from this zone are *Aequitriradites, Cicatricosisporites* and *Contignisporites* but *Foveosporites canalis* Balme and *Murospora florida* (Balme) though rare, are recorded.

Baculatisporites Zone

The *Baculatisporites* Zone occurs in W.L. 7, W.L. 6, W.L. 5 below 548.6 m, W.L. 4 below 427.3 m and W.L. 3 below 411.5 m. It may also be represented by samples in W.L. 2 at 595.0 m, W.L. 1 at 495.5 m and 504.4 m (see Fig. 63).

An increase in the number of *Baculatisporites* spp. and a decrease of *A. australis* and *C. classoides* marks the base of the *Baculatisporites* Zone. In addition *Microcachryidites antarcticus* Cookson *Aequitriradites* spp., *Contignisporites* spp. and many other numerically less prominent forms appear.

A number of spores, which include forms assignable to *Baculatisporites comaumensis* (Cookson) and *Osmundacidites wellmanii* Couper, have been grouped under *Baculatisporites* spp. in Table 27 because of the difficulty in assigning many individual spores of this type to a particular species. These forms become very abundant in nearly all samples in the *Baculatisporites* and *Cicatricosisporites* Zones, comprising almost 50 per cent of the individual palynomorphs observed in some samples.

Cicatricosisporites Zone

All samples above the *Baculatisporites* Zone in boreholes W.L. 1 to 5 and Agaton 7 belong to the *Cicatricosisporites* Zone with the exception of the top two samples in W.L. 1.

Basically assemblages from this zone are similar to those of the *Baculatisporites* Zone. *Baculatisporites* spp. are still abundant and the numbers of other forms remain relatively unchanged. The first appearance of *Cicatricosisporites* marks the base of this zone. Other forms to appear at various levels in this zone are *Pilosisporites notensis* Cookson and Dettman, *Cyathidites concavus* (Bolkhovitina) and *Inaperturopollenites limbatus* Balme. *P. notensis* has been recorded from a small number of samples in W.L. 3 and Agaton 7, and although not a common species in the Yarragadee Formation it has been noted in the Otorowiri Siltstone Member (Ingram 1967b). *C. concavus* and *I. limbatus* are rare in this zone and become slightly more abundant in the overlying *Concavus* Zone.

An unusually large number of *C. classoides* is present in a few samples from the *Cicatricosisporites* Zone in W.L. 1 but throughout most of this zone it is rare.

Concavus Zone

The *Concavus* Zone occurs in the two samples from Agaton 19 and in W.L. 1 at 153.9 m and 285.3 m. It is characterized by the more frequent occurrence of *C. concavus* and *I. limbatus* and by the considerably higher count of *M. antarcticus* and *C. classoides*. *Baculatisporites* spp. decline in abundance but are still common. Several forms seem to disappear in this zone (see Table 28) but no new forms appear.

Remanie forms

Remanie forms occur frequently in the *Baculatisporites* and *Cicatricosisporites* Zones. No sample shows the abundance and diversity of remanie forms which Ingram (1967b) recorded from the Otorowiri Siltstone Member of the Yarragadee Formation farther north near Mingenew. Remanie forms were not recorded from the *Dampieri* or *Concavus* Zones, suggesting that little or no erosion of the nearby source rocks was taking place during those periods. The most common forms are *Parasaccites* spp., *Potoniesporites* spp., *Platysaccus* sp. and various striate bisaccate forms, indicating a Permian or Early Triassic age. *Veryhachium* is also probably a remanie form derived from the Early Triassic Kockatea Shale in which it is often abundant.

FIGURE 64 (opposite)

Photomicrographs of palynomorphs from the Watheroo Line boreholes.

Magnification of all specimens on Figure 64 and 65 x 500. G.S.W.A. fossil registration numbers follow figure description. Coordinates on Leitz Orthoplan microscope number 834965 are given in brackets.

a. *Aequitriradites acusus* (Balme), F8189/2 (50·1 x 107·4)
b. *Aequitriradites hispidus* Dettmann and Playford, F8190/3 (46·3 x 106·6)
c. *Cicatricosisporites australiensis* (Cookson), F6595/3 (47·2 x 109·9)
d. *Cicatricosisporites ludbrooki* Dettmann, F6495/3 (42·5 x 108·9)
e. *Classopollis classoides* Pflug, F6595/3 (45·3 x 100·2)
f. *Concavisporites jurienensis* Balme, F6595/3 (32·1 x 109·5)
g. *Concavisporites jurienensis* Balme, F666/2 (38·1 x 104·3)
h. *Cyadopites nitidus* (Balme), F7928/1 (40·7 x 97·5)
Contignisporites multimuratus Dettmann, F5591/5 (32·7 x 106·0)
j. *Coronatispora perforata* Dettmann, F8466/1 (42·5 x 103·0)
k. *Coronatispora telata* (Balme), F6660/1 (29·6 x 107·4)
Cyathidites concavus (Bolkhovitina), F6660/3 (26·7 x 104·5)
m. *Foveosporites canalis* Balme, F6595/3 (289 x 99·9)
Foveotriletes parviretus (Balme), F8200/4 (27·1 x 92·9)
o. *Laevigatosporites sp.*, F6669/1 (36·6 x 102·6)
p. *Inaperturopollenites limbatus* Balme, F6660/4 (47·3 x 110·5)
q. *Leptolepidites verrucatus* Couper, F8200/2 (38·6 x 99·7)
r. *Leptolepidites major* Couper, F6661/1 (37·3 x 106·1)
s. *Lycopodiumsporites circolumenus* Cookson and Dettmann, F6595/3 (35·3 x 101·7)

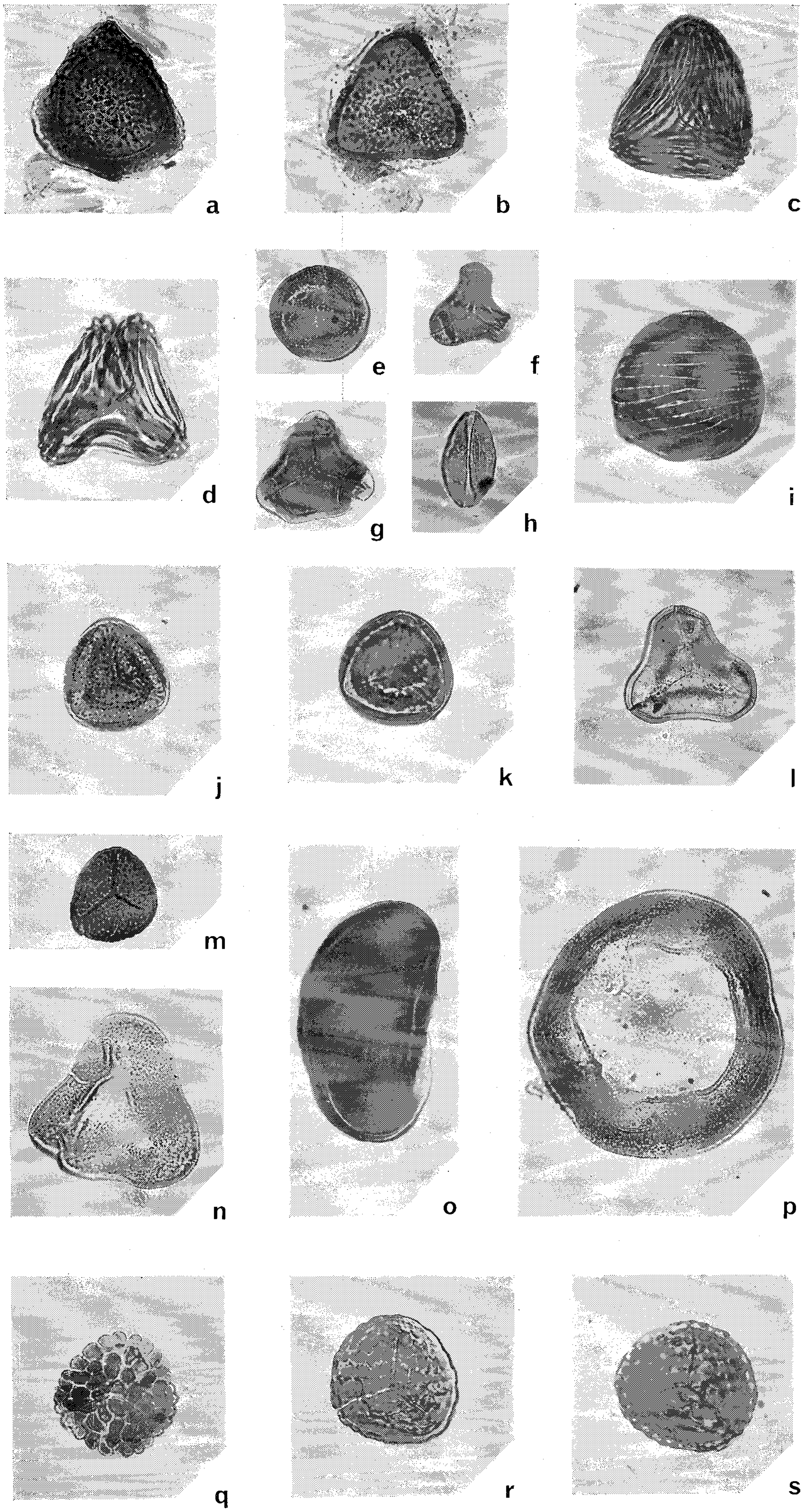

Figure 64.

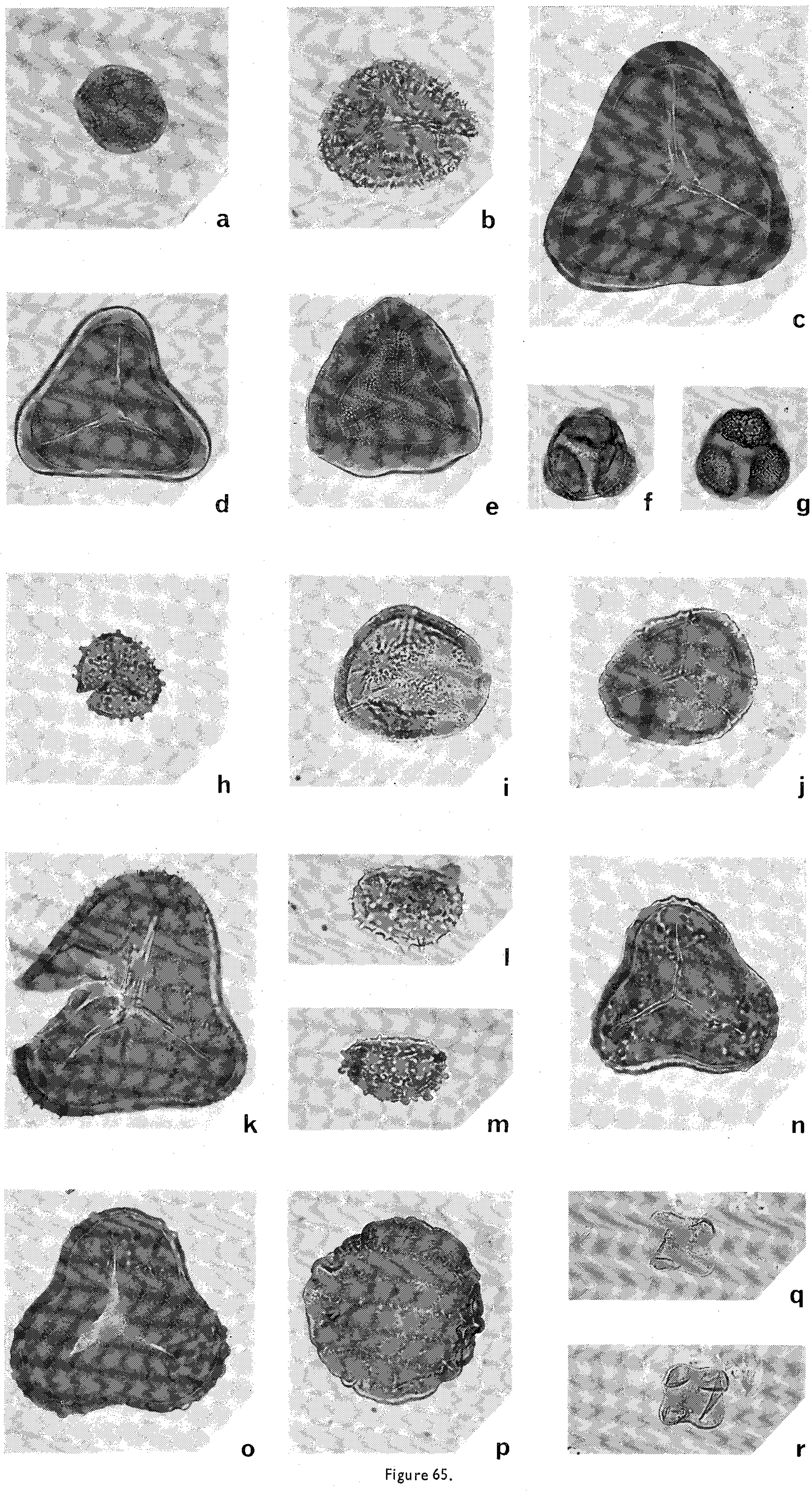

Figure 65.

TABLE 29. CORRELATION OF LATE JURASSIC AND EARLY CRETACEOUS ZONATIONS IN AUSTRALIA

Age	Balme 1964	Evans 1966a, b.	Ingram 1967	Dettmann and Playford 1969	This Paper
Cretaceous		Unit Kla	Zone C	*Dictyotosporites speciosus* Zone	*Concavus* Zone
	Microcachryidites Assemblage			- - - - - ? - - - - -	
- - - - ? - - - - -				*Crybelosporites stylosus* Zone	*Cicatricosisporites* Zone
			- - - - - ? - - - - -	- - - - - ? - - - - -	
		Unit J5–6	Zone B		*Baculatisporites* Zone
		- - - - - ? - - - - -			
Jurassic	*Dampieri* Assemblage	Unit J4–5	Zone A		*Dampieri* Zone

COMPARISON WITH OTHER ZONATIONS

Table 29 indicates the correlation of the proposed zones with those of Balme (1964) and Ingram (1967a), and also the probable correlation with zonations in eastern Australia erected by Evans (1966a) and Dettmann and Playford (1969).

The correlation between the Watheroo Line zonation and that of Balme is fairly clear. Ingram's Zones B and C are more difficult to correlate with the Watheroo Line zonation. *M. florida* is recorded in the lowest zone in the Watheroo Line but is restricted to the highest zone (Zone C) in Ingram's Gingin Brook zonation.

Unit J5-6 of Evans is correlated wth the *Baculatisporites* Zone on the basis of the first appearance of *C. cooksonii*. However *Lycopodiumsporites circolumenus* Cookson and Dettmann and *M. florida*, which first appear in unit J5 in the Injune Creek Beds (Evans 1966a), occur in the *Dampieri* Zone in the Watheroo area. The base of Evans' Kla unit is established as the first appearance of *C. australiensis*. In the Watheroo Line zonation the first appearance of *Cicatricosisporites* is taken as the base of the *Cicatricosisporites* Zone. The presence of *M. florida* in the *Concavus* Zone indicates this zone also correlates with Evans' Kla unit. Evans (1966a, 1966b) suggests *C. australiensis* may occur in the Upper Jurassic in the Canning Basin and that unit Kla probably commences in the Jurassic. Allowing for the possible occurrence of *C. australiensis* in the Late Jurassic, the Jurassic-Cretaceous boundary probably occurs in the lower part of the *Cicatricosisporites* Zone.

If the *Crybelosporites stylosus* Zone of Dettmann and Playford (1969) is represented in the Watheroo area it must be within the *Cicatricosisporites* Zone, possibly in a thin section below the first occurrence of *P. notensis*. Forms comparable to *Cooksonites variabilis* Pocock and *Aequitriradites hispidus* Dettmann and Playford, occur in the *Baculatisporites* and *Cicatricosisporites* Zones, and overlap the range of *P. notensis* in W.L. 3 and Agaton 7. In Dettmann and Playford's zonation *A. hispidus* and *P. notensis* do not overlap and *C. variabilis* only appears at the top of the *Crybelosporites stylosus* Zone to which *A. hispidus* is restricted. These anomalies, and the absence of positively identified specimens of *Crybelosporites stylosus* Dettmann and *Dictyotosporites speciosus* Cookson and Dettmann, make Dettmann and Playford's zonation difficult to apply in the Watheroo Line boreholes.

FIGURE 65 (opposite)

Photomicrographs of palynomorphs from the Watheroo Line boreholes.

a. *Lycopodiumsporites* sp. cf. *L. eminulus* Dettmann, F6595/3 (44·5 x 99·4)
b. *Lycopodiumsporites* sp. cf. *L. nodosus* Dettmann, F6669/1 (42·3 x 109·2)
c. *Matonisporites* sp., F6666/2 (33·0 x 104·6)
d. *Matonisporites crassiangulatus* (Balme), F7928/1 (41·4 x 109·1)
e. *Murospora florida* (Balme), F6669/1 (34·2 x 105·4)
f.g. *Microcachryidites antarcticus* Cookson. Proximal and distal focii, F6660/2 (32·0 x 99·0)
h. *Neoraistrickia truncatus* (Cookson), F6595/3 (30·5 x 99·0)
i. *Nevesisporites vallatus* de Jersey and Paten, F6668/2 (39·5 x 111·9)
j. *Nevesisporites* sp., F6684/1 (37·7 x 104·1)
k. *Pilosisporites notensis* Cookson and Dettmann, F6686/1 (31·2x105·9)
l. *Reticuloidosporites* sp., F6665/1 (40·0 x 106·0)
m. *Reticuloidosporites* sp., F6666/2 (38·3 x 91·8)
n. *Trilobosporites purverulentus* (Verbitskaya), F6665/1 (44·0 x 101·7)
o. *Trilobosporites purverulentus* (Verbitskaya), F6665/2 (43·0 x 97·9)
p. *Zonalapollenties dampieri* Balme, F6595/3 (39·5 x 98·2)
q. *Horologinella* sp., F7928/1 (44·3 x 95·9)
r. *Horologinella* sp., F7928/1 (38·8 x 110·4)

CONCLUSIONS

This zonation has been applied only to the Watheroo Line boreholes in the Perth Basin. Further work may result in modification to the zonation and to the range of individual species. For example, study of further samples from the *Concavus* Zone may reveal species which, because of their rarity, were missed in the four samples examined from the Watheroo Line.

Further study of material from the Gingin Brook boreholes may show a closer correlation between the Yarragadee Formation in the Gingin Brook and Watheroo Line boreholes. Present drilling, on the Eneabba boreholes to the north of Watheroo, will provide additional information on the palynology of the Upper Jurassic and Lower Cretaceous in the Perth Basin.

REFERENCES

Balme, B. E., 1957, Spores and Pollen grains from the Mesozoic of Western Australia: Australia C.S.I.R.O. Fuel Research T.C. 25, p. 1-48.

——— 1964, The palynological record of Australian pre-Tertiary floras, *in* Ancient Pacific Floras: Univ. Hawaii Press.

Dettmann, M. E., 1963, Upper Mesozoic microfloras from south eastern Australia: Royal Soc. Victoria Proc. v. 77, p. 1-148.

Dettmann, M. E., and Playford, G., 1969, Palynology of the Australian Cretaceous: A Review, *in* Campbell K.S.W. (Ed.), Stratigraphy and Palaeontology: Essays in honour of Dorothy Hill: Australia Nat. Univ. Press.

Evans, P. R., 1966a, Mesozoic stratigraphic palynology in Australia: Australasian Oil and Gas Jour. v. 12, No. 6, p. 58-63.

——— 1966b, Contribution to the Palynology of northern Queensland and Papua: Australia Bur. Mineral Resources Rec. 1966/198 (unpublished).

Ingram, B. S., 1967a, A preliminary palynological zonation of the Yarragadee Formation in the Gingin Brook bores: West. Australia Geol. Survey Ann. Rept. 1966 p. 77-79.

——— 1967b, Palynology of the Otorowiri Siltstone Member, Yarragadee Formation: West. Australia Geol. Survey Ann. Rept. 1966 p. 79-83.

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TRIASSIC CONCHOSTRACANS FROM THE KOCKATEA SHALE

by A. E. Cockbain

ABSTRACT

The well-known northern hemisphere conchostracan *Cyzicus minuta* is illustrated for the first time from the Early Triassic Kockatea Shale in the southern Carnarvon Basin. Conchostracans are also known from this formation in the Perth Basin and from the Blina Shale in the Canning Basin. All occurrences are in marine strata and probably represent specimens swept out to sea by floods.

INTRODUCTION

Conchostraca are small crustaceans with a translucent bivalved shell which is never strongly calcified and bears growth lines. Present day conchostracans live chiefly in impermanent ponds, but fossil forms are reported from fresh-water, brackish-water and marine environments. However, there is some debate as to whether conchostracans were ever truly marine or whether they lived in fresh and brackish waters and were carried into the sea by floods (Tasch, 1969).

In Western Australia, Triassic conchostracans have been recorded from the Blina Shale in the Canning Basin and from the Kockatea Shale in the Perth and Carnarvon Basins. Marine fossils have been found in both these formations. This paper will summarise these occurrences, describe and illustrate the Kockatea Shale conchostracan species for the first time, and comment on the significance of these fossils from Western Australia.

OCCURRENCE

Triassic conchostracans are known from the Blina Shale and from the Kockatea Shale (Fig. 66).

1. *Blina Shale.* Brunnschweiler (1954, 1957) recorded two species of *Cyzicus* from the Blina Shale under the names *Isaura* sp. cf. *I. minuta* and *I.* sp. cf. *I. ipsviciensis.* He pointed out (Brunnschweiler, 1954) that the bivalve *Carbonicola minutissima* described by Chapman and Parr in 1937 is a conchostracan (the first to be figured from Western Australia), and that Teichert (1950) had also recorded *"Estheria"* from the Blina Shale in Mayalls bore. Other records of conchostracans from this formation are given by Veevers and Wells (1961). The associated fauna includes *Lingula* and fish and amphibian remains. Brunnschweiler (1954) considered that the abundance of *Cyzicus* suggested a Late Triassic age for the Blina Shale. However, Lindner (*in* McWhae and others, 1958) thought that the formation might be Early Triassic and this has since been confirmed by Balme (1969) on palynological grounds.

2. *Kockatea Shale.* Conchostracans were first recorded from the Kockatea Shale by Dickins and McTavish (1963). The conchostracans, which were not identified, occur in cores 25 and 26 in B.M.R. (Beagle Ridge) No. 10 bore and are found in association with bivalves, ammonites and fish remains. The ammonites date the formation as Griesbachian (early Early Triassic) at this locality, but near Mount Minchin on the Northampton Block the lowest beds of the Kockatea Shale are Smithian (late Early Triassic, Playford and others, in press).

More recently, conchostracans have been found in the Kockatea Shale south of Kalbarri. This is the type region of the Wittecarra Formation (Johnstone and Playford *in* McWhae and others, 1958). This unit has been regarded as probably of Late Jurassic age on the basis of fossil leaves. Playford and others (in press) have re-interpreted the sequence at this locality as follows:

McWhae and others, 1958	Playford and others, (in press).
	Birdrong Sandstone
	UNCONFORMITY
Wittecarra Formation	Kockatea Shale
	Wittecarra Sandstone
UNCONFORMITY	UNCONFORMITY
Tumblagooda Sandstone	Tumblagoodoo Sandstone

The conchostracans come from the lower part of the Kockatea Shale in this section and are described below as *Cyzicus minuta.*

SYSTEMATIC PALAEONTOLOGY

Phylum ARTHROPODA

Superclass CRUSTACEA

Class BRANCHIOPODA

Subclass DIPLOSTRACA

Order CONCHOSTRACA

Suborder SPINICAUDATA

Superfamily CYZICOIDEA

Family CYZICIDAE

Cyzicus Audouin, 1837

1837 *Cyzicus* Audouin

1837 *Estheria* Rüppel (not *Estheria* Robineau-Desvoidy, 1830)

1841 *Isaura* Joly

The name *Estheria* by which these animals are widely known was originally given to a genus of Diptera. Brunnschweiler (1954) followed Bock (1953) in considering *Isaura* as the correct name for the genus. However, Dechaseaux (1953) and Tasch (1969) point out that the name *Cyzicus* has priority.

Cyzicus (Euestheria) minuta (von Zieten)
Figures 67 D and E.

1833 *Posidonia minuta* von Zieten: p. 72, pl. 54, fig. 5 (not seen).

1890 *Estheria minuta* (Alberti); Jones: p. 387, pl. 12, figs. 4-7.

?1907 *Estheria* sp. Etheridge Jr.: p. 11, pl. 8, fig. 11.

?1937 *Carbonicola minutissima* Chapman and Parr: p. 178, pl. 16, fig. 6.

1950 *Estheria (Euestheria) minuta* (Alberti); Defretin: p. 215, pl. 8, figs. 1-6, pl. 9, fig. 1, text fig. 1.

1953 *Isaura minuta* (Goldfuss); Bock: p.68, pl. 11, figs. 5-7.

1954 *Isaura* cf. *I. minuta* (Goldfuss); Brunnschweiler: p. 43.

1957 *Isaura* cf. *I. minuta* (Goldfuss); Brunnschweiler: p. 5.

1969 *Euestheria minuta* (von Zieten); Defretin-Lefranc: p. 127, pl. 1, figs. 3, 4 (with synonymy).

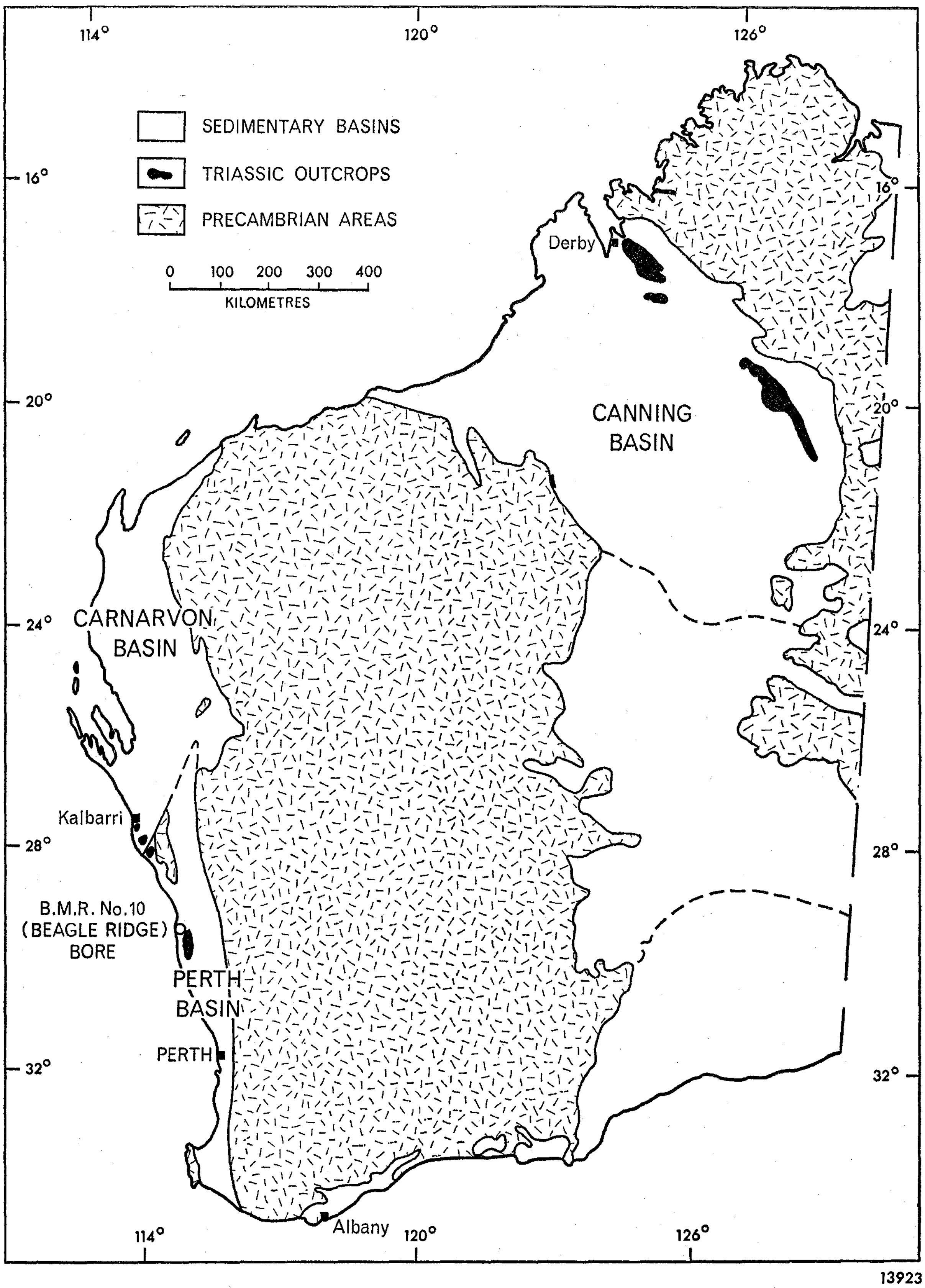

Figure 66. Location map of Blina and Kockatea Shales.

Material: G.S.W.A. registered number F8320, some 20 internal and external moulds preserved in a pale-grey to white siltstone; Kockatea Shale, 7.2 km south of Red Bluff, near Kalbarri, southern Carnarvon Basin.

Remarks: The specimens average about 3 mm in length. Growth lines are fairly well marked, but no trace of micro-ornament between growth lines is preserved. The material is identified as *Cyzicus minuta* on the basis of the size and general shape of the shells.

Distribution: The species occurs throughout the Triassic in Europe, but is most abundant in the late Middle Triassic Lettenkohle (Defretin, 1950). The Western Australian specimens come from the Early Triassic Kockatea Shale. The species also occurs in Greenland (Defretin-Lefranc, 1969), but is apparently absent from North America (Bock, 1953).

SIGNIFICANCE

The conchostracans from the Triassic of Western Australia are associated with a variety of fossils as summarised below:

lingulid brachiopods—1, 2, 3
marine bivalves—2
ammonites—2
fish and amphibian remains—1, 2
acritarchs—1, 2
spores and pollen—1, 2

(1) Blina Shale (Brunnschweiler, 1954, 1957)
(2) Kockatea Shale, B.M.R. No. 10 bore (Dickins and McTavish, 1963)
(3) Kockatea Shale, near Kalbarri (this paper)

The acritarchs, lingulid brachiopods, ammonites and bivalves suggest a marine environment, whilst the spores, pollen, amphibian remains and some of the fish remains are characteristic of fresh water or a continental environment. McKenzie (1961) postulated a quiet marine gulf with a large delta to account for the deposition of the Blina Shale and Balme (1969) suggested similar conditions for the Kockatea Shale. Under this hypothesis the non-marine faunal and floral elements could easily be carried into the sea during floods. The conchostracans may have been marine, but it is more likely that they too were swept into the sea by flood waters, a suggestion supported by the lack of articulated specimens of *Cyzicus minuta* in the Kalbarri material.

Tasch (1971) has endeavoured to use conchostracan fossils to indicate fresh and brackish-water dispersal routes across Gondwanaland. Such evidence must be applied with caution for as Tasch himself points out (1969), conchostracan eggs are very resistant and can be readily dispersed by wind and water. Modern conchostracans are cosmopolitan. The Western Australian Triassic conchostracan fauna contains one species (*C. minuta*) which is widespread in the northern hemisphere. This suggests that conchostracan species were cosmopolitan in the Triassic and that they must have been dispersed across wide stretches of land and sea with equal ease.

REFERENCES

Balme, B. E., 1969, The Triassic System in Western Australia: Australian Petroleum Explor. Assoc. Jour., v. 9, p. 67-78.

Bock, W., 1953, American Triassic estherids: Jour. Paleontology, v. 27, p. 62-76.

Brunnschweiler, R. O., 1954, Mesozoic stratigraphy and history of the Canning Desert and Fitzroy Valley, Western Australia: Geol. Soc. Australia Jour. v. 1, p. 35-54.

——— 1957, The geology of the Dampier Peninsula, Western Australia: Australia Bur. Mineral Resources Rept. 13.

Chapman, F., and Parr, W. J., 1937, On the discovery of fusulinid Foraminifera in the Upper Palaeozoic of North-west Australia; with a note on a new bivalve: Victorian Naturalist v. 53, p. 175-179.

Dechaseaux, C., 1953, Sous-classe des branchiopodes *in* Piveteau, J. (Ed.) Traité de Paléontologie: Paris, Masson et Cie, v. 3, p. 257-268.

Defretin, S., 1950, Sur quelques *Estheria* du Trias francais à faciés germanique et de l'Hettangian: Soc. Géol. Nord Annales, v. 70, p. 214-227.

Defretin-Lefranc, S., 1969, Les conchostraces Triasiques du Groenland Oriental: Medd. om GrΦnland v. 168, no. 2, p. 124-136.

Dickins, J. M., and McTavish, R. A., 1963, Lower Triassic marine fossils from the Beagle Ridge (BMR 10) bore, Perth Basin, Western Australia: Geol. Soc. Australia Jour., v. 10, p. 123-140.

Etheridge, R., Jr., 1907, Fossils of the Port Keats bore, thirty miles north of Fossil Head, Treachery Bay *in* Official contributions to the palaeontology of South Australia: Supp. to Parliamentary Paper 55 of 1906, Adelaide, Govt. Printer, p. 11-15.

Jones, T. R., 1890, On some fossil Estheriae: Geol. Mag. (Great Britain), decade 3, v. 7, p. 385-390.

McKenzie, K. G., 1961, Vertebrate localities in the Triassic Blina Shale of the Canning Basin, Western Australia: Royal Soc. West. Australia Jour. v. 44, p. 69-76.

McWhae, J. R. H., Playford, P. E., Lindner, A. W., Glenister, B. F., and Balme, B. E., 1958, The stratigraphy of Western Australia: Geol. Soc. Australia Jour. v. 4, pt. 2.

Playford, P. E., Cope, R. N., Cockbain, A. E., Low, G. H., and Lowry, D. C., in press, Phanerozoic *in* Geology of Western Australia: West. Australia Geol. Survey Mem. 2.

Tasch, P., 1969, Branchiopoda *in* Moore, R. C. (Ed.) Treatise on Invertebrate Paleontology, Part R, Arthropoda 4 v. 1, p. R128-R191: Geol. Soc. America and Univ. Kansas, Lawrence, Kansas.

——— 1971, Antarctic and other Gondwana conchostracans and insects: new data; significance for drift theory: Internat. Gondwana Symposium, 2nd. South Africa 1970, Proc. and Papers, p. 589-592.

Teichert, C., 1950, Some recent additions to the stratigraphy of Western Australia: Am. Assoc. Petroleum Geologists Bull. v. 34, p. 1787-1794.

Veevers, J. J., and Wells, A. T., 1961, The geology of the Canning Basin, Western Australia: Australia Bur. Mineral Resources Bull. 60.

FIGURE 67 (opposite)

A, B. *Cyclammina incisa* (Stache); Pallinup Siltstone, South Stirling; WAM 73·93; x 40

C. *Cyclammina incisa* (Stache); Pallinup Siltstone, South Stirling; WAM 73·93; equatorial section; x 40

D. *Cyzicus minuta* (von Zieten); Kockatea Shale, near Kalbarri; F8320; x 3

E. *Cyzicus minuta* (von Zieten); Kockatea Shale, near Kalbarri; F8230; x 10

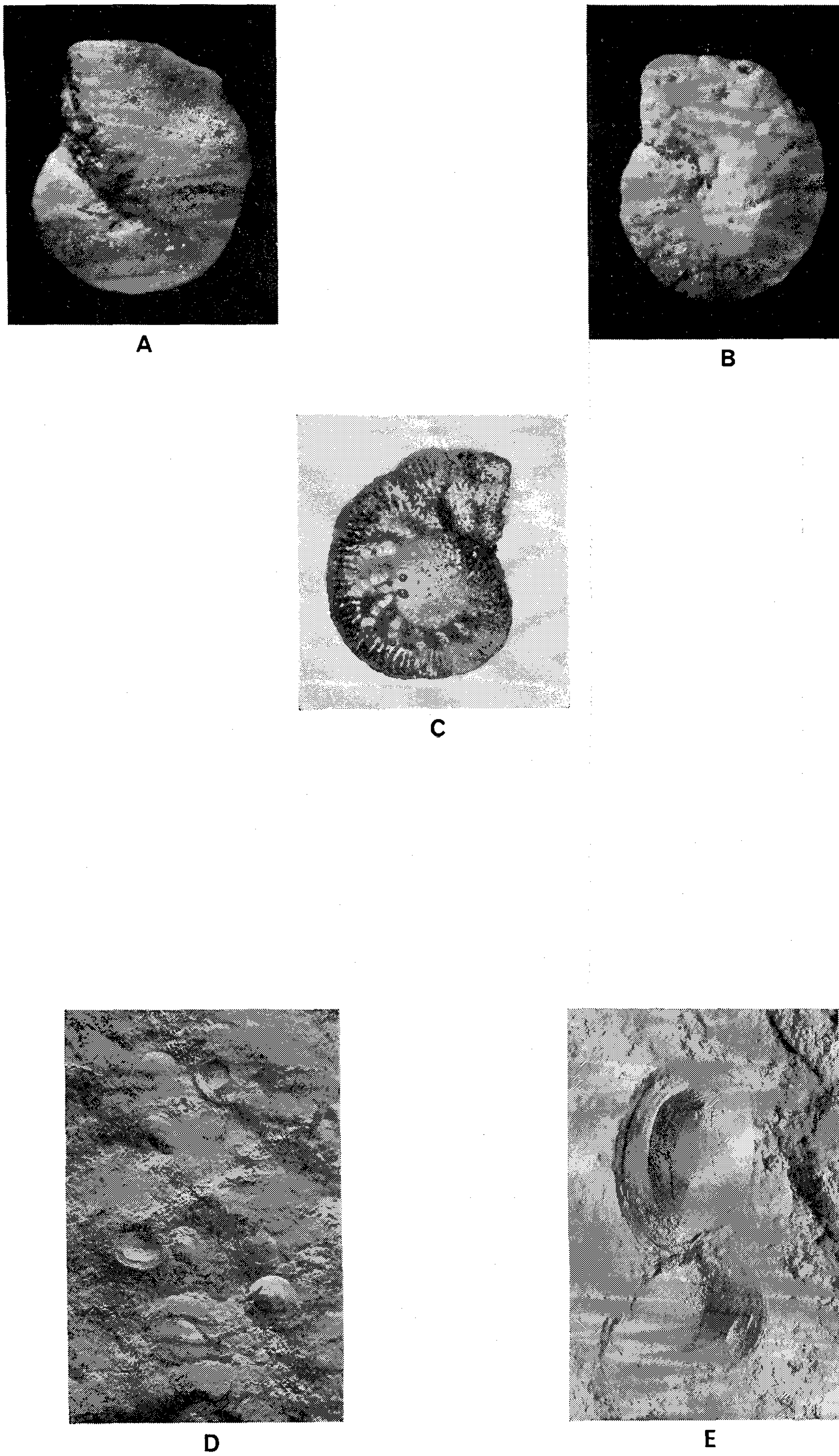

Figure 67.

THE FORAMINIFER CYCLAMMINA FROM THE PLANTAGENET GROUP

by A. E. Cockbain

ABSTRACT

Cyclammina incisa (Stache) is recorded from the Plantagenet Group for the first time. This Western Australian record, together with records from Victoria are from shallow water and support Robinson's (1970) suggestion that *Cyclammina* became confined to bathyal depths in the late Tertiary and had a shallower (? wider) depth range in the early Tertiary.

INTRODUCTION

A sample containing abundant foraminifers of the genus *Cyclammina* was forwarded to the Geological Survey by Mr. G. W. Kendrick of the Western Australian Museum. The sample came from a water bore on the property of P. M. and W. T. Grocock, Plantagenet location 5666, near South Stirling. The approximate co-ordinates are: Mount Barker 1 : 250 000 map Sheet, 615725: lat. 34° 36′ 00″ S, long. 118° 08′ 20″ E (see Fig. 68). The sample is a cuttings sample from 12-21 m depth and is given the Western Australian Museum registered number 73-93.

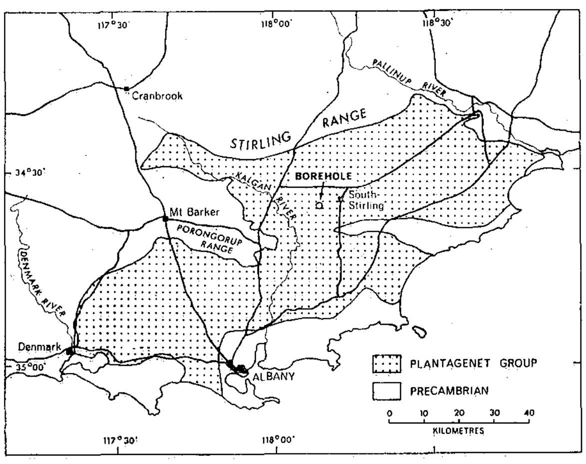

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Figure 68. Location of South Stirling borehole.

The foraminifers occur in a brown-grey, medium-grained sand which contains a few sponge spicules. This lithology is typical of the Pallinup Siltstone of the Plantagenet Group, from which the sample comes. All the foraminifers belong to the one species, and this is the first record of *Cyclammina* from the Plantagenet Group.

SYSTEMATIC PALAEONTOLOGY

Phylum PROTOZOA

Subphylum SARCODINA

Class RHIZOPODEA

Order FORAMINIFERIDA

Suborder TEXTULARIINA

Superfamily LITUOLACEA

Family LITUOLIDAE

Genus CYCLAMMINA Brady, 1879

Cyclammina incisa (Stache)
Figures 67 A, B and C.

1864 *Haplophragmium incisum* Stache: p. 165, pl. 21, fig. 1.

1864 *Haplophragmium maoricum* Stache: p. 166, pl. 21, fig. 2.

1930 *Cyclammina longicompressa* Chapman and Crespin: p. 97, pl. 5, figs. 3, 4.

1965 *Haplophragmoides* cf. *incisa* (Stache); Taylor: p. 150, figs. 2d, 3 (3a and 3b), 4 (4a and 4b).

1971 *Cyclammina incisa* (Stache); Hornibrook: p. 34, pl. 6, figs. 88-91, text fig. 9.

Remarks: Mr. Kendrick had picked out some 80 specimens of the species ranging in size from 1.1 mm to 2.7 mm in diameter. The number of chambers in the final whorl ranges from 11 to 15. No apertural pores were seen. The specimens vary somewhat in proportions, some being laterally compressed and others being fairly well rounded. Several specimens have more than the 11-12 chambers in the final whorl that is typical of *C. incisa*, but otherwise resemble that form; all are here considered to belong to the one species. A few specimens are distorted and thereby resemble *Cyclammina longicompressa* Chapman and Crespin, which, following Taylor (1965) I place in *C. incisa*.

There has been some doubt as to whether *incisa* is a *Cyclammina* (see Hornibrook, 1971). Taylor (1965) claimed that *incisa* (and other species usually assigned to *Cyclammina*) from the Paleocene and Eocene of Victoria should be placed in the genus *Haplophragmoides*. Ludbrook (1971) disputes this and supports the *Cyclammina* determination, as does Hornibrook (1971). If Taylor's (1965) figure 2d of *Haplophragmoides* cf. *incisa* is compared with Hornibrook's (1971) text figure 9 of *Cyclammina incisa* it will be seen that both are essentially the same and show the labyrinthic wall structure characteristic of *Cyclammina*. A thin section of a specimen from the Plantagenet Group (Fig. 67c) clearly shows the labyrinthic wall.

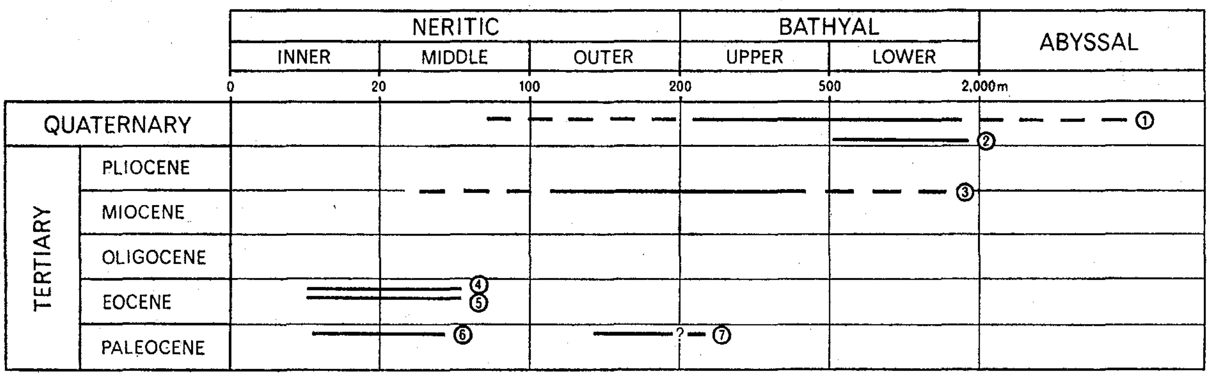
Distribution: In New Zealand *Cyclammina incisa* ranges through the Eocene and Oligocence with the upper limit uncertain (Hornibrook, 1971). Taylor (1965) records a similar range for the species in Victoria, and states that it is not associated with Paleocene and older faunas. In the Otway Basin Ludbrook (1971) has recorded the species from Cretaceous and Paleocene rocks, and in Western Australia *Cyclammina incisa* occurs in the type section of the King's Park Shale (Parr, 1938) which is now known to be of late Paleocene age (McGowran, 1964). The overall stratigraphic range of the species would seem to be at least Cretaceous to Oligocene.

DEPTH RANGE OF CYCLAMMINA

Since the work of Akers (1954) it has been generally considered that *Cyclammina* is a deep-water genus. Phleger (1960) states that it occurs in depths greater than 200 m whilst Bandy (1960) and Bandy and Arnal (1960) consider areanceous genera with labyrinthic walls (such as *Cyclammina*) to be characteristic of bathyal depths. Examination of Akers' (1954) data shows that the genus is found at depths between 80 m and 5 800 m. Only 7 per cent of the records are from waters shallower than 250 m and 86 per cent of the occurrences fall in the depth range 250 m to 2 500 m.

The Pallinup Siltstone is a shallow-water deposit. Fossil sponges from the formation suggest a water depth during deposition of between 20 and 200 m (de Laubenfels, 1953).

The borehole from which *Cyclammina incisa* is recorded is situated some 20 km south of the Stirling Range which was an island when the Pallinup Siltstone was deposited. It is probable that the species lived in water less than 50 m deep.



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① Present day; Akers,1954
② Gulf Coast; Robinson,1970
③ Gulf Coast; Robinson,1970
④ Pallinup Siltstone, Western Australia; this paper
⑤ Johanna River Sands and Demon Bluff Formation, Victoria; Taylor,1965
⑥ Dilwyn Clay, Victoria; Taylor, 1965
⑦ Kings Park Shale, Western Australia; Parr, 1938

Figure 69. Depth distribution of the genus *Cyclammina* from the Cainozoic.

The Paleocene and Eocene *Cyclammina*-bearing sediments of Victoria are also shallow-water deposits—a fact that persuaded Taylor (1965) that the species belonged not to *Cyclammina* but to the shallow-water genus *Haplophragmoides*. Taylor (1965) considers the formations yielding *Cyclammina* (Dilwyn Clay, Johanna River Sands and Demons Bluff Formation) to be near-shore paralic sequences.

In view of the descrepancy between these early Tertiary shallow-water records of *Cyclammina* and the present day, predominantly deep-water depth range, Robinson's (1970) observations on Gulf Coast *Cyclammina* are pertinent. He concluded that the genus became restricted in its depth range to the upper bathyal and deeper zones during the late Pliocene. In the early Pliocene and late Miocene the genus extended into the neritic depth zone. Early Tertiary *Cyclammina* from Victoria and Western Australia also have a neritic depth distribution. Data on the depth distribution of *Cyclammina* in the Cainozoic are summarised in Figure 69.

It is suggested that early Tertiary *Cyclammina* in Australia lived in the neritic zone; possibly the genus ranged into the bathyal zone. During the late Tertiary, as Robinson (1970) documents, the genus became a predominantly bathyal form and at the present time is extremely uncommon in the neritic depth zone. The genus may have been forced out of the neritic zone by competition with other forms. *Cyclammina* seems to be a fairly tolerant genus. Present day forms have a rather wide temperature tolerance (12.1° C to 1.2° C according to Akers, 1954), and Boltovskoy (1963) remarks that the genus can survive low concentrations of oxygen. Wide variation in environmental factors is a characteristic feature of near-shore shallow waters and *Cyclammina* would have been preadapted for the lower temperatures of bathyal depths.

REFERENCES

Akers, W. H., 1954, Ecologic aspects and stratigraphic significance of the foraminifer *Cyclammina cancellata* Brady: Jour. Paleontology v. 28, p. 132-152.

Bandy, O. L., 1960, General correlation of foraminiferal structure with environment: Internat. Geol. Congr., 21st, Norden 19 pt. 22, p. 7-19.

Bandy, O. L., and Arnal, R. E., 1960, Concepts of foraminiferal paleoecology: Am. Assoc. Petroleum Geologists Bull, v. 44, p. 1921-1932.

Boltovskoy, E., 1963, Foraminiferos y sus relaciones con el medio: Argentino Mus. Cienc. Nat. Rev., Hidrobiologia v. 1, p. 21-107.

Chapman, F., and Crespin, I., 1930, Rare Foraminifera from deep borings in the Victorian Tertiary. Part II: Royal Soc. Victoria Proc. v. 43, p. 96-100.

de Laubenfels, M. W., 1953, Fossil sponges of Western Australia: Royal Soc. West. Australia Jour. v. 37, p. 105-117.

Hornibrook, N. de B., 1971, A revision of the Oligocene and Miocene Foraminifera from New Zealand described by Karrer and Stache in the reports of the "Novara" expedition (1864): New Zealand Geol. Survey Paleont. Bull. 43.

Ludbrook, N. H., 1971, Stratigraphy and correlation of marine sediments in the western part of the Gambier Embayment *in* Wopfner, H., and Douglas, J. G. (Eds.), The Otway Basin of southeastern Australia: South Australia and Victoria Geol. Surveys Spec. Bull., p. 47-66.

McGowran, B., 1964, Foraminiferal evidence for the Paleocene age of the King's Park Shale (Perth Basin, Western Australia): Royal Soc. West. Australia Jour. v. 47, p. 81-86.

Parr, W. J., 1938, Upper Eocene Foraminifera from deep borings in King's Park, Perth, Western Australia: Royal Soc. West Australia Jour. v. 24, p. 69-101.

Phleger, F. B., 1960, Ecology and distribution of Recent Foraminifera: Baltimore, The Johns Hopkins Press.

Robinson, G. S., 1970, Change of the bathymetric distribution of the genus *Cyclammina:* Gulf Coast Assoc. Geol. Socs. Trans. v. 20, p. 201-209.

Stache, G., 1864, Die Foraminiferen des Tertiären Mergel des Whaingaroa-Hafens (Provinz Auckland): Novara Exped. Geol. Theil v. 1, p. 161-304.

Taylor, D. J., 1965, Preservation, composition, and significance of Victorian Lower Tertiary "*Cyclammina* faunas": Royal Soc. Victoria Proc. v. 78, p. 143-160.

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DIVISION V

Report of the Superintendent Surveys and Mapping for the Year 1973

The Under Secretary for Mines:

For the information of the Hon. Minister, I submit my report on the activities of the Surveys and Mapping Branch for the year ended 31st December, 1973.

STAFF

The membership of the staff now totals 118 officers comprising 99 males and 19 females in the following categories:

Professional	37
Clerical	12
General	34
Technical	5
Cadet Cartographers	30
	118

Cadet Cartographers Messrs. Cresswell and Taylor qualified in the Diploma of Cartography and were appointed to the Level 1 Career range as Cartographic Draftsmen.

Eight Cadets qualified in the latter part of the year, and are eligible for appointment to the Level 1 Cartographic range in the new year.

Of the six Level 1 Survey Examiners loaned to this Department from the Lands Department on 19th June, 1972, five are still with us, and the survey examination of mining tenement surveys still continues unabated.

The number of Surveyors authorised by the Hon. Minister to perform cadastral surveys for this Department now stands at 81.

The accumulated balance of deposited survey fees which stood at $5 419 862 at the beginning of the year was reduced to $3 497 600 as at 31st December.

For the first time since the year 1964 there was a falling off of value of surveys performed. The value dropped from $625 517 in 1972 to $400 501 in 1973.

Under the terms of the various Agreement Acts (Iron, Nickel etc.) the State is primarily required to perform the survey of the selected mineral leases, the cost of which survey is then recouped to the State. These amounts do not appear in the Treasury Suspense Account, Statement No. 4 showing deposited survey fees under the Mining Act, but are included in the total value of surveys performed.

The transition to metrication of our surveys, initiated last year, is progressing smoothly.

The plotting attachment to the Hewlett-Packard 9810A computer was acquired during the year and proved its worth as a labour saving device.

All dealings under the Petroleum legislation in both the "onshore" and "offshore" areas and under the Petroleum Pipelines Act are being handled expeditiously and all maps show the up-to-date situation at any given time.

The drawing of maps for the Geological Survey Branch and the cadastral maps for the Mining Registrars is progressing favourably, with a heavy increase in the former expected in the new year when the full impact of the geological survey staff fulfilment is felt.

Itemised reports of the activities of the three main sections of the Branch are appended hereto.

A. A. HALL,
Superintendent, Surveys and Mapping.

SURVEY SECTION

1. Surveys

Survey of mining leases, claims, special act mining leases, sections of temporary reserve boundaries and other tenements were carried out during the year by Licensed Surveyors by commission from this Department. Survey work done is summarised by the following tables:

Table A

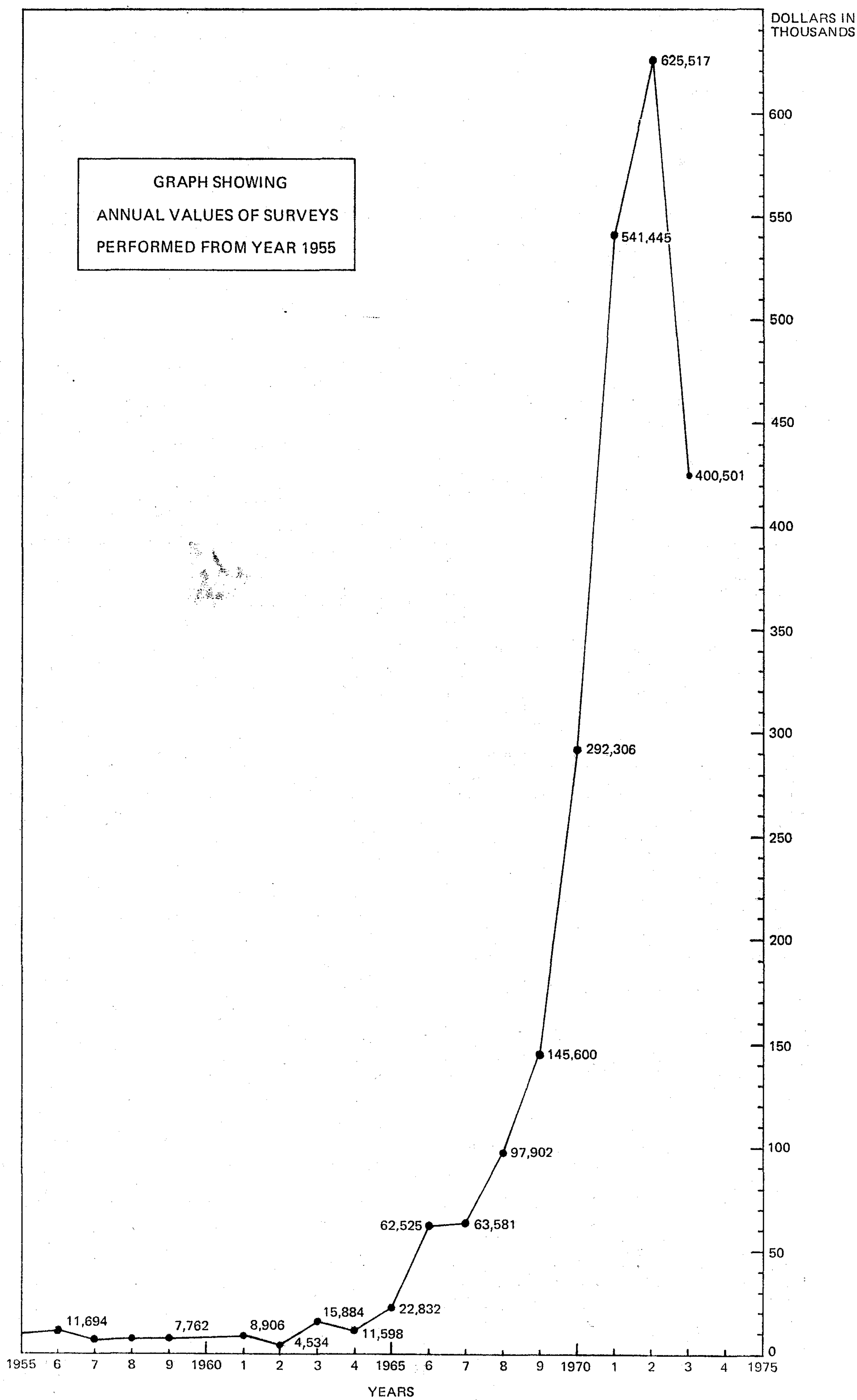
Number of Surveyors	31
Number of survey field parties used (est.)	40
Number of tenements surveyed	2 162
Number of field books lodged	288
Total boundary line run	5 755·533 km
Total traverse or connection line run	363·168 km
Total area delineated by survey	230 758 ha
Total distance travelled	79 993 km
Total value of survey work	$350 119.83
Total value of photogrammetric survey	$ 40 580.00
Total value of " control " survey	$ 9 801.22
Total (see graph)	$400 501.05

Table B

Surveyor	Field Books	Surveys	Hectares
McKimmie, Jamieson and Partners Pty. Ltd.—			
M. J. McKimmie	44	317	36 559
J. A. Jamieson	25	143	18 953
T. L. Markey	8	18	5 088
W. N. Thompson	1	....	....
M. M. Fisher and Assoc.—			
M. M. Fisher	28	270	29 968
F. R. Rodda Pty. Ltd.—			
F. R. Rodda	21	236	25 058
Land and Engineering Surveys Pty. Ltd.—			
R. J. Benetti	18	153	10 900
K. J. Croghan	6	64	6 905
McCarthy, Smirk and Associates—			
D. H. Stewart	16	171	19 802
D. F. V. Wilson and Associates—			
D. F. V. Wilson	13	104	10 699
K. F. Paterson	15	120	12 223
Pascott and Zadnik Pty. Ltd.—			
G. Pascott	6	54	5 828
J. P. Zadnik	5	42	4 859
M. J. Byrne	21	104	7 313
Hille and Thompson—			
A. G. Thompson	5	46	5 180
P. J. Hille	3	16	1 790
W. A. Berryman and Associates—			
A. C. Watson	6	42	4 703
R. Babb	2	16	1 828
J. Guidice	5	49	4 895
Warren F. Johnson Pty. Ltd.—			
K. Amsuss	5	40	4 622
J. Ranieri	5	40	4 400
R. J. Rule	4	11	1 153
B. A. McNamara	4	14	1 042
A. K. King	3	19	1 279
Gordon and Hams—			
I. M. Gordon	4	15	839
G. C. Callaghan	3	22	1 520
H. W. Denton	3	16	1 492
L. J. Burkett	1	8	926
Privett Associates Pty. Ltd.—			
L. G. Privett	1	8	676
C. D. McAllister	1	1	20
Compiled	....	3	238
Australian Aerial Mapping	....	....	*
Associated Surveys—			
D. W. Thompson	6	....	†
	288	2 162	230 758

* Photogrammetric Surveys only (excludes 167 tenements ground marked but not yet lodged).

† Control Surveys only.


GRAPH SHOWING
ANNUAL VALUES OF SURVEYS
PERFORMED FROM YEAR 1955
DOLLARS IN THOUSANDS
625,517
541,445
400,501
292,306
145,600
97,902
62,525
63,581
22,832
15,884
11,598
11,694
7,762
8,906
4,534
0
50
100
150
200
250
300
350
400
450
500
550
600
1955
6
7
8
9
1960
1
2
3
4
1965
6
7
8
9
1970
1
2
3
4
1975
YEARS

Thirty-one surveyors are shown as submitting work to the Department, whilst this figure can be increased to 40 effective survey parties in the field.

Surveys have continued to be issued to surveyors following a letter to each applicant notifying him of the intended survey. This procedure has proved most satisfactory.

2. *Special Projects*

The survey of those Sections of ML249SA under the Goldsworthy Iron Mining Agreement in the Shay Gap, Goldsworthy and Ord Range areas were contnued this year. This work involves the running of the boundaries and the connections therefrom to the local geodetic control using electronic distance measuring instruments.

A similar connection using electronic distance measuring instruments was commenced in the Paterson Range area.

3. *Survey Fees and Regulations*

Further negotations took place concerning a new scale of survey fees. It is anticipated that a new scale will be introduced early in 1974.

4. *Geodetic*

4.1 In association with the photogrammetric survey recently carried out in the Ora Banda area north of Kalgoorlie an extensive network of basic carastral control was commenced and completed.

4.2 This work has resulted as follows in:

4.2.1 The implementation of a permanent cadastral control system.

4.2.2 The incorporation into this system of all previous cadastral control traverses associated with the Ora Banda Photogrammetric Survey.

4.2.3 The transfer of all data processing requirements by the surveys section to the CYBER 72 Computer at the WARCC.

4.2.4 The use of automatic plotting in conjunction with the CYBER 72 Computer to provide basic cadastral control plot sheets as an integral part of the permanent system mentioned in (1).

4.3 Original Work in Ora Banda Area

4.3.1 To supplement the photogrammetric work carried out by Associated Surveys Pty Ltd in the Ora Banda area in August-November 1971, a network of traverses was computed by the Surveys Section through existing cadastral surveys and tied into the primary control network where connections were available. This work was completed between December 1971 and October 1972 using the N.C.R. 315 Computer at the W.A. Treasury A.D.P. Centre.

A total of 61 main traverses were completed and filled under the general prefix of ORA BANDA traverses.

4.3.2 The primary control used for this original cadastral traversing consisted of:—

(1) State/National Geodetic network.
Juardi.
Carnage.
Comet NMF/140.
Vetters NMF/660.
Ellis.

(2) Photo control established.
S.W. cnr. MC 142 S.
N.E. cnr. MC 2339 W.
N.E. cnr. MC 230x.

In addition to the primary control listed above, the A.M.G. co-ordinates of a number of survey marks determined by photogrammetric methods were also used as control.

4.3.3 A complete list of the horizontal control used for the photogrammetric project in the Ora Banda area is given on page 125 of 1036/71.

Due to the lack of cadastral connections it was not possible to fully utilise this control in establishing the cadastral traverse network.

4.4 Integration of Original work into new system

4.4.1 In March 1973 all data processing work for the Surveys Section was transferred to the CYBER 72 Computer at the W.A.R.C.C. This provided access to Traverse programme LACORD 1 together with the plot programme LACPLOT, developed by the Lands and Surveys Department.

4.4.2 In order to strengthen the control for the cadastral traverse network in the Ora Banda area an additional 10 cadastral points were tied in to the primary control network by tellurometer traverses. This additional control was provided by Associated Surveys in June 1973. (D. Thompson Field Books 4-8).

4.4.3 Between May and September, 1973 the whole of the original cadastral traverse network in the Ora Banda area was updated to include the additional control described in 4.4.2. Where necessary a numbed of additional photo points were also used for control. This updated network was recomputed on the CYBER 72 Computer simultaneously producing traverse plot data for use with the plot programme (see 4.4.5).

4.4.4 As the original traverse data used on the N.C.R. 315 Computer was also suitable for input in programme LACORD 1 on the CYBER 72 Computer, the updated network was organized in such a way as to include as much of the original data as possible. In some cases the original traverses were completely rerouted. Where possible the original traverse numbers were retained.

All traverses in the updated network have been prefixed with KALGOORLIE 250 000 and are numbered sequentially 1-65. These traverses are filed in numerical order under Kalgoorlie 250 000 Standard Traverses, allowing for further expansion within this map sheet area when required.

A completely new set of traverse index sheets has been drawn up on the 1 : 50 000 series.

4.4.5 Cadastral control Base Plots were produced from the traverse data using programme LACPLOT and the 718 Flatbed plotter. The base plots produced under this new system consist of the following 1 : 50 000 sheets:—

Comet Vale.
Siberia.
Scotia.
Ringlock.
Credo.
Ora Banda.
Broad Arrow.
Dunnsville.
Kunanalling.
Kalgoorlie.

In addition to the above 50 000 series base plots, a number of larger scale plots have also been produced in selected areas within thses sheets.

4.5 Work Summary

4.5.1 The implementation of the new system and the updating of the cadastral traverses was carried out between May-September 1973. Staff involved:—

Draftsman (Level 1)—1
Drafting Assistants—2

4.5.2 Total distance of traversing covering the updated network:—

1 412 km (877 miles).

Error in traverse closures:—

Max. vector error	9.330 m
Mean vector error	1.263 m

4.5.3 Computer and Plotter time taken for producing the updated traverse network together with the base plots listed in 4.4.5:—

CYBER 72 Computer—

Traverse runs	0.194 hrs
Plot production	0.173 hrs
Total Computer time	0.367 hrs

Flatbed Plotter time—

10 basic control plots (1 : 50 000)	3.0 hrs

4.6 Conclusion

4.6.1 Although this cadastral traverse system was an extension of the Ora Banda Photogrammetric project, the system now forms part of a total carastral mapping system.

4.6.2 Provided sufficient primary horizontal control exists with cadastral ties, the Surveys Section can introduce cadastral traverse networks in particular project areas undergoing mining development. This can be done independent of photogrammetric work if required, and as part of a standard cadastral mapping programme. The introduction of such a system will also assist in the tying of mining tenement surveys into the State integrated Surveys system on the Australian Map Grid (A.M.G.).

5. Office Computer

The Hewlett Packard Model 9810A computer-calculater unit operated by the Survey Section is now operating close to maximum capacity. During the year a 9862A Plotter was obtained together with a Tape Cassette 9865A Memory as peripheral equipment for the basic calculater.

The library of survey programmes has been extended and modified to be compatible with these new units.

Other branches of the Department, the State Mining Engineers' Branch and the Geological Survey have been invited to make use of this computting facility and officers from those branches have requested programmes and machine time appropriate to their needs.

Programmes developed and written under this arrangement have been a programme with plot of oil-bore pressures, a seismic refraction programme with plot and a composite series of aquifer analysis programmes with plot options.

6. Petroleum

The collation and compilation of the presently known bathymetry of the continental shelf in the offshore area of the Perth Basin extending from north of Geraldton to Cape Leeuwin was commenced at a scale of 1 : 500 000.

All dealings in both "onshore" and "offshore" areas and under the Petroleum Pipelines Act were handled expeditiously and all maps show the up-to-date situation at any given time.

MAPPING DIVISION

Standard Mapping

A total of 133 new plans at a scale of 1 : 50 000 were prepared covering areas in the Pilbara of Wyloo, Pyramid, Mt. Bruce, Roy Hill, Turee Creek, Ningham. There were 103 new plans started and revision work was carried out on 223 plans covering 1 : 250 000 sheet areas of:—

Kirkalocka.
Duketon.
Belele.
Wiluna.
Cue.

A further 6 plans at 1 : 100 000 scale were completed and 3 more commenced.

Four large wall plans covering 20 1 : 250 000 sheets showing development in the Pilbara Region were prepared for the Department and the Department of Development and Decentralisation.

Geological Mapping 1 : 250 000 Series

The mapping programme continued and the following sheets were completed and sent for printing:—

Geraldton—drawn by Contractors in Canberra.
Malcolm—Cape Arid.
Murgoo.
Mason.

Preliminary Editions were published of:—

Yalgoo.
Dongara—Hill River.

Work continued on the following sheets:—

Seemore.
Mason.
Vernon.
Yalgoo.
Ravensthorpe.
Lake Johnston.

New sheets started were:—

Cundeele.
Rason.
Plumridge.
Leonora.
Laverton.

Other Work

Approximately 400 miscellaneous plans were drawn for various hydrological reports, bulletins, Annual Report and other publications including diagrams for A.N.Z.A.A.S. and A.I.M.M. conference.

Photographic Section

This section continued to be under pressure throughout the year and regular overtime was necessary to meet the demand.

1 877 items were prepared on the Process Camera comprising reductions, enlargements and same size copy

1 790 items of process work were prepared using Vacuum Frames and 58 metal plates were made for the A. B. Dick machine.

Work on the Enlarger increased to 4 172 items and 119 rolls of 35 mm film was processed both colour and black and white for slide preparation and prints which included 643 in colour.

Plan Printing

Plan printing work was constant with 39 859 prints of various kinds being done on the Ammonia machine.

5 448 plans were mounted on cloth and 2 140 photo copies were produced.

Microfilming

Various programmes of microfilming were done and preparation work was done in this section and actual filming of G.S.W.A. reports and other library publications was carried out by staff members.

Staff

Staff remained fairly constant but below strength by 3 Level 1 draftsmen.

Three Level 1 draftsman were successful in being reclassified to Draftsman Special, Level 1A.

PUBLIC PLAN SECTION

During 1973 the following applications were charted on the Public Plans:—

Mineral Claims	7 500
Mineral Leases	57
Gold Mining Leases	984
Licenses to Treat Tailings	176
Prospecting Areas	565
Coal Mining Leases	262
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.	269
	9 813

346 applications for new temporary reserves were processed besides processing of annual renewals and cancellations.

Backlogs of processing carried over from 1972 were cleared with a minimum use of overtime. No abnormal backlogs were carried to 1974.

Much staff time has been used searching records to satisfy public enquiry on old Gold Mining Areas.

Emphasis is now being given to checking of internal cross reference of records and renewal of plans.

Head Office Plan Sales totalled $9 482.79 for the sale of:—

Dyelines	11 642
Transparencies	429
Photo copies and Microfilm copies	4 368
T.R. list Iron	58
T.R. list Other Minerals	56
State Map	216
Gazetteer	190
Mineral Occurrence Map	163
Gold Map	64

DIVISION VI

CONTENTS

DIVISION VI

Government Chemical Laboratories Annual Report—1973

Under Secretary for Mines:

I submit a summarised Annual Report on the operations of the Government Chemical Laboratories for the calendar year 1973.

Administration

At 31 December, 1973, the Government Chemical Laboratories consisted of 7 Divisions, 5 on the Plain Street site, 1 at Bentley and 1 at Kalgoorlie, a Library and a central office under the control of the Director (Government Mineralogist, Analyst and Chemist) as follows:

Director—R. C. Gorman, B.Sc., M.A.I.A.S., A.R.A.C.I.

Deputy Director—vacant.

Agriculture Division—H. C. Hughes, B.Sc., M.A.I.A.S., A.R.A.C.I., Chief of Division.

Engineering Chemistry Division—B. A. Goodheart, B.Sc., A.M.I.E. Aust., A.R.A.C.I., Chief of Division.

Foods, Drugs, Toxicology and Industrial Hygiene Division—N. R. Houghton, B.Sc., A.R.A.C.I., Chief of Division.

Industrial Chemistry Division—E. B. J. Smith, B.Sc., D.Phil., M.A.I.A.S., A.R.I.C., A.R.A.C.I., A.P.I.A., Chief of Division.

Kalgoorlie Metallurgical Laboratory—G. H. Muskett, A.W.A.S.M., M. Aust. I.M.M., Officer in Charge.

Mineral, Division—G. H. Payne, M.Sc., A.W.A.S.M., A.R.A.C.I., Chief of Division.

Water Division—N. Platell, B.Sc., A.R.A.C.I., Chief of Division.

Librarian—N. L. Lombardi, A.L.A.A.

Office—D. E. Henderson, Senior Clerk.

On March 3 Dr. L. W. Samuel, Director of these Laboratories since July 24, 1957, went on 35 weeks of accumulated annual leave prior to retiring on November 14, 1973. Dr. Samuel thus became the longest serving Director of these Laboratories.

In the 17 years of which he was Director there were considerable changes made for which he was responsible with respect to staff, buildings and work functions. The staff has grown from 57 to 136, and there have been three extensive building programmes more than doubling the floor space at the Plain Street site. The Engineering Chemistry Division, formerly with the Department of Industrial Development and the Kalgoorlie Metallurgical Laboratory have, in that time, come under the jurisdiction of the Laboratories. With this growth in size and functions has come increasing respect and status of the Laboratories due to the service and efficiency that he encouraged.

Dr. Samuel's dedication to duty, his attention to detail, his capacity for work and his clear logical scientific reasoning are a few of the personal attributes for which his term as Director will always be remembered. All staff wish him a long and happy retirement.

In November, Mr. R. C. Gorman, Deputy Director since December 1964, was appointed as the new Director.

The close association of these Laboratories with other Government Departments and kindred associations was maintained and extended during 1973. Special effort was made during the year to extend our assistance, where possible, to other departments beyond that of purely supplying an analytical service, but to provide practical professional advice.

Various members of the staff are members of the following Committees:

Australian Water Resource Council:
- Technical Committee on Water Quality. State Working Group.

Ecology of the Ord Dam—Sub-Committee and Pesticide Sampling Study Group.

Fluoridation of Public Water Supplies Advisory Committee.

Food and Drugs Advisory Committee.

Laporte Effluent Disposal Committee.

Laporte Industrial Factory Agreement, Review Committee.

Lupin Technology Committee.

(11)—39934

Oils Committee of the Government Tender Board.

Paints Advisory Committee of the Government Tender Board.

Pesticides Registration Committee.

Pesticides Residues Advisory Committee.

Poisons Advisory Committee.

Rivers and Waters Technical Advisory Committee.

Scientific Advisory Committee under the Clean Air Act and Fluoride Sub-Committee.

Standards Association of Australia; Iron Ore Analysis Committee.

Swan River Conservation Board.

Veterinary Medicines Advisory Committee.

Water Purity Advisory Committee.

Most of the committees are very active and involve a considerable amount of the time of the officers concerned. This is not only in meetings but in the necessary inspections, preparation of information and collection and examination of samples. A great deal of effort was devoted during the year to a long standing problem of the Swan River Conservation Board with respect to a wool-scouring effluent. Similarly, a considerable amount of time was devoted to the study of the Laporte effluent problem.

Staff

As of 31 December, 1973 the establishment of the Laboratories was as follows:

Professional	78
General	44
Clerical	11
Wages	3
Total	136

Although four more positions were created in 1973 this was insufficient to cope with the back-log of work or with the urgent requirements of various Departments. Additional staff are necessary to provide the chemical service demanded by the growing professional staff in other Departments. In many cases professional staff of other Departments are hampered in their research or advisory work because of our inability to meet their requirements either in numbers of analyses required or in the speed of return of results. This can, and has led to the increase in growth of chemists in other Departments without any saving to the Treasury in salaries but with a probable overall loss of efficiency.

It is pleasing to record the increased participation of the staff in professional societies particularly in the executive of these societies. Because of the broad function of the Laboratories the need for knowledge of other over-lapping disciplines and association with the professionals of these disciplines is essential to provide an efficient and valued service.

The breadth of activities can be gauged from the scientific societies to which staff members belong and actively participate; these cover over 20 such societies in the fields of chemistry, engineering, agriculture, chemical engineering, health, toxicology, plastics, paints, water pollution, waste water, geology, mining, metallurgy, corrosion and fuels.

Various members of the staff have acted as laboratory assessors for the National Association of Testing Authorities during the year.

Library

The continuing growth of the Library and the need to maintain this growth is being restricted by available shelf space. The congestion in the Library has required a severe culling of older books and journals which are now stored away from the main Library. An up to date appropriately stocked Library is an essential requirement for a laboratory covering the range of functions of our seven Divisions.

During the year an additional 3 104 items were added to the Library. These consisted of 358 monographs, 2 254 periodicals and 492 reports.

Buildings

By early in 1973 all damage to the building by the disastrous fire of early 1972, had been repaired. The efforts of the Department of Public Works in reconstruction after the fire were exceptional and we are greatly indebted to them for this.

Additional changes will be required on the Plain Street site in 1974 if the planned Australian Water Resources Council Net-Work Survey commences. This will require considerably increased space for the Water Division. Approval for further needed extensions to the Engineering Chemistry Division at Bentley is still required.

The Kalgoorlie Metallurgical Laboratory is occupying old buildings on the School of Mines' site at Kalgoorlie. As the long term plan of the School of Mines involves the use of the land on which the Kalgoorlie Metallurgical Laboratory is situated, a decision will be required soon on re-building and possible re-siting of the Kalgoorlie Metallurgical Laboratory.

Equipment

Major equipment obtained during the year includes an Applied Research Laboratories Spectrograph, a Beckman Amino Acid Analyser, another gas chromatograph and an X-ray diffractometer.

Blood Alcohol

During 1973 243 samples of blood were received for alcohol analysis from persons killed in traffic accidents out of a total of 371 road fatalities.

Of the motor vehicle drivers fatally injured, half of these had 0.150 per cent or greater of alcohol in their blood, that is equivalent to about 15 or more middies of beer, and over two thirds had a blood alcohol content of over 0.08 per cent.

Under the Traffic Act, nearly 700 samples of blood of offending drivers were submitted for analysis. Of these, 90.5 per cent had 0.08 per cent or more alcohol in their blood. This is comparable with previous years and again emphasises that unless a greater effort was made to catch offending drivers little would be achieved by the suggested lowering of the offence level from 0.08 to 0.05 per cent alcohol.

General

The number of samples received in 1973 of 23 741 is only a very slight increase on the 23 642 received in 1972.

The number of samples received give some measure of our activities but far from completely describes our work. A major factor in this is the variation in the amount of work associated wth different samples. Also, it is not possible to give a statistical account of the time and effort devoted to the various Committees mentioned; to advisory work for Government Departments, industrial firms and the general public; attendance at Courts; visits to factories, etc.

The source of the samples received and their allocation to the various Divisions are shown in Table 1. In a number of cases samples were allocated to more than one Division because for the full elucidation of the problem it was necessary to call on the ability and experience of different specialists. This co-operation between and mutual assitance of Divisions is part of the policy that we are one laboratory, not seven separate Divisions. Discussion and interchange of ideas between Divisions is encouraged since the problems received by one Division may be helped by, or rely on, specialists in other Divisions.

TABLE 1

SOURCE AND ALLOCATION OF SAMPLES RECEIVED DURING 1973

Source	Division						Total
	Agriculture	Engineering Chemistry	Food and Drug	Industrial Chemistry	Mineral	Water	
STATE—							
Aboriginal Affairs Authority	41	....	....	....	33	11	85
Agriculture Department	6 986	....	604	10	182	81	7 863
Community Welfare Department	....	....	....	....	....	1	1
Consumer Protection Bureau	....	....	2	....	1	9	12
Government Chemical Laboratories	1	36	35	2	304	9	387
Development and Decentralisation Department	....	....	....	....	1	....	1
Education Department	8	....	1	....	....	....	9
Environmental Protection Department....	....	....	6	....	....	....	6
Fisheries and Fauna Department	....	....	288	....	....	28	316
Forests Department	....	....	4	....	....	....	4
Geological Survey	....	....	....	....	1 227	164	1 391
Harbour and Lights Department	....	....	1	1	....	....	2
Hospitals	2	....	121	....	1	1	125
Labour Department	....	....	94	18	2	....	114
Local Government Association	....	....	....	....	3	....	3
Main Roads Department	....	....	2	....	3	....	5
Medical Department	....	....	....	....	4	2	6
Metropolitan Water Board	....	3	....	....	2	2 286	2 291
Milk Board of W.A.	....	....	170	....	....	....	170
Mines Department	....	....	60	....	488	1	549
National Parks Board	....	....	....	....	....	3	3
Peel Inlet Advisory Committee	....	....	....	....	....	60	60
Police Department	....	....	2 276	....	37	....	2 313
Public Health Department	195	1	1 825	4	1 043	62	3 130
Public Works Department	....	....	165	10	93	1 942	2 210
State Housing Commission	....	....	4	....	8	....	12
Swan River Conservation Board	....	....	1	....	1	261	263
Tender Board	....	....	....	84	29	....	113
University of W.A.	....	....	....	....	2	....	2
COMMONWEALTH—							
Various Departments	....	....	3	....	11	20	34
PUBLIC—							
Free	4	....	....	....	43	3	50
Pay	113	36	679	7	738	638	2 175
TOTAL	7 350	76	6 341	136	4 256	5 582	23 741

There have been increases in numbers of certain samples during the year. In particular there was a considerable increase in the total number of shark, fish, prawns and crayfish samples from 452 in 1972 to 1 161 in 1973. This increase is primarily due to the interest of the Fisheries and Fauna Department and the Department of Public Health in mercury in fish. Also increased were the numbers of horse doping samples from 211 last year to 346 this year. Work in this area is likely to increase more in 1974 with the advent of greyhound racing, as we will be doing this work for the Greyhound Racing Board of Control. The samples of dust from air pollution and industrial hygiene studies also were an area of major increase, nearly 40 per cent more than 1972. With the increased number of private analytical laboratories now operating in Western Australia, it has been our policy not to compete with these laboratories in the public sphere. As a result, the number of samples from private sources has decreased over the years, this has been particularly so in the mineral field where these private laboratories have been most active. Samples from private sources are generally not accepted unless these consultant laboratories are unable to do the work, which is still fairly common.

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 traditional subjects. As a consequence of this, officers of the Laboratories are making a fuller professional contribution to these fields than purely a service one of supplying analytical data and resulting in increased job satisfaction.

R. C. GORMAN,
Director.

AGRICULTURE DIVISION

Staff

Since March when Mr. Hughes became Acting Deputy Director Mr. Jago has been Acting Chief of Division. Thus the Division operated for 10 months of the year with one senior officer below strength. This in turn resulted in the curtailment of much investigational work, a measure which is unavoidable, unfortunate and most undesirable. since it is imperative to maintain an active programme of research if the Division is to continue functioning efficiently.

The requirement for more staff to cope with the Division's work as mentioned in the annual report for 1972 was partly recognised by creation of a Level 1 position. However, an appointment had not been made at the end of December.

Professional

Mr. Hughes became a member of the Lupin Seed Technology Committee formed under the auspices of the Grain Pool of Western Australia. Mr. Jago remained President of the Western Australian Branch of the Australian Society of Soil Science. Mrs. B. Reed prepared a paper entitled "The Determination of Sulphur in Plant Material by X-ray Fluorescence Spectroscopy" which was published in the Journal of the Science of Food and Agriculture. Mr. R. Taylor prepared a paper entitled "The Atomisation Mechanism of Calcium in an Air Acetylene Flame" which he presented at the 9th Australian Spectroscopy Conference in Canberra in August.

The talks and discussion programme conducted monthly in the Division was continued in 1973.

Equipment

The replacement of services damaged by fire in 1972 was completed with the installation of grinding mills in the sample preparation section and the receipt of a Spectrographic Analyser (Applied Research Laboratories, Model 26000-1) in place of the Hilger & Watts large quartz prism spectrograph which had been destroyed.

A Packard dual channel gas chromatograph and an Infotronics automatic digital integrator system was commissioned in October. These two instruments were supplied by the makers as replacements for a system delivered in 1971 which was never fully operational. The replacements have given good service.

A Beckman Amino Acid Analyser, Model 118 was delivered in October but was not operational at the end of the year because of trouble with base line drift. We are indebted to the Commonwealth Extension Services Grants for the finance to purchase this instrument. It is expected to be fully utilised for work for the Department of Agriculture especially in relation to poultry and pig nutrition studies.

Nature of Samples

The sources, types and numbers of samples received are shown in Table 2.

TABLE 2

AGRICULTURE DIVISION

	Aboriginal Affairs	Agriculture Department	Education Department	Public		Public Health Department	Other	Total
				Free	Pay			
Animal—								
Blood	....	99	....	....	....	....	....	99
Fat	....	51	....	....	....	....	....	51
Liver	....	251	....	....	....	....	....	251
Tissue	....	335	....	....	2	....	....	337
Urine	....	18	....	....	....	....	....	18
Various	....	6	....	....	1	....	....	7
Cereal—								
Oats	....	99	....	....	1	....	....	100
Wheat	....	683	....	....	4	....	....	687
Various	....	12	....	....	3	....	1	16
Fertiliser—								
Fertiliser Act	....	154	....	....	....	....	....	154
Various	....	14	....	....	17	1	....	32
Horticulture—								
Apples Fruit	....	75	....	....	....	....	....	75
Tree parts	....	443	....	....	....	....	....	443
Bananas	....	20	....	....	....	....	....	20
Carrot leaves	....	256	....	....	....	....	....	256
Citrus leaves	....	264	....	....	....	....	....	264
Grapevine	....	183	....	....	....	....	....	183
Native vegetation	....	362	....	....	....	....	....	362
Peach	....	61	....	....	....	....	....	61
Various	....	154	....	....	....	....	....	154
Miscellaneous—								
Filter papers	....	....	....	....	....	31	....	31
Human tissue	....	....	....	....	....	135	....	135
Rapeseed	....	32	....	....	15	....	....	47
Rape tops	....	108	....	....	....	....	....	108
Safflower seeds	....	36	....	....	....	....	....	36
Various	....	16	....	1	13	4	2	36
Pasture and Fodder—								
Clover	....	51	....	....	1	....	....	52
Feeding stuffs	....	171	8	....	24	....	....	203
Feeding stuffs Act	....	182	....	....	....	....	....	182
Grass	....	24	....	....	1	....	....	25
Hay	....	203	....	....	....	....	....	203
Lucerne	....	106	....	....	....	....	....	106
Lupins	....	72	....	....	3	....	....	75
Pasture	....	1 444	....	....	....	....	....	1 444
Various	....	4	....	....	8	....	....	12
Soil—								
Soil	41	997	....	3	20	24	....	1 085
TOTAL	41	6 986	8	4	113	195	3	7 350

Seven thousand three hundred and fifty samples were received. This is 505 less than in 1972 and slightly more than the average (7 130) for the five years 1968-1972.

Output of samples was 7 266. It is a credit to the members of the Division that this was achieved in spite of the difficulties with staff arrangements since it is only 84 samples less than the number received and is slightly greater than the average (7 099) output for the five years 1968-1972.

The number of samples in hand at the end of the year was 2 864 and as in 1972 the bulk of these are related to experimental work in agriculture, some received as early as July, 1973.

Compared with 1972, there was a large reduction in the number of soil samples received and no peanut kernels were received. This was compensated for by the receipt of larger numbers of native vegetation mainly from environmental studies and carrot and wheat plant tops from Department of Agriculture field experiments. An increase in the number of samples of animal origin was due mainly to 198 samples of lamb meat from a study of meat quality.

Soils

One thousand and eighty five samples were received, a decrease of one third compared with the previous year.

Most of the samples arose from the continued monitoring of effects of fertiliser and management practices on soil fertility, and classical analyses for classification of soils sampled during surveys of research stations at Manjimup and Mt. Barker, and assessment of irrigation potential at Packsaddle Plains.

Soil Testing

Analysis by rapid soil test type methods were requested on 284 samples. This is the first call on the Division for analysis of any appreciable numbers of samples by these methods and reflects an increase in the use of soil analysis as a guide in prediction of fertiliser requirements for crops and pastures in Western Australia. Apart from the activity of government research workers there has been an increased utilisation of private soil testing service by farmers. This has resulted in an increase in the number of enquiries from the public received by the Division. These enquiries have been referred to private analytical services. There are a number of such services operating in Western Australia apart from the commercial scheme conducted by a large local manufacturer of fertilisers.

Phosphorus and Potassium

Two hundred and fourteen of the samples were analysed for phosphorus and potassium extractable by 0.5 M sodium bicarbonate solution (pH 8.5). All these samples were from soils under pasture in the southwest areas of the State where investigations of fertiliser requirement for pasture production are being conducted by the Department of Agriculture.

The samples were submitted early in the year before the growing season and before fertiliser applications for 1973 had been made.

At a soil: solution ratio of 1 : 100 shaken overnight this extractant is in common use in Australia for soil testing for phosphorus and it was convenient to measure potassium in the same extract.

Phosphorus is determined by spectrophotometry and potassium by atomic absorption spectroscopy on the undiluted extract. Tentative "critical levels" for optimum yield of clover pasture are:

Extractable potassium:

- Less than 80 p.p.m.—90 per cent chance of response to fertiliser.
- Greater than 100 p.p.m.—90 per cent chance of no response to fertiliser.

Extractable phosphorus:

- Less than 40 p.p.m.—response to fertiliser is likely. More data is required in respect of extractable phosphorus and pasture responses before critical levels can be defined more closely.

Results for potassium were much higher than those obtained by a different laboratory using a soil: solution ratio of 1 : 5 and a shaking time of 30 minutes. Subsequent work on a limited number of samples showed that the amount of potassium extracted by 0.5 M sodium bicarbonate was:

(i) Beyond a minimum time, independent of time of extraction of the sample for a 1 : 5 soil: solution ratio.

(ii) Very dependent on the ratio of soil to extractant over the range 1 : 5 and 1 : 100.

(iii) Increased by grinding the sample before extraction.

The observations confirm that when reporting results of "extractable" element, the method and extractant solution used must be closely specified.

Zinc

Fifty eight samples were analysed for zinc extractable by ammonium carbonate (1 M)—EDTA (0.01 M) solution (pH 8.6). Results obtained by this method have proved useful in diagnosing zinc deficiency in rice crops grown in the Ord River irrigation area.

Iron

Twelve samples were analysed for iron extracted by 1 M ammonium acetate solution (pH 4.8) as described by Olsen & Carlson (1949) Soil Sci. Soc. Amer. Proc. 14:109. Eight samples were from experiment sites on peaty sands where iron deficiency symptoms developed in plants unless a basal dressing of ferrous sulphate was applied to the soil, and four samples were from a site where no iron deficiency occurred. Results shown in Table 3 indicate that this analysis has promise as a rapid test for iron deficiency.

TABLE 3

AMMONIUM ACETATE EXTRACTABLE IRON

Depth cm	0–10	10–20	20–30	30–40
	Iron, Fe parts per million in soil			
Deficient	0·6	0·2	0·1	0·2
Deficient	0·4	0·2	0·1	0·1
Not deficient	12	11	9	7

Copper in Soils

The importance of copper fertiliser for crop and pasture production in Western Australia was responsible for analysis of 316 samples of soils which are copper deficient in the virgin state. Two hundred and fifty two of the samples were carried over from 1972.

Copper was extracted from the samples by four procedures:

(i) Total—Hydrofluoric and perchloric acids digest.

(ii) Extractable by 0.05 M EDTA.

(iii) Extractable by 0.2 M ammonium oxalate.

(iv) Extractable by 0.1 M hydrochloric acid.

Copper was determined in the final solution in each case by atomic absorption spectroscopy. The scale expansion facilities and readout stability obtained with modern instruments permits the determination of copper at the very low levels of detection required for the analysis of the limited amounts of copper which are extracted from soils deficient in copper. In some cases, such as in deep white sands found at Badgingarra Research Station, total copper may be as low as 1 p.p.m. and extractable copper (EDTA and/or ammonium oxalate) about one-tenth of this.

For total copper perchloric acid alone was found unsuitable, the amount of copper extracted being too dependent on the period of digestion of the sample and the type of soil. In some soils only 50 per cent of the total (hydrofluoric acid digest) copper was extracted by perchloric acid.

Comparison of Extractants. Extractant (iv) was used for 48 samples from a long term copper fertiliser trial at Newdegate to compare the amount of copper extracted by this method and by ammonium oxalate. Macias (1973) Soil Sci. 115:276 found a highly significant correlation between the two methods. The results for the Newdegate soils also showed reasonable correlation between the two methods. Consequently 0.1 M HCl is to be preferred as extractant for a rapid soil test since copper can be determined directly on the extract by atomic absorption spectroscopy. Ammonium oxalate (0.2 M) solution is not amenable to direct aspiration and the soil extracts must be evaporated and the oxalate destroyed by acid digestion before determination of the copper.

However, whereas ammonium oxalate has been shown by calculation to account for about 95 per cent of the copper applied as fertiliser to a range of soils, the 0.1 M hydrochloric acid extract accounted for only about 60 per cent of applied copper and therefore more work is required before it can be accepted that this extractant is suitable for use on a range of soil types.

Alternatively the speed of the analysis of ammonium oxalate extracts could be improved if sensitive non flame atomisation techniques (such as carbon rod atomiser which is to be tried) prove suitable for direct analysis of copper in this type of extractant.

In the case of the samples from Newdegate, each extractant recovered a larger proportion of the total copper as the rate of copper applied to the soil four years previously increased. Results of the analysis of the less than 2 mm fraction are shown in Table 4. Each result is the mean of results for eight samples of top soil from sub plots of the experiment.

TABLE 4

COPPER IN NEWDEGATE SOIL

Treatment	Copper, Cu in less than 2 mm fraction				
	Total	Extractable in			
Copper sulphate		0·2 M Amm. Oxalate		0·1 M HCl	
kg/ha	p.p.m.	p.p.m.	per cent of total	p.p.m.	per cent of total
nil	2·1	0·3	14	0·2	10
2·8	2·8	1·0	36	0·7	25
5·5	2·8	1·3	46	1·0	36
8·2	3·4	1·9	56	1·4	41
11·0	4·3	2·7	63	2·0	46
11·0 + 0·55 per year	3·9	2·6	67	1·9	48

Residual Copper. A white sand was sampled to a depth of 40 cm at Badgingarra where copper sulphate and zinc oxide were applied in 1965 and analysed for total and extractable copper in an attempt to establish quantities and location of residual copper in the soil profile. The 0-20 cm and 20-40 cm depths from 10 plots which had received fertilisers and 9 plots which had not been treated were analysed separately.

The means of the values found are given in Table 5.

TABLE 5

COPPER IN BADGINGARRA SAND

Copper sulphate	Depth	Copper, Cu		
		Total	Amm. Oxalate extractable	EDTA extractable
kg/ha	cm	parts per million		
nil	0–20	1·2	0·2	0·1
nil	20–40	1·1	0·1	0·1
8·2	0–20	1·4	0·5	0·4
8·2	20–40	1·0	0·1	0·1

The soils have an extremely low cation exchange capacity of 2 milliequivalents per 100 g or less and it seems quite likely that leaching losses have been significant since although copper was found in the 0-20 cm depth, about two-thirds of the copper applied as fertiliser in 1965 cannot be accounted for.

A larger proportion (about 30 per cent) of the total copper in the top soil from treated plots was in an extractable form than was in the subsoil or "nil copper" plots (about 10 per cent). Sandy topsoils (0-15 cm) from an experiment at Esperance showed a similar difference in results between treated and "nil copper" plots.

A similar effect was evident in results for samples from a different soil type at Lake Grace. Sampling at three depths was carried out on a paddock which had received copper fertiliser 15 years previously.

The means of the results for samples from eight locations in the paddock are shown in Table 6.

TABLE 6

COPPER IN LAKE GRACE SOIL

Depth	Copper, Cu in less than 2 mm fraction		
	Total	Amm. Oxalate extractable	EDTA extractable
cm	parts per million		
0–15	2·6	1·1	0·8
15–30	2·0	0·2	0·1
45–60	2·0	0·15	less than 0·1

Extractable copper forms a greater proportion of the total copper in the top soil, where fertiliser residues in either inorganic or organic form would be present, than in the subsoils.

Ammonium oxalate (0.2. M) extraction has given more consistent results than 0.05 M EDTA extraction in our experience and it appears capable of being used as the basis for a soil test to distinguish residues of fertiliser copper from "native" soil copper.

Fractionation of Soil Copper. Chemical analysis of 18 samples of soil from a pot experiment was undertaken to gain information about the transformation of fertiliser copper in soils under crop and over a period of time. This should assist in understanding residual effects and long term requirements for copper fertiliser of various soils.

Copper sulphate was added to soil to give the equivalent of 1 and 10 p.p.m of added copper. Analysis of sub-samples showed that mixing was uniform. Lupins were grown in pots of the treated soils for 10 weeks. The soils were then dried for analysis. Chemical fractionation was based on the procedure of Estepp and Keefer (1971) Soil Sci. 112:325 with modifications to permit determination of copper in the extracts by atomic absorption spectroscopy.

The fractionation scheme was designed to measure the proportions of fertiliser copper which exist in soil as—

(a) water soluble—susceptible to leaching;
(b) fixed in the soil and unavailable for plant growth; and
(c) the remainder which is available to plants.

Two treatment sequences were used, as indicated in Table 7 which shows the results obtained for the soils to which 10 p.p.m. of copper had been added.

Sequence A incorporated two steps before treatment with 0.2 M ammonium oxalate solution as used in the soil test for copper described above. The first was an extraction with an acidic (pH 5.0) acetate buffer followed by treatment with hydrogen peroxide to remove copper present in organic matter.

In sequence B the acetate buffer was replaced by dilute (2.5 per cent) acetic acid and peroxide treatment was omitted before ammonium oxalate extraction.

TABLE 7

COPPER IN SOIL FRACTIONS

Sample	1		2		3		4		5		6	
Clay, per cent	4		5		4		10		7		5	
Sequence of extraction	A	B	A	B	A	B	A	B	A	B	A	B
	Copper, Cu parts per million in unextracted soil											
Acid soluble												
pH 5·0	0·2	....	0·2	....	0·2	....	0·2	....	0·4	....	0·3	....
pH 2·7	....	1·0	....	0·6	....	0·3	....	1·0	....	1·2	....	0·9
Hyd. peroxide soluble	3·2	....	2·9	....	4·4	....	2·1	....	1·6	....	6·8	....
Amm. oxalate extractable	1·7	7·3	2·5	7·4	0·8	7·4	2·9	7·1	3·2	5·4	0·4	7·2
Residual (on sand, silt and clay)	3·7	2·3	2·9	1·2	1·5	1·4	2·5	1·9	5·6	4·1	1·3	1·7
Total												
by summation	8·8	11·0	8·5	9·2	6·9	9·1	7·7	10·0	11·0	11·0	8·8	9·8
by analysis	8·2		9·0		11·0		7·6		8·6		9·4	
in untreated soil	2·8		1·9		1·9		1·7		3·0		2·6	

The water soluble fraction was 0·04 parts per million or less in each case.

The agreement between the totals derived by summation and analysis is reasonable considering the amounts of copper involved, but the total amounts found generally are too low to properly account for the added copper and that already present in the soils. Nevertheless the amounts found in the residues (sand + silt + clay fractions) remaining after the fractionation sequences are sufficiently close to the levels in the soils without added copper to show that the extractants removed a large proportion of the copper present and most of this would be derived from that added as copper sulphate.

Ammonium oxalate was particularly effective. The effect of hydrogen peroxide treatment is unexplained. With the exception of sample 6, peroxide treatment did not remove more than about 30 per cent of the copper. However, the most marked effect was an increase in the amount of copper found in the sand + silt + clay fractions at the expense of the amount of copper extracted subsequently by ammonium oxalate.

If hydrogen peroxide solubilised organic copper which was then absorbed by the mineral components of the soil it is not clear why a following extraction with ammonium oxalate failed to extract this copper since on its own this solution extracted more copper than the hydrogen peroxide treatment.

Nitrogen

Experiments located at Avondale, Merredin and Wongan Hills to investigate the effects of continuous cropping of wheat with nitrogenous fertilisers on wheat production and soil chemical properties continued. At Merredin and Wongan Hills sites, high rates of sulphate of ammonia (S/A) have resulted in reduced wheat yield compared with calcium ammonium nitrate (C.A.N.) and urea at equivalent rates of nitrogen.

The accompanying changes in soil pH, total exchangeable bases (T.E.B.) and aluminium extracted by 1 M potassium chloride are shown in Table 8 for the 0-10 cm topsoil at Avondale, where yields were not affected, and Wongan Hills. The marked drop in pH and T.E.B. and increase in extractable aluminium found in the Wongan Hills samples for the S/A treatment was also evident at the Merredin site and raises the possibility of aluminium toxicity being involved.

TABLE 8

NITROGEN FERTILISERS ON WHEAT SOILS

Treatment	pH		T.E.B.		Extractable Aluminium	
			meq/100 g		p.p.m.	
	A	W	A	W	A	W
Nil	6·3	5·8	3·8	2·1	2	2
CAN 376 kg/ha	5·7	5·5	3·9	2·0	2	4
Urea 168 kg/ha	5·8	5·2	3·4	1·6	4	10
S/A 376 kg/ha	5·2	4·8	3·4	0·8	9	27

0–10 cm layer A—Avondale W—Wongan Hills.

Potassium

Evaluation was commenced of potassium status as indicated by a range of extracting solutions and the chemical and physical properties of soils from 40 experimental sites in the State. The project is planned to continue for three years to investigate the relationship between soil parameters and the yield response to potassium fertiliser of clover based pasture. The results will be used for multiple regression analysis by computer.

Other

Soils were examined for salinity in relation to problems of establishing turf cricket pitches and pastures, and mechanical analysis was carried out on soils from housing areas for advice on drainage of septic tanks. Peaty soils were evaluated for horticultural purposes.

Fertilisers Act

One hundred and fifty four samples of fertilisers were received, an increase of twenty four compared with 1972. Certificates of Analysis were issued for 152 samples examined including thirty three brought forward from 1972.

Deficiencies were found in sixty one (40 per cent) of the samples examined. The number of individual deficiencies (159) was, as reported in 1972, largely attributable to mixtures used in home gardening particularly in respect of trace elements. Deficiencies of water soluble potash (24 samples) were also common in this type of product. It is expected that modifications to manufacturers claims for trace elements content will effect an improvement.

Feeding Stuffs Act

The number of samples of registered feeding stuffs received for examination increased to 182 compared with 123 in the previous year. Certificates of Analysis were issued for 192 samples including 49 brought forward from 1972.

Deficiencies or excesses were found in 149 (78 per cent) of the samples analysed. Crude protein was the major deficiency (35 cases), followed by calcium (31), phosphoric acid (30) and sodium chloride (29). Excesses were mainly in respect of crude fat (46 cases) and calcium (45), followed by phosphoric acid (42), sodium chloride (37) and crude fibre (23).

Animal Tissues

(a) The presence of mercury in whalemeal used as a source of protein for animal feeding stuffs was reported in our Annual Report for 1971.

One hundred and thirty one samples of porcine tissues were analysed for total mercury content to establish levels and sites of accumulation of mercury ingested with the diet. The samples were taken from pig carcasses at the end of experiments conducted at the Medina Research Station. Feeds contained up to 12 per cent of added whalemeal. Samples of liver, muscle, fat and kidney were analysed separately and in general showed that as the content of the whalemeal in the diet increased the concentration of mercury in the tissues increased. Liver and kidney contained more mercury than muscle tissue. There was no effect on the level of mercury found in the samples of fat and this was very low at 0.02 p.p.m. or less. The means of results from treatments of one trial are shown in Table 9. The trends are very clear.

TABLE 9

TOTAL MERCURY IN PIG TISSUE

Whalemeal in diet	Mercury, Hg		
per cent	parts per million as received		
	Kidney	Liver	Muscle
Nil	0·04	0·02	0·01
4	0·30	0·23	0·09
8	0·44	0·27	0·12

Results from two other trials showed that the mercury content of porcine muscle was 0.12 and 0.10 parts per million from pigs receiving 4 and 6 per cent whalemeal in the diet. The indication is that even at the 4 per cent level in the feed the amount of mercury finding its way to the muscle is above the level considered to be permissible for human food (0.03 p.p.m.)

(b) Sheep faeces were analysed for ash and nitrogen content in an attempt to relate differences in body weight changes of sheep to differences in feed intake. Sheep grazing Seaton Park clover gained weight while those on Dinninup barely maintained weight although similar amounts of feed were available. The ash contents of faeces of sheep on Dinninup and Woogenellup cultivars were lower than for those from sheep on Daliak, Seaton Park or Uniwager. Highest nitrogen levels were in faeces from animals grazing Daliak. No differences in ash or nitrogen content were clear in samples from a similar trial at Chowerup.

Other samples of faeces and urine were analysed in feeding studies of pigs at Medina and cattle at Kimberley Research Station where there are lot feeding trials using feeds based on rice, cottonseed and sorghum. Chromium oxide was used as a tracer and was determined in feeds and faeces.

(c) Ovine and bovine liver samples were analysed for cobalt and selenium mainly in relation to experimental work and in assistance with diagnosis of ill thrift or deaths of stock.

(d) Bones were analysed for ash, calcium, phosphorus and fluoride. It was shown that fluoride in bone could be conveniently determined by a selective ion electrode method developed in the Division for analysis of soils and plant materials for fluoride content. If the weight of bone sample taken for analysis was about 0.1 gram results for fluoride by electrode agreed with those by the tedious distillation procedure. Larger sample weight gave lower results so that a result of 180 parts per million F using a 0.1 g sample fell to 28 parts per million for 0.2 g and 7 parts per million if 1 g of bone was used.

(e) One hundred and ninety eight samples of lamb mince meat were analysed for moisture, ash, crude protein and crude fat to check the correlation between actual carcass composition (ratio of meat: fat : bone) and the composition predicted from live sheep characteristics such as sex, breed, age and horn length.

Human Tissues

(a) Examination of blood, liver and kidney specimens was carried out for selenium content following suggestions that imbalance of this element may be involved in the problem of "cot deaths" of infants. The results for livers fell within the normal range of values for adults (0.18 to 0.66 p.p.m. fresh weight basis) but blood levels were lower than the adult normal (0.2 p.p.m.). Analysis of kidney cortex and medulla separately gave selenium results following the pattern found in animal kidneys i.e. the cortex has higher levels of selenium than the medulla. In addition the concentration of selenium in the kidney was greater than in the liver as found in animals.

(b) Other samples were a tissue biopsy associated with a metal implant failure which was analysed for metals present in the implant to aid in identifying the cause of breakdown, and samples of blood from the Red Cross Blood Transfusion Service to check on storage procedure using aluminium cans.

Fatty Acid Composition of Pig Fats

The consistency of pig fat is important in marketing, a "soft" fat being less appealing to consumers. The firmness of the fat is inversely proportional to the iodine number which is a useful guide in assessing consistency. Iodine number is dependent on the degree of unsaturation of the fat and with pigs this is in turn very dependent on the amount and composition of the oil or fat in the feed.

The annual report for 1972 showed the iodine number and fatty acid composition of fat from pigs fed varying proportions of lupin meal in the diet.

Fifty seven samples of fat from similar experiments using rapeseed meal in the feed were examined for iodine number, and fatty acid composition was determined in 24 of the samples by gas-liquid chromatography of the methyl esters of the acids. Rapeseed oil contains appreciable amounts of unsaturated fats and it would be expected to cause an increase in the unsaturation of the pig fat.

Results are shown in Table 10. Each figure is the mean of the results of six samples, there being six replicates (animals) per treatment. Fatty acids present at less than 1 per cent are not reported with the exception of erucic acid.

TABLE 10.

FATTY ACID COMPOSITION OF PIG FAT.

		Rapeseed Meal per cent			
Ration		0	10	15	20
Iodine No.		52	56	58	61
Fatty acid—		per cent of fatty acids			
Myristic	14·0	1·7	2·0	1·9	2·2
Palmitic	16·0	27	28	28	26
Palmitoleic	16·1	4·5	5·1	4·5	5·1
Stearic	18·0	15	14	14	12
Oleic	18·1	42	39	38	37
Linoleic	18·2	6·6	7·8	8·5	10
Linolenic	18·3	0·9	1·4	1·8	2·1
Eicosenoic	20·1	0·7	1·6	2·1	2·9
Erucic	22·1	less than 0·1	0·4	0·6	0·9
Total Saturated		44	44	44	40

The effects of the treatments were very slight. Oleic acid, a major component of rape oil, decreased as the content of rapeseed meal in the diet increased. On the other hand the proportions of unsaturated acids in the fat (linoleic, linolenic, eicosenoic and erucic) each increased with increase in percentage of rapeseed meal in the diet, which is consistent with the accompanying slight increase in iodine number of the fat. The total percentages of the saturated fats (myristic, palmitic and stearic) were remarkably consistent, with a slight decrease for the highest rate of rapeseed meal. The absence of erucic acid in the fat from the animals which did not receive the meal in the diet is of interest.

Rapeseed

Twenty six samples of rapeseed from growers in the south-west of Western Australia were analysed for erucic acid content under a grading and certification scheme. The requirement was that the erucic acid content should not exceed 4.5 per cent of the total fatty acids in the oil extracted from the seed.

The samples comprised two low erucic acid varieties which gave quite marked differences in erucic acid content.

	Erucic acid per cent of fatty acids	
Variety	Range	Mean
Span	3·2–4·4	3·9
Zephyr	0·3–1·2	0·5

No samples were received under the scheme at the end of the year because of the impact of the fungus disease black leg in influencing growers not to plant rape in 1973.

Fifteen samples were analysed for oil content in respect of bills of sale. The oil content ranged from 38.3 to 42.6 per cent with a mean of 40.3 per cent.

Horticulture

1. Apple Trees

(a) Three hundred and ninety six samples of parts of apple trees were analysed for calcium, nitrogen, phosphorus and potassium.

The samples were from young trees which had been grown in containers and treated with a fertiliser for one year before being sectioned into leaves, shoots, old wood, stumps, large roots and fine roots. The fertiliser was a mixture of 25 parts superphosphate, 22 parts calcium ammonium nitrate and 3 parts potassium sulphate. Application of 250, 500, 1 000 or 1 500 grams was made either below the tree or on the surface of the soil as single or split dressings. Watering was carried out at fortnightly intervals.

The effects of the treatments on the concentrations of the nutrients in the various parts of the tree were:

(i) Nitrogen increased in all parts of the trees and especially in the leaves. Placement of fertiliser below the tree was least effective particularly at low rates of fertiliser and surface-split dressings gave highest concentrations at each rate of application.

(ii) The two highest rates only were effective in increasing the phosphorus content of leaves. There was little difference between methods of application of the fertiliser but surface-split dressings were slightly better than placement below the tree.

A similar effect was found for the other sections except that below tree placement even at the highest rate of fertiliser did not raise the phosphorus concentration above that of the controls (no fertiliser).

(iii) The lowest rate of fertiliser was as good as the highest rate for increasing the potassium concentration in leaves and each method of placement was satisfactory although least effect was obtained from below tree placement. There was a slight increase of potassium in fine roots for surface applications of fertiliser and in shoots at the highest rates but none of the treatments had an effect in the other sections of the trees, probably because this element is mobilised to the growing tissues.

(iv) Leaf calcium increased for all treatments but least uptake was from below tree placement of fertiliser. Fine roots also showed increase in calcium content as the rate of fertiliser application increased but there was no difference due to method of application. The other sections of the trees showed little increase in calcium content but where this did occur it was due to surface-split dressings.

The significant result overall was the undoubted uptake of phosphorus from the superphosphate which supports the recommendation of the Department of Agriculture that superphosphate is important in the establishment of young apple trees. Phosphorus deficiencies of older trees are notoriously difficult to correct.

(b) Manganese. An experiment to assess the efficiency of uptake of manganese sprays showed that only one of the five spray treatments used was effective in increasing manganese content of leaves sampled in January. This was a 4 per cent solution of manganese sulphate applied in September which raised leaf manganese concentration to 20 parts per million dry basis compared with 14 parts per million in leaves from control trees.

(c) It has become a regular practice of the Division to analyse leaf samples for calcium, magnesium, nitrogen, phosphorus, potassium, copper, manganese and zinc since instrumental methods of analysis make it convenient to examine batches of samples for all the above elements. This has quite often revealed deficiencies or near deficiencies of elements which otherwise may not have been detected in the samples and also helps confirm that there are no limiting factors to growth other than the fertilisers under test. For example experiments with fertilisers investigating nitrogen, phosphorus and potassium nutrition would normally be analysed only for these three elements. Analysis for the trace elements of samples from an experiment with N.P.K. fertilisers at Bridgetown revealed very low levels of copper in the leaves sufficient to suggest a deficiency (less than 4 p.p.m.) and marginal levels of zinc (10 to 13 p.p.m.).

(d) Other apple leaf samples similarly analysed arose from experiments on growers' properties or at Research Stations in the Manjimup, Donnybrook, Bridgetown, Capel and Stoneville areas. Experiments to test the effect of nitrogen fertiliser at different rates and applied in spring and/or autumn in combination with high or low rates of superphosphate and potassium sulphate, and with or without lime, showed a marked increase in potassium content of leaves of trees receiving 2.2 kg of potassium sulphate per annum, but there was little effect on the other elements determined.

(e) A similar response to potassium only was apparent from leaf concentrations of nutrients in trees from a Stoneville trial in which fertilisers for nitrogen at three rates, phosphorus at two rates and potassium at two rates were applied to Granny Smith trees.

2. Apple Fruit

(a) Granny Smith apple fruits were analysed for calcium and potassium in continued investigation of the role of calcium in the problem of bitter pit. Sound and pitted fruits from trees which produced 36, 44 and 84 per cent of fruit affected with bitter pit were analysed separately and compared with a control sample of sound fruit. The mean calcium content of the control was 55 parts per million (fresh weight basis). The sound fruit from the trees which produced 36 and 44 per cent of affected fruit contained 50 and 55 parts per million of calcium whereas the level in the fruit from the trees which produced 84 per cent of pitted fruit was only 32 parts per million. This, however was only slightly higher than the calcium content of pitted fruit from the same tree (28 p.p.m.) and was no greater than in the fruit from the two other trees (30 and 32 p.p.m.).

Hence, while it is clear that calcium levels are low in pitted fruit it does not follow that fruit with low calcium show pitting although the susceptibility to pit may be greater.

Potassium content of the sound fruit was least in the sound control fruit (1 110 p.p.m.) and greatest in the fruits of the tree which produced 84 per cent of pit (1 490 p.p.m.) but there was no clear relationship between potassium levels of sound and affected fruits from the same tree.

(b) Analyses of fruits from a survey of orchards also demonstrated the lower calcium levels in pitted fruit (28 p.p.m.) compared with sound fruit (54 p.p.m.). Potassium was slightly higher in the pitted fruit at 1 490 parts per million (sound fruit 1 360 p.p.m.). Magnesium was also determined but showed no differences between pitted (54 p.p.m.) and sound (57 p.p.m.) nor between trees with and without symptoms of magnesium deficiency.

(c) Twenty-seven fruits from trees receiving calcium, nitrogen, phosphorus and potassium fertilisers were analysed for those four elements. The calcium levels ranged from 27 to 64 parts per million fresh weight basis and bore no relationship to fertiliser treatments. Nitrogen ranged from 610 to 1 200 parts per million, phosphorus ranged from 87 to 260 parts per million and potassium from 1 400 to 2 400 parts per million and each was dependent on the treatment, high levels of fertiliser producing highest levels of these nutrients in the fruit.

3. Citrus

(a) Seventy-two samples of Valencia orange leaves from a property at Capel gave unusual results. The trees were fertilised with calcium ammonium nitrate, potassium sulphate and superphosphate and half the trees received lime.

The most noticeable results were the low levels of potassium in the leaves of trees not receiving potassium fertiliser. At 0.7 per cent dry basis and lower these trees would be regarded as suffering from potassium deficiency but no leaf symptoms were observed in the field. The effects of calcium ammonium nitrate and superphosphate, each of which depressed potassium leaf concentrations in the absence of potassium fertiliser, may have enhanced this potassium stress. Calcium content of leaves also showed a curious pattern. Both potassium sulphate and calcium ammonium nitrate decreased calcium levels and the decrease was greater in the absence of superphosphate.

(b) One hundred and sixty samples of Washington Navel orange leaves were analysed for nitrogen, phosphorus, potassium and calcium and showed uptake by leaves in response to potassium and nitrogen fertilisers but urea was less effective than ammonium nitrate if applied in spring compared with autumn.

Ten samples of Valencia orange leaves from Wiluna showed the familiar high levels of boron (200-280 p.p.m. dry basis) associated in leaf material from this district.

4. Viticulture

The increased interest in grape growing for table wine production is indicated by the establishment of vines on a number of private properties in the South West. At Frankland near Mt. Barker two trials have been initiated to investigate problems in establishment and leaf scorch symptoms suspected of being potassium deficiency. One hundred samples of leaves (blades and petioles) from these trials were analysed.

The first trial with Shiraz vines was planted with fertiliser treatments in 1970. Superphosphate at 2.5 tonnes per ha at 30-38 cm depth gave good growth response but leaf scorch was induced on older leaves. Potassium analysis confirmed general low levels in the blades and petioles for all treatments but deep placement of superphosphate was associated with higher levels of leaf potassium. Levels of chloride in the blades and sodium in the blades and petioles did not suggest that excess salinity was the cause of the leaf scorch.

The second trial which included Cabernet, Malbec, Rhine Riesling and Shiraz varieties studied the effect of potassium fertiliser. Leaf analysis showed a marked uptake of potassium compared to the unfertilised vines especially for Cabernet and Shiraz vines as shown in Table 11.

TABLE 11

Grape Vine Leaf Potassium

Treatment	kg per vine			
Potassium sulphate	nil	0·45	nil	0·45
	Potassium, K per cent dry basis			
Variety	Blades		Petioles	
Malbec	0·84	0·98	1·44	1·95
Cabernet	0·55	1·07	0·30	3·20
Shiraz	0·61	0·79	0·24	1·32

5. Other

Peach leaves and bark from unhealthy trees at Manjimup were analysed to supply information on the reason for poor growth. Samples of banana fruit from Gascoyne Research Station were analysed for information relating to fruit quality. Comparison with bananas from Queensland and New South Wales showed that Carnarvon bananas had higher levels of boron in the flesh and skin and higher calcium and phosphorus in the skin than the Eastern States samples. The concentrations of chloride, nitrogen, potassium and sodium and the ratio by weight of skin and flesh were very similar.

Pastures and Hay

Automated instrumentation was used for analysis of pasture and hay samples for nitrogen, phosphorus and potassium. The samples came mainly from the south west of the State and most were from trials at Wokalup on irrigated pastures. Effects of several factors which might influence pasture and hay production were under study such as a comparison of nitrogenous fertilisers (ammonium sulphate and urea), stocking rates, and intervals and rate of flow of irrigation. Analysis was of assistance in assessing quality. Other samples were from the higher rainfall areas as part of a general survey of hay quality and production methods on farmers' properties. Lucerne production was also surveyed. More intensive studies to assess the losses in quality during hay making involved analysis of samples taken at pre-cutting and post-baling of the hay.

Over 500 samples of pasture were received from trials at Denmark Research Station.

Pasture analyses provided additional information for a time of calving experiment and for a trial comparing responses of twelve summer fodder crops grown under dryland conditions to high rates of fertiliser and various cutting techniques.

Samples from the Cobalt Deficiency Investigation were separated into grass, clover and weeds before analysis for the elements of importance to animal nutrition, cobalt, copper, molybdenum, selenium, sulphur, and zinc, in addition to nitrogen, phosphorus and potassium. Selenium levels were low, being in the range of 0.01 to 0.02 parts per million with a few samples as much as 0.05 parts per millon dry basis only.

Nitrogen. Total and nitrate nitrogen in kikuyu pasture treated with up to 336 kg/ha of ammonium nitrate applied at or 4 weeks after germination showed no accumulation of nitrate except at the highest rate of fertiliser applied at germination and this corresponded to the highest content of total nitrogen. It was thought that nitrate toxicity may have been induced by the fertiliser because the soil could have contained high residual nitrate from a clover stand of the previous year.

Phosphorous. Twenty-eight samples of pasture which had been sprayed with phosphoric acid solution were analysed for nitrogen, phosphorus, potassium and sulphur in a study of dry feed palatability. Phosphoric acid was sprayed at a rate designed to increase the phosphorus content of the dry feed by about 0.2 per cent on dry basis. Samples were taken before and at time of spraying and at 30 days and 60 days afterward and showed that after 30 days the phosphorus content of the feed was still at the level induced by the spray treatment (0.24 per cent). By 60 days the level was almost the same as prior to spraying (0.10 per cent). It is possible that the pasture on which the spray had fallen had been grazed off by this time.

Trace Elements. Samples from experiments throughout the State were analysed for cobalt, copper, manganese, molybdenum, selenium and zinc in work which continues from year to year in assessment of long term effects of fertiliser dressings.

Clover. Samples were analysed mainly for copper and zinc following uptake of these elements from fertilisers. In one experiment at Esperance in which copper sulphate was applied in 1967 the copper content of the clover was 2.5 parts per million for nil treatment, 3.7 parts per million for 1.1 kg/ha of bluestone, 4.6 parts per million for 2.2 kg/ha, 5.6 parts per million for 4.4 kg/ha and 7.4 parts per million for 9 kg/ha of bluestone. There was little difference in copper content of clover which received 0.3 or 0.6 kg/ha bluestone in subsequent years.

Clover seed from an experiment at Newdegate had from 1.5 parts per million to 13 parts per million of copper, depending on the rate at which bluestone had been applied. Rates ranged from nil to 11 plus 0.6 kg/ha annually.

Diagnostic. Samples of pasture were analysed for diagnostic purposes and clarified questions of molybdenum, cobalt, copper and potassium deficiencies. Manganese deficiency in lucerne at a property near the coast at Harvey was confirmed by chemical analysis.

Native grasses, herbs and shrubs. The continuing work on grazing trials in the pastoral regions of the state resulted in the Division analysing a a range of species of plants for feed value. Samples came from Port Hedland, Derby, Meekatharra, Yalgoo and Kalgoorlie. An interesting development was the use of fertilisers in limited trials. Neurachne mitchelliana treated with superphosphate at 336 kg/ha and urea at 182 and 364 kg/ha showed an increase in nitrogen content of the material collected at an early cut but generally the effects were inconsistent. The effect of burning on production of grass and herbs with and without fertiliser treatment was studied at Kalgoorlie but no effect on nutrient content was evident.

Samples of salt resistant species Thelkeldia diffusa and Puccinellia ciliata for proximate analysis were received. Thelkeldia contained 2.9 per cent of oxalates.

Cereals

Wheat. Twenty grain and ten flour samples represented the Western Australian F.A.Q. wheat grain and a sample classified Western Australian Hard. Protein calculated to 13.5 per cent moisture gave 10.7 per cent for F.A.Q. and 11.4 per cent respectively for the flours. The zone samples gave the following results:

Zone	Protein per cent on 13·5% moisture basis
Albany	10·4
Bunbury	11·5
Esperance	10·2
Fremantle	10·7
Geraldton	10·1

Molybdenum deficiency was shown by 16 samples of wheat grain from experiments at Merredin and Wongan Hills where nitrogenous fertilisers had caused distinct lowering of pH of the soils. The levels of molybdenum found were all less than the suggested critical level of 0.08 parts per million in the grain. Where sulphate of ammonia had been applied to the plots the grain contained 0.005 parts per million of molybdenum (Merredin) and 0.035 parts per million (Wongan Hills). Nil treatments gave figures of 0.009, 0.019 parts per million (Merredin) and 0.035, 0.069 parts per million (Wongan Hills). At these levels a response to molybdenum fertiliser by the next crop would be almost certain.

The response by wheat and rape plants to boron, calcium, magnesium and potassium was tested at Esperance. There was no marked effect on the concentration of these elements in the tops of wheat and rape plants analysed, with one exception. Magnesite raised the magnesium content of rape tops from 0.36 per cent to 0.44 per cent.

Samples of wheat plants from copper and zinc residual trials were analysed for these elements to give information on availability of fertiliser residues and effects of cropping after plots had been under clover.

Air Pollution

The Division's involvement in chemical work designed to assist in evaluation of environmental studies increased in 1973.

The monitoring of fluoride contents of peppermint leaves near a fertiliser works at Picton Junction, of grapevine leaves from vineyards in the Middle Swan adjacent to brickworks and vegetation and cattle urine from grazing properties near a brickworks at Byford was continued. 165 samples were received for these projects. In addition a system of static monitoring of fluoride emissions from brickworks at Middle Swan was investigated. The method is simple and consists of exposing filter paper discs (previously impregnated with lime water) in selected positions around the sources of the emissions. The papers were set at intervals of about one month and collected after 3 to 4 weeks' exposure. Analysis by fluoride-selective ion electrode is relatively simple. Unexposed papers used as reference contained 1 to 2 micrograms of fluoride compared with from 14 up to 155 micrograms in exposed papers depending on the site and period of exposure to emission. With astute control of exposure times and strategic placement of the papers this method could be developed into an inexpensive monitoring system.

Fluorosis of dairy cattle at Byford was confirmed by analysis of urine samples. A group of nine animals grazed since November 1972 near brickworks were showing loss of condition, stiffness of gait and exostosis in April 1973. Urine sampled at that time contained extremely high concentrations of fluoride (35 to 61 p.p.m., mean 48 p.p.m.). The cattle were removed to an area remote from the works and health improved. Urine samples taken in August 1973 contained normal levels of fluoride (2 to 10, mean 6 p.p.m.) compared with 2 to 5 parts per million in November 1972 before the animals were placed on the affected pastures, showing that most of the fluoride had been excreted or immobilised.

The fluoride-selective ion electrode has proved of immense value in the direct analysis of urines.

Coogee Air Pollution Survey. The major part of the chemical work in this field was from the regular quarterly sampling of leaves of banksia, blackboy, eucalyptus and pine seedlings. Analyses for aluminium, chloride and sulphate were designed to assist in defining areas which might be affected by dust or fumes from the industrial sites near the Naval Base-Kwinana area. Three hundred and ninety-three samples were received.

Aluminium analysis of plant material by conventional procedures involves sample solution by acid digestion and solvent extraction of an organic-metal complex to separate the aluminium before determination by spectrophotometry. This was found to be too involved for this project and determination by atomic absorption spectroscopy directly on the solution of the digested sample with potassium chloride as ionisation suppressor was tried. A nitrous oxide-acetylene flame gave results in good agreement with the spectrophotometric method of Frink and Peaslee (1968) Analyst 93 : 469 for samples containing 100 parts per million dry basis or more of aluminium. Since some of the samples from the survey contained up to 0.4 per cent and most had more than 200 parts per million the more rapid method was a great advantage.

The digestion of the sample and subsequent dissolution of the residue need care. Provided complete dissolution was achieved the results obtained were comparable with fusion of the sample with sodium carbonate.

Methods of sampling and sample preparation, particularly for banksia, were examined in some detail and showed that aluminium content of leaves was very variable even within leaves on a single tree. Chloride and sulphate levels were satisfactorily uniform within a single tree but between sites the variability was quite marked and no pattern was apparent. In general the aluminium content increased as the distance between the sample site and the alumina refinery decreased. This is analytical confirmation of what is fairly obvious by visual inspection.

Miscellaneous

(a) Cadmium content of fertilisers has been investigated elsewhere in Australia. A long history of top dressing with superphosphate contributed little to the cadmium content of wheat grain. A sample of locally manufactured superphosphate contained 42 parts per million which is very smiliar to results reported by Williams and David (1973) Aust. J. Soil Research 11:43. Eight samples analysed by them contained from 27 to 48 parts per million with a mean of 40 parts per million.

(b) Samples of bran flakes were examined for human feed value. Crushed egg shell, fish, abattoir waste, clover seed, lupin seed, whalemeal, soyabean meal, dust from barley and wheat grain and paunch contents were analysed for evaluation as animal feeds. Samples of oat grain to which a mineral/vitamin supplement had been added were examined to determine whether the mixture was uniform. The samples came from a private enterprise at Kalannie aimed at breeding and domestication of emus.

ENGINEERING CHEMISTRY DIVISION

A consistent demand from both companies and individuals for a wide variety of test work continued throughout 1973 and ensured that sponsored investigations at both laboratory and pilot plant level were again the main activity of the Division. The results of these sponsored investigations remain confidential to the client.

In addition, some progress was maintained on Departmental projects in which the emphasis is placed on achieving results of a broad significance and on long term benefits to the State.

The number of samples registered fell from 170 in the previous year to 76, but this was mainly a reflection of a falling off in the number of samples submitted for minor routine assessments, such as fuels and feeding stuffs for analyses.

In all, nineteen major reports embracing both sponsored and internally innovated projects were issued during the year.

Staff and General

Mr. L. Brennan maintained a professional interest in air pollution in his continuing position of fuel technologist member of the Scientific Advisory Committee as constituted under the Clean Air Act. The main involvement was attendance at meetings, but on site inspections of problem areas and technical appraisal of equipment were also required. The keynote being to ensure a harmonious co-operation between industry and government to maintain a high quality of respirable air in spite of increasing industrialisation.

Mr. B. Goodheart was again Western Australia's non-voting representative of the Board of Directors of the Australian Coal Industries Research Laboratories, and was a member of the inter Divisional Study Group convened to consider the chemical treatment of a troublesome industrial effluent.

A paper entitled "The modified metallurgical upgrading of ilmenite to produce high grade synthetic rutile" was presented by Mr. P. F. Rolfe to the 1973 Annual Conference of the Australasian Institute of Mining and Metallurgy, which was held in Perth in May. The paper dealt with research work carried out by the Division.

Mr. R. V. Field made separate trips to Three Springs and Greenbushes in association with consultative research projects.

Mr. B. Goodheart took the opportunity of visiting the Australian Mineral Development Laboratory when in Adelaide on staff selection matters in January. During a five day tour of major iron ore processing facilities in July, Mr. Goodheart visited Newman, Port Hedland, Dampier, Cape Lambert and Marble Bar. In July he travelled to Kalgoorlie to the Metallurgical Laboratory and earlier in the year journeyed to Three Springs and Eneabba for collaboration on an investigational project.

Buildings and Equipment

The continuing emphasis on work of a pilot plant nature and the lack of a suitable all weather covered area to carry out preparation work such as crushing, sizing and pelletising, prompted a submission for extensions to the main pilot plant building.

The acquisition of a high capacity ore sample drying oven (Stainless Steel internal) and a one ton capability mobile hydraulic drum lifter was of considerable assistance in the processing and handling of bulk quantities of ore samples and products.

A type 30 Ingersoll Rand Air Compressor was installed to replace an antiquated unit. The new machine was fitted with an after cooler and provides oil free, high pressure air at a free air delivery rate of 85 m^3 per hour, and is capable of furnishing all pilot plant process air requirements.

In conjunction with the Diatomite project, several new items were fabricated. These included a 45 cm diameter classification cyclone with attachment for secondary air introduction, and a laboratory scale stainless steel pressure filter of standard dimensions for comparing filtration rate characteristics of potential filter aid products.

The pilot rotary kiln (36 cm internal diameter and 5 metre overall length) was again in frequent use for a wide range of investigations and the need for a small bench scale unit for preliminary test roasting under dynamic conditions, prompted the design and planned fabrication of a 15 cm diameter x 25 cm length reactor. The reactor will be constructed from high temperature resistant alloy steel and will provide for rotation within the hot zone of an electric furnace. When completed, the reactor unit should enable ready assimilation of rotary kiln type processes on a conveniently small scale.

The basic requirements for precise chemical analyses were again well satisfied by the Mineral Division and others. However, this Division maintains a comprehensive laboratory for rapid process control analysis and the procurement of a second-hand AA3 atomic absorption instrument further extended this capability.

Investigational Projects

Utilisation of W.A. Diatomites

The Departmental research programme aimed at assessing the possibility of processing locally occurring diatomite deposits to substitute for high cost imported materials was advanced during the year.

The project to date has been concentrated on basic studies and laboratory testing of samples obtained from a range of deposits in the South West of the State. Imported commercial diatomites have been used for comparative assessment of properties in relation to utilisation potential.

Microscopic examination provided preliminary information as to the nature and proportion of both contained diatom frustules and associated impurities. In general, the frustules of local diatomites were found to be pennate and typically lacking in centric forms. The main impurities were organic matter, mineral silica and spicules, clay and water soluble salts.

To satisfy the major market requirement for diatomite, the raw material requires processing to remove impurities and conversion to a finely dispersed, low bulk density product. In this form both calcined and natural materials are marketed and frustule size distribution and other physical properties can be controlled to suit the ultimate application.

An essential pre-requisite for the separation of the bulk of impurities from diatomite frustules was dispersion or liberation of the frustules from one another and from the impurities without fragmentation of the frustules themselves. Both a laboratory microniser and a centrifugal blower were found to be suitable units for this dispersion.

Wet and dry cycloning methods were found to be the most effective means of separating impurities, since in the absence of a sufficient specific gravity difference to aid separation, these methods utilised shape and size differences between frustules and associated gangue to give the desired separation.

Heat treatment was shown to serve a number of functions depending on the nature and degree of treatment used. In addition to volatilising organics and removing odour, colour and taste, it effectively agglomerated impurities not removed during pre-cleaning into a form which enabled their removal during post-cleaning treatments. More importantly, heat treatment modified physical properties such as size distribution, bulk density and specific surface, which, in conjunction with post sizing treatments, yielded a wider range of potentially commercial products than would otherwise have been possible. Two temperature levels — 600 and 1 000° C were used in the initial series and sodium chloride and sodium carbonate employed as flux reagents under controlled conditions.

To assess filtration utilisation potential, processed samples and standard commercial grades of filter aid were tested under comparative conditions. It was clearly shown that the effect of removing the finer particles was to increase the flow rate. Natural and straight calcined products gave filtration rates that were too low for most commercial applications. The filtration characteristics of the flux calcined products were found to be more favourable. The test work has shown that sodium carbonate is a more effective flux reagent than sodium chloride.

The test programme is continuing with emphasis on:

(i) Confirming findings of the initial basic studies.

(ii) Examining areas, other than filtration, of potential utilisation of diatomites.

(ii) Scaling up of test equipment to achieve consistency and to provide data for full scale engineering design and costing.

During the year, there were at least two companies formulating plans to commence production of diatomite from W.A. deposits and sponsored test work on selected samples was carried out at the request of one of these groups.

Copper Ores

Since the discovery of the Wanerenooka deposit in 1842, copper ores have been mined in W.A. from the Kimberley Division in the north to Ravensthorpe in the south. However, the majority of these deposits have been small and contain ore of satisfactory grade only in the oxidised zones, which rarely extend further than 30 metres below the surface; and in most cases mining ceased when these easily won reserves had been exhausted.

An investigational programme was initiated by the Division to assess the potential application of copper hydrometallurgical extraction methods with regard to W.A. conditions. Most of the State's known copper deposits occur in isolated areas and this remoteness, coupled with small size, generally makes most conventional treatment methods uneconomic. On site leaching appears to be worthy of consideration.

Ammonia leaching methods are of growing importance in Australia but involve quite complex circuitry, and the more common acid leaching technique is not applicable to ore bodies that contain a high level of acid consuming gangue (principally in the form of carbonates). Recovery of copper from the leach liquor must also be considered when investigating a process for such remote areas.

An alternative and somewhat novel approach to copper recovery from high carbonate ores is to use amino acids to selectively solubilise the copper. Ethylenediaminetetra-acetic acid (EDTA) has a difference in its stability constants of copper and calcium of a factor of 10^8. Thus copper can be selectively extracted from ores containing calcium and by varying the operating conditions, i.e., leaching in a basic environment, iron will hydrolyse and precipitate as the hydroxide.

The possiblity of recovery of copper from two indigenous oxidised ore bodies using EDTA as the leaching agent is being evaluated, and the programme carried out so far has verified that copper can be recovered from the leach solution either by lime precipitation or by reduction.

Small scale laboratory extraction experiments have studied the effects of varying the mole ratio of EDTA to copper, varying the solution pH, reaction temperature and time and the influence of grind size.

In addition to its selectivity, the stability and non volatile nature of EDTA provide advantages for reagent recovery and recycle. The high cost of the reagent however makes it imperative that an efficient recycle step is operative and recovery methods were investigated on this basis.

This initial test work has produced promising results but insufficient data to arrive at a reliable economic assesment. It is now proposed to expand the scale of operations to enable the processing of 500 gram per hour on a semi continuous basis. This will enable a better appraisal to be made of the extent of EDTA losses and the loss of actual extractive power of the recycle liquor. It will also establish whether the process has economic viability, and is amenable to other copper ores.

Coal Characteristics

Although these Laboratories are now less active in the field of fuel analysis and research, a large volume of data was accumulated over the years 1947-1973. This Division is currently compiling a catalogue of the characteristics of coals found in Western Australia. This is essentially a recall of data from the Laboratories' files and the rearrangement of these data in a publishable form.

In the broad sense, coal in Western Australia consists of Collie and other coals. The latter include some large deposits as at Wilga, Eradu, Irwin River, Hill River and Fitzgerald River and isolated occurrences of coal found in oil bores, water bores, etc. At present, the only commercial source is in the non-caking Collie coal and most of the work done relates to the numerous seams in this field. Some of the report will be of historical significance only because several seams at Collie have been worked out, flooded by expansion of Wellington Dam or otherwise have become unavailable.

The report will be as extensive as possible and will include an outline of the major investigations by these Laboratories aimed at increasing the utilisation of Collie coal, e.g.

(1) the development of a coke substitute;

(2) gasification;

(3) metallurgical and chemical uses.

In relation to other Western Australian coals the report will indicate the basic properties of the coals recovered by exploratory drilling and chance encounters in water bores, etc. Much of this information has been published in the annual reports of the Mines Department. In particular relation to Collie coal, the catalogue is intended to complement the reports of the Geological Survey.

Lime Sands

Western Australia has reasonably large reserves of relatively high grade limestone, but important deposits such as at Naretha (Nullarbor Plain) and at Hamelin Pool (Shark Bay) are situated far from the existing and potential industrial areas.

On the other hand, there are huge deposits of calcareous (lime) sand along the west and south-west coast. These deposits generally take the form of dunes, some of which reach considerable size, and the deposits are a potential source of lime especially for large chemical industries. In recognition of this, the Division has carried out extensive research into possible methods of beneficiation and calcination (Refer Annual Reports 1960-1970).

A major local Company has recently commenced large scale utilisation of these calcareous sands and this Company requested a series of trials aimed at optimising processing variables. The investigation embraced two rotary kiln trials, each of several days of continuous 24 hour operation.

Mineral Sands

A problem common to all of the heavy mineral sands mining Companies operating within the State is caused by the presence of adherent coatings on the individual mineral grains. These coatings range from clays to organic materials and iron oxides and are frequently resistant to normal mining and washing techniques. The coatings create separational difficulties in the treatment plant, and may also lower the quality of the final product to such an extent that market specifications cannot be met.

This Division has previously worked on this problem and during the year undertook a further study at the request of a beach sand mining Company. The accent of this work was on basic studies and the evaluation of novel methods of coating removal.

Ilmenite Upgrading

Another upsurge in TiO_2 pigment demand together with a shortfall in rutile supply, ensured that this topic retained widespread interest for research groups throughout the world.

One W.A Company is well advanced on the installation of a fully commercial 30 000 ton per annum upgrading plant, and on request a further programme of trials was carried out utilising the Division's expertise and equipment pertinent to the aeration stage of the process.

Gold

The rise in the price of gold stimulated renewed interest in the processing of low grade ore deposits and tailings materials. One project undertaken on this topic was aimed at verifying the application of volatilisation roasting techniques to the processing of refractory tailings materials.

The investigational programme, which began in 1972, was continued during the year at the request of the Sponsor Company, and involved both bench and pilot scale test work. During a four day continuous trial mounted towards the end of the year, joint co-operative studies with representatives from an overseas Company enabled data to be obtained for evaluation of a means of gold recovery, which is of critical importance to the whole process.

In response to another request from a different Sponsor, tests were made to determine the most suitable grinding and classifying circuitry for enhanced cyanidation of agglomerated dump material.

Beneficiation Studies

Several requests were received and work undertaken on a range of beneficiation projects. One of the more extensive programmes was directed to investigation of the removal of surface contaminating materials for beneficiation of lump talc.

A treatment circuit comprising crushing, attritioning, classifying and magnetic separation was tested as part of a feasibility study on the production and export potential of glauconite for water treatment purposes.

Other beneficiation trials were directed to magnetic separation of the nine titano-magnetic ore samples, the upgrading of a limonitic iron ore by gravity separation and magnetising roasting methods and to the recovery of heavy minerals (cassiterite, tantalite) from clay agglomerates.

The investigation of the beneficiation and the utilisation potential of three samples of vermiculite bearing material, which commenced late in 1972, was completed early in the year.

Uranium Ore

The involvement of a local Company in the development of a process for treatment of uranium bearing ores resulted in two separate requests for pilot scale processing trials. These processing trials were carried out on a continuous 24 hour basis and were directed at influencing separation characteristics and optimising the feed to subsequent processing operations.

Char Utilisation

Work that commenced in 1972, at the request of a producing Company, on ancillary uses of char derived from Collie coal was continued—the main theme being establishing the bonding performance of various additives.

A vacuum pressing technique for the production of char briquettes was evaluated on a Departmental basis. When briquettes are produced by normal pressure methods, "springback" is observed. Springback is known to be associated with char elasticity and the expansion initiates cracks in the briquette, so that the carbonised briquette has a reduced crushing strength. The vacuum technique was developed to assess the effect of porosity and entrapped air. However, comparative testing showed that vacuum pressing produced briquettes with crushing strengths that were only marginally greater than that produced by the standard method.

Other sets of trials, that were carried out on request, concerned activation of char and assessment of the magnetic susceptibility of various impurity materials.

Fuels and Related

As in previous years, requests were received for determination of physical and chemical characteristics of various fuels. Such materials examined this year included coals, lignites, furnace oils, marri bark and sewage wastes.

Miscellaneous

In this category a range of samples was submitted such as potential stock food materials for analysis, cement dusts for sizing tests and a sample of fruit drink on which a determination of dietetic calorific value was made.

Consultative Service

During the year, advice was given and discussion held on numerous aspects of the Division's projects and areas of activity. Examples of the wide range of topics were recommendations on rotary kiln design and instrumentation for closer circuit control, reviews of patented and other possible processes for iron oxide pigment manufacture and calculation of diesel exhaust gas volumes for underground mining purposes.

In addition, appraisals were made on several major investigational reports submitted by various potential Development Companies, and comments prepared for the benefit of the Mines and other Government Departments.

Included among the overseas and interstate visitors to the Division during the year were:

Mr. K. Ono—General Manager and Chief Metallurgist, Nitleton Mining Consultants, Tokyo.

Mr. A. Doy—Mitsui Co Ltd, Tokyo.

Mr. F. Cady—International Exploration Manager, Johns Manville Prop. Ltd. New York, U.S.A.

Dr. R. A. Durie—Assistant Chief, C.S.I.R.O. Division of Mineral Chemistry, Sydney.

Mr. C. Whitehead—Technical Director, Lodge Cottrell Ltd, Birmingham, England.

Mr. G. Reyrink—Simon Carves (Australasia) Ltd, Sydney.

Dr. H. Pietsch and Dr. G. Mager—Lurgi Chemie, Frankfurt, West Germany.

Mr. T. Barnes—(formerly Director of Mines, South Australia) and a group of overseas technical visitors.

FOODS, DRUGS, TOXICOLOGY AND INDUSTRIAL HYGIENE DIVISION

The work of the Division in 1973 was concerned chiefly with samples from the Police Department and the Department of Public Health. Although significantly less by comparison, the other principal sources of samples were the Departments of Agriculture and Fisheries and Fauna, the Western Australian Trotting Association and samples classed as Pay Public. Because of their mutual interest in the subject of mercury in shark tissue, a number of samples originating with the Department of Fisheries and Fauna were submitted through the Department of Public Health and are included in the figure of 1 825 samples from that Department.

Samples—Following the reconstruction, late in 1972, of the fire-damaged portion of the Division, the early part of 1973 was directed to clearing as many as possible of the 1 054 samples still "in hand" at the end of 1972.

Six thousand three hundred and forty one samples were received during 1973, which was an increase of 20 per cent on the number received in 1972, and of 9 per cent on the number received in the last "normal" year, 1971. 648 samples were still "in hand" at the end of 1973.

Table 12 shows the source and condensed description of samples received during 1973.

TABLE 12

FOODS, DRUGS, TOXICOLOGY AND INDUSTRIAL HYGIENE DIVISION

	Agriculture Department	Fisheries & Fauna Department	Hospitals	Labour Department	Milk Board of W.A.	Mines Department	Pay Public	Police Department	Public Health Department	Public Works Department	Western Australian Trotting Association	Other	Total
FOODS—													
Aerated waters	....	....	....	....	....	....	....	....	30	....	....	....	30
Crayfish	....	....	....	....	....	....	....	....	38	....	....	....	38
Eggs	....	....	....	....	....	....	14	....	7	....	....	1	22
Fish	....	136	....	....	....	....	....	....	328	....	....	....	464
Fruit juices	38	....	3	....	....	....	....	....	9	....	....	....	50
Liquor	....	....	....	....	....	....	....	1	54	....	....	1	56
Meat	....	....	....	....	....	....	....	....	37	....	....	....	37
Milk	15	....	....	....	170	....	2	....	53	....	....	....	240
Potatoes	1	....	....	....	....	....	....	....	17	....	....	....	18
Prawns	....	....	....	....	....	....	....	....	72	....	....	....	72
Shark	....	....	....	....	....	....	....	....	587	....	....	....	587
Various	11	....	....	....	....	....	1	....	180	....	....	....	192
INDUSTRIAL HYGIENE—													
Blood	....	....	....	....	....	....	1	....	3	....	....	....	4
Urine	....	....	4	93	....	9	63	....	57	....	....	....	226
Various	....	....	....	....	....	21	....	....	34	....	....	2	57
MISCELLANEOUS—													
Animal bait	33	....	....	....	....	....	2	5	....	....	....	....	40
Animal tissue	127	19	....	....	....	....	....	....	....	....	....	....	146
Bird tissue	....	104	....	....	....	....	....	....	....	....	....	....	104
Criminal	....	....	....	....	....	....	....	188	....	....	....	....	188
Crockery	....	....	....	....	....	....	....	....	105	....	....	....	105
Detergents	....	....	....	....	....	23	....	....	....	....	....	....	23
Drugs	....	....	1	1	....	11	....	131	1	....	....	....	145
Explosives	....	....	....	....	....	16	....	....	....	....	....	....	16
Horse doping	....	....	....	....	....	....	....	....	....	....	346	....	346
Lupin seeds	15	....	....	....	....	....	....	....	12	....	....	....	27
Maritime pollution	....	....	....	....	....	....	....	42	....	....	....	1	43
Pasture	115	....	....	....	....	....	....	....	....	....	....	....	115
Pelican eggs	....	22	....	....	....	....	....	....	....	....	....	....	22
Pesticides	30	....	....	....	....	....	5	....	5	19	....	1	60
Soil	95	....	....	....	....	....	....	....	3	1	....	....	99
Toys	....	....	....	....	....	....	....	....	45	....	....	....	45
Water	5	7	....	....	....	....	3	....	8	139	....	3	165
Various	64	....	1	....	....	23	3	....	59	6	....	21	177
TOXICOLOGY—													
Animal	55	....	....	....	....	....	2	4	3	....	....	....	64
Human—													
Toxicology	....	....	16	....	....	....	....	963	2	....	....	....	981
Sobriety	....	....	....	....	....	....	197	495	....	....	....	....	692
Specimens from patients	....	....	96	....	....	....	25	....	76	....	....	1	198
Traffic death	....	....	....	....	....	....	....	447	....	....	....	....	447
TOTAL	604	288	121	94	170	95	326	2 276	1 825	165	346	31	6 341

Foods

The number of samples of food received during the year was the highest on record being an increase on the previous highest year 1972, of over 50 per cent. This was due chiefly to the sharp increase in the number of fish and shark samples submitted for examination.

In a survey of sharks from around the coast of Western Australia conducted by the Departments of Fisheries and Fauna and Public Health, together with "seized" samples suspected of having been transported interstate, a total of 587 samples of shark tissue were analysed for mercury content.

Eighty-four samples of local fish and 83 of imported fish were also analysed for mercury. Analyses for arsenic were also carried out on 68 samples, while 16 samples were examined for cadmium, 23 for lead and 34 for zinc.

Ten samples of imported fish were received for identification of colouring matter, while 43 local fish products and 230 imported fish samples were analysed for total volatile bases as a measure of incipient deterioration.

One hundred and seventy samples of cows' milk were received from the Milk Board of Western Australia for checking against the chemical standards prescribed by the Milk Act Regulations. 154 of these were "legal" samples taken by Inspectors—

(1) because of prima facie evidence of non-compliance with legal standards, or

(2) in connection with the Board's Milk Improvement Scheme.

It was found that 2.4 per cent of the samples analysed contained less than the legal minimum of fat (3.2 per cent), 73 per cent contained less than the legal minimum of solids not fat (8.5 per cent), and 58 per cent failed to comply with the legal standard for freezing-point (0.54 degree C below zero). The proportion of samples failing to comply with chemical standards shows an improvement over those for 1972, particularly in respect of freezing-point.

The distribution of analytical figures is shown in the following tables:

Milk Fat

Per cent in sample	No. of samples
Less than 3.20	4
3.20-3.50	29
3.51-4.00	58
More than 4.00	63
	154

Milk Solids not Fat

Per cent in sample	No. of samples
Less than 8.00	4
8.00-8.49	109
8.50-9.00	41
	154

Freezing Point

Degree C below zero	No. of samples
0.520-0.529	11
0.530-0.539	78
0.540-0.550	62
More than 0.550	3
	154

Samples of bottled milk from country and metropolitan treatment plants were also analysed in the course of regular monthly "screening" for organo-chlorine insecticide residues.

The Horticultural Division of the Department of Agriculture continued investigations into the residues of ethylene dibromide following fumigation procedures. Twenty-two samples of lemon juice, 15 of mandarin juice and one orange juice from experimental treatments were received and analysed for ethylene dibromide. In separate experiments, two samples of orange fruit were analysed as soon as posible after fumigation, and then at intervals for a period of seven days in an attempt to determine the rate of decrease in ethylene dibromide levels. In one case the concentration of fumigant decreased to 25 per cent of its original level after 3 days and to 10 per cent after 7 days; in the other it decreased to 50 per cent after 3 days and to 20 per cent after 7 days.

In contrast to the previous year, only four samples of commercial orange juice were received for examination to Food and Drug Regulations, with particular reference to juice content. A sample labelled Orange Concentrate gave analytical figures suggesting that it was an orange juice which had been concentrated to about two-thirds of its original volume, and to which had been added sugar, phosphorus and a "fruit acid".

Fifty-six samples of spirits were received for analysis for alcohol content; 33 failed to comply with the standards prescribed under the Health Act.

A case of alleged misrepresentation of spirits was of interest in its technical details: It was alleged that the proprietor of a night-club had substituted cheap bulk whisky, rum and gin respectively for the more expensive products. Laboratory examination involved the use of gas chromatography to compare the "suspect" samples with a genuine sample of the same batch number as that on the suspect bottles. This examination revealed that the principal congeners of the whisky and rum samples were n-propanol, isobutanol, iso-amyl alcohol and ethyl acetate. No congeners were detected in the suspect or genuine samples of gin. Quantitative determination of the n-propanol, isobutanol and ethyl acetate was made isothermally at 190° C using a six-foot Porapak Q column. The iso-amyl alcohol was determined at 220° C. Standards for the determination were prepared in a 40 per cent v/v solution of ethanol in water to ensure that any "tailing" effect would be similar in both standard and sample. Using this simple technique excellent linearity and reproducibility were obtained; the figures are tabulated in Table 13.

TABLE 13

Analyses of Suspect and Genuine Liquors

	Whisky		Rum		Gin	
	Suspect	Genuine	Suspect	Genuine	Suspect	Genuine
	parts per million					
n-propano	140	200	68	121	nd*	nd
isobutanol	350	290	59	20	nd	nd
iso-amyl alcohol	330	220	47	47	nd	nd
ethyl acetate	180	160	263	84	nd	nd
	per cent w/v					
Acidity (as acetic acid)	0·017	0·016	0·013	0·010	negligible	
Total solids	0·13	0·22	0·113	0·422	0·009	0·002

*nd—not detected.

As in each case the suspect and genuine samples bore the same Batch Number the analytical figures clearly indicate differences between the suspect and genuine samples of whisky and rum, but apart from a difference in total solids the two gin samples cannot be differentiated analytically by this procedure. They were, however, fairly readily differentiated by organoleptic examination.

There was a marked increase in the number of samples of meat and meat products received for examination.

Twelve samples of tripe were checked for compliance with Food and Drug Regulations in respect of pH and absence of formaldehyde; sausages and sausage meats were analysed for meat content (calculated according to a "prescribed method" based on the early work of More and Stubbs); while numerous samples were analysed for nitrite and/or nitrate content.

As a result of a Court case where evidence was given for the defence that the nitrite content of a "manufactured meat" could increase during storage despite refrigeration, four investigations were carried out in collaboration with the Department of Public Health. Samples of bulked bacon, sliced bacon, uncooked corned silverside and sausage meat, to which nitrite had been added as in normal processing, were analysed shortly after preparation and then at 48 hour intervals. After ten days there was no change in the nitrite concentration of the bulked bacon, but the nitrite level of the sliced bacon and sausage meat had decreased to one-half the original level, while in the case of corned silverside the nitrite had decreased to three-quarters of the original concentration.

A number of samples of meat "additives" were analysed variously for nitrite, nitrate, protein, sulphur dioxide and ascorbic acid.

Two technical problems of interest were encountered in the course of this work:

(1) A meat additive, a "deep burgundy" coloured powder containing ascorbic acid, was found to contain the red colouring matter of beetroot, betanin. The colour was readily absorbed from aqueous solution on to a column of Woelm aluminium oxide, acid, activity grade 1, and then eluted with ammonia as a mauve colour, fading to a permanent yellow. Sodium hydroxide also produced a change to yellow and hydrochloric acid gave a violet-red.

Paper chromatography of the red colour in two solvents alongside a beetroot control gave the following Rf values for the sample and control and mixed chromatograms gave a single spot.

Solvent	Rf value	Colour on chromatogram
2% trisod. citrate in 5% ammonia	0·72	Yellow
$BuOH/EtOH/H_2O$ (1+1+1)	0·20	Mauve

For the determination of ascorbic acid, the colour was first removed from a dilute oxalic acid solution by adsorption on alumina previously washed with 0.25 per cent oxalic acid to prevent oxidation of ascorbic acid.

(2) The sodium erythorbate present in some "beef cures" was found to suppress colour development by Cleves acid in the determination of nitrite. This was satisfactorily overcome by treatment with carbon in a solution buffered at pH 9.5 in the preparatory stage, as used in the method of Adriaanse and Robbers (J. Sci. Fd. Agric., 1969, 20, p. 321). Interference from sodium erythorbate present up to 100 times the weight of nitrite was shown to be eliminated completely by this treatment. The same treatment also overcame the high results due to the presence of erythorbates when the permanganate titration method for nitrite was used for concentrated "beef cures".

Human Toxicology

Exhibits were received from approximately 500 cases of sudden death which were the subject of police investigation. Of this number, 201 cases comprising 873 exhibits, as registered, were submitted for examination for poisons or drugs.

In 92 cases no evidence of any poison or drug could be established, but in 109 cases at least one drug or poisonous substance was detected, although in a number of cases the concentration of the drug made its toxicological significance uncertain.

Details are listed in Table 14.

TABLE 14

DRUG AND POISON CASES

Drug or Poison	No. of Cases
Carbon Monoxide	25
Pentobarbitone	20
Amylobarbitone	8
Diazepam	8
Cyanide	5
Phenytoin	5
Quinalbarbitone	5
Strychnine	5
Amitriptyline	4
Dibenzepin	4
Phenobarbitone	4
Thioridazine	4
Chloral	3
Chlorpromazine	3
Methaqualone	3
Paracetamol	3
Salicylate	3
Alcohol (ethyl)	2
Carbromal	2
Codeine	2
Digoxin	2
Methanol	2
Orphenadrine	2
*Various (one of each)	22
Negative	92

*Acetone, arsenic, beclamide, butobarbitone, carbamazepine, chlorbutol, chlordiazepoxide, cocaine, dextromoramide, dextropropoxyphene, diphenhydramine, glutethimide, halothane, imipramine, kerosine, methadone, methapyriline, nicotine, nitrazepam, phentermine, primidone, salicylamide.

In 164 of these cases a sample of blood was available for alcohol determination. 105 cases were negative and in 28 cases the alcohol concentration was 0.150 per cent or greater.

Eighty three exhibits of post-mortem blood and urine were also received from fifty cases of "sudden death" where full toxicological examination was not considered necessary by the pathologist. Of these 50 cases, 52 per cent were negative, (i.e., blood alcohol was nil), while in 28 per cent of cases the blood alcohol was 0.150 per cent or more, and in 36 per cent it was 0.080 per cent or more. In only two cases was the figure greater than 0.300 per cent.

Several of the toxicology cases were of "technical" interest.

1. Two fatal cases of suspected digoxin overdose were examined by the radio-immunoassay facilities of the State Health Laboratories. One involved an infant only a few weeks old and the other a person in the mid-seventies. In each case digoxin was detected in the post-mortem blood at a level approximately ten times that at which arrhythmias are stated to occur, namely 3.3 nanograms per ml. (A. S. Curry: Advances in Forensic and Clinical Toxicology, 1972, p. 157). As published methods of analysis deal with the determination of digoxin in blood serum from the living patient, modifications were necessary to adapt a method for use with post mortem blood. In the case of the older person, digoxin was found in the liver and kidney to the extent of 280 and 200 nanograms per gram respectively.

2. In another case the cause of death was subsequently established as unrelated to drug overdose. Deceased had been prescribed phentermine, and the levels determined in the blood and stomach and contents indicated that excessive ingestion had not occurred. "Therapeutic" levels were therefore determined in the bile, liver and urine for future reference where overdose might be suspected. Figures as under were submitted for publication in the Bulletin of the International Association of Forensic Toxicologists.

Exhibit	Phentermine
Stomach and contents	3 mg
	parts per million
Bile	6.5
Blood	0.9
Liver	4
Urine	50

3. Post mortem exhibits were also examined in connection with death following oral ingestion of a relatively large amount of crystalline cocaine hydrochloride. Cocaine levels were determined in the urine, liver, kidney, spleen and bile as well as in the stomach and contents. As no previously recorded levels for cocaine poisoning could be found in the literature the results of analyses were submitted for publication in the Bulletin of the International Association of Forensic Toxicologists.

Exhibit	Cocaine
Stomach and contents	1.4 gram
	parts per million
Bile	25
Blood	8
Kidney	12
Liver	8
Spleen	30
Urine	50

Blood Alcohol (Traffic Deaths)

Four hundred and forty-seven samples of blood and/or urine were received from the Police Department in connection with investigations into fatal traffic accidents. Two hundred and forty-three of these were post mortem blood samples which were analysed for alcohol, although it was noted that the "road toll" for Western Australia in 1973 was 371.

The distribution of blood alcohol figures for the various categories of persons whose blood was analysed is shown in Table 15.

TABLE 15

TRAFFIC DEATHS—BLOOD ALCOHOL LEVELS

Alcohol per cent	Motor vehicle drivers	Passengers	Pedestrians	*Motor cycle riders	Pillion passengers	Unknown
Negative	34	27	24	13	....	1
0·050 and less	6	6	5	2	....	....
0·051—0·079....	3	2	....	1	....	1
0·080—0·099....	5	2	....	....	....	1
0·100—0·149....	8	3	3	2	....	....
0·150—0·200....	20	3	5	1	1	1
0·201—0·250....	17	7	5	....	....	....
0·251—0·300....	12	2	1	....	....	....
More than 0·300	7	5	7	....	1	....
TOTAL	112	56	50	19	2	4

* Includes motor-scooters

(12)—39934

Table 15 shows that 50 per cent of fatally injured motor vehicle 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 29 per cent and 36 per cent respectively, and that for motor-cycle riders was 5 per cent.

Blood alcohol levels of 0.080 per cent or more were recorded for 62 per cent of motor vehicle drivers, 38 per cent of passengers and of pedestrians, and 16 per cent of motor-cycle riders.

Negative results (i.e. no blood alcohol) were recorded for 30 per cent of motor vehicle drivers, 48 per cent of passengers, 32 per cent of pedestrians, and 68 per cent of motor-cycle riders.

Blood Alcohol (Traffic Act)

Six hundred and ninety-two samples of blood were submitted by Police and Local Traffic Authorities under section 32B of the Traffic Act, which provides for samples of blood to be analysed for alcohol in connection with suspected breaches of the Act, e.g.

(1) Under section 32AA of the Traffic Act, it is an offence to drive a motor vehicle on a road or public place if the blood-alcohol concentration of the driver is 0.08 per cent or more.

(2) Under section 32C(4) of the Act, a blood alcohol concentration of 0.15 per cent or more "is conclusive evidence that the person was, at that time, under the influence of alcohol to such an extent as to be incapable of having proper control of a motor vehicle . . ."

The results of the analyses of samples taken under the provisions of the Traffic Act are set out in Table 16, the figure being the alcohol content at the "time of occurrence of event", calculated as prescribed in Regulation 12 of the Blood Sampling and Analysis Regulations, 1966.

TABLE 16

TRAFFIC ACT—BLOOD ALCOHOL LEVELS

Alcohol, per cent	No. of Cases	Per cent of Cases
0·050 and less	31	4·5
0·051—0·079	35	5·0
0·080—0·099	34	4·9
0·100—0·149	134	19·4
0·150—0·200	182	26·3
0·201—0·250	155	22·4
0·251—0·300	79	11·4
More than 0·300	42	6·1
	692	100·0

In accordance with normal practice, each analysis was repeated independently by another chemist.

Table 16 shows that 458 persons, or 66.2 per cent of the total, had a blood-alcohol figure of 0.150 per cent or more; 592 persons or 85.6 per cent, had a figure of 0.100 per cent or more, 626 persons, or 90.5 per cent, had a figure of 0.080 or more, and that 661 persons, or 95.5 per cent had a figure greater than 0.050 per cent.

Specimens from Patients

One hundred and ninety-eight samples were received for examination under this classification. These were chiefly samples of urine, whole blood, plasma or serum, with smaller numbers of miscellaneous samples.

These were analysed in connection with the medical examination of patients for clinical purposes, as distinct from the requirements of industrial hygiene and toxicology. The different types of analyses performed in this connection are detailed in Table 17.

TABLE 17

SPECIMENS FROM PATIENTS—ANALYSES

Analysis	Number
Arsenic	87
Lead	40
Silver	31
Thallium	8
Mercury	7
Cadmium	6
Amphetamines	3
Cyanide	3
Drugs (general)	3
Morphine	3
Nickel	3
Cocaine	2
Fluorine	2
Strychnine	2
*Various (one of each)	13

*Alcohol (ethyl), amitriptyline, antimony, barbiturates, boron, codeine, dextromoramide, dieldrin, methadone, pethidine, "phenothiazines", phosphorus, sodium.

A large proportion of the arsenic analyses were carried out initially for diagnosis, and then in order to monitor the progress of a patient suffering from arsenic poisoning, the cause of which could not be satisfactorily determined.

Thirty samples were examined for silver in order to obtain data on the degree of absorption of silver by the body following the use of silver sulphadiazine ointment in the treatment of severe burns. The method of analysis involved modification of the procedures of Freideberg (Anal. Chem., *27*, 305) and of Sachdev and West (Anal. Chem. Acta, *44*, 301).

Analyses of untreated "controls" indicated that the normal levels of silver were: less than 0.05 mg/l in the blood, less than 0.005 mg/l in the urine and 0.2-0.5 mg/kg in the faeces, while in treated patients the levels varied up to about 0.2 mg/l in the blood, 0.7 mg/l in the urine, and up to 30 mg/kg in the faeces.

Animal Toxicology

There was a marked increase is the number of exhibits examined in connection with the deaths of animals.

Sixty four exhibits were received from 38 post-mortem examinations. Of these, 23 cases were negative, while strychnine was detected in 11 cases, dieldrin in two, sodium fluoroacetate in one, and procaine in one.

Of a number of samples submitted which were considered to have been responsible for animal deaths, only one was found to contain any harmful material. This was a sample of wheat "contaminated" with fenthion, and was no doubt responsible for the death of a number of birds to whom it was fed.

Samples of suspected poison baits were received from veterinary surgeons, the Police and the Department of Agriculture; all were negative.

Industrial Hygiene

Two hundred and eighty-seven samples were examined during the year in connection with industrial hygiene investigations. Two hundred and twenty six of these were samples of urine from workers in situations where exposure to a potential hazard, chiefly lead, was suspected. Analyses were carried out to assist clinical diagnosis or to provide "screening" to exclude the possibility of undue exposure.

Of these samples of urine, 173 were analysed for lead, 33 for fluorine, 8 for arsenic, 10 for mercury and two for dieldrin, D.D.T., etc.

Analysis of the 173 samples examined for lead revealed that 47 per cent contained not more than 0.08 mg per litre of lead (as Pb), 35 per cent contained 0.09-0.15 mg per litre, 16 per cent contained 0.16-0.20 mg per litre, and 16 per cent contained more than 0.20 mg per litre.

Samples of blood and hair were also examined variously for arsenic, cadmium, lead, mercury and organo-chlorine insecticides (D.D.T., dieldrin, etc.) in connection with possible exposure to hazardous conditions.

Inspections were made of working conditions in several factories, and samples of air were examined for—

(1) formaldehyde levels in a timber factory using resorcinol-formaldehyde resin as a "bonding agent";

(2) irritant gases formed during welding operations in the presence of Freon refrigerant gases;

(3) levels of D.D.V.P. in a factory where pesticide resin strips containing D.D.V.P. were incorporated into dog collars;

(4) carbon monoxide in a freight storage depot where fork-lift trucks were used for moving heavy goods.

Inspections were carried out as required to check the safety of working conditions during the unloading of cargo from ships. These were requested as a result of spillage, or leaking from containers of the chemicals methyl bromide, hydrochloric acid, Desmodur (methylene bisphenyl isocyanate); from the use of maldison, D.D.V.P. and lindane as fumigants; and complaint of irritant fumes resulting from the use of fork-lift trucks in a ship's hold.

"On the spot" assessments of the degree of hazard were made by the chemist carrying out the inspection, and advice given on ventilation and other measures necessary to ensure safe working conditions.

Miscellaneous

Maritime pollution.—There was no diminution in the number of samples received in connection with maritime pollution, and the problem of identifying the offending source. Forty three samples of oil were examined, comprising those constituting the "pollution" as well as samples from possible offenders, which were examined in attempts to identify the origin of the particular case of pollution.

Vermin poisons.—Two samples of strychnine and one of sodium monofluoroacetate ("1080") were assayed for the Agriculture Protection Board, and 27 samples of prepared dingo baits were analysed variously for strychnine and "1080" to assist the Board in checking the efficiency of their methods for preparing these baits.

Pesticides.—There was a decrease in the number of pesticides as such received for analysis, 60 samples as compared with 87 in 1972. The types of pesticide are listed in Table 18:

TABLE 18

PESTICIDE—EXAMINATIONS

Type of pesticide	No. of Samples
Concentrates and Emulsions	
Aldrin	22
D.D.T.	1
Diazinon	2
Fenitrothion	2
Heptachlor	4
2,4-D amine or ester	16
2,4,5-T ester	5
Various	3
Formulations	5

Samples of aldrin concentrate and diluted emulsion were examined for the Architectural Division, Public Works Department, as a check on the quality of materials used in "white ant" preventive treatments in building projects.

Sample of diazinon and heptachlor were assayed for the Biological Services Division of the Department of Agriculture, weedicide concentrates were assayed as a measure of quality control for the Weed Control Branch, while samples of fenitrothion were checked for use in programmes of grasshopper and locust control.

Criminal.—One hundred and eighty-eight exhibits were examined for the Police Department in connection with investigations by the Criminal Investigation Branch. These included 85 exhibits taken from 20 cases of suspected arson. In six cases residues of petrol were identified, in two cases there was evidence of kerosene, and in another there was evidence of an aromatic hydrocarbon such as benzene or toluene.

Twenty-five exhibits were connected with the offence of "breaking and entering", 16 with theft, 13 with alleged wilful damage to property, 15 with food suspected of containing poison, and there were 18 miscellaneous exhibits.

Drugs.—There was a marked increase in the number of exhibits received from the Police Drug Squad in connection with suspected possession of drugs. In 117 exhibits where a drug was identified there were 75 of cannabis, 22 of L.S.D. (19 of these from the one person), 4 of morphine, 3 of cocaine, 2 of pethidine and methyl phenidate, one of methadone and 8 miscellaneous prohibited drugs.

The first sample of hallucinogenic mushrooms to be seized in this State and examined by these Laboratories was found to contain 0.08 per cent of psilocybin but was free of psilocin. The precise botanical identification has not yet been determined. (The sample was thought to have originated in Queensland or the Northern Territory.)

In co-operation with the Chief Forensic Chemist of the Australian Customs Department these Laboratories together with other State Laboratories, took part in a collaborative study in the identification and quantitative determination of a number of illicit drugs. Although the results of the collaborative study have not yet been released, the exercise has prepared these Laboratories for the analysis of types of drugs which to date have rarely been encountered in this State.

Horse doping tests.—There was a marked increas in the number of samples received from the Western Australian Trotting Association in connection with the "swabbing" of winners of trotting races. 344 samples (338 of horse urine, 6 of saliva) were examined in 1973, as compared with 209 in 1972. This increase occurred through the introduction of the practice of testing all winners at the trotting headquarters, Gloucester Park, instead of the previous practice of "random" testing.

Four positive cases were detected—two cases of caffeine and metabolites, one of phenylbutazone and metabolites, and one case where an unusually high concentration of vitamin B_1 was detected. A surprising feature of the positive cases was that three of the four were from Gloucester Park where it was common knowledge that the winner of each race would be tested.

Detergents.—Ninety-two samples of detergents were received from the Government Tender Board in connection with 144 tenders received for the supply of detergents for use in Government institutions. Considerable effort was entailed in giving consideration to the tenders in order to make the necessary recommendations as to suitability, as the samples varied considerably in type and the use for which they were intended. The various preparations included synthetic detergent mixtures, composite soap powders, laundry adjuncts, liquid soap type detergents, steam-cleaning compounds, solvent type degreasers and preparations for specialised laundry use.

Pesticide residue analyses.—There was considerable variety in the types of pesticide residue samples submitted for analysis in 1973. In addition to approximately 500 samples held over from 1972 due to interruption of this work by fire damage, more than 1 000 samples were received and examined during the year. Some indication of the variety of this work is given in Table 19.

TABLE 19

PESTICIDE RESIDUE ANALYSES

Sample (and analyses)	Number
Milk, ex treatment plants (O.C's)	48
Water, S.W. rivers (O.C's and herbicides)	45
Silt, S.W. rivers (O.C's and 2,4,5-T)	6
Water, Ord area and N.W. (O.C's, O.P's, herbicides)	106
Pasture, Kununurra (O.C's)	86
Stock feed, Kununurra (O.C's)	25
Fat, cattle (O.C's)	104
Fat, sheep (O.C's)	24
Bird tissues, Ord area (O.C's)	121
Fish tissues, Ord area (O.C's)	76
Fish tissues, Swan River (O.C's)	54
Trout tissues (O.C's, O.P's)	6
Eggs, wildlife (O.C's)	15
Pelican eggs (O.C's and fat)	22
Cattle faeces, K.R.S. (O.C's)	18
Lupin seeds (diquat, paraquat)	12
Lupin seed (diuron, simazine)	15
Pastures, dairying (O.C's)	32
Milk, dairying (O.C's)	15
Vegetables, dairying (O.C's)	6
Various, dairying (O.C's)	4
Peanuts (O.C's)	8
Cauliflower (O.C's)	9
Potatoes (O.C's and arprocarb)	14
Potatoes (O.C's and rotenone)	2
Bean sprouts, peas, tomatoes (O.C's)	9
Cheeses, local and imported (O.C's)	16
Strawberries (dichloran)	6
Grapefruit, pear (O.C's)	4
Eggs (O.C's)	5
Soil (atrazine, bromacil, diuron)	61
Soil (O.C's parathion)	21
Soil (dalapon)	4
Various	33

Miscellaneous samples received and examined during the year included:

Eighteen samples of mine air analysed for carbon monoxide and oxides of nitrogen in connection with underground trials of various blasting agents conducted by the Mines Department, Kalgoorlie.

Twelve "Streamer Bombs" examined for the Explosives Branch to check for the presence of prohibited constituents.

Forty-four toys submitted for lead analyses of paint and metal portions in connection with suspected lead poisoning of a child.

Sixteen samples of different types of explosives which were analysed for the Explosives Branch as a check on their composition.

Eight samples of lemon-grass oil from experimental growths of lemon grass, which were analysed for citral content.

Four childrens "rag" books, analysed for lead and cadmium; one was found to contain significantly high levels of "extractable" lead.

Four samples of ceramic "glazes" as used by amateur "potters", two of which contained significant concentrations of lead.

Nine samples of air analysed for ethylene dibromide in connection with experimental fumigation at a country centre, and 6 samples of air analysed for methyl bromide in the course of calibrating a "Riken" gas indicator for use with a portable fumigation chamber.

One hundred and three samples of crockery and earthenware analysed for "extractable lead" at first according to A.S.T.M. C555-71 suitably modified, later according to British Standard No. 4860 : 72, "Permissible Limits of Metal Release from Glazed Ceramic Ware."

Numerous enquiries for technical information and advice were received during the year, and expert evidence was tendered in various Courts, as required, by officers of the Division in connection with their official duties.

General

Mr. G. A. Taylor attended the Conference of Scientific Officers engaged in Industrial Hygiene and the National Symposium on the Forensic Sciences held at Sydney in February.

Mr. F. E. Uren deputised for Mr. N. R. Houghton in attending the meeting of the Food Analysis (Reference) Sub-Committee of the National Health and Medical Research Council, held at Melbourne in September.

Mr. F. E. Uren assisted at the Police Training School and gave two series of lectures on "How the Research Chemist can Assist in the Detection of Crime."

In November 1973 these Laboratories acted as host for the Annual Conference of Forensic Toxicologists, which was attended by representatives from each of the State Laboratories. On this occasion the Conference was enlarged by the attendance of four Commonwealth representatives. The Conference was very successful in providing a forum for the discussion of varied toxicological problems, and it was resolved that in conjunction with future meetings, there should also be held a conference of officers engaged in the analysis of illicit drugs. The need for such a conference had become apparent as a result of the problems encountered by the analysts who took part in the collaborative study of illicit drugs, referred to earlier in this report.

INDUSTRIAL CHEMISTRY DIVISION

There has been a reduction in the number of samples submitted for examination this year and only 132 were received.

There has, however, been no falling off in the number of enquiries received on a wide range of subjects in which the Division is concerned. These enquiries come from other Government Departments, private companies and the general public. Many short literature searches were necessary in order to answer some of these enquiries and again interest in plastics was considerable.

Staff

Dr. Smith again delivered the final lecture of the annual "Know Your Plastics" series organised by the Plastics Institute of Australia. A lecture on corrosion control with plastics was delivered to a meeting of the Australian Corrosion Association and another lecture on flammability and fire tests on plastics was delivered to a meeting of the Institute of Fire Engineers.

The Oil and Colour Chemists Association held their annual convention in Perth for the first time this year. Dr. Smith was a member of the committee which organised the technical programme.

Dr. Smith also attended Ausplas '73, the exhibition and convention organised by the Plastics Institute of Australia, in Melbourne. The opportunity was taken during the visit to call on C.S.I.R.O. Division of Building Research and Forest Products Laboratory, the Defense Standard Laboratories, the Secretary, Commonwealth Paint Committee and the Rohm and Haas Co.

Details of Work

1. Routine

(a) Building materials.—Continuing our work on carpet testing for the Furniture Section, Public Works Department, seven samples of carpet were submitted to the tests described in previous Annual Reports.

Three samples were first submitted. Two of these were synthetic needle-felted carpets, one being homogeneous and the other being foam backed. The third sample was a carpet tile probably also based on synthetic fibres and rubber backed. In the abrasion test, the results showed up the poor service to be expected from many backed carpets or tiles with only a comparatively thin layer of fibre. In resistance to ultraviolet light the two carpets behaved very well and showed no visible change after 100 hours . The carpet tile, however, faded badly. Dimensional stability was good for all three samples with no change greater than 0.5 per cent taking place. Resistance to stains was generally similar to previous results with crayon, biro, marking pen, shoe polish and blood stains being the most difficult to remove.

Two further samples comprised a needle-felted carpet and a foam backed carpet of loop-pile construction. Fading in ultraviolet light was slight to moderate for the needle-felted sample and moderate for the loop-pile sample.

Dimensional stability of the loop-pile carpet was very good, whilst the needle-felted sample developed a permanent shrinkage of 0.8 per cent. Staining was much as before, except that the loop-pile carpet readily absorbed most staining agents and crayon, biro, marking pen, shoe polish and blood left permanent stains, whilst the other sample only retained slight permanent stains with the last four staining agents.

The final two samples consisted of carpet tiles of the same manufacture as the tile in the first three samples.

Two samples of carpet adhesive from the same manufacturer were also tested as described in our last Annual Report. One of the adhesives was significantly better than the other, giving appreciably higher bond strengths as measured by the peel test. Generally, bond failure was gradual, but some sudden failures occurred if open drying time was not long enough.

A large number of paint samples were again tested for the Government Tender Board. During the year 21 samples of paint from Government Stores stocks were tested to compare results obtained from the samples supplied for the 1973 tender. Generally, the samples compared well with the originals. However, there were three samples in which property variations exceeded the allowable variations as laid down in the appropriate standard. The Government Tender Board were advised to inform the three paint companies involved of the discrepancies in their product.

The 62 samples which were submitted in 1972 for the 1973 tender were reported to the Government Tender Board early in 1973. Late in the year we received 63 samples to examine for the 1974 tender and work on these was completed in time for the report to be considered by the Paint Advisory Committee during December.

The Public Works Department asked for advice on paint systems to be used in extensions to a metropolitan hospital. They were concerned about the performance of two pot polyurethane paints since some failures had occurred in other similar jobs. A study was made of the specifications and the recommendations made by several paint manufacturers. A report was prepared on the basis of this study including suggestions for alternative paint systems which could be tried.

(b) Plastics.—The Chief Inspector of Factories submitted five samples of plastic tanks all of which had failed in service after varying periods of time. Four of the five samples were from tanks which had been fabricated from thermoplastic sheet and then reinforced on the outside with glass reinforced plastic. The sheet used for one tank was polypropylene and for the other three rigid polyvinyl chloride. The fifth tank was constructed of glass reinforced plastic only and with a very thick gel coat (50 mil).

From the very small samples provided it was difficult to decide what might have caused the tanks to fail. The resin content was determined in each of the five samples. In two samples the resin content was satisfactory at 66.7 and 68.3 per cent, whilst in the other three the resin content was somewhat high at 72.5, 75.5 and 81.3 per cent. The last two are particularly high figures.

Three of the tanks were described as sulphuric acid breakdown tanks and the other two as aluminium sulphate tanks. Chemically, the tank lining materials should all withstand the effects of these chemicals. The fault must therefore lie in the design of the tanks or in their construction or both. In some samples there was evidence of poor wetting out of the glass fibre by the resin, which could lead to serious weakness in the tanks.

The Department of Public Health submitted a sample of polyester resin used for glass reinforced plastics manufacture. The boat builder concerned claimed that this particular batch of resin was affecting his workers more severely than usual and thought that the styrene content might be excessive or that other volatile materials were present. Only styrene was found and its content at 32 per cent was not excessive.

Two other samples were submitted by the Public Health Department consisting of sandwich panels with a foam core and plastic facings. These materials were made in Italy and were proposed for use as insulating panels in cool rooms. The white foam core in each sample was found to be polystyrene and the facings in each case were polyurethane. Thus the panels would probably be safe for use near foodstuffs, but both were flammable and burned readily.

As a result of a fire in a store the Factories and Shops Department submitted 13 samples of plastic toys so that the plastics could be identified and some comment made as to the possible toxicity of the gases produced on burning. Quite a number of different plastics were represented, particularly as some of the samples were multi-component with different plastics used for each component. The samples were composed of the following types of plastics:— polyethylene, polypropylene, cellulose acetate, polycarbonate, polyurethane, melamine-formaldehyde, acrylonitrile - butadiene - styrene (ABS), polyvinyl chloride, natural and butyl rubbers. In the report some general comments were made on the decomposition or combustion products of these plastics in a fire.

Last year the flammability of standard polyurethane foam and polyisocyanurate foam was compared for the Harbour and Light Department and prior to that tests were made for stability under temperature cycling, effect of kerosene and a high aromatic solvent and water absorbency on polyurethane foam. A sample of polyisocyanurate foam has now been tested for effect of temperature cycling, solvents and water. The density and buoyancy were also determined before and after the tests. The results were quite similar to those obtained previously and the polyisocyanurate foam was little affected by the tests.

Compared with the large number of concrete underlay materials tested for Public Works Department last year only one sample was received this year. The sample was a blue woven polyethylene fabric, 0.015 inch thick, coated on one side with a 0.001 inch layer of clear polyethylene. Water absorption was apparently very high but this was undoubtedly caused by mechanical entrapment of water within the weave of the fabric. It passed the hydrostatic pressure test of 10 lbs per sq. inch for 5 minutes and finally failed at a pressure of 65 lbs per sq. inch. Impact resistance, as expected for this type and thickness of material, was very good, requiring a drop height of 34 inches for penetration to occur. In addition an abrasion resistance test carried out according to ASTM D968.51 was done. This gave a satisfactory result.

Public Health Department submitted a sample of hardener for a urea-formaldehyde adhesive to identify active ingredients. These were found to be phosphoric acid and lactic acid.

(c) Miscellaneous.—Last year it was reported that 42 samples of lignite from the Fitzgerald River deposit had been submitted by the Geological Survey. Work on these samples was completed early in the year. All samples were extracted with benzene, then one in five were extracted with benzene/ethanol and hexane. For some property determinations the various samples of wax obtained from the benzene extractions were combined into four bulk samples to provide sufficient material for the determinations. The properties determined were melting point, acid value, saponification value, resin content and density.

Yields of wax from all the extractions were low from most samples, ranging from 0.72 per cent to 8.47 per cent, but only 7 samples had a wax content higher than 3 per cent. The quality of the waxes was not as good as German Montan Wax, the melting points being lower and resin contents very high.

2. Assistance to Industry

(a) Lemon grass oil.—A further 10 samples of lemon grass from Kununurra were steam distilled and the oil recovered. The first two samples took too long to arrive and yield of oil was so small that citral content could not be determined. The other 8 samples arrived together and in good time and gave reasonable yields of oil except for one sample which gave a low yield of an oil which was also low in citral content.

(b) Vitamins.—A local company is interested in the extraction of vitamins from natural sources. They had on hand a large volume of extract which they were unable to concentrate to small volume in equipment available to them. This was satisfactorily done in the Division's falling film evaporator. Later in the year a successful grinding test was carried out on the solid material recovered.

(c) Solvent extraction.—In previous years considerable work was done on solvent extraction by the Cavsol process of such materials as whole fish for the production of fish protein concentrate. Such a project is being undertaken in Tasmania on a commercial scale, using a different solvent extraction process. Interest has now revived in the Cavsol process and a request was received to process two lots of fish during the year.

(d) Fish.—Another company interested in processing tuna required samples to be minced. One northern yellow fin and one northern blue fin tuna were supplied and these were filletted, skinned and the fillets minced.

(e) Floor tiles.—A firm of architects requested tests on vinyl floor tiles because a client had complained of considerable surface damage. An indentation test was carried out and it was found that the tiles complied not only with AS A132-1962 for Vinyl Asbestos Floor Tiles, but also with BS 3261-1960 for Flexible PVC Flooring.

3. Investigational

(a) Painting of karri timber.—The external exposure trial is continuing. Two inspections were carried out during the year which showed that most samples were behaving well with little deterioration.

(b) Printers' rollers.—This project is continuing and work is done when materials are available. Two PVC rollers of different formulations were prepared and supplied to the Government Printer for trial. Both formulations were designed to improve adhesion of the PVC to the metal stock. In experiments before casting the rollers the formulations were found to increase adhesion.

Little success has been obtained with our polysulphide rubber rollers. One curing system for these rubbers is based on manganese dioxide and it has not been possible to locate material which has the right activity. Similar problems are now occurring with lead dioxide, but the Defence Standards Laboratories have advised of a particular brand of lead dioxide which they have found suitable for curing these rubbers. Further work on the project is waiting on supplies of the lead dioxide.

(c) Polyester drafting film.—Work on this project has not progressed very far this year since it has not been given a high priority. In addition it has not been possible to obtain many of the coating materials needed to complete the work. A company supplying such materials was visited in Melbourne in October and it was thought that these samples would soon be received. A large amount of literature arrived in December but so far no samples.

(d) Rust treatment.—This project has been continued and salt spray cabinet tests are still in progress. These are expected to be completed by April or May, 1974. Already significant differences between treatments have been noted and the project will go on by preparation of selected systems for outdoor exposure trials.

(e) Clear lacquers for timber.—This project is continuing and some interesting results have been obtained. The first series of exposure trials has ended and these gave an insight into the general behaviour of pigmented clear lacquers when exposed to ultraviolet light and moisture. Alkyd, polyurethane and acrylic emulsion resins have been used as binders.

The acrylics weathered very well when pigmented, but the alkyds tended to chalk severely with high pigment loadings. Nevertheless, in all cases a small amount of pigment (about 5 per cent w/w) made an appreciable improvement to weatherability.

Current work has been designed to reduce the the rate of chalking by using silane coupling agents to provide chemical bond between pigment and resin. Also the weathering process will be monitored more closely by measuring such properties as water absorption, film thickness, chalking, etc. The final tests to be done will be outdoor exposure trials of selected systems.

(f) Wood waste utilisation.—Very little work was done on this project during the year. A visit to the C.S.I.R.O. Forest Products Laboratory in Melbourne disclosed that they have established a similar project.

(g) Enzyme chemistry.—Many industrial processes utilise yeasts, moulds, etc., to produce useful chemical products. The active agents in each case are usually enzymes. Many enzymes are available as such either as single enzymes or as mixtures of several enzymes. They are expensive and it is normally not possible to recycle them. There are two ways in which enzymes can be utilised more than once. One process requires the use of membrane filters with pores of a size which will hold back the enzyme and the raw material used but allows the product to pass through. An example would be the production of simple sugars from carbohydrates. The other process immobilises the enzyme by binding it chemically to an inert base such as a suitable plastic.

Processes of this kind can be used in treating waste materials of many kinds and it may be possible to produce useful products from such wastes. A project was started to study enzyme chemistry. A literature survey has been completed and some contact has been made with suppliers of enzyme preparations.

(h) Testing of polishes.—A survey of methods of testing floor polishes was made during the year. It is intended to carry out some practical trials on as many of these tests as may be necessary to assess the value of selected tests in relation to polish tenders.

4. Other Activities

Scaevola spinescens.—Supply of an extract of this plant to a few cancer sufferers was continued during the year and reports are still received of patient benefits. No collecting trip was necessary during the year but supplies are now running low.

The results of the pharmacological work carried out at the University of Western Australia have now been written up as a full paper for publication in 1974. It is understood that further research will be done on the extract in the Pharmacology Department. It is possible also that a limited amount of chemical work may be done at the W.A. Institute of Technology.

The sample of spray-dried extract which was sent to the Wellcome Research Laboratories has now been screened in America for antitumour activity and it has been reported that no such activity was found. The Wellcome Research Laboratories may still carry out further pharmacological work when time permits.

5. Consultative

Again a large range of consultative work was undertaken and a selection from enquiries received is given below:

- Incineration of disposable plastics ware in hospitals.
- Materials of construction for butterfly valves in nickel sulphide slurry lines at Kambalda.
- Bacterial contamination of P-traps in hand basins in hospital intensive care units and use of replaceable plastic traps which can be sterilised.

Reason for breakdown and cracking of a plastic star wheel feeder in a fertiliser distributor.

Formulation of metal buffing and polishing compounds.

Treatment of soft plaster on walls.

Extraction of vinyl chloride monomer from PVC bottles used for alcoholic drinks.

Blistering of fibreglass reinforced plastic swimming pools.

Production of eucalyptus oil in the North West.

KALGOORLIE METALLURGICAL LABORATORY

Two hundred and ninety-seven certificates of testing or analysis were issued during the year, an increase of one hundred and one over the previous year.

Six CSIRO reports were issued, but most of the research work was carried out for mining companies who did not want their results to be made public.

Report 772—Cyanide Agitation and a Leaching Test on a Residue Dump from Grants Patch.

Report 773—Reduction Roasting and Leaching of Surface Samples Containing Nickel.

Report 774—Treatment of Antimonial ores and Plant Products from New England Antimony Mines N.L., Hillgrove, N.S.W.

Report 775—Gold recovery from Dump Material located at Grants Patch.

Report 776—Agitation Cyanidation of Mill Tailings from Mt. Magnet.

Report 777—Straking and Cyanidation tests on Accumulated Plant Refuse Dumps at Sons of Gwalia Mine at Leonora.

Research work during the year reflected the growing interest in gold with Companies and prospectors examining old residue dumps with the object of retreatment.

The Carbon in Pulp process offers a low cost method with a high throughput for retreating a large tonnage of these old tailings and combined with the Zadra Process, the cyanide soluble gold which has been absorbed onto the carbon can be recovered and the carbon reused a number of times.

The Carbon in Pulp process would be suitable for Companies starting new mines as a means of reducing the Capital and the operating cost of the plant.

As the price of gold rises we can expect more enquiries in the coming year concerning its recovery from a variety of ores.

A summary of the year's work is shown in Table 20 and reflects the work of increased staff in handling 2 750 assays as against 1 702 for the previous year.

Equipment

A new AA 1200 was obtained and is operating satisfactorily with improved accuracy. The old AA3 was forwarded to the Engineering Chemistry Division.

The purchase of a nitrous oxide burner for the AA 1200 has extended the number of elements that can be determined.

The laboratory's gas used for heating was changed from vapourised Shellite to Clean Heat gas, which is operating satisfactorily.

TABLE 20

KALGOORLIE METALLURGICAL LABORATORY
ASSAYS

Ore and Minerals	Mines Department	Police Department	Aboriginal Affairs Planning Authority	Public		Total
				Free	Pay	
Gold :						
Ore	36	9	4	....	1 099	1 148
Tails	18	....	....	....	856	874
Nickel	....	....	1	....	357	358
Copper	1	....	1	....	56	58
Molybdenum	....	....	....	....	16	16
Tungstic Oxide WO_3	....	2	....	....	15	17
Arsenic	....	....	....	....	10	10
Other	1	2	1	....	265	269
	56	13	7	....	2 674	2 750

MINERAL DIVISION

General

The total number of samples received in the Division was 4 253, being a reduction of about 6 per cent on the figures for the previous year but still appreciably in excess of the annual figures for 1968-1971.

The number of dusts and gold ores and tailings continued the upward trend of the previous year, reflecting respectively the growing awareness of pollution problems and the revival of interest in gold following price rises. The increase in the number of talc and clay samples submitted was largely due to increased activity in the search for and development of suitable high grade deposits of these minerals, while practically all the unusual number of zircon samples originated from research programmes at Engineering Chemistry Division.

Fewer full mineral analyses were completed though a great many were well in hand at the end of the year. Samples of building materials and exhibits submitted by the police were less than in 1972.

Almost half the samples reported during the year originated from branches of the Mines Department including Geological Survey, State Mining Engineer, Explosives and internal Government Chemical Laboratories work.

Of the 1 043 samples from Public Health Department, all but ten were dusts of various types.

The total number from Government sources made up about 82 per cent of all samples submitted, the remaining 18 per cent originated from public sources.

Details of the source and type of samples handled are listed in Table 21.

TABLE 21
MINERAL DIVISION

	Agriculture Department	Mines Department	Public Health Department	Public Works Department	Other Departments	Public			Total
						Pay	Concession	Free	
Building Materials....	....	....	....	3	21	16	....	....	40
Complete Analyses	....	89	....	....	3	3	....	....	95
Dusts	....	407	1 033	....	1	....	....	....	1 441
Geochemistry	....	1 009	....	....	....	1	9	....	1 019
Mineral identifications	....	233	....	....	23	93	18	7	374
Miscellaneous	....	16	8	86	30	16	....	1	156
Ores and minerals—									
Beryl	....	17	....	....	....	3	....	....	20
Clay	179	52	....	3	....	16	....	12	262
Copper	....	22	....	....	4	9	7	....	42
Diatomite	....	22	....	....	....	1	....	....	23
Fluorite	....	1	....	....	....	25	....	....	26
Gold ores	....	16	....	....	3	128	49	20	216
Gold tailings (incl. umpires)	....	63	....	....	....	22	12	....	97
Gold investigational	....	....	....	....	....	57	2	....	59
Heavy sands	....	5	....	....	1	5	2	....	13
Iron	....	7	....	....	7	5	6	....	25
Lime, lime sands	....	21	....	....	7	1	....	1	30
Talc	....	....	....	....	....	41	....	....	41
Vanadium	....	3	....	....	....	4	32	....	39
Zircon	....	1	....	....	....	103	....	....	104
Various other	....	35	2	....	4	21	28	2	92
Police exhibits	....	....	....	....	38	....	....	....	38
Total	179	2 019	1 043	92	142	570	165	43	4 253

Staff

Mr. M. Pryce attended "Microsymposium—73" held in Canberra in February. Overseas specialists participated and discussion covered all phases of microscopy with some emphasis on photomicrography. The opportunity was taken to inspect appropriate equipment in the Geology Department of the Australian National University and a visit was also made to the Bureau of Mineral Resources.

The Analytical Symposium organised by the Royal Australian Chemical Institute was attended by Mr. J. Gamble. This meeting was held in Sydney in May and covered many aspects of analytical techniques directly applicable to mineral work.

Mr. G. Payne attended a meeting in Adelaide of the Standards Association Committee dealing with the analysis of iron ore.

At the invitation of the National Association of Testing Authorities, Mr. D. Burns made a visit of inspection to laboratories in the Pilbara in connection with their application for registration by N.A.T.A.

Publications

The following lists publications by Divisional staff during 1973:

Urea, a new mineral, and neotype phosphammite from Western Australia. Bridge, P. J., Min. Mag., 39, 346 (1973).

List of cave minerals in the Simpson and Mineral Division Collections of the Western Australian Government Chemical Laboratories, 11. Bridge, P. J., Western Caver, 13 (5), 193 (1973).

1011 Face development forming a calcite straw. Bridge, P. J., Western Caver, 12 (6), 168 (1973).

Guano minerals from Murra-el-elevyn cave, Western Australia. Bridge, P. J., Min. Mag., 39, 467 (1973).

Tungsten-and antimony-substituted rutile. Graham, J., (CSIRO) and Morris, R. C., Min. Mag., 39, 470 (1973).

Low-iron cordierite in phlogopite schist from White Well, Western Australia. Pryce, M. W., Min. Mag., 39, 241 (1973).

Papers on the following subjects have been prepared and submitted for publication to appropriate journals:

A monoclinic form of bismuth orthovanadate.

A magnesian variety of collinsite.

A new nickel copper basic carbonate with the approved name of glaukosphaerite.

Crystal structure analyses of collinsite and calcium sulphosilicate (jointly with University staff).

Field Trips

In March, Mr. M. Pryce visited the nickel deposits at Scotia and Carr Boyd Rocks seeking, in particular, secondary copper-nickel carbonate minerals.

In July, Mr. L. Hodge collected interesting specimens from the Windarra, Agnew, Mt. Keith, Yeelirrie and Scotia areas, while in November an extensive collection was made by Mr. E. Beng and Mr. P. Bridge during an extended trip which included visits to Kambalda, St. Ives, Mt. Pleasant, Londonderry and many other mining centres in the Central Goldfields.

On a short trip towards the end of the year, Mr. G. Payne visited a pegmatite mine near Rothsay, and collected specimens also from Koolanooka, Three Springs and Eneabba.

These trips result in considerably enlarging our collection of Western Australian minerals with the resultant opportunity to further the study of the mineralogy of the State and the possibility of discovering new mineral species. The localities of origin are more accurately recorded than is the case with many donated samples and the geological environment and associated minerals can also be recorded. Personal contact with mining people at all levels leads to useful liaison of mutual benefit.

Equipment

The only major item of equipment installed during the year was a Philips PW 1050/25 vertical diffractometer with counting electronics, recorder and printer. The unit was fitted to the existing PW 1130/00 X-ray generator.

As well as for mineral diffraction work the new unit will be used extensively for quantitative determinations on dust samples taken by officers of the Public Health Department and the State Mining Engineer's Branch from mines, quarries and other industries with dust hazards.

Diffraction studies of clay samples will also be facilitated and semi-quantitative diffraction work on mineral mixtures and metallurgical plant products can be done more accurately. This equipment is also available for use by specialist officers of the Geological Survey.

A Philips 5.73 cm diameter Debye-Scherrer camera PW1026 was also purchased for routine film work to replace an old unserviceable unit.

Other items ordered included a reflectometer and viscometer for use mainly in determining the brightness and viscosity of clay samples.

Computing

During the year, Divisional use of the facilities of the Regional Computing Centre at the W.A. University has grown considerably. The internal labour avoided by our use of computers in the fields of X-ray diffraction and X-ray spectrometry is so considerable that should such facilities become unavailable, the output of certain routine and development work would either be reduced by a factor of perhaps five, or involve many additional staff; some classes of work would become completely impracticable.

This is particularly true of X-ray spectrometry. Current work on geochemical samples for the Geological Survey Branch involves processing 756 samples each requiring 17 elemental determinations. The conversion of raw data and storage of results, with instant retrieval as required, are performed with adequate security at the Centre.

The conversion, storage and retrieval routines were developed and collated by Mr. A. Thomas in the first half of this year. This involved further development of existing W.A. Regional Computing Centre "software" to produce a satisfactory operating system. The data file design is such that the results are available in report form and also in a form suitable for use in plotting programmes used by specialist Geological Survey of Western Australia staff to produce contour maps of the geochemical data.

However, the present method of data transfer from the X-ray spectrometer to a form suitable for processing at the Centre is cumbersome and time consuming. The Division is examining the feasibility of acquiring a small computing facility to relieve this bottleneck in the work flow.

Nevertheless, continued and perhaps increasing use by analysts and mineralogists of the sophisticated facilities available at the Centre will be necessary.

During 1973, computing by the mineralogists both diversified and increased.

The purchase by the University of two new computers necessitated several X-ray programme changes with consequent extra computing activity.

Late in 1972 the University phased out the Batch computing service on the PDP-6 computer in the old Regional Centre and partially released it for customer operation. Simultaneously the new C.D.C. 6200 computer in the new Centre gradually took over the Batch work.

During this convenient change-over period Mr. M. Pryce commenced two crystal structure analyses (calcium sulphosilicate and collinsite) on the PDP-6 while Mr. L. Hodge adapted the G.C.L. X-ray crystallography programmes from the PDP-6 to run on the new C.D.C. computer.

During 1973 the two structure analyses were completed using the X-ray 72 series of programmes purchased and adapted for the C.D.C. computer by Dr. E. N. Maslen, Director, Crystallography Centre of the University of Western Australia.

Later in 1973 a change of the control cards, for C.D.C. computing, from SCOPE 3.3 to 3.4 necessitated recompiling the G.C.L. X-ray programmes a second time.

Towards the end of 1973 the PDP-6 computer was closed down, progressively upgraded to a PDP-10 and is now operational primarily for teletype work while the C.D.C. 6200 handles the Batch work. The sophisticated INDEX programme, originally compiled on the PDP-6 would require major alteration for use on the C.D.C. unit. However, the advent of the PDP-10 has saved the labour of the change and INDEX has now been adapted with little change for use by the Division's officers on the PDP-10.

A scheme for data processing of Mineral Division reports has been proposed. The scheme is designed for flexibility and includes laboratory and collection numbers, rock and mineral names, chemical analyses, and comments. Complete chemical analyses are in a format compatible with a C.I.P.W. Norm programme.

Mineral Collections

The addition of 159 specimens during the year brought the number of samples in the Mineral Division reference collection to 5 154. This was almost 100 less than in the previous year but even with this moderate rate of growth it will become imperative in the near future to find further floor space to house the Mineral Division and Simpson collections.

About 20 per cent of the new additions were from outside the State. This is a larger proportion than usual as such material is not normally deliberately sought but is accepted if donated gratuitously. However, a number of overseas specimens were obtained in 1973 as they had direct bearing on investigational work being carried out on related materials from Western Australia. Amongst these were rosasite from Mexico and from the type locality (Rosas Mine) in Sardinia, sampleite from Chile, varlamoffite from Malaya, dumortierite from California and Nevada, and a suite of cave minerals from Sarawak and Sabah.

Local sulphide minerals added to the collection included arsenopyrite (Day Dawn), galena (Northampton, Meentheena, Bamboo Creek, Towera Station), pentlandite (Mt. Keith, Nepean, Scotia, Carr Boyd), valleriite (Nepean, Scotia, Carr Boyd), chalcopyrite (Scotia, Carr Boyd, Kalgoorlie, Kumerina), sphalerite (Youanmi, Kalgoorlie), pyrrhotite (Youanmi, Scotia, Carr Boyd), cobaltite (Ravensthorpe), tetrahedrite (Kalgoorlie) and gersdorffite (Bamboo Creek).

Vanadium minerals added were vanadinite, descloizite and brackebuschite from Braeside and bismuth vanadates from Londonderry, Rothsay, Corinthia and Yinnietharra.

Pegmatite minerals originating from a number of localities on Yinnietharra station included beryl, apatite, bismutite, bismutoferrite, uvarovite and zircon, while selected specimens from the Londonderry pegmatites contained spodumene, eucryptite, petalite, prehnite, garnet and cookeite. From a newly opened pegmatite near Rothsay samples of beryl, columbite and pucherite were added.

The only radioactive minerals added to the collection were carnotite from Mt. Seabrook, phosphouranylite from Telfer Creek West and tanteuxenite, monazite and uraninite from Yinnietharra while silicates included nontronite from Lionel and Yundamindra, glauconite from Bloodwood Bore in the far north east, celadonite from Halls Creek, epidote (Wyemandoo Hill), albite and microcline (Rothsay), vermiculite (Young River) and daphnite on quartz crystals from the South Kalgurli shaft.

A considerable number of cave minerals were also added to the collection and are discussed in detail elsewhere in this report.

New Mineral Localities

Localities from which specific minerals were recorded for the first time in these Laboratories during 1973 are listed below. An asterisk* indicates species identified for the first time in Western Australia.

As information regarding localities is in many cases confidential only general localities are listed. Further details could be available on application depending on the source of the original sample.

(a) Kimberley Division

Amethyst	.... Turner Station

(b) North West Division

Atacamite	.... Meentheena
*Bismutoferrite	.... Yinnietharra
Brochantite ..	.... Meentheena
Brochantite ..	.... Towera
Cerussite	.... Towera
*Clinobisvanite	.... Yinnietharra
Copper (native)	.... Ilgarari
Fluorite	.... Meentheena
Galena	.... Meentheena
Galena	.... Towera
Gersdorffite	.... Bamboo Creek
Leucophosphite	.... Yinnietharra
Malachite	.... Meentheena
Psilomelane	.... Yinnietharra
Pyrite	.... Yinnietharra
Pyrolusite	.... Copper Hills
Tourmaline	.... Yinnietharra
Uraninite	.... Yinnietharra
Zircon	.... Yinnietharra

(c) Murchison Division

Arsenopyrite	.... Day Dawn
Chrysocolla	.... Windimurra
*Collinsite	.... Milgun
*Crandallite	.... Milgun
*Montgomeryite	.... Milgun
Sphalerite	.... Youanmi
Variscite	.... Wilgiemia

(d) South West Division

Beryl	.... Rothsay
*Birnessite	.... Jingemia, Watheroo
Bityite	.... Rothsay
Columbite	.... Rothsay
Gahnite	.... Phillips River
*Krohnkite	.... Ravensthorpe
*Mendozite	.... Ravensthorpe
Pucherite	.... Rothsay
*Sampleite	.... Jingemia, Watheroo
Taranakite	.... Jingemia, Watheroo
*Todorokite	.... Jingemia, Watheroo

(e) Central Division

Alunite	.... St. Ives
Celestite	.... Yeelirrie
Chalcocite	.... Mt. Pleasant
Clinobisvanite	.... Corinthia
Copper (native)	.... Mt. Pleasant
Daphnite	.... Kalgoorlie
Glaukosphaerite	.... St. Ives
Millerite	.... Kambalda

(f) North East Division

*Brackebuschite	.... Braeside
Glauconite	....Bloodwood Bore

(g) Eucla Division

*Aphthitalite	.... Cocklebiddy
*Guanine	.... Cocklebiddy
Gypsum	.... Cocklebiddy
*Hannayite	.... Cocklebiddy
*Monetite	.... Cocklebiddy
*Taylorite	.... Cocklebiddy
*Whitlockite	.... Cocklebiddy

Complete Analyses

The big majority of complete analyses was done by X-ray fluorescence on suites of rock samples for Geological Survey.

A number of samples however could be handled better by classical methods while two could be analysed satisfactorily only by special techniques.

These latter were meteorite samples submitted for complete analysis on behalf of the Museum Meteorite Advisory Committee. The chlorination process was used whereby the various meteorite phases are separated and analysed individually.

Result of analysis of one of these, the Oldfield River meteorite is tabulated below:

Non-magnetic, attacked (sulphides)	per cent	parts per million
Fe	2·93	....
Mn	....	23
Ca	....	523
Mg	....	287
Ti	....	less than 5
Cr	....	less than 1
Cu	....	16
Zn	....	5
Ge	....	less than 0·5
Ga	....	less than 0·5
S	1·76	....
Total	4·78	

Magnetic, attacked (metal and schreibersite)	per cent	parts per million
Fe	17·16	....
Ni	1·17	....
Co	....	724
Si	....	93
Ge	....	6·7
Ga	....	2·8
P	....	10
Total	18·41	

Magnetic, unattacked (nickel-rich taenite)	per cent	parts per million
Fe	1·19	....
Ni	0·66	....
Co	....	46
Ge	....	n.d.
Ga	....	5·9
Total	1·85	

Non-magnetic, unattacked (silicates, phosphates, oxides)	per cent	parts per million
SiO_2	36·28	....
TiO_2	0·11	....
Al_2O_3	1·89	....
Cr_2O_3	0·51	....
FeO	9·29	....
MgO	23·53	....
MnO	0·26	....
CaO	1·69	....
Na_2O	0·77	....
K_2O	0·10	....
P_2O_5	0·21	....
C	0·04	....
H_2O^+	0·20	....
H_2O^-	0·03	....
Ge	....	n.d.
Ga	....	0·5
Total	74·91	
Grand Total	99·95	

n.d. not determined.

Analyst: R. S. Pepper.

Dravite crystals from Yinnietharra have attained world status by virtue of their size and perfection and are currently for sale from overseas dealers at premium prices. They occur in a phlogopite schist. Analysis of these minerals showed the dravite figures to fall within the ranges of published analyses with the exception of ferrous oxide, which at 0.09 per cent is considerably less than published figures which range upwards to 2.94 per cent.

The same comments apply to the phlogopite analysis.

A magnesian variety of collinsite was recorded for the first time in W.A. The mineral originated from Milgun Station. A purified sample was analysed.

The garnet of a garnet-clinopyroxene-"opaques" rock from 7 km south south east of Bartlett Bluff was separated, purified and analysed for rock classification purposes at the request of the Geological Survey.

	per cent
SiO_2	37.1
Al_2O_3	18.6
Fe_2O_3	7.0
FeO	23.0
CaO	10.0
MgO	3.2
MnO	0.8
Cr_2O_3	not detected
	100.5

Analyst: M. B. Costello

Calculations based on the above figures show a garnet composed approximately of the following end-member molecules:

	per cent
Almandine	57
Grossular	7
Andradite	23
Spessartine	2
Pyrope	11

Complete analyses of Yinnietharra dravite and phlogopite and of Milgun collinsite are detailed below:—

	dravite	phlogopite	collinsite
	per cent		
SiO_2	37·00	42·24	—
B_2O_3	10·46	....	....
Al_2O_3	32·97	14·54	....
Fe_2O_3	0·41	1·10	....
FeO	0·09	0·28	0·07
MgO	11·41	26·05	11·4
CaO	0·53	0·13	35·7
Na_2O	2·37	0·31	0·01
K_2O	0·01	8·18	0·02
TiO_2	0·91	0·75	....
P_2O_5	....	0·03	41·8
H_2O^-	0·01	0·27	0·15
H_2O^+	3·94	5·27	10·8
F	0·13	0·72	0·01
	parts per million		
MnO	100	150	....
Li_2O	90	3 500	....
Cr_2O_3	25	25	....
V_2O_5	100	90	....
CO_2	n.d.	n.d.	....
S	n.d.	n.d.	....
	100·27	100·25	99·97
Less O=F	0·05	0·30	0·01
Total	100·22	99·95	99·96

n.d. not detected
Analysts : P. Hewson (dravite, phlogopite)
R. W. Lindsey (collinsite)

Mineral Identifications and Analyses

1. General

The minerals described below represent a selection from the more interesting specimens examined during the year.

The Londonderry feldspar quarries continue to be a rich source of interesting specimens. A specimen of petalite with two well developed cleavages was of gem quality, while a pink spodumene was an unusual occurrence associated with deep lilac rosettes of lithian muscovite, albite, quartz and orange garnet. Bavenite and moraesite rosettes occurred in cavities within a feldspar rock together with well-formed quartz crystals, stilbite and prehnite.

Eucryptite, assaying 8.25 per cent lithium oxide, was isolated from a Londonderry specimen composed predominantly of quartz, feldspar, bavenite, cookeite and prehnite. Two forms of bismuth vanadate were isolated, one was pucherite, the other was of the same chemical composition but crystallographically different.

Samples from a pegmatite near Rothsay contained beryl with minor amounts of columbite, pucherite, nontronite and bityite.

A new mineral was discovered in a Yinnietharra pegmatite. It was a bismuth vanadate probably described in the past from its chemical properties as pucherite. Pucherite however crystallises in the orthorhombic system, whereas the new mineral (clinobisvanite) is monoclinic. The mineral was subsequently found in samples from Londonderry, Menzies, Wodgina, Corinthia and Westonia.

Associated with the Yinnietharra clinobisvanite were bismutite, bismutoferrite, uvarovite, uraninite, zircon, columbite-tantalite, garnet, rockbridgeite and several unknowns.

A paper on clinobisvanite has been prepared for publication.

Of sulphide samples, a specimen of sphalerite from Freddies Well was of particular interest as it represented a new occurrence relatively remote from previously known deposits. After separation from its associated actinolite-tremolite rock, it was analysed with the following results:

	per cent
Zinc, Zn	51.2
	parts per million
Cadmium, Cd	1 800
Gallium, Ga	25
Indium, In	70
Silver, Ag	4

These figures represent a cadmium content of the same order as that in sphalerites from Northampton and Ragged Hills, but double those from Mundijong and much less than in those from Kununurra. The gallium content is low compared with other deposits.

The second Western Australian occurrence of the nickel arsenic sulphide gersdorffite was recorded in an underground sample of quartz-magnesite-pyrophyllite rock from Bamboo Creek, associated with pyrite, galena and tourmaline.

Some interesting copper and nickel minerals were examined, including more common minerals showing minor substitutions by these elements.

A suite of secondary minerals was collected from surface dumps near the glory hole of the Great Boulder nickel mine at Carr Boyd Rocks. It contained a range of copper and nickel minerals, including glaukosphaerite, malachite, paratacamite and takovite as well as a number of unidentified species.

One of the latter contained between 25 and 30 per cent of nickel. It was a bluish green mineral, occurring mainly in the form of friable coatings having a botryoidal structure, with individual globules ranging up to 0.2 mm in diameter. It is very soft, with an earthy lustre, density approximately 2.5, refractive index 1.54 to 1.57, birefringence low to moderate and gave somewhat diffuse X-ray powder patterns. Its associated minerals are gypsum, paratacamite, magnesite and goethite, with minor takovite. Further work will be carried out on this material as opportunities arise.

A nickel-bearing dolomite occurs near the surface in serpentinites at the Scotia nickel mine. In samples collected it occurred in crystalline crusts associated with secondary quartz crystals, chalcedony, nickeloan magnesite, nontronite, glaukosphaerite and other weathered serpentinite products. The flattened crystals up to 5 mm in diameter are zoned with a clear green core and an outer lighter coloured crust.

Chemical analysis of the crystals, and electron microprobe analysis of the separate zones, are tabulated below in percentages:—

	Whole crystal	Inner zone	Outer zone
NiO	2·34	2·51	1·39
CaO	29·9	28·2	32·6
MgO	20·2	19·9	20·6
FeO	0·03	....	....
MnO	less than 0·01	....	....
CO_2	46·6	....	....

The results show the Ni/(Ca + Mg) ratio in the inner zone to be twice that in the outer zone.

This material represents the first Western Australian occurrence recorded by us of a nickeloan dolomite.

A green dolomite from Thaduna assayed 2.6 per cent copper, while a sample from Ilgarari showed native copper.

The basic copper nickel carbonate glaukosphaerite, first described in 1967 from a Widgiemooltha deposit, has now been recorded in surface material from a number of other localities including Kambalda, Windarra, Scotia and Carr Boyd Rocks. This distribution suggests that the mineral could be a pointer to nickel sulphide mineralization. Associated minerals were goethite, secondary quartz, paratacamite, gypsum and nickelian varieties of magnesite, malachite and clays. A paper has been prepared for publication which includes discussion on the relationships between glaukosphaerite and rosasite and malachite.

A glauconite assaying 2 per cent nickel was found associated with glaukosphaerite on the Dordie North prospect south of Widgiemooltha while takovite, a nickel aluminium hydroxide, was identified in material from the Perseverance mine near Agnew and from the Carr Boyd mine.

Two uncommon oxidised copper minerals received were krohnkite and chalconatronite. The first, associated with mendozite, was identified in material from the bottom of a 90 ft shaft on MC 34 at Ravensthorpe containing also chalcanthite, atacamite, pyrite and marcasite.

Chalconatronite, a very rare copper sodium carbonate, was found in the glory hole of the Carr Boyd nickel mine associated with trona, thenardite and malachite. This is believed to be only the second world recording of chalconatronite.

The nickel sulphate morenosite and the magnesium chromium carbonate stichtite occurred together in samples from the Mt Keith nickel mine.

A rock from Mt Pleasant composed essentially of quartz, goethite and calcite was heavily impregnated with grains of native copper up to 2 mm across, intergrown with cuprite and chalcocite.

Two carbonate minerals of interest were pyroaurite from Mt Keith representing the first Western Australian occurrence, and huntite. Huntite, an uncommon calcium magnesium carbonate, $Mg_3Ca(CO_3)_4$ was identified in a sample from Meekatharra. It occurred as a powdery mixture with magnesite coating a specimen composed of quartz, goethite, malachite, azurite, brochantite, antlerite and muscovite.

A purified celestite, recovered from a rock originating from Yeelirrie, assayed 97 per cent strontium sulphate and 0.5 per cent barium sulphate, figures which readily meet United States National Stockpile specifications for this mineral. The main use for the mineral is in pyrotechnics with minor demand in purification of caustic soda, in fillers, drilling muds and the manufacture of chemicals.

The first occurrence of brackebuschite in Western Australia was recorded when the mineral was identified in samples from Braeside. Brackebuschite, a vanadate of lead containing appreciable iron, manganese and zinc was first described in 1880 from the western part of Sierra de Cordoba, Argentina and this had remained the only undisputed world occurrence until identified in the Braeside material.

The mineral occurs as minute dark brown translucent crystals in a vanadinite-descloizite ore body. Sufficient pure material was not available to allow of a complete analysis by conventional means but an electron probe analysis gave the following results:—

	per cent
PbO	55.9
ZnO	0.71
FeO	8.29
MnO	0.14
V_2O_5	22.4

The X-ray diffraction pattern corresponded with that recorded for brackebuschite, in the powder diffraction card 6-284.

A specimen of vanadiferous iron ore from the Barrambie deposit was examined qualitatively by electron probe microanalyzer at the C.S.I.R.O., to determine the distribution of vanadium. The ore, which partial chemical analysis showed to contain V_2O_5 0.57 per cent, TiO_2 28.1 per cent, Fe_2O_3 54.1 per cent, contained martitized titaniferous magnetite and altered ilmenite ("pseudorutile") as the main phases. The microprobe showed a marked concentration of vanadium in the martite fraction where it was evenly distributed and negligible vanadium in the altered ilmenite thus agreeing with similar findings reported previously for Coates Siding ore.

A single fragment (168 g) of zircon, containing a few inclusions of xenotime, showed the properties of low birefringence, diffuse X-ray powder pattern, large cell size ($a = 6.7$, $c = 6.1$) and high radioactivity normally associated with a metamict state. The density of 3.4-3.5 is abnormally low. Further work is in hand on this unusual specimen.

A particularly impressive specimen of the iron arsenate mineral scorodite was received from Wyloo as a pale-green fine-grained admixture with quartz.

Samples collected from a deposit on Milgun Station have yielded a number of rare phosphate minerals. Some have been identified and described but work continues on several samples containing unknown species. A paper on one of the identified species collinsite (see also Complete Analyses) has been accepted for publication by the Mineralogical Magazine, while another paper is in preparation describing the two closely related basic phosphates of calcium and aluminium, montgomeryite and overite.

Amethyst and smoky quartz crystals in quartz geodes from the Antrim Basalts sixteen kilometres south of the old Turner homestead represented the first amethyst recorded from this area.

Common opal from Barloweerie gave a spectacular green fluorescence under ultra-violet light. The uranium content of the opal, 10 parts per million, was two to three times average background, giving some support to the theory that response by some opal to ultra-violet rays is due to trace amounts of this element.

2. Gold

A sample of mine water, pH 7.1, was found to contain 0.001 mg of gold per litre. This assay was done by the Denver method on a sample concentrated by evaporation.

A number of scheelite concentrates, originating from old goldfields dumps, were submitted for gold assay.

As in the past, requests were received from companies and private laboratories for checks by fire assay on samples that had previously been analysed for gold by atomic absorption technique. Where atomic absorption figures were known, agreement was generally reasonable but there were some gross exceptions.

The new potential of old mine dumps due to the increase in the price of gold, led to an increase in the number of such samples submitted. A Wilfley table concentrate from one such dump assayed 33 ounces per ton.

A sample of cyanide residues from a dump in the Marble Bar area was found to consist of sericite, quartz, calcite and a little pyrite, the latter carrying occasional inclusions of free gold 5 to 10 microns in diameter. Even after grinding the residues to minus 300 mesh this extremely fine gold would not be exposed to cyanide attack. However, after calcination the material was amenable to cyanidation, over 70 per cent of the original 3.8 dwt per ton being recovered.

Difficulty had been experienced in amalgamating strakes concentrates from a Southern Cross ore. The concentrates were composed mainly of actinolite and quartz with a small heavy fraction which contained the nickel arsenides niccolite and maucherite and the nickel arsenic sulphide gersdorffite. It was concluded that these nickel-arsenic minerals were the cause of "black amalgam" formed during amalgamation.

Localities from which prospecting samples were received include Burbidge, Cullculli, Davyhurst, Donnybrook, Higginsville, Jerramungup, Lake Grace, Leonora, Marvel Loch, Menzies, Mt. Eaton, Mt. Morgan, Northam, Nullagine, Paynes Find, Wiluna and Yundamindera.

3. Cave minerals

Unusual occurrences of phosphate minerals in Nullarbor caves have been examined. The guano deposit of Murra-el-elevyn Cave has been described in the December, 1973, issue of the Mineralogical Magazine.

Uric acid and guanine were discovered in caves near Cocklebiddy and were approved as the new minerals uricite and guanine. A short description will be submitted for publication.

A sample from Jingemia cave, at Watheroo, provisionally identified some years ago as the copper phosphate mineral tagilite was re-examined by electron microprobe and X-ray diffraction techniques. It proved to be sampleite $NaCaCu_5(PO_4)Cl.5H_2O$, a mineral previously recorded only from Chile. It is a blue green mineral in this instance intimately associated with atacamite, gypsum, iron and manganese oxides and only small quantities could be separated in a degree of purity to justify analysis. A sample of the mineral was obtained from the type locality of Chuquicamata, Chile and comparative analyses carried out with the results in percentages tabulated below.

	Jingemia a	Jingemia b	Chuquicamata b	Theoretical
Na	2·0	3·3	8·3	2·60
Ca	6·3	4·2	4·3	4·52
Cu	35·2	35·1	30·2	35·85
P	12·6	16·0	15·7	13·98
Cl	3·8	1·5	1·4	4·00

a microchemical
b electron microprobe

Other minerals identified from the Watheroo cave included birnessite, taranakite, todorokite and ? whitlockite.

Taylorite, a rare ammonium potassium sulphate was found encrusting crevices in old guano piles in a cave near Cocklebiddy. In the same cave uricite, brushite, and biphosphammite were found.

Pure taylorite could not be separated but analysis of the best available material showed the molecular ratio $(K+NH_4):SO_4=1.98$ to be in good agreement with the theoretical formula of $(K,NH_4)_2SO_4$.

A further cave to the east of Cocklebiddy contained brushite, monetite and gypsum.

Suites of cave minerals from Sabah and Sarawak, obtained primarily for comparative work in connection with an investigation of an ardealite-bearing deposit in a cave at Jurien Bay were found to contain a wide range of mineral species. As well as ardealite, the following were identified—leucophosphite, gypsum, collophane, variscite, brushite, hannayite, whitlockite, taranakite, newberyite, struvite, monetite, opal and possibly dittmarite.

4. Artificial minerals

A heavy white sample from Northampton proved to be dried putty consisting of powdered lead carbonate with some vegetable oil.

A specimen from the Kojonup area showed a smooth fine-grained surface with progressively coarser crystals towards the centre, suggesting that it may have crystallised from a molten state. It consisted of high purity zincite and was unlikely to represent a natural occurrence.

A metallurgical recarburizer submitted by the Customs and Excise Department was shown to be fine-grained graphite.

5. Special

The Division continues its participation in the collaborative test programme organised through Committee MT 11/2 of the Standards Association of Australia dealing with the analysis of iron ores.

Work involved investigation of copper and free water contents of iron ores.

In the copper investigation, 5 ores were chosen with copper contents ranging from about 0.002 to 0.8 per cent and the copper determined by two methods, photometric and atomic absorption. The former method, based on the red-violet complex of copper (I) formed with 2.2 biquinoline in the presence of dimethyl formamide, gave good results but was less convenient and no more accurate or precise than the simpler atomic absorption method. Neither method could handle satisfactorily copper contents below 0.005 per cent.

In addition to nine Australian organisations, laboratories in Canada, France, Germany, India, Japan and Sweden also participated in this test work, the ultimate object of which is the production of an International Organisation for Standardisation procedure acceptable internationally by both buyers and sellers of iron ores.

The work on hygroscopic moisture in iron ores was carried out mainly to support an Australian contention that satisfactory moisture figures could not always be obtained by simply drying a test portion in air at 105° C to constant mass. Under these conditions goethitic ores in particular re-absorb moisture so rapidly that reliable weighings cannot be obtained. The proposed alternative involves heating the sample at 105°-110° C in a stream of oxygen-free dry nitrogen and collecting and weighing the water released.

An investigation by the Engineering Chemistry Division on the removal of surface coatings from mineral sands led to a great many samples being submitted for surface and total iron figures as well as analyses for zirconia and determination of semi-quantitative distribution of the mineral species concerned. It was found that the microscopic determination of the zircon content of a sand product was usually lower than that calculated from its chemically determined ZrO_2 content but that on the whole agreement was satisfactory for semi-quantitative purposes especially as zircon contents ranged from 0.1 per cent up to 85 per cent.

Microscope, X-ray diffraction and electron microprobe techniques were used in the examination of surface coatings on zircon and the conclusion reached that these coatings are a variable mixture of goethite and kaolin with appreciable gibbsite.

A urinary calculus, received through the Animal Division of the Department of Agriculture, was shown by X-ray diffraction to be essentially 4-methoxyequol. Both 4-methoxyequol and equol were suspected but as neither appeared in the current Powder Data file pure samples of each were obtained as reference standards.

Miscellaneous

1. Building materials

Most samples under this heading were potential concrete aggregates, tested mainly for compliance with Australian Standard A.77-1957, involving mineral identification and sizing and the determination of organic impurities, sugar and soluble salts as well as tests designed to assess the possibility of deleterious reactions occurring between the aggregate and the alkalies of cement. The latter property, the potential alkali reactivity, is determined usually by a rapid chemical method but a number of samples were also subjected to the longer and more meaningful mortar bar test in which test bars are stored and measured periodically over a period of 6 to 12 months.

Many of the aggregate samples originated from the North West and Kimberley areas, being in most cases river shingle containing a range of mineral and rock types.

Three samples received during the year indicated potentially reactive aggregates, a fourth was borderline. The potentially reactive materials were:

(1) Three quarter inch aggregate from a Derby stockpile consisting of fine-grained quartzite made up of irregular quartz grains cemented together by clay, amorphous silica and iron oxides.

(2) Crushed river shingle from Mt. Newman composed of very fine-grained hematite and quartz, with a little chert, vein quartz and epidote.

(3) Rock from One Arm Point on King Sound which was essentially rounded quartz grains cemented with amorphous silica.

The components most likely to be responsible for this potential reactivity would be the amorphous silica and the chert.

To determine reactivity chemically the reduction in alkalinity (Rc) and dissolved silica (Sc) are measured in an alkaline solution which has been in contact with the crushed aggregate under autoclaving conditions. If Sc is greater than $35 + \frac{1}{2}$ Rc the aggregate is potentially reactive.

Figures for the above three suspect materials were:

	Rc	Sc
	millimoles per litre	
Derby	52	91
Mt. Newman	32	62
One Arm Point	16	120

A second sample from One Arm Point was sand composed of calcite (as shell fragments) with some quartz, salt and iron oxides. With a water-soluble content of 0.26 per cent some efflorescence might result if this material was used as concrete aggregate but it was innocuous as far as reactivity with alkali was concerned, giving the rather unusual figures of Rc 138, Sc 3.

None of the samples subjected to the mortar bar test caused excessive expansion.

A number of problems associated with concrete were investigated for Government departments.

The Medical Department submitted a concrete core sample taken from a hospital floor which was deteriorating due to surface "pop-outs". These pop-outs caused small lumps to appear which forced the covering vinyl sheet into unsightly and potentially dangerous mounds. In the sample examined, the upper surface showed a crater about 4 cm in diameter and 1 cm deep. At the bottom of the crater was a brown wax-like material differing from the normal aggregate. This brown material was shown by X-ray diffraction to be kaolin and fine-grained quartz, and the conclusions reached were that the pop-outs were due to the internal pressures resulting from the expansion of this clay following reaction with a cement environment. No remedial action could be recommended.

Samples from a concrete aircraft runway that had also been experiencing pop-outs were received from the Commonwealth Department of Works. Concrete fragments up to 4 cm in diameter had been ejected from the runway. Examination by X-ray diffraction and electronmicroscopy confirmed the presence of clay which was predominantly kaolin but contained also about 10 per cent of halloysite. Halloysite shows roughly twice as much expansion as kaolin due to water absorption and the conclusion was reached that the clay content of the concrete, originating from weathered aggregate, was the prime cause of the pop-outs due to its expansive properties under conditions of cyclic variation in water content and temperature.

Other samples submitted by the Department of Works were from a bituminous concrete airstrip which was showing deterioration. Cavities up to 2.5 cm in diameter and 2.5 cm deep were resulting from surface pop-outs. At the bottom of these cavities there was a spongy organic growth and it was concluded that this growth, rather than any inorganic constituent of the filler, was responsible for the internal force causing the eruption.

2. Dusts

A discussion was held with officers of the Public Health Department and the State Mining Engineer's Branch aimed at standardising techniques for sampling of airborne dusts. Sampling units, filter types, safe transport of samples to the laboratory and general sampling procedures were considered.

It was decided that the assessment of airborne asbestos dust be made by the method recommended by the Asbestosis Research Council which involved, among other things, the application of the phase-contrast optical equipment to actual fibre counting.

Work on dusts fell into two categories, general air pollution and industrial health hazards.

Though odd samples were received as a result of specific complaints by householders in the vicinity of industrial plants, most air pollution samples were submitted by the Public Health Department in connection with their dust monitoring programmes.

Samples from CERL gauges were regularly submitted from Port Hedland for iron and manganese determinations, from Esperance for nickel, copper and iron, from the Clarence (Naval Base) area for aluminium, iron and water-soluble sodium and from the Rivervale area for calcite, lime and cement. Other samples from the city area, were collected on filter papers and their lead content determined to measure the pollution level from motor traffic.

Most samples submitted in connection with health hazards involved determination of free silica or lead. Exceptions were the measurement of fibrous material in dusts from talc and nickel mines and the determination of asbestos concentration in air in industrial plants. Cement, a possible source of chromate dermatitis, was analysed and found to contain a total chromium content of 80 parts per million, less than 1 per cent of which was water-soluble.

Many samples originated from a survey by State Mining Engineer field officers of airborne dusts on mining sites at Goldsworthy, Mt. Newman, Mt. Tom Price, Paraburdoo, Robe River and Pannawonica.

Quartz or free silica was required on samples varying from massive to microgram quantities. In the former, determination by chemical means usually gives satisfactory results but a sample of talc did not respond to the usual treatment, the talc apparently resisting the breakdown by phosphoric acid at 250°C which normally allows of the separation of free silica or quartz from silicate silica.

Microscopic examination can in some cases give quartz figures close enough for practical purposes but far more satisfactory results are obtained by X-ray diffractometry. Diffractometry however, is not without its problems when applied to dust samples taken on filter papers due to such factors as uneven distribution, excessive deposits, and variable filtering media. The diffractometry unit installed during the year has resulted in quicker handling and more satisfactory analyses of a variety of dust samples.

Lead samples collected on filter papers from air in the city area, have all been handled by atomic absorption.

In addition to lead samples submitted in connection with general atmospheric pollution, a number were received that had been taken in situations of individual exposure to high lead concentrations in industrial plants such as battery and tube manufacturers.

Highest levels however were obtained in mine and other laboratories concerned in fire assays for gold and silver where lead oxide is extensively used as a flux. Very high concentrations, in one case as high as 17 000 micrograms of lead per cubic metre of air were measured from fluxing rooms of such laboratories.

3. Metals and alloys

Work on metals and alloys led in most cases to the conclusion that the samples represented material different from that specified.

It was found that aluminium rivets were being used to rivet a copper roof when monel metal had been specified. As a result both roof and rivets were badly corroded.

Aluminium alloy scaffolding had failed on a construction site. Specifications fixed the range of eight trace constituents, of which four (copper, silicon, magnesium and chromium) did not comply.

Steel tools which had purportedly been given additional hardness and wear resistance by an electrochemical process showed no evidence of treatment subsequent to manufacture except an extremely thin coating of copper.

4. Police exhibits

A number of samples were examined for the Criminal Investigation Branch and consisted mainly in the comparison of two like materials to determine if they had a common origin.

Wool fibres, soils and marking inks were compared from a station locality and a bale of allegedly stolen wool.

Fibres and paint from the clothing of a deceased pedestrian were compared with fibres and paint from the bonnet of the car thought to have been involved in the hit-and-run fatality. The colour and crystalline constituents of the paints were similar while the fibres were identical as regards colour, thickness, refractive index, birefringence, dye pigment and general form.

In connection with the breaking and entry of two pharmacies comparisons were made of material from the entry points in the roof, dust and paint from a drug safe, and dust and paint smears from a small crowbar.

Optical and photomicrographical comparisons were made of sand and the fine aggregate of mortar adhering to timber, thought to have been stolen, with sand from the construction site, the scene of the alleged theft.

Powder in the motor of an aircraft alleged to have been tampered with, was identified as carborundum.

WATER DIVISION

General

Although total sample numbers increased only slightly during the year there has been increased involvement of the Division at both State and National levels in matters associated with water quality, particularly in relation to pollution. This has led to the creation of an additional position within the Division.

Mr. J. C. Weir, though still on our staff, is now attached to the Metropolitan Water Board's laboratory at Leederville, where he is in charge of the laboratory and directs investigations at laboratory, pilot and full plant scale on treatment of shallow underground water supplies.

An increase in staff was particularly necessary in relation to the impending involvement during 1974-75 in Network Survey samples being sponsored by the Australian Water Resources Council. It is envisaged that the ultimate number of samples involved per annum will be approximately 7 000 and that automated analytical equipment to determine an average of 20 components per sample, will be required. The additional requirements for this increase could be approximately equal to that already existing in relation to staff numbers and floor space but there will be a much greater accent on equipment. It is predicted that the new building will be housed at 30 Plain Street with a minimum disruption to existing facilities.

Mr. N. Platell attended the Australian Water and Wastewater Association Summer School at Canberra on Water Treatment, in February and both he and Mr. Jack gave addresses on corrosion to various organisations during the year. Senior members of the Division are still actively associated with committees and organisations involved with water treatment and corrosion.

Two review articles on methods of mercury and phosphorus analysis were prepared by Mr. T. Webb and Mr. P. Jack respectively for publication in Australian Water Resources Project 71/35.

A paper "Black Stain in Glass Reinforced Plastic Swimming Pools" by Mr. N. Platell has been submitted to the Australian Water and Wastewater Association for publication.

Table 22 shows the source type and number of samples received during the year. The major variations over previous years are the increased number of investigations and effluents.

Table 22

WATER DIVISION

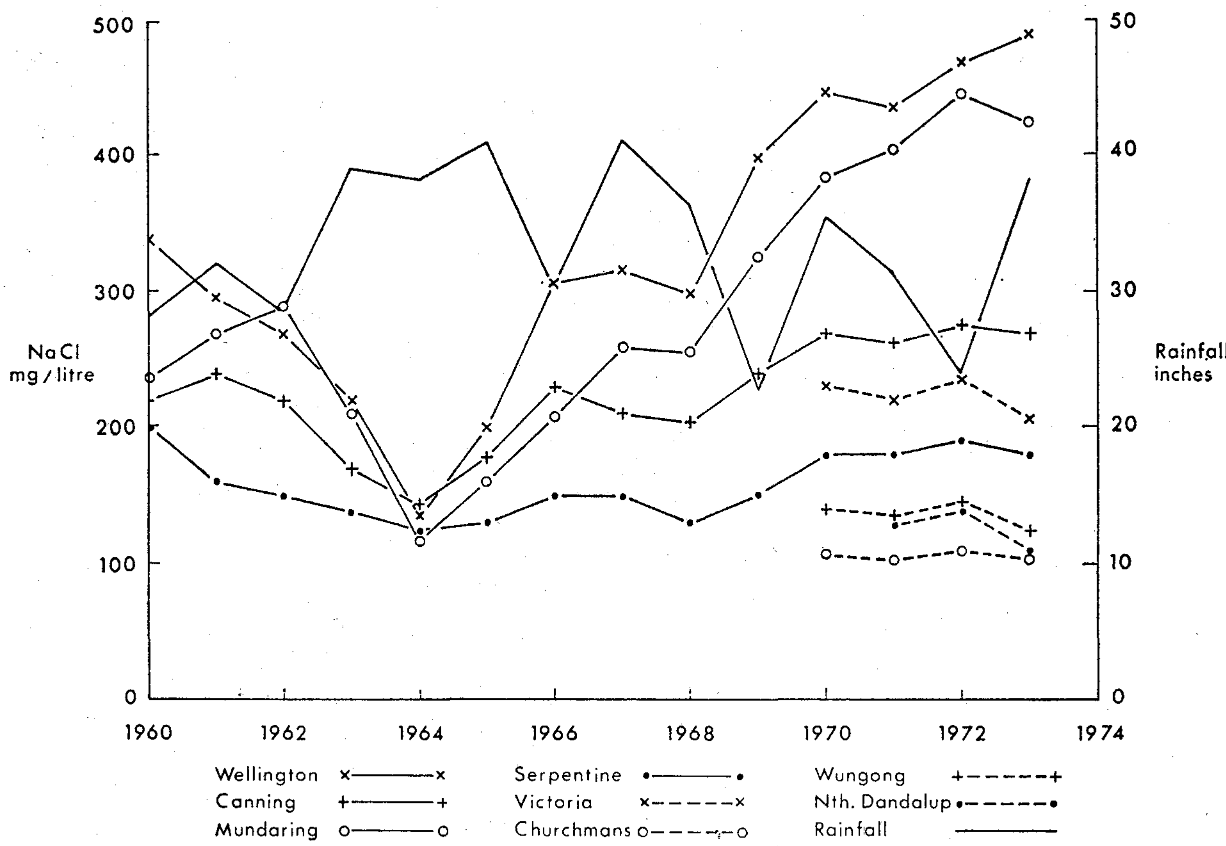
	Aboriginal Affairs	Agriculture Department	Consumer Protection Bureau	Fisheries & Fauna Department	Metropolitan Water Board	Mines	Other Government Departments		Public		Peel Inlet Advisory Committee	Public Health Department	Public Works Department	Swan River Conservation Board	Total
							Federal	State	Free	Pay					
Brine	....	....	....	....	....	....	....	....	....	10	....	....	....	....	10
Corrosion	....	....	....	....	1	....	....	....	....	4	....	....	5	....	10
Deposits	....	....	2	....	1	....	....	....	....	3	....	....	4	2	12
Effluents	....	....	....	....	7	....	1	....	....	61	....	....	3	19	91
Investigations	....	....	1	....	3	6	....	....	....	....	....	....	....	....	10
Sand	....	....	....	....	....	....	....	....	....	2	....	....	7	5	14
Treatment chemicals	....	....	....	....	25	....	....	....	....	....	....	....	2	....	27
Water															
Fluoridated	....	....	....	....	769	....	....	....	....	....	....	....	743	....	1 512
General	11	81	3	28	1 479	167	19	7	3	558	....	62	1 129	16	3 563
Pollution Survey															
Bunbury	....	....	....	....	....	....	....	....	....	....	....	....	48	....	48
Peel Inlet	....	....	....	....	....	....	....	....	....	....	60	....	....	....	60
Swan River	....	....	....	....	....	....	....	....	....	....	....	....	....	219	219
Various	....	....	3	....	1	1	....	....	....	....	....	....	1	....	6
Total	11	81	9	28	2 286	174	20	7	3	638	60	62	1 942	261	5 582

Public Water Supplies

(a) Salinity versus Rainfall: For a number of years until 1973 all major catchment dams in the South West used for public water supplies had been increasing in salinity. Although many factors contribute to this result the main reason is considered to be a series of seasons with average or below average rainfalls. In the graph below, sodium chloride content (average over the whole year) of the water from the surface of the dam has been plotted for the reservoirs concerned as has also the annual rainfall recorded at the Perth Weather Bureau, Figure 1. For the conversion of sodium chloride to total dissolved solids multiplication by 1.2 gives a sufficiently accurate result. With the exception of Wellington Dam the salinity is obviously patterned in the rainfall, but the inability of Wellington Dam to reduce its average salinity during 1973 with an above average rainfall implies that other factors involved are more significant. One of these factors is the significant increase of cleared land in the Wellington Dam catchment area which is accepted as a cause of increasing salinity of streams. This is a cause for concern because a first class irrigation water should have a total dissolved solids content of less than 500 mg per litre.

FIGURE 1

SALINITY OF HILLS CATCHMENT RESERVOIRS



(b) Fluoridation: The table below shows the arithmetic mean of fluoride levels from various centres from which samples were submitted for analysis.

Fluoridated supply	Number of samples	Mean level mg per litre	Intended level mg per litre
Perth Metropolitan	716	0·78	0·8±0·1
Mundaring Weir	122	0·77	0·8±0·1
Wellington Dam	71	0·68	0·8±0·1
Albany	155	0·71	0·9±0·1
Collie	94	0·76	0·8±0·1
Esperance	100	0·81	0·9±0·1
Geraldton	95	0·71	0·8±0·1
Manjimup	108	0·86	0·9±0·1

Only two of the centres have average fluoride levels marginally below those intended and this is mainly due to the sodium silicofluoride at these centres being difficult to feed. Significant improvement in flow characteristics has been effected by the addition of a proprietory brand of finely ground siliceous material at a rate equivalent to 0.005 mg per litre in the fluoridated water. More recently portion of a batch at one of these centres, apart from poor feeding characteristics developed a pungent odour. This was shown to be due to the presence of chloride at 0.2 per cent, which caused evolution of hydrochloric acid. While not a desirable feature, mainly because of the dangers in handling, the chloride level is considered to be due to imperfect manufacturing conditions employing hydrofluorosilic acid and sodium chloride as raw materials and would not adversely affect the treated water at the dosed levels.

Over a 24 hour period, with a constant setting on water flow and on the sodium silicofluoride feeder, hourly samples from two separately fluoridated mains at Serpentine showed maximum variation of the fluoride level from the arithmetic mean of ±0.06 and ±0.02 mg per litre respectively the latter being within the limits of analytical reproducibility.

(c) Metropolitan Area Shallow Ground Water: Shallow ground waters at present and proposed treatment plant sites at Mirrabooka, Gwelup and Wanneroo have been tested at laboratory, pilot and full plant scale. Despite the success of other types of treatment at particular bore sites, the recommended treatment of all waters is basically the same with alum the present choice as primary coagulant and sodium alginate the selected coagulant aid irrespective of whether the problem is one of turbidity, colour or iron removal or a combination of all three. Bentonite addition and optimum chlorination conditions for prevention of algal growths are two additional aspects that were investigated during the year. The use of ferric sulphate or chlorinated ferrous sulphate is still receiving consideration as an alternative primary coagulant but although improved or equal settling characteristics are obtained there are disadvantages due to a manganese contamination of the iron sulphate and also to the increased iron levels in the treated water.

(d) South Dandalup Dam: New dams can cause problems due to deterioration of the hypolimnion or lower layers during summer. Because South Dandalup dam water has had natural levels of about 20 Hazen units of colour and 0.3 mg per litre of iron it is anticipated that problems could be worse than those experienced in the initial use of Serpentine Dam. Regular depth samples have been taken since winter, 1973 and the most recent sample of mid December has shown no significant deterioration in either the iron or colour levels, although oxygen depletion was quite obvious at this early stage of summer.

(e) Manganese in Bunbury Town Supply: Several bores, which are potential sources for the Bunbury Water Supply, contain levels of manganese between 4 and 8 mg per litre and this troublesome component is not removed by the generally practised lime treatment for iron removal. Several methods of manganese removal from these bores were investigated. Although a treatment involving chlorination and raising the pH is considered conventional, it was not efficient at pH values of 9 or lower and the final recommendation for these waters was to raise the pH to about 10 by lime addition. Chlorine was not necessary because at this pH value the manganese was co-precipitated with calcium carbonate as the insoluble hydrated manganous oxide. An upflow clarifier was recommended and the pH of the resultant water should be subsequently lowered to a neutral level by acid or carbon dioxide addition.

Pollution or Contamination of Water

Measurement of contamination or pollution of water in a number of areas commenced during 1971 and 1972 is still continuing and includes:

(1) Natural underground and suface waters in the vicinity of the Western Mining nickel refinery.

(2) Estuarine samples from the main estuary and tributaries of the Swan River system, the Peel inlet and Harvey estuary systems at Mandurah and the Leschenault inlet system at Bunbury.

(3) South west irrigation rivers.

(4) Alumina refinery mud disposal areas at Mandogalup and Pinjarra.

(5) Upper Swan Wildlife Sanctuary.

Some of the following are isolated instances of contamination of surface and underground waters and others are areas where regular sampling is intended:

(a) Algal bloom at Mandurah: An algal bloom of the blue-green species "Nodularia Spumigena" persisted in the Harvey estuary and Peel inlet for more than one week in the middle of November. This species is reputed to be toxic when consumed in large quantities by animals but its effect on fishlife is uncertain. Because of the absence of any reports from this outbreak on unusual deaths, it can be assumed that its toxic effect on fish is not great. The bloom was more intense in the Harvey estuary and did not extend to any extent up the Serpentine, Murray or Harvey rivers. It was deduced that the unusually warm conditions when the estuary was still predominantly Harvey river water was a major cause of the bloom.

(b) Ord River Dam: Samples from the surface and depth are received at monthly intervals for extensive analysis. This is the best irrigation water of all major reservoir constructions in the State with a total salts content of between 100 and 150 mg per litre of which the major component is calcium bicarbonate. Nitrogen and phosphorus are at very low levels, the maximum total nitrogen level so far recorded being 0.2 mg per litre and the maximum total phosphorus level being 0.03 mg per litre. Average levels of these components are 0.1 and 0.01 mg per litre respectively in the dam water.

(c) Underground pollution at Lake Thompson due to wool scour effluent: A number of samples from observation bores in the vicinity of Lake Yangebup have shown a considerable but variable contamination of the aquifer. The final effluent pond from the woolscourers has ammonia nitrogen levels of the order of 60 mg per litre and also has high ratios of alkalinity and potassium to chloride. Its effect on nearby Lake Yangebup is variable because biological activity in the lake can reduce the ammonia nitrogen level to less than 1 mg per litre but the high ratios of alkalinity and potassium to chloride are consistently persistent. Depending on the dilution of the pond effluent in the nearby aquifer the water within 100 metres of the pond is sometimes noticeably affected but at other times apparently unaffected. Investigations in this area are continuing.

(d) Farm dam contamination: 24 dams in the Narrogin area, on which investigations commenced in 1972 were again examined during 1973. Six of the dams experienced what was considered to be a "flash summer run-off" in the middle of April. The colours of the waters from these six dams were generally in the range 200 to 800 Hazen units, the dissolved oxygen values were generally less than 1 mg per litre, the total nitrogen values were in the range 3 to 20 mg per litre; the ammonia nitrogen values were in the range 1 to 8 mg per litre and the total phosphorus values varied from 2 to 10 mg per litre. These waters taken from 6 inches beneath the surface were obviously grossly contaminated and two of the waters gave positive tests for salmonella. There was no study of stock growth or health with these experiments but the effect of such waters on growth and health is receiving consideration by officers from the Department of Agriculture.

(e) Wool scouring effluent contamination of the Swan River: During July a number of samples collected in the discharge area between the discharge outlet and the Fremantle traffic bridge showed that during periods of natural voluminous winter river flow the rate of discharge of the effluent has a barely significant effect on the suspended solids or 5 day BOD of the natural water. A discharge flume was not visible due to the natural coloured water already containing 8 mg per litre of suspended solids. A calculated increase in suspended solids over the area of discharge at the Fremantle traffic bridge was only 4 mg per litre. With a lower flow in summer, and a clearer, colourless water, the contamination should be more significant.

(f) Industrial contamination of a stormwater drain: Excessive corrosion of a drainage pump and analysis of the water causing it led to the discovery of excessive quantities of copper and zinc in a shallow water seepage. Because this water ultimately found its way into the Swan river via a stormwater drain, the responsible authorities were advised and carried out appropriate action.

(g) Contamination of shallow aquifers by rubbish disposal: Because a significant portion of Perth water supply will be drawn from shallow aquifers within the confines of the Metropolitan area, a study of the effect of land-fill rubbish tips on this water was commenced this year. Nine boreholes, in groups of three at selected depths, situated at three sites upstream, on and downstream of the rubbish disposal site at Hertha Road have been sunk and preliminarly testing to ensure that the water samples collected are from the sites and depths selected, are now completed. Sealing of the PVC bore casing with cement has caused some problems due to potential heavy metal precipitation and alteration of some major chemical characteristics by the intrusion of alkaline components of the cement to the adjacent water. By regular weekly pumping of the boreholes for several hours at a rate commensurate with minimum disturbance of the water in the aquifer, the pH values have dropped to a level where contamination of the water by the cement has been eliminated. With relatively constant chloride, sulphate and nitrogen values at each borehole and a gradual reduction of the pH from values above 9 to approximately 7, the sampling for comprehensive analyses of many pertinent components is ready to commence.

(h) Nitrate levels in underground water: Significant nitrate levels have been recorded in a number of shallow underground aquifers throughout the State. The most recent is at Robbs Jetty, no doubt due to the seepage of wastes from the slaughtering industry. At least 6 wells and bores in the immediate vicinity of the plant are affected with nitrate levels varying from 43 to 89 mg per litre NO_3.

(13)—39934

Swimming Pools

There has been considerable involvement at analytical and consultative level concerning both pool waters and components of manufacture. This increased involvement has been primarly due to the tremendous increase in the number of pools in private homes and the black spot or stain that is evident on a large number of pools of reinforced plastic construction. Other facets of swimming pool activity have involved examinations and recommendations for filter sand, the level of iron and manganese that can cause pool surface or water discoloration, examination of the role and level of isocyanurates as stabilisers and the advisability of addition of certain organic complexing agents at present being used for the removal of black spots, but which require excessive chlorine dosages to restore the pool to a satisfactory chlorinated state.

(a) Black stain or black spot: Examination of a number of affected pools and comparisons of analyses of stained and unstained areas by swabbing with hydrochloric acid has led to the deduction that the prime cause of the problem is chemical staining and not organic growths of either algal or fungal origin.

(i) Probable causes: The results below in Table 23 show the analyses of the swabbings from a bady affected pool and while the copper and iron values appear significant in the analyses presented, cobalt appears to be more significant. Because it is difficult to swab an area quantitatively the results have also been expressed in ratio form and they now imply a major role for cobalt, a minor role for copper and an insignificant role for iron and manganese.

TABLE 23.

SWABBINGS FROM THE GEL COAT SURFACE

	Above water	Below water: Without black stain	Below water: 25% of area stained black
	micrograms per cm^2		
Cobalt	less than 0·01	0·45	1·3
Copper	0·03	0·42	0·67
Iron	0·41	0·42	1·0
Manganese	0·25	0·31	0·32
		Ratio of conc. in below water to conc. in above water	
Cobalt		+45	+130
Copper		14	22
Iron		1·0	2·5
Manganese		1·2	1·3

Observations from a number of pools have indicated that blister formation in the gel coat precedes the formation of a black stain. The black stain apparently forms after perforation of the blister, the pressure in the blister being supplied by osmotic pressure between the fresh water in the pool and the water soluble components behind the surface of the gel coat. Blisters are almost completely absent in the above water gel coat indicating that entrained air or gases do not play a significant role in their formation. The leakage of the blister contents into the pool follow the convection and recirculating pump flow patterns in the pool as evidenced by the "tails" on the stains. Chlorine in the pool water is capable of oxidising cobaltous ions to hydrated cobaltic oxide and this apparently occurs in the close proximity of the blister perforation.

(ii) Removal of the stain: Stain removal cannot be effected by mild abrasives but can be removed with dilute acid. Present practice by pool manufacturers or chemical suppliers is to either drop the pH to about 5 by the addition of sodium bisulphate or other suitable inorganic acid or to drop the pH to nearer 6 by the addition of complexing organic acids such as sulphamic, ascorbic or EDTA. Both methods require restoring the pH to the recommended pool water pH for swimming, namely 7.2 to 7.6, by the addition of sodium carbonate and also to chlorinate to a condition equivalent to break point chlorination. With the inorganic acids this presents no problems but the complexing organic acids will require excessive chlorine dosage to restore the pool to a breakpoint chlorination condition. The pool should not be used during the 1 week period normally required to remove the stain by one of the above procedures. Due to its nature the stain is likely to recur at less frequent intervals and may require regular treatment for a number of years.

(iii) Role of organic growths: A number of factors listed below show that these growths are not likely to cause the black stain condition. These growths are undoubtedly present at most sites but are generally located close to the perforation where they apparently get a foothold with some protection from chlorine.

Organic growths can normally be removed from a smooth surface by mild abrasion whereas the black stain cannot.

Organic growths are not soluble in cold dilute acid whereas these black stains obviously are by the evidence of swabbing tests and the removal methods practiced.

The presence of tails on the black spots do not indicate organic growths because organic growth would not be restricted by the relatively slow convective flow.

(iv) Remedy: Because it is considered that the cause of the black stain is the cobalt naphtenate incorporated as a promoter in the gel coat, the use of an alternative promoter that does not contain a metallic componente capable of being oxidised to a dark hydrated oxide on contact with chlorinated water is recommended. Alternatively, closer control of formulation, application or curing conditions may prevent blister formation and the mobility of the cobalt with the gel coat.

(b) Chlorinated isocyanurates as stabilisers. It has been the habit of some pool owners to dose solely with chlorinated isocyanurates to maintain recommended chlorine levels. With the normal recommended daily chlorine doses of 2-4 mg per litre during summer it can be seen that without decomposition or significant spillage from the pool, over a 4 month period the isocyanuric acid content from dosing with dichloroisocyanurates would be approximately 150 mg per litre. Levels of isocyanurate above 60 mg per litre necessitate larger chlorine residuals than without isocyanurates to ensure similar bacteriocidal action and levels above 100 mg per litre are not recommended.

An investigation of breakdown of isocyanuric acid in a large container exposed to the outside atmosphere for 12 months showed no significant breakdown.

The recommended treatment for privately owned swimming pools is to initially dose with chlorinated isocyanurates until the isocyanurate level builds up to about 50 mg per litre. Subsequent chlorine treatment should be maintained with either calcium or sodium hypochlorite. Sodium hypochlorite is preferred because of the possibility of calcium carbonate precipitation after several years operation at the recommended pH values.

(c) Manganese levels for discoloration: A bore water from Applecross with no iron and a manganese content of 0.08 mg per litre produced a noticeable discoloration in the pool water when it was chlorinated. By using an artifically prepared water with the same level of manganese it was shown that this level of manganese is capable of producing an apparent colour in the water after chlorination equivalent to 20 to 30 Hazen units. This colour is due to precipitation of hydrated manganic oxide in a colloidal form and it is distinctly noticeable in a volume of water like a swimming pool.

Miscellaneous

(a) Green hair discoloration: A sample of grey hair stained green was received from the occupant of a home served by the Two People Bay water supply at Albany. The stain was shown to be due to an excessive copper level in the water being used to wash the hair with soap. The hair contained 4 700 mg per kg of copper, much of which was surface adherent and could be removed by carbon tetrachloride. The cause of the high copper content in the home supply was the slightly acid nature of the partially aerated supply at its source and an apparent long residence time in the copper pipe. Subsequent testing of the water from a well flushed tap gave copper levels of less than 1 mg per litre although levels in the hot water supply were marginally in excess of this value. The recommendation to the Department of Public Works was to raise the pH of the supply to neutral or slightly alkaline condition to reduce copper corrosion and to advise the home occupant to wash with water from a well flushed tap or to use detergent based shampoo instead of soap for washing hair.

(b) Reverse osmosis: Several firms contemplating reverse osmosis to obtain a less saline water supply for drinking and domestic purposes have submitted samples for analysis and requested advice. The main problem with reverse osmosis equipment has been blockage and costly replacement of the membranes, the blockage material including iron, calcium carbonate and calcium sulphate. Effective methods for iron removal to less than 0.2 mg per litre and optimum methods of treatment to prevent deposition of either of the other components need consideration and calculation should be based on the effluent water being considerably more saline than the raw water.

(c) Chlorphenol tastes: Based on tastes produced by subsequent chlorination the desirable maximum level of phenol in a water supply has been set at 0.001 mg per litre. Serpentine Dam is a Hills source supply requiring chlorination and which consistently has phenol reactive substances at this level. An investigation to ascribe taste factors to phenol types was performed during the year. Industrial or artificial phenols may behave differently to natural phenols and the effect of chlorination of phenol, thymol and guaiacol at levels of 0.001 mg per litre with chlorine at levels of 0.2, 0.5 and 1.0 mg per litre was carried out. The results of the tests were not conclusive as might be expected from a subjective assessment such as taste. The predominant type of phenol present at Serpentine could not be assessed and the only positive result was that the presence of artificial and natural phenols at 0.001 mg per litre when subsequently chlorinated produced tastes that were considered objectionable by a significant portion of the taste panel. An earlier assumption that natural phenols were less likely to produce objectionable tastes was not borne out. All taste tests were carried out 2 hours after chlorination and because consumers of Serpentine water do not complain of the taste it can only be assumed that the 24 hour traverse down the pipeline to the metropolitan area significantly reduces the taste from an objectionable to a barely detectable level.

(d) Trickle irrigation: Blockage of outlet orifices from trickle irrigation systems in some instances is a problem which can offset its main advantages of requiring less water and reducing possibility of salt buildup in the soil. A number of waters producing blockage problems have been received for analysis, the problems including both organic and inorganic particulate material, bacterial growths within the pipe system, calcium carbonate deposition and hydrated iron oxide deposition. Apart from filtration of the water entering the pipe system which prevents access by particulate material, other recommendations include—

(i) periodical dosage of the system with chlorine to prevent significant bacterial growth within the system;

(ii) removal of the iron to a level where significant iron bacterial growth will not occur. Iron may be present from corrosion of borehole equipment and it is sometimes advantageous to discard the first water after start-up from the system;

(iii) where possible use of a trouble free water such as metropolitan mains at the end of the irrigation period to remove the last remnants of the troublesome water from the system during the idle period.

(e) Deposit from a chiller set: A deposit from the sump of a chiller set at the Bunbury Regional Hospital was identified as ferrous chloride. The cause of the problem was diagnosed as cooling water ingress to the Freon refrigerant, decomposing the Freon to hydrochloric acid which subsequently attacked the steel of the system. After ensuring that the corrosion problem was restricted to the sump, regular checking to ensure no leaks and regular testing of the Freon for water and acid were recommended.

(f) Condenser tube corrosion: Internal or water side corrosion of finned copper cooling tubes from a condenser at the Perth Medical Centre was found to be due to impingement attack. In some areas the undercut had become deeply pitted almost to the point of perforation. The flow through the tubes was calculated at 10 to 11 feet per second, a figure which was claimed by the manufacturers to be satisfactory, but which, in our opinion, is too high for the relatively high chloride level in Perth water. The recommendation included reducing the capacity of the system by lessening the cooling water flow to 7 feet per second and if this was not possible to replace the tubes with a more resistant material such as cupro nickel.

DIVISION VII

Annual Report of the Chief Inspector of Explosives for the Year 1973

The Under Secretary for Mines:

In accordance with Section 10 of the Explosives and Dangerous Goods Act, 1961-1967, I submit for information of the Hon. Minister this report on the work of the Explosives Branch for the year ended 31st December, 1973.

STAFF

There was no change in the basic staff structure which remains the same but owing to contingencies on Long Service Leave and extended Annual Leave it was necessary to have a technical officer seconded from the Government Chemical Laboratories for a period of six months.

LEGISLATION

It was proposed that further amendments be made to the Explosives Regulations but Parliamentary Counsel advised that they would not be valid without amendment of the Act. It is therefore intended that suitable amendments to the Act be prepared as soon as possible. Only one amendment was made to the Flammable Liquids Regulations in respect of providing for the display of signs at petrol service stations. Work was completed on the metrication of all legislation and drafts to all necessary amendments were prepared and submitted for further action.

AUTHORISATION OF EXPLOSIVES

During the year, five overseas manufacturers of explosives requested authorisation of their products in Western Australia but only one new explosive was actually authorised. An amendment of the definition was approved in respect of two slurry explosives manufactured in Australia.

Authorised

Class 3—

Nitro-compound, division 1.

Asahi Sakura-Dynamite (ZZ).

One new Japanese explosive submitted for authorisation consisted of a low velocity deflagrating composition intended for the demolition of concrete and masonry with minimum shattering and no projectile effects. It was examined by chemical analysis and by extensive practical tests but proved difficult to classify. Classification was finally discussed and agreed upon at the Interstate Conference held in November and authorisation was therefore delayed until after the end of this year.

Authorisation was refused in the case of another product which was found by analysis to contain a large proportion of a toxic and highly flammable substance which could in itself be a danger to the health and safety of persons using the explosive.

Samples were received from two other European manufacturers but the usual investigations prior to authorisation were not completed before the end of the year.

A new aluminised slurry explosive was introduced this year from the Australian factory in Melbourne and was approved under an existing authorisation with an amended definition. The new product is available in small-size cartridges and, although it can be detonated by a No. 8 detonator it possesses most of the safe handling properties of a slurry explosive. A trial consignment was received in November and further progress will be followed with interest.

MANUFACTURE OF EXPLOSIVES

Nine licences were issued under the Act for the Manufacture of Explosives. Two licences were renewed for the small fireworks factories near Perth producing display fireworks and three licences are held for small factories at Woodman Point, Kalgoorlie and Port Hedland where nitrate mixtures are blended and packaged for distribution to mines. The remaining licences were issued to large mining companies who manufacture their own special nitrate explosives on the mine site.

Large quantities of ammonium nitrate are blended with fuel oil at the places of use by the smaller mines, quarries and contractors. This practice is authorised by the issue of a Licence to Manufacture Blasting Agent and 112 such licences were either issued or renewed during the year.

At the large open cut mines in the Pilbara it is now well established practice to manufacture the nitrate-based explosive mixtures on a vehicle which moves around the mine site and from which the explosive mixture is delivered directly into large boreholes. This practice can be compared with a vehicle which mixes concrete for direct delivery to a construction site. Additional mobile explosive-mixing units were brought into operation this year.

Prior to 1960, no mining explosives were manufactured in Western Australia and all blasting materials were imported into the State. Since that time the developments in mining in Western Australia have brought the total use of all blasting explosives to about twenty times the quantity formerly used and the general application of nitrate-mixture explosives has made it possible to manufacture a very large proportion of the material within the State. The conventional nitro-glycerine-based explosives continue to be imported together with all detonators, detonating fuse, safety use and other accessories but nearly 90 per cent of all bulk blasting materials now consists of ammonium nitrate manufactured at Kwinana and further blended or mixed within Western Australia under authority of licences issued under the Explosives and Dangerous Goods Act.

IMPORTATION OF EXPLOSIVES

The pattern of importations has undergone a marked change this year. Consignments of nitro-compounds, detonators and fuses have hitherto been shipped from the Melbourne factory on small vessels which discharged at Woodman Point jetty. Subsequently the route was changed to include some deliveries direct to Koolan Island and to Port Hedland. About 10 years ago Kalgoorlie commenced receiving supplies by rail from Melbourne and since completion of the standard gauge rail line there has been a steady increase in the quantities conveyed by rail.

About nine or ten shipments were formerly received at Woodman Point each year but in recent years with increasing rail supplies shipments were reduced to about four each year. In 1973 the vessel "Blythe Star" delivered only one consignment to Western Australian Ports before being withdrawn from the service. It is now the established practice to supply this State entirely by railway conveyance from Melbourne and shipping from the Nobel factory has ceased.

Explosives continued to be imported from the U.S.A. and the Australian agents have maintained a well established market for these products. It is however on a smaller scale of distribution and only one shipment was delivered to the magazines at Woodman Point during the year.

Two consignments of electric delay detonators were consigned to Perth Airport by special air freight from the Nobel factory in Scotland. This represented a total of 467 cases containing 208 300 detonators to meet urgent needs of mines in the Kalgoorlie area. Several small consignments of demolition charges were also received by air freight from Japan.

Although not an authorised explosive, ammonium nitrate is a major basic ingredient of slurry explosives and blasting mixtures which are manufactured at blasting sites. Western Australia has become self-sufficient in ammonium nitrate since the Kwinana factory came into production but supplies continue to be supplemented by small importations from overseas. The attached summary therefore includes the total amount of ammonium nitrate which has been consumed during the year for slurry explosives, ANFO and other nitrate-mixture explosives of Class 2.

Ammonium Nitrate—
Total quantity used for blasting 54 912 tonnes.

Nitro-Compound Explosives (Class 3 division 1)—
Total quantity received—1 507 tonnes.

Marine Blasting Powder (Class 3 division 2)—
One shipment to Broome—31.75 tonnes.

Blasting Powder (gunpowder) Class 1—
40 cases—907 kilograms.

Other Explosives—Plain detonators, electric and delay detonators, safety fuse, detonating fuse and priming charges are all imported in large quantities either by rail conveyance from Melbourne or from the U.S.A. In addition there were small consignments of whaling explosives and propellant powders.

Although eight licences were issued for the importation of explosives, there were also thirty nine Entry Permits issued during the year. An Entry Permit authorises the importation of one small consignment and is used to cover signal flares, Christmas crackers, whaling accessories and other small items which contain explosive substances. Entry Permits are also issued for small sample consignments of unauthorised explosives prior to official approval and authorisation. In each case a Release Certificate is issued as a condition of release by the Collector of Customs.

LICENCES AND INSPECTIONS

A total of 498 licences are now held under the Explosives Regulations as compared with 533 at the end of the previous year. The difference is largely due to cancellation of 42 licences issued in respect of vehicles to convey explosives. Many of these were held by smaller contractors operating in northern districts; after completing the work in hand they have seen no further need to convey explosives and have cancelled the licence. Otherwise there was little change in the licences issued and the distribution was as follows:—

Licences to Manufacture	9
Licences to Import	8
Licences to Manufacture Blasting Agent	112
Licences to Sell Explosives	53
Licensed Premises	50
Licensed Magazines	203
Licences to Convey Explosives	63
	498

A total of 101 magazines, stores and premises were inspected and the inspectors were frequently called to investigate blasting operations in town areas. With the exception of the Kimberley and North Eastern Goldfields, all areas of the State were inspected during the year and this included a visit to certain premises located on remote parts of the Eyre Highway. The inspectors gave special attention this year to vehicles conveying explosives and in southern areas of the State such conveyance is under satisfactory control. In the northwest the control is found to be more difficult and some irregularities in road conveyance are likely to continue unless there is more frequent inspection.

EXPLOSIVES DESTROYED

A total quantity of 12 953 kg of explosives was removed and destroyed by the inspectors on twenty four occasions during the year and in addition the usual surplus of sample material and explosives received from the Police were destroyed at Woodman Point.

In October a major operation was the destruction of 13 tonnes of deteriorated dynamite from old stocks at Port Hedland. This was done on a pastoral property under the supervision and control of an inspector. The explosives were detonated in quantities of one or two tonnes each and the stacks were separated by appropriate distances derived from the Table of Inside Distances. At these distances and even at somewhat shorter distances, there was no sympathetic detonation. In this way the operation was used to gain evidence that the accepted "inside" safety distances are in fact sufficient to prevent sympathetic detonation. The explosive had deteriorated on being stored three years in a hot climate but was still capable of yielding full explosive power on detonation.

About 130 pyrotechnic signals were received from Harbour and Light Department for destruction and arrangements were made to destroy them by dumping at sea. The signals had been confiscated on account of age and previous experience has shown that they can behave in an irregular and dangerous manner when fired in the normal way. It is therefore necessary to destroy by dumping in deep water at adequate distance from the coast.

DISPLAYS OF FIREWORKS

The number of Permits issued this year totalled 38 as compared with 19 in the previous year. For each application it is required that approval be obtained from the local Police and Fire Officer as well as from the Council. This system of local approvals ensures that conditions will be satisfactory and that the display is conducted without disturbance, danger or offence to people living in the vicinity. In this year one major display was organised to mark the opening of the State Parliament which was held in the evening. The fireworks were manufactured and the display given by a local pyrotechnican who provided an impressive display from the river foreshore for the occasion.

ANALYSIS AND TESTING

Heat tests on nitro-compound explosives were carried out as usual by Branch Officers at Woodman Point and new explosives submitted for authorisation were tested for sensitivity, velocity of detonation and detonation by influence. All new explosives were analysed for chemical composition at the Government Chemical Laboratories. Regular samples of ammonium nitrate prills for blasting were also examined at the Laboratories as a check on the specification required by railway and shipping authorities.

Consignments of safety fuse were tested on arrival for burning rate which under Mines Regulations is required to be within 80 and 100 seconds per yard of fuse. Owing to closure of the fuse factory at Deer Park, Victoria, safety fuse is now imported from a factory in South Africa. This new product was found to burn at a slower rate and some samples exceeded 100 seconds per yard. Some of the early consignments from South Africa were rejected as being outside the prescribed limits but after negotiations with the factory the burning rate was corrected to comply with Australian requirements.

SHOTFIRERS' PERMITS

Issue of Shotfirers' Permits commenced in the previous year and 34 Permits were issued prior to 31st December, 1972. During 1973 a further 125 Permits were issued bringing the total of all such Permits issued to 159 at 31st December, 1973.

Courses of instruction for Shotfirers were continued under control of the Technical Education Branch and three complete courses were given in this year. The State Government Industrial Safety Committee again requested that the Explosives Branch conduct an in-service training programme for Government Shotfirers. One such course was held in October and was extended to a full five days so that those attending might cover the whole syllabus and take the examination. From the total number of 16 men attending, 15 were successful and were issued with Shotfirers' Permits.

Shotfirers' Permits are now prescribed in the Construction Safety Regulations for all blasting carried out at construction or excavation sites and many Shire Councils are making the Shotfirers' Permit a necessary requirement before granting approval for blasting in residential or town areas. A considerable improvement in small blasting operations has resulted from the issue of the Permits to men who have been instructed in safe working with explosives. Shotfirers themselves have shown considerable interest in the training courses and there has been a heavy demand for enrolment. Experienced Shotfirers have also made direct application for Permits which are issued provided the applicants can pass the written examination with satisfactory results.

EXPLOSIVES RESERVES

Woodman Point—This Reserve continues to be used as the main centre for distribution of explosives in the south-west. Two importers have magazine storage for their explosives and one of them operates a small manufacturing plant for mixing a Class 2—Nitrate mixture which is used in mines and quarries around the Metropolitan Area. Much of the Reserve has never been fully cleared of trees and scrub and the fire which occurred on 12th January caused considerable anxiety for the safety of magazines. Fire entered the Reserve from an outbreak on adjacent Commonwealth land and several Fire Brigade appliances attended and endeavoured to confine the fire to the southern part of the area. Several magazines were in danger and the efforts of Departmental staff averted what might have been a disaster. After the main fire had burned itself out there was continued danger of renewed outbreaks from burning timber and it was necessary to recall the Fire Brigade three times on the following two days. For a further ten days the staff dealt with minor outbreaks before the area could be considered safe. Action has since been taken to improve facilities at the Reserve for dealing with any further outbreak of fire.

Kalgoorlie—This Reserve has been in constant use for bulk storage of explosives since it was first created early in the century. At the present time it is becoming even more important as a centre of distribution to all mining areas both north and south of Kalgoorlie. A licenced factory operates on the Reserve for production of Class 2—Nitrate mixture and the packaged product is distributed to all mines at Kalgoorlie and to adjacent mining fields. It is probable that new and larger magazines will be installed to meet the demand in these areas and efforts were made during the year to extend the Reserve so as to provide a buffer safety zone around any large magazines which might be constructed at Kalgoorlie.

Geraldton—The Reserve at Geraldton continues to be used for small scale storage mainly by the Harbours and Rivers Department who are now unable to store explosives in the vicinty of their main works depot at Geraldton.

Other Reserves—Those at Port Hedland, Meekatharra and Southern Cross continue to be used but numerous other Reserves in now abandoned mining areas are becoming superfluous. Applications for Mining Tenements sometimes encroach on these Reserves and no objection has been raised if the Reserve is not used and is not likely to be used in the foreseeable future.

ACCIDENTS AND EXPLOSIONS

Explosion—Fireworks Factory

In the early morning hours of 21st July a work building at a small fireworks factory in Jandakot was destroyed by fire and explosion. A youth was fatally injured within the building and another youth who remained outside suffered injuries from fire and blast. It was found that three youths had broken a locked and bolted shutter on the building in an endeavour to gain access to the contents. One youth actually entered and caused ignition of the pyrotechnic compositions and gunpowder used for manufacture of fireworks. The factory was licensed under the Explosives and Dangerous Goods Act and all buildings had been constructed to a high standard of security. The five small brick buildings were separated by approved distances and the explosion therefore did not cause damage to any other building on the site.

Detonation by Lightning

On 10th January a vehicle loaded with Seismic explosives of Class 3 division 2 and a quantity of detonating fuse blew up on the Wittenoom Road about 16 kilometres from Port Hedland. The vehicle was stopped partly off the road due to fuel pump failure and a flat tyre. While the driver was absent seeking assistance, an intense thunderstorm passed over the area and the vehicle and its load were destroyed by explosion. Meteorological records confirmed that direct lightning strikes occurred in that area and at the time the vehicle exploded. It was assumed therefore that the explosion was caused by lightning. The area is quite devoid of any trees and the seismic explosives were contained in metal canisters. The vehicle was licenced and complied with the Regulations.

Dust Explosion in Manufacture

On 8th and 24th February there were two ignitions of fine aluminium used in manufacture of a slurry explosive at a mine in the Pilbara. The explosions occurred because of mechanical failure in the augering system used to transfer the dry powder to the mixing truck. Superficial burns were sustained by an employee in the first explosion and after an investigation, recommendations were made to reduce the risk of further ignitions.

Children Injured by Detonators

Five accidents occurred when children picked up detonators. In one case the detonator was exposed to heat of the sun in a quarry and it exploded when touched. Two young girls at Laverton picked up a box containing 30 detonators and suffered injuries when match sticks were inserted into the open ends. A boy aged 13 lost two finger joints when a detonator exploded in his hand. Another accident caused stomach injuries to a 15 year old boy who was carrying a home-made device which involved batteries and electric detonators. A boy suffered injuries to his face after connecting torch batteries to an electric detonator which he had picked up on a vacant block in Belmont.

Explosion of Domestic Water Heaters

At Swan View on 16th April and again at Maida Vale on 10th August two explosions caused extensive damage to houses and were investigated by the Explosives Branch. There was no evidence that the explosions were caused by oil fuel or L.P. Gas and it was apparent in both occurrences that these were mechanical explosions caused by malfunction of safety control devices and build-up of excessive steam pressure within the heaters. In each case there was very extensive damage but fortunately no fatality or severe injury to any person.

Explosion in Refrigerator

Investigation of explosion and fire in a domestic refrigerator in a backyard indicated that flammable liquid was used in a deliberate attempt to burn the refrigerator.

Explosion in Weighbridge Office

A person threw a partly filled container of petrol into a Weighbridge Office near Kalgoorlie and ignited the liquid. There was a vapour explosion which destroyed the office.

Hospital Fire

The reception building of a psychiatric hospital was severely damaged by fire and smoke. Investigation indicated that a commercial flammable product had caused the fire and a psychiatric patient was subsequently charged with arson.

Power Line Sabotage

A 24 metre tower for power transmission at Helena Valley was damaged by a charge of gelignite. The concrete base was cracked to a depth of one metre and a 3 metre section of one leg was blown 300 metres away. The tower did not have any power lines attached and it remained upright.

House Blast Fatality

On 13th November at Kalgoorlie a house was demolished and the occupant killed in an explosion thought to be motivated by suicide. Investigation showed the damage to be consistent with the detonation of about 22 kg of explosive in a confined space. On the day of the explosion the deceased had purchased 22 kg of gelignite together with detonators and fuse.

Ammonium Nitrate Fire

On 31st December a railway truck carrying 20 tonnes of bagged ammonium nitrate was destroyed by fire at Dongara. No detonation occurred and the fire burned itself out. The cause was believed to have been an overheated axle bearing.

FLAMMABLE LIQUIDS REGULATIONS

The total number of premises licensed at the end of 1973 was 4 856 which includes 391 new licences issued during the year. As in the previous year there were a number of licences cancelled or not renewed because flammable liquids had ceased to be stored on the premises.

One inspector was absent for 30 working days as a result of injuries sustained in the course of his duties. Inspections were however maintained in all areas and 3 049 registered premises were inspected. In addition inspections were made at 47 premises where flammable liquids were stored but where no licence was required under the Regulations. On 351 occasions the inspectors examined vehicles used for conveyance and issued advice or instructions in accordance with the Regulations.

Storage of flammable liquids is now very considerably improved on all premises registered under the Regulations and the number of older premises which continue in breach of the Regulations is being steadily reduced. Numerous enquiries were again received from Councils requesting advice or assistance with particular storage problems in townsites.

Conveyance of flammable liquids on vehicles continues to present some problems in country districts where there are frequent changes in drivers and motor vehicles. In the southern part of the State the regulations are more generally complied with but in northern areas vehicles deteriorate rapidly and contract drivers continue to operate with little regard for regulations and secure in the knowledge that inspections are made only at infrequent intervals.

Only one amendment was made to the Regulations during the year and this was for the purpose of having signs displayed at all petrol service stations warning customers that there must be no smoking and that vehicle engines should be stopped while filling at the pumps. The Regulations were converted to metric system and submitted for further action.

ACCIDENTS—FLAMMABLE LIQUIDS

Vehicle Fire and Fatality

On 18th July near Hall's Creek a semi-trailer vehicle was destroyed and the driver received fatal burns. The vehicle carried three demountable tanks containing petrol and distillate together with two drums of petrol. The Senior Inspector of Explosives made an investigation at the site and prepared a report for the Coroner. When the fire occurred, the driver was located on top of one of the petrol tanks and there were at least two possible explanations for the ignition of petrol vapour.

Depot Fire

On 26th November at Muntadgin a fire occurred within a small bulk fuel depot when a petrol-powered tank vehicle was using its power-take-off pump to load fuel to elevated tanks. The fire was not controlled and quickly spread to the storage tanks. A 4.5 kilolitre petrol tank exploded projecting the end plate to a distance of 33 metres against the wall of the adjacent hotel building. No person was injured but the vehicle and depot were completely destroyed. The depot will be reconstructed to comply with the Regulations. Vehicles with power-take-off pumps should be driven only by diesel engines and petrol engine vehicles are being phased out of use.

Petrol Tankers Overturned

On 15th October a petrol tanker overturned at Mundijong and although some spillage occurred there was no fire. The road was under repair and collapsed at the edge as the tanker was passing a front end loader.

On 29th November a tank vehicle collided with a car at an intersection in Wembley. The tanker overturned and petrol was spilled on the road. Police and Fire Officers cleared the area and applied foam to the vehicles and spillage. No fire occurred.

Fires in Fibreglass Manufacture

On 19th February a fire started within 10 minutes after a factory in North Fremantle was closed for the day. The cause was not known but was thought to be associated with the dangerous goods used in fabrication of fibreglass products.

On 18th December a fire destroyed a Bayswater factory where fibreglass was manufactured. Investigation indicated that flammable vapours could have been ignited by a static electric spark.

COMMITTEES AND LECTURES

Standards Association of Australia

Work of the Committee ME-17 on flammable liquids continued throughout the year. Various working panels submitted drafts of documents which were prepared and circulated for comment. In November, a meeting of the Committee was held in Melbourne to review the progress of the work.

Advisory Committee on Transport of Dangerous Goods

The Chief Inspector attended the eighth meeting of the Committee which was held in Sydney on 1st June. Questions were raised about implementation of the Model Code in various States and it appeared that portions of the Code will be implemented by reference under existing legislation; adoption of the Code in its entirety might require a special Act of Parliament. The Committee is proceeding to reprint the Model Code in metric units and is working with the Standards Association on information cards.

Association of Australian Port and Marine Authorities

The Chief Inspector attended meetings of the Dangerous Goods Committee in Sydney on 30th and 31st May. The "Rules for Handling Dangerous Goods in Ports" were further reviewed and certain amendments confirmed.

Committee of Flammable Liquids Statutory Authorities

A short meeting was held while members were already in Melbourne for another Conference. The "Code for Tank Wagons" is to be reprinted in metric units.

C.I.B. Detectives' Training School

Two Training Courses No. 5 and No. 6 were held this year and at each course a technical officer of the Branch delivered a lecture on "Explosives and Explosions".

Training Course in Mineral Exploration and Administration

A course for overseas mining officers was conducted by the Mines Department and on 27th June the Chief Inspector addressed the members briefly on functions of the Explosives Branch. Two members of the course subsequently visited the Explosives Branch to pursue their interest in the work of the Branch.

Fire Prevention Seminar

The Industrial Foundation for Accident Prevention organised a Fire Seminar which was held in four different industrial zones of the metropolitan area. On October 23rd, 24th, 25th and 26th, the Chief Inspector delivered a lecture on the hazardous properties of flammable liquids.

Explosives Conference

The Eleventh Conference of Chief Inspectors of Explosives was held in November of this year in Melbourne. It was attended by all Australian States and by the Chief Inspector from New Zealand. For the first time delegates from both Australian Capital Territory and the Northern Territory participated in the Conference.

Shotfirers' Training Courses

Three full evening courses of lectures and practical instructions were given by staff members during the year and a similar course of five days duration was conducted for a class of selected shotfirers employed by Government Departments. At various times throughout the year the inspectors arranged for experienced shotfirers to take the examinations both in the City and at country centres. Those who passed were then issued with a Shotfirer's Permit. With only limited staff it was not possible to meet all demands for instruction of shotfirers.

CONCLUSION

The Branch continues to receive good co-operation from the W.A. Fire Brigades in matters relating to fire protection at licensed premises and relations with Shire Councils, Police and other Government Departments continue to be very satisfactory. The year under review has been difficult owing to contingencies of Annual Leave, Long Service and Sick Leave but with excellent co-operation from all staff members, the Branch has been able to fulfil its obligations and normal functions. Appreciation is expressed to the Director of the Government Chemical Laboratories who readily agreed to second a Chemist from the laboratories as a temporary relieving officer in the Explosives Branch during this period of staff shortage.

G. A. GREAVES,
Chief Inspector of Explosives.

DIVISION VIII

Report of Superintendent, Mine Workers' Relief Act, and Chairman, Miners' Phthisis Board 1973

The 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, 1973.

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, Cardup, Jarrahdale, Pinjarra, Bunbury, Gelorup, Stratham, Capel, Yoganup, Greenbushes (2 sites), Wonnerup, Carnamah, Eneabba, Three Springs, Koolanooka, Geraldton, Northampton, Useless Loop, Lake McLeod, Pannawonica, Dampier, Cape Lambert, Mt. Tom Price, Paraburdoo, Wittenoom, Port Hedland, Finucane Island, Shay Gap, Mt. Goldsworthy, Marble Bar, Nullagine, Mt. Newman, Kumarina, Meekatharra, Mt. Magnet and Paynes Find.

3. *Mine Workers' Relief Act*

3.1 *Total Examinations*

The examinations made under the Mine Workers' Relief Act during the year totalled 5 330 and compared with 4 982 for the previous year; an increase of 348. The results of examinations are as follows:—

Normal	5 078
Silicosis early, previously normal	21
Silicosis early, previously silicosis early	215
Silicosis advanced, previously normal	—
Silicosis advanced, previously silicosis early	3
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	2
Asbestosis early, previously normal	
Asbestosis early, previously asbestosis early	1
Asbestosis advanced, previously normal	
Asbestosis advanced, previously asbestosis early	—
Silico-asbestosis early, previously normal	1
Silico-asbestosis early, previously asbestosis early	—
Silico-asbestosis early, previously silicosis early	5
Silico-asbestosis early, previously silico-asbestosis early	—
Silico-asbestosis advanced, previously silico-asbestosis early	—
Silico-asbestosis advanced, previously silicosis early	1
Silico-asbestosis plus tuberculosis, previously normal	—
Silico-asbestosis advanced plus tuberculosis, previously silico-asbestosis early	—
Total	5 330

The 1973 figures, together with figures for previous years are shown on the table annexed hereto. Graphs are also attached illustrating the trend of examination 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 5 078 or 95.27 per cent of the men examined and include men having first class lives or suffering from fibrosis only. The figures for the previous year being 4 647 or 93.30 per cent of the men examined.

3.2.2. *Early Silicosis*

These numbered 236 of which 21 were new cases and 215 had previously been reported; the figures for 1972 being 326 and 20 respectively. Early silicotics represent 4.43 per cent of the men examined, the percentage for the previous year was 6.50 per cent.

3.2.3. *Advanced Silicosis*

There were 7 cases reported 3 of which advanced from early silicosis. Advanced silicotics represent 0.13 per cent of the men examined, the percentage for the previous year being 0.15 per cent.

3.2.4. *Silicosis Plus Tuberculosis*

There were no cases reported. This compares with the year 1972.

3.2.5. *Tuberculosis Only*

There were two new cases of Tuberculosis reported during the year and represents 0.04 per cent of the men examined. There was none reported in 1972.

3.2.6. *Asbestosis*

There was one case of early asbestosis reported during the year and this had been previously reported.

3.2.7 *Silicosis-Asbestosis*

Six cases of early silicosis-asbestosis were reported during the year, only one being a new case. This category represents 0.11 per cent of the men examined.

4. *Mines Regulation Act*

4.1. *Total Examinations*

Examinations under the Mines Regulation Act totalled 8 133. There was an increase of 3 450 under this Act in 1973 as compared with 1972.

Of the total of 8 133 examined, 7 609 were new applicants and 524 were re-examinees. In addition, Provisional Certificates were issued to 883 persons in isolated country areas.

4.2 Analyses of Examinations

Particulars of examinations are as follows:—

4.2.1 New Applicants

Normal	7 594
Silicosis early	1
Silicosis early with tuberculosis	—
Tuberculosis	2
Other conditions	12
Total	7 609

4.2.2. *Re-examinees*

Normal	523
Silicosis early	—
Silicosis early with tuberculosis	—
Tuberculosis	1
Other conditions	—
Total	524

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 Certificate (Form 2)	8 071
Temporary Rejection Certificates (Form 3)	1
Rejection Certificates (Form 4)	15
Re-admission Certificates (Form 5)	46
Special Certificate (Form 9)	—
Total	8 133

5. *Miners' Phthisis Act*

The amount of compensation paid during the year was $7 121.00 compared with $7 988.00 for the previous year.

The number of beneficiaries under the Act as on 31/12/1973 was 30 being 2 ex-miners and 28 widows.

6. *Administrative*

Mr V. T. Foster was appointed as Superintendent of the Mine Workers Relief Act and Chairman of the Miners' Phthisis Board as from 2 April, 1973.

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)

Year	Normal		Silicosis Early				Silicosis Advanced					Silicosis plus Tuberculosis					Tuberculosis Only		Asbestosis									Total
	Total	Per Cent.	Previously reported as Normal etc.	Previously reported as Silicosis Early	Total	Per Cent.	Previously reported as Normal etc.	Previously reported as Silicosis Early	Previously reported as Silicosis Advanced	Total	Per Cent.	Previously reported as Normal etc.	Previously reported as Silicosis Early	Previously reported as Silicosis Advanced	Total	Per Cent.	Total	Per Cent.	Asbestosis early previously normal	Asbestosis early previously asbestosis early	Asbestosis advanced previously normal	Asbestosis advanced previously asbestosis early	Asbestosis advanced previously asbestosis advanced	Asbestosis plus tuberculosis previously normal	Asbestosis plus tuberculosis previously asbestosis	Total	Per Cent.	
1925 1926 }	3,239	80·5	....	....	459	11·4	....	....	....	183	4·5	....	....	....	131	3·3	11	0·3	....	....	....	....	....	....	....	....	....	4,023
1927	3,116	83·6	33	348	381	10·2	8	....	85	93	2·5	39	27	62	128	3·4	10	0·3	....	....	....	....	....	....	....	....	....	3,728
1928	2,977	85·5	59	303	362	10·4	3	16	79	98	2·8	18	14	10	42	1·2	4	0·1	....	....	....	....	....	....	....	....	....	3,483
1929	2,120	81·9	102	224	326	12·6	....	34	60	94	3·6	8	14	19	41	1·6	7	0·3	....	....	....	....	....	....	....	....	....	2,588
1930	2,785	81·9	136	247	383	11·3	2	22	43	67	2·0	8	60	46	114	3·3	50	1·5	....	....	....	....	....	....	....	....	....	3,399
1931	2,530	84·0	94	252	346	11·5	....	18	35	53	1·8	4	35	19	58	1·9	25	·8	....	....	....	....	....	....	....	....	....	3,012
1932	3,835	89·5	35	338	373	8·7	....	6	47	53	1·2	3	9	4	16	·4	8	·2	....	....	....	....	....	....	....	....	....	4,285
1933	2,920	86·5	57	322	379	11·2	1	15	44	60	1·8	2	9	4	15	·4	3	·1	....	....	....	....	....	....	....	....	....	3,377
1934	5,140	92·4	54	315	369	6·6	1	24	12	37	·7	6	6	....	12	·2	5	·1	....	....	....	....	....	....	....	....	....	5,563
1935	4,437	92·3	35	303	338	7·0	....	24	2	26	·6	....	5	....	5	·1	2	·0	....	....	....	....	....	....	....	....	....	4,808
1936	6,972	94·7	29	323	352	4·8	1	15	4	20	·3	3	8	....	11	·1	8	·1	....	....	....	....	....	....	....	....	....	7,363
1937	7,487	95·4	15	319	334	4·3	....	14	4	18	·2	1	10	....	11	·1	2	·0	....	....	....	....	....	....	....	....	....	7,852
1938	6,833	95·7	13	266	279	3·9	....	15	2	17	·2	1	8	....	9	·1	3	·0	....	....	....	....	....	....	....	....	....	7,141
1939	6,670	95·6	18	264	282	4·0	....	7	3	10	·1	1	9	1	11	·2	2	·0	....	....	....	....	....	....	....	....	....	6,975
1940	7,023	96·2	12	245	257	3·5	....	10	1	11	·2	....	4	....	4	·0	4	·0	....	....	....	....	....	....	....	....	....	7,299
1941	6,840	95·8	32	248	280	3·9	....	11	3	14	·2	....	....	....	....	....	7	·1	....	....	....	....	....	....	....	....	....	7,141
1942	5,469	93·9	61	264	325	5·6	....	20	5	25	·4	....	2	....	2	·0	3	·1	....	....	....	....	....	....	....	....	....	5,824
1943	3,932	91·5	63	262	325	7·6	....	25	7	32	·7	....	5	....	5	·1	4	·1	....	....	....	....	....	....	....	....	....	4,298
1944	4,079	91·5	70	270	340	7·5	....	21	14	35	·8	1	7	....	8	·2	6	·1	....	....	....	....	....	....	....	....	....	4,468
1945	3,071	92·1	54	166	220	6·6	....	26	10	36	1·1	3	2	....	5	·2	2	·1	....	....	....	....	....	....	....	....	....	3,334
1946	5,294	94·4	89	172	261	4·7	1	36	2	39	·7	3	1	2	6	·1	6	·1	....	....	....	....	....	....	....	....	....	5,606
1947	6,021	93·3	101	237	338	5·2	....	49	9	58	1·0	13	11	1	25	·3	8	·1	....	....	....	....	....	....	....	....	....	6,450
1948	4,827	94·0	24	239	263	5·1	....	18	17	35	·7	1	3	....	4	·1	5	·1	....	....	....	....	....	....	....	....	....	5,134
1949	5,162	94·0	24	239	263	4·8	....	20	31	51	1·0	3	2	1	6	·1	7	·1	....	....	....	....	....	....	....	....	....	5,489
1950	5,077	93·6	14	269	283	5·2	....	14	41	55	1·0	....	1	2	3	·1	8	·2	....	....	....	....	....	....	....	....	....	5,426
1951	4,642	93·9	13	248	261	5·3	....	9	20	29	·6	....	4	2	6	·1	4	·1	....	....	....	....	....	....	....	....	....	4,942
1952	5,073	94·6	8	234	242	4·5	....	4	31	35	·6	....	2	....	2	·1	7	·1	....	....	....	....	....	....	....	....	....	5,359
1953	4,474	93·03	74	225	299	6·22	....	8	24	32	·6	....	2	....	2	·1	2	·1	....	....	....	....	....	....	....	....	....	4,809
1954	5,142	91·33	154	275	429	7·62	....	22	21	43	·76	1	6	2	9	·1	7	·1	....	....	....	....	....	....	....	....	....	5,630
1955	4,559	90·40	63	386	449	8·90	....	9	22	31	·62	1	1	1	3	·06	1	·02	Segregation of asbestosis diagnoses commenced in 1959									5,043
1956	4,600	90·78	25	401	426	8·41	....	8	25	33	·65	1	3	....	4	·08	4	·08	....	....	....	....	....	....	....	....	....	5,067
1957	3,925	89·08	30	424	454	10·30	....	8	10	18	·41	1	4	....	5	·12	4	·09	....	....	....	....	....	....	....	....	....	4,406
1958	5,154	90·20	46	483	529	9·26	....	15	9	24	·42	....	6	....	6	·10	1	·02	....	....	....	....	....	....	....	....	....	5,714
1959	5,242	90·10	66	485	551	9·47	....	9	....	....	·15	1	5	1	7	·12	3	·05	6	....	....	....	....	....	....	6	....	5,818
1960	5,214	90·54	50	473	523	9·08	....	5	....	5	·09	2	9	....	11	·19	3	·05	2	....	....	....	....	1	....	3	....	5,759
1961	5,188	90·18	54	479	533	9·26	....	13	....	13	·23	2	3	....	5	·09	3	·05	5	5	....	1	....	....	....	11	·19	5,753
1962	5,183	89·98	50	499	549	9·53	1	10	....	11	·19	1	5	....	6	·10	1	·02	2	7	....	1	....	....	....	10	·18	5,760
1963	4,795	87·21	188	451	639	11·62	....	22	....	22	·40	7	6	....	13	·24	3	·05	10	11	....	4	....	1	....	26	·47	5,498
1964	3,484	83·85	64	561	625	15·04	....	9	1	10	·24	....	1	....	1	·02	2	·05	13	17	....	2	....	....	1	33	·80	4,155
1965	3,770	87·39	53	459	512	11·87	....	6	....	6	·14	....	1	....	1	·02	5	·12	5	15	....	....	....	....	....	20	.46	4,314
1966	3,411	86·56	26	469	495	12·56	....	14	....	14	·36	3	1	....	4	·10	1	·02	4	12	....	....	....	....	....	16	·40	3,941
1967	1,644	81·03	19	332	351	17·30	....	7	1	8	·39	....	2	....	2	·10	5	·24	8	6	....	5	....	....	....	19	·94	2,029
1968	3,364	86·93	39	431	470	12·14	....	18	3	21	·54	....	1	1	2	·05	1	·03	5	4	....	3	....	....	....	12	·31	3,870
1969	3,406	87·77	36	412	448	11·55	....	13	1	14	·36	....	1	....	1	·03	1	·01	2	7	....	2	....	....	....	11	·28	3,881
1970	3,841	89·73	30	400	430	10·04	....	6	....	6	·14	....	1	....	1	·02	3	·07	....	....	....	....	....	....	....	....	....	4,281
1971	3,915	91·80	15	327	342	8·02	....	5	2	7	·16	....	....	....	....	....	1	·02	....	....	....	....	....	....	....	....	....	4,265
1972	4,647	93·30	20	308	328	6·55	....	5	2	7	·15	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	4,982
1973	5,078	95·27	27	215	242	4·54	....	4	3	7	·13	....	....	....	....	....	2	·04	....	1	....	....	....	....	....	....	·02	5,330

MINING STATISTICS
to 31st December, 1973

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TABLE 1

PRODUCTION OF GOLD AND SILVER AS REPORTED TO THE MINES DEPARTMENT DURING 1973.

(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 1973					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. 1118	Kitchener	....	....	541·55	10·106	....	....	....	2 325·22	78·254	·110
	1203	Mt. Prophecy	....	....	267·42	1·755	....	....	....	5 572·76	82·633	3·536
Marble Bar	1345	Coongan Star	....	....	96·98	·129	....	....	....	96·98	·129	....
	927	Halley's Comet	....	....	....	17·794	2·335	....	....	6 462·06	216·555	23·469
	1209	Ironclad	....	....	324·73	·784	....	....	....	483·23	1·179	·006
	1458	Kangaroo	....	....	33·99	·787	....	....	....	33·99	·787	....
	1451	Maria	....	....	42·98	·274	....	....	....	42·98	·274	....
	1331	The General	....	....	46·18	·222	....	....	....	46·18	·222	....
		Sundry Claims	....	....	430·60	4·366	....	2·086	7·939	22 655·39	406·614	·341
		State Battery, Marble Bar	....	....	....	*7·747	2·194	....	....	12·19	*471·031	18·718
NULLAGINE DISTRICT.												
Nullagine	G.M.L. 395L	Junaldy	....	....	29·01	·041	....	....	....	29·01	·041	....
		Sundry Claims	....	....	12·19	·478	....	9·995	21·649	6 997·72	330·819	·583
West Pilbara Goldfield												
Yule River	M.C. 305 W.P.	Yule River Mining Pty. Ltd.	....	....	....	1·439	....	....	....	....	1·439	....
Gascoyne Goldfield												
Mangaroon Station	G.M.L. 46	Star of Mangaroon	....	....	....	·037	....	....	·195	3 766·99	169·386	3·136
District Generally	....	Sundry Claims and Leases	....	....	12·45	·013	....	....	....	12·45	·013	....
Peak Hill Goldfield.												
Peak Hill	G.M.L. 621	Atlantic North....	....	·380	....	....	....	....	·380	....	....	....
		Sundry Claims	....	·266	....	....	....	1·913	15·139	35 932·85	280·895	·166
East Murchison Goldfield.												
BLACK RANGE DISTRICT.												
Barrambie	G.M.L. 1117B	Scheelite Leases	....	....	106·02	1·646	....	....	....	1 799·77	34·327	·610

(14)—39934

Murchison Goldfield.

CUE DISTRICT.

Cue	....	Sundry Claims	....	....	19·30	·055	....	7·867	27·976	48 260·18	639·766	·178
		L.T.T. 20/1 (1973H)—Sears, E. L.	....	....	334·74	·392	....	....	....	334·74	·392	....

MEEKATHARRA DISTRICT.

Meekatharra	G.M.L. 2087N	Bonanza Lode	....	....	35·56	·029	....	....	....	35·56	·029	....
	2016N	Commodore	....	....	39·98	·436	....	....	....	52·17	·650	....
	2068N	Halcyon	....	....	528·35	1·346	....	....	....	2 735·20	5·796	....
	2015N	Haveluck	....	....	2 872·06	4·919	....	....	....	9 865·51	18·928	....

MOUNT MAGNET DISTRICT.

Jumbulyer	....	Sundry Claims	....	....	103·38	·153	....	·632	3·616	1 348·50	28·409	....
Lennonville	G.M.L. 1714M	Ard Patrick	....	....	51·56	·041	....	....	....	51·56	·041	....
		Sundry Claims	....	....	272·55	·458	....	·808	3·638	16 147·54	189·178	·344
Mt. Magnet	1670M	Black Cat	....	....	200·67	·322	....	....	....	247·71	·452	....
	1282M, etc.	Hill 50 Gold Mine N.L.	....	....	59 170·51	523·362	36·201	....	....	3 198 227·49	41 986·900	2 134·581
	1727M	Monarch	....	....	18·70	·141	....	....	....	18·70	·141	....
		Sundry Claims	....	....	283·99	·481	....	4·913	81·779	63 540·70	943·374	·918

Yalgoo Goldfield.

Goodingnow	G.M.L. 1063	Ark	....	....	131·48	9·418	....	....	·388	2 786·91	71·869	....
Warda Warra	1267	The Shamrock	....	....	96·67	1·283	....	....	....	96·67	1·283	....
		Sundry Claims	....	....	10·16	·091	....	....	....	1 136·70	15·911	·265

Mt. Margaret Goldfield.

MT. MORGANS DISTRICT.

Linden	G.M.L. 582F	Green Hills	....	....	452·14	·646	....	....	....	452·14	·646	....
		Sundry Claims	....	....	30·48	·093	....	4·109	7·619	20 199·37	432·842	·071
Mt. Morgans	592F	Treasure Chest....	....	....	150·38	·104	....	....	....	150·38	·104	....
Redcastle	....	Sundry Claims	....	....	76·20	·159	....	....	3·541	1 327·54	20·751	....

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 1973					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
			Mt. Margaret Goldfield—cont.									
			MOUNT MALCOLM DISTRICT.									
Cardinia	G.M.L. 2025C	Faye Marie	....	....	50·80	·060	....	....	....	50·80	·060	....
Diorite	1974C	Puzzle	....	....	27·99	·298	....	....	....	52·88	·524	....
		Sundry Claims	....	....	55·88	·278	....	·348	10·330	5 107·51	160·905	....
Lake Darlot	(1978C)	Weebo Mine	....	....	176·79	·206	....	....	....	225·56	·311	....
		Sundry Claims	....	....	432·84	·483	....	4·041	28·454	14 299·71	219·346	1·405
Leonora	1897C	Bon Boo	....	....	545·11	1·635	....	....	...	1 988·45	21·273	....
	2026C	Ficara Mine	....	....	56·90	·062	....	....	....	56·90	·062	....
	2015C	Island	....	....	45·72	2·245	....	....	....	45·72	2·245	....
	1948C	Jessie Alma	....	....	254·01	·129	....	....	....	254·01	·129	....
	1762C	Sons of Gwalia....	....	·213	1 289·77	3·556	....	....	·213	1 289·77	3·556	....
	1906C	Two Glads	....	....	1 547·19	13·820	....	....	....	2 012·28	19·162	....
		Sundry Claims	....	....	121·62	·347	....	1·173	12·211	24 495·52	409·384	·833
Mertondale	....	Sundry Claims	....	....	307·20	·818	....	·168	2·667	4 028·13	73·470	·027
		State Battery, Leonora	....	....	....	*10·519	....	....	....	92·46	*52·968	1·434
		L.T.T. 37/5 (1985H)—Moreschetti, D.	....	....	1 011·98	2·650	....	....	....	1 011·98	2·650	....
		L.T.T. 37/9 (2037H)—Bray, F.	....	....	212·36	·922	....	....	....	212·36	·922	....
			MOUNT MARGARET DISTRICT.									
Laverton	G.M.L. 2633T	Admiral Hill	....	....	419·73	·105	....	....	....	419·73	·105	....
	2679T	Bulldog	....	....	371·87	·360	....	....	....	371·87	·360	....
	2624T	Confusion	....	....	116·85	·096	....	....	....	116·85	·096	....
		Sundry Claims	....	....	14·22	·568	....	6·705	46·434	17 848·38	288·487	341·626
		L.T.T. 38/21 (2231H)—Connelly & Noonan	....	....	....	·008	....	....	....	....	·008	....
			North Coolgardie Goldfield.									
			MENZIES DISTRICT.									
Menzies	G.M.L. 5815Z	Espasia	....	....	101·60	1·068	....	....	....	101·60	1·068	....
		Sundry Claims	....	....	19·00	·757	....	1·769	19·419	43 777·79	827·477	25·311
			ULARRING DISTRICT.									
Morleys	G.M.L. 1094U	First Hit	....	....	197·88	1·044	....	....	2·595	5 892·94	232·597	·370
Mulline	1173U	Riverina	....	....	22·10	·132	....	....	....	1 639·14	6·335	....
		Sundry Claims	....	....	37·59	·645	....	·336	9·219	12 517·08	312·282	·035
		L.T.T. 29/9 (1861H)—Perks, C. J.	....	....	91·44	·324	....	....	....	91·44	·324	....

NIAGARA DISTRICT.

Kookynie	....	Sundry Claims	....	....	174·35	·603	....	1·895	3·370	10 269·49	219·517	·130

YERILLA DISTRICT.

Yarri	G.M.L. 1126R, etc.	Porphyry (1939) G.M.N.L.	....	....	634·12	2·157	....	....	....	70 206·91	315·743	8·147
		Prior to transfer to present holders	....	....	....	....	....	....	....	30 831·44	169·477	15·785
	1418R	Pinola	....	....	64·47	·115	....	....	....	64·47	·115	....
	1407R	Watergate	....	....	449·09	·725	....	....	....	449·09	·725	....
		Sundry Claims	....	....	66·04	·494	....	·027	·184	18 861·94	200·190	·043

Broad Arrow Goldfield.

Bardoc	....	Sundry Claims	....	....	33·23	·200	....	1·709	37·887	19 710·17	267·666	....
Broad Arrow	G.M.L. 2341W	Chancelot	....	....	654·33	·597	....	....	....	1 419·42	1·943	....
	2353W	Oversight	....	....	294·65	·538	....	....	....	543·58	1·079	....
	2346W	Sunday Eve	....	....	30·48	·699	....	....	....	229·37	8·421	....
	2357W	V.M.P.	....	....	44·91	·302	....	....	....	85·55	1·101	....
	2348W	Wentworth	....	....	162·57	1·557	....	....	....	292·62	2·936	....
Grants Patch	2311W	Bent Tree	....	....	1 453·76	2·515	....	....	....	1 669·16	7·112	....
		Sundry Claims	....	4·227	....	....	....	·137	15·912	7 955·26	105·841	·133
Ora Banda	2270W, 2290W	Gimlet South Leases	....	....	5 187·43	7·147	....	....	....	59 205·56	196·348	5·120
	2300W	Sleeping Beauty	....	....	2 014·97	3·684	....	....	....	5 733·96	36·715	·035
		Sundry Claims	....	....	148·14	·515	....	....	14·531	17 930·03	163·696	....
Riches Find	....	Sundry Claims	....	....	30·02	·060	....	....	17·078	2 187·09	78·833	·004
Smithfield	....	Sundry Claims	....	....	419·37	·414	....	....	3·866	4 452·66	43·959	·003
		L.T.T. 24/11 (1898H) Rymer Bracegirdle and McDonald	....	....	431·01	·508	....	....	....	431·01	·508	....

North-East Coolgardie Goldfield.

KANOWNA DISTRICT.

Gindalbie	G.M.L. 1594X	Binti Binti	....	....	227·59	·333	....	....	....	353·08	1·488	....
		Sundry Claims	....	....	56·39	·330	....	....	22·286	6 087·41	103·713	....
Kalpini	1597X	Kalpini North East	....	....	553·75	2·018	....	....	....	553·75	2·018	....
Kanowna	1587X	White Feather	....	....	38·61	·428	....	....	....	347·28	4·805	....
	1586X	Kanowna Red Hill	....	....	12·19	·020	....	....	....	10 221·18	46·268	·060
	1585X	New Kanowna	....	....	56·09	·522	....	....	....	370·80	6·570	....
		Sundry Claims	....	....	68·07	1·243	....	3·898	67·465	29 413·10	384·143	·053

KURNALPI DISTRICT.

Jubilee	....	Sundry Claims	....	....	46·74	·157	....	·795	·420	1 331·02	16·558	....
Kurnalpi	....	Sundry Claims	....	....	18·79	·076	....	10·081	22·624	4 752·16	74·245	....

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 1973					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
East Coolgardie Goldfield.												
EAST COOLGARDIE DISTRICT.												
Boorara	G.M.L. 6658E	Waterfall	....	....	23·37	·159	....	....	....	433·34	5·468	....
Boulder	5345E, etc.	Kalgoorlie Lake View Pty. Ltd.	....	....	184 215·40	1 086·359	359·535	....	....	184 215·40	1 086·359	359·535
	5345E, etc.	Gold Mines of Kalgoorlie (Aust.) Ltd.	....	....	107 339·26	630·340	471·928	....	....	6 628 840·09	51 040·996	16 774·510
		Prior to transfer to present holders	....	....	....	....	....	....	26·436	16 172 340·34	199 581·996	25 477·581
	5708E, etc.	Lake View & Star Ltd.	....	....	221 924·96	1 442·139	194·907	....	....	23 315 628·84	197 643·071	22 311·094
		Prior to transfer to present holders	....	....	....	....	....	....	·264	16 045 921·05	284 572·670	41 929·223
	5431E, etc.	North Kalgurli Mines Ltd.	....	....	131 693·90	735·300	450·174	....	3·967	9 946 247·95	74 337·785	22 874·307
Feysville	....	Sundry Claims	....	....	38·10	·365	....	....	6·189	1 547·18	21·386	....
Hampton Plains	P.P.L. 277, Loc. 50	Kalgoorlie Lake View Pty. Ltd.	....	....	625·88	3·299	....	....	....	625·88	3·299	....
	P.P.L. 277, Loc. 50	Lake View & Star Ltd.	....	....	2 293·68	10·658	....	....	....	35 344·66	104·729	....
		Prior to transfer to present holders	....	....	....	....	....	....	....	15 107·35	44·966	·064
Kalgoorlie....	G.M.L. 5510E	Golden Dream	....	....	232·67	·821	·115	....	....	1 029·76	2·239	·115
	6537E	Golden Key	....	....	50·80	1·160	....	....	....	169·17	5·773	....
	6563E, etc.	Kalgoorlie Lake View Pty. Ltd. (Mt. Charlotte)	....	....	282 989·38	942·373	....	....	....	282 989·38	942·373	....
	6563E, etc.	Gold Mines of Kalgoorlie (Aust.) Ltd. (Mt. Charlotte)	....	....	435 228·77	1 599·870	....	....	....	4 860 502·16	21 186·166	....
		Prior to transfer to present holders	....	....	....	....	....	....	·180	87 099·20	565·063	5·336
	6589E	Grays Central	....	....	85·55	1·993	....	....	....	1 055·11	10·605	·092
	6485E	Maritana Hill	....	....	75·70	·133	....	....	....	6 426·75	20·480	....
	6615E	Middle Hannans	....	....	253·00	·889	....	....	6·440	3 531·27	23·055	....
	6639E	Old Hinchcliffe	....	....	152·41	·586	....	....	....	1 955·13	6·759	....
Wombola	G.M.L. 5497E 5500E	Daisy Leases	....	....	665·21	18·024	....	....	....	27 074·50	801·729	27·519
	5497E	Daisy	....	....	....	....	....	....	....	6 383·06	156·511	....
	5500E	Happy-Go-Lucky	....	....	....	....	....	....	....	2 108·55	52·125	....
	6698E	Eastern Return	....	....	60·86	·449	....	....	....	454·83	1·068	....
	6780E	Gute Hoffnung	....	....	98·05	·508	....	....	....	98·05	·508	....
	6635E	Hodad	....	....	53·09	·310	....	....	....	3 736·26	17·728	1·611
	6487E	Leslie	....	....	32·26	·969	....	....	....	892·60	15·280	·036
	6614E	Logans Gold Mine	....	5·227	1 176·38	8·134	....	....	5·227	6 180·15	37·446	·039
	6781E	Promise....	....	....	12·19	·094	....	....	....	12·19	·094	....
	6676E	Rosemary	....	....	292·88	3·507	....	....	....	665·00	10·635	....
		Sundry Claims	....	....	923·28	16·022	....	....	22·336	28 758·07	485·214	·006
		State Battery, Kalgoorlie	....	....	....	*11·204	1·112	....	....	396·97	*1 308·945	24·113

BULONG DISTRICT.

Balagundi	G.M.L. (1355Y)	Mount Bellew	....	....	107·96	16·327	....	....	....	107·96	16·327	....
Majestic	....	Sundry Claims	....	....	16·26	·045	....	1·334	4·808	2 005·76	30·323	....
Randalls	1357Y	Hill Gold Mine....	....	....	514·98	2·250	....	....	....	514·98	2·250	....
	1356Y	Majestic	....	....	773·36	1·147	....	....	....	773·36	1·147	....

Coolgardie Goldfield.

COOLGARDIE DISTRICT.

Bonnievale	G.M.L. 5622	Lucky Hit	....	....	17·43	1·306	....	....	·102	1 269·04	27·492	....
	6151	Melva Maie	....	....	430·25	·855	....	....	·037	1 059·18	3·043	....
	6174	Mystery	....	....	21·34	·147	....	....	....	21·34	·147	....
	5890	Rayjax	....	1·030	29·46	2·356	....	....	1·030	1 230·69	53·387	·159
		Sundry Claims	....	....	53·85	·223	....	....	12·075	11 850·79	182·551	·034
Bulla Bulling	6173	May Joy	....	....	47·75	·260	....	....	....	73·15	·552	....
Burbanks	6200	Gentle Favour	....	....	102·62	·050	....	....	....	102·62	·050	....
	6203	Hope of Good Luck	....	....	115·68	·026	....	....	....	115·68	·026	....
	6187	Ivanhoe	....	....	205·24	3·055	....	....	....	205·24	3·055	....
	6217	Lady Robinson	....	....	76·41	·126	....	....	....	76·41	·126	....
		Sundry Claims	....	....	238·57	·625	....	1·712	15·475	18 791·94	295·785	·030
Coolgardie	G.M.L. 6166	Bayleys	....	....	239·28	·212	....	....	....	239·28	·212	....
	6199	Fly Flat	....	....	....	·439	....	....	....	....	·439	....
	6209	Gwenn	....	....	55·88	·012	....	....	....	55·88	·012	....
	6193	Marlene	....	....	170·70	·103	....	....	....	170·70	·103	....
	6024	New Cock Shot	....	....	170·70	·113	....	2·054	....	218·45	·611	·016
	6188	Redemption	....	....	101·60	·037	....	....	....	101·60	·037	....
	6195	Rose Hill	....	....	116·84	·112	....	....	....	116·84	·112	....
	6176	Three Mile	....	·017	271·49	·132	....	....	·017	1 010·15	1·447	....
	6046	Valerie May	....	....	469·26	·198	....	....	....	482·47	·266	....
		Sundry Claims	....	·841	521·33	·373	....	7·345	95·544	92 701·62	940·880	·059
Gibraltar	5723	Lloyd George	....	....	84·84	·153	....	....	·110	959·65	5·952	....
Hampton Plains	P.P.L. 484, Loc. 59	Baker, T. R.	....	....	645·70	1·904	....	....	....	755·43	2·263	....
	P.P.L. 490, Loc. 48	Rennie, D.	....	....	86·36	·161	....	....	·058	204·22	1·584	....
Higginsville	G.M.L. 5647	Fair Play Gold Mine	....	....	917·49	1·206	....	·137	1·950	30 809·84	103·572	·001
	6106	Liberator	....	....	113·80	1·224	....	....	....	338·34	4·795	....
	6061	Two Boys	....	....	562·89	4·013	....	....	9·074	1 791·54	25·694	....
		Sundry Claims	....	....	40·64	·176	....	....	5·824	3 962·34	62·342	....
Londonderry	....	Sundry Claims	....	....	16·76	·081	....	·519	2·512	4 392·28	83·982	·697
Ryans Find	5999	Consolidated Gold Mining Areas N.L.	....	....	94·34	1·775	....	....	....	1 209·96	26·659	....
		Prior to transfer to present holders	....	....	....	....	....	....	97·256	245·63	76·812	....
		State Battery, Coolgardie	....	....	....	*·473	....	....	....	783·38	*1 345·569	·911

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 1973					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.												
Carbine	....	Sundry Claims	....	....	50·80	·606	....	4·328	3·016	6 975·04	75·608	....
Jourdie Hills	....	Sundry Claims	....	....	86·37	·224	....	·058	1·549	2 191·11	29·216	·033
Kintore	G.M.L. 1059S	New Haven	....	....	1 208·84	3·424	....	....	....	2 527·67	9·534	....
Kunanalling	1052S	Catherwood	....	....	79·76	·269	....	....	....	573·30	1·344	....
		Sundry Claims	....	....	15·24	·173	....	6·735	30·928	18 120·96	322·148	·674
		L.T.T. 16/12 (2011H)—Regan, F. and Vergo, A.	....	....	231·66	2·545	....	....	....	231·66	2·545	....
Yilgarn Goldfield.												
Bullfinch	G.M.L. 4535	Casas	....	....	487·19	1·588	....	....	....	942·13	8·137	....
	4607	Open Cut	....	....	331·49	1·054	....	....	....	331·49	1·054	....
		Sundry Claims	....	·326	....	....	....	·263	1·741	7 913·88	133·937	·755
Eenuin	4540	North End	....	....	8·13	·042	....	....	....	104·65	·529	....
Golden Valley	4427	W.A. Gold Development N.L.	....	....	5 125·45	70·109	....	....	....	8 820·15	109·816	1·400
Greenmount	4543	Devs Reward	....	....	302·99	·621	....	....	....	1 124·97	4·278	3·789
Marvel Loch	4556	Apache	....	....	55·88	·043	....	....	....	154·18	·156	·003
	3724	Frances Firness	....	....	203·21	·502	....	....	18·410	25 306·43	328·910	9·543
Parkers Range	4512	Constance Una	....	....	317·77	4·409	....	....	....	8 187·81	179·328	2·628
	4670	Garibaldi	....	....	104·65	·807	....	....	....	216·67	1·346	....
	4589	King of the Range	....	....	58·93	·191	....	....	....	119·89	·398	....
	4621	The Dollar	....	....	74·43	·238	....	....	....	201·18	1·559	....
		Sundry Claims	....	....	66·55	·398	....	·205	9·453	14 675·83	178·111	·101
Southern Cross	4634	Frasers	....	....	2 651·37	114·544	....	....	....	3 962·58	124·931	....
		Sundry Claims	....	....	30·99	·070	....	2·983	20·218	8 916·74	85·756	·298
		State Battery, Marvel Loch	....	....	....	*8·795	·045	....	....	149·36	*171·814	82·466
		L.T.T. 11/72 (1947H)—Wright, L.	....	....	....	·928	....	....	....	....	·928	....

Dundas Goldfield.

Beete	G.M.L. 2044	Beete	....	....	202·19	3·929	....	....	6·106	285·51	8·799	1·710
		Sundry Claims	....	·334	....	....	....	....	·334	423·18	12·220	....
Dundas	(2163)	Albermarle	....	....	42·67	·379	....	....	....	42·67	·379	....
	2128	Maybe	....	·166	36·58	·449	....	....	·270	46·74	·492	·013
Norseman	1936, etc.	Central Norseman Gold Corpn. N.L.	....	....	151 903·08	1 135·307	742·223	....	....	5 354 492·18	73 889·236	50 854·202
		Sundry Claims	....	....	74·17	·122	....	32·729	112·653	50 784·01	704·840	7·623

Phillips River Goldfield.

Kundip	G.M.L. 277	Western Gem	....	....	50·80	·513	....	....	....	717·33	7·017	·001
		Sundry Claims	....	....	27·43	·402	....	2·808	2·271	6 565·37	61·112	1·700

State Generally

		Reported by Banks and Gold Dealers	....	....	....	1·182	....	37·351	34·582	....	38·312	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 1973.

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	....	....	....	....	....	....	....	....	....	....	1·439	1·439	....
Pilbara	Marble Bar	....	....	1 784·43	43·964	43·964	4·529	....	....	1 825·63	44·483	44·483	4·529
	Nullagine	....	....	41·20	·519	·519	....						
Ashburton	....	....	....	....	....	....	....	....	....	....	....	....	....
Gascoyne	....	....	....	....	....	....	....	....	....	12·45	·050	·050	....
Peak Hill	....	....	....	....	....	....	....	....	·646	....	....	·646	....
East Murchison	Lawlers	....	....	....	....	....	....	....	....	106·02	1·646	1·646	....
	Wiluna	....	....	....	....	....	....						
	Black Range	....	....	106·02	1·646	1·646	....						
Murchison	Cue	....	....	354·04	·447	·447	....	....	....	63 931·35	532·135	532·135	36·201
	Meekatharra	....	....	3 475·95	6·730	6·730	....						
	Day Dawn	....	....	....	....	....	....						
	Mt. Magnet	....	....	60 101·36	524·958	524·958	36·201						
Yalgoo	....	....	....	....	....	....	....	....	....	238·31	10·792	10·792	....
Mt. Margaret	Mt. Morgans	....	....	709·20	1·002	1·002	....	....	·213	7 768·03	40·167	40·380	·260
	Mt. Malcolm	....	·213	6 136·16	38·028	38·241	·260						
	Mt. Margaret	....	....	922·67	1·137	1·137	....						
North Coolgardie	Menzies	....	....	120·60	1·825	1·825	....	....	....	1 857·68	8·064	8·064	....
	Ularring	....	....	349·01	2·145	2·145	....						
	Niagara	....	....	174·35	·603	·603	....						
	Yerilla	....	....	1 213·72	3·491	3·491	....						
Broad Arrow	....	....	....	....	....	....	....	....	4·227	10 904·87	18·736	22·963	....
North-East Coolgardie	Kanowna	....	....	1 012·69	4·894	4·894	....	....	....	1 078·22	5·127	5·127	....
	Kurnalpi	....	....	65·53	·233	·233	....						
East Coolgardie	East Coolgardie	....	5·227	1 370 537·03	6 515·665	6 520·892	1 477·771	....	5·227	1 371 949·59	6 535·434	6 540·661	1 477·771
	Bulong	....	....	1 412·56	19·769	19·769	....						
Coolgardie	Coolgardie	....	1·888	6 018·50	21·926	23·814	....	....	1·888	7 691·17	29·167	31·055	....
	Kunanalling	....	....	1 672·67	7·241	7·241	....						
Yilgarn	....	....	....	....	....	....	....	....	·326	9 819·03	204·339	204·665	·045
Dundas	....	....	....	....	....	....	....	....	·500	152 258·69	1 140·186	1 140·686	742·223
Phillips River	....	....	....	....	....	....	....	....	....	78·23	·915	·915	....
South-West Mineral Field	....	....	....	....	....	....	....	....	....	....	....	....	....
Northampton Mineral Field	....	....	....	....	....	....	....	....	....	....	....	....	....
State Generally	....	....	....	....	....	....	....	....	....	....	1·182	1·182	....
Outside Proclaimed Goldfield	....	....	....	....	....	....	....	....	....	....	....	....	....
Total	....	....	....	....	....	....	....	....	13·027	1 629 519·27	8 573·862	8 586·889	2 261·029

TABLE III

Return showing total production reported to the Mines Department, and respective Districts and Goldfields from whence derived, to 31st December, 1973.

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	....	....	....	....	....	....	....	197·789	11·655	25 300·54	759·720	969·164	59·428
Pilbara	Marble Bar	483·062	142·506	359 195·47	10 564·972	11 190·540	1 045·761	810·067	233·204	511 899·42	14 780·236	15 823·507	1 079·381
	Nullagine	327·005	90·698	152 703·95	4 215·264	4 632·967	33·620						
Ashburton	....	....	....	....	....	....	....	288·283	15·006	6 916·33	90·617	393·906	1 305·455
Gascoyne	....	....	....	....	....	....	....	21·725	3·860	4 271·21	197·266	222·851	3·973
Peak Hill	....	....	....	....	....	....	....	105·372	171·175	795 636·62	10 038·284	10 314·831	118·009
East Murchison	Lawlers	221·544	73·823	2 055 146·12	25 749·984	26 045·351	848·153	280·939	691·665	12 832 044·31	113 716·923	114 689·527	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	1 760 849·54	29 731·182	30 362·057	707·085						
Murchison	Cue	160·036	283·352	6 925 354·34	43 657·704	44 101·092	8 548·605	802·141	1 856·553	15 755 079·67	188 603·882	191 262·576	16 331·263
	Meekatharra	457·405	583·467	2 379 094·85	40 824·941	41 865·813	164·191						
	Day Dawn	102·381	352·769	2 070 636·73	42 787·477	43 242·627	5 270·404						
	Mt. Magnet	82·319	636·965	4 379 993·75	61 333·760	62 053·044	2 348·063						
Yalgoo	....	....	....	....	....	....	....	56·477	101·502	452 664·54	8 236·183	8 394·162	47·372
Mt. Margaret	Mt. Morgans	111·191	292·434	1 238 443·67	22 333·909	22 737·534	181·374	366·729	1 103·921	11 701 660·60	154 580·996	156 051·646	8 175·802
	Mt. Malcolm	126·518	520·533	7 893 551·58	95 729·114	96 376·165	5 935·667						
	Mt. Margaret	129·020	290·954	2 569 665·35	36 517·973	36 937·947	2 058·761						
North Coolgardie	Menzies	52·773	219·168	1 987 264·53	44 623·803	44 895·744	1 218·623	151·123	621·652	3 801 317·67	80 568·037	81 340·812	2 255·904
	Ularring	4·033	227·041	548 224·33	13 932·328	14 163·402	693·202						
	Niagara	53·451	56·717	960 195·46	16 443·242	16 553·410	177·793						
	Yerilla	40·866	118·726	305 633·35	5 568·664	5 728·256	166·286						
Broad Arrow	....	....	....	....	....	....	....	684·367	881·715	1 460 518·05	23 525·713	25 091·795	177·393
North-East Coolgardie	Kanowna	3 314·052	424·115	1 057 176·03	19 649·725	23 387·892	94·903	3 713·342	682·491	1 072 318·50	20 248·566	24 644·399	95·298
	Kurnalpi	399·290	258·376	15 142·47	598·841	1 256·507	·395						
East Coolgardie	East Coolgardie	1 049·478	1 295·163	103 293 579·69	1 217 166·626	1 219 511·267	205 369·817	1 901·885	1 794·922	103 487 071·40	1 221 332·810	1 225 029·617	205 372·920
	Bulong	852·407	499·759	193 491·71	4 166·184	5 518·350	3·103						
Coolgardie	Coolgardie	535·383	696·713	3 078 146·09	48 256·693	49 488·789	1 694·486	582·719	879·720	3 455 930·57	56 172·481	57 634·920	1 718·531
	Kunanalling	47·336	183·007	377 784·48	7 915·788	8 146·131	24·045						
Yilgarn	....	....	....	....	....	....	....	68·389	199·828	8 448 830·27	76 367·941	76 636·158	6 734·308
Dundas	....	....	....	....	....	....	....	70·176	519·883	7 434 771·16	104 154·304	104 744·363	63 856·293
Phillips River	....	....	....	....	....	....	....	18·883	25·608	133 500·68	3 915·827	3 960·318	2 520·036
South-West Mineral Field	....	....	....	....	....	....	....	9·738	1·513	5 017·58	78·450	89·701	·472
Northampton Mineral Field	....	....	....	....	....	....	....	....	....	....	....	....	164·423
State Generally	....	....	....	....	....	....	....	37·351	34·582	27·43	318·546	390·479	1 015·922
Outside Proclaimed Goldfield	....	....	....	....	....	....	....	....	....	....	....	....	39·177
Total	....	....	....	....	....	....	....	10 450·149	9 925·635	171 408 077·46	2 078 224·700	2 098 600·484	314 112·368

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	135·591	....	135·591	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	29 221·389	....	29 221·389	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	36 204·373	58 195·767	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	12 017.468	37 600.957	49 618·425	13 552 548
1910	7 277·291	38 464·478	45 741·769	12 493 696
1911	4 989·690	37 649·056	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	200·489	22 631·509	22 831·998	7 237 018
1920	163·639	19 053·399	19 217·038	7 197 862
1921	223·035	16 999·914	17 222·949	5 885 052
1922	165·475	16 575·855	16 741·330	5 051 624
1923	184·562	15 507·497	15 692·059	4 464 372
1924	80·409	15 005·865	15 086·274	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	20 149·390	20 258·887	11 117 746
1935	306·951	19 880·732	20 187·683	11 404 298
1936	1 711·456	24 608·548	26 320·004	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	34 695·858	37 767·012	23 685 928
1940	2 229·512	34 829·707	37 059·219	25 393 006
1941	2 050·526	32 453·117	34 503·643	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	9 799 994
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	25 458·682	25 626·526	26 598 184
1954	96·081	26 358·675	26 454·756	26 627 236
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	27 109 868
1959	72·222	26 882·326	26 954·548	27 083 858
1960	64·342	26 552·728	26 617·070	26 743 322
1961	91·524	27 025·885	27 117·409	27 413 780
1962	141·179	26 588·160	26 729·339	26 871 460
1963	145·109	24 744·257	24 889·366	25 035 372
1964	95·516	22 076·504	22 172·020	22 299 886
1965	93·204	20 417·579	20 510·783	20 722 164
1966	45·475	19 511·666	19 557·141	19 765 287
1967	85·325	17 830·931	17 916·256	18 071 924
1968	28·580	15 887·163	15 915·743	16 785 723
1969	43·951	14 431·968	14 475·919	17 707 219
1970	49·089	10 576·110	10 625·199	11 069 049
1971	29·183	10 795·117	10 824·300	11 921 570
1972	....	10 850·502	10 850·502	16 042 688
1973	6·098	7 934·406	7 940·504	18 326 747
	361 002·089	1 785 593·558	2 146 595·647	1 139 377 117

	1972	1973
	$A	$A
Estimated Mint value of above production	1 102 096 289	1 109 600 296
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	13 774 877	24 597 617
Estimated Total	$A1 121 050 370	$A1 139 377 117
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	29 169 983	29 200 611
Gross estimated value of gold won	$A1 150 543 249	$A1 168 900 624

TABLE V

Quantity and Value of Minerals, other than Gold, Reported during the year 1973

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonnes	Metallic Content	Value $A
		ALUMINA			
M.L. 1SA	South-West	Alcoa of Australia (W.A.) Ltd.	1 199 058·28	....	75 527 700·00
M.L. 1SA	South-West	Alcoa of Australia (W.A.) Ltd.	530 070·65	....	33 388 600·00
			1 729 128·93	....	108 916 300·00 (*l*)
		BERYL (*g*) (*h*)		BeO Units	
M.C. 874	Yalgoo	Seleka Mining & Investments Ltd.	161·95	1 947·25	(*b*) 29 711·50
		BUILDING STONE (Quartz)			
M.C. 2110H	South-West	Snowstone Pty. Ltd.	2 449·67	....	22 128·80
		BUILDING STONE (Quartz Crystal)			
M.C. 2110H	South-West	Snowstone Pty. Ltd.	1 546·42	....	18 308·40
		BUILDING STONE (Spongolite)			
M.C. 1062H	South-West	Worth, H.	47·75	....	658·00
		BUILDING STONE (Quartzite)			
.C. 1158H, 1159H	South West	House, R. P.	770·16	....	5 070·00
		BUILDING STONE (Sandstone)			
M.C. 990H	South-West	Caporn, C. A.	16·26	....	96·00
		CLAYS (Bentonite)			
M.C. 1055H	South-West	Scott, J. W.	543·58	....	8 045·00
M.C. 1042H	South-West	Scott, M. E., W. T., R. J.	289·57	....	3 663·00
			833·15	....	(*a*) 11 708·00
		CLAYS* (Brick Pipe and Tile Clay)			
M.C. 1438H	South-West	Concrete Industries (Monier) Ltd.	49 705·01	....	48 920·00
Private Property	South-West	Swaby, F. W.	30 481·40	....	75 000·00
		†Unspecified Producers	53 126·04	....	50 770·00
			133 312·45	....	(*c*) 174 690·00
		CLAYS (Cement Clays)			
M.C. 788H	South-West	Bell Bros. Pty. Ltd.	18 613·98	....	51 296·00
M.C. 492H, etc.	South-West	Cockburn Cement Pty. Ltd.	16 348·78	....	40 226·45
			34 962·76	....	(*c*) 91 522·45
		CLAYS (Fireclay)			
M.L. 436H, 437H	South-West	Midland Brick Co. Pty. Ltd.	122 072·95	....	29 940·53
M.L. 435H	South-West	Midland Brick Co. Pty. Ltd.	20 947·84	....	4 903·50
M.C. 304H	South-West	Clackline Refractories Ltd.	2 641·72	....	5 200·00
M.C. 522H, 523H	South-West	Bridge, J. S. and T. D.	7 487·25	....	7 369·00
M.C. 1302H	South-West	Bridge, J. S.	65 879·46	....	64 839·00
			219 029·22	....	(*c*) 112 252·03
		CLAYS (White Clay—Ball Clay)			
M.C. 109H	South-West	H. L. Brisbane & Wunderlich Ltd.	548·67	....	(*c*) 6 480·00

* 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
		COAL			
C.M.L. 448, etc.	Collie	Griffin Coal Mining Co. Ltd.	595 855·40	....	3 077 764·06
C.M.L. 437, etc.	Collie	Western Collieries Ltd.	575 213·14	....	3 970 961·86
			1 171 068·54	....	7 048 725·92 (*e*)

TABLE V.—*Quantity and Value of Minerals, other than Gold, Reported during the Year 1973—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 Nickel Mining)			
				Cobalt Tonnes	
M.L. 150, etc.	Coolgardie	Western Mining Corporation Ltd.	....	111·94	399 890·88
M.C. 39W	Broad Arrow	Great Boulder Mines Ltd. and North Kalgurli Mines Ltd.	....	19·49	77 200·00
			....	131·43	(*f*) 477 090·88
		COPPER (Metallic By-Product Nickel Mining)			
				Copper Tonnes	
M.L. 150, etc.	Coolgardie	Western Mining Corporation Ltd.	....	371·76	(*f*) 434 800·00
		COPPER ORE AND CONCENTRATES (*g*) (*h*)			
				Copper Units	
M.C. 97P	Peak Hill	Group Explorations Pty. Ltd.	26·42	858·56	6 980·00
M.C. 2577	Kimberley	Husche, H.	8·99	159·34	1 454·00
			35·41	1 017·90	(*a*) 8 434·00
		FELSPAR			
M.L. 80, etc.	Coolgardie	Australian Glass Manuf. Co. Pty. Ltd.	318·02	....	(*a*) 4 695·00
		GLASS SAND			
M.C. 417H, 418H	South-West	Australian Glass Manuf. Co. Pty. Ltd.	10 159·45	....	13 478·65
M.C. 521H	South-West	Bell Bros. Pty. Ltd.	1 634·82	....	2 413·50
M.C. 1074H, etc.	South-West	Ready Mix Group (W.A.)	58 783·39	....	N.A.
M.C. 6056H	South-West	Zaninovich, L. V.	73·15	....	28·80
M.C. 619H, etc.	South-West	Westralian Sands Ltd.	2 023·96	....	7 470·00
M.C. 1191H	South-West	Silicon Quarries Pty. Ltd.	149 994·94	....	116 594·50
			222 669·71	....	(*c*) 139 985·45
		GYPSUM			
M.C. 30, etc.	Yilgarn	Ajax Plaster Co. Pty. Ltd.	8 735·97	....	17 001·00
M.C. 50	Yilgarn	H. B. Brady & Co. Pty. Ltd.	16 851·49	....	41 532·50
M.C. 9, etc.	Yilgarn	West Australian Plaster Mills	22 690·89	....	46 886·19
M.C. 43, etc.	Gascoyne	Garrick Agnew Pty. Ltd.	114 646·67	....	394 927·00
M.C. 485H, etc.	South-West	Swan Portland Cement	1 064·71	....	2 650·03
M.C. 1419	South-West	Forsyth, V.	40·64	....	80·00
M.C. 12, etc.	Dundas	McDonald and Whitfield	224·55	....	221·00
			164 254·92	....	(*a*) 503 297·72

Plaster of Paris reported as manufactured during the year being 32 743·13 tonnes from 46 861·10 tonnes of gypsum by three companies.

Gypsum used in the manufacture of cement = 2 923·06 tonnes.

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonnes	Metallic Content	Value $A
		IRON ORE (Pig Iron)			
			Ore Treated Tonnes	Pig Iron Recovered Tonnes	
M.L. 2SA	Yilgarn	Charcoal Iron and Steel Industry	96 819·11	58 077·24	3 844 002·00 (*c*) (*d*)
		IRON ORE (Ore railed to Kwinana)			
				Av. Assay Fe %	
M.L. 2SA	Yilgarn	Dampier Mining Co. Ltd.	*2 573 130·65	63·00	18 951 065·00 (*n*)
		IRON ORE (Ore shipped to Eastern States)			
M.L. 10, etc.	West Kimberley	Dampier Mining Co. Ltd.	351 011·69	66·41 }	2 483 692·00
M.L. 50/60	West Kimberley	Dampier Mining Co. Ltd.	9 498·01	66·90 }	(*n*)
M.L. 244SA	Peak Hill	Mt. Newman Mining Co. Pty. Ltd.	2 754 997·96	64·00	16 252 446·00 (*b*)
		IRON ORE (Ore exported Overseas)			
M.L. 50/60	West Kimberley	Dampier Mining Co. Ltd.	1 836 571·83	66·87	10 645 311·00 (*b*)
M.L. 10, etc.	West Kimberley	Dampier Mining Co. Ltd.	682 273·46	66·67	4 005 265·00 (*b*)
T.R. 2401H	West Pilbara	Cliffs W.A. Mining Co. Pty. Ltd.	4 395 969·59	57·60	16 687 173·00 (*b*)
M.L. 4SA	West Pilbara	Hamersley Iron Pty. Ltd.	25 068 955·25	64·11	144 388 923·80 (*b*)
M.L. 235SA	Pilbara	Goldsworthy Mining Ltd.	8 294 960·15	63·22	48 950 502·00 (*b*)
M.L. 244SA	Peak Hill	Mt. Newman Mining Co. Pty. Ltd.	23 300 503·66	63·00	136 798 974·00 (*b*)
M.C. 876H, etc.	South-West	Western Mining Corporation Ltd.	788 521·48	59·46	5 167 026·00 (*b*)
			70 056 393·73	....	404 330 377·80

* Includes 1 466 340·60 W.L. Tonnes shipped to Eastern States.

TABLE V.—*Quantity and Value of Minerals, other than Gold, Reported during the Year 1973—continued*

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonnes	Metallic Content	Value $A
		IRON ORE—Pellets (Exported Overseas)			
M.L. 4SA	West Pilbara	Hamersley Iron Pty. Ltd.	2 073 527·49	63·72	17 979 062·30 (b)
T.R. 2401H	West Pilbara	Cliffs W.A. Mining Co. Pty. Ltd.	3 766 560·03	62·45	32 364 800·00 (b)
			5 840 087·52	....	50 343 862·30
		LEAD ORES AND CONCENTRATES (g) (h)		Lead Tonnes	
M.L. 268	Northampton	Tycho Mining Pty. Ltd.	73·31	58·65	9 000·00
M.C. 76	Northampton	Mitchell, G. H. & J. M.	73·46	41·49	8 512·85
			146·77	100·14	(b) 17 512·85
		* LIMESTONE (For Building, Burning Purposes, etc.)			
M.C. 1662H	South-West	Bell Bros. Pty. Ltd.	44 560·77	....	35 985·60
M.C. 1290H	South-West	V. Bellombra	2 274·93	....	6 493·10
M.C. 1988H, 1989H	South-West	Cockburn Cement Ltd.	22 199·61	....	21 849·00
M.C. 3343H	South-West	J. D. Clarkson	213 486·69	....	210 115·00
M.C. 1542H	South-West	Caroleo, R. D.	7 663·02	....	7 542·00
M.C. 1227H	South-West	Korsunski, G.	195 254·24	....	96 085·75
M.C. 2133H	South-West	List, F. & Sons	132·09	....	52·00
M.C. 1386H	South-West	Marks, H. O.	20 355·48	....	10 017·00
M.C. 1093H	South-West	Menchetti, E. N.	108·71	....	107·00
M.C. 1105H, 1702H	South-West	Moore, F. W.	2 101·18	....	4 136·00
M.C. 1093H	South-West	Multari, N.	103·64	....	331·50
M.C. 709H	South-West	Snader, R.	10 929·62	....	5 378·50
M.C. 713H	South-West	Steel Bros. Aust.	4 149·53	....	2 654·60
M.C. 1660H	South-West	Swan Portland Cement Ltd.	271 120·88	....	430 580·32
M.C. 1284H	South-West	W.A. Limestone Co.	31 466·97	....	46 454·00
M.C. 727H	South-West	Thiess Bros. Pty. Ltd.	22 621·27	....	6 679·20
	South-West	†Unspecified Producers	504 326·05	....	540 765·00
			1 352 854·68	....	1 425 225·57 (c)
		*LIMESTONE (For Agricultural Purposes)			
M.C. 1298H	South-West	Cable, D. K.	447·06	....	440·00
M.C. 50	Dundas	Esperance Lime Supply	277·38	....	1 092·00
			724·44	....	(c) 1 532·00

* 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
		LITHIUM ORES (Petalite)		Li20 Units	
M.L. 80, etc.	Coolgardie	Australian Glass Manuf. Co.	221·50	930·29	(a) 3 466·20
		MANGANESE (Metallurgical Grade)		Av. Assay Mn %	
M.C. 487	Pilbara	Westralian Ores Pty. Ltd.	26 306·47	48·31	(b) 428 000·00
		MINERAL BEACH SANDS (Ilmenite) (g)		Av. Assay TiO 2%	
Sussex Loc. 7	South-West	Cable (1956) Ltd.	30 539·58	54·00	N.A.
M.C. 746H, etc.	South-West	Ilmenite Minerals Pty. Ltd.	106 860·33	53·99	N.A.
M.L. 389, etc.	South-West	Western Mineral Sands Pty. Ltd.	194 229·56	54·00	N.A.
M.C. 619H, etc.	South-West	Westralian Sands Pty. Ltd.	175 483·32	57·16	N.A.
M.C. 516H, etc.	South-West	Western Titanium N.L.	210 321·00	54·86	N.A.
			717 433·79	55·02	9 169 702·59 (b)
		MINERAL BEACH SANDS (Upgraded Ilmenite) (g)			
M.C. 516H, etc.	South-West	Western Titanium N.L.	13 061·34	91·10	N.A.
		MINERAL BEACH SANDS (Reduced Ilmenite) (g)			
M.C. 516H, etc.	South-West	Western Titanium N.L.	605·56	65·86	N.A.
		MINERAL BEACH SANDS (Rutile) (g) (h)		TiO2 Tonnes	
M.C. 516H, etc.	South-West	Western Titanium N.L.	1 910·57	98·09	(b) 193 932·61

TABLE V.—*Quantity and Value of Minerals, other than Gold, Reported during the Year 1973—continued*

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonnes	Metallic Content	Value $A
		MINERAL BEACH SANDS (Leucoxene) (*g*) (*h*)			
				TiO_2 Tonnes	
Sussex Loc. 7	South-West	Cable (1956) Ltd.	1 038·65	914·19	78 190·50
M.C. 746H, etc.	South-West	Ilmenite Minerals Pty. Ltd.	3 115·96	2 742·60	234 571·50
M.C. 516H, etc.	South-West	Western Titanium N.L.	1 135·01	1 029·69	78 329·00
M.C. 619H, etc.	South-West	Westralian Sands Ltd.	10 105·91	8 955·29	716 097·00
			15 395·53	13 641·78	1 107 188·00 (*b*)
		MINERAL BEACH SANDS (Monazite) (*g*) (*h*)			
				ThO_2 Units	
Sussex Loc. 7	South-West	Cable (1956) Ltd.	96·02	644·68	13 209·75
M.C. 746H, etc.	South-West	Ilmenite Minerals Pty. Ltd.	288·05	1 934·04	39 629·25
M.C. 516H, etc.	South-West	Western Titanium N.L.	1 366·73	8 802·01	166 749·25
M.C. 619H, etc.	South-West	Westralian Sands Ltd.	1 264·84	8 221·43	175 210·00
			3 015·63	19 602·18	(*b*) 394 798·25
		MINERAL BEACH SANDS (Zircon) (*g*) (*h*)			
				ZrO_2 Tonnes	
Sussex Loc. 7	South-West	Cable (1956) Ltd.	6 254·33	4 068·05	193 302·15
M.C. 746H, etc.	South-West	Ilmenite Minerals Pty. Ltd.	18 762·98	12 205·03	581 754·95
M.C. 516H, etc.	South-West	Western Titanium N.L.	27 628·33	18 176·10	652 050·75
M.C. 619H, etc.	South-West	Westralian Sands Ltd.	37 051·72	24 268·89	1 247 035·00
			89 697·36	58 718·07	2 674 142·85 (*b*)
		MINERAL BEACH SANDS (Xenotime) (*g*) (*h*)			
				Y_2O_3 kg	
M.C. 516H, etc.	South-West	Western Titanium N.L.	45·24	13 863·96	(*b*) 31 925·92
		NICKEL CONCENTRATES			
				Av. Assay Ni%	
M.L. 150, etc.	Coolgardie	Western Mining Corporation Ltd.	249 343·42	13·58	79 676 000·00
M.C. 39W	Broad Arrow	Great Boulder Mines Ltd. and North Kalgurli Mines Ltd.	18 365·93	19·18	7 757 400·00
M.C. 41Z	North Coolgardie	Great Boulder Mines Ltd. and North Kalgurli Mines Ltd.	3 922·30	9·93	893 400·00
			271 631·65	....	88 326 800·00 (*o*)
		NICKEL ORE			
				Av. Assay Ni%	
M.C. 1288, M.L. 248	Coolgardie	Metals Exploration N.L.	80 866·19	3·05	4 497 262·86
M.L. 246, 283	Coolgardie	Anaconda Australia Inc.	674·65	1·06	8 500·00
			81 540·84	3·03	4 505 762·86
		PALLADIUM (*h*) (Metallic By-Product Nickel Mining)			
				kg	
M.L. 150, etc.	Coolgardie	Western Mining Corporation Ltd.	....	23·37	41 000·00
		PLATINUM (*h*) (Metallic By-Product Nickel Mining)			
				kg	
M.L. 150, etc.	Coolgardie	Western Mining Corporation Ltd.	....	6·97	23 900·00
		PETROLEUM (Crude Oil)			
			Barrels		
1H	Ashburton	West Australian Petroleum Pty. Ltd.	14 578 230·00	....	32 509 452·90 (*m*)
		PETROLEUM (Natural Gas)			
			M.C.F.		
Lic. 1	South-West	West Australian Petroleum Pty. Ltd.	28 677 043·00	....	5 161 867·74 (*p*)
		PETROLEUM (Condensate)			
			Barrels		
Lic. 1	South-West	West Australian Petroleum Pty. Ltd.	30 310·00	....	N.A.
		SALT			
		State Total (Reported to Mines Department)	3 333 937·42	....	9 837 959·00 (*b*)

TABLE V.—*Quantity and Value of Minerals, other than Gold, Reported during the Year 1973—continued*

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonnes	Metallic Content	Value $A
		SEMI PRECIOUS STONES (Amethyst)			
M.C. 444	Gascoyne	Soklich, F.	kg 2 321·49	....	1 651·90
		SEMI PRECIOUS STONES (Chalcedony)			
M.C. 498, etc.	Gascoyne	Soklich, F.	kg 948·00	....	758·00
		SEMI PRECIOUS STONES (Moss Opal)			
M.C. 60	Dundas	Soklich, F.	kg 12 008·40	....	5 225·20
		SEMI PRECIOUS STONES (Quartz)			
P.A. 395	Pilbara	Soklich, D.	kg 20 241·11	....	7 354·30
		SEMI PRECIOUS STONES (Tourmaline)			
M.C. 346	Gascoyne	Soklich, D.	kg 207·29	....	466·90
		SEMI PRECIOUS STONES (Tiger Eye)			
M.C. 3023WP	West Pilbara	Sterpini, M.	kg 1 542·21	....	4 973·67
		SILVER			
		By-Product Gold Mining	kg 7 919·76	....	437 446·80
		TALC			
M.C. 190P....	Peak Hill	Westside Mines N.L.	400·32	....	N.A.
M.L. 433H	South-West	Three Springs Talc Pty. Ltd.	36 788·01	....	N.A.
			37 188·33	....	N.A.
		TANTO COLUMBITE ORES AND CONCENTRATES (*g*) (*h*)			
M.L. 660, etc.	Greenbushes	Greenbushes Tin N.L.	272·59	Ta205 Units 9 002·62	718 167·16 (*b*)
		TIN CONCENTRATES (*g*) (*h*)		Sn Tonnes	
M.L. 660, etc.	Greenbushes	Greenbushes Tin N.L.	780·13	560·97	1 721 209·00
M.L. 647, etc.	Greenbushes	Vultan Minerals Ltd.	98·70	68·85	206 987·00
D.C. 497	Pilbara	J. M. Henderson & Sons	4·38	3·04	7 475·22
M.C. 1348, 1349	Pilbara	Johnston, J. A.	100·07	71·59	220 459·00
M.C. 5433	Pilbara	McLeod, D. W.	2·68	1·88	5 681·00
D.C. 53, etc.	Pilbara	Marshall, W.	11·16	7·82	23 265·60
M.C. 700	Pilbara	Edwards, M. R.	6·00	4·09	11 791·15
D.C. 195, etc.	Pilbara	Pilbara Tin Pty. Ltd.	184·65	129·25	397 793·31
	Pilbara	Crown Lands—District Generally	8·25	5·83	16 824·37
M.C. 305WP	West Pilbara	Yule River Mining Pty. Ltd.	19·51	14·19	41 937·00
			1 215·53	867·51	2 653 422·65 (*b*)
		VERMICULITE			
M.C. 965	Yilgarn	Mineral By-Products Pty. Ltd.	426·10	....	3 564·65 (*a*)

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 Dept. of Mines based on the price for Alumina F.O.B. Jamaica.
(*m*) Value based on the price per barrel as assessed by the Tariff Board for Barrow Island Crude Oil at Kwinana.
(*n*) Nominal value.
(*o*) Estimated nominal 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.

TABLE VI

TOTAL MINERAL OUTPUT OF WESTERN AUSTRALIA

Recorded mineral production of the State to 31st December, 1973, 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)	”	7 594 542·11	474 710 940·00
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	”	8 941·44	125 551·90
Bauxite (Crude Ore) (*g*)	”	37 330·58	187 069·50
Beryl	”	4 019·69	1 015 633·00
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	”	8·48	146·00
Prase	”	9·65	275·00
Quartz (Dead White)	”	1 617·78	33 914·00
Quartz Crystal	”	1 759·79	21 500·40
Quartz	”	21 591·93	242 990·35
Quartzite	”	10 025·33	44 569·00
Sandstone	”	680·75	4 020·00
Sandstone (Donnybrook)	”	84·33	3 486·00
Slate	”	238·77	2 115·00
Spongolite	”	3 814·74	41 424·00
Tripolite	”	268·24	264·00
Calcite	”	5·08	50·00
Chromite	”	14 650·43	416 593·50
Clays—			
Brick, Pipe and Tile Clays	”	1 040 146·44	1 556 155·16
Bentonite	”	13 266·34	91 254·52
Cement Clays	”	486 971·92	875 072·91
Fireclay	”	1 360 121·17	1 521 556·59
Fullers Earth	”	466·77	3 821·00
White Clay—			
Ball Clay	”	29 995·34	204 565·60
Kaolin	”	6 511·83	24 739·97
Coal	”	44 520 366·22	150 556 825·92
Cobalt (Metallic By-Product Nickel Mining)	”	1 048·93	3 361 075·88
Copper (Metallic By-Product Nickel Mining)	”	5 855·04	5 095 938·00
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	18 799·68	4 642·00
Emery	tonne	21·49	750·00
Felspar	”	73 418·13	549 080·06
Fergusonite	”	·30	782·80
Gadolinite	”	1·02	224·00
Glass Sand	”	930 642·96	(*g*) 646 724·78
Glauconite	”	(*h*) 6 570·77	300 769·00
Gold (Mint and Export)	kg	2 146 595·66	1 139 377 117·00
Graphite	tonne	155·66	2 608·40
Gypsum	”	1 722 922·55	4 133 149·22
Iron Ore—			
Pig Iron Recovered	”	920 096·60	46 351 346·12
Ore Exported	”	269 616 711·95	1 753 102 929·05
Pellets Exported	”	15 794 079·37	150 225 739·33
Locally Used Ore	”	10 441 498·43	61 425 944·00
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	”	9 436 722·27	9 754 552·19
Lithium Ores—			
Petalite	”	8 040·97	124 107·40
Spodumene	”	108·29	3 627·20
Magnesite	”	31 350·76	335 422·86
Manganese—			
Metallurgical Grade	”	1 897 834·96	40 864 952·08
Battery Grade	”	2 253·85	90 860·20
Low Grade	”	5 135·47	81 538·20
Mica	kg	14 936·79	7 968·48

TABLE VI.—Total Mineral Output of Western Australia—*continued*

Mineral		Quantity	Value $A
Mineral Beach Sands—			
Ilmenite Concentrates	tonne	6 165 931·22	63 523 260·52
Monazite Concentrates	,,	26 998·21	3 176 727·29
Rutile	,,	15 378·38	1 272 497·80
Leucoxene	,,	66 969·41	4 012 377·14
Zircon	,,	431 649·08	12 033 574·95
Xenotime	,,	176·30	191 853·24
Crude Concentrates (Mixed)	,,	158·45	1 553·00
Molybdenite	,,	78·74	1 730·00
Nickel Concentrates	,,	1 196 443·12	373 793 714·00
Nickel Ore	,,	279 674·16	12 776 180·41
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.	91 426 671·00	254 011 715·63
(Natural Gas)	m.c.f.	53 365 242·00	8 496 829·61
(Condensate)	bbls.	73 939·00	N.A.
Palladium (By-Product Nickel Mining)	kg	33·35	50 656·00
Platinum (By-Product Nickel Mining)	,,	66·74	216 285·00
Pnosphatic 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
Salt	,,	10 388 608·80	32 082 275·00
Semi Precious Stones—			
Amethyst	kg	25 271·63	20 534·34
Beryl (coloured)	,,	90·72	100·00
Chalcedony	,,	72 266·79	27 872·30
Chrysoprase	,,	122 202·34	121 142·00
Dravite	,,	8 640·03	15 593·78
Magnesite	,,	5 072·98	2 780·00
Moss Opal	,,	65 178·96	25 506·63
Moss Agate	,,	16 256·75	4 800·00
Opaline	,,	11·34	7·50
Prase	,,	3 955·33	729·50
Quartz	,,	28 633·02	11 789·10
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	425 117·60	9 047 954·69
Soapstone	tonne	574·48	3 855·70
Talc	,,	259 479·28	(*g*) 4 719 451·65
Tanto/Columbite Ores and Concentrates	,,	1 974·66	4 463 985·04
Tin	,,	31 532·92	27 750 774·41
Tungsten Ore and Concentrates—			
Scheelite	,,	171·87	143 424·24
Wolfram	,,	309·84	125 810·16
Vermiculite	,,	3 028·03	31 613·13
Zinc (Metallic By-Product) (*d*)	,,	2 934·08	(*j*)
Zinc Ore (Fertiliser)	,,	20·32	200·00
Total Value to 31st December, 1973			$4 738 395 147·08

(*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 Tariff Board 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.

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TABLE VII

Showing average number of men employed above and below ground in the larger mining companies operating in Western Australia during 1972 and 1973.†

Company	1972			1973		
	Above	Under	Total	Above	Under	Total
Gold*—						
Central Norseman Gold Corporation N.L.	128	91	219	112	85	197
Hill 50 Gold Mine N.L.	60	52	112	52	51	103
‡Gold Mines of Kalgoorlie (Aust.) Ltd. (Boulder) .... } ‡Lake View & Star Ltd.	579	407	986	....	....	....
Kalgoorlie Lake View Pty. Ltd. (Boulder)	....	....	....	558	387	945
‡Gold Mines of Kalgoorlie (Aust.) Ltd. (Mt. Charlotte)	14	128	142	....	....	....
Kalgoorlie Lake View Pty. Ltd. (Mt. Charlotte)	....	....	....	16	132	148
North Kalgurli Mines Ltd.	126	127	253	117	98	215
All Other Operators	159	111	270	232	161	393
State Average	1 066	916	1 982	1 087	914	2 001
Alumina (from Bauxite)—						
Alcoa of Australia (W.A.) N.L.	1 671	....	1 671	1 798	....	1 798
Coal—						
Griffin Coal Mining Co. Ltd.	174	....	174	174	....	174
Western Collieries Ltd.	132	311	443	137	308	445
Iron Ore—						
Charcoal Iron & Steel	11	....	11	11	....	11
Dampier Mining Co. Ltd.	373	....	373	459	....	459
Goldsworthy Mining Ltd.	457	....	457	625	....	625
Hamersley Iron Pty. Ltd.	985	....	985	1 549	....	1 549
Mt. Newman Mining Co. Pty. Ltd.	804	....	804	997	....	997
Western Mining Corporation	92	....	92	72	....	72
Cliffs Western Australian Mining Co. Pty. Ltd.	104	....	104	173	....	173
Mineral Beach Sands—						
Cable (1956) Ltd.	5	....	5	4	....	4
Ilmenite Minerals Pty. Ltd.	54	....	54	53	....	53
Western Mineral Sands Pty. Ltd.	45	....	45	44	....	44
Westralian Sands Ltd.	71	....	71	84	....	84
Western Titanium N.L.	159	....	159	152	....	152
Nickel—						
Anaconda Australia Inc.	12	14	26	5	3	8
Great Boulder Gold Mines Limited and North Kalgurli Mines Ltd.	264	67	331	269	110	379
Metals Exploration N.L.	70	116	186	89	125	214
Western Mining Corporation	763	498	1 261	780	600	1 380
Petroleum—Crude Oil—						
West Australian Petroleum Pty. Ltd.	133	....	133	158	....	158
Salt—						
Dampier Salt Limited	89	....	89	114	....	114
Lefroy Salt Co.	....	....	....	16	....	16
Leslie Salt Co.	28	....	28	36	....	36
Texada Mines Pty. Limited	173	....	173	270	....	270
All Other Minerals	280	10	290	279	....	279
State Total—Other than Gold	6 949	1 016	7 965	8 348	1 146	9 494

* 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.

‡ Became Kalgoorlie Lake View Pty. Ltd. late 1973.

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