DEPARTMENT OF MINES ANNUAL REPORT 1974

DEPARTMENT OF MINES

Annual Report

1974

REPORT OF THE

DEPARTMENT *of* MINES

WESTERN AUSTRALIA

FOR THE YEAR 1974

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

By Authority: WILLIAM C. BROWN, Government Printer
1975

48396/7/75

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 1974, *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, 1975.

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WESTERN AUSTRALIA

Report of the Department of Mines for the Year 1974

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 1974.

The estimated value of the mineral output of Western Australia (including gold, coal and petroleum) for the year was $952.0 million, an increase of almost $198 million compared with the figure for the previous year. This was an increase of about 26 per cent and the total an all-time record, due in the main to increase in the value of iron ore, nickel and alumina.

To the end of 1974 the progressive value of the whole mineral production of the State amounted to $5 690 million of which gold accounted for $1 161.7 million. Ten years ago the relevant figures were $1 253 million and $989 million respectively, when gold represented 80 per cent of the total. Today it is only 20 per cent.

ROYALTIES

Royalty revenue collected during the year amounted to $36.3 million, an increase of $5.2 million above the previous year's figure. Iron ore royalties accounted for $33.1 million, 91 per cent of the total. 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 75.8 million tonnes in 1973 to 87 million tonnes in 1974, an increase of 14.8 per cent. The value of the iron ore rose from $454.6 million in 1973 to $589.1 million in 1974, representing a rise of 29 per cent, due not only to some higher prices received and increased sales but also a more favourable exchange rate in the last quarter of the year.

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 1974 increased by 252 000 tonnes to 1.98 million tonnes, worth an estimated $124.8 million.

NICKEL

The total value of nickel in concentrates and nickel briquettes and powder amounted to an estimated $126.3 million compared with $92.8 million in 1973. Nickel concentrates and nickel ore produced during the year increased by 96 600 tonnes and 12 700 tonnes respectively above the figures for 1973.

The price per lb quoted by International Nickel Company Limited for four inch square electrolytic nickel cathodes F.O.B. Fort Colborne, Canada (the price upon which nickel royalties are calculated) had remained constant at $US1.53 per lb from 4th September, 1972, to 4th January, 1974, when it was increased to $US1.62. Further increases (to $US1.85 on 28th June, 1974, and $US2.01 on 20th December, 1974) have since occurred.

PETROLEUM
(Crude Oil and Natural Gas)

Sales of oil from Barrow Island during 1974 were down slightly from 14.6 million barrels valued at $32.5 million in 1973 to 13.8 million barrels valued at $31.2 million in 1974.

The Dongara and Mondarra gas fields supplied a total of 831.6 million cubic metres of natural gas valued at $5.3 million to sales outlets in Perth-Fremantle-Kwinana-Pinjarra area.

Offshore exploration in 1974 was centred mainly on the North West Shelf but activity was at a greatly reduced level. The West Tryal Rocks No. 2 appraisal well enhanced the possibility of economic gas production from that field. Three locations were declared over the Angel, North Rankin and Goodwyn Fields as a first stage towards the application for production licences. The combined raw gas reserves of these fields are about 12 million million cubic feet (about 340 thousand million cubic metres).

Onshore exploration activity was also at a reduced level compared with 1973 and no new discoveries of hydrocarbons were made.

GOLD

The estimated value of gold received at the Perth Mint during 1974 was $22 324 330, an increase of $3 997 583 compared with the figure for 1973. This increase in value was due solely to the high prices obtained on the free market, as the quantity of gold won decreased by 1 309 kg from 7 940 kg in 1973 to 6 631 kg in 1974.

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 of Part 2. The quantity of auriferous ore treated was 1 379 000 tonnes being 250 000 less than in 1973.

Western Australian gold included in sales on overseas premium markets by the Gold Producers' Association Ltd. for the period November, 1973 to October, 1974, was 6 593.515 kg. The premium received in excess of the Mint value amounted to $16 010 063, an overall average of $2 428.153 0 per kg compared with an average of $1 124.365 7 per kg for the period from October, 1972, to October, 1973.

No subsidy was paid during the year by the Commonwealth Government under the Gold Mining Industry Assistance Act. Only $30 627 was paid in 1973 and that was prior to July of that year. While very high prices for gold have been obtained on the free market, it is apparent that no Western Australian gold producer has qualified for the subsidy since July, 1973.

COAL

Coal production from Collie during the year showed an increase of 274 979 tonnes over that for 1973, and the overall average value per tonne rose by 30.5 cents.

During 1974 a shipment of 10 000 tonnes was exported to Taiwan.

Figures for the last three years were:—

	1972	1973	1974
Tonnes	1 167 540	1 171 069	1 446 048
Total Value	$5 907 162	$7 048 726	$9 144 982
Average Value per Tonne	$5·0595	$6·019 0	$6·324 1
Average Effective Workers	617	619	685
Proportion of Deep Mined Coal	36·19%	36·08%	33·95%

OTHER MINERALS

Other minerals to yield over a million dollars for the year were: Salt $11.6 million, Ilmenite $11.2 million, Zircon $5 million, Tin Concentrates $2.9 million, Leucoxene $1.6 million, Rutile $1.5 million and Limestone $1.3 million, while Pig Iron valued at $3.9 million was produced by the Charcoal Iron and Steel Industry at Wundowie.

OUTLOOK

The mineral production continues to grow: iron ore output increased by 16 per cent (70 million tonnes to 81.4 million tonnes) in 1974 over the previous year's production; alumina was up 252 000 tonnes; ilmenite, 138 000; coal, 275 000; nickel concentrates, 96 626 and salt, 572 000 compared with the previous year's figures. This has been achieved despite industrial unrest and unfavourable Commonwealth Government policies. These difficulties coupled with increasing cost inflation however, do not augur well for the ensuing year, and may well retard expansion of established mines and commencement of new projects.

Nevertheless, with its great mineral potential and mining expertise, the industry in Western Australia is soundly based and will in the long term progress as it has in the past.

PART 2—COMPARATIVE STATISTICS

TABLE 1

SUMMARY

Mineral Production : Quantity, Value, Persons Engaged

	1973	1974	Variation
IRON ORE—			
Tonnes	75 954 558	**87 054 190**	+ 11 099 632
Value ($A)	$458 518 242	**$593 051 596**	+ $134 533 354
Persons Engaged	3 886	**4 050**	+ 164
ALUMINA—			
Tonnes	1 729 129	**1 981 205**	+ 252 076
*Value ($A)	$108 916 300	**$124 800 000**	+ 15 883 700
Persons Engaged	1 798	**1 965**	+ 167
NICKEL—			
Tonnes (ore and concentrates)	353 172	**437 049**	+ 83 877
Value ($A)	$92 832 563	**$126 292 134**	+ $33 459 571
Persons Engaged	1 981	**2 090**	+ 109
PETROLEUM—CRUDE OIL—			
Barrels	14 578 230	**13 801 191**	— 777 039
†Value ($A)	$32 509 453	**$31 257 312**	— $1 252 141
Persons Engaged	158	**146**	— 12
GOLD—			
Reported to Department (Mine Production)—			
Ore treated (tonnes)	1 629 519	**1 378 991**	— 250 528
Gold (Kilograms)	8 587	**6 583**	— 2 004
Average Grade (grams per tonne)	6·3	**4·8**	— 1·5
Persons Engaged	2 001	**2 027**	+ 26
Mint and Export (Realised Production)—			
Gold (Kilograms)	7 940	**6 631**	— 1 309
Estimated Value ($A) (including Overseas Gold Sales Premium)	$18 326 747	**$22 324 330**	+ $3 997 583
COAL—			
Tonnes	1 171 069	**1 446 048**	+ 274 979
Value ($A)	$7 048 726	**$9 144 982**	+ $2 096 256
Persons Engaged	619	**685**	+ 66
MINERAL BEACH SANDS—			
Tonnes	841 166	**972 009**	+ 130 843
Value ($A)	$13 571 690	**$19 818 642**	+ $6 246 952
Persons Engaged	337	**550**	+ 213
OTHER MINERALS—			
Value ($A)	$22 463 344	**$25 329 542**	+ $2 866 198
Persons Engaged	715	**755**	+ 40
TOTAL ALL MINERALS—			
Value ($A)	$754 187 065	**$952 018 538**	+ $197 831 473
Persons Engaged	11 495	**12 268**	+ 773

* 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 1973 *and* 1974

Western Australia

Mineral	1973		1974		Increase or Decrease for Year Compared with 1973	
	Quantity	Value	Quantity	Value	Quantity	Value
	Tonnes	$	Tonnes	$	Tonnes	$
Alumina (from Bauxite)	1 729 129	108 916 300	**1 981 205**	**124 800 000**	+ 252 076	+ 15 883 700
Beryl	162	29 711	**79**	**14 124**	— 83	— 15 587
Building Stone (Quartzite)	770	5 070	**608**	**5 850**	— 162	+ 780
(Quartz)	2 450	22 129	**4 206**	**110 765**	+ 1 756	+ 88 636
(Quartz Crystal)	1 546	18 308	**70**	**3 467**	— 1 476	— 14 841
(Lepidolite)	....	....	**76**	**567**	+ 76	+ 567
(Sandstone)	16	96	....	....	— 16	— 96
(Spongolite)	48	658	**79**	**1 092**	+ 31	+ 434
Clays (Bentonite)	833	11 708	**569**	**7 869**	— 264	— 3 839
(Cement Clay)	34 963	91 522	**34 975**	**95 670**	+ 12	+ 4 148
(Fire Clay)	219 029	112 252	**220 943**	**88 576**	+ 1 914	— 23 676
(White Clay—Ball Clay)	549	6 480	**719**	**6 881**	+ 170	+ 401
(Brick, Pipe and Tile Clay)	133 312	174 690	**310 893**	**309 863**	+ 177 581	+ 135 173
Coal	1 171 069	7 048 726	**1 446 048**	**9 144 982**	+ 274 979	+ 2 096 256
Cobalt (By-product of Nickel Mining)	131	477 091	**135**	**608 308**	+ 4	+ 131 217
Copper (By-product of Nickel Mining)	372	434 800	**267**	**341 520**	— 105	— 93 280
Copper Ore and Concentrates	35	8 434	....	....	— 35	— 8 434
	Carats		Carats		Carats	
Emeralds (cut)	....	....	**19**	**1 400**	+ 19	+ 1 400
	Tonnes		Tonnes		Tonnes	
Felspar	318	4 695	**880**	**17 487**	+ 562	+ 12 792
Glass Sand	222 670	139 985	**280 670**	**306 075**	+ 58 000	+ 166 090
Gypsum	164 255	503 298	**162 136**	**460 667**	— 2 119	— 42 631
Iron Ore (Pig Iron Recovered)	58 077	3 844 002	**53 378**	**3 906 401**	— 4 699	+ 62 399
(Exported and locally used)	70 056 394	404 330 378	**81 442 070**	**534 996 420**	+ 11 385 676	+ 130 666 042
(Pellets)	5 840 087	50 343 862	**5 558 742**	**54 148 775**	— 281 345	+ 3 804 913
Lead Ore and Concentrates	147	17 513	....	....	— 147	— 17 513
Limestone	1 353 579	1 426 758	**1 157 315**	**1 275 064**	— 196 264	— 151 694
Lithium Ores (Petalite)	222	3 466	**1**	**16**	— 221	— 3 450
Manganese (Metallurgical Grade)	26 306	428 000	**18 107**	**336 655**	— 8 199	— 91 345
Mica	....	....	**34**	**418**	+ 34	+ 418
Mineral Beach Sands (Ilmenite)	731 101	9 169 702	**868 697**	**11 237 932**	+ 137 596	+ 2 068 230
(Monazite)	3 016	394 798	**2 662**	**386 461**	— 354	— 8 337
(Rutile)	1 911	193 933	**11 275**	**1 515 196**	+ 9 364	+ 1 321 263
(Leucoxene)	15 396	1 107 188	**15 668**	**1 635 905**	+ 272	+ 528 717
(Zircon)	89 697	2 674 143	**73 681**	**5 022 111**	— 16 016	+ 2 347 968
(Xenotime)	45	31 926	**26**	**21 037**	— 19	— 10 889
Nickel Concentrates	271 632	88 326 800	**368 258**	**121 458 359**	+ 96 626	+ 33 131 559
Nickel Ore	81 541	4 505 763	**68 791**	**4 833 775**	— 12 750	+ 328 012
	kg		kg		kg	
Palladium (By-product of Nickel Mining)	23	41 000	**164**	**428 700**	+ 141	+ 387 700
Platinum (By-product of Nickel Mining)	7	23 900	**60**	**227 200**	+ 53	+ 203 300
Ruthenium (By-product of Nickel Mining)	....	....	**5**	**7 300**	+ 5	+ 7 300
	bbls		bbls		bbls	
Petroleum—Crude Oil (barrels)	14 578 230	32 509 453	**13 801 191**	**31 257 312**	— 777 039	— 1 252 141
	$m^3 10^3$		$m^3 10^3$		$m^3 10^3$	
Natural Gas ($m^3 10^3$)	812 363	5 161 868	**831 604**	**5 285 738**	+ 19 241	+ 123 870
	Tonnes		Tonnes		Tonnes	
Condensate	3 756	N.A.	**4 284**	**N.A.**	+ 528	N.A.
Salt	3 333 937	9 837 959	**3 906 492**	**11 576 831**	+ 572 555	+ 1 738 872
	kg		kg		kg	
Semi-precious Stones	37 269	20 430	**27 746**	**30 875**	— 9 523	+ 10 445
	Tonnes		Tonnes		Tonnes	
Talc	37 188	N.A.	**61 653**	**N.A.**	+ 24 465	N.A.
Tanto/Columbite Ores and Concentrates	273	718 167	**138**	**729 163**	— 135	+ 10 996
Tin Concentrates	1 216	2 653 423	**880**	**2 918 919**	— 336	+ 265 496
Vermiculite	426	3 565	**225**	**2 768**	— 201	— 797
Total	....	735 773 950	....	**929 564 494**	....	+ 193 790 544

TABLE 1 (*b*)

Quantity and Value of Gold and Silver received at the Perth Mint during the Years 1973 *and* 1974

Mineral	1973		1974		Increase or Decrease for Year Compared with 1973	
	Quantity	Value	Quantity	Value	Quantity	Value
	kg	$	kg	$	kg	† $
Gold	*7 940·504	†18 326 747	***6 630·958**	**†22 324 330**	— 1 309·546	+ 3 997 583
Silver	*2 144·861	86 368	***1 718·213**	**129 714**	— 426·648	+ 43 346
Total		18 413 115		**22 454 044**		+ 4 040 929
Grand Total		754 187 065		**952 018 538**		+ 197 831 473

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

† Includes overseas gold sales premium.

TABLE 2
ROYALTIES

Mineral	Royalty Collected 1973	Royalty Collected 1974	Increase or Decrease Compared with 1973
Alumina	396 996·34	410 737·19	+ 13 740·85
Amethyst	8·11	11·43	+ 3·32
Bentonite	9·90	40·55	+ 30·65
Beryl	28·40	17·86	— 10·54
Beryl (Green)	....	7·52	+ 7·52
Building Stone	380·68	398·91	+ 18·23
Chalcedony	3·67	7·13	+ 3·46
Chrysoprase	15·00	....	— 15·00
Clay	14 644·89	15 541·36	+ 896·47
Coal	28 517·57	32 765 ·18	+ 4 247·61
Cobalt	766·51	924·67	+ 158·16
Felspar	11·65	43·11	+ 31·46
Glass Sand	10 417·69	14 350·17	+ 3 932·48
Gypsum	8 222·02	7 815·91	— 406·11
Ilmenite	67 094·14	59 051·64	— 8 042·50
Iron Ore	28 030 157·31	33 111 946·15	+5 081 788·84
Lepidolite	....	1·23	+ 1·23
Leucoxene	1 386·70	533·13	— 853·57
Limestone	42 443·22	38 402·20	— 4 041·02
Magnesite	5·80	....	— 5·80
Manganese	5 415·45	3 387·72	— 2 027·73
Mica	....	1·68	+ 1·68
Monazite	1 769·05	1 831·19	+ 62·14
Moss Opal	26·51	20·97	— 5·54
Natural Gas	320 198·18	270 980·83	— 49 217·35
Natural Gas Condensate	542·73	3 864·29	+ 3 321·56
Nickel	577 935·63	841 403·27	+ 263 467·64
Oil (Crude)	1 362 522·06	1 254 762·53	— 107 759·53
Opal	....	78·97	+ 78·97
Opal (Tiger Eye)	....	24·87	+ 24·87
Opalite	....	2·00	+ 2·00
Palladium	78·46	583·78	+ 505·32
Petalite	22·40	·05	— 22·35
Platinum	42·54	305·69	+ 263·15
Quartz Chrystal	65·85	17·33	— 48·52
Quartz (Semi-precious)	....	8·91	+ 8·91
Ruthenium	....	14·03	+ 14·03
Rutile	552·30	493·68	— 58·62
Salt	202 914·54	221 004·21	+ 18 089·67
Talc	3 663·27	5 239·72	+ 1 576·45
Tanto-Columbite	2 788·79	3 455·58	+ 666·79
Tin	270·94	1 237·94	+ 967·00
Tourmaline	1·90	13·15	+ 11·25
Vermiculite	31·28	11·07	— 20·21
Xenotime	....	52·13	+ 52·13
Zircon	7 994·05	8 103·85	+ 109·80
Total	31 087 945·53	36 309 494·78	+5 221 549·25

TABLE 3

Gold production reported to the Mines Department for every goldfield, the percentage for the several goldfields of the total reported and the average yield in grams per tonne of ore treated

Goldfield	Reported Yield		Percentage for each Goldfield		* Average Yield per tonne of ore treated	
	1973	**1974**	1973	**1974**	1973	**1974**
	kg	**kg**	Per cent.	**Per cent.**	grams	**grams**
Kimberley	....	....	....	....	....	....
West Kimberley	....	....	....	....	....	....
Pilbara	44·483	**39·720**	·52	**·61**	24·4	**11·0**
West Pilbara	1·439	....	·02	....	....	....
Ashburton	....	....	....	....	....	....
Gascoyne	·050	....	....	....	4·0	....
Peak Hill	·646	**·232**	·01	....	....	**6·6**
East Murchison	1·646	**2·887**	·02	**·04**	15·5	**2·3**
Murchison	532·135	**192·429**	6·20	**2·93**	8·3	**8·0**
Yalgoo	10·792	**21·287**	·13	**·33**	45·3	**17·0**
Mt. Margaret	40·380	**29·891**	·47	**·46**	5·2	**4·2**
North Coolgardie	8·064	**8·655**	·09	**·13**	4·3	**3·8**
Broad Arrow	22·963	**7·252**	·27	**·11**	1·7	**2·2**
North-East Coolgardie	5·127	**4·201**	·06	**·06**	4·8	**4·0**
East Coolgardie	6 540·661	**5 206·263**	76·17	**79·38**	4·8	**4·3**
Coolgardie	31·055	**81·030**	·36	**1·24**	3·8	**7·8**
Yilgarn	204·665	**56·833**	2·38	**·87**	20·8	**8·8**
Dundas	1 140·686	**904·741**	13·28	**13·79**	7·5	**7·9**
Phillips River	·915	**·275**	·01	....	11·7	**11·9**
South-West Mineral Field	....	**·043**	....	....	....	**·8**
State Generally	1·182	**3·069**	·01	**·05**	....	....
	8 586·889	**6 558·808**	100·00	**100·00**	5·3	**4·8**

* Averages exclude alluvial and dollied gold.

TABLE 4

Total Coal Output from Collie River Mineral Field, 1973 *and* 1974, *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
1973	422 568	3 430 122	100	308	....	....	1 372	1 036
1974	490 891	4 440 893	100	323	....	....	1 520	1 160
Open Cut Mining—								
1973	748 500	3 618 604	....	....	211	3 547	....	....
1974	955 157	4 704 089	....	....	262	3 646	....	....
Totals—								In All Mines
1973	1 171 068	7 048 726	100	308	211	....	....	1 892
1974	1 446 048	9 144 982	100	323	262	....	....	2 111

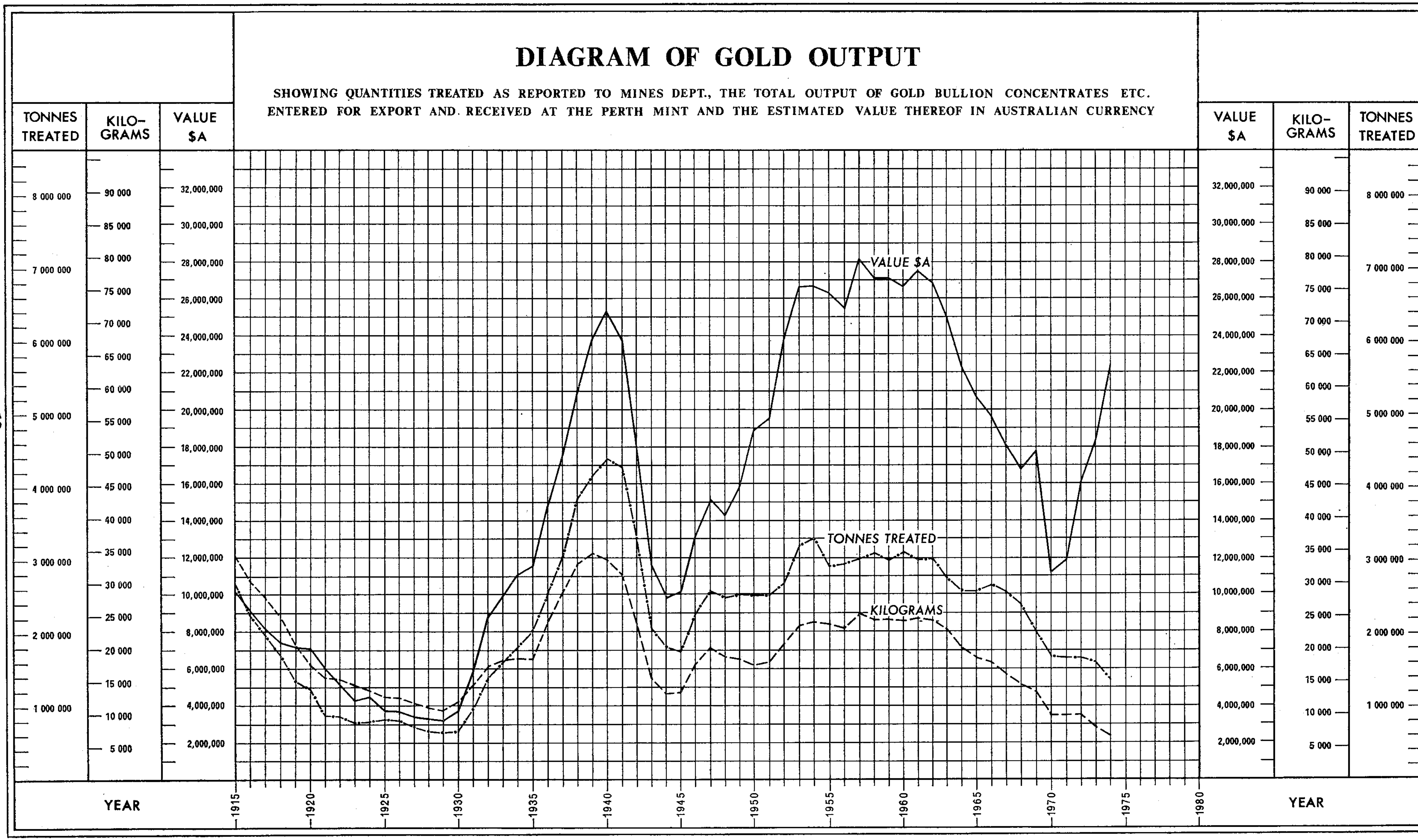
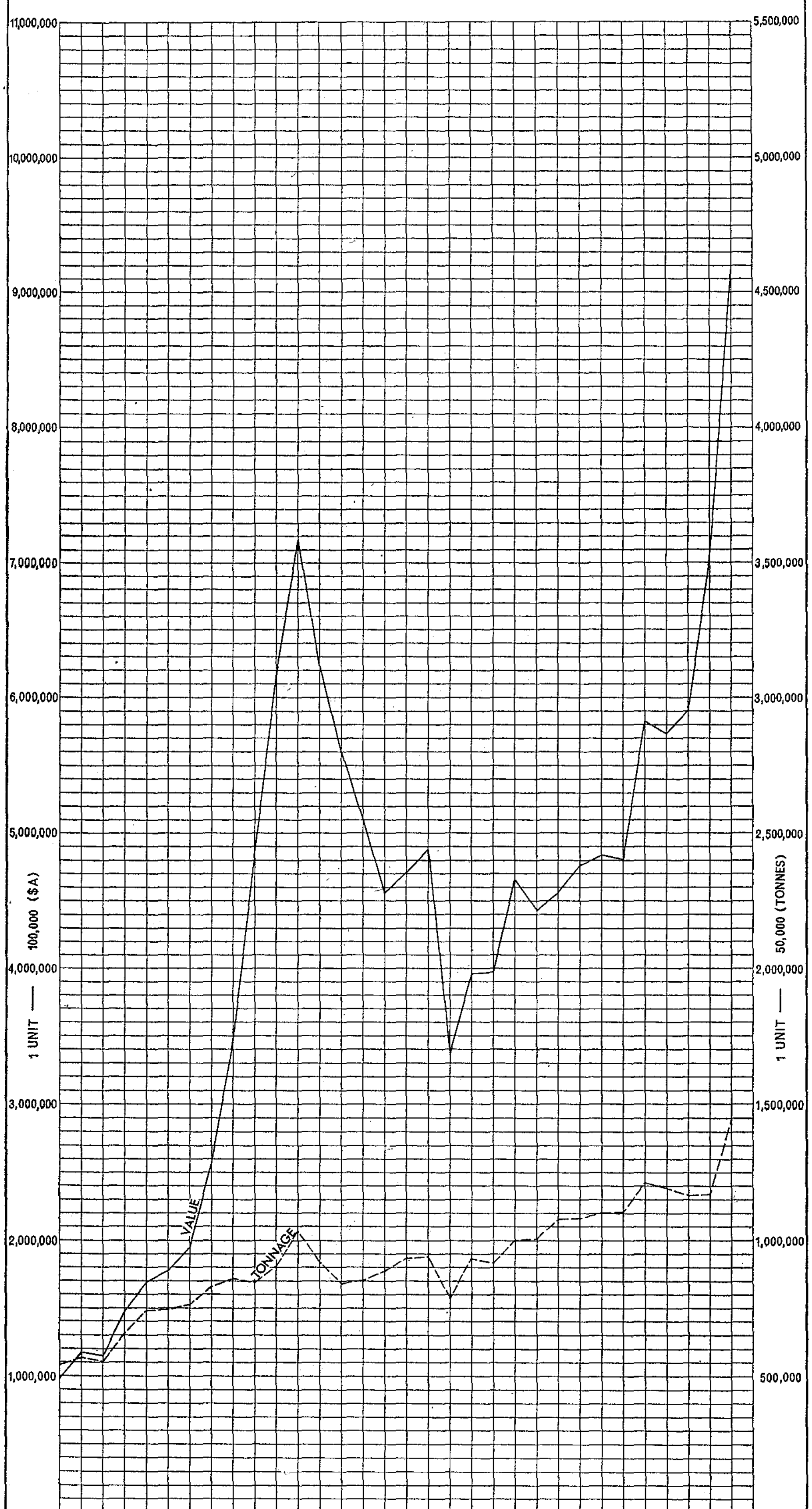


DIAGRAM OF GOLD OUTPUT
SHOWING QUANTITIES TREATED AS REPORTED TO MINES DEPT., THE TOTAL OUTPUT OF GOLD BULLION CONCENTRATES ETC. ENTERED FOR EXPORT AND RECEIVED AT THE PERTH MINT AND THE ESTIMATED VALUE THEREOF IN AUSTRALIAN CURRENCY
TONNES TREATED
KILO-GRAMS
VALUE $A
8 000 000
7 000 000
6 000 000
5 000 000
4 000 000
3 000 000
2 000 000
1 000 000
90 000
85 000
80 000
75 000
70 000
65 000
60 000
55 000
50 000
45 000
40 000
35 000
30 000
25 000
20 000
15 000
10 000
5 000
32,000,000
30,000,000
28,000,000
26,000,000
24,000,000
22,000,000
20,000,000
18,000,000
16,000,000
14,000,000
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
VALUE $A
TONNES TREATED
KILOGRAMS
YEAR
1915
1920
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980

GRAPH OF COAL OUTPUT

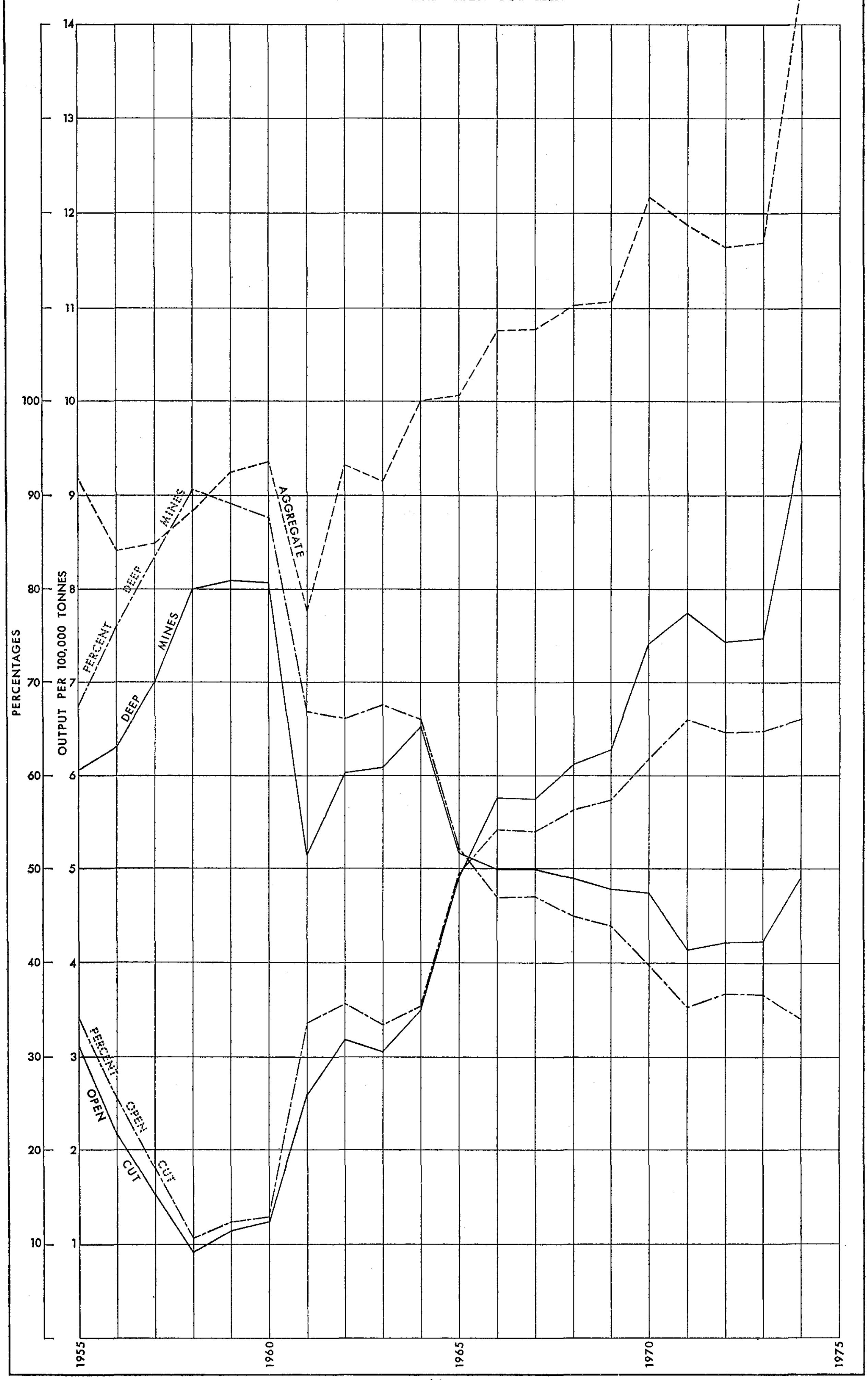
SHOWING QUANTITIES AND VALUES AS REPORTED TO MINES DEPARTMENT



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	9,144,982	1,446048
1975		

GRAPH OF TREND IN COAL OUTPUT

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



LEASES AND OTHER HOLDINGS UNDER VARIOUS ACTS RELATING TO MINING.

TABLE 5

MINING ACT, 1904.

Total Number and Area of Mining Tenements applied for during 1974 and in force as at 31st December, 1974 (compared with 1973)

—	Applied for				In Force			
	1973		**1974**		1973		**1974**	
	No.	Hectares	No.	Hectares	No.	Hectares	No.	Hectares
Gold—								
Gold Mining Leases	988	8 568	**575**	**4 807**	2 188	17 548	**2 275**	**18 310**
Dredging Claims	145	17 095	**14**	**1 471**	14	1 100	**2**	**243**
Prospecting Areas	418	3 423	**398**	**3 307**	367	3 206	**282**	**2 364**
Temporary Reserves	15	163 400	**6**	**685**	8	78 400	**14**	**1 602**
Totals	1 566	192 486	**993**	**10 270**	2 577	100 254	**2 573**	**22 519**
Coal—								
Coal Mining Leases	2	235	**110**	**13 089**	60	7 005	**113**	**13 177**
Prospecting Areas	....	....	**1**	**120**	9	10 037	**1**	**1 214**
Temporary Reserves	30	524 500	**4**	**63 200**	29	523 500	**5**	**65 200**
Totals	32	524 735	**115**	**76 409**	98	540 542	**119**	**79 591**
Other Minerals—								
Mineral Leases	82	7 497	**257**	**27 177**	447	38 073	**544**	**47 691**
Dredging Claims	19	287	**38**	**3 174**	284	9 586	**253**	**8 805**
Mineral Claims	6 247	689 089	**5 422**	**600 159**	16 610	1 729 921	**14 833**	**1 543 918**
Prospecting Areas	44	358	**24**	**203**	25	230	**23**	**199**
Temporary Reserves	126	1 744 400	**41**	**516 428**	71	958 800	**275**	**4 433 277**
Totals	6 518	2 441 631	**5 782**	**1 147 141**	17 437	2 736 610	**15 928**	**6 033 890**
Other Holdings—								
Miner's Homestead Leases	1	8	**2**	**16**	326	23 658	**390**	**13 349**
Miscellaneous Leases	2	41	**7**	**41**	186	7 863	**121**	**832**
Residence Areas	....	....	**1**	**1**	56	22	**49**	**17**
Business Areas	1	1	....	....	20	13	**17**	**7**
Machinery Areas	4	7	**5**	**10**	24	29	**25**	**33**
Tailings Areas	9	48	**14**	**96**	21	34	**32**	**123**
Garden Areas	8	16	**8**	**17**	71	109	**74**	**125**
Quarrying Areas	43	396	**57**	**495**	147	1 256	**160**	**1 361**
Water Rights	11	775	**5**	**1 264**	103	795	**112**	**854**
Licenses to Treat Tailings	175	....	**200**	....	199	....	**132**	....
Totals	254	1 292	**299**	**1 940**	1 153	33 779	**1 112**	**16 701**
Grand Totals	8 370	3 160 144	**7 189**	**1 235 760**	21 265	3 411 185	**19732**	**6 152 601**

TABLE 5 (a)

SPECIAL ACTS

Leases applied for during 1974 and in force at 31st December, 1974 (Compared with 1973)

Mineral	Applied for				In Force			
	1973		**1974**		1973		**1974**	
	No.	Hectares	No.	Hectares	No.	Hectares	No.	Hectares
Bauxite	....	....	....	....	7	269 612·17	**7**	**1 269 612·17**
Iron	....	....	**1**	**546 25·00**	7	200 832·85	**8**	**255 457·85**
Salt	....	....	**1**	**14 710·00**	3	241 532·58	**4**	**256 242·58**
Totals	....	....	**2**	**69 335·00**	17	1 711 977·60	**19**	**1 781 312·60**

TABLE 5 (b)
PETROLEUM ACTS

Permits, Licences and Leases applied for during 1974 *and in force as at* 31*st December*, 1974 (*Compared with* 1973)

Holding	Applied for				In Force			
	1973		**1974**		1973		**1974**	
	No.	Blocks	No.	Blocks	No.	Blocks	No.	Blocks
Onshore—								
Petroleum Act, 1967—								
Exploration Permits	....	....	**2**	**204**	58	7 260	**49**	**5 413**
Production Licences	....	....	....	....	3	14	**3**	**14**
Petroleum Lease (Barrow Island)	....	....	....	....	1	8	**1**	**8**
Totals	....	....	**2**	**204**	62	7 282	**53**	**5 435**
Petroleum Pipelines Act, 1969—						km		**km**
Pipeline Licences	....	....	....	....	5	444·9	**5**	**444·9**
Totals	....	....	....	....	5	444·9	**5**	**444·9**
Offshore—						Blocks		Blocks
Petroleum (Submerged Lands) Act, 1969:								
Exploration Permits	....	....	....	....	33	9 828	**30**	**8 032**
Production Licences	....	....	....	....	....	....	....	....
Petroleum Lease (Barrow Marine)	....	....	....	....	1	12	**1**	**12**
Totals	....	....	....	....	34	9 840	**31**	**8 044**
Grand Totals	....	....	**2**	**204**	96	17 122	**89**	**13 479**

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

TABLE 5 (c)
MINING ACT, 1904

Leases in Force at 31*st December*, 1974 *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	1 010·03	....	....	....	....
Black Range	18	132·67	10	1 205·90	....	....	....	....
Broad Arrow	47	326·68	2	227·43	....	....	....	....
Bulong	24	215·65	....	....	....	....	....	....
Collie	....	....	....	....	....	....	58	6 786·30
(Private Property)	....	....	....	....	....	....	2	210·43
Coolgardie	120	890·19	222	24 681·70	22	752·26	5	13·35
Cue	34	310·46	1	40·46	4	450·33	1	2·02
Day Dawn	26	213·16	....	....	1	8·09	....	....
Dundas	443	3 947·35	....	....	17	365·33	....	....
East Coolgardie	385	2 763·24	3	148·30	61	1 321·35	76	569·22
Gascoyne	10	86·10	5	70·42	....	....	....	....
Greenbushes	....	....	72	4 293·61	9	230·65	....	....
Kanowna	49	434·08	5	221·34	12	284·03	....	....
Kimberley	1	9·71	1	121·40	....	....	....	....
Kunanalling	15	110·84	....	....	2	210·43	....	....
Kurnalpi	19	178·87	....	....	....	....	....	....
Lawlers	21	158·29	8	967·16	5	447·98	....	....
Marble Bar	230	1 841·54	20	1 898·74	....	....	14	86·13
Meekatharra	87	715·32	....	....	10	738·50	1	0·40
Menzies	58	490·19	1	28·73	7	299·43	1	4·04
Mount Magnet	97	660·74	....	....	1	4·04	....	....
Mount Malcolm	95	805·38	....	....	9	513·91	....	....
Mount Margaret	77	722·97	59	6 021·56	7	23·43	....	....
Mount Morgans	75	684·53	1	12·14	....	....	....	....
Niagara	7	42·49	....	....	1	8·09	....	....
Northampton	....	....	5	53·04	....	....	....	....
(Private Property)	....	....	3	15·10	....	....	....	....
Nullagine	26	197·39	....	....	2	8·89	2	19·42
Peak Hill	14	113·50	7	270·10	5	101·00	1	6·00
Phillips River	3	12·14	17	713·83	105	5 798·67	....	....
(Private Property)	....	....	9	1 091·39	....	....	....	....
South-West	....	....	....	....	....	....	4	191·40
(Private Property)	....	....	....	....	....	....	9	809·73
Ularring	21	165·03	1	121·40	1	8·09	....	....
West Kimberley	....	....	23	304·60	....	....	40	5 179·60
West Pilbara	7	63·11	19	487·99	3	14·15	10	91·00
Wiluna	4	34·00	29	3 250·30	16	1 399·00	2	1·20
Yalgoo	38	293·88	3	185·74	....	....	....	....
Yerilla	71	542·41	....	....	1	4·04	....	....
Yilgarn	137	1 010·33	5	248·86	23	357·62	8	39·25
(Private Property)	16	138·35	....	....	....	....	....	....
Outside Proclaimed	....	....	....	....	....	....	....	....
Totals	2 275	18 310·59	544	47 691·27	324	13 349·31	234	14 009·49

	No.	Hectares
Gold Mining Leases on Crown Land	2 259	18 172·24
Gold Mining Leases on Private Property	16	138·35
Mineral Leases on Crown Land	53	46 584·78
Mineral Leases on Private Property	12	1 106·49
Miner's Homestead Leases on Crown Land	324	13 349·31
Other Leases on Crown Land	223	12 989·33
Other Leases on Private Property	11	1 020·16

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TABLE 5 (d)

MINING ACT, 1904

Claims and Authorised Holdings in Force at 31st December, 1974 in each Goldfield, Mineral Field or District

Goldfield, Mineral Field or District	Prospecting Areas		Dredging Claims		Mineral Claims		Residence Areas		Business Areas		Machinery Areas		Tailings Areas		Garden Areas		Quarrying Areas		Water Rights	
	Number	Hectares	Number	Hectares	Number	Hectares	Number	Hectares	Number	Hectares	Number	Hectares	Number	Hectares	Number	Hectares	Number	Hectares	Number	Hectares
Ashburton	1	9·71	....	....	276	28 430·58	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Black Range	4	33·90	....	....	417	45 155·28	3	1·20	....	....	....	....	....	....	....	....	....	....	....	....
Broad Arrow	28	211·86	....	....	190	19 631·07	1	0·40	1	0·40	....	....	....	....	....	....	....	....	4	3·62
Bulong	6	48·54	....	....	245	28 385·31	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Collie	....	....	....	....	....	....	....	....	....	....	1	2·00	....	....	....	....	1	10·00	....	....
(Private Property)	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Coolgardie	47	398·15	....	....	927	96 045·58	3	0·30	....	....	1	0·40	....	....	4	4·43	24	203·19	5	18·06
Cue	10	74·54	....	....	379	40 228·77	2	0·20	....	....	1	2·02	....	....	....	....	1	9·71	....	....
Day Dawn	1	9·71	2	242·80	22	2 175·48	....	....	....	....	....	....	....	....	4	8·08	....	....	....	....
Dundas	7	42·75	....	....	423	40 797·39	....	....	....	....	....	....	....	2·02	....	....	2	19·42	2	4·85
East Coolgardie	22	159·84	....	....	270	28 966·92	31	12·40	....	....	1	0·80	1	18·57	11	19·78	22	191·75	12	12·57
Gascoyne	1	9·71	2	165·91	314	32 260·99	....	....	....	....	....	....	10	....	....	....	5	45·30	....	....
Greenbushes	....	....	....	....	1	8·09	1	1·00	....	....	....	....	....	....	9	21·00	....	....	2	15·00
Kanowna	10	72·78	....	....	269	30 476·68	....	....	....	....	....	....	....	....	....	....	....	....	1	0·40
Kimberley	....	....	....	....	572	63 960·70	....	....	....	....	....	....	....	....	2	3·00	11	92·55	....	....
Kunanalling	8	65·55	....	....	151	18 111·19	....	....	....	....	....	....	....	....	....	....	....	....	2	9·71
Kurnalpi	8	77·67	....	....	153	17 293.64	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Lawlers	4	38·85	....	....	1 166	128 625·67	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Marble Bar	16	140·05	241	8 043·02	1 222	119 649·16	....	....	3	1·20	8	11·91	1	2·02	17	31·45	28	226·50	26	172·26
Meekatharra	8	62·90	5	516·30	222	25 268·74	....	....	....	....	....	....	....	....	....	....	....	....	2	2·00
Menzies	3	23·06	....	....	505	53 645·77	....	....	....	....	....	....	....	....	....	....	....	....	4	4·02
Mount Magnet	26	242·40	....	....	141	16 555·48	....	....	....	....	....	....	....	....	5	5·20	....	....	4	2·40
Mount Malcolm	13	110·45	....	....	481	53 256·74	....	....	....	....	....	....	....	....	9	14·52	....	....	3	1·60
Mount Margaret	3	29·13	....	....	341	39 938·51	....	....	....	....	2	4·04	5	10·10	2	2·82	....	....	3	1·20
Mount Morgans	5	44·52	....	....	351	39 617·29	....	....	....	....	....	....	....	....	....	....	....	....	2	2·45
Niagara	4	31·57	....	....	64	7 360·75	....	....	....	....	....	....	....	....	....	....	....	....	3	2·43
Northampton	....	....	....	....	....	....	....	....	....	....	....	....	8	83·76	....	....	....	....	....	....
(Private Property)	....	....	....	....	26	1 859·41	....	....	....	....	....	....	1	2·42	....	....	....	....	....	....
Nullagine	1	9·71	1	121·40	317	21 371·79	....	....	....	....	2	0·80	3	1·60	2	2·01	....	....	11	11·27
Peak Hill	3	21·40	....	....	314	32 181·72	....	....	1	0·40	2	3·00	1	2·00	1	1·90	7	67·90	2	8·80
Phillips River	1	9·23	....	....	308	29 135·13	....	....	....	....	1	0·81	....	....	....	....	1	2·02	....	....
(Private Property)	....	....	....	....	154	17 426·07	....	....	....	....	....	....	....	....	....	....	....	....	....	....
South West	7	1 262·60	9	624·92	353	24 714·53	....	....	....	....	....	....	....	....	....	....	....	....	1	2·83
(Private Property)	1	9·71	....	....	665	58 755·82	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Ularring	2	14·56	....	....	27	3 018·14	....	....	....	....	1	0·40	2	1·61	....	....	....	....	3	1·60
West Kimberley	....	....	1	121·40	215	21 144·32	....	....	....	....	2	4·04	....	....	....	....	17	123·37	2	19·42
West Pilbara	5	48·44	2	15·37	920	92 888·43	4	1·60	6	2·40	....	....	....	....	4	7·67	37	338·62	9	16·94
Wiluna	....	....	....	....	657	74 636·60	....	....	....	....	1	0·40	1	1·20	....	....	....	....	2	534·50
Yalgoo	11	101·80	....	....	830	92 329·78	....	....	6	2·40	....	....	....	....	....	....	2	11·70	1	0·40
Yerilla	9	67·98	....	....	81	8 605·92	....	....	....	....	....	....	....	....	....	....	....	....	5	4·82
Yilgarn	33	284·54	....	....	796	86 252·73	8	0·88	....	....	2	2·02	....	....	4	3·00	2	19·42	....	....
(Private Property)	1	2·42	....	....	4	367·70	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Outside Proclaimed	....	....	....	....	6	535·58	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Totals	309	3 770·03	263	9 851·12	14 769	1 540 619·78	53	17·98	17	6·80	25	32·64	33	125·30	74	124·86	160	1 361·45	111	853·15

TABLE 6

MEN EMPLOYED

Average number of Men employed in Mining during 1973 *and* 1974

Goldfield	District	Gold		Other Minerals		Total	
		1973	**1974**	1973	**1974**	1973	**1974**
Kimberley	....	....	....	4	....	4	....
West Kimberley	....	....	....	362	**349**	362	**349**
Pilbara	Marble Bar	28	**47**	700	**782**	729	**829**
	Nullagine	4	**1**	13	....	17	**1**
West Pilbara	....	....	....	1 844	**2 059**	1 844	**2 059**
Ashburton	....	....	....	158	**146**	158	**146**
Gascoyne	....	2	....	276	**317**	278	**317**
Peak Hill	....	2	**7**	1 009	**913**	1 011	**920**
East Murchison	Lawlers	....	**1**	....	....	....	**1**
	Wiluna	....	....	....	....	....	....
	Black Range	2	**5**	....	....	2	**5**
Murchison	Cue	2	**4**	....	**5**	2	**9**
	Meekatharra	8	**13**	....	....	8	**13**
	Day Dawn	....	**3**	....	....	....	**3**
	Mt. Magnet	123	**101**	....	....	123	**101**
Yalgoo	....	4	**10**	3	**4**	7	**14**
Mt. Margaret	Mt. Morgans	5	**8**	....	**1**	5	**9**
	Mt. Malcolm	33	**40**	....	....	33	**40**
	Mt. Margaret	8	**4**	....	....	8	**4**
North Coolgardie	Menzies	3	**9**	63	**75**	66	**84**
	Ularring	7	**10**	....	....	7	**10**
	Niagara	3	**7**	....	....	3	**7**
	Yerilla	9	**14**	....	....	9	**14**
Broad Arrow	....	31	**38**	316	**31**	347	**355**
North-East Coolgardie	Kanowna	19	**11**	....	....	19	**11**
	Kurnalpi	4	**7**	....	**3**	4	**10**
East Coolgardie	East Coolgardie	1 361	**1 343**	....	....	1 361	**1 343**
	Bulong	7	**6**	....	....	7	**6**
Coolgardie	Coolgardie	66	**42**	1 620	**1 718**	1 686	**1 760**
	Kunanalling	9	**14**	....	....	9	**14**
Yilgarn	....	47	**57**	115	**134**	162	**191**
Dundas	....	208	**221**	4	**3**	212	**224**
Phillips River	....	5	**2**	....	....	5	**2**
South-West Mineral Field	....	....	**2**	2 276	**2 642**	2 276	**2 644**
Northampton Mineral Field	....	....	....	8	....	8	....
Greenbushes Mineral Field	....	....	....	104	**88**	104	**88**
Outside Proclaimed Goldfield	....	....	....	....	....	....	....
Collie Coalfield	....	....	....	619	**685**	619	**685**
Total—All Minerals	....	2 001	**2 027**	9 494	**10 241**	11 495	**12 268**

	1973	**1974**
Minerals Other than Gold—		
Alumina (from Bauxite)	1 798	**1 965**
Beryl	3	**5**
Building Stone	4	**7**
Clays	10	**18**
Coal	619	**685**
Copper	13	....
Emeralds	....	**3**
Felspar	2	**5**
Glass Sand	11	**13**
Gypsum	5	**9**
Iron Ore	3 886	**4 050**
Lead Ore and Conc.	8	....
Limestone	30	**33**
Manganese	13	....
Mica	....	**2**
Mineral Beach Sands	337	**550**
Nickel	1 981	**2 090**
Petroleum (Crude Oil)	158	**146**
(Natural Gas)	7	**7**
Salt	436	**497**
Semi-precious Stones	10	**7**
Talc	12	**17**
Tin	149	**130**
Vermiculite	2	**2**
Total, Other Minerals	9 494	**10 241**

PART 3—STATE AID TO MINING

(a) State Batteries

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

From inception to the end of 1974, gold, silver, tin, tungsten, lead, copper and tantalite ores to the value of $44 072 702 have been treated at the State Batteries. $41 911 709 came from 3 855 803 tonnes of gold ore, $476 184 from 85 364.5 tonnes of tin ore, $41 087 from 4 293.6 tonnes of tungsten ore, $1 554 040 from 70 863.1 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 $4 489 recovered as a by-product from the cyaniding of gold tailings.

During the year 46 317.8 tonnes of gold ores were crushed for 298.603 kilograms bullion, estimated to contain 253.064 kilograms fine gold equal to 5.46 grams per tonne. The average value of sands after amalgamation was 2.00 grams per tonne, making the average head value 7.46 grams per tonne. Cyanide plants produced 26.844 kilograms of fine gold, giving a total estimated production for the year of 279.908 kilograms of fine gold valued at $1 024 406.

The working expenditure for the year for all plants was $945 127 and the revenue was $100 623 giving a working loss of $844 505 which does not include depreciation, interest or Superannuation. Since the inception of State Batteries, the capital expenditure has been $1 962 692 made up of $1 471 130 from General Loan Funds; $406 746 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 $142 160 compared with $109 979 for 1973.

The actual expenditure from inception to the end of 1974 exceeds revenue by $9 195 532.

(b) Prospecting Scheme

At the end of the year 5 men were in receipt of prospecting assistance as compared with 9 at the end of 1973.

Total expenditure for 1974 was $4 239.40 and refunds amounted to $858.97.

Assisted prospectors crushed 735 tonnes of ore during the year for 2.228 kilograms of gold.

Progressive total figures since the inception of the scheme are:

Expenditure—$1 050 606.
Refunds—$203 832.
Ore crushed—130 300 tonnes.
Gold won—1 810.926 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.

There was an unprecedented increase in the number of samples received for examination during 1974. A total of 30 158 samples was received compared with 23 741 in 1973. The increase has been mainly in the Agriculture Division from samples received from the Department of Agriculture, and the increase in that Division was 89 per cent over the figure for 1973.

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 1974 numbered 417. Some 254 inspections of explosives in storage, conveyance, etc. were made throughout the year. Also 4 588 licences were held under the Flammable Liquids Regulations and some 3 500 inspections were made.

The total consumption of explosives for 1974 used throughout Western Australia was 80 360 tonnes and it is interesting to note that this quantity is greater than the total quantity of explosives used in the State in the sixty years from 1892 to 1951.

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

Under arrangement with this Department, the State Public Health Department continued the periodic x-ray examination of mine workers throughout the year.

A total of 14 526 examinations were made of which 5 164 were made under the Mine Workers' Relief Act and 9 362 under the Mines Regulation Act. Of the latter 8 838 were new applicants and 524 were re-examinees. In addition, Provisional Certificates were issued to 1 162 persons in isolated country areas.

Compensation payments under the Miners' Phthisis Act amounted to $6 202 compared with $7 121 for the previous year. The number of beneficiaries under the Act as at 31/12/1974 was 29 being two ex-miners and 27 widows.

PART 7—SURVEYS AND MAPPING BRANCH

Surveys of mining tenements were carried out in almost all areas of the State and, during the year, 1 764 surveys were completed compared with 2 162 in 1973. 6 607 applications for mining tenements were received for processing.

The new provisional maps at a scale of 1 : 50 000 were prepared in the Pilbara covering Edmund and 32 new plans were redrawn on the Australian Map Grid of Yarraloola and Pyramid. There were 42 new A.M.G. sheets started to replace the provisional plans of Dampier, Roebourne and Port Hedland. A large number of other plans and drawings were prepared and some 2 800 items were prepared on the Process Camera, comprising reductions, enlargements and same size copy.

PART 8—STAFF

Members of the staff both in Perth and the outstations are to be congratulated on the manner in which they carried out their duties during the year under review.

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

B. M. ROGERS,
Under Secretary for Mines.

Department of Mines,
Perth.

DIVISION II

Report of the State Mining Engineer for the Year 1974

Under Secretary for Mines:

I hereby submit the 1974 Annual Report for the State Mining Engineer's Branch which is divided into the following sections—

Mineral and Metal Production—by G. J. Dodge, Mining Engineer-District Inspector of Mines.

Mine Inspection and Accident Statistics—by J. M. Faichney, Mining Engineer—Acting Principal Senior Inspector of Mines.

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

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

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

MINERALS METALS AND COAL

In Western Australia's mineral metal and coal production for the 1974 year, the value of iron ore production was again the highest at $589 145 195 followed by nickel ore and concentrates at $126 292 134, alumina at $124 800 000 and gold at $22 258 720.

Of the main iron ore companies Hamersley Iron Pty. Ltd. reported exports of 31 931 278 tonnes at a grade of 63.78 per cent Fe. Mt. Newman Mining Co. Pty. Ltd. 26 534 197 tonnes at 63.00 per cent Fe, Cliffs W.A. Mining Co. Pty. Ltd. 10 659 493 tonnes at 59.49 per cent Fe and Dampier Mining Co. Ltd. 3 188 854 tonnes at 67.39 per cent Fe.

Nickel, nickel ore and concentrate production valued at $126 292 134 was obtained from Kambalda, Nepean, Redross, Scotia, Carr Boyd Rocks and Windarra. Western Mining Corporation's nickel smelter at Hampton completed its first full year of production, treating 144 757 tonnes of concentrate which gave a recovery of 20 607 tonnes of matte containing 14 632.4 tonnes of nickel.

Alumina sales by Alcoa of Australia (W.A.) Ltd. continued to increase during 1974 with a total of 1 981 205 tonnes produced.

Coal production increased from 1 171 068 tonnes in 1973 to 1 446 048 tonnes this year valued at $9 144 982.

DRILLING

During 1974 the Drilling Section was responsible for the drilling of 13 933 metres in 391 bores and the testing by pumping of 35 bores.

As part of the State-wide groundwater investigation drilling programmes were carried out at Eneabba, Moora, Joondalup, Bunbury and in the Canning Basin.

For the purpose of locating additional groundwater sources for Port Hedland and for Roebourne and associated towns additional investigations were carried out in the De Grey and Cooya Pooya-Millstream areas respectively.

The Drilling Section was also involved in the new role of drilling to provide soil samples and monitoring bore holes for the purpose of detecting changes in groundwater salinity, which may result from clearing timber for mining at Alcoa's Del Park and for the wood chip industry at Manjimup.

STAFF

Appointments—

Jance, J., Mechanical Engineer-Special Inspector of Mines	5/3/74
Lindon, G. J., Ventilation Officer	8/4/74
Rimes, M. J., Ventilation Officer	8/4/74

Retirement—

Kelly, J., Workmen's Inspector of Mines	13/12/74

A. Y. WILSON,
State Mining Engineer.

MINERAL AND METAL PRODUCTION

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

Mineral production for the year 1974 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—Overseas Iron Ore Exports.

Table 5—Nickel Producers.

TABLE 1

Mineral and Metal Output

Mineral Product	1973 Production	1973 Value	1974 Production	1974 Value
	Tonne (t)	$A	Tonne (t)	$A
Alumina	1 729 128·93	108 916 300	1 981 205·00	124 800 000
Bentonite	833·15	11 708	568·99	7 869
Beryl	161·95	29 712	79·00	14 124
Building Stone	4 830·26	46 261	5 039·46	121 741
Clays	387 853·10	384 944	567 529·82	500 990
Coal	1 171 068·54	7 048 726	1 446 047·93	9 144 982
Cobalt	131·43	477 091	135·00	608 308
Copper—				
Ore and Concentrates	35·41	8 434	....	....
Metal	371·76	434 800	267·00	341 520
Emeralds Carats (Cut)	....	....	19·00	1 400
Felspar	318·02	4 695	880·43	17 487
Glass Sand	222 669·71	139 985	280 669·87	306 075
Gold (kg)	8 586·90	18 917 671	6 583·43	22 258 720
Gypsum	164 254·92	503 298	162 135·99	460 667
Ilmenite	731 100·69	9 169 703	868 696·65	11 237 842
Iron Ore	75 896 481·25	454 674 240	87 000 812·00	589 145 195
Iron Ore—Pig Iron	96 819·11	3 844 002	86 936·00	3 906 401
Lead Ore and Concentrates	146·77	17 513	....	....
Leucoxene	15 395·53	1 107 188	15 667·80	1 635 905
Limestone	1 353 579·12	1 426 758	1 157 315·73	1 275 064
Lithium Ore—Petalite	221·50	3 466	1·00	16
Magnesite	....	....	....	....
Manganese	26 306·47	428 000	18 107·04	336 655
Mica	....	....	34·00	418
Monazite	3 015·63	394 798	2 661·66	386 461
Nickel Ore and Concentrates	353 172·49	92 832 563	437 048·61	126 292 134
Ochre	....	....	....	....
Palladium (kg)	23·37	41 000	163·72	428 700
Petroleum—				
Crude Oil (barrels)	14 578 230·00	32 509 453	13 801 191·00	31 257 312
Natural Gas (10^3m^3)	812 043·58	5 161 868	831 604·36	5 285 738
Condensate (tonne)	3 727·25	Not available	4 287·54	Not available
Platinum (kg)	6·9	23 900	59·54	227 200
Ruthenium (kg)	....	....	5·28	7 300
Rutile	1 910·57	193 933	11 275·02	1 515 196
Salt	3 333 937·42	9 837 959	3 906 492·38	11 576 831
Semi-Precious Stones	37·27	20 430	27·75	30 875
Silver (kg)	2 144·86	86 368	1 718·21	129 714
Talc	37 188·33	Not available	61 653·00	Not available
Tantalo-Columbite	272·59	718 167	138·01	729 163
Tin Concentrate	1 215·53	2 653 423	880·45	2 918 919
Vermiculite	426·10	3 565	225·00	2 768
Xenotime	45·24	31 926	26·00	21 037
Zircon	89 697·36	2 674 143	73 681·27	5 022 111
Totals	....	754 777 991	....	951 952 838

1 barrel = 42 U.S. gallons = 34·972 Imperial gallons = 158·987 litres.
Condensate : 8·322 barrels per tonne.
1 Kilogram (kg) = 32·150 75 troy ounces = 35·273 96 ounces.
1 Tonne (t) = 0·984 206 5 ton.

TABLE 2

Reported Mine Development

Gold or Mineral Field	Mine	Shaft Sinking Metres	Decline and Incline Metres	Driving and Cross Cutting Metres	Rising and Winzing Metres	Exploratory Drilling Metres	Total Metres
Gold—							
Murchison	Hill 50 Gold Mine N.L.	....	....	488	210	488	1 186
Dundas	Central Norseman Gold Corporation N.L.	....	....	405	37	11 868	12 310
East Coolgardie	North Kalgurli Mines Ltd.	....	....	126	....	496	622
	Kalgoorlie Lake View Pty. Ltd.						
	Fimiston	....	....	5 697	1 086	13 403	20 186
	Mt. Charlotte	....	323	2 438	1 538	8 099	12 398
	Daisy Mine	....	....	7	....	....	7
East Murchison	Scheelite Gold Mine	....	....	37	23	....	60
Yilgarn	Marvel Loch Gold Mine	....	....	11	....	104	115
	Frasers Gold Mine....	....	....	100	....	....	100
	W.A. Gold Development (Radio Mine)	10	....	50	....	....	60
	Totals in Gold Mines	10	323	9 359	2 894	34 458	47 044
Nickel—							
Coolgardie....	Western Mining Corporation Ltd.	189	4 157	9 410	2 918	155 677	172 351
	Metals Exploration N.L.	34	134	499	659	4 080	5 406
	Anaconda Aust. Inc.	....	....	2 953	1 219	....	4 172
	Selcast Exploration Ltd.	....	....	935	669	2 504	4 108
Broad Arrow	Scotia (Great Boulder-North Kalgurli)	18	....	387	166	47	618
North Coolgardie	Carr Boyd Rocks (Great Boulder-North Kalgurli)	....	....	497	255	2 533	3 285
Mt. Margaret	Windarra Mines Pty. Ltd.	33	3 691	....	995	13 983	18 702
	Total in Nickel Mines	274	7 982	14 681	6 881	178 824	208 642
Copper—							
Broad Arrow	Odin Mining and Exploration	1	....	43	....	....	44
	Totals in Copper Mines	1	....	43	....	....	44
	Totals in All Mines	285	8 305	24 083	9 775	213 282	255 730

ALUMINA

Alcoa of Australia (W.A.) Ltd. continued its expansion of bauxite and alumina production during 1974. Bauxite production amounted to 4 575 000 tonnes from the Jarrahdale No. 2 minesite and 3 067 000 tonnes from Del Park. Alumina sales totalled 1 981 205 tonnes having an estimated value of $124 800 000 f.o.b. Kwinana.

Rehabilitation of mined areas continued with 77 ha being completed at Jarrahdale No. 2 minesite and 11 ha at Del Park. In addtiion, rehabilitation of the crushing plant area, associated with the No. 1 minesite, was completed.

Expansion of the Pinjarra Refinery continued, with construction of the 3rd unit being well advanced by the end of the year. Construction of units 4 and 5 had commenced.

The average number of persons employed throughout the year was 1 966, of which, 332 were employed on bauxite production and 1 634 on alumina production.

BENTONITE

Lake deposits near Marchagee and Gunyidi were the source of the year's production of 569 tonnes.

BERYL

Seleka Mining and Investments Ltd. produced 68 tonnes from their Rothsay deposit. Seleka ceased production during the year following a marked decrease in beryl content within the pegmatite.

Other producers reported the production of 11 tonnes from the Yalgoo and Murchison Goldfields, bringing the total production to 79 tonnes with an estimated value of $14 124.

BUILDING STONE

Production from mining tenements, granted under the provisions of the Mining Act, was 5 039 tonnes valued at $121 741.

Snowstone Pty. Ltd. was the largest producer with 2 607 tonnes of crushed quartz from stockpiles at Mukinbudin. Other producers reported the production of 1 669 tonnes of quartz from Manjimup, 608 tonnes of decorative quartzite from Toodyay, 79 tonnes of spongolite from the Fitzgerald River area and 76 tonnes of Lepidolite from Londonderry in the Coolgardie Goldfield.

CLAYS

Clay production is reported from the Metropolitan, Bullsbrook, Byford, Goomalling, Clackline, Armadale and Gosnells areas, totalling 567,530 tonnes with an estimated value of $500 990.

COAL

The total output from all mines in the Collie Coalfield was 1 446 048 tonnes with a pit head value of $9 144 982. This resulted in an increase in production of 274 979 tonnes over the previous year.

The Muja open cut, operated by the *Griffin Coal Mining Co. Ltd.*, was the source of 742 638 tonnes of coal, representing 51.36 per cent of the total output of the field. *Western Colleries Ltd's* output of 703 410 tonnes was obtained from the Western No. 2 Mine (490 891 tonnes) and Western No. 5 open cut (212 519 tonnes). The report of the Senior Inspector of Coal Mines appears elsewhere in this Branch Report.

COBALT

Western Mining Corporation Ltd. reported that 135 tonnes of cobalt were contained in Nickel concentrates, produced from its treatment plants. The value of this production is estimated as being $608 308.

COPPER

Western Mining Corporation Ltd. reported that nickel concentrates produced from its treatment plants contained 267 tonnes of metallic copper having an estimated value of $341 520.

EMERALDS

Mr. R. D. Bellairs reported the recovery of 19 carats (cut) of emeralds, valued at $1 400, from old dump material on the site of the original emerald mine at Poona.

FELSPAR

Australian Consolidated Industries reported the production of 856 tonnes from its Londonderry Quarry in the Coolgardie Goldfield. *Seleka Mining and Investments Ltd* recovered 18 tonnes from its beryl operation at Rothsay, while a further 6 tonnes was reported from the Mukinbudin District.

The total production of 880 tonnes has an estimated value of $17 487.

GLASS SAND

Glass sand production totalled 280 670 tonnes valued at $306 075 which value does not include the value of 28 643 tonnes mined by the *Readymix Group* at Jandakot. The major producers were *Bell Bros. Pty. Ltd.* with 121 530 tonnes and *Silicon Quarries Pty. Ltd.* with 117 988 tonnes.

GOLD

The ore treated during the year amounted to 1 378 991 tonnes as compared with 1 630 732 tonnes for the previous year. Gold recovered was 6 583.433 kg which was 2 033.467 kg less than the 1973 production of 8 586.90 kg. Grade of ore mined was lower, recovery being 4.8 grams per tonne as compared with 5.27 grams per tonne in 1973.

The calculated value of the gold produced was $22 258 720 which included $15 990 160 distributed by the Gold Producers Association from the sale of 6 593.515 kg of gold at an average premium of $2 242.15 per kilogram.

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

TABLE 3

Principal Gold Producers

Mine	1973			1974		
	Tonnes Treated	Yield Kilograms	Grams Per Tonne	Tonnes Treated	Yield Kilograms	Grams Per Tonne
Gold Mines of Kalgoorlie (Aust.) Ltd.	542 568	2 230·21	4·11	....	....	....
Kalgoorlie Lake View Pty. Ltd.	467 831	2 032·03	4·34	470 932	2 400·62	5·1
Kalgoorlie Lake View Pty. Ltd. (Mt. Charlotte)	....	....	....	690 537	2 605·01	3·8
Lake View and Star Ltd.	224 218	1 452·80	6·48	....	....	....
Central Norseman Gold Corporation N.L.	151 903	1 135·31	7·47	114 199	900·31	7·9
North Kalgurli Mines Ltd.	131 694	735·30	5·58	35 265	161·10	4·6
Hill 50 Gold Mine N.L.	59 171	523·36	8·84	21 493	187·07	8·7
Minor Producers	53 347	477·89	8·96	46 565	329·33	7·1
Total State Production	1 630 732	8 586·90	5·27	1 378 991	6 583·43	4·8

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

Kalgoorlie Lake View Pty. Ltd. continued to operate all major shafts throughout the year, but a critical shortage of miners is considerably restricting their potential, along with other gold mining companies, to take full advantage of the continuing high price of gold.

In its first full year of operation, following the amalgamation in 1973 of leases owned by *Gold Mines of Kalgoorlie (Aust.) Ltd.* and *Lake View and Star Ltd.*, the company treated a total of 1 161 469 tonnes of ore for a recovery of 5 005.63 kg of fine gold; average recovery being 4.33 grams per tonne. The Mt. Charlotte ore body accounted for 690 537 tonnes. Approximately 75 000 tonnes of oxidised ore was mined from open cuts on the Ivanhoe, Hannans Star, Oroya and Paringa leases. Underground operations on Fimiston leases accounted for the remainder.

At Mt. Charlotte, the internal decline was driven a further 323.3 metres and has reached the No. 14 level. In all, the company carried out 11 082.7 metres of development work and 21 502 metres of diamond drilling. Ore Reserves, as at the 18th June, 1974, are reported as being 5 932 000 tonnes at an average grade of 6.1 grams per tonne. The average number of personnel employed was 1 283.

Central Norseman Gold Corporation N.L. treated 114 199 tonnes for a recovery of 900.31 kg of fine gold. Mining continues to be restricted to previously developed low grade blocks and only 442.5 metres of development work was completed during the year. Exploration was continued, with 11 868 metres of diamond drilling being achieved. Ore reserves decreased only slightly, being 245 481 tonnes at an average grade of 9.7 grams per tonne on the 30th June, 1974. An average of 252 personnel were employed throughout the year.

North Kalgurli Mines Ltd. continued mining operations on a limited scale from the Main and Kalgurli shafts. The Croesus shaft was placed on care and maintenance about mid-year. Tonnage of ore broken totalled 34 659 tonnes, but 35 265 tonnes were treated for a recovery of 161.095 kg of fine gold, being an average of 4.6 grams per tonne.

North Kalgurli ore is now treated at the *Kalgoorlie Lake View Pty. Ltd.'s* Chaffers plant, the Croesus plant being used for the treatment of nickel ore from *Anaconda's Redross Mine.* Construction of a second circuit, which will be used to treat nickel ore from *Selcast Exploration Ltd.'s* mine at Spargoville, was commenced during May.

The company reported the completion of 125.6 metres of development work and 496 metres of exploratory diamond drilling. An average of 150 personnel were employed throughout the year.

Hill 50 Gold Mine N.L. treated only 21 493 tonnes of ore during 1974 for a return of 187.067 kg of fine gold; average recovery being 8.7 grams per tonne.

An underground development programme is under way at the Hill 50 Mine. It involves the deepening of the internal shaft and the development of ore blocks above the 13, 14 and 15 levels. The Morning Star shaft is to be deepened to approximately 330 metres, with ore above this horizon being developed. Major modifications to the treatment plant have also been carried out during the year.

The company reports that 488 metres of driving and cross-cutting, 210 metres of rising and 488 metres of diamond drilling was completed during the year. An average of 82 personnel were employed throughout the year.

Great Boulder Mines Ltd. have outlined sufficient free milling, open cut ore to warrant the installation of a small treatment plant. This plant is expected to be in operation by mid-1975.

Roebourne Exploration and Mining Ltd. have erected a 90 tonne per hour alluvial concentrating plant on the outskirts of Coolgardie to process the auriferous overburden. The plant commenced production late in the year on ore mined from a 1.5-2 metre face located on the Bayleys South lease.

Marvel Loch Gold Mine. Rehabilitation of this mine continued throughout the year. Development was commenced with 11 metres of cross-cutting being completed. Short diamond drill holes, totalling 104 metres, proved the existence of several lodes at the 3 level. By the end of the year, 11 men were employed.

Mulga Mines Pty. Ltd. as managers of the Blue Spec Mine at Nullagine continued underground exploration until the end of May. Metallurgical and feasibility studies were continued, culminating in a decision to re-develop the mine and commence production by mid-1976.

Exploration consisted of 187 metres of driving, 88 metres of cross-cutting and 786 metres of diamond drilling. 300 tonnes of ore was broken, of which 35 tonnes were despatched for metallurgical test work. Ore reserves of 80 000 tonnes have been reported.

Simplex Mining Company Pty. Ltd. are carrying out exploration work on the Kitchener Mine at Bamboo Creek. A winze from the 76 metre level was advanced 18 metres. Parcels totalling 500 tonnes and averaging 15 grams per tonne were put through the Marble Bar State Battery.

Smaller producers of note were *Frasers* at Southern Cross with 28.70 kg from 3 424 tonnes, *Radio* at Golden Valley with 17.46 kg from 1 063 tonnes, *Daisy* at Mount Monger with 15.60 kg from 694 tonnes, *Halley's Comet* at Marble Bar with 22.01 kg from tailings treatment and the *Ark* at Paynes Find with 20.35 kg from 454 tonnes.

GYPSUM

Total gypsum production for the year was 162 136 tonnes valued at $460.667. Of this production, *Garrick Agnew Pty. Ltd.* reported the export of 74 609 tonnes from Useless Loop in the Shark Bay area. Plaster of Paris manufacturers reported the use of 43 601 tonnes in the manufacture of 30 412 tonnes of Plaster of Paris.

ILMENITE, LEUCOXENE, MONAZITE, RUTILE XENOTIME AND ZIRCON

Sales of ilmenite totalled 868 697 tonnes valued at $11 237 842 f.o.b. Bunbury and Geraldton. This figure includes the sales of 907 tonnes of reduced ilmenite and 14 126 tonnes of upgraded ilmenite.

Sales of other minerals recovered by beach sand miners totalled 103 312 tonnes with an f.o.b. value of $8 580 709.

A very strong demand for zircon, together with major development programmes being undertaken at the Eneabba Field, resulted in intensive activity and high capital expenditure throughout the Beach Sand Industry during the year. This expansion is expected to continue throughout 1975.

Western Titanium N.L. remain the largest producer with 280 259 tonnes of ilmenite assaying 54.59 per cent of titanium dioxide, 12 068 tonnes of upgraded ilmenite assaying 91.79% TiO_2, 907 tonnes reduced ilmenite assaying 67.64% TiO_2, 1 198 tonnes of leucoxene, 1 789 tonnes of monazite, 3 813 tonnes of rutile, 26.0 tonnes of xenotime, and 23 325 tonnes of zircon.

Mining covered an area of 27 ha, from which 2 101 000 tonnes of ore and 207 000 tonnes of waste were excavated. Rehabilitation of 12 ha at a cost of $16 000 was completed during the year.

The new, 30 000 tonnes per year, commercial upgrading plant was commissioned in mid June. This has resulted in the work force being increased by 53 persons to a total of 224. The Company is constructing brick homes within the Capel townsite to house staff personnel.

Western Mineral Sands Pty. Ltd. reported sales of 194 594 tonnes of ilmenite assaying 54.0 per cent TiO_2. This company mined 853 200 tonnes of ore from 8 ha on Mineral Claims 421H and 423H. All other minerals were sold to Westralian Sands Ltd. as a bulk concentrate.

During the year the dry mining method was replaced by dredging. A new, 250 t.p.h. Watson dredge was built, along with a new floating wet plant containing 12 Reichert Cones. The new units were commissioned during September/October and were in full production by the end of the year.

Westralian Sands Limited reported sales of 148 634 tonnes of Ilmenite assaying 56.68 per cent TiO_2, 2 058 tonnes of secondary ilmenite (HYTI 68), 8 911 tonnes of leucoxene, 32 128 tonnes of zircon and 324 tonnes of monazite.

During the year the company expanded its zircon production circuit and recommenced mining and wet concentration at Yoganup, where 236 000 tonnes of ore was mined. At Yoganup Extended 1 505 000 tonnes of ore was mined from 10.4 ha on Mineral Claims 674H and 1839H.

At the end of the year the company was preparing for a major construction programme involving the expansion of the Capel Dry Plant facilities and the commencement of a new mine in the Busselton area.

Rehabilitation of old mining pits in the Yoganup area was commenced. 24 ha have now been partially rehabilitated at a cost of $60 000.

Cable Sands Pty. Ltd. (previously *Ilmenite Minerals Pty. Ltd.* and *Cable (1956) Ltd.*) reported the sales of 199 998 tonnes of ilmenite at 54.97 per cent TiO_2, 13 393 tonnes of zircon, 5 234 tonnes of leucoxene and 549 tonnes of monazite.

Although the company cut back production during the first half of the year, the negotiation of new contracts resulted in a return to maximum output by the end of the year.

At Stratham, mining by dredging produced 767 000 tonnes from 4 ha while at Wonnerup 464 000 tonnes were mined by dry mining methods from 6.2 ha. Rehabilitation of mined areas was carried out progressively behind the mining face.

Jennings Mining Limited commenced production of mineral sands during the year. The initial mining site, which is located approximately 3 km east of the Eneabba Townsite, had produced 2 341 000 tonnes of ore from 19.75 ha by the end of the year. Mining of the compact sands is relatively simple and is performed by bulldozers which push the sands into a transportable feed hopper. The sands are conveyed to a pulping hopper, from which they are pumped to the Wet Concentration Plant.

The Wet Concentration Plant is of a basically standard design, using Reichert Cones and spirals for concentration of the heavy minerals.

Extremely high water loss, due to high ground porosity, has proved to be a major operating problem. The company is planning the installation of two × 60 metre diameter thickeners to eliminate the necessity of the existing settling dams which result in such losses.

The mineral concentrates are road hauled to Dongara, from where they are railed to the Dry Separation Plant which is situated approximately 10 km south of Geraldton.

The company reports that it had extracted 27 041 tonnes of ilmenite assaying 59.59 per cent TiO_2, 325 tonnes of leucoxene, 7 125 tonnes of rutile and 4 627 tonnes of zircon from 166 917 tonnes of concentrates produced at Eneabba.

This new operation has resulted in the employment of 108 personnel directly involved in the mining and production of mineral sands.

Allied Eneabba Pty. Ltd. commenced construction of plant for a major mineral sand mining venture following successful trial runs in its pilot plant. The company is expected to commence mineral production in mid 1975.

During the operation of the pilot plant the company produced 3 138 tonnes of ilmenite assaying 61.0% TiO_2, 337 tonnes of rutile and 208 tonnes of zircon.

W.M.C. Mineral Sands Ltd. commenced plant construction on its claims at Jurien Bay following the successful take over of *Black Sands Ltd.* Production of mineral concentrates is expected to commence during the first quarter of 1975. Unlike the Eneabba operations, dry plant facilities are being installed on site, and only mineral products will be transported to Geraldton.

IRON ORE

Iron ore production increased by 14.6 per cent to 87 087 748 tonnes valued at $593 051 596. This figure includes the production of 5 558 742 tonnes of pellets valued at $54 148 775 and 1 080 573 tonnes of ore used in the production of pig iron. Iron ore exports, including pellet and sinter sales are tabulated in Table 4.

TABLE 4

Overseas Iron Ore Exports

Company	Sales Tonnes (t)	Grade % Fe
Hamersley Iron Pty. Ltd.	31 931 278	63·78
Mt. Newman Mining Co. Pty. Ltd.	26 534 197	63.00
Cliffs W.A. Mining Co. Pty. Ltd.	10 659 493	59·49
Goldsworthy Mining Ltd.	7 762 307	63·35
Dampier Mining Co. Ltd.	3 188 854	67·39
Western Mining Corporation Ltd.	527 601	59·89
Totals	80 603 730	63·03

Hamersley Iron Pty. Ltd. exported 30 343 465 tonnes of iron ore and 1 587 813 tonnes of pellets having a total value of $216 338 428 f.o.b. Dampier.

At Tom Price 36 085 000 tonnes of material was broken, of which 19 961 000 tonnes was high grade ore, 11 335 000 tonnes low grade ore and 4 789 000 tonnes was waste.

A total of 15 553 000 tonnes of ore was delivered to the crusher.

The company currently mines from eight production benches in three pits covering an area of 4 400 metres by 1 000 metres.

At Paraburdoo, mining was concentrated in an area 1 400 metres long by 800 metres wide from which 31 533 000 tonnes of material was broken. Of this, 19 023 000 tonnes were delivered to the crusher.

During the year the company increased its work force by 737 persons to a total of 3 713.

Mount Newman Mining Co. Pty. Ltd. exported 26 534 197 tonnes of iron ore valued at $178 707 933 f.o.b. Port Hedland. In addition, 4 035 930 tonnes, valued at $22 167 180, was shipped to the Eastern States.

At Mt. Whaleback 83 030 000 tonnes of material was broken, being 47 496 000 tonnes of ore and 35 534 000 tonnes of waste.

The company is currently expanding mine, port and railway facilities to meet a planned, yearly production of 40 000 000 tonnes of iron ore by 1976. In addition to the equipment listed below which was introduced during the year, Mt. Newman Mining have ordered 22 cu.yd. shovels and 180 tonne haulage trucks.

Major Items of Plant introduced during 1974

- 2 off B.E. 60—R Rotary Blast Hole Drills.
- 1 off Cat. 824 B Rubber tyred Dozer.
- 5 off Cat. D9G Crawler Dozers.
- 1 off Cat. 16 G Road Grader.
- 6 off Wabco 120B 120S. ton trucks.
- 1 off Allis Chalmers 2 000 t.p.h. Gyratory Secondary Crusher.
- 1 off 3.5 Megawatt Generator.
- 1 off 6 000 t.p.h. Bucket Wheel Reclaimer.
- 6 off 3 900 hp Goodwin Alco Locomotives.
- 380 off 110 long ton Gondola Ore Cars.

During the year the company increased its work force by 433 persons to a total of 2 608.

Cliffs W.A. Mining Co. Pty. Ltd. increased exports by 30.59 per cent over the previous year with shipments totalling 3 970 929 tonnes of pellets and 6 688 564 tonnes of sinter fines with a combined value of $73 138 082 f.o.b. Cape Lambert.

From its single bench pits on the tops of flat mesas in the Robe River Valley, the company produced 12 240 000 tonnes of material, all of which is road hauled directly to the rail loading facility for transportation to Cape Lambert as ore.

The average number of personnel employed by the company was 1 176, being an increase of 408 personnel over the previous year.

Goldsworthy Mining Ltd. reported the sale of 7 762 307 tonnes of iron ore valued at $54 759 149 f.o.b. Port Hedland. This is a decrease of 532 653 tonnes on the previous years sales.

The ore was obtained from Mt. Goldsworthy, Shay Gap and Sunrise Hill, where a total of 7 843 805 tonnes of ore and 15 353 958 tonnes of waste was broken. The company employed an average of 1 108 personnel during the year.

Exploration and feasibility studies for the proposed operation based on the Marra Mamba Iron Formation in Mining Area "C" continued throughout the year. This project is expected to cost in excess of $400 million and envisages the construction of a major pelletising plant. Mining is expected to commence by 1978-1979.

Dampier Mining Co. Ltd. produced a total of 5 550 006 tonnes of iron ore from its quarries which are located at Koolyanobbing and on Cockatoo and Koolan Islands.

From Koolan Island, 2 550 962 tonnes, with an f.o.b. value of $19 071 411, were shipped overseas, and 25 083 tonnes were shipped to the Eastern States. From Cockatoo Island, 534 254 tonnes (68.90% Fe) with an f.o.b. value of $4 416 443 were shipped overseas, and 194 601 tonnes were shipped to the Eastern States.

On Koolan Island mining continued along the southern shore line on the 98 and 110 metre horizons, from which 2 598 875 tonnes of ore and 2 771 024 tonnes of waste were broken. A total of 32 500 000 tonnes of ore and waste has now been mined from the Island.

Increased production is planned from Koolan Island and 5 new R85 Euclid Haul Trucks were placed in operation during the year. Engineering investigations, ore reserve studies and 650 metres of exploration drilling have outlined ore reserves of 40 000 000 tonnes at an average grade of 65.5% Fe. Mining is expected to eventually reach the—60 metre horizon and may even be possible to the—145 metre horizon.

On Cockatoo Island mining continued along the southern shore line on the 12 and 24 metre horizons, from which 935 434 tonnes of ore and 516 310 tonnes of waste were broken. A total of 34 700 000 tonnes of ore and waste has now been mined from the Island.

Koolyanobbing Production was 2 245 106 tonnes averaging 63.0 per cent Fe and having a nominal value of $15 452 738. Of this production, 1 251 469 tonnes was shipped from Kwinana to the Eastern States, 103 638 tonnes to overseas buyers and the remaining 889 999 tonnes was delivered to the Kwinana blast furnace.

Material broken during the year consisted of 2 203 084 tonnes of ore and 2 234 825 tonnes of waste. Exploration drilling continued with a further 2 272 metres being completed.

Of the 439 personnel employed, 200 were located on Koolan Island, 134 on Cockatoo Island and 105 at Koolyanobbing.

Western Mining Corporation Ltd. at Morawa ceased production during the year after having completed its contract commitments.

During the year the company exported 527 601 tonnes of 59.89 per cent Fe ore valued at $3 580 424. Some ore still remained in stockpiles at Geraldton awaiting shipment during 1975.

Before closing down Western Mining crushed and screened 355 100 tonnes of ore, of which, 106 729 tonnes was from Mungada and the remainder from Koolanooka stock piles. The company had been progressively reducing its workforce and only 50 personnel were employed at Morawa during the year. A further eight men were employed at Geraldton. The Geraldton ship loading facilities will remain in service for the loading of mineral sands from the Eneabba and Jurien Bay producers.

Western Mining commenced mine development in 1965 for commencement in 1966 of an eight year contract to supply 5 200 000 tonnes (5 100 000 tons) of iron ore to Japanese interests. By the end of 1974 the company had exported 5 240 389 tonnes of 60.09 per cent Fe ore valued at $39 028 289.

Wundowie Iron and Steel is the company formed to operate the Charcoal Iron and Steel Industry following its purchase from the Western Australian Government by a division of Agnew Clough.

At the Koolyanobbing mine site the company produced 103 000 tonnes of ore, of which 92 000 tonnes was railed to Wundowie. Eleven men were employed at the minesite throughout the year. At Wundowie, 86 936 tonnes of ore was treated for the production of 53 378 tonnes of pig iron valued at $3 906 401.

Australian Iron and Steel Limited reports that it processed 1 050 000 tonnes of iron ore for the recovery of 646 000 tonnes of pig iron. For this production 160 000 tonnes of limestone, 12 000 tonnes of manganese and 445 000 tonnes of coke were consumed. An average of 360 employees were engaged in the blast furnace operations.

The blast furnace was relined during the year, necessitating a seven week shut down.

LEAD

Mining activity continued at a low ebb during 1974 and no sales were reported to the Mines Department. The Northampton State Battery treated 705 tonnes of ore from *McGuires Lead Mine*, for a recovery of 102.6 tonnes of concentrate. Also treated, were 205 tonnes from the *North Ellen*, for a recovery of 18.7 tonnes of concentrate, and 1 033 tonnes from the *Mt. Erin Syndicate*, for a yield of 72.3 tonnes of combined Lead-Zinc concentrate.

LIMESTONE

Reported production of limestone was 1 157 316 tonnes valued at $1 275 064. The only major producer away from the Metropolitan and surrounding districts was Hamersley Iron Pty. Ltd. with 232 962 tonnes from the West Pilbara.

LITHIUM

Australian Glass Manufacturers Co. Pty. Ltd. reported the production of 1 tonne of Petalite from its Londonderry quarry.

MANGANESE

Westralian Ores Pty. Ltd. reported the shipment of 18 107 tonnes valued at $336 655 from its stockpiles.

MARBLE

Kinetic Mining worked the Nanutarra and Wyloo deposits throughout the year. Although production figures have not yet been reported to this Department, the District Inspector reports that a trial sample has been shipped to Italy and the remaining production transported to Perth.

MICA

Mineral By-Products Pty. Ltd. report the production of 34 tonnes of Mica from Yellowdine in the Yilgarn Goldfield. The f.o.r. value is estimated at $418.

NICKEL

The value of nickel ore and concentrate production increased by 36.04 per cent, to a new high of $126 292 134. This includes production from Kambalda, Scotia, Carr-Boyd Rocks, Redross and Nepean, but not Windarra, as the operating company had not reported its figures to this Department in time for publication.

Statistics relating to the Nickel Industry are tabulated in Table "5".

TABLE 5
Nickel Producers

Product and Producer	Centre	Quantity Tonnes	Grade % Ni	Value $
NICKEL CONCENTRATES				
Western Mining Corporation Ltd.	Kambalda	337 339·00	12·26	109 956 965
Great Boulder Mines Ltd. and North Kalgurli Mines Ltd.	Scotia	8 665·88	16·01	3 677 000
Great Boulder Mines Ltd. and North Kalgurli Mines Ltd.	Carr-Boyd Rocks	11 593·43	9·36	3 006 200
Anaconda Australia Inc.	Redross	10 659·30	16·07	4 818 194
Sub Total		368 257·61	12·367	121 458 359
NICKEL ORE				
Metals Exploration N.L.	Nepean	68 791·00	3·36	4 833 775
Total Ore and Concentrates		437 048·61		126 292 134

Western Mining Corporation Ltd. at Kambalda produced 337 339 tonnes of Nickel Concentrates averaging 12.26 per cent Ni from the treatment of 1 301 178 tonnes of ore. In addition, Western Mining processed 68 791 tonnes of ore from the Nepean Mine. A vigorous development programme was continued throughout the year, with 189 metres of shaft sinking, 4 157 metres of decline, 9 410 metres of driving and cross-cutting, 18 metres of winzing and 2 901 metres of rising being completed.

Exploratory diamond drilling of 96 427 metres outlined sufficient new ore to slightly increase reserves to 24 550 000 tonnes at 3.22 per cent Ni. At Kambalda, additions were made to ore potential at depths to about 800 metres. On the eastern side of the dome, extensions to Long, Victor, Gibbs and Lunnon shoots were proved. On the northern side, the Juan mineralisation was extended. In the Paris-St. Ives area, testing on the East Bluebush line located nickel sulphide mineralisation. Drilling on Lake Lefroy between Kambalda and St. Ives indicated major southern extensions of the Lunnon and Hunt ore bodies.

Two new mines were commenced during the year, namely the Jan vertical shaft at St. Ives and the Edwin inclined shaft further south. Besides these two shafts, the Company operates the Durkin and Silver Lake shafts and the Hunt, Otter-Juan, Fisher and McMahon declines.

Surface plant was increased by the installation of No. 10 alternator and two additional 1 000 tonne silos with rail loading facilities.

Silver Lake Shaft. Shaft sinking ceased at the 13 level and development of the 11 and 12 levels commenced. Stoping of the Hunt ore body at the 9 level began during the year. Placement of sand in cut and fill stopes, and in old open stopes increased during the year. A balance has now been achieved between ore broken and fill placed.

Durkin Shaft. Steady ore production of approximately 26 000 tonnes per month was maintained; development continued on all levels.

Sinking of the Jan shaft commenced in the first quarter with a depth of 160 metres (4 level) being reached by the end of the year. Retractable air legs anchored on overhead chains were introduced on this operation. The 22½° inclined Edwin Shaft had reached a depth of 30 metres by the end of the year. This shaft is 13 kilometres south of the Jan shaft and is to be sunk to a depth of 300 metres on a small high grade shoot.

Otter-Juan Decline. Development of the decline on the Jan shoot has now passed the 11 level. Preparations are under way to install an underground crusher at the 10 level. Crushed ore will be hauled to the surface through a 2.44 metre diameter raise bore hole. Production continued from all levels.

Hunt Decline. The decline has now reached a position between the 4 and 5 levels at a distance of 1 100 metres from the portal.

Level development and production continued from the Hunt and McMahon declines.

Western Mining Corporation's Nickel Smelter at Hampton completed its first full year of production. Treatment of 144 757 tonnes of concentrate gave a recovery of 20 607 tonnes of matte containing 14 632.4 tonnes of nickel. During the last quarter the capacity of the smelter was increased by approximately 50 per cent following the commissioning of a 200 tonne per day oxygen generating plant. A second slag cleaning furnace and a third Pierce Smith converter were under construction at the close of the year.

Treatment of concentrates from the Windarra Nickel Mine began during the last quarter.

The company's nickel refinery at Kwinana produced 20 522 tonnes of briquettes and powder. By-products produced, consisted of 3 077 tonnes of copper sulphide, 373 tonnes of mixed sulphides and 140 354 tonnes of ammonium sulphate.

Of the 2 329 personnel employed by Western Mining on nickel operations, 1 596 were employed at Kambalda, 313 at the smelter and 420 at the Kwinana Refinery.

The Scotia operations of the *Great Boulder Mines Ltd* and *North Kalgurli Ltd.* partnership, produced 8 665.88 tonnes of 16.01 per cent nickel concentrate valued at $3 677 000. The ore treated at Fimiston was only 82 067 tonnes representing a decrease of 47 607 tonnes on the previous years throughput. This decrease was brought about by the failure of the floor pillar below the 660 level and the subsequent hanging wall collapse on July 9th, which halted all ore production from and above the 830 level in the main stoping block. Rehabilitation of the mine and the introduction of a cut and fill mining method has allowed resumption of mining on a reduced scale.

Development during the year consisted of 18 metres of shaft sinking, 322 metres of driving, 64 metres of cross-cutting and 166 metres of rising. Ore reserves have been cut to 554 900 tonnes at 2.1% Ni, largely as a result of the hanging wall collapse.

At Carr-Boyd Rocks, production for the year was more than doubled, with 96 112 tonnes being treated for the recovery of 11 593 tonnes of 9.36 per cent nickel concentrates valued at $3 006 200. Production was rapidly increased following the Scotia hanging wall collapse. Development for the year was 446 metres of driving, 51 metres of cross-cutting, 4 metres of winzing and 251 metres of rising. Also completed were 2 533 metres of diamond drilling. At the end of June, ore reserves above the 300 metre horizon were reported as being 793 510 tonnes averaging 1.61% Ni and 0.50% Cu. An average of 392 personnel were employed at Scotia, Carr Boyd and Fimiston.

Anaconda Australia Inc., treated 71 870 tonnes of ore at the Croesus plant. The company reported production of 10 659 tonnes of 16.07% Ni concentrate valued at $4 818 194. A lack of skilled miners considerably hampered mine production throughout the year. Development consisted of 2 889 metres of driving, 64 metres of cross-cutting and 1 219 metres of rising. (Includes 728 metres of raiseboring).

Ore reserves are reported as being 768 400 tonnes at 3.5% Ni. Personnel employed averaged 126.

A sand fill plant for the supply of fill to the cut and fill stopes was constructed during the year. Also constructed were workshops, administrative buildings and explosives magazines at the minesite, and an administrative building and houses at Norseman.

Metals Exploration N.L. reported the production of 68 791 tonnes of ore assaying 3.36% Ni and valued at $4 833 775. All ore was treated by Western Mining at Kambalda.

The shaft was sunk a further 34 metres and an ore bin has been commissioned below the 8 level. Development was carried out on the 7 and 8 levels, with the 7 level being connected to the internal decline from the 6 level. Stoping operations were progressively converted from gravel filled rill stopes to flat back cut and fill stopes. Prolonged wet weather necessitated the installation of a fill drying plant and storage shed. Mine production has been hampered by a shortage of suitable labour and the company is erecting several houses in Coolgardie in an effort to attract married men to the district.

Development for the year consisted of: shaft sinking 34 metres, decline 134 metres, driving and cross-cutting 499 metres, winzing 66 metres and rising 594 metres. Diamond drilling amounting to 4 080 metres was also carried out.

Selcast Exploration Limited confined its operations, almost entirely, to development and exploration drilling. Development consisted of: driving 438 metres, cross-cutting 497 metres, winzing 7 metres and rising 662 metres. Diamond drilling totalled 2 504 metres.

The company reports ore reserves as being 493 036 tonnes at 3.19% Ni. When production commences, the ore will be treated at the Croesus plant of North Kalgurli Mines Ltd. which is now undergoing extensions to meet the increased throughput. An average of 75 men were employed throughout the year.

Windarra Nickel Mines Pty. Ltd. have commenced production from both the Mt. Windarra and the South Windarra deposits. Development rapidly increased following the injection of finance and expertise into the operation by Western Mining Corporation Ltd. Production commenced in earnest following the commissioning of the concentrator in September.

The concentrator treated 186 406 tonnes, being 126 759 tonnes from Mt. Windarra and 59 647 tonnes from South Windarra, from which approximately 17 000 tonnes of concentrates were produced.

At Mt. Windarra, the main decline was at the 200 metre vertical horizon. "A", "E" and "D" shoots are being worked at various horizons using the long hole drilling—open stope mining method. As stopes are mined out they will be filled with dry sand and waste rock. All ore handling is performed by diesel powered, trackless equipment.

The South Windarra open-cut is approximately 60 metres deep and is being mined by conventional quarrying methods using airtrac drills and front end loaders on 10 metres high benches.

During the year the company completed 33 metres of shaft sinking at South Windarra, along with 3 691 metres of decline crosscuts and drives, plus 995 metres of rising at Mt. Windarra. Exploration drilling covering both deposits totalled 13 983 metres.

Ore reserves are reported as being 5 600 000 tonnes averaging 1.93% Ni at Mt. Windarra and 3 200 000 tonnes averaging 1.96% Ni at South Windarra. 360 personnel were employed throughout the year.

Agnew Mining Co. Pty. Ltd. (previously *Western Selcast)* is a new company formed during the year by *Western Selcast Pty. Ltd.*, and *Mount Isa Mines* to operate the Perseverance project at Agnew.

Work on the project was confined to feasibility studies and only nine men were employed at the site. Ore reserves are now reported as being 47 321 000 tonnes at 2.03% Ni.

PALLADIUM AND PLANTINUM

Western Mining Corporation Ltd. reported the sale of nickel matte containing 163.72 kg of palladium valued at $428 700 and 59.54 kg of platinum valued at $227 200.

PETROLEUM

Shipments of Barrow Island Crude Oil totalled 13 801 191 barrels having an estimated value of $31 257 311 at the Kwinana refinery. Production of gas from Dongara was 831.6 million cubic metres with a nominal well head value of $5 285 738. Condensate recovery from the gas amounted to 4 287.5 tonnes. The report of the Senior Petroleum Engineer covers more fully the activities of companies engaged in oil search and production.

SALT

Salt production increased by 572 555 tonnes to 3 906 492 tonnes with an estimated f.o.b. value of $11 576 831.

Texada Mines Pty. Ltd. reported the shipment of 1 513 556 tonnes of salt. Total langbeinite production of 68 800 tonnes was stockpiled. The company extracted its products from the mining of 2 011 000 tonnes of raw salts concentrated in 1 800 hectares of ponds. An average of 267 personnel are now employed by the company.

Dampier Salt Ltd. shipped 1 317 267 tonnes of salt from Mistaken Island. Thirty crystalliser ponds covering 738 hectares are now in production and during the year they produced 1 336 664 tonnes of raw salt. Throughout the year, 135 persons were employed.

Leslie Salt Company shipped 981 304 tonnes from Port Hedland. The company mined 1 049 891 tonnes from 16 crystallizer ponds covering an area of 512 hectares. Number of personnel employed was 53.

Lefroy Salt Pty. Ltd. shipped 94 365 tonnes of salt recovered from its operations on Lake Lefroy. During the year a large washing plant was installed and plans are in hand for the construction of further washing facilities to give a combined capacity of 500 000 tonnes per year. Sixteen men were employed throughout the year.

Other salt producers in the State were *Shark Bay Salt* and *W.A. Salt Supply*. The production of *Shark Bay Salt* is not recorded by this Department. *W.A. Salt Supply* is a small operation producing for the local market.

SEMI-PRECIOUS STONES

Amethyst, chalcedony, green beryl, moss opal, opal and quartz valued at $30 875 were obtained from deposits in the Gascoyne, Murchison, Dundas, North East Coolgardie and Pilbara Goldfields.

Of particular note was the recovery of 4.323 kg of opal valued at $16 994 from the Kurnalpi district.

SILVER

Silver is now being produced as a by-product from both gold and nickel mining. Gold mining accounted for 1 604.213 kg valued at $118 458, while nickel mining produced 114.14 kg valued at $11 256.

TALC

Three Springs Talc Pty. Ltd. increased sales over the previous year by 54.9 per cent to 56 985 tonnes. Some of this increase was as the result of sales of second grade talc, much of which was recovered from mine stockpiles.

From the quarry, the company mined 51 800 tonnes of talc and 30 000 tonnes of waste. 10 men were employed throughout the year.

Westside Mines N.L. experienced considerable difficulty in achieving steady production during the year. Buyers specifications necessitated the re-development of the pit to open up higher grade ore and bad road conditions considerably restricted transportation between the Mine and Meekatharra.

The company reports that 4 668 tonnes were produced and an average of 10 personnel were employed. Plans are in hand for the construction of a grinding mill at North Fremantle.

TANTALO-COLUMBITE

The Greenbushes Mineral Field was the only source of production, with 138.01 tonnes valued at $729 163 for a Ta_2O_5 content of 5 912 units.

TIN

Production for the year was 880.5 tonnes of concentrates containing 606.3 tonnes of tin valued at $2 918 919. Although production of contained tin decreased by 261 tonnes on the 1973 production, the escalation in the price of tin yielded an increase in the gross income by $265 500.

Greenbushes Tin N.L. remain the State's leading producer with 611.09 tonnes of concentrate valued at $2 167 495. The company has continued to concentrate its mining into larger open cuts, sited on primary ore lodes. Mining depths of 30 to 40 metres are anticipated in some areas. 1 297 000 tonnes of ore was mined and treated. Waste removal amounted to 354 700 tonnes, of which a considerable quantity was used as back filling in old mining pits. The average number of personnel employed was 86.

Vultan Minerals Ltd. mined and treated 423 000 tonnes of ore, mainly from Mineral Lease 648 known as "Tantalite Corner". Sales of 138.58 tonnes of tin concentrates, valued at $330 612, were reported to the Mines Department.

In the Pilbara the principal producers were *Pilbara Tin Pty. Ltd.* with 37.96 tonnes and *J. A. Johnston* and *Sons Pty. Ltd.* with 22.09 tonnes of concentrates. *Yule River Mining Pty. Ltd.* at Friendly Creek in the West Pilbara, recovered 48.31 tonnes of concentrate valued at $156 675.

VERMICULITE

Mineral By-Products Pty. Ltd. reported the production of 225 tonnes of vermiculite valued at $2 767, from its open cut at Mt. Palmer.

MINE INSPECTION AND ACCIDENT STATISTICS

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

ACCIDENT STATISTICS

The statistics are for accidents reported to the Mines Department and cover all classes of mining but do not include those accidents associated with oil exploration and production.

There were 12 (12) fatal and 699 (507) serious accidents. (The corresponding figures for the previous year are shown in brackets.)

A diagram showing the fatal accidents segregated according to the class of mining operation and extending over the past twenty years appears below. (The accidents occurring in the oil exploration and production operations shown in this diagram in past years have been removed.)

Table A gives the number of serious accidents segregated according to the nature of the injury, and 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.

DIAGRAM OF FATAL ACCIDENTS

SEGREGATED ACCORDING TO CLASS OF MINING

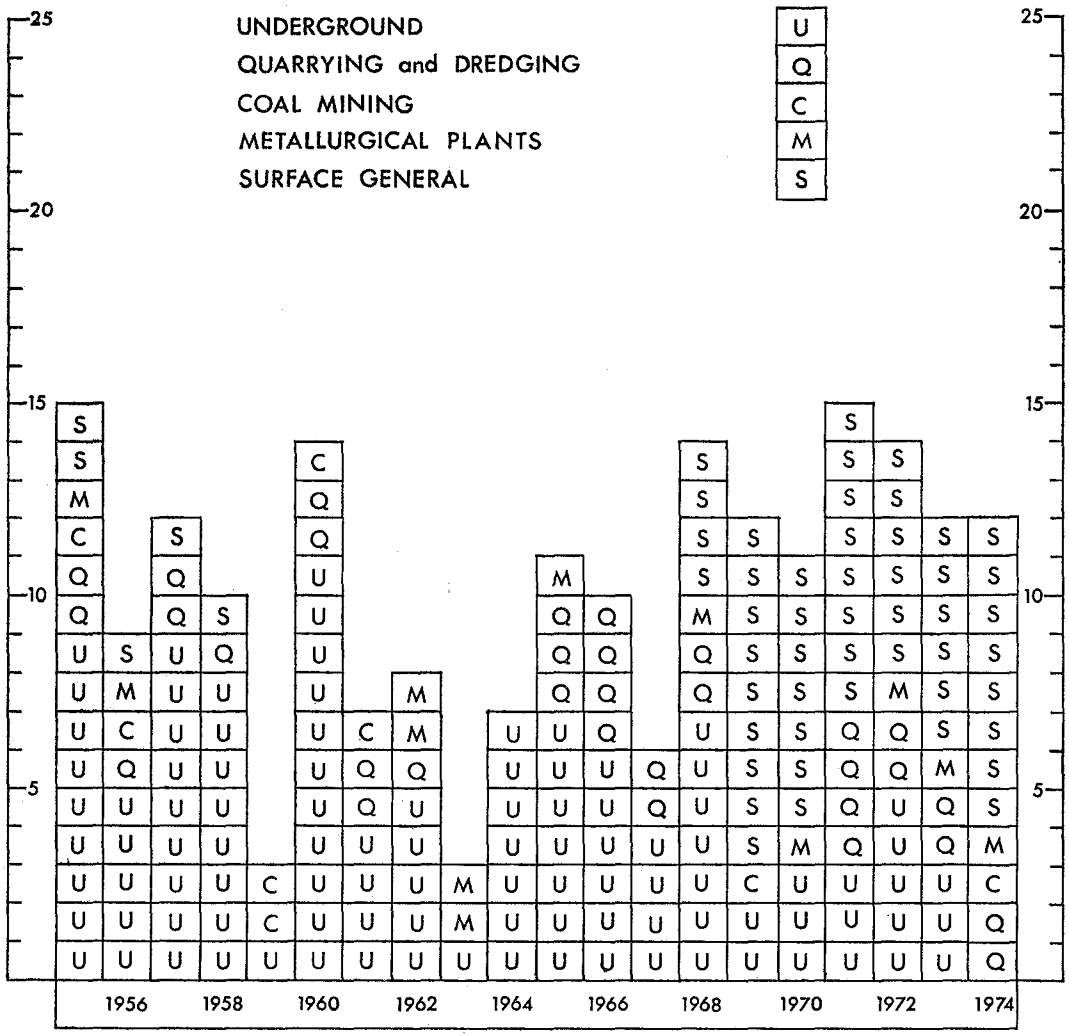


TABLE "A"
SERIOUS ACCIDENTS FOR 1974

Class of Accident	West Kimberley	Pilbara	West Pilbara	Peak Hill	Gascoyne	Murchison	North Coolgardie	Mount Margaret	Broad Arrow	East Coolgardie	Coolgardie	Dundas	Yilgarn	South West	Greenbushes	Collie	Total
Major Injuries (exclusive of fatal)—																	
Fractures—																	
Head	....	1	....	....	....	....	....	....	1	....	....	....	....	....	....	....	2
Shoulder	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Arm	....	....	2	2	....	....	....	....	....	....	1	....	....	3	....	....	8
Hand	....	....	....	....	....	....	1	1	....	3	4	....	....	2	....	....	11
Spine	....	....	....	....	1	....	....	....	....	....	....	....	....	2	....	....	3
Rib	....	....	1	....	2	....	....	....	2	3	2	....	....	....	....	2	12
Pelvis	....	....	....	....	....	....	....	....	....	1	1	....	....	....	....	....	2
Thigh	....	....	1	1	....	....	....	....	....	1	1	....	....	....	....	....	4
Leg	....	....	4	....	1	....	....	....	....	2	5	....	1	2	....	1	16
Ankle	....	1	....	1	....	....	....	2	....	....	2	....	....	2	....	....	8
Foot	....	....	2	....	....	....	....	....	....	1	5	....	....	2	....	2	12
Amputations—																	
Arm	....	....	....	....	....	....	....	....	....	1	....	....	....	2	....	....	3
Hand	....	....	....	....	....	....	....	....	....	....	1	....	....	....	....	....	1
Finger	....	....	....	....	....	....	....	....	....	....	4	....	1	1	....	....	6
Leg	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Foot	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Toe	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Loss of Eye	....	....	....	....	....	....	....	1	....	1	....	....	....	....	....	....	2
Serious Internal	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Hernia	....	1	1	1	....	....	....	....	....	4	1	....	....	1	....	1	10
Dislocations	....	....	1	1	....	....	....	....	....	1	....	....	....	1	....	....	4
Other Major	....	1	....	1	1	....	....	....	....	....	....	....	....	5	....	....	8
Total Major	....	4	12	7	5	....	1	4	3	18	27	....	2	23	....	6	112
Minor Injuries—																	
Fractures—																	
Finger	....	1	3	1	....	....	....	....	1	8	10	....	....	3	....	....	27
Toe	....	....	....	....	....	....	....	....	....	....	3	....	....	3	1	1	8
Head	....	1	1	....	1	....	....	....	....	3	3	....	....	1	....	....	10
Eye		1	....	1	1	....	....	....	....	7	6	1	....	1	....	....	18
Shoulder	....	2	....	1	2	....	....	....	....	5	4	....	....	2	....	3	19
Arm	....	4	4	....	3	1	....	....	....	11	8	2	....	4	....	3	40
Hand	....	4	5	1	1	3	1	3	1	40	22	1	....	16	....	3	101
Back	....	9	10	2	2	....	3	1	3	30	25	3	2	31	....	26	147
Rib	....	1	....	....	....	....	....	....	....	3	....	....	....	1	....	1	6
Leg	....	7	12	2	3	1	....	1	....	21	22	3	....	9	....	12	93
Foot	....	4	4	....	3	....	1	2	2	17	13	2	....	7	....	6	61
Other Minor	1	2	7	1	2	....	....	....	....	23	7	2	....	3	....	9	57
Total Minor	1	36	46	9	18	5	5	7	7	168	123	14	2	81	1	64	587
Grand Total	1	40	58	16	23	5	6	11	10	186	150	14	4	104	1	70	699

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

TABLE "B"

ACCIDENTS SEGREGATED ACCORDING TO MINERAL MINED AND PROCESSED

Mineral	Men Employed	Accidents		
		Fatal	Serious	Minor
Bauxite (Alumina)	1 966	....	52	60
Coal	685	1	70	316
Gold	2 219	2	169	297
Gypsum	29	....	1	7
Ilmenite etc.	583	....	15	88
Iron	9 465	7	123	599
Nickel	3 589	1	228	705
Salt	650	....	24	80
Tin	123	....	1	11
Other Minerals	170	....	2	....
Rock Quarries	183	1	14	31
Totals	19 662	12	699	2 194

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	....	....	....	....	....	....	....	....	....	....	....	1	....	1
Pilbara	....	....	....	....	....	....	....	....	....	....	3	40	3	40
West Pilbara	....	....	....	1	....	....	....	....	....	....	4	57	4	58
Ashburton	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Peak Hill	....	....	....	....	....	....	....	....	....	....	....	16	....	16
Gascoyne	....	....	....	....	....	....	....	....	....	....	....	23	....	23
Murchison	....	....	....	....	....	1	....	....	....	4	....	....	....	5
East Murchison	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Yalgoo	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Northampton	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Mount Margaret	....	....	....	....	....	....	....	....	....	5	....	6	....	11
North Coolgardie	....	....	....	....	....	....	....	....	....	5	....	1	....	6
Broad Arrow	....	....	....	2	....	....	....	....	....	7	1	1	1	10
North East Coolgardie....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
East Coolgardie	....	1	....	1	....	3	....	3	....	87	1	91	1	186
Coolgardie	....	1	....	11	....	2	....	....	....	100	....	36	....	150
Yilgarn	....	....	....	....	....	1	....	....	....	....	....	3	....	4
Dundas	....	....	....	1	....	....	....	....	....	8	1	5	1	14
Phillips River	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Greenbushes	....	....	....	....	....	....	....	....	....	....	....	1	....	1
South West	....	....	....	....	....	....	....	....	....	....	1	104	1	104
Collie	....	....	....	6	....	....	....	....	....	48	1	16	1	70
Nabberu	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Warburton	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Eucla	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Total for 1974	....	2	....	22	....	7	....	3	....	264	12	401	12	699
Total for 1973	1	4	1	20	....	5	....	....	1	191	9	287	12	507

WINDING MACHINERY ACCIDENTS

Nine accidents involving winding machinery and associated equipment were reported during the year and are briefly as follows:

Overwinds (4). On the 9th January an overwind occurred in the Mt. Charlotte haulage shaft of Kalgoorlie Lake View Pty. Ltd. when ore was being hoisted from the No. 10 level loading pocket. Although the driver applied full dynamic braking when the fast moving east skip passed the brace, the skip was not stopped till it reached a point above the normal highest working position and became jammed in the headframe. No damage resulted from this accident.

Inattention on the part of the driver was responsible for an overwind at the change of shifts at the Mt. Charlotte haulage shaft on the 22nd January. The empty west skip was stationary about six metres below the brace when the driver applied power in the wrong direction and before he realised his mistake the detaching hook entered the thimble and the rope was detached from the skip. No damage was caused to the rope or skip.

The east skip was in the tipping position, at the Mitchell shaft at Scotia on the 16th September, when the driver applied power in the wrong direction. The rope was detached and the skip suspended by the thimble.

On the 19th September the south skip in the Ivanhoe shaft, Kalgoorlie Lake View Pty. Ltd., was overwound and the rope detached from the skip when adjustments were being carried out to the limit switch.

Cage/Skip hang up (5). Small rocks caused two skips to become jammed at the dumping positions in the headframes at the Silver Lake and Durkin shafts of Western Mining Corporation Ltd.

No person was injured when a descending cage, in which seven men were travelling, was hung up in the Silver Lake shaft on the 23rd July when the emergency brake was applied.

At the No. 12 level of the Silver Lake shaft on the 20th November the platman signalled for the chaired cage to be lowered to the No. 13 level. Several metres of rope was let out before the platman realised his mistake. The damaged rope was cut and reshod.

The jamming of the north skip in the headframe at the Redross shaft of Anaconda Australia Inc. on the 11th December caused the rope to become slack in the south compartment with the result that the skip was supported on its grippers. A build up of rock particles around the hinges of the north skip dump door prevented it from closing properly and the leading edge fouled the shaft set.

PROSECUTIONS

It was found necessary to prosecute six persons during the year. All were successfully conducted by a Departmental officer.

A mine manager was prosecuted for employing men underground on a Sunday. The prosecution was only initiated after it was found that the men were being employed for long periods without having at least one day off work per week.

Five employees of the company were prosecuted for accepting employment contrary to the provisions of sections 38 and 39 of the Mines Regulation Act.

CERTIFICATES AND PERMITS

Sunday Labour Permits: Ten permits were issued covering installation of a primary ventilation fan, ore pass construction, dam construction, removal of pentice, stripping, road maintenance and diamond drilling. Except for the construction of the dam, where continuity of the concrete pour was required, all permits were granted to avoid a loss of time in the subsequent working of the mines.

Permit to Fire Outside Prescribed Times: Three permits were issued and the work specified was subject to special conditions to ensure general safety and to provide for the fumes from firing being exhausted direct to the surface.

Certificates of Exemption: No permits were issued under section 46 of the Mines Regulation Act.

Permits to Rise: Fifty two permits were issued for the construction of 83 rises having a total length of 2 399 metres.

AUTHORISED MINE SURVEYORS

The Survey Board issued three certificates during the year. The successful applicants were:—

R. F. Milnes—certificate No. 191.
D. Watkins—certificate No. 192.
N. E. Rollo—certificate No. 193.

VENTILATION

Inspections of the underground workings of metalliferous mines throughout the State were made during the year. Dust counts and temperatures were recorded at all working places, and a general appreciation was made of conditions and primary and secondary airflows throughout each mine. In addition a dust inspection was made of the coal mines in the Collie district. Inspections were also made of most crushing and screening installations throughout the State, viz: metalliferous treatment plants, hard rock quarries, dry treatment plants associated with the heavy mineral sands and iron ore operations.

The testing of toxic fumes and vapours associated with the various Assay Laboratories and reduction plants was continued. Extensive testing of mine atmosphere and exhaust gases was carried out wherever diesel equipment was used underground. All fuming accidents were investigated and a detailed report of each accident was completed by Officers from this section.

Assistance was given to various mines and companies throughout the State in conducting primary and secondary airflow surveys, overcoming dust collection problems, assisting with any other problem associated with ventilation and dust control which may have been encountered.

During the year the total number of konimeter dust samples taken was 1 503 as compared with 1 458 for the previous year. In addition 618 gravimetric dust samples were taken. Results of the konimeter dust sampling are tabulated in the following table.

Dust Samples from	No. of Samples	Samples Giving Over 1 000 p.p.c.c.	Average Count
Surface Plants	122	32	451
Stoping	773	1	141
Levels	347	6	246
Development	261	2	196
Totals	1 503	41	200

Counts of 1 000+p.p.c.c. are included in the average count.

Lead Hazards in Assay Offices: Inspections were carried out and 37 samples of lead in air were taken. Forty-one (41) urine samples were collected. Satisfactory conditions were maintained in the assay offices inspected.

Diesel Engine Testing: 321 engines and 112 working places were tested to determine the levels of carbon monoxide and oxides of nitrogen. In the working places the levels of carbon dioxide were measured.

Thirty one (31) vehicles were found to have excessive carbon monoxide and 32 to have excessive oxides of nitrogen in their exhausts. In only one instance was an excessive level of oxides of nitrogen measured in mine atmospheres.

Ventilation standards were generally good in diesel mines. The Lira Carbon Monoxide Analyser was used extensively to analyse engine exhaust gases. The samples were collected at the mine, in a plastic bag and brought into Kalgoorlie for analysis.

Fuming Accidents: The year was completed without a fatality caused by fumes. A total of 29 fuming incidents involving 50 men were investigated.

48396—(3)

FATAL ACCIDENTS

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

Name and Occupation	Date	Mine	Details and Remarks
Gomes, N. A. (Electrical Fitter)	19/1/74	Mt. Newman Mining Co. Pty. Ltd.—Port Hedland	Electrocuted whilst repairing a damaged fluorescent light.
Jonathan, H. M. (Truck Driver)	12/2/74	Hamersley Iron Pty. Ltd.—Paraburdoo	Received crush injuries when he drove a truck into the rear of a similar vehicle.
Harding, J. (Loader Driver)	20/3/74 Died 25/3/74	Bell Bros. Quarries Pty. Ltd.—Maddington	He was pinned in the cabin of a front end loader which over-turned after the engine stalled and it ran backwards down a decline.
Searle, R. R. (Mill Operator)	11/4/74	Central Norseman Gold Corporation	When a water hose he was using became entangled in a trommel at the discharge end of a Rod mill he was drawn into the hopper and crushed.
Gallagher, R. R. (Truck Driver)	9/7/74	Great Bou.der Mines Ltd.—Scotia	He drove a utility into a hole, caused by a collapse of ground, and which was obscured by dust.
Brown, J. M. (Truck Driver) and Nani, F. (Truck Driver)	13/8/74 13/8/74 Died 6/9/74	Hamersley Iron Pty. Ltd.—Tom Price	Trucks driven by the deceased were involved in a head on collision.
Nicholas, G. (Plant Operator)	13/10/74	Goldsworthy Mining Pty. Ltd.—Goldsworthy	He apparently fell through a chute in a stockpile of iron ore and received injuries when carried along a conveyor belt into a rail wagon.
Moore, A. E. (Loader Operator)	19/10/74	Western Collieries Ltd.	The front end loader he was driving overturned and pinned him underneath.
De Freitas, J. (Trades Assistant)	10/12/74	Mt. Newman Mining Co. Pty. Ltd.—Port Hedland	Whilst manoeuvring the slewing ring gear box on a Reclaimer the lifting beam swung and crushed his head.
Jones, N. F. (Electrical Trades Assistant)	17/12/74	Hamersley Iron Pty. Ltd.—Tom Price	Electrocuted whilst preparing to join sections of power cable.
Mills, C. A. (Truck Driver)	26/12/74	Kalgoorlie Lake View Pty. Ltd.	He was crushed between two ore trucks parked side by side when one truck rolled down a decline.

COAL MINING

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

The one underground and two open cut collieries at Collie each achieved record outputs of coal and a record output of 1 446 048 tonnes was produced on the coal field during the year. This was an increase of 274 978 tonnes over the 1973 output of 1 171 070 tonnes.

The Open Cut component of the total output increased by 2.13 per cent to 66.05 per cent.

The total value of the coal produced during 1974 was $9 144 982 an increase of $2 096 257 compared with the 1973 value of $7 048 725.

Coal mining commenced at Collie practically 77 years ago in 1898. Since then, 45 966 542 tonnes of coal have been produced for a total value of $159 848 854.

Western Collieries Ltd.—Western No. 2 Mine.

The output of coal from this colliery was 490 891 tonnes, an increase of 68 322 tonnes over the previous year's output of 422 569 tonnes.

The workings of this colliery which commenced production in 1952 now extend over a very wide area. The total quantity of coal produced from the mine was 5 952 626 tonnes, or nearly 6 million tonnes to the end of 1974.

Pillar splitting was practically completed in No. 6 West "C" Panel and was continuing satisfactorily in No. 4B West "A" Panel.

Mining continued satisfactorily in widespread areas in No. 1 West District "B" and "C" Panels, No. 4 West District "F" Panel, the No. 3 East Dips, No. 6 West "Dl" Panel, and in the area near the intersection of the No. 6 West Headings and the Main Slants. There were also drivages on opening out work in No. 6 East "B" Panel, the No. 6 West "D" Panels group of Dip Headings and in the No. 3B West Development Headings.

Wet and inferior conditions due to hydraulically induced weight were experienced in the No. 6 West "D" Panels Dips and in the No. 3B West Development Headings, but conditions were generally very good in most other areas. Some erosional cavities and sedimentary intrusions or "vughs" were encountered in No. 1 West District but the immediately adjoining working places had excellent conditions.

Six additional Melroe Bobcat diesel powered front-end-loaders and an additional Wagner PT 14 Supplies and Personnel Carrier were installed during the year.

Work was continuing on S.E.C. Pumping installations underground in the Main Slants to eventually replace the present group of borehole submersible pumps.

On the surface, coal handling facilities comprising a crusher, conveyors, stockpile area, reclamation tunnel, surge bin and a unit train weigh bridge and loading assembly were constructed.

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

There were significant developments at this colliery which produced 212 519 tonnes of coal, an increase of 59 874 tonnes over the previous year's output of 152 645 tonnes. The total amount of coal produced from this mine since the commencement of production in March, 1970, amounted to 752 715 tonnes.

The various excavations commenced close near the sub-crop of the Cardiff Seam, were connected, and now extend over a distance of approximately 1.4 km.

The excavation of the river diversion channel to the West and dip side of the Cardiff Seam excavation was completed in March, and progress was made on overburden removal, from, and across a portion of the old river bed.

Overburden removal is mainly accomplished by mobile scrapers and by wheel loaders and trucks. Stripping was commenced towards the end of March in an area near the sub-crop of the Wyvern Seam approximately 1.6 km from the Cardiff-Neath excavations. Very good progress was made and coal production commenced from the area on the 15th October.

The bulk of the coal output was won from the Cardiff Seam. Coal was not produced from the Neath Seam during the year.

A coal haulage road was constructed to connect from near the Wyvern Seam excavation directly across to a crusher and unit train loading facilities erected at the Western No. 2 Mine Sidings.

There were 101 employees at this mine at the end of the year, of whom nine were new entrants and 59 had transferred from Western No. 2 Underground Mine.

The Griffin Coal Mining Company Limited—Muja Open Cut.

This colliery produced just over half, or 51.36 per cent of the total output of coal from the field. The output of 742 638 tonnes was 146 782 tonnes more than the output of 595 856 tonnes produced in 1973. Nearly 8 million tonnes were produced since mining commenced in 1953.

The workings are extensive at this multi seam open cut where the maximum depth of the excavations now exceed 80 metres. Coal was won in varying quantities from the Diana, Eos, Flora, Galatea and Hebe Seams. Most of the output came from the Hebe Seam over widespread areas on Block No. 4 and the Connection Panel which were worked out and from Blocks Nos. 5. and 6 where mining is continuing. The Hebe Seam is approximately 12 metres thick in these areas.

The steeply dipping contours of the strata necessitated benched working of coal in several areas, particularly at the South end of Block No. 6, and at the Connection Panel where the coal was won over galleries of the abandoned Hebe underground Mine.

Good progress was made on developing East Section Panel No. 6, on initial opening out in the East Section North extension, and overburden removal from Block No. 7. Most of the overburden was transported to the surface dumps, but backfilling of selected material continued satisfactorily in the mined out area to the South West of the workings.

Three shift working, comprising three successive six hour shifts between 6 a.m. and mid-night on each working day, was introduced on the 16th September. This resulted in a more effective utilisation of equipment at the mine and contributed greatly to the favourable exposed coal reserves situation.

Wall, berm and dump conditions were stable and safe.

Road conditions were maintained to high standards, and lighting arrangements were extended to illuminate the widespread new working areas.

General

A fatality occurred at Western No. 5 Open Cut Mine on the 19th October when the driver of a Wheel Loader was crushed under the machine when it overturned. This was the second fatal accident in the coal industry during the past five years. There were 387 reported accidents of which 316 were minor, 70 were classified as serious, and the 1 fatal accident.

All of the collieries at Collie have the potential to produce increased outputs of coal and current developments are being directed to this goal. The demand for coal increased dramatically and suddenly during the year at a time when mining equipment was difficult to obtain.

There were 208 new entrants to the coal industry during the year, which, balanced against retirements, etc. gave a nett increase of 169 employees to 708 persons employed at the end of the year.

DRILLING OPERATIONS

D. A. Macpherson—Drilling Engineer

During 1974, the Drilling Secion was responsible for the drilling of 13 932.93 metres in 391 bores and the development and testing of 26 bores. The drilling of 8 880.3 metres and the testing of all 26 bores was carried out by Departmental employees and equipment. The remaining 5 052.63 metres in 40 bores was carried out by contract.

This year, the total metreage controlled by the Drilling Section is the highest on record. In 1968, 10 680 metres were controlled by the Section.

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

Comments on Staff and Plant matters are also given.

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 commences about 24 kilometres west of Winchester and runs west along the Carnamah/Eneabba Road, and continues west past Eneabba to within 8 kilometres 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 depth. The bores are left in suitable condition for continuous water level measurements.

At the start of the year the deep bore on site 2 had been completed, during the year construction work was completed at sites 2, 1, 11, 10, 9 and 8 and some development and testing work was completed. At the end of the year all construction work was completed and development work remained to be done on sites 10, 9 and 8.

MOORA LINE

This programme is identical to the Eneabba Line job above, except for location. The Moora Line commences at Moora and runs west to within 5 kilometres of the coast.

Drilling was commenced on this line during the year and at the end of the year all drilling at site 1 had been completed.

BUNBURY/YOGANUP

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

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

During the year two bores were constructed and at the end of the year the screening and testing remained to be done.

CANNING BASIN

The Canning Basin 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 is extending outwards from there.

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

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

The work was re-commenced in 1974 at the cessation of the wet season. The work proceeded smoothly except for transport difficulties caused by the sandy terrain. Work was suspended for the wet season and will be commenced in 1975 on cessation of the wet season.

JOONDALUP

Joondalup drilling 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 at each site is left in suitable condition for continuous water level measurement.

The work was continued in 1974 and by the end of 1974 the bulk of the work had been completed. It is expected the job will be completed in 1975.

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.

The work carried out during 1974 consisted of extended pumping tests on a bore constructed in previous years. The job has been closed down but further work may be carried out in future years.

PORT HEDLAND WATER SUPPLY

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

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

During 1974, four bores were drilled and screened at selected sites, using rotary drilling techniques. These bores are to be developed and tested in 1975.

ALCOA—DEL PARK

This is an investigation into the effects of bauxite mining on the ground water regime in the Darling Ranges. The work is being carried out for an investigating committee and is financed by the Department of Mines.

The work consisted of drilling pairs of bores, one within the mined area and one adjacent to the mined area, and taking core samples to allow comparison of ground water quality and water levels within the mined areas and adjacent to them.

Twenty bores were drilled, using hollow auger drilling and coring techniques. The work was relatively slow and expensive because considerable effort was put into finding the most suitable drilling methods for the work.

Further work in this area is being carried on by Alcoa as an agent of the investigating committee.

MANJIMUP WOOD CHIP INDUSTRY

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

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

The work was started in 1974 and at the end of the year was progressing smoothly.

MILL STREAM

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

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

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

This work was commenced and completed in 1974, and it is likely that the work will be continued in 1975.

EASTERN GOLDFIELDS TECHNICAL COLLEGE

This job was carried out for, and financed by the Department of Public Works. The job was intended to find out whether there was a danger of collapse of old mineshafts at the proposed site for a new technical college in Kalgoorlie.

The job was to be done by drilling three bores, each nine metres deep at the filled in mineshafts on the building site.

It proved impossible to locate the positions of the mine shafts accurately and only one bore of those drilled encountered obvious fill material.

STAFF

On 11th January, 1974 Mr. I. Cochran joined the Staff as a temporary General Assistant G.VII.1.

On 29th January, 1974 Mr W. Henderson, previously a foreman with the Section joined the Staff as an Assistant Drilling Supervisor.

On 20th September, 1974 Mr. D. Hardy, a General Assistant resigned from the Staff.

On 1st November, 1974 Mr. N. Francis, a General Assistant was promoted from G. VII. 1 to G. VII. 1/2.

PLANT

During 1974, the multi purpose drilling rig received towards the end of 1973 was placed in service.

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

TABLE SHOWING WORK CARRIED OUT DURING YEAR ENDED 31/12/74

Place	Purpose	Type of Work	Done By	No. of Bores	Metreage
Eneabba Line	Groundwater Investigation	Rotary Drilling	Dept. of Mines	11	3 368
		Rotary Drilling	Contractor	2	1 555
		Bore Testing	Dept. of Mines	13	....
Moora Line	Groundwater Investigation	Rotary Drilling	Dept. of Mines	3	1 380
Bunbury/Yoganup	Groundwater Investigation	Rotary Drilling	Contractor	2	2 318
Canning Basin	Groundwater Investigation	Rotary Drilling	Dept. of Mines	281	1 933·5
		Bore Testing	Dept. of Mines	1	....
Joondalup	Groundwater Investigation	Rotary Drilling	Dept. of Mines	14	801
		Cable Tool Drilling	Contractor	17	1 008·63
		Bore Testing	Dept. of Mines	11	....
Cooya Pooya	Groundwater Investigation	Bore Testing	Dept. of Mines	1	....
Port Hedland Water Supply	Groundwater Investigation	Rotary Drilling	Dept. of Mines	4	320
Alcoa—Del Park	Investigation of Effects of Mining on Groundwater	Rotary (Auger) Drilling	Dept. of Mines	20	496
Manjimup Wood Chip	Investigation of Effects of Logging on Groundwater	Rotary (Auger) Drilling	Dept. of Mines	7	99
Mill Stream	Groundwater Investigation	Rotary Drilling	Dept. of Mines	11	482·8
Eastern Goldfields (Kalgoorlie)	Foundation Investigation	Rotary Drilling	Contractor	19	171
			Totals—		
			Drilling	391	13 932·93
			Testing	26	

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, 1974.

Mining Law Examination

This examination was held on April 8, 1974 and details are as follows:—

Entries	12
Admitted	12
Pass	12

The names of the successful candidates were:

Brown, R. J. M.
Dowd, P. J.
Durrant, P. S.
Harding, C. G.
Hoskings, R.
Johnson, D. C.
Jansson, B. R. M.
Annandale-James, J. A.
Middlemass, V.
Sheppard, A.
Smith, G. M.
Wregg, C. B.

Underground Supervisor's Examination

In addition to the general examination held in September 1974, two special examinations were held during the year. The first was at the request of Windarra Nickel Project, who reported an extreme shortage of Supervisor's on their site. This was reported by Mr. Boyland at the Board meeting held on March 12, 1974 and it was resolved that a Special examination be scheduled for Windarra on March 13, 1974 for the four applicants from that centre. The meeting of March 12, 1974 was continued on March 14, when the results of the Special examination at Windarra were reviewed. The following were approved for issue:—

Bacci, M.
Kelly, W. L.
Stretton, B. F.

In each case the certificate to be endorsed "Restricted to Windarra Nickel Project only". Each candidate was advised to sit for the general examination in September.

Another Special examination for the Underground Supervisor's Certificate in Mining Law section only, was approved for Mr. C. E. Plume of Marvel Loch, who subsequently passed the examination and was issued with a certificate.

The general examination was held on September 3, 1974 and applications were received from the following centres:—

Kalgoorlie	25
Windarra	4
Norseman	1

Results were as follows:

Passed	16
Failed	13

Retain restricted certificate—1 (Mr Stretton of Windarra).

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

Kalgoorlie—

Axwell, W. C.
Bailey, J.
Bennett, G.
Budge, D. M.
Cain, J. S.
Chambers, J. H.
Clark, C. J.
Florance, R. A.
Green, F. J.
Jordan, G. H.
Parsons, H. D.
Ross, P. A.
Sztermula, J. T.

Norseman—

Venturini, G.

Windarra—

Bacci, M.
Valenti, M. D.

Mine Manager's Certificates

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

Holly, W. J.
Hoskings, R.
Middlemass, V.
Meiklejohn, G.
Bell, R. W.
Brown, R. J. M.

General

Five meetings were held during the year on March, 12, March 14, May 7, July 23 and October 3, 1974.

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

DIVISION III

Report of the Superintendent of State Batteries—1974

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, 1974.

Crushing Gold Ores

One 20 head, five 10 head, and nine 5 head mills crushed 46 317.8 tonnes of ore made up of 397 separate parcels, an average of 116.7 tonnes per parcel. The bullion recovered amounted to 298.603 kilograms, estimated to contain 253.064 kilograms of fine gold, equal to 5.46 grams per tonne of ore.

The average value after amalgamation but before cyaniding was 2.00 grams per tonne, giving an average value of ore received of 7.46 grams per tonne, compared with 10.72 grams per tonne for 1973.

The cost of crushing the 46 317.8 tonnes was $16.95 per tonne. In 1973 49 595.1 tonnes were crushed at the gold plants, for a cost of $13.17 per tonne.

Cyaniding

Six plants treated 8 319 tonnes of tailings from amalgamation for a production of 26.844 kilograms of fine gold. The average content was 4.56 grams per tonne before cyanidation, while the residue after treatment was 1.19 grams per tonne giving a theoretical recovery of 73.6 per cent. The actual extraction was 70.8 per cent. The cost of cyaniding was $14.12 per tonne, higher than the previous year when 10 505.7 tonnes were treated at a cost of $9.74 per tonne.

Silver recovered by the cyaniding of gold tailings was valued at $137.00.

TREATMENT OF ORES OTHER THAN GOLD

Lead Ores

During the year the Northampton State Battery crushed 2 056.9 tonnes of lead ore with an average content of 7.59 per cent lead and 4.85 per cent zinc. There were 8 separate parcels giving an average of 257.1 tonnes per parcel.

A total of 197.9 tonnes of concentrates were recovered. These averaged 60.1 per cent lead and 10.3 per cent zinc, giving an estimated content of 119.0 tonnes of lead and 20.3 tonnes of zinc. Tailings discarded amounted to 1 859.0 tonnes, having an average content of 2.02 per cent lead and 4.27 per cent zinc. The recovery in the concentrates was 76.2 per cent of the lead and 20.4 per cent of the zinc in the ore delivered to the plant.

The cost of operating the Northampton State Battery, including administration was $42 285.00 being $20.60 per tonne of ore treated. The corresponding figures for 1973 when 2 539.6 tonnes were treated were, operating cost $38 206.24 being $15.28 per tonne.

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

	1974 $	Since Inception $
Gold	1 024 406	41 911 709
OTHER METALS		
Silver	137	4 489
Tin (Concentrates)	....	476 184
Tungsten (Concentrates)	....	41 087
Copper (ores for agricultural use)	....	11 932
Lead and Zinc (Concentrates)	57 830	1 554 040
Tantalite-Columbite (Concentrates)	....	73 261
Total other metals	$57 967	$2 160 993
Grand total	$1 082 373	$44 072 702

FINANCIAL

	Tonnes	Expenditure $	Receipts $	Loss $
Crushing—Gold Mills	46 317·8	785 240	76 855	708 386
Crushing—Northampton Lead plant	2 056·9	42 285	4 447	37 838
Magnetic Seperator Plant—Marble Bar	....	134	....	134
Cyaniding	8 319	117 468	19 321	98 147
Total	56 693·7	945 127	100 623	844 505

The loss of $844 505 is an increase of $115 109 on the previous year. It does not include depreciation and interest on capital.

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

		$
Kalgoorlie	New Assay Office and Workshops	22 981
Laverton	Noise Suppression	3 748
Marble Bar	Water Supply	3 600
Norseman	Bins and Conveyor	3 873
Meekatharra	Bins	242
General Plant	Calibrator for Sound Meter	112
		$34 556

Cartage Subsidy

Comparative figures on cartage subsidy paid on ore carted to State Batteries during the last three years are:

Year	Tonnes Crushed	Tonnes Subsidised	% Subsidised
1972	47 424·34	23 676·86	49·93
1973	52 135·97	12 998·85	24·93
1974	48 374·70	18 954·25	39·18

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

Administrative

Expenditure was $142 159.91, equal to $2.51 per tonne crushed and cyanided, compared with an expenditure of $109 979.31, $1.75 per tonne for 1973.

	1973 $	1974 $
Salaries	58 566·53	73 546·34
Payroll Tax	21 823·82	30 878·36
Workers' Compensation	15 920·63	27 348·01
Travelling and Inspection	5 785·96	3 774·24
Sundries	7 882·37	6 612·96
	$109 979·31	$142 159·91

Staff

Manager T. Edge resigned late in the year.

General

State Battery charges for crushing gold ores, which had been practically unchanged for over 70 years, were approximately trebled in August, 1974. The increases were necessary to reduce the rapidly rising operating losses, and to reduce the amount of very low grade ore being crushed due to high gold prices and low treatment charges. The increased charges caused some reduction in the amount of gold ore crushed, from 49 565.1 tonnes in 1973, to 46 317.8 tonnes in 1974. The average ore grade received for treatment was very considerably lower than the previous year. The lower grade ore and reduced tonnages, caused a big reduction in the amount of gold recovered, but due to big increases in the price of gold, the value of gold produced remained practically the same.

The Nullagine State Battery was dismantled during the year. There had been very little activity in the district for many years, and the Battery had operated last in 1968. This plant was 20 miles from Nullagine, and it has become impossible to obtain a caretaker, so all useful equipment was removed before it was stolen, or destroyed by vandals and storms.

High rainfall and low amounts of purchased tailings again reduced the tonnage cyanided. Treatment in plastic vats could not be continued as suitable plastic was unobtainable for most of the year. Supplies of plastic were received late in the year and this work will be resumed in 1975.

Supplies of lead ore to the Northampton Battery were again low. No ores of minerals other than gold and lead were treated, and no concentrates were treated at the Marble Bar magnetic separator plant.

K. M. PATERSON,
Superintendent, State Batteries.

Schedule No. 1

NUMBER OF PARCELS TREATED, TONNES CRUSHED, GOLD YIELD BY AMALGAMATION AND HEAD VALUE FOR THE YEAR ENDED 31st DECEMBER, 1974

Battery	Number of Parcels Treated	Tonnes Crushed	Yield by Amalgamation		Amalgamation Tailings Content Fine Gold	Contents of Ore—Fine Gold	
			Bullion	Fine Gold		Total	Per Tonne
			kilograms	kilograms	kilograms	kilograms	grams
Boogardie	18	953·2	5·066	4·293	2·001	6·294	6·60
Coolgardie	53	5 270·5	25·189	21·348	10·172	31·520	5·98
Kalgoorlie	68	12 040·6	84·305	71·448	24·018	95·466	7·93
Lake Darlot	14	930·0	3·251	2·755	1·430	4·185	4·50
Laverton	2	669·8	1·330	1·127	0·521	1·648	2·46
Leonora	37	4 098·0	21·703	18·393	12·240	30·633	7·47
Marble Bar	35	3 627·0	22·247	18·854	4·825	23·679	6·53
Marvel Loch	41	5 039·9	48·156	40·812	11·122	51·934	10·30
Meekatharra	15	1 610·0	6·219	5·271	4·455	9·726	6·04
Menzies	19	1 958·3	12·294	10·419	4·946	15·365	7·84
Norseman	13	2 655·9	11·959	10·135	2·953	13·088	4·93
Ora Banda	40	3 970·6	13·614	11·538	7·652	19·190	4·83
Paynes Find	9	654·5	30·685	26·005	2·177	28·182	43·06
Sandstone	12	1 250·5	4·303	3·647	2·280	5·927	4·74
Yarri	21	1 589·0	8·282	7·019	1·771	8·790	5·53
	397	46 317·8	298·603	253·064	92·563	345·627	7·46

Average per Parcel .... 116·7 Tonnes
Average Yield by Amalgamation (Fine Gold) .... 5·46 Grams per Tonne
Average Value of Tailings (Fine Gold) .... 2·00 Grams per Tonne

Schedule No. 2

DETAILS OF EXTRACTION TAILINGS TREATMENT 1974

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	2 550·0	4·7	12·003	1·1	2·790	9·214	76·8	8·204	68·3
Leonora	3 600·0	3·7	13·395	1·1	3·903	9·446	70·5	9·759	72·8
Marvel Loch	1 247·0	5·3	6·608	1·6	1·973	4·635	70·1	4·463	67·5
Norseman	570·0	6·5	3·699	1·3	·744	2·954	79·8	2·769	74·8
Yarri	222·0	3·9	·876	·9	·211	·665	75·9	·667	76·1
Marble Bar	130·0	10·4	1·352	2·5	·325	1·027	76·0	·982	72·6
	8 319·0	4·56	37·933	1·19	9·946	27·941	73·6	26·844	70·8

Schedule No. 3

DIRECT PURCHASE OF TAILINGS YEAR ENDED 31st DECEMBER, 1974

Battery	Tonnes of Tailings Purchased	Initial Payment to \$28.00 per ·0311 kg
		$
Boogardie	54·0	24·32
Coolgardie	485·9	732·75
Kalgoorlie	302·4	412·33
Lake Darlot	16·2	26·10
Leonora	1 264·5	1 040·65
Marble Bar	464·4	216·90
Marvel Loch	436·7	1 479·07
Meekatharra	61·2	60·27
Menzies	420·2	697·69
Ora Banda	205·9	255·54
Paynes Find	112·5	70·23
Sandstone	81·0	275·57
	3 904·9	5 291·42

Schedule No. 4

STATEMENT OF RECEIPTS AND EXPENDITURE FOR THE YEAR ENDED 31st DECEMBER, 1974

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	953·2	9 930·08	6 554·97	2 162·45	18 647·50	19·56	2 199·97	7 091·53	27 939·00	29·31	1 193·38	1·25	....	26 745·62
Coolgardie	5 270·5	14 981·34	23 509·61	3 352·04	41 842·99	7·94	4 721·26	15 609·51	62 173·76	11·80	7 783·17	1·48	....	54 390·59
Cue	....	....	....	....	....	....	....	....	....	....	1 633·50	....	1 633·50	....
Kalgoorlie	12 040·6	20 835·42	69 061·14	17 549·20	107 445·76	8·92	15 490·55	43 143·36	166 079·67	13·79	19 879·33	1·65	....	146 200·34
Lake Darlot	930	8 118·46	12 019·46	1 466·66	21 604·58	23·23	783·26	2 450·36	24 838·20	26·71	1 688·26	1·82	....	23 149·94
Laverton	669·8	7 789·39	9 224·43	1 979·25	18 993·07	28·36	1 298·52	2 039·23	22 330·82	33·34	238·00	·36	....	22 092·82
Leonora	4 098	7 991·96	29 110·28	8 817·18	45 919·42	11·21	5 300·59	16 547·77	67 767·78	16·54	6 557·35	1·60	....	61 210·43
Marble Bar	3 627	17 574·42	21 397·42	6 358·60	45 330·44	12·50	5 786·01	12 717·53	63 833·98	17·60	6 609·78	1·82	....	57 224·20
Marvel Loch	5 039·9	13 897·67	36 953·66	7 608·34	58 459·67	11·60	4 905·03	14 271·61	77 636·31	15·40	8 681·69	1·72	....	68 954·62
Meekatharra	1 610	10 483·62	21 526·41	4 452·70	36 462·73	22·65	5 255·39	5 745·40	47 463·52	29·48	1 798·51	1·12	....	45 665·01
Menzies	1 958·3	14 005·48	18 871·86	3 217·66	36 095·00	18·43	5 883·26	8 124·42	50 102·68	25·58	3 567·04	1·82	....	46 535·64
Norseman	2 655·9	9 001·92	23 269·63	2 529·66	34 801·21	13·10	2 695·95	7 721·09	45 218·25	17·03	4 169·26	1·57	....	41 048·99
Nullagine	....	....	2 465·13	....	2 465·13	....	....	....	2 465·13	....	....	....	....	2 465·13
Ora Banda	3 970·6	14 929·25	25 210·70	7 978·91	48 118·86	12·12	2 453·67	10 021·88	60 594·41	15·26	5 566·10	1·40	....	55 028·31
Paynes Find	654·5	4 082·53	5 890·84	705·62	10 678·99	16·32	545·85	2 734·93	13 959·77	21·33	1 426·72	2·18	....	12 533·05
Sandstone	1 250·5	6 751·83	9 636·07	711·61	17 099·51	13·67	597·02	3 556·46	21 252·99	17·00	3 476·86	2·78	....	17 776·13
Yarri	1 589	6 758·71	15 315·85	2 043·10	24 117·66	15·18	2 440·73	5 026·02	31 584·41	19·88	2 585·74	·63	....	28 998·67
Head Office														
Sub total	46 317·8	167 132·08	330 017·46	70 932·98	568 082·52	12·26	60 357·06	156 801·10	785 240·68	16·95	76 854·69	1·62	1 633·50	710 019·49
Marble Bar (Mag. Plant)	....	....	....	....	....	....	....	134·26	134·26	....	....	....	....	134·26
Northampton	2 056·9	16 459·44	11 990·95	2 481·25	30 931·64	15·07	5 846·10	5 507·18	42 284·92	20·60	4 447·40	2·16	....	37 837·52
Total	48 374·7	183 591·52	342 008·41	73 414·23	599·104 16	12·38	66 203·16	162 442·54	827 659·86	17·11	81 302·09	1·65	1 633·50	747 991·27

Operating Loss $746 357·77

Schedule No. 5

STATEMENT OF RECEIPTS AND EXPENDITURE FOR THE YEAR ENDED 31st DECEMBER, 1974

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	....	....	....	32·09	32·09	....	....	361·43	393·52	....	70·41	....	....	323·11
Kalgoorlie	2 550	6 567·33	28 034·81	10 288·21	44 890·35	17·60	335·41	9 709·92	54 935·68	21·54	10 489·17	4·11	....	44 446·51
Lake Darlot	....	....	....	....	....	....	....	10·23	10·23	....	....	....	....	10·23
Laverton	....	....	....	....	....	....	....	158·36	158·36	....	....	....	....	158·36
Leonora	3 600	5 959·57	14 911·94	5 235·31	26 106·82	7·25	542·78	12 399·77	39 049·37	10·85	7 434·95	2·06	....	31 614·42
Marble Bar	130	....	....	....	....	....	....	801·40	801·40	6·16	360·00	2·77	....	441·40
Marvel Loch....	1 247	257·46	4 285·32	1 274·70	5 817·48	4·67	67·20	1 849·46	7 734·14	6·20	4 184·77	3·36	....	3 549·37
Norseman	570	....	4 856·26	639·04	5 495·30	9·64	....	2 319·13	7 814·43	13·71	850·70	1·49	....	6 963·73
Yarri	222	1 808·92	2 703·59	929·36	5 441·87	24·51	165·28	963·64	6 570·79	29·60	251·44	1·13	....	6 319·35
Total	8 319	14 593·28	54 791·92	18 398·71	87 783·91	10·55	1 110·67	28 573·34	117 467·92	14·12	23 641·44	2·84	....	93 826·48
								Interest Paid to Treasury			4 320·00			4 320·00
									117 467·92		19 321·44			98 146·48

Operating Loss $98 146·48

STATE BATTERIES

TRADING AND PROFIT AND LOSS ACCOUNT FOR THE YEAR ENDED 31st DECEMBER, 1974

1973 $		$	1974 $
	Trading Costs—		
473 436	Wages	594 985	
100 337	Stores	91 813	
70 144	Repairs Renewals and Battery Spares	67 314	
155 003	General Expenses and Administration	195 336	
798 920			949 448
	Earnings—		
69 524	Milling and Cyaniding Charges		104 944
729 396	Operating Loss for the Year		844 504
	Other Charges—		
61 896	Interest on Capital	61 881	
25 392	Depreciation	32 902	
15 566	Superannuation—Employers' Share	17 027	
102 854			111 810
832 250	Total Loss for the Year		956 314

BALANCE SHEET AS AT 31st DECEMBER, 1973

Funds Employed

31st December, 1973			31st December, 1974
	Capital—		
1 471 465	Provided from General Loan Fund	1 471 130	
360 349	Provided from Consolidated Revenue Fund	406 746	
1 831 814			1 877 876
	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—		
2 699 105	Interest on Capital		2 760 986
	Other Funds—		
8 328 403	Provided from Consolidated Revenue Fund (Excess of payments over collections)		9 195 532
12 944 138			13 919 210
	Deduct—		
	Profit and Loss :		
11 880 946	Loss at Commencement of year	12 713 196	
832 250	Loss for Year	956 314	
12 713 196	Total Loss from Inception		13 669 510
230 942			249 700

Employment of Funds

31st December, 1973			31st December, 1974
	Fixed Assets—		
1 820 631	Plant Buildings and Equipment	1 866 693	
1 593 490	Less Depreciation	1 626 393	
227 141			240 300
	Current Assets—		
22 800	Debtors	36 273	
105 174	Stores	118 156	
16 744	Battery Spares	25 856	
	Purchase of Tailings :		
22 971	Treasury Trust Account	31 375	
74 998	Tailings not Treated	64 874	
4 110	Estimated Gold Premium	11 390	
246 797			287 924
473 938	Total Assets		528 224
	Deduct—		
62 184	Current Liabilities : Creditors	75 125	
174 733	Liability to Treasurer (Superannuation—Employer's Share)	191 760	
	Purchase of Tailings :		
1 969	Creditors	249	
4 110	Estimated Premium Due	11 390	
242 996			278 524
230 942			249 700

DIVISION IV

Annual Report of the Geological Survey Branch of the Mines Department for the Year 1974

CONTENTS

REPORTS

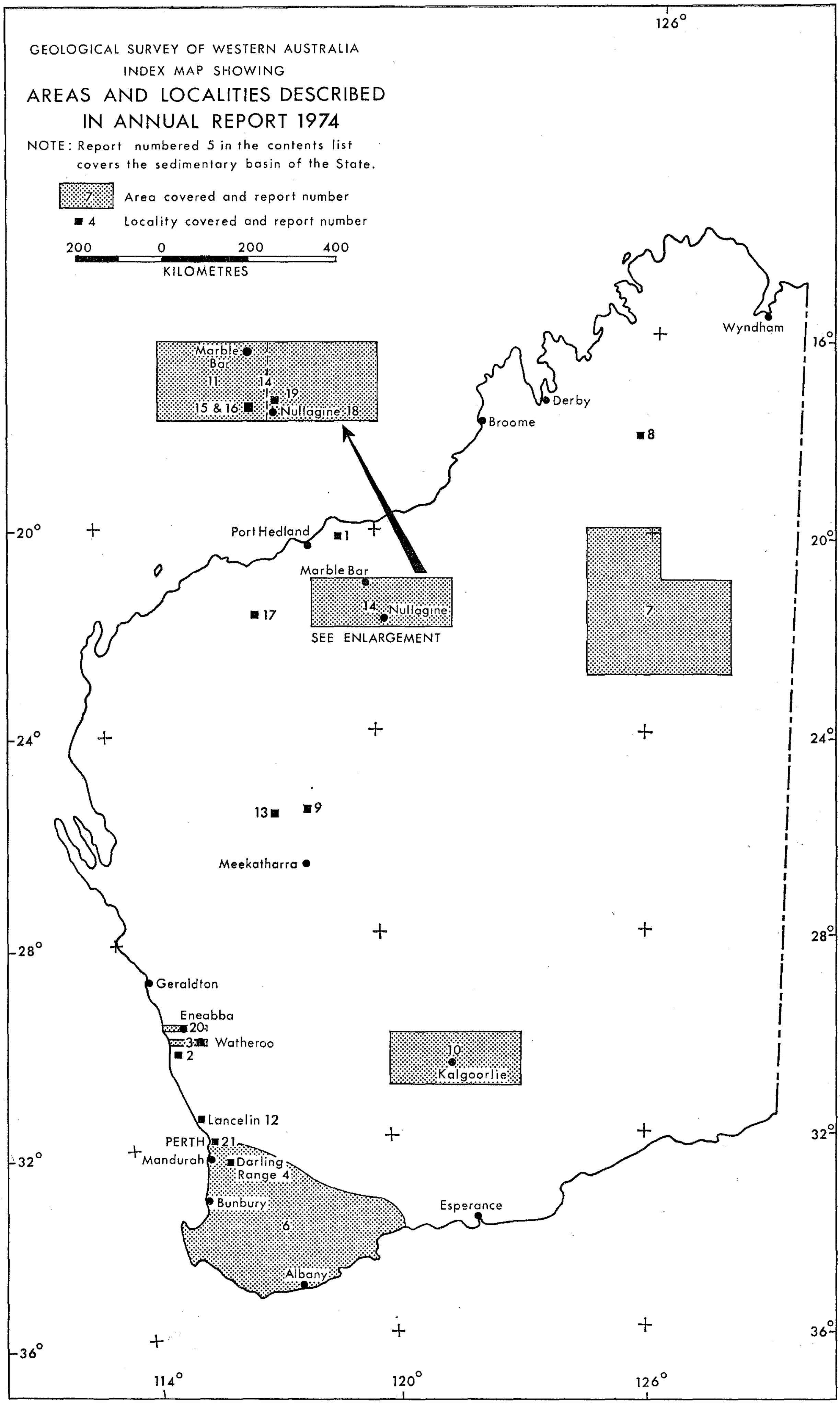


Figure 1. Index map showing areas and localities described in Annual Report for 1974.

LIST OF FIGURES

DIVISION IV

Annual Report of the Geological Survey Branch of the Mines Department for the Year 1974

Under Secretary for Mines:

My report on the activities on the Geological Survey of Western Australia during 1974, together with some of the reports on investigations made for departmental purposes, are submitted for the information of the Honourable Minister for Mines.

INTRODUCTION

The reduction trend in exploration which was evident in 1973, continued in 1974 mainly due to the unfavourable Commonwealth Government policy towards overseas explorers, which in turn has adversely affected the smaller-Australian companies.

During the year 47 new temporary reserves for mineral exploration were granted, as compared with 182 in 1973.

Iron ore exploration has been continued by interested companies on a similar scale to 1973. Most work was done in extending the knowledge of known occurrences. While producing companies were able to extend existing sales contracts, no new major contracts were written. Goldsworthy Mining Limited announced that by about 1978 it would commence mining a production rate of 10 million tonnes per year from its "Mining Area C" deposits. These ore bodies have reserves of 750 million tonnes of high grade ore with a low phorphorus content. The small Koolanooka mine, which was the first to export iron ore in March 1966, closed, having exhausted its ore body and fulfilled the contract of 5.1 million tonnes.

Bauxite exploration is at a standstill. The feasibility study for Alwest to establish an alumina plant at Worsley near Collie was completed favourably, but agreement could not be reached with the Commonwealth Government on several aspects, particularly that of the environment.

The great interest in uranium exploration decreased during 1974, probably due to the lack of further potentially economic finds since Yeelirrie, and also to the uncertainty of permission being granted to develop any discoveries. The search this year has concentrated on the Murchison, Gascoyne, Ashburton and Kimberley areas.

Exploration for nickel continues, but on a reduced scale. The results of exploration by Australian Selection near Agnew has proved an ore body containing about 40 million tonnes, averaging 2 per cent nickel. Good drilling results are still being reported from Forrestania. No new finds have been reported to the Department of Mines. The Carr Boyd rocks mine commenced production, while mines at Widgiemooltha and Redross are being developed.

Gold prospecting continues to be active due to the increased price. The Paterson Range gold find has reported reserves of 3.8 million tonnes, averaging 8.78 gm (0.31 oz) per tonne and the development of a mine is planned. Preparations are being made to reopen the Blue Spec mine near Nullagine for the production of gold and antimony.

The main mineral sands activity has been the development of earlier discoveries, particularly at Eneabba where Jennings Mining Ltd. (reserves 9.5 million tonnes) has commenced production, Allied Minerals (reserves 9.0 million tonnes) should commence production in 1975, and Western Titanium (reserves 9.8 million tonnes) plan to commence production late in 1976. The Geological Survey has studied the mineral sands deposits of the State and estimates the resources as 72.9 million tonnes, of which 20 million tonnes are uneconomic at present.

General exploration for other metallic and non-metallic minerals continued on a reduced scale. Mining and export of talc commenced at Mount Seabrook. Full scale plant for the production of diatomite is being established near Dongara, while there is a proposal to ship a large parcel of magnesite from near Ravensthorpe. Exploration and drilling have outlined a prospective copper-zinc deposit near Golden Grove 93 km northwest of Paynes Find. Additional work is being done to determine its economic importance.

The amount of oil exploration work done, both onshore and offshore, showed a continued decline. Only 16 test wells were completed in 1974, a decrease of 20 per cent as compared with 1973. Total footage for all wells drilled was 51 487 m, a decrease of 19 per cent. There was a decrease of 69 per cent in land seismic work and 21 per cent decrease in marine seismic work, as compared with 1973.

This decrease in exploration for oil and gas at the time of an energy crisis throughout the world must have a serious adverse effect on Australia's future ability to attain any self-sufficiency in this form of energy.

The present situation of about 70 per cent self-sufficiency, has been achieved only by continuous exploration over many years and we cannot afford to allow this decrease in the exploration rate to continue.

The only significant results during the year were from the West Tryal Rocks No. 2, 75 km northwest of Barrow Island, where a gas flow of 255 000 to 314 000 cubic metres per day was reported and from Lambert No. 1 where some oil showings occurred.

The upsurge in prospecting for coal, which developed in 1973, tapered off towards the end of 1974 without any significant economic discoveries being made.

Two lecture evenings followed by field excursions were conducted. One was at Marble Bar where the lectures were given in conjunction with a three day excursion on the Marble Bar and Nullagine 1 : 250 000 geological sheets. The other was in Perth where the lecture evening was held at the University, followed by a two day excursion on the Precambrian of the Perth 1 : 250 000 sheet. About 73 and 58 persons respectively attended the field excursions.

STAFF

Continued difficulties were experienced in filling vacancies which required experience or training in sedimentary geology or hydrogeology. It is hoped that all such positions will be filled early in 1975.

Two geologists were engaged to specialise in environmental geology while two additional staff were appointed to the Sedimentary (Oil) Division to assist in particular with the handling of technical information being received from companies.

Difficulty is being experienced in retaining geological and technical assistants. Staff recruited for such positions soon loose interest in routine work and resign.

PROFESSIONAL

Appointments

Name	Position	Effective Date
Elias, M., B.Sc. (Hons.)	Geologist, Level 1	7/1/74
Briese, E., B.Sc. (Hons.)	Geologist, Level 1	7/6/74
Drake, J. R. B.Sc. (Hons.)	Geologist, Level 1	14/6/74
Davy, R., Ph.D.	Geochemist, Level 4	17/6/74
Biggs, E. R., B.Sc. (Hons.)	Geologist, Level 2	1/7/74
Archer, R. H., B.Sc. (Hons.)	Geologist, Level 1	26/8/74
Megallaa, M. N., B.Sc.	Geophysisict, Level 3	1/10/74
Hocking, R. M., B.Sc. (Hons.)	Geologist, Level 1	11/12/74

Temporary Relief

Drake, J. R. B.Sc. (Hons.	Geologist, Level 1	14/1/74
Novak, V., B.Sc.	Geologist, Level 1	30/1/74
Hirschberg, K. J. B., Ph.D.	Geologist, Level 1	15/5/74

Promotions

Davidson, W. A.	Geologist, Level 2	15/11/74

Resignations

Janse, R.	Geologist, Level 1	8/2/74
Novak, V.	Geologist (temp.) Level 1	22/2/74
Barnes, R. J.	Geologist, Level 1	24/4/74
Forth, J. R.	Geologist, Level 2	26/9/74
Boegli, J. -C.	Geologist, Level 1	29/11/74

Transfer Out

Cope, R. N.	Geologist, Level 4	27/5/74

CLERICAL AND GENERAL

Appointments

Name	Position	Effective Date
Muldownie, C.	Technical Assistant	17/1/74
Rankin, P.	Geological Assistant	21/1/74
Bazely, M. J.	Typist	4/2/74
Williams, S. J., B.Sc. (Hons.)	Geological Assistant	6/2/74
Douglas, S. R.	Geophysical Assistant	5/2/74
Berkmann, S.	Typist	15/3/74
Pearman, M.	Messenger	22/3/74
Ridley, J.	Typist	1/4/74
Green, M.	Technical Assistant	16/4/74
Lutter, M. D.	Technical Assistant	30/4/74
Hargrave, D. J.	Typist	30/4/74
Yule, J. G. C.	Geophyiscal Assistant	27/5/74
O'Brien, B.	Geological Assistant	4/6/74
Dowling, N.	Technical Assistant	7/5/74
Wakeham, J. I.	Library Assistant	1/7/74
Baints, R.	Technical Assistant	8/7/74
Ritchie, L.	Geological Assistant	29/7/74
Bontemps, T. H.	Geological Assistant	29/8/74
Thomas, H.	Geological Assistant	26/8/74
Butherway, P.	Geohpysical Assistant	10/10/74
Hammill, N. C.	Clerical Assistant	23/9/74
Slater, R. M.	Geophysical Assistant	9/12/74

Resignations

Formato, E.	Geophysical Assistant	11/1/74
Darby, N. D.	Geological Assistant	15/2/74
Nutt, M. D.	Typist	8/3/74
Muldownie, C. E.	Technical Assistant	22/3/74
Butherway, P.	Geophysical Assistant	22/3/74
Grenfell, R. A.	Messenger	22/3/74
Marrell, G.	Technical Assistant	29/3/74
Berkmann, S.	Typist	1/4/74
Douglas, S. R.	Geophysical Assistant	26/4/74
Bazely, M. J.	Typist	2/5/74
Pearson, J.	Library Assistant	23/4/74
O'Brien, B.	Geological Assistant	8/7/74
Beere, M.	Clerical Assistant	20/9/74
Yule, J. G. C.	Geophysical Assistant	5/9/74
Ritchie, L.	Geological Assistant	22/11/74

Transfers Out

Mouritzen, C.	Geological Assistant	31/5/74
Lyons, W. A.	Senior Clerk	17/6/74

Transfers In

McNamara, T.	Senior Clerk	17/6/74

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, G. W. A. Marcos, W. A. Davidson, A. S. Harley, R. E. J. Leech, J. C. Barnett, D. P. Commander, J. M. Campbell, G. Klenowski and E. H. Briese.

Hydrogeology

Further progress was made with the programme of exploratory drilling for water in the Perth Basin sediments. Two of the deepest bores ever to be drilled for ground water investigation were drilled at Picton Junction and Yoganup to depths of 1 200 and 1 120 metres respectively. The latter, known as Quindalup No. 6, intersected sediments containing water of domestic quality to a depth of nearly 1 000 metres, confirming the existence of a very large water resource.

The deep drilling west of Winchester along the Eneabba cross-section was completed. This established that large reserves of potable water exist down to at least 750 metres at and east of Eneabba. Drilling has commenced on a new cross-section between Moora and Grey.

The long term investigation of the shallow aquifers in and near the Perth Metropolitan area has made considerable progress. A further seventeen sites have been drilled as part of the Joondalup programme and the Metropolitan Water Board has continued exploration in the vicinity of Lake Thompson, 21 bores being drilled to depths of up to 64 metres. Further shallow production bores have been drilled at Wanneroo, and deep bores at Mirrabooka and at Wanneroo Reservoir. One deep stratigraphic bore has been drilled at Whitfords. Close liaison continues to be maintained with the Metropolitan Water Board in all aspects of groundwater exploration and development.

The investigation into the water resources of the western part of the Canning Basin has continued. A further nine boreholes were drilled and an extensive seismic programme has been completed. At Millstream nine exploratory bores were drilled east of the area investigated in 1968, these being part of a project to better define the limits of the important calcrete groundwater storage. Further drilling has also been carried out along the De Grey River where seismic work has indicated the presence of a deep buried channel.

Several inter-departmental committees have been set up to study the effects of the bauxite mining and Manjimup woodchip industries on the various aspects of hydrology in the region of the Darling Range. This Branch has actively participated so far as the availability of staff would allow.

Twenty boreholes were drilled in a wide area at Del Park, and it is expected that subsequent monitoring will delineate the groundwater response to mining and dieback *(Phytopthora cinnamomi)* in the adjoining forest.

Advice continues to be provided in connexion with work done by groundwater consultants for mining and other companies. However, activity remains at a low level. Landholders throughout the State continue to seek advice regarding the development of groundwater supplies and although there has been an increase in enquiries at the office, there has been a reduction in the number of on-site inspections.

Engineering Geology

A number of proposed dam sites were investigated for the Department of Public Works, including:

(a) Dogger Gorge and Gregory Gorge—geological mapping and drilling to compare the sites.

(b) Moochalabra Creek dam—additional geological mapping and drilling for the proposed raising of the wall.

(c) Harvey dam site—report completed and issued.

(d) Burekup dam site—detailed study with drilling—report issued.

(e) Bullinnarwa Pool dam site—report prepared.

(f) Robe River dam site—a reconnaissance and report on a proposed site.

The following investigations were made for the Metropolitan Water Board:

(a) South Dandalup dam—geological information updated during construction of this dam.

(b) Wungong, South Canning and North Dandalup dam sites—detailed study including mapping, drilling and seismic work continuing.

(c) Minor work has been done on the Wungong tunnel site and the Beenyup waste water plant outfall tunnel.

SEDIMENTARY (OIL) DIVISION

P. E. Playford (Supervising Geologist), G. H. Low, W. J. E. van de Graaff (Senior Geologists), M. N. Megallaa (Geophysicist), R. W. A. Crowe, R. M. Hocking.

Information received from petroleum companies was evaluated and collated, and methods for accession, storage, retrieval, and distribution of data were further developed. The flow of information from companies greatly increased during the year, largely due to the requirement for submission of comprehensive data packages when permits or parts of permits are relinquished. These data are microfilmed and are made available to the public in this form when required.

The Division continued to deal with numerous enquiries from companies and other Government departments on exploration for petroleum and coal in the State.

The Geological Survey's contribution to the Officer Basin project (which is being carried out in conjunction with the Bureau of Mineral Resources) was completed in draft form. Preliminary editions of 1 : 250 000 geological maps of the basin are being issued progressively and a bulletin on the geology of the basin is to be produced.

The Noonkanbah 1 : 250 000 Sheet in the Canning Basin was mapped (jointly with the Bureau of Mineral Resources). Preliminary compilation of data for the basin study of the Carnarvon Basin was commenced during 1974 and mapping will begin in 1975.

REGIONAL GEOLOGY DIVISION

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

The programme of regional mapping of the Precambrian area of the State for publication on a scale of 1 : 250 000 continued. Progress is shown in Figure 2.

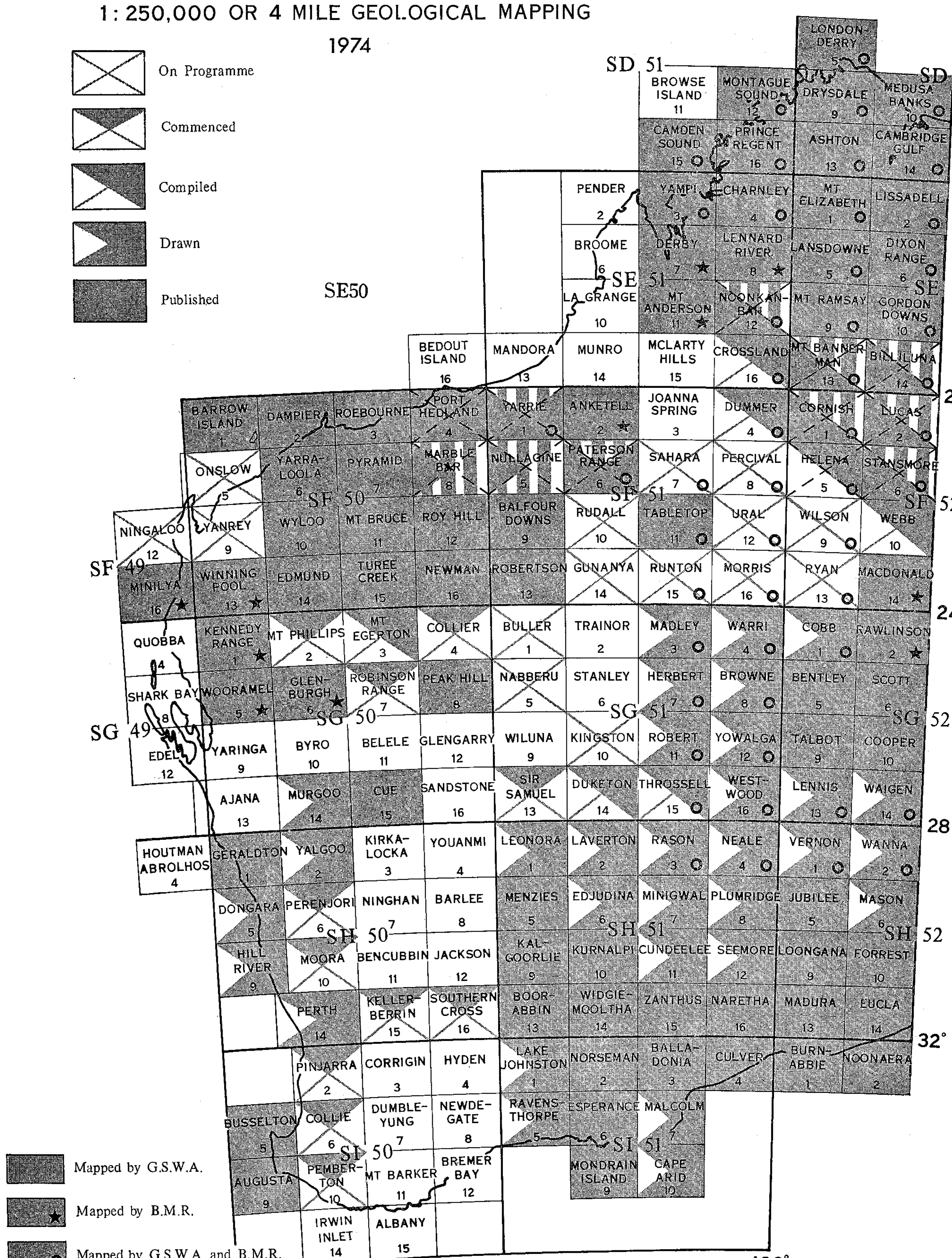
Field mapping on the Nullagine, Sir Samuel and Collier Sheets, plus the Precambrian portions of Mt. Bannerman, Patterson Range and Yarrie, was completed. The latter two sheets were mapped in conjunction with the Mineral Resources Division. Mapping continued on the Southern Cross Sheet and commenced on Robinson Range Sheet.

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

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

1: 250,000 OR 4 MILE GEOLOGICAL MAPPING

1974



Broken lines or shading indicates remapping

Figure 2.

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(ii) Preparation of a bulletin and completion

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

2. Continuation of mapping on the Southern Cross 1 : 250 000 Sheet.

3. Mapping of the pre-Bangemall rocks of the Kingston 1 : 250 000 Sheet.

4. Completion 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, copper, vanadium, chromium, tungsten, and molybdenum deposits of Western Australia.

3. Remapping of the Port Hedland 1 : 250 000 Sheet and commence re-assessment of the regional and economic geology of the Pilbara Block.

4. Continuation of regional mapping of the Darling Range on the Pinjarra, Collie and Moora 1 : 250 000 Sheets and study of the bauxite occurrences.

5. Mapping of the Precambrian of the Yanrey 1 : 250 000 Sheet and examination of copper occurrences in the Ashburton area.

The various specialist groups in the Common Services Division will provide support wherever required.

PUBLICATIONS AND RECORDS

Issued during 1974

Annual Report, 1973.

Bulletin 123: The geology of the Blackstone Region, Western Australia.

Geological map 1 : 2 500 000 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 Esperance-Mondrain Island 1 : 250 000 Sheet (SH/51-6 and 10 International Grid) with explanatory notes.

Geological map of Norseman 1 : 250 000 Sheet (SI/51-2 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 Press

Memoir No. 2: The geology of Western Australia.

Information Pamphlets; 2nd Edition: Tin, Copper. Precious and Semiprecious stones.

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

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

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

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

Geological map of Mason 1 : 250 00 Sheet (SH/52-6 International Grid) with explanatory notes.

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

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

Geological map of 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.

Reprints

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

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

In Preparation

Bulletin 124: The geology of the Perth Basin.

Bulletin 125: The geology of the Eastern Goldfields.

Mineral Resources Bulletins: Tin, Heavy mineral sands, Copper.

Geological maps 1 : 250 000 with explanatory notes, the field work having been completed: Billiluna, Browne, Cobb, Cundeelee, Duketon, Laverton, Lennis, Leonora, Lucas, Madley, Marble Bar, Minigwal, Mount Bannerman, Mount Egerton, Neale, Nullagine, Paterson Range, Perth, Rason, Robert, Sir Samuel, Stansmore, Throssell, Vernon, Waigen, Wanna, Warri, Westwood, Yarrie, Yowalga.

Geological map 1 : 1 000 000 Kalgoorlie.

Geological map 1 : 1 000 000 Esperance.

Records Produced

1972/25 vol. 2. The geology of the proposed North Pole dam site, Shaw River, by J. M. Campbell (restricted).

1974/1 Dolerite geochemical study, Northampton district, W.A., by A. A. Gibson.

1974/2 Wells drilled for petroleum exploration in W.A. to the end of 1973, by G. H. Low.

1974/3 Lower Wungong proposed dam site—rock quarry site 2 km upstream (Site No. 2), by G. Marcos (restricted).

1974/4 Explanatory notes on the Cobb 1 : 250 000 geological sheet, W.A., by W. J. E. van de Graaff.

1974/5 Explanatory notes on the Vernon 1 : 250 000 geological sheet, W.A., by W. J. E. van de Graaff.

1974/6 West Canning Basin hydrology: investigation geophysics, 1973 progress report, by D. L. Rowston (restricted).

1074/7 Burekup proposed dam site—seismic refraction survey, by I. R. Nowak (restricted).

1974/8 Explanatory notes on the Leonora 1 : 250 000 geological sheet, by R. Thom and R. G. Barnes.

1974/9 Explanatory notes on the Neale 1 : 250 000 geological sheet, W.A., by W. J. E. van de Graff and J. A. Bunting.

1974/10 Robe River dam site "D"—geological reconnaissance, by R. P. Mather (restricted).

1974/11 Explanatory notes on the Plumridge 1 : 250 000 geological sheet, W.A., by W. J. E. van de Graaff and J. A. Bunting.

1974/12 Explanatory notes on the Cundeelee 1 : 250 000 geological sheet, W.A., by J. A. Bunting and W. J. E. van de Graaff.

1974/13 Lower Wungong proposed dam site, rock quarry site No. 1 (6 km upstream): geological investigation, by G. Marcos (restricted).

1974/14 Lower Wungong proposed dam site: construction area geological conditions, by G. Marcos (restricted).

1974/15 Explanatory notes on the Archaean rocks of the Perth 1 : 250 000 geological sheet, W.A., by S. A. Wilde.

1974/16 Devonian brachiopods from the reef complexes of the Canning Basin, by K. Grey.

1974/17 Explanatory notes on the Minigwal 1 : 250 000 geological sheet, W.A., by J. A. Bunting and J.-C. Boegli.

1974/18 West Canning Basin groundwater investigations: progress report, March, 1974, by R. E. J. Leech (restricted).

1974/19 Kangan Pool dam site, Sherlock River: seismic refraction survey, by D. L. Rowston (restricted).

1974/20 Explanatory notes on the Marble Bar 1 : 250 000 geological sheet, W.A., by A. H. Hickman and S. L. Lipple.

1974/21 Burekup proposed dam site, Collie River: geological investigation progress report, by G. Klenowski (restricted).

1974/22 Dogger Gorge proposed dam site: seismic refraction survey, by I. R. Nowak (restricted).

1974/23 The hydrogeology of the Watheroo-Jurien Bay line, Perth Basin, by A. S. Harley.

1974/24 Lime resources between Lancelin and Mandurah, W.A., by J. L. Baxter and J. P. Rexilius.

1974/25 Heavy mineral reserves in Western Australia, March, 1973, by J. L. Baxter (confidential).

Reports in other publications

Trendall, A. F., 1974, Time, Life and Iron: West Australia Institute of Technology, Gazette v. 7, no. 2, p. 10-13.

1st February, 1975.

J. H. LORD,
Director.

HYDROGEOLOGY OF THE DE GREY RIVER AREA

by W. A. Davidson

ABSTRACT

The De Grey River groundwater investigation comprised part of the search for supplies for Port Hedland. It included a bore census, exploratory drilling, geophysics, and test-pumping of alluvial sediments along the De Grey, Strelley and Shaw Rivers. Test-pumping showed that 2 000 m^3/day should be obtainable.

The volume of groundwater in storage was estimated to be 82 x 10^6 m^3. As much as 40 per cent of this quantity has a salinity of 1 000-2 000 ppm TDS and the remainder, which falls in the potable range (300-1 000 ppm TDS), includes the annual recharge over 170 km^2. These estimates are based on an assumed storage co-efficient of 0.1.

Without drawing on storage and neglecting the effects of increased river recharge and reduced transpiration losses, 7 600 m^3/day of potable water should be obtainable from the aquifer. Under prolonged pumping this estimate could be conservative.

INTRODUCTION.

The rapidly increasing demand for water, as a result of population growth and industrial development in Port Hedland, has made it necessary to find additional reserves of groundwater.

To identify areas having groundwater possibilities a pastoral property bore and well census was made during 1969. As a result the De Grey River system and its associated alluvium was chosen for a more intensive investigation between 1969 and 1972.

The aim was to find a groundwater source capable of producing more that 30 000 m^3 per day of groundwater with a salinity of less than 1 000 ppm of Total Dissolved Solids (TDS). These minimal requirements were set by the Public Works Department.

The De Grey River system is at the northern edge of the Pilbara Block, and the area investigated is approximately 100 km east of Port Hedland (Fig. 3, inset).

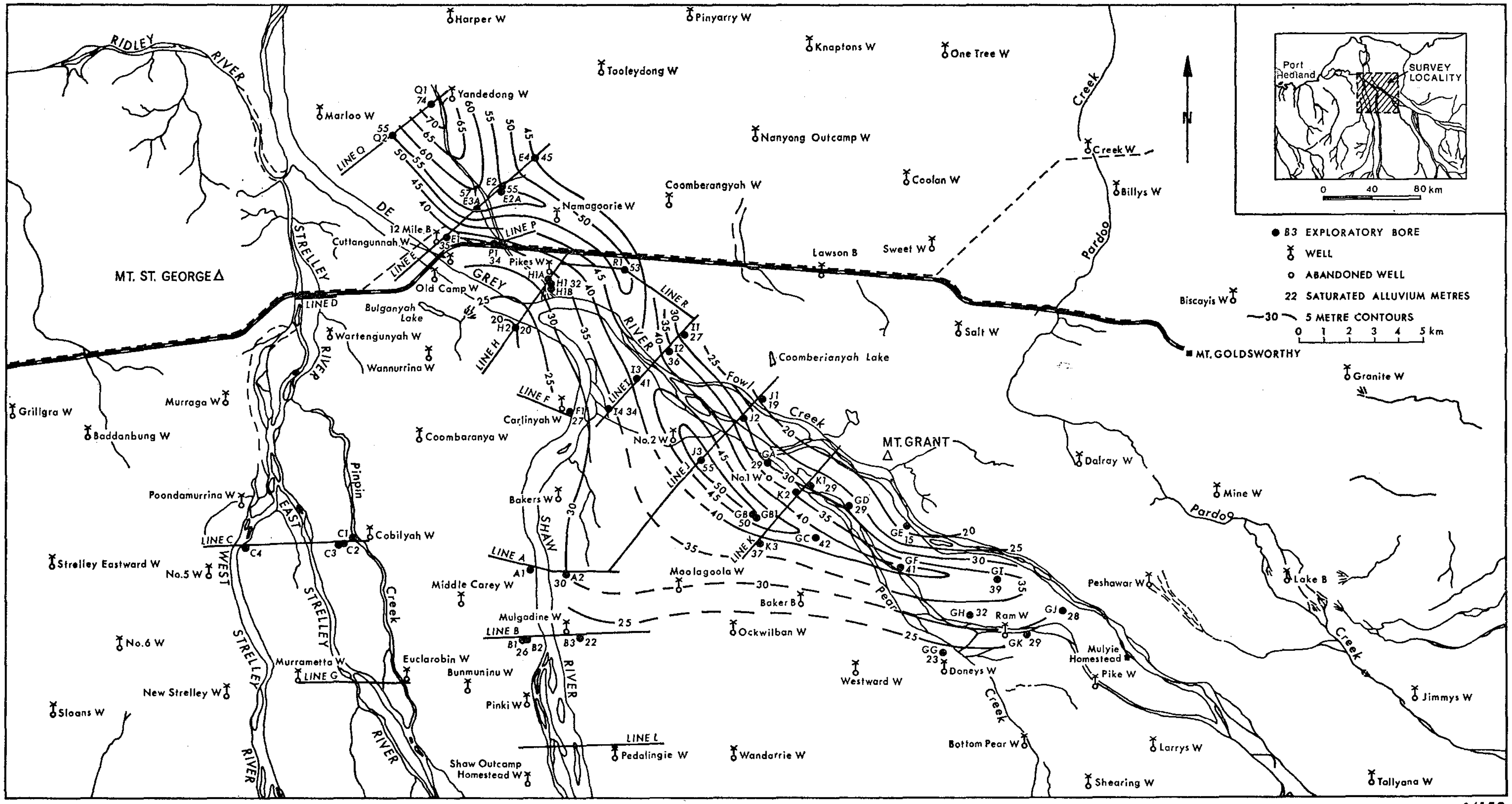

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Figure 3. De Grey River groundwater—isopachs of saturated alluvium in metres for 23/8/72.

Investigations.

Forty nine bores were drilled through the alluvium to weathered and sometimes fresh bedrock. Depths ranged between 18 m and 119 m and the aggregate depth was 2 972 m. Details of the boreholes are given in Table 1.

The bores were sited by geophysical methods (seismic refraction and resistivity profiling) in an attempt to delineate ancient buried river channels.

The seismic lines, boreheads, wells and river pools were accurately levelled and related to standard mean sea level datum.

TABLE 1. BOREHOLE DETAILS OF THE DE GREY RIVER AREA

Bore	Commenced	Completed	Reduced levels		Total depth m	Casing		Screens		Developed by surging (hours)	Drilling method
			Casing m	NS m		Length m	Diam. OD mm	Interval m	Diam. OD mm		
A1	24/8/69	2/9/69	34·49	33·83	48·8	28·7	76	4·6–28·7	76	....	Cable tool
A2	7/11/70	20/11/70	36·99	36·39	42·7	27·4	203	27·4–42·1	178	36	Cable tool
B1	2/10/69	6/10/69	38·92	38·15	47·2	47·2	76	3·1–47·2	76	....	Cable tool
B2	7/10/69	28/10/69	38·85	38·24	52·4	44·9	152	open hole		....	Cable tool
B3	28/10/69	8/11/69	39·08	38·28	37·5	35·1	76	35·1–37·5	76	....	Cable tool
C1	4/9/69	29/9/69	30·45	29·92	23·5	23·5	76	3·1–23·5	76	....	Cable tool
C2	7/9/69	10/9/69	31·78	31·08	23·8	23·8	76	3·7–23·8	76	....	Cable tool
C3	10/9/69	10/12/69	31·30	30·89	55·5	38·2	152	open hole		....	Cable tool
C4	30/9/69	1/10/69	33·91	33·11	18·3	18·3	76	4·6–18·3	76	....	Cable tool
E1	11/11/69	4/12/69	23·25	22·34	118·9	39·6	76	4·6–39·6	76	....	Cable tool
E2	24/4/70	24/5/70	24·21	23·34	112·8	61·0	76	15·2–61·0	76	....	Cable tool
E2A	22/10/70	29/11/70	23·73	23·29	54·6	17·8	203	17·8–54·4	178	84	Cable tool
E3	22/6/71	10/8/71	23·80	23·80	59·4	24·7	305	24·7–59·1	152	70	Cable tool and Rotary
E3A	5/7/71	29/7/71	24·04	23·81	91·4	24·4	76	24·4–59·7	76	Air lifted	Cable tool
E3B	11/8/71	19/8/71	23·87	23·35	59·4	59·4	101	8·2–59·4	101	Air lifted	Rotary
E4	20/8/71	13/9/71	21·56	20·93	105·4	21·3	76	21·3–51·8	76	Air lifted	Rotary
E4A	4/10/71	13/10/71	20·99	20·88	51·8	24·1	305	24·1–51·8	152	40	Rotary
E4B	14/9/71	1/10/71	21·66	20·90	51·8	21·3	76	21·3–51·8	76	Air lifted	Rotary
F1	27/10/70	5/11/70	31·05	30·58	44·2	11·0	203	11·0–29·3	178	48	Cable tool
H1	27/5/70	4/6/70	27·55	26·93	93·0	93·0	76	11·6–93·0	76	....	Cable tool
H1A	30/9/70	23/11/70	27·33	26·77	51·8	7·8	203	7·8–21·6	178	48	Cable tool
H1B	7/10/70	....	27·35	26·88	79·3	58·6	203	58·6–80·0	178	24	Cable tool
H2	8/7/70	16/7/70	27·40	26·44	48·2	48·2	76	12·2–48·2	76	....	Cable tool
I1	5/6/70	10/6/70	28·65	27·66	53·0	53·0	76	18·3–30·5	76	....	Cable tool
I2	11/6/70	21/6/70	29·96	28·98	77·4	77·4	76	15·2–42·7	76	....	Cable tool
I3	10/7/70	18/7/70	31·01	29·72	82·3	79·3	76	9·1–79·3	76	....	Cable tool
I4	14/10/70	24/11/70	29·09	28·17	70·1	17·9	203	17·9–40·5	178	24	Cable tool
J1	22/6/70	29/6/70	33·56	32·39	42·7	42·2	76	12·2–27·4	76	....	Cable tool
J2	30/6/70	7/7/70	33·55	32·03	58·8	51·8	76	21·3–33·5	76	....	Cable tool
J3	24/8/71	13/9/71	31·74	31·45	78·3	25·6	319	25·6–63·1	152	16	Cable tool
K1	31/7/70	4/8/70	34·04	33·14	36·0	35·1	76	9·1–35·1	76	....	Cable tool
K2	23/7/70	30/7/70	33·08	32·16	40·2	40·2	114	9·1–40·2	114	....	Cable tool
K3	2/8/71	21/8/71	36·30	36·07	103·0	25·3	273	25·3–95·4	Casing 152	20	Cable tool
P1	5/11/70	15/11/70	24·55	24·01	45·7	17·8	203	17·8–36·7	178	48	Cable tool
Q1	14/10/71	3/11/71	20·56	20·41	108·8	22·3	305	22·3–54·3	152	35	Rotary
Q2	3/11/71	25/11/71	18·30	18·41	100·9	22·9	305	22·9–95·4	152	70	Rotary
R1	16/9/71	14/10/71	25·84	25·39	94·5	28·7	319	28·7–62·5	152	14	Cable tool
GA	19/6/70	22/8/70	32·51	32·14	36·3	16·1	203	16·1–35·4	178	60	Cable tool
GB	18/7/70	7/8/70	35·51	35·14	106·7	59·5	203	59·5–105·2	178	72	Cable tool
GB1	8/8/70	17/8/70	35·51	35·29	47·2	22·7	203	22·7–46·2	178	60	Cable tool
GC	22/8/70	8/9/70	35·44	35·04	70·1	17·4	203	17·4–45·1	178	48	Cable tool
GD	6/8/70	15/8/70	35·31	34·80	36·0	12·0	203	12·0–36·1	178	48	Cable tool
GE	18/8/70	27/8/70	38·22	37·60	31·7	12·1	203	12·1–30·5	178	24	Cable tool
GF	28/8/70	7/9/70	37·62	37·37	50·3	22·3	203	22·3–41·8	178	36	Cable tool
GG	8/9/70	17/10/70	40·05	39·71	45·1	23·2	203	23·2–43·9	178	36	Cable tool
GH	19/9/70	4/11/70	40·66	40·28	40·5	16·1	203	16·1–39·6	178	36	Cable tool
GI	9/9/70	....	39·34	38·97	56·4	18·2	203	18·2–48·2	178	48	Cable tool
GJ	23/9/70	29/9/70	41·84	41·20	43·9	17·9	203	17·9–41·6	178	24	Cable tool
GK	21/9/70	....	42·44	42·04	44·5	11·9	203	11·9–43·0	178	60	Cable tool

TABLE 2. STRATIGRAPHIC UNITS OF THE PORT HEDLAND 1 : 250 000 GEOLOGICAL SHEET

Age	Map Symbol	Name of Unit	Lithology	Occurrence	Topography	Economic Geology
Quaternary	Qr	....	Alluvial clay, silt, sand, gravel and conglomerate	In some areas adjacent to major drainages the alluvium is up to 82 m thick	Valley floors, flats and river systems	Water
Tertiary	Tk	....	Pisolitic ironstone and kankar	Areas along Strelley River	Limited exposures on edge of some drainage channels. Isolated, small, flat-topped hills	Water—some station wells
	To	Oakover Formation	Siltstone, limestone and chalcedony	Areas along Strelley River		
	M	Anketell Sandstone	Sandstone, shale and claystone	Bore E1 proved a thickness greater than 76 m	Hill capping, small mesas and buttes	Water—some station wells
Jurassic-Triassic	M	Callawa Formation	Current-bedded, coarse sandstone and conglomerates	Possibly intersected in bores E2, E3A, E4, H1, H2, I1, I2, I3, I4, P1, Q1, Q2, and R1	Hill capping, small mesas and buttes	Water—some station wells
ANGULAR UNCONFORMITY						
Archaean	q	....	Quartz reefs and blows	Many of the bores	Ridges or elongated hills	Water
	d	....	Quartz dolerite dykes	H2 and possibly I2, I4 and GB		Road metal
	Agr	....	Granite, granite gneiss	Many bores	Scattered outcrops and low level sand-covered plains	Ballast for railways
	Agn	....	Partly granitized Archaean			Water
	STRONG FOLDING AND GRANITE INTRUSION					
	Ai	Gorge Creek Formation	Argillite, quartz and conglomerate with iron-bearing formations and volcanics	Many of the bores	Dissected ranges and hills	Iron ore and manganese
	Aw	Warrawoona 'series'	Basic volcanic pillow lavas, serpentines, coarse-grained basic intrusives, conglomerate sandstone, shale, jaspilite and associated schistose rocks		Dissected ranges and hills	Iron ore

GEOLOGY

The lowermost sediments of the De Grey valley are Coongan and Shaw alluvium, overlain by Oakover and Nullagine River sediments deposited after river capture. The uppermost sediments consist of recent alluvium from all four rivers. This sequence of sediments rests on a basement floor consisting of granite, volcanics and indurated sediments of the Gorge Creek Formation, all of Archaean age.

The regional geology is shown on the Port Hedland 1 : 250 000 Geological Sheet and described by Low (1965). Table 2 illustrates the stratigraphic units.

HYROGEOLOGY

The six different aquifers that have been recognized are considered in order of increasing storage potential.

Granite. Many of the bores terminated in weathered to fresh granite, which yielded small supplies. For example bore grant B was pumped at 1 156 m^3/day for 48 hours with a drawdown of 10 m.

Drilling samples from bore A1 show exfoliation of the granite basement. Immediately below the exfoliation plates there is a build up of water-bearing clean quartz sand. This weathering profile is thought not to be very extensive and can be regarded only as a source of windmill-water for stock.

There are two types of weathered granitic material, one is a series of exfoliated plates, and the other is probably colluvial in origin. The colluvial granitic material seems to be the better aquifer because useful thicknesses can be expected (e.g. K3, 45-94.5 m).

Volcanics and Gorge Creek Formation. Several bores ended in volcanic rocks, and two were tested by pumping; e.g. H1A was pumped at 785 m^3/day for 7½ hours with about 7 m of drawdown.

Although the rocks do not have a large potential, Goldsworthy Mining Ltd. reported pumping "large volumes" of water from their open cut, presumably from joints and fractures in the cherts of the iron formation.

Mesozoic sediments. Fourteen of the exploratory bores penetrated sediments of possible Mesozoic age; most of the samples were very rich in clay and silt. Borehole E1, which terminated in a grey shale, possibly belonging to the Anketell Sandstone, had a very low yield. Others could be better, such as R1, which ended in quartz sand (possibly Callawa Formation), but was not tested.

In borehole cuttings weathered Mesozoic sandy siltstone is similar to the sandy siltstone of the Archaean Gorge Creek Formation. Gamma-ray logging has shown that the sediments at 35.5 m depth in borehole I1 have the same radiation pattern as the sediments in I2 at 45 m and I3 at 50 m. Bores I1, I2 and I3 may have terminated in either Mesozoic or Archaean sediments.

Kankar. Their are two sets of geological conditions under which the kankar has developed.

The water table kankar is the more important, and is usually the source of stock and domestic water supplies. Essentially it is a calcareous, weakly cemented alluvium about 1 m-thick and therefore not a large individual producer of water.

The kankar which develops at the top of the granite weathering profile can be quite thick, e.g. 45-62 m in bore K3. It appears to be *in situ* and is probably a product of a chemically weathered basement.

Alluvium. The aquifers in the river alluvium range in thickness from a few metres to about 75 metres, and may be roughly grouped into an upper and lower unit. This division is fairly arbitrary along the De Grey River, where there is often a hydraulic connection between the two.

The upper sand or water table aquifers usually have coarse-grained sand and gravel at the water table and sometimes a thin kankar horizon. The water in these sands may be fully confined, as in bore B2, but this is not commonly so.

The lower sands vary in thickness and permeability and are sometimes separated from the upper sands by silty clay. They occur as thin beds and lenses, so that through 75 m several sandy beds may be intersected. Occasionally a thick gravel bed is present.

The lower sand aquifers associated with the De Grey River are more extensive and also less clayey than those of the Shaw and Strelley Rivers.

Alluvial Trough

The present course of the De Grey River no longer coincides with the axis of the alluvial filled trough (Fig. 3). In its downstream part the river has migrated several kilometres southwestward, although farther up-stream it has moved to the northeast. The positions roughly coincide between cross-section lines H and I.

HYDROCHEMISTRY

There is a wide range of salinities, the better quality water generally occurring close to the present river course.

Throughout the area the salinity of the groundwater is suitable for stock consumption, and beneath nearly half of the area it is suitable for domestic use.

The isohaline map (Fig. 4) shows the regional groundwater salinity pattern and reflects the presence of the buried river channel downstream from near bore H1. Drilling has shown that the aquifer in this area has a comparatively high permeability.

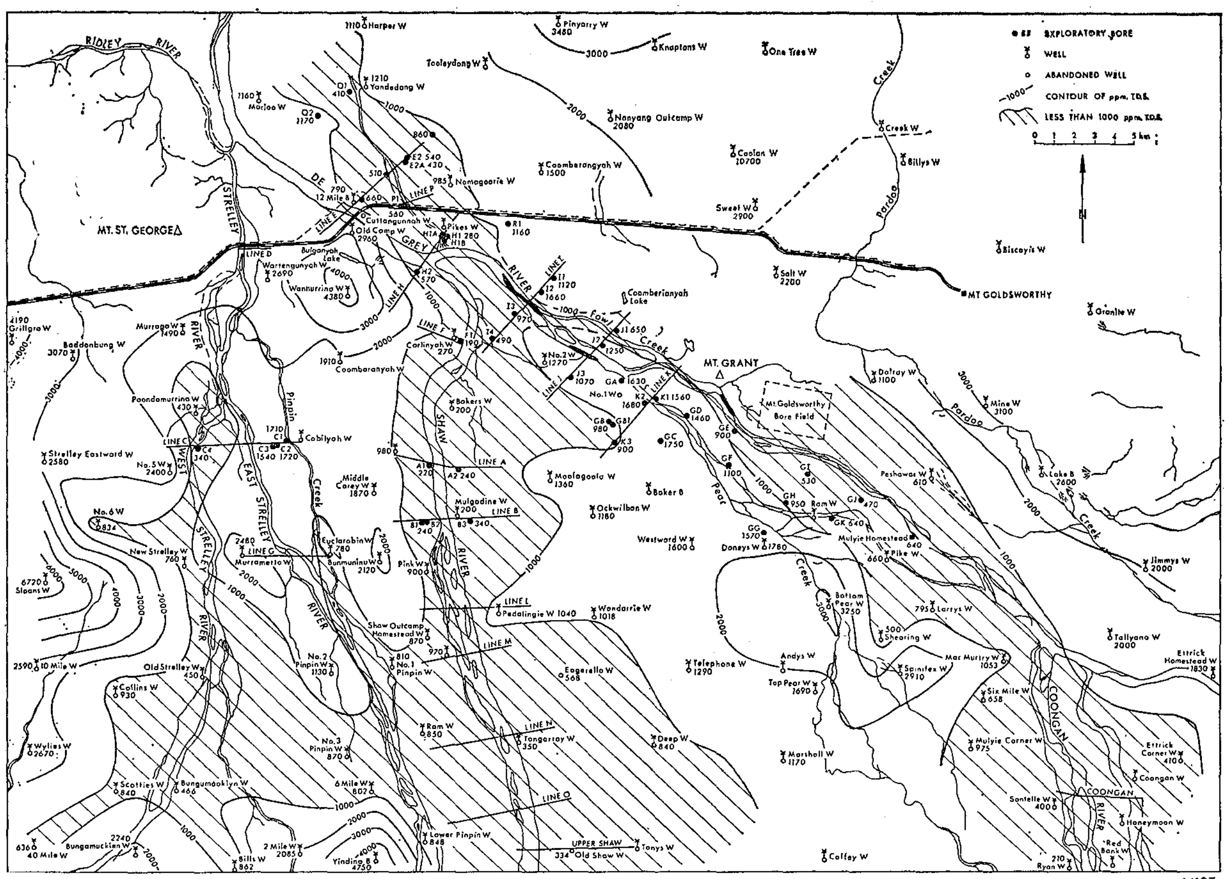

Figure 4. De Grey River groundwater—hydrochemistry and isohalines in ppm TDS.

PUMPING TESTS

Twenty-seven bores were tested for periods of up to 48 hours.

Because of the heterogeneous nature of the aquifer, and because both confined and unconfined conditions could occur at each site, leaky artesian, delayed yield, water table and boundary conditions were likely to be experienced in any one test. Most of the bores were pumped without observation bores and many were only partially penetrating.

Time-drawdown curves plotted from pumping-test data proved very difficult to analyse. A summary of results is shown in Table 3.

GROUNDWATER MOVEMENT

The direction of groundwater movement, along flow lines, is perpendicular to the poteniometric contours indicated on the flow net diagram (Fig. 5). The flow channels are defined by flow lines passing through points of origin distributed along the 18 metre poteniometric contour at equal intervals.

TABLE 3. DE GREY RIVER PROJECT PUMPING-TEST DATA

Bore	Screened Interval m	Pumping-Test			Transmissivity		Hydraulic Conductivity	
		Duration Hours	Rate m³/d	Total Drawdown m	T m³/d/m	Method	Saturated Alluvium m	K m³/d/m²
A2	27·4–42·1	1·5	200	13·41	15	Specific capacity	29·8	0·5
B3	28·0–35·1	8	349	10·13	30	Specific capacity	21·8	1·4
C3	Open Hole	0·9	273	20·91	Bore pumped on the fork			
E2A	17·8–54·4	48	2 400	2·13	1 400	Specific capacity	54·7 E2	25·6
E3	24·7–59·1	48	3 100	6·17	940	Part penetration	57·3 E3A	16·4
E4A	24·1–51·8	48	3 060	8·85	1 940	Theis curve	44·7 E4	43·4
F1	11·0–29·3	1	160	Bore pumped on the fork				
H1A	7·8–21·6	7·7	786	6·86	50·70	Delay	32·3 H1	2·2
H1B	58·6–80·0	Pumped Test Failed						
I4	17·9–40·5	48	1 266	4·72	220	Specific capacity	33·6	6·6
J3	25·6–63·1	48	4 580	8·53	500	Specific capacity	55·0	9·1
K3	25·3–95·4	48	2 620	7·77	200	Delay	36·7	5·4
Q1	22·3–54·3	48	3 900	8·38	510	Specific capacity	73·8	6·9
Q2	22·9–95·4	48	4 580	5·48	600	Specific capacity	54·9	10·9
R1	28·7–62·5	48	4 866	6·40	1 440	Const. D.D.	52·8	27·3
GA	16·1–35·4	48	1 593	4·12	370	Specific capacity	29·2	12·7
GB	59·5–105·2	48	1 156	9·91	58	Delayed yield	50·1	1·2
GB1	22·7–46·2	48	3 338	15·85	220	Theis curve	50·1 GB	4·4
GC	17·4–45·1	48	2 837	4·57	300	Delayed yeild	41·8	7·2
GD	12·0–36·1	48	1 440	2·29	300	Delayed yeild	28·8	10·4
GE	12·1–30·5	48	1 309	7·92	inadequate test		15·2	....
GF	22·3–41·8	48	1 527	2·44	280	Delayed yield	41·1	6·8
GG	23·2–43·9	0·7	854	20·12	50	Specific capacity	23·0	2·2
GH	16·1–39·6	48	2 837	6·10	200	Delayed yield	?32·4	6·2
GI	18·2–48·2	48	1 746	2·74	270	Delayed yield	38·5	7·0
GJ	17·9–41·6	40	1 811	18·29	60	Delayed yield	28·4	2·1
GK	11·9–43·0	48	2 837	2·90	Inadequate, not conclusive test		29·4	....

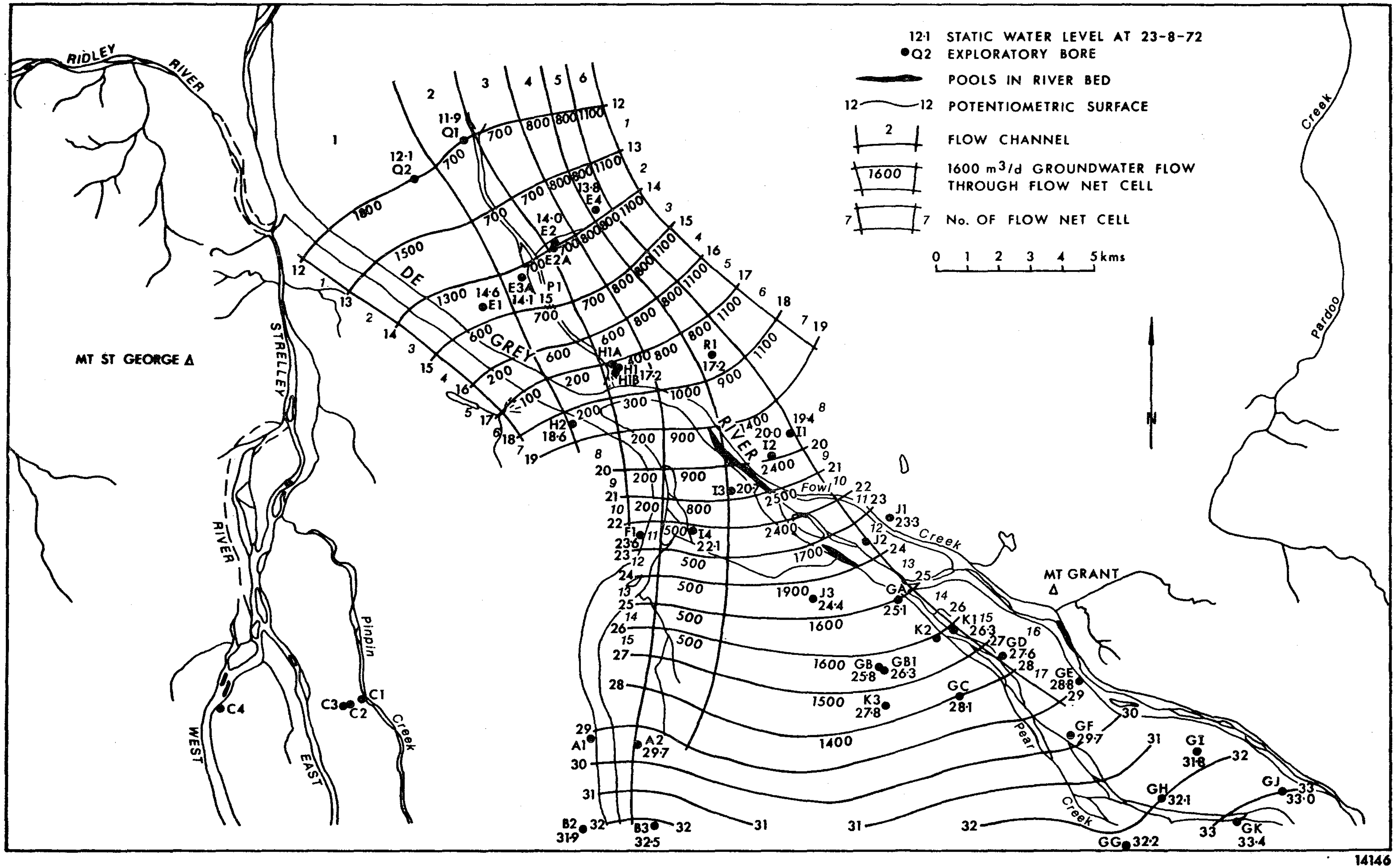

Figure 5. De Grey River groundwater—flow net for 23/8/72 potentiometric surface.

To evaluate the volume of water passing through individual cross-sectional areas defined by the flow net, the transmissivities, gradients and cross-section lengths, have to be determined. This volume can then be calculated by using the simple expression Q = Til.

Where Q = volume passing through section, m^3/d.

T = transmissivity, $m^3/d/m$.

i = gradient, dimensionless.

l = cross-section length, m.

The hydraulic gradient and cross section lengths may be directly measured from the flow net but the transmissivity for each section has to be estimated from the distribution of values derived by test pumping. This estimate, together with the derived flow volumes, is only roughly correct because of the variability of these values.

The flow net has six flow channels. In channel 1 there is a large net groundwater gain from the De Grey River. Along channel 2 there is a large net gain from the De Grey-Shaw River junction, with no gain or loss throughout the rest of the flow channel. Along channel 3 there is a large net gain from the De Grey River near the Shaw River junction; the remainder of the flow channel showing no gains or losses. Channel 4 shows a small net gain from the Shaw and De Grey Rivers and also some net loss which is possibly a transpiration loss. Above the granitic basement between the De Grey and the Shaw Rivers, channel 5 shows a steady increase in groundwater volumes from both rainfall and De Grey River flow. The net loss where permanent pools occur in the De Grey River, on lines J and I, is due to evaporation and transpiration. The remainder of the flow channel shows no gains or losses. Channel 6 is probably in a state of balance, though this might not be so if the channel were extended along the De Grey past Mount Grant, where evaporation and transpiration losses would be large.

The quantity of groundwater moving through the area can be calcluated by adding the contributions made by each flow channel. For example at the northern end of the flow net system a total of 5 900 m^3 per day is moving through the section indicated by the 12 m potentiometric line (i.e. about 1.3 x 10^6 imperial gallons per day).

Recharge Systems

The recharge-discharge regime is shown diagrammatically on Figure 6, the relative importance of each element being shown by the numbers on the arrows.

Recharge comes from river flow and from direct rainfall percolation.

River flow recharge is the most important source of intake to the alluvium, even though the rivers flow only for short periods. Typically the De Grey may flow twice in one year and not at all in the next, which means that there are long periods during which discharge from the aquifers takes place.

Most of the rain falling directly on the riverbed sands soaks in, whereas a high percentage of the rainfall on the interfluvial areas is lost by evaporation. In areas not affected by river recharge, if all the chloride ion in the groundwater comes from directly percolating rainfall, then the chloride concentration in the groundwater is a measure of the proportion of rainwater which becomes recharged after evapotranspiration losses.

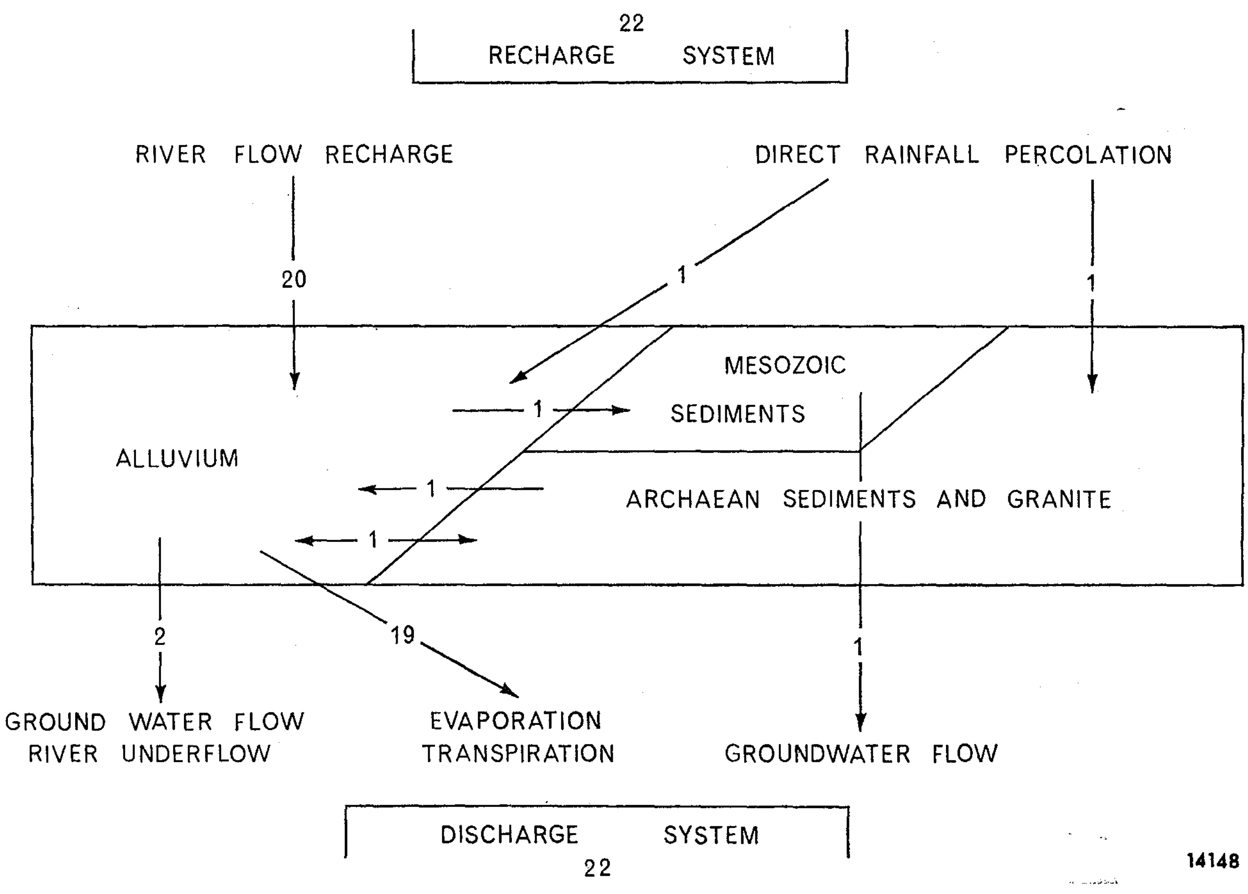

Figure 6. De Grey River groundwater—recharge-discharge regime.

There is about 8 ppm chloride in rainwater in this district, and it can be assumed that all the chloride in the groundwater in the areas listed in Table 4 comes from rainfall. It follows that about 3 per cent of the rainfall reaches the water table in an average rainfall year.

TABLE 4. RAINFALL RECHARGE BASED ON CHLORIDE CONCENTRATION.

Well bore	ppm chloride ground-water	ppm chloride rainfall	Distance from coast km	per cent rain recharged	per cent rain evapor-ated
J3	270	8	40	$\frac{8}{270} \times 100 = 3$	97
GB1	324	8	40	$\frac{8}{324} \times 100 = 2$	98
K3	225	8	40	$\frac{8}{225} \times 100 = 4$	96
Moolagoola	309	8	40	$\frac{8}{309} \times 100 = 3$	97
Ockwilban	210	8	40	$\frac{8}{210} \times 100 = 4$	96

The figure of 3 per cent can probably be applied to the whole area to derive the total volume of recharge from rainfall.

The area of interest, as shown by the flow net, is about 170 km² and the average annual rainfall is 275 mm.

$$\therefore \text{volume of infiltration} = 170 \times \frac{1000^2 \times 275}{1000} \times \frac{3}{100}$$

$$= 1\,400\,000 \text{ m}^3/\text{year.}$$

The average rise in water table, during recharging periods, is about 1 m per year. By assuming an average storage coefficient of 0.1 for the upper unconfined part of the aquifer, the total annual recharge to 170 km² of alluvium can be calculated.

$$\text{Total recharge} = 170 \times 1000^2 \times 1 \times 0.1$$

$$= 17\,000\,000 \text{ m}^3 \text{ per year}$$

If 1.4×10^6 m³ per year results from direct rainfall the remaining 15.6×10^6 m³ per year appears to come from river recharge. This means that only 8 per cent of the annual recharge of the groundwater in the alluvial flats is the result of direct downward infiltration of rain falling on the surface, the remaining 92 per cent being leakage from river flows.

Discharge Systems

The discharge components consist of transpiration, evaporation, groundwater flow and river underflow leaving the system.

From aerial photographs it has been estimated that approximately 11×10^6 m² of vegetation along river banks is contributing to transpiration. According to the Forestry Department a transpiration rate of 50 per cent pan evaporation could be applicable, and may even be conservative. If this premise is accepted, the amount of discharge through transpiration can be calculated as follows:

Annual pan evaporation = 2.5 m

Transpiration = 50 per cent evaporation = 1.25 m

Area of vegetation = 11 000 000 m²

∴ total volume water transpired per year

= 1.25 x 11 000 000

= 13 750 000 m³ per year

The amount of evaporation from surface water, such as pools in the De Grey River, has been calculated as follows:

Estimate of pool surface area = 250 000 m²

Surface evaporation per year (Bureau of Meteorology) = 2.5 m

∴ volume evaporated = 250 000 x 2.5 per year

= 625 000 m³ per year

Groundwater and river underflow leaving the system was calculated by flow net analysis to be 5 900 m³ per day or approximately 2.2×10^6 m³ per year.

Groundwater Balance

Input m³/year		Losses m³/year	
Recharge from river	15 600 000	Transpiration	13 750 000
Rainfall	1 400 000	Pool evaporation	650 000
		Groundwater outflow	2 200 000
Total	17 000 000		16 575 000
		i.e. approx.	17 000 000

Groundwater Resources

When a relatively shallow aquifer is pumped for a long period of time the water levels fall, full drainage conditions are achieved, and the areas over which confined conditions occur are progressively eliminated. In this circumstance a specific yield of 0.1 or more is thought reasonable for use in calculating abstractable storage from a material that is predominantly sandy.

An isopach map (Fig. 3) was drawn of the saturated alluvium for 23/8/72 when the water table was very low. The amount of groundwater within the area shown by Figure 7 is the volume in storage, at a particular moment, and excludes the annual recharge from rain or river flow.

The area has been divided into three sub-regions, two containing groundwater of less than 1 000 ppm TDS, and the third exceeding 1 000 ppm TDS. Volumes were calculated using an assumed storage coefficient of 0.1. The volume of good quality water was found to be 37.9×10^6 m³, and of poor quality water 27.1×10^6 m³. Mixing the two gives 65×10^6 m³ of water in storage at minimum water table level. After average annual recharge the total water in storage would be 65×10^6 m³ + 17×10^6 m³ or 82×10^6 m³ of which about 17×10^6 m³ will be lost to transpiration, evaporation and groundwater outflow per year.

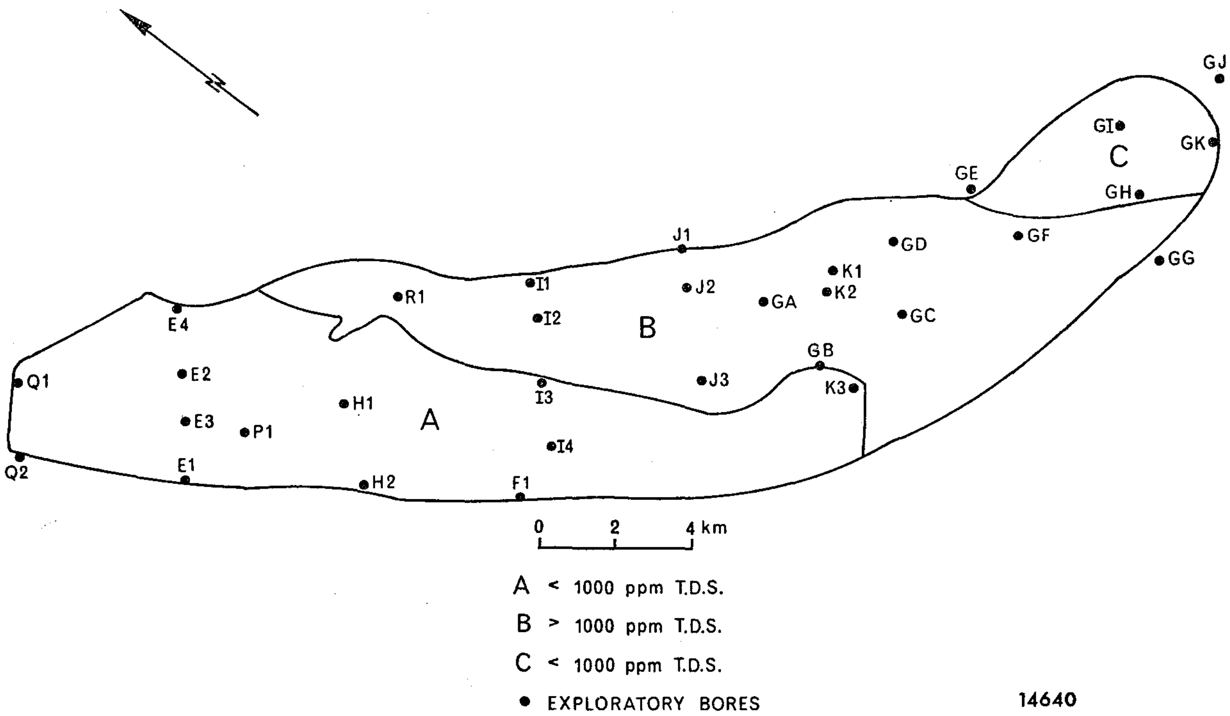

Figure 7. De Grey groundwater—salinity sub-regions.

Groundwater available for pumping

In summary, the volume of available groundwater is expressed by:

$$Q = GF + IR + RT + E$$
$$= 5\,900 \text{ m}^3 + IR + RT + 1\,700 \text{ m}^3$$
$$= 7\,600 \text{ m}^3 + RT$$

Where Q = volume of groundwater available for pumping in m^3 per day.

GF = groundwater outflow in m^3 per day.

IR = portion of groundwater which is held in storage and which will be gained by induced additional recharge.

RT = the amount by which transpiratory loss is reduced by lowering the water table. This could be substantial.

E = the saving in evaporative loss when the water table is sufficiently lowered by pumping.

At present the safe yield of the aquifer is 7 600 m^3 per day, exclusive of any gain due to reduced transpiratory losses, and assuming that no additional recharge due to lowering of the water table takes place. It is not known what effect these other factors will have on the value of a new safe yield which might be arrived at after prolonged pumping, and a changed water balance. The effect could be assessed only by pumping at a rate in excess of 7 600 m^3/day and by monitoring the water levels and salinities.

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EARTH TIDE INFLUENCE ON GROUND WATER LEVELS, HILL RIVER AREA, PERTH BASIN

by A. S. Harley

ABSTRACT

Hydrographs from two unconnected bores to the east of Jurien Bay, in the Perth Basin, show water level fluctuations in confined aquifers. The generally larger more random fluctuations can be attributed to atmospheric pressure changes. The smaller, periodic, semi-diurnal fluctuations correspond closely to fluctuations of lunar-solar origin in the earth's gravity field. The ocean tides have no discernable effect on the water levels. Only the water level in bore Watheroo Line 11 shows any obvious response to rainfall. Similar fluctuations due to earth tides are noted in other bores in Western Australia.

INTRODUCTION

Bores on the Watheroo Line, W.L. 11 and W.L. 12A, are on the western end of a line of deep bores drilled by the Geological Survey along the 30° 19′ S latitude between Watheroo and Jurien Bay. Bore W.L. 11 penetrated interbedded sandstones and mudstones of the Cockleshell Gully Formation, and bore W.L. 12A intersected the Lesueur Sandstone. Regionally the geology is complicated by a series of faults (Fig. 8).

Both bores are screened in confined aquifers but, as the bores were exploratory, the extent of the aquifers and the intake areas are unknown. When formation testing was completed, water level recorders were set up on the two bores.

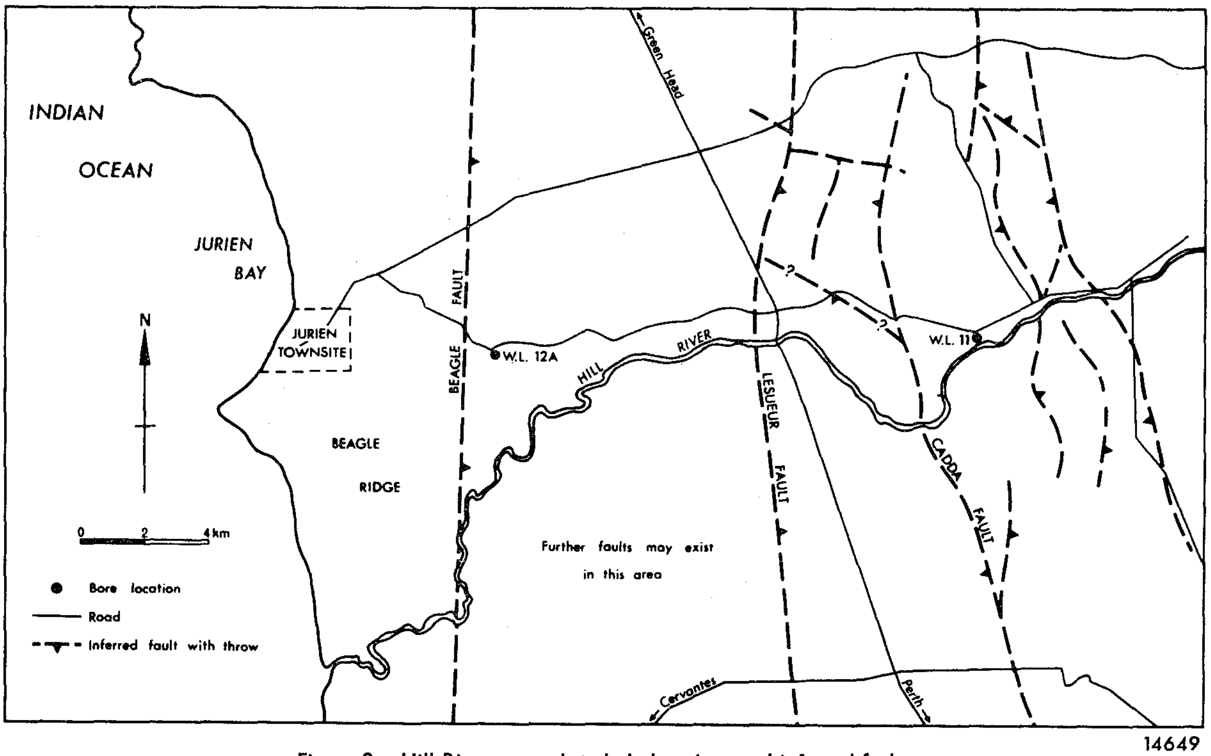

Figure 8. Hill River area—borehole locations and inferred faults.

HYDROGRAPHIC FLUCTUATIONS

Fluctuations in the water levels of both bores were analyzed with respect to atmospheric pressure, rainfall, ocean and earth tides. The periodic, semi-diurnal fluctuations were of special interest.

It was not possible to run the hydrographic and barographic recorders simultaneously, but it was possible to compare for a short time the W.L. 11 hydrographs with barographs at W.L. 12, and later compare both the W.L. 11 and W.L. 12A hydrographic records with barographs from near Eneabba, 53 km to the northeast. The hydrographs showed an inverse relationship with the barographs (Fig. 9), and the relatively large fluctuations were more frequent in the variable winter climate. The water levels are therefore affected by atmospheric pressure variations.

Small semi-diurnal barometric fluctuations were observed approximately at the same time each day, and had a constant amplitude, whereas the hydrographic semi-diurnal fluctuations varied in amplitude and had a semi-diurnal time lag of approximately 23 minutes. This indicates that the two types of semi-diurnal fluctuations have different origins.

Rainfall over the summer months was very low and intermittent, and so can be ruled out as the cause of the semi-diurnal fluctuations. However the W.L. 11 hydrographs do show a response to heavy or continuous rain.

Ocean and earth tides are generally semi-diurnal and are caused by fluctuations in the earth's gravity field due to the varying attraction of the moon, and to a lesser extent, the sun. However the ocean tides are modified by physiographic factors, thus on the west coast the tides are predominantly diurnal with a small range (Hodgkin and Di Lollo, 1958). Ocean tides can cause fluctuations in adjacent confined aquifers, but although the Watheroo hydrographs show the same spatial variation in amplitude intensities, the fluctuations are semi-diurnal and not diurnal (Fig. 10).

Assuming that the earth tide dilations are in phase with the gravity fluctuations, the inverted computed gravity corrections (Goguel, 1972), plotted at 3-hour intervals, compare favourably with the hydrographic semi-diurnal fluctuations. In particular the alternating large and small troughs, due to the upper and lower lunar culminations, correspond well.

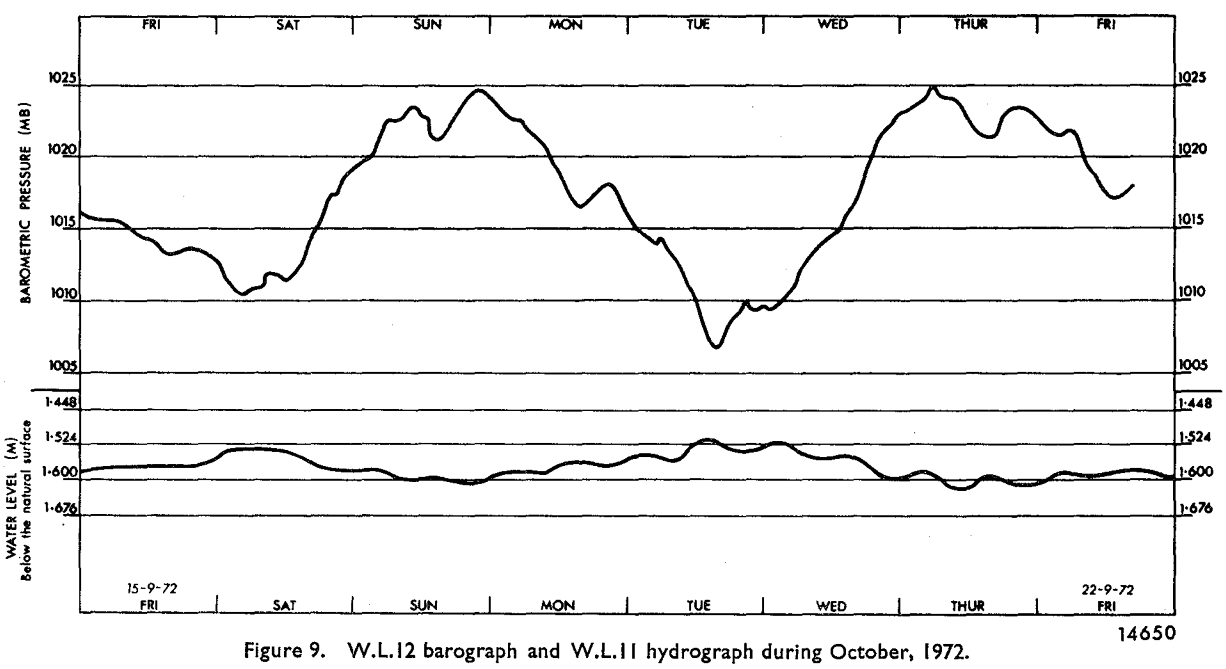

Figure 9. W.L.12 barograph and W.L.11 hydrograph during October, 1972.

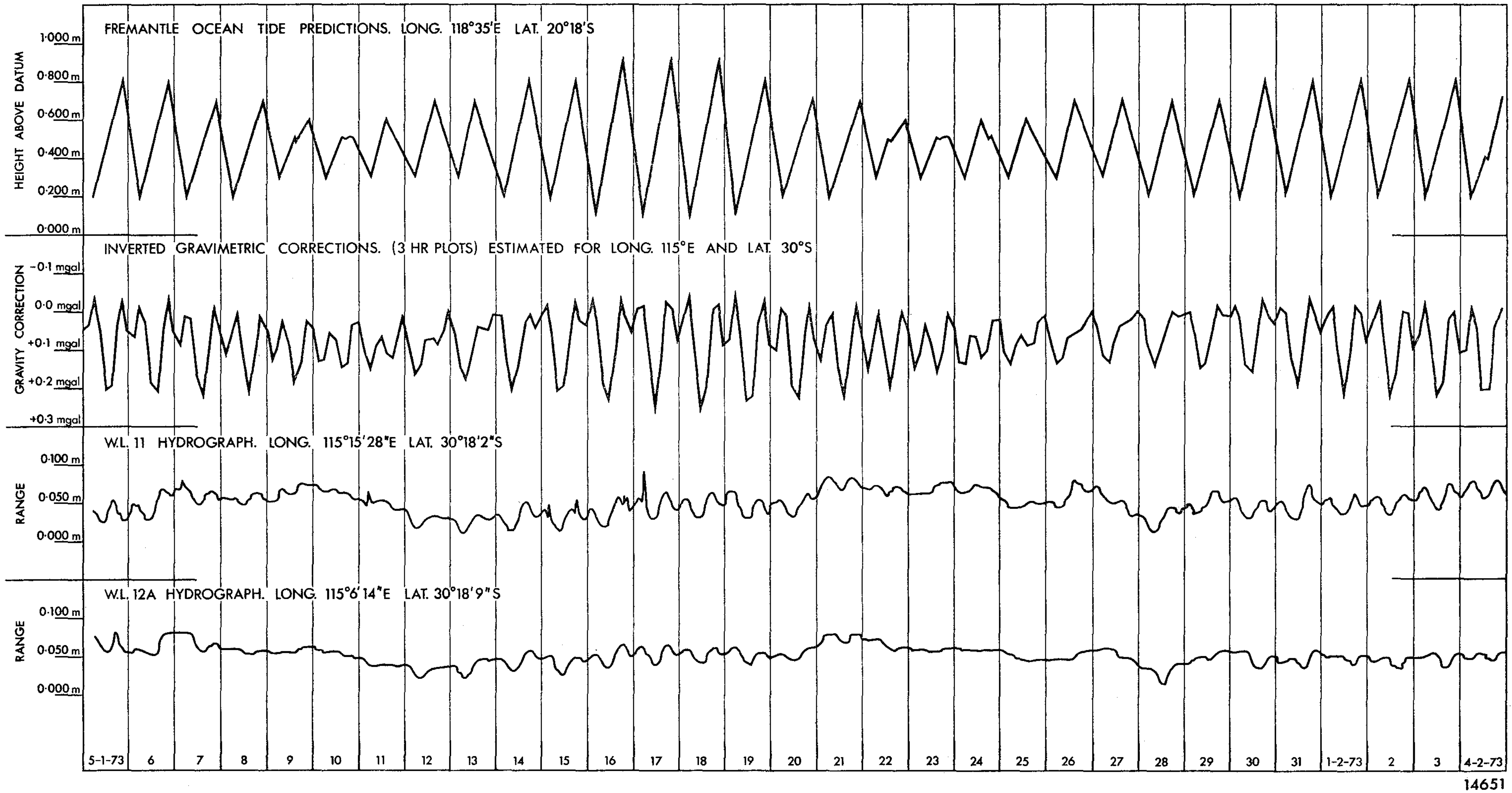

Figure 10. Hydrographs, gravimetric correction and ocean tidal predictions.

ADDITIONAL SEMI-DIURNAL RECORDINGS

Similar semi-diurnal fluctuations, attributed to earth tides, have been observed in Early Jurassic sediments near Pinjarra in the Perth Basin, and reported from a Tertiary calcreted drainage near Agnew in the Eastern Goldfields (Geotechnics, 1972), and in Recent alluvium just southwest of Mount Goldsworthy in the Pilbara (Davidson, 1973).

The maximum range of the semi-diurnal fluctuations lies between 10 mm and 40 mm, although the bore near Mount Goldsworthy is an exception with a maximum of 210 mm.

CONCLUSIONS

Critical examination of the data has reasonably established that although water level fluctuations in the Watheroo bores are affected by changes in the atmospheric pressure, and to a lesser extent rainfall, the periodic semi-diurnal fluctuations can be attributed to earth tides. Ocean tides appear to have no effect.

ACKNOWLEDGEMENTS

Sincere thanks are expressed to the Commonwealth Bureau of Meterology and the West Australian Astronomical Observatory for the help and information that their officers have given.

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THE GEOHYDROLOGY OF THE WATHEROO-JURIEN BAY DRILLHOLE LINE, PERTH BASIN

by A. S. Harley

ABSTRACT

The line completed a further section of the continuing deep-drilling project investigating the pressure waters of the Perth Basin. Twelve sites were drilled to a maximum depth of 762 m on a line extending across the Perth Basin from near Watheroo in the east, to Jurien Bay on the coast. Additional information has been used from 8 State Government and private bores on, or adjacent to, the line.

Predominantly continental sediments of Early Triassic to Recent age were intersected across the graben-faulted Dandaragan Trough between the Precambrian shield and the Beagle Ridge. Movements occurred at the end of the Jurassic, in the Neocomian, and in either the Late Cretaceous or Tertiary or both.

Aquifers containing potable water, and with good permeabilities, are recognized in the Coastal Limestone, the Warnbro Group, the Yarragadee Unit I, and the Lesueur Sandstone. The Yarragadee Unit III mudstones are an important confining unit separating the Agaton groundwater system from that at Badgingarra.

INTRODUCTION

The Watheroo-Jurien Bay Line is part of a long-term drilling investigation of the hydrogeology of the Perth Basin. The line of bores was drilled along an east-west section on the 30° 19′ S parallel, about 185 km north of Perth, and extends 86 km from the salt lakes, 7.6 km southwest of Watheroo, westward to the coast at Jurien Bay. Figure 11A shows the positions of the bore sites.

Drilling on Watheroo Line (W.L.) bore 1 started in May, 1967, but after W.L.4 the Mines Department was asked to investigate the area to the north and south of the bores then drilled, to determine whether a potable groundwater supply could be found to supplement the Northern Comprehensive Water Supply Scheme. By September, 1969, a further 22 sites were drilled for the Agaton Project (Balleau and Passmore, 1973), which covered an area of about 500 km^2 within latitudes 30° 11′ S and 30° 32′ S, and longitudes 115° 39′ E and 115° 55′ E. The Watheroo-Jurien Bay project recommenced in February, 1971, and was completed with W.L.12 in October, 1972.

The bores were drilled to a maximum depth of 762 m at an average spacing of 7 km. Agaton bores (A) 7, 18, 19, 24 and W.L.9 were additional bores to further clarify the hydrogeology. Bores W.L.11 and 12 had a spacing of 14.4 km because information from the oil well, Cadda 1, was available (Elie and others, 1965). The Jurien Bay (J.B.) 1 bore, on the western end of the line, was drilled in 1962. On sites W.L.2, 5, 6, 7, 8, 10, 11, and 12, one or more observation bores were drilled to test shallower aquifers. Information from the Magnetic Observatory bore, drilled in 1936, and from J.B.11 bore has also been used.

Suitable bores were capped and left for long-term water level observation, others being either abandoned or converted for use by the landowner.

DRILLING AND TESTING PROCEDURES

Four bores were drilled by percussion cable tool rig, the others by rotary methods. Sludge samples from the deepest bore on each site were logged every 3m, and conventional cores from the earlier rotary-drilled bores were taken at approximately 60 m intervals. From W.L.7 onwards sidewall cores were recovered on the completion of drilling, together with one or more conventional cores from the adjacent observation bores. The sidewall coring supplied the most useful samples for palynological examination, although the conventional cores gave a better idea of the rock type.

Gamma-ray and electric logs were run on each deep bore with additional logs on W.L.7, and W.L.12B. Step-out bores W.L.7A, W.L.11A, and W.L. 12B were also geophysically logged. Only gamma-ray logs could be taken in percussion bores A.7 and A.18 because of the casing. No geophysical logs were run in J.B.1, J.B.11, or the Magnetic Observatory bore, all drilled some years ago.

Drill-stem tests using both Johnson and Halliburton test-strings were made in open-hole conditions in bores W.L.1, W.L.2, W.L.3, W.L.5, W.L.6, and W.L.9. However, only two water samples, those recovered in W.L.1, appeared to be uncontaminated with drilling mud, and only one other sample, from the upper interval in W.L.6, approached the expected formation water salinity. Although pressure heads could be calculated using the Halliburton tester, the pressure records were not good enough to determine aquifer characteristics.

All the bores, except W.L.9, were cased and water samples collected from selected screened or slotted intervals either by bailing, pumping or air lifting.

Bore data are summarized in Table 5. All potentiometric levels are related to the State mean sea level datum.

TABLE 5. CHEMICAL ANALYSES OF WATER SAMPLES FROM WATHEROO-JURIEN BAY LINE

Bore	Screened interval (metres b.n.s.)	Formation	Appearance	TDS		pH	Ca		Mg		Na		K		Fe	HCO_3		CO_3	SO_4		Cl		NO_3	SiO_2	Remarks	No. Points on Fig. 11B
				Evap.	Cond.		ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	ppm	epm	ppm	ppm	epm	ppm	epm	ppm	ppm		
W.L.1	208·5–217·6	Leederville	Clear	8 610	9 160	6·1	110	5·49	249	20·48	2 630	114·35	76	1·94	0·1	55	0·90	0	575	11·97	4 580	129·16	1	11	....	....
W.L.1	506·0–515·1	Yarragadee Unit V	Clear	14 300	13 600	6·1	230	11·48	450	37·0	4 210	183·05	118	3·02	0·1	18	0·30	0	877	18·26	7 660	216·01	<1	11	....	....
A.18	206·4–213·7	Leederville	Clear with sl. brown deposit	650	710	5·3	7	0·35	19	1·56	186	8·09	10	0·26	1·4	12	0·20	0	42	0·87	325	9·17	<1	31	....	....
A.18	260·9–272·8	Leederville	Very sl. cloudy	750	830	5·3	3	0·15	21	1·73	207	9·00	23	0·59	5·6	6	0·10	0	42	0·87	370	10·43	2	49	Total Fe content	....
W.L.2	224·3–229·8	Leederville	Very pale yellow with black deposit	620	700	8·9	13	0·65	10	0·82	193	8·39	32	0·82	<0·1	278	4·56	15	2	0·04	194	5·47	7	<1	Probably cement contamination	....
W.L.2	342·9–349·0	Yarragadee Unit VI	Clear with brown deposit	800	950	6·7	16	0·80	24	1·97	247	10·74	15	0·38	3·1	137	2·25	0	39	0·81	381	10·74	6	12	....	....
W.L.2A	143·3–164·6	Leederville	Clear with sl. brown deposit	640	710	7·5	12	0·60	10	0·82	200	8·70	8	0·20	0·7	61	1·00	0	31	0·65	307	8·66	<1	35	....	....
A.24	91·0–146·7	Leederville	Clear with sl. brown deposit	350	370	5·3	2	0·10	11	0·90	92	4·00	9	0·23	5·0	6	0·10	0	38	0·79	154	4·34	<1	26	....	....
A.7	203·0–212·1	Yarragadee Unit VI	Clear	570	640	5·6	4	0·20	24	1·97	133	5·78	15	0·38	0·3	18	0·30	0	13	0·27	276	7·78	<1	32	....	....
W.L.3	151·5–160·0	Yarragadee Unit V	Clear with sl. brown deposit	560	610	6·5	12	0·60	20	1·64	145	6·30	15	0·38	0·1	49	0·80	0	21	0·44	273	7·70	1	31	....	....
W.L.4	130·2–177·1	Yarragadee Unit VI	Clear with grey deposit	480	660	6·8	15	0·75	11	0·90	141	6·13	2	0·05	<0·1	55	0·90	0	18	0·37	232	6·54	<1	14	....	....
W.L.5	391·5–398·0	Yarragadee Unit II	Clear with sl. brown deposit	1 630	1 850	7·6	60	2·99	25	2·06	509	22·13	17	0·43	0·14	195	3·20	0	106	2·21	787	22·19	1	23	....	....
W.L.5	740·3–746·9	Yarragadee Unit II	Clear with sl. brown deposit	1 570	1 780	7·9	58	2·89	27	2·22	476	20·70	16	0·41	0·05	177	2·90	0	66	1·37	778	21·94	<1	21	....	....
W.L.5A	255·4–258·6	Yarragadee Unit III	Clear with sl. brown deposit	1 480	1 730	7·9	13	0·65	24	1·97	511	22·22	14	0·36	0·06	183	3·00	0	94	1·96	718	20·25	<1	41	....	....
W.L.6	392·6–399·0	Yarragadee Unit II	Sl. cloudy with sl. brown deposit	1 410	1 550	6·9	14	0·70	35	2·88	388	16·87	29	0·74	5·0	7	1·15	0	82	1·71	649	18·30	1	52	....	....
W.L.6	392·6–399·0	Yarragadee Unit II	Sl. cloudy with sl. brown deposit	1 260	1 390	7·2	19	0·95	28	2·30	346	15·04	27	0·69	5·0	110	1·80	0	74	1·54	554	15·62	2	54	Probably downhole contamination	....
W.L.6	672·1–678·2	Yarragadee Unit II	Clear with heavy brown deposit	1 400	1 600	8·5	60	2·99	22	1·81	419	18·22	33	0·84	<0·05	156	2·56	12	158	3·29	623	17·57	4	4	Probably cement contamination	....
W.L.6A	177·4–183·5	Yarragadee Unit II	Clear with heavy deposit	1 220	1 390	6·9	8	0·40	41	3·37	348	15·13	18	0·46	<0·05	92	1·51	0	46	0·96	601	16·95	<1	6	....	....
W.L.7	714·6–724·2	Yarragadee Unit I	Clear with sl. brown deposit	430	500	7·6	10	0·49	12	0·99	124	5·39	12	0·31	0·25	128	2·10	0	18	0·37	167	4·71	<1	22	....	14
W.L.7A	521·9–528·2	Yarragadee Unit II	V. pale yellow with sl. deposit	900	1 030	7·0	7	0·35	19	1·56	274	11·91	12	0·31	0·6	82	1·34	0	46	0·96	420	11·84	0	47	....	....
W.L.7B	178·9–181·3	Yarragadee Unit II	Clear	740	850	7·3	19	0·95	15	1·23	203	8·83	19	0·49	<0·05	67	1·10	0	12	0·25	359	10·12	1	48	....	....
W.L.8	586·8–596·5	Yarragadee Unit I	Clear with brown deposit	560	640	5·5	10	0·50	29	2·38	116	5·04	17	0·43	1·2	3	0·05	0	13	0·27	284	8·01	<1	44	....	16
W.L.8A	170·7–174·3	Yarragadee Unit II	V. pale yellow with sl. brown deposit	720	760	6·6	9	0·45	15	1·23	188	8·17	16	0·41	2·8	34	0·56	0	55	1·15	298	8·40	<1	83	....	....
W.L.10	381·1–387·5	Yarragadee Unit I	V. sl. cloudy with deposit	300	320	7·7	32	1·60	3	0·25	55	2·39	12	0·31	0·05	134	2·20	0	16	0·33	71	2·00	<1	27	....	18
W.L.10A	224·5–230·8	Yarragadee Unit II	Cloudy	340	360	6·6	9	0·45	7	0·58	81	3·52	11	0·28	0·05	46	0·75	0	18	0·37	130	3·67	2	19	....	....
W.L.11	207·0–213·4	Cockleshell Gully	Clear with black deposit	4 340	4 480	7·5	172	8·59	90	7·40	1 200	52·18	24	0·61	0·15	183	3·00	0	252	5·25	2 150	60·63	<1	16	....	....
W.L.11	207·0–213·4	Formation	Clear with sl. brown deposit	2 770	3 140	8·0	86	4·29	29	2·39	870	37·83	17	0·44	<0·05	192	3·15	0	138	2·87	1 380	38·92	<1	18	Downhole contamination	....
W.L.11A	692·8–699·2	Cattamara Coal Measures	Clear with brown deposit	4 920	5 550	7·9	136	6·79	67	5·51	1 610	70·00	31	0·79	<0·05	177	2·90	0	290	6·04	2 630	74·17	<1	18	....	....
W.L.11B	14·0– 20·1	Member.	Cloudy with deposit	710	750	7·6	5	0·25	12	0·99	213	9·26	4	0·10	<0·05	58	0·95	0	65	1·35	266	7·50	50	67	....	....
Midland No. 7	36·6– 42·7	Coastal Limestone	Clear	460	540	7·0	48	2·40	16	1·32	95	4·13	4	0·10	<0·05	164	2·69	0	18	0·37	173	4·48	1	17	....	26
W.L.12	712·4–718·6	Woodada	Clear with sl. brown deposit	570	680	8·0	13	0·65	19	1·56	160	6·94	30	0·77	<0·05	152	2·51	0	42	0·87	232	6·54	<1	15	....	24
W.L.12A	135·2–141·5	Lesueur	Clear with sl. brown deposit	340	410	7·1	8	0·40	9	0·74	99	4·30	7	0·18	0·15	95	1·56	0	15	0·31	133	3·75	<1	16	....	22
W.L.12B	572·2–578·5	Lesueur	Clear with sl. brown deposit	400	470	7·4	24	1·20	15	1·23	83	3·61	20	0·51	<0·05	98	1·61	0	15	0·31	164	4·62	<1	18	....	23
J.B.11	23·7– 26·8	Coastal Limestone	Clear	620	690	7·4	88	4·39	16	1·32	113	4·91	4	0·10	<0·1	268	4·39	0	19	0·40	209	5·89	2	13	....	27
J.B.1	153·9-181·4	Woodada	....	49 300	....	6·7	1 280	63·88	1 210	99·51	15 400	669·59	570	14·58	....	64	1·05	0	3 160	65·79	27 700	781·14	2	....	....	25

Analyses **: Government Chemical Laboratories.**

CLIMATE

The climate is typically mediterranean, characterized by cool, wet, winters and warm, dry, summers. The annual average rainfall is 452 mm at Jurien Bay, 564 mm at the Badgingarra Research Station, and 428 mm at Watheroo.

GEOLOGY

Figure 12A shows the geological cross section. The geology has been described in detail in an earlier report (Harley, 1974).

In summary, the bores intersected predominantly continental sediments of Early Triassic to Recent age across the deep, graben-faulted, Dandaragan Trough between the Precambrian shield and the structural "high" of the Beagle Ridge. Marine transgressions occurred in the Early Triassic, Middle Jurassic, and the Late Cretaceous. Faulting and gentle folding occurred at the end of the Jurassic during the Neocomian when there was a period of non-deposition, and during Tertiary time.

Continuous erosion has taken place since the Cretaceous, but lateritization during the Pleistocene or Tertiary or both has formed a residual surface resistant to erosion. The coastal plain has developed as a result of marine erosion with subsequent modification and the deposition of several Pleistocene to Recent dune systems.

Since the writing of of the Agaton report by Balleau and Passmore (1972) there have been revisions of the Cretaceous stratigraphical nomenclature and further drilling of the Yarragadee Formation. Consequently the Molecap Greensand (Coolyena Group), Dandaragan Sandstone (Warnbro Group), and the non-marine Leederville Formation (Warnbro Group) have been recognized, and the subdivision of the Yarragadee has been altered.

GEOHYDROLOGY

Aquifers exist in all the formations from Quaternary to Triassic in age, and are described according to their geological form, rather than by groundwater systems. The Agaton bore field in the east has been comprehensively described and evaluated by Balleau and Passmore. Figure 12B is a cross section showing the potentiometric levels and groundwater salinities in the individual bores. Detailed results are given in Tables 5 and 6.

QUATERNARY

Agaton Area

Thin, localized, perched aquifers are found in the Quaternary sands overlying the less permeable late Cretaceous marine formations, the salinities ranging from 100 ppm to 1 800 ppm, the higher salinities resulting from evaporation and transpiration. Recharge is by infiltration of rainfall and groundwater movement down dip above the underlying impermeable beds. As yet there appears to be no problem with high nitrate values caused by the leaching of artificial fertilizers.

TABLE 6. SUMMARY OF BORE DATA

Bore	Total depth (m)	*R or †P	Natural surface elevation m.s.l. (m)	Potentiometric level elevation m.s.l. (m)	Observation interval		Test pumping rate m³/day	Air-lift flow rate m³/day	Formation tester	Recovered salinity (by conductivity) ppm	Status abd: abandoned obs: observation
					Depth (m) b.n.s.	Screen or slots					
W L.1	551·7	R	234·1	209·8	208·5–217·6	....	....	....	Johnson	9 160	abd
W L.1	....	....	....	211·3	506·0–515·1	....	....	....	Johnson	13 600	....
Magnetic Observatory	106·7	P	238·7	232·5	15·2– 21·3	slots	....	....	....	11 400	abd
A.19	588·3	R	237·4	210·9	216·4–225·6					....	....
A.19	....	....	....	....	276·8–289.0	slots	....	....	....	820	obs
A.19	....	....	....	....	314·2–320·3					....	....
A.18	282·9	P	255·5	....	206·4–213·7	screen	218	....	....	710	cased off
A.18	....	....	....	211·1	260·9–272·8	screen	163	....	....	830	obs
W.L.2	637·0	R	261·2	210·3	224·3–229·8	casing gap	....	....	....	(contaminated 700)	obs (blocked)
W.L.2	....	....	....	162·9	342·9–349·0	slots	....	....	....	950	cemented off
W.L.2A	164·6	P	261·0	211·1	143·3–164·6	?	....	....	....	710	obs (blocked)
A.24	371·2	R	262·1	211·0	91·0–102·9						
A.24	....	....	....	....	112·2–127·7	slots	....	....	....	370	....
A.24	....	....	....	....	134·2–146·7						
A.7	304·8	P	256·6	211·1	Below 125·0	open hole	....	....	....	....	obs (blocked)
A.7	....	....	....	211·9	203·0–212.1	screen	1 253	....	....	640	casing withdrawn
W.L.3	603·5	R	314·2	217·4	151·5–160·0	screen	....	....	....	610	in use by farmer
W.L.9	319·4	R	323·95	(resistivity log 220·4)	Not tested	....	....	....	....	....	abd
W.L.4	573·9	R	334·9	221·3	130·2–141·4	slots	....	....	....	660	obs (blocked)
					167·9–177·1						
W.L.5	765·3	R	286·2	101·2	391·5–398·0	slots	....	10	....	1 850	obs
W.L.5	....	....	....	102·4	489·0–502·9	....	....	....	Halliburton	....	....
W.L.5	....	....	....	100·1	593·1–616·6	....	....	....	Halliburton	....	....
W.L.5	....	....	....	101·1	740·3–746·9	slots	....	13	....	1 780	cemented off
W.L.5A	258·6	R	286·5	192·6	255·4–258·6	screen	....	15	....	1 730	obs
W.L.6	762·3	R	216·9	101·0	392·6–399·0	slots	....	55	....	1 550	obs
W.L.6	....	....	....	99·1	465·4–485·5	....	....	....	Halliburton	(1 850)	....
W.L.6	....	....	....	98·0	672·1–678·2	slots	....	....	....	(contaminated 1 600)	cemented off
W.L.6A	183·8	R	216·8	100·9	177·4–183·5	screen	....	....	....	1 390	abd
W.L.7	757·7	R	186·5	105·7	714·6–724·2	screen	....	143	....	500	obs
W.L.7A	547·1	R	186·9	105·1	521·9–528·2	screen	....	143	....	1 030	obs
W.L.7B	198·1	R	187·0	104·9	178·9–181·3	screen	....	93	....	850	obs
W.L.8	755·0	R	148·6	120·7	586·8–596·5	screen	....	196	....	640	obs
W.L.8A	202·7	R	147·1	118·9	170·7–174·3	screen	....	196	....	760	obs
W.L.10	764·7	R	141·0	116·8	381·1–387·5	screen	....	44	....	320	obs
W.L.10A	304·0	R	141·2	117·3	224·5–230·8	screen	....	11	....	360	obs
W.L.11	762·0	R	78·6	77·2	207·0–213·4	screen	....	196	....	4 480	obs
W.L.11 (annulus)	....	....	....	76·8	Below 97·5	....	....	....	....	....	obs
W.L.11A	746·6	R	78·3	65·0	692·8–699·2	screen	....	225	....	5 550	obs
W.L.11A (annulus)	....	....	....	73·0	Below 59·4	....	....	....	....	....	obs
W.L.11B	26·8	R	77·7	69·4	14·0– 20·1	screen	....	58	....	750	obs
Midland No. 7	42·7	P	50·8	15·8	36·6– 42·7	slotted	....	....	....	540	Farmer's bore
W.L.12	762·3	R	49·7	25·8	712·4–718·6	screen	....	185	...	680	obs
W.L.12 (annulus)	....	....	....	18·6	Below 41·6	....	....	....	....	....	obs
W.L.12A	155·4	R	48·8	18·4	135·2–141·5	screen	....	157	....	410	obs
W.L.12B	583·7	R	48·7	19·6	572·2–578·5	screen	....	202	....	470	obs
W.L.12B (annulus)	....	....	....	18·6	Below 48·8	....	....	....	....	....	obs
J.B.11	45·7	P	19·5	0·2	23·7 –26·8	screen	1 177	....	....	690	obs
J.B.1.	191·4	P	3·6	0	6·1					4 710	abd
				0	26·5	open hole	....	....	....	2 760	
				1·8	153·9–181·4					49 300	

*R: Rotary drilled

†P: Percussion drilled

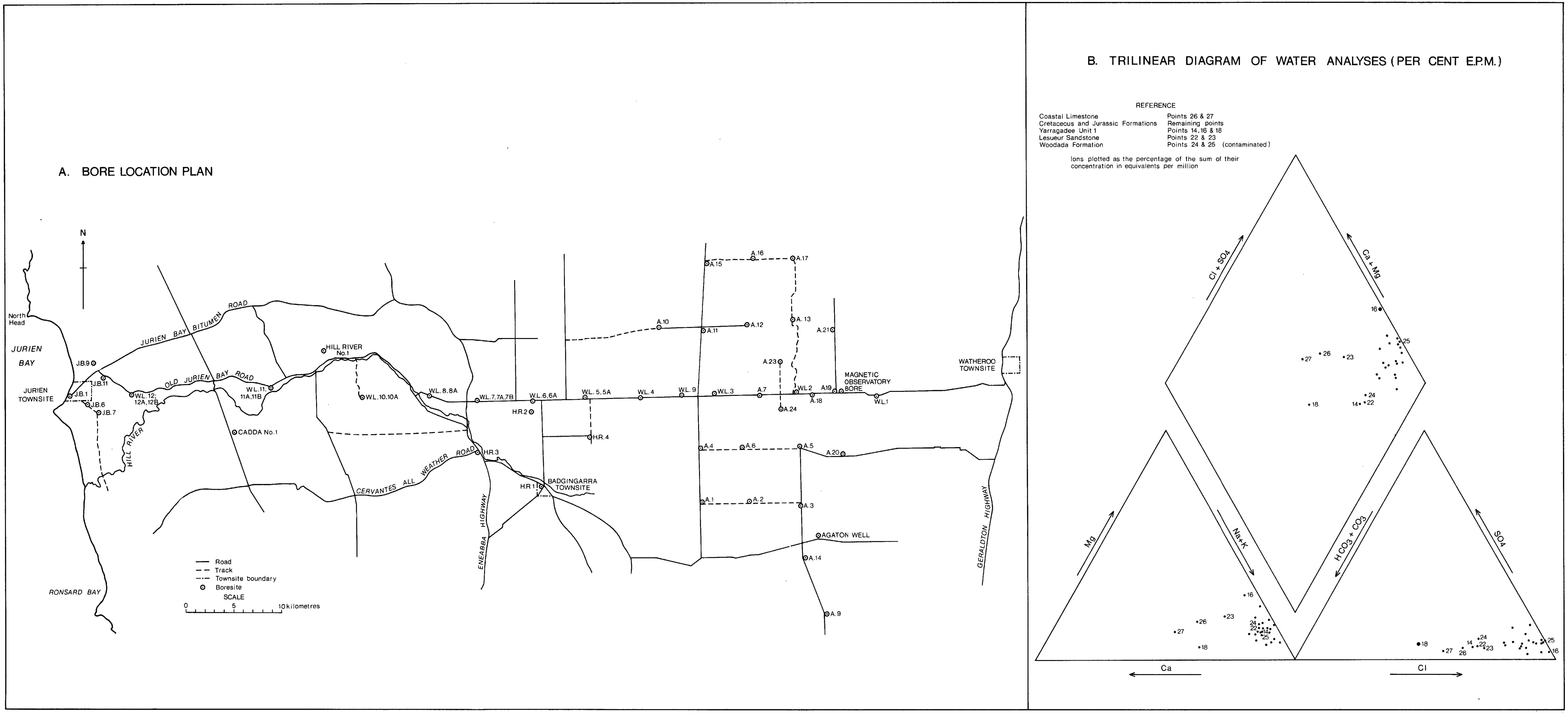

Fig. 11. Watheroo—Jurien Bay drillhole line.

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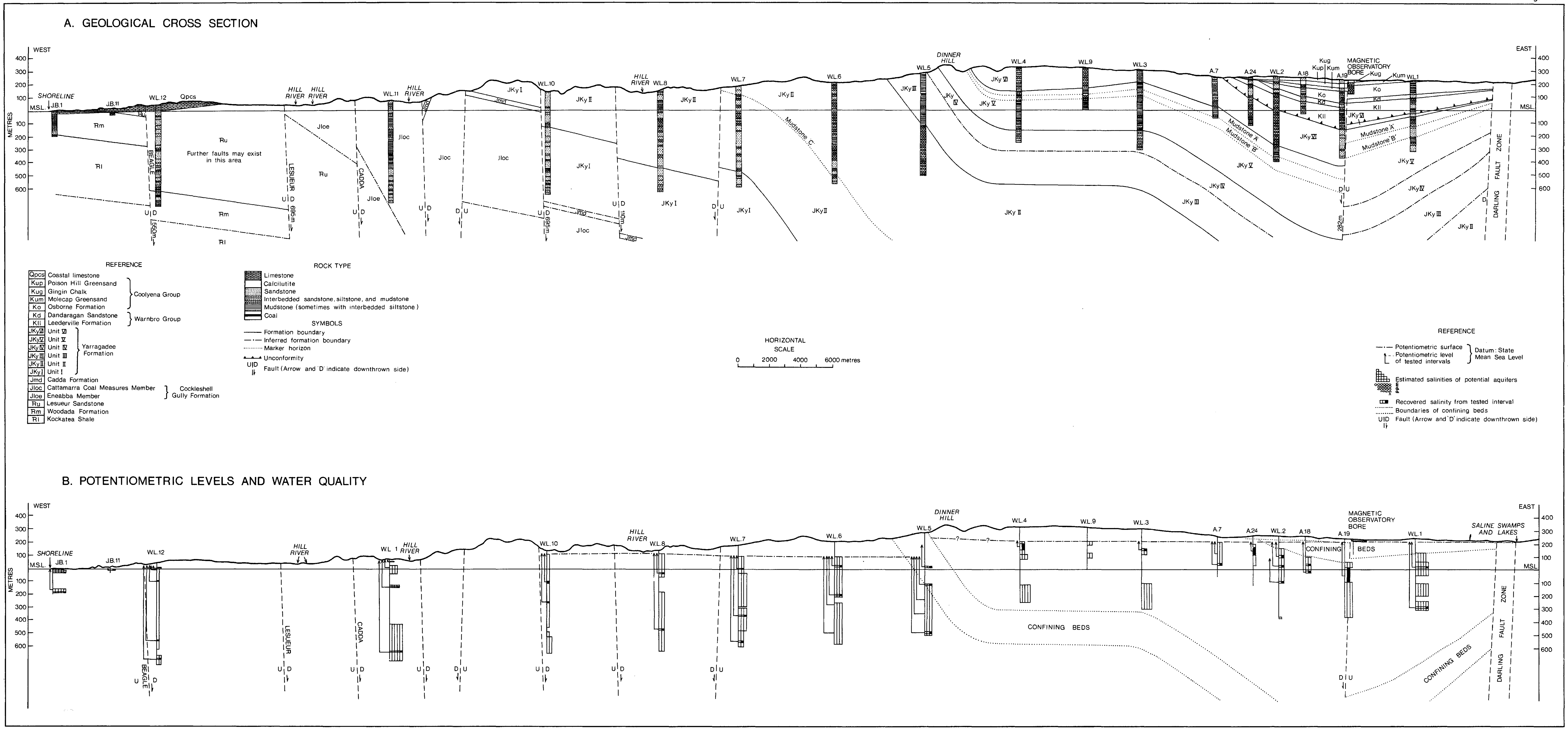

Fig. 12 Watheroo—Jurien Bay drillhole line.

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Dandaragan Scarp

Thin, localized, perched aquifers occur along the Dandaragan Scarp (Low, 1972) in the vicinity of Dinner Hill. The line of shallow soaks and wells tapping Quaternary sands is parallel to the apparent strike of the underlying impermeable Yarragadee Unit III mudstone.

Salinities vary from less than 100 ppm to more than 2 000 ppm but most are less than 500 ppm. Nitrate contents range from 1 ppm to 33 ppm, indicating pollution from artificial fertilizers. The higher salinities result from evaporation and transpiration. Recharge is from rainfall.

Coastal Limestone

The Coastal Limestone is a sandy calcarenite which extends westward to the coast from about 10 km inland, and crops out offshore. It varies in thickness from about 40 m, near W.L. 12, to 17 m at the coast near J.B. 1. East of the Beagle Ridge the aquifer is probably partially confined by the underlying laterite, and on the Beagle Ridge is underlain by relatively impermeable, argillaceous sediments of the Woodada Formation. Where exposed, the top part of the Coastal Limestone is lithified, but at depth the sediments are poorly consolidated and very permeable.

In J.B. 11 a pumping rate of 49 m^3/hour produced a drawdown of 0.71 m and similar results were reported from several other bores. Salinities increased from about 600 ppm, 4 km east of Jurien Bay, to 1 400 ppm near the townsite. In J.B. 1 the salinity increased with depth from 4 700 ppm, near the water table, to 27 600 ppm at the base of the aquifer (Berliat and Morgan, 1962) because of salt water intrusion.

The potentiometric levels in most of the bores are very close to mean sea level. Higher levels recorded in bores J.B. 1 and 10 were associated with deeper confined aquifers, while the level of + 15.8 m in the bore near W.L. 12 is probably due to the proximity to an intake, and recharge from the underlying Lesueur Sandstone aquifer. The salinity contours indicate that groundwater movement is from the northeast (Milbourne, 1966). Recharge is by infiltrating rainfall moving from the northeast through solution tubes and cavities in the limestone, and pressure water may also move upward from the underlying Lesueur Sandstone.

COOLYENA GROUP

Except for the Poison Hill Greensand the Coolyena Group beds are clayey and relatively impermeable, and act as a hydraulic barrier between the Poison Hill Greensand and the Warnbro Group, although the Molecap Greensand and the Osborne Formation become more sandy to the westward. Perched waters occur on the more sandy beds, but are normally of a fairly high salinity, exceeding 1 000 ppm in the Gingin Chalk in A. 18 and 5 000 ppm in the Observatory bore. The high salinities reflect low permeability of the aquifers, and evapotranspiration losses. Perched waters could perhaps be found in the sandy sediments of the Poison Hill Greensand but there is no evidence for this.

Recharge is direct from rainfall. Because some of the perched aquifers are above the potentiometric surface of the underlying pressure waters, there is a potential for downward leakage. Balleau and Passmore (1972) have demonstrated this from examination of the Ca + Mg/Na + K ratios in recovered water samples.

WANBRO GROUP

Dandaragan Sandstone

The Dandaragan Sandstone is a fine to coarse-grained marine sandstone, about 40 m thick in the Watheroo section. It is confined at the top and bottom by clayey beds, but crops out on the western edge of the marine basin. Although this Sandstone was not tested in the Watheroo bores, results from the Agaton bore field suggest that the permeability may be relatively high. Hydraulic conductivities between 26 and 27 $m^3/d/m^2$ have been reported.

Salinities calculated from the resistivity logs indicate values less than 1 000 ppm on the western side of the marine basin, but the salinity increases eastward. The high salinity in W.L. 1 is probably caused by leakage from the saline drainage along the Darling Fault zone, but the fault west of the Magnetic Observatory bore prevents contamination of the aquifer by westerly movement of the saline water. This also applies to the water in the Leederville and the Yarragadee aquifers.

Results from the Agaton bore field show that the potentiometric levels in the Dandaragan Sandstone are very similar to those in the underlying Leederville and Yarragadee aquifers, and therefore the groundwater flow is in a south-easterly direction. Recharge is from rainfall, where the formation crops out along the margin of the marine basin, by horizontal flow from the Leederville Formation, and by leakage from the overlying sediments of the Coolyena Group.

Leederville Formation

This is an interbedded sandstone, siltstone, and mudstone with generally fairly thin and sometimes discontinuous aquifers confined by the more impermeable beds, except where the formation crops out along the western margin of the marine basin. The hydraulic conductivity is less than that in the overlying Dandaragan Sandstone.

Water samples were recovered from several bores, the salinity being less than 500 ppm in A.24, but gradually increasing eastward. In W.L. 1 the salinity exceeded 5 000 ppm, due to local intake from the saline drainage along the Darling Fault zone. Some of the samples had several parts per million iron content.

Potentiometric levels were fairly constant from east to west and may decrease slightly with depth. The level in W.L. 1 was recorded in a drill-stem test and was not reliable. Balleau and Passmore (1972) show the groundwater flow to be in a southeasterly direction. Recharge is from rain falling where the formation crops out along the western and northern margins of the marine basin, upward movement from the underlying Yarragadee Formation, and downward leakage from the overlying Dandaragan Sandstone.

YARRAGADEE FORMATION

Units IV, V and VI

These units are a series of interbedded sandstone, siltstone, and mudstone beds, and their several aquifers are confined except on the western edge of the basin. The permeability is similar to that in the Leederville Formation, an average hydraulic conductivity of 4.7 $m^3/d/m^2$ having been calculated for the two formations (Balleau and Passmore, 1972).

Salinities in the western section of the basin are less than 1 000 ppm but increase both to the eastward and with depth. The high salinity in W.L. 1 is probably due to local intake.

The potentiometric levels are very similar between bores W.L. 1 and A. 7 but show a rise westward of A. 7. However the level in W.L. 1 was recorded in a drill-stem test and is not reliable.

The relatively steep decline between W.L. 3 and A. 7 is probably due to the influence of the small anticline near W.L. 3. The easterly gradient indicates an apparent direction of groundwater flow, but when the Agaton bore field is considered, the overall movement is southeasterly. Potentiometric levels may decrease slightly with depth. The unusually low water level in W.L. 2 is thought to be unrepresentative of the aquifer and caused by silting up of the slotted interval. Recharge is from rainfall in the west, leakage from overlying aquifers, and direct downward infiltration through the unsaturated zone.

On the Watheroo-Jurien Bay Line the Agaton groundwater system is confined by the underlying Yarragadee Unit III mudstone and the Darling Fault. There is groundwater flow into the area from the north, and a discharge to the south.

Unit III

This thick mudstone is considered to be an important confining unit separating the Agaton and the Badgingarra groundwater systems (Fig. 12B). From the W.L. 5 geophysical logs the interval between 291 m and 340 m appears to be particularly impermeable. Two thin interbedded sandstones were tested in bores W.L. 5A and Hill River (potentiometric level 186.2 m and salinity 2 190 ppm), the results suggesting that these thin aquifers are independent of either the Agaton or the Badgingarra groundwater systems.

Units I and II

These units are essentially sandstone with minor mudstone beds. The aquifers are confined at depth but are unconfined where they crop out to the westward. Because of the fines and poor sorting in the upper sediments of Unit II their permeability is low, but the sandstone towards the base of Unit II and in Unit I are coarser grained and have less intergranular clay, so their permeability is relatively greater.

The groundwater salinity around W.L. 10 is less than 500 ppm, but it gradually increases to the eastward and also increases with depth. The markedly higher resistivity values on the electric logs of the top section of Unit I indicate a decrease in salinity. Several of the tested horizons had an iron content high enough to necessitate treatment.

The potentiometric surface rises slightly from W.L. 10 to W.L. 8, and then falls gradually to the eastward. The rise to the W.L. 8 level is slightly unusual because the salinity increases uniformly to the eastward from W.L. 10. However, local factors may be involved such as discharge near W.L. 10 to Hill River, or recharge near W.L. 8 from Hill River. Except in W.L. 10 the potentiometric level decreases slightly with depth. It is suggested that the flow of groundwater is in a southeasterly direction, but this cannot be confirmed with the present information. Recharge is from rainfall to the basically unconfined aquifer system, and there is possibly some seasonal recharge from the Hill River in the vicinity of W.L. 8.

The Badgingarra groundwater system is bounded to the west by the faulted blocks of older sediments.

CADDA FORMATION

This was not intersected and little is known of its hydrogeological characteristics.

COCKLESHELL GULLY FORMATION

Cattamarra Coal Measures Member

The member is an interbedded sandstone and mudstone. Bore W.L. 11 intersected several discrete aquifers separated by thick mudstones.

Except in the top aquifer, the groundwater salinity in W.L. 11 is more than 1 000 ppm, and increases with depth to more than 5 000 ppm. The top aquifer is thin, unconfined, probably not continuous because of surface erosion, and the water has a high nitrate content which may result from contamination from artificial fertilizers. Aquifers in the Cattamarra Coal Measures Member rarely have salinities of less than 1 000 ppm.

The different aquifers show marked variations between their potentiometric levels (Table 6). W.L. 11 was drilled in a narrow fault block and it is not known whether the faults are boundaries to the groundwater flow. The topography indicates that the groundwater flow is probably southward to the Hill River. Recharge is from infiltration where the aquifers crop out, and by leakage through the confining beds.

Eneabba Member

This was not intersected by the Watheroo bores but other evidence indicates that it is an interbedded sandstone and mudstone. Cadda 1 water bore gave a salinity of 1 100 ppm, and aquifer characteristics in the Eneabba Member probably resemble those in the overlying Cattmarra Coal Measures Member.

LESUEUR SANDSTONE

This is a thick, permeable sandstone with infrequent thin mudstone beds becoming more numerous near the base of the formation. It appears to be confined under a thin "laterite" around W.L. 12, but to the east is probably unconfined.

In the section drilled the groundwater salinity was less than 500 ppm, but there was a noticeable iron content. The potentiometric levels appear to increase with depth, and as these levels are higher than that in the overlying Coastal Limestone there may be upward movement. Recharge into the Lesueur aquifers is probably from rainfall farther east beyond the Coastal Limestone.

It is not known whether the Lesueur and Beagle Faults are hydraulic boundaries, but the general direction of groundwater flow is probably southward towards the Hill River.

WOODADA FORMATION

This is an interbedded sandstone and mudstone and tests in W.L. 12 and J.B. 1 indicate that the aquifers are confined by the more argillaceous beds.

The recovered salinity in W.L. 12 was about 700 ppm, whereas the reported salinity in J.B. 1 was 49 300 ppm due to salt water contamintation. Although the yield by air-lifting was relatively good in W.L. 12, the resistivity logs from W.L. 12 suggest a relatively low permeability.

The potentiometric level in W.L. 12 is higher than those from the Lesueur Sandstone in the same bore, indicating potential for leakage into the overlying aquifer in which the water is hydrochemically very similar. The source of recharge is unknown.

KOCKATEA SHALE

This is a thick silty mudstone unit and from present evidence has little groundwater potential.

HYDROCHEMISTRY

Water analyses are listed in Table 5 and plotted on a trilinear diagram (Fig. 11B).

The measured pH values generally range between 6.5 and 8.0, but the true pH could be very different because of aeration of the water samples.

Iron is only present in sufficient quantities to be a problem in the Leederville Formation and Yarragadee Unit II waters, but most water samples contained some precipitated iron. Nitrate is the only other significant ion, and was found in noticeable amounts in the perched aquifers along the Dandaragan Scarp and on top of the Cockleshell Gully Formation. However where there is rainwater intake to a shallow aquifer through an artificially fertilized soil, the nitrate content should be monitored.

Waters from the Jurassic and Cretaceous aquifers are essentially sodium chloride-rich (Fig. 11B). The more calcium bicarbonate-rich waters are those from the sandstones of Yarragadee Unit I (points 14, 18), the Lesueur Sandstone (22, 23), and surprisingly the Woodada Formation in W.L. 12 (24). Not unexpectedly the water from the Coastal Limestone is also calcium bicarbonate-rich (26, 27). Sample 16 from the Yarragadee Unit I aquifer, in W.L. 8, appears to be magnesium chloride-rich, and is rather unusual. It is thought that the relatively calcium bicarbonate-rich waters in the Lesueur and Woodada Formations in W.L. 12 are the result of recharge through the calcareous dune systems. The origin of the Yarragadee Unit I water is uncertain, but there could be some connection with the calcaresous Cadda Formation.

The high proportion of sodium chloride in the groundwater is due to recharge by rainfall, concentrated to some extent by evapotranspiration near the surface.

CONCLUSIONS

Aquifers were found in all the formations above the Early Triassic Kockatea Shale, with water salinities as high as 50 000 ppm. There are four major aquifer systems with salinities of less than 1 000 ppm.

The Coastal Limestone is an important permeable non-pressure aquifer containing potable water (less than 1 000 ppm) east of Jurien Bay, but the salinity increases towards the coast. Recharge is from the northeast.

The Agaton groundwater system in the east includes the Warnbro Group and upper units of the Yarragadee Formation. It is confined below, and to the west, by the mudstones of Yarragadee Unit III, and to the east by the Darling Fault. Potable water can be obtained from the aquifers west of the synclinal axis. However the best economic prospects are the water-bearing beds of the Warnbro Group, which are largely overlain by the confining beds of the Coolyena Group. The Dandaragan Sandstone has good hydraulic conductivities of the order of 26.5 $m^3/d/m^2$ with estimated salinities less than 1 000 ppm west of the synclinal axis. The Leederville Formation has slightly better quality water but is high in iron. Hydraulic conductivities are lower, an average of 4.7 $m^3/d/m^2$, because of the more argillaceous nature of the sediments. In the Agaton groundwater system the groundwater movement is southeastward across the Watheroo-Jurien Bay Line.

The Badgingarra groundwater system farther west includes the basal two units of the Yarragadee Formation. It is bounded on the west by faulted, older sedimentary blocks and to the east by the mudstones of Unit III. Salinities increase from less than 500 ppm, in W.L. 10, to nearly 2 000 ppm in W.L. 5. The best aquifer is the thick, permeable sandstone in the upper part of Unit I. The groundwater flow has an easterly component and possibly moves southeastward.

The Lesueur Sandstone intersected in W.L. 12 contains thick aquifers with salinities of less than 500 ppm, and apparent good permeabilities. The aquifers are bounded to the westward by the Beagle Fault, and probably to the eastward by the Lesueur Fault. The general groundwater movement is probably southward towards the Hill River, but there may be some discharge into the overlying Coastal Limestone, which has a lower potentiometric level.

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SHEAR ZONES IN PRECAMBRIAN ROCKS OF THE DARLING RANGE: NATURE, ORIGIN AND ENGINEERING SIGNIFICANCE

by G. Klenowski

ABSTRACT

Two sets of shear zones are common in Precambrian rocks of the Darling Range. One set has a northerly trend and occurs in the margins of metadolerite dykes and the adjacent country rock. Southwards from the Canning Tunnel to the Burekup area the shearing nature changes from predominantly dolerite deformation, associated with hydrothermal activity, to predominantly country rock deformation under increasing metamorphic grade, and movement direction changes from dip-slip to strike-slip. The other set, of more variable trend, becomes more extensive southwards to the Burekup area, and offsets some dykes.

Tectonites derived from deformation of dolerite include hornblende schist, actinolite schist, biotite schist and chloritic schist. Deformation of country rock produced porphyroclastic augen gneiss, augen schist and mica schist. Mylonitic rocks also occur.

Shear zones are important in engineering geology because they form zones of weak rock which, where closely fractured, may act as pathways for water percolation, and lead to localized deep weathering. Such zones occurred in the excavations at the South Dandalup dam site and the Canning Tunnel, and remedial work was necessary.

INTRODUCTION

The western margin of the Yilgarn Block is characterized by numerous shear zones developed in the margins of metadolerite dykes and in the adjacent country rock. These zones have been investigated in the Canning Tunnel, North and South Dandalup and Burekup dam sites (Fig. 13). Both the 5.5 km Canning Tunnel and the deeply incised Collie River Valley near Burekup present excellent rock exposure for structural analysis.

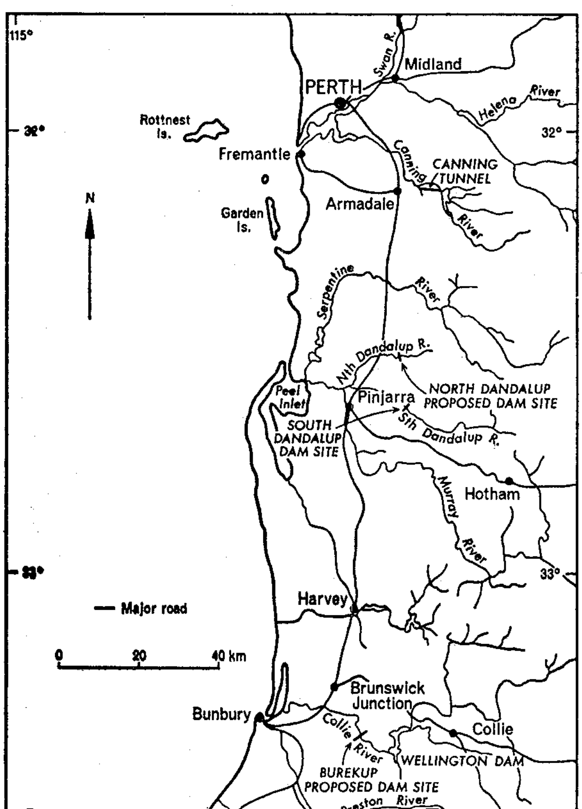

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Figure 13. Darling Range area—engineering geology investigation sites.

Shear zones are important in engineering geology because they form zones of weak rock which where closely fractured, may act as pathways for water percolation and lead to localized deep weathering. These require remedial work.

TECTONIC SETTING

The four areas studied are east of the northerly trending Darling Fault, which has displaced the west block 10 000 to 15 000 m downward, and are underlain by Archaean granitic rocks intruded by Upper Proterozoic dolerite (now metadolerite). The granitic complex includes hybrid gneiss, granitic gneiss, augen gneiss, massive granite, pegmatite and aplite. The granitic gneiss of the Yilgarn Block has been dated at 3 000 m.y. and the massive granite at 2 700 m.y. (Compston and Arriens, 1968). The dolerite of the western margin of the Yilgarn Block is considered to be 650 m.y. (Wilson and others, 1958).

The tectonic history in the areas investigated may be divided into pre-dolerite and post-dolerite tectonism. Pre-dolerite tectonism involved the formation of the granitic complex and subsequent deformation which included shearing, faulting and minor folding. Post-dolerite tectonism is recognized by shearing occurring in the margins of metadolerite dykes and in the adjacent country rock, and by faulting which off-sets some dykes. A Rb-Sr age of 560-590 m.y. has been obtained from sheared and metasomatized dyke margins (Compston and Arriens, 1968). This tectonic episode is important because it occurs on a regional scale, and has produced considerable variation of the original rock types. Southwards from the Canning Tunnel to the Burekup area, the shearing nature in the margins of metadolerite dykes and in the adjacent country rock changes from predominantly dolerite deformation, associated with hydrothermal activity, to predominantly country rock deformation under increasing regional metamorphic grade.

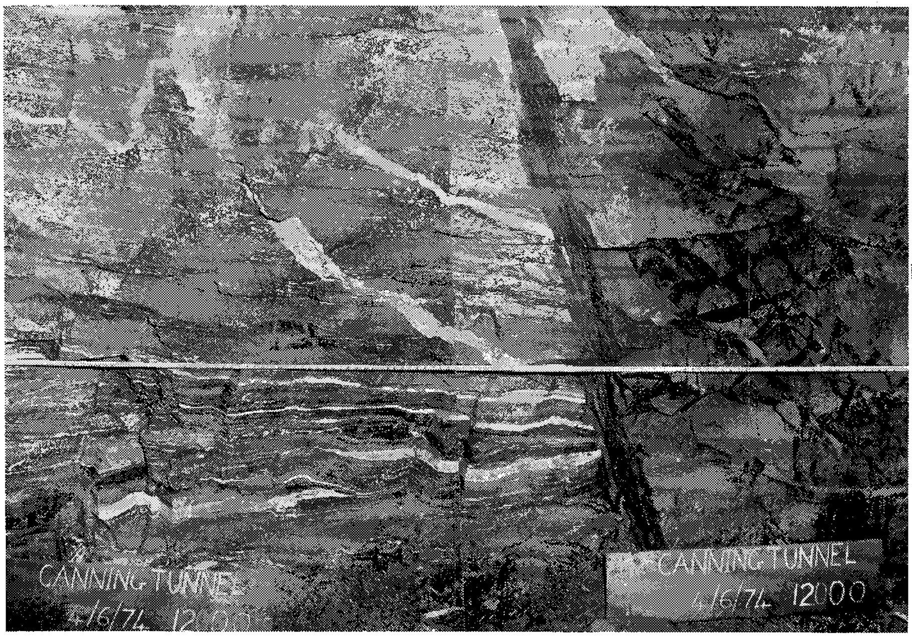
STRUCTURAL ANALYSIS

Data for detailed structural analysis were collected from the Canning Tunnel and the North Dandalup and Burekup proposed dam site areas. Modal attitudes of dykes and shear zones were determined using Rose and Pi diagrams (Klenowski, 1973, 1974). The metadolerite dykes generally strike north and dip steeply east or west. Many have well jointed sheared margins, with the shearing showing considerable variation in intensity. No definite controlling pattern of shearing could be identified, but generally the westerly dipping dykes are more intensely sheared on their western margins. In all areas, shear zones vary in width from less than one centimetre to 35 metres. Shearing always increases in intensity towards the contacts between the metadolerite and the country rock.

In the Canning Tunnel the metadolerite dykes generally trend NNW. The metadolerite is always more intensely sheared than the country rock (Fig. 14). The direction of movement was dip-slip, west blocks down, determined by S-shaped drag structures in the metadolerite, dragging of adjacent gneissic foliation (Fig. 16A), displacement of pegmatite veins on either side of metadolerite dykes, and the development of slickensides. A secondary strike-slip component was also identified from slickensides.

At North Dandalup the metadolerite dykes generally trend NNW. Although exposure is poor, the metadolerite appears to be less extensively sheared, and the country rock more extensively sheared than in the Canning Tunnel. Shear zones up to one metre wide, and varying in trend from NW to NE, are also common in the country rock. General movement directions could not be established because of insufficient evidence.

Around the Burekup dam site the metadolerite dykes generally trend NE. Movement directions in shear zones were determined by the alignment of microcline porphyroclasts, offsetting of metadolerite dykes, shear-step structures developed in quartz



3682·45 m 3684·91 m

Figure 14. Canning Tunnel—sheared, westerly dipping margin of meta-dolerite dyke. Country rock is hybrid gneiss.

A

B

Figure 15. Burekup proposed dam site.

A. Right bank—shear zone in margin of meta-dolerite dyke and adjacent country rock.

B. Left bank—shear zone in country rock adjacent to metadolerite dyke.

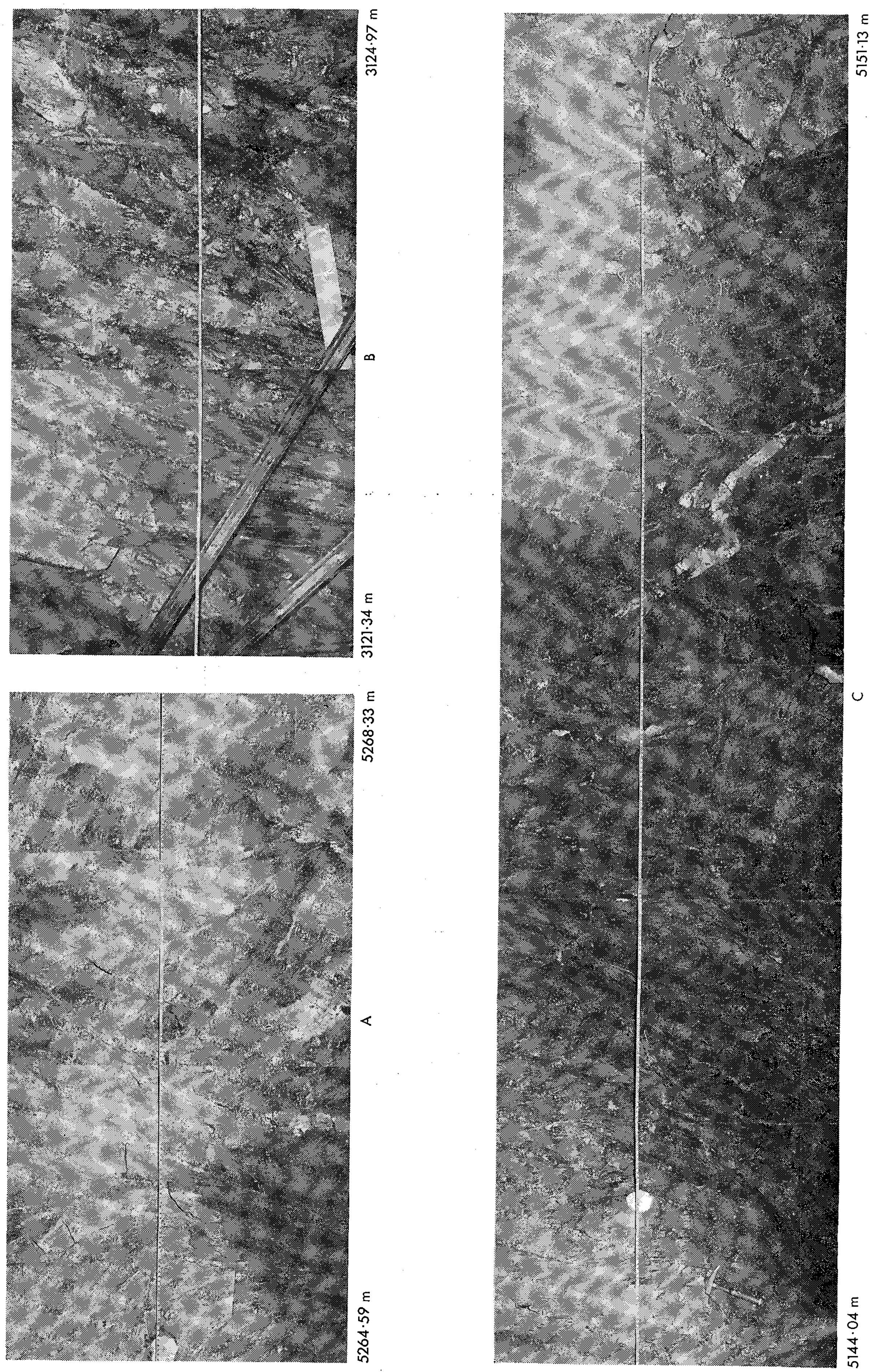


Figure 16. Canning Tunne

A. Thin, sheared, easterly dipping metadolerite dyke. West-block down movement is indicated by dragging of gneissic foliation in adjacent country rock.
B. Part of metadolerite dyke sheared to chloritic schist. This zone required temporary rib support during excavation, and later, reinforced concrete lining.
C. Extensively sheared metadolerite dyke margin which required pneumatically applied mortar.

Note: All Canning Tunnel wall photographs are of the south wall, and distances are from the Canning portal.

veins, and rare slickensiding. One set of shear zones occurs in the margins of the metadolerite dykes and in the adjacent country rock, the movement being generally strike-slip, with some NW blocks having moved northward and others southward. In a second set trending NW, the NE blocks moved northward, and some dykes are offset.

PETROLOGY

Rocks occurring in shear zones are known as metamorphic tectonites. A tectonite is a deformed rock the fabric of which is due to the systematic movement of the individual components under a common external force (Spencer, 1969, p. 137). Various aspects of deformational processes and textures have been discussed by writers such as Spry, 1963; Turner and Weiss, 1963; Spencer, 1969 and Stauffer, 1970.

Deformation by applied stress occurs in two ways (Williams and others, 1954, p. 199). Direct (cataclastic) componental movements are favoured by rapid deformation at low temperatures, and relatively low confining pressures. Indirect (crystalloblastic) componental movements are most effective at high temperatures, under prolonged stress with available chemically active pore fluids, and where stress-unstable minerals occur in the parent rock.

Stauffer (1969) has divided deformational processes into fracture (low temperature), recrystallization (high temperature), intergranular dislocation (low-intergranular cohesion) and crystallographic glide (high-intergranular cohesion). Each process produces distinctive structures and textures.

Tectonites formed in shear zones along the Darling Range are divisible into deformed dolerites and deformed country rock. Ideally the margins of dolerite dykes would be expected to have a higher shear strength than the gneissic country rock. This is supported by uniaxial compressive strength tests done by the Snowy Mountains Engineering Corporation (1972). However, in the Canning Tunnel the metadolerite is more intensely sheared. It appears that the deformation was accompanied by high hydrothermal activity, producing uralitization of pyroxene in the dolerite, concomitant quartz-epidote veining and sulphide mineralization. Some shear zones contain abundant epidote.

Around Burekup hydrothermal activity in the dyke rock was less than in the Canning Tunnel, and more intense shearing occurred in the country rock (Figs. 15A and B). The rocks of this area appear to have been subjected to the physical conditions of the upper amphibolite or lower granulite facies. The gneisses have been recrystallized in this facies, and recrystallization has penetrated part way into the dykes. This is shown by garnet porphyroblasts in the fine-grained rock at dyke margins, and by recrystallized pyroxene. Recrystallization is also indicated by granofelsic transition zones which are coarser than primary dolerite, and have an increasingly doleritic texture and mafic composition towards the centres of dykes. The country rock is a pyroxene bearing, porphyroblastic, microcline gneiss, often with large pseudomorphs of myrmekitic plagioclase after the microcline. The formation of the shear zones appears to have accompanied the metamorphism.

Around North Dandalup the physical conditions affecting deformational processes were between those of the Canning Tunnel and Burekup areas. Quartz mylonites are well developed in several shear zones.

TECTONITES DERIVED FROM DEFORMATION OF DOLERITES

Petrologically the dolerites of the Darling Range area are metadolerites, as shown by alteration of the original texture and mineralogy. The dolerite deformed under shear cleavage with strong indirect componental movements. In the Canning Tunnel there are two general tectonite sequences from the centres of dykes towards the contacts:

(1) Metadolerite ⟶ lepidoblastic hornblende schist ⟶ lepidoblastic biotite schist ⟶ chloritic schist.

(2) Metadolerite ⟶ nematoblastic actinolite schist ⟶ chloritic schist.

Deformational mechanisms in the first sequence included fracture, recrystallization to more stress-stable mineral assemblages and crystallographic glide. In the actinolite-schist stage, of the second sequence, a strong intergranular dislocation component produced extensive mylonitization of the plagioclase. The chloritic schist generally forms a thin veneer at the contacts.

Around Burekup shearing reached several metres into dyke margins. The tectonite formed is a lepidoblastic hornblende schist which becomes distinctly more leucocratic towards the contacts with the country rock.

TECTONITES DERIVED FROM DEFORMATION OF COUNTRY ROCK

Strong deformation of country rock occurred in the Burekup area under both direct and indirect componental movements. The general tectonite sequence towards the contacts is:

Porphyroblastic gneiss ⟶ porphyroclastic augen gneiss ⟶ augen schist ⟶ lepidoblastic mica schist.

Deformation mechanisms included fracture, intergranular dislocation, recrystallization and crystallographic glide. Goatee texture, caused by intergranular dislocation of microcline porphyroblasts, is well defined. This texture results when material is plucked from the ends of competent granules and incorporated into the strain shadows.

At North Dandalup the country rock is a microcline bearing granitic gneiss, and fracture and intergranular dislocation mechanisms have predominated in rock deformation. Shearing is not as extensive in the metadolerite as around the Canning Tunnel area, nor as extensive in the country rock as around Burekup. Shear zones not adjacent to dykes are common, and occur as intensely fractured zones up to a metre in width, whereas at Burekup they have strong mylonitic lamination or strong alignment of microcline porphyroclasts.

CONCLUSIONS

The general northerly trend of the metadolerite dykes suggests strong east-west tensional forces of a regional scale during intrusion. In the Canning Tunnel, which trends at 292° for most of its length, 28 per cent of excavated rock was metadolerite. Most of the dykes trend NNW and therefore volumetric dilation caused by magmatic intrusion would appear to have been close to this percentage.

Intrusion was followed by metamorphism and tectonism. Textural and mineralogical changes in the dolerite and country rock indicate increasing metamorphic grade southwards from the Canning Tunnel area to the Burekup area.

Tectonism is recognized by the shear zones. In the Canning Tunnel area the intense shearing of dolerite dyke margins was accompanied by high prevailing hydrothermal activity. Southwards to Burekup the more intense shearing of the country rock than the dolerite was accompanied by an increasing grade of metamorphism, and decreasing effect of hydrothermal activity. In zones not adjacent to contacts between metadolerite and country rocks shearing increases in intensity southwards to Burekup. In the Canning Tunnel area, the dip-slip, west-block down movements, indicate east-west tensional forces. A secondary strike-slip component also occurs. Around Burekup strong transcurrent forces resulted in strike-slip movement. Although some west blocks show northward and others show southward movements, more information is required from this area, and farther southwards, to clarify the tectonic trends.

This metamorphism and tectonism, which occurred in the late Precambrian, could have provided the impetus for the development of the Perth Basin in the Palaeozoic.

ENGINEERING SIGNIFICANCE

Rock weakened by shearing, requires structural support in tunnels, may lead to differential settlement in dam sites, and to rapid erosion in spillways.

Immediate grouting is needed to prevent rapid leakage caused by the downward percolation of water in tunnels. Piping caused by percolation under dams is prevented by constructing cut-offs and grout curtains. Deeply weathered shear zones may require chemical grouting, which is more penetrative in weathered material than is cement grout. Shear zones extending from reservoirs to spillways require special measures to prevent foundation uplift caused by build up of pore pressures.

Shear zones directly assist in differential weathering by forming pathways for the downward percolation of water, and extend deep weathering into the country rock along joints and foliation planes. Sheet joints, which are common in country rock along the Darling Range, actively extend weathering. Penetration of water along gneissic foliation planes causes selective weathering of dark bands followed by the decay of feldspars in light bands.

Metadolerite dykes and shear zones have had a strong influence on the topography of the Darling Range area. Dykes often form ridges with gully development at contacts. This process is assisted by the presence of sheared margins. Completely sheared dykes may form saddles. Variations in topographic expression, caused by numerous factors, occur. These include gullies eroded along thin dykes, regardless of degree of shearing, deflection of water-courses along resistant dykes, terracing formed by dykes parallel to the slopes. Dykes with clay-filled joints form barriers to underground water flow, resulting in deeper weathering on the upslope sides of dykes.

Mechanical weathering of metadolerite dykes has formed bouldery metadolerite outcrops, and where chemical weathering is acute also forms reddish doleritic soil. Chemical weathering reduces the surface exposure of metadolerite. The end product is the laterite cap, covering both the metadolerite and the country rock. The localized weathering product of sheared dolerite is often greenish chloritic clay. Micaceous clay results from weathering of sheared country rock.

Shear zones which required remedial work were encountered in the construction of the South Dandalup Dam and the Canning Tunnel.

SOUTH DANDALUP DAM

Geological investigation of the excavated foundation area for the South Dandalup Dam was done by Marcos (1971). Irregular weathering observed during excavation is related to geological structures. Shear zones are common in the granitic gneiss, and vary in width from 2.5 mm to 0.6 m. Shearing of metadolerite dyke margins also occurs. The exposure of shears, faults, and joints during excavation meant more excavation and remedial work, including grouting, than was expected. A double line of curtain grout holes were necessary in several zones of weakness. Faulting accompanied by shearing and hydrothermal activity in a zone about 3 m wide, required special grouting and concrete work.

CANNING TUNNEL

The 5.5 km long Canning Tunnel was constructed to increase the rate of delivery of water from the Canning Dam to the Perth metropolitan area.

Weathered rock generally requires temporary support during excavation. Steel ribbing with timber lagging and cribbing was used at both ends of the tunnel. Ribbing was extended 56 m into the tunnel at the Canning Dam end, and 18 m at the Roleystone end. The greater distance of weathered rock at the Canning heading is due to the steeply dipping gneissic foliation (60° to 80° E), and the sheared metadolerite dyke margin 44 m in from the portal. These structures have facilitated deeper percolation of water. At the Roleystone heading the more gently dipping gneissic foliation (24° W), and the less sheared metadolerite margin 16 m into the tunnel, have resulted in less weathering of both the metadolerite and the gneiss.

Leaking shear zones and joints in the tunnel did not warrant immediate grouting. Although the degree of weathering in shear zones is variable, temporary rib support was required in only one shear zone.

Because water flows through the tunnel steel liners surrounded by concrete were extended, from the portals into the tunnel, to where the weight of vertical ground cover approximately equals the maximum hydrostatic head. The length was 152.70 m at the Canning end (115.82 m of steel liners and 36.88 m of reinforced concrete) and 275.84 m at the Roleystone end. Elsewhere in the tunnel most of the lining treatment was needed for sheared dolerite (Fig. 16B and C). Lining treatments, excluding portal areas, and distances covered are given below:

Rock Type	Pinned mesh and pneumatically applied mortar	Concrete lining	Concrete lining reinforced with steel sets
Granitic complex (includes shear zones, cavities and completely altered zones)	14·02 m	6·10 m	....
Metadolerite (shear zones)	100·58 m	39·01 m	14·63 m

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PETROLEUM EXPLORATION IN WESTERN AUSTRALIA IN 1974

by G. H. Low

ABSTRACT

The downward trend in petroleum exploration activity in Western Australia which has been evident since 1972 continued in 1974. The number of test wells completed was 20 per cent less, and land seismic and marine seismic activity was 69 per cent and 21 per cent respectively, less than the 1973 figure.

Most drilling activity was in the offshore Carnarvon and Canning Basins. A few offshore wells were drilled in the Bremer, Perth, Carnarvon and Canning Basins.

Twenty-one wells of all types were completed during the year (excluding Hilda No. 1 which was abandoned above the objective formations, at a total depth of 1 546 m, because of unsatisfactory hole conditions) for a total of 46 626 m of drilling. Geophysical activity consisted of land and marine seismic surveys, one aeromagnetic survey, and limited gravity and surface geological surveys.

During the year onshore tenements in the Officer, Canning, Carnarvon, and Perth Basins, and offshore areas in the Eucla, Perth, Carnarvon and Canning Basins were surrendered, relinquished or cancelled. Surrender was pending in several other offshore and onshore areas at the end of the year.

INTRODUCTION

Exploratory drilling carried out in the search for petroleum in Western Australia over the past two years is shown in the following tabulation:

	Wells completed		Wells drilling on 31st December	
	1973	1974	1973	1974
New field wildcat wells	16	15*	2	0
Extension test wells	3	1	0	0
Deeper pool test wells	1	0	0	0
Development wells	0	1	0	0
Stratigraphic wells	2	4	1	0
	22	21	3	0

Total effective drilling : 1973—63 612 m
1974—46 626 m*

* The aborted new field wildcat well Hilda No. 1, which reached a total depth of 1 546 m, is not included in these figures.

Three successful wells were completed during 1974. Lambert No. 1 was a successful test of a new structure in the offshore Carnarvon Basin and is classified as a gas and condensate discovery. West Tryal Rocks No. 2, an extension test step-out located 3.6 km northeast of the discovery well, encountered the same gas-bearing sands about 130 m higher than the first well. Dongara No. 20 was successfully completed as a development well, in the Dongara gas field, located in the northern Perth Basin.

Geophysical survey and surface geological survey activity also declined compared with 1973. The totals for 1974 are as follows (with the 1973 figures in brackets):

Type of Survey	Line km	Party months or geologist month
Land seismic	559 (1 776)	....
Marine seismic	11 815 (14 904)	....
Gravity (land)	....	1·0 (7·0)
Aeromagnetic	6 373 (Nil)	....
Geological	....	3·0 (3·5)

PETROLEUM TENEMENTS

During the year two offshore tenements in the Eucla Basin were cancelled, and partial relinquishments of tenements were made in the offshore Perth, Carnarvon and Canning Basins. Surrenders of other offshore tenements in the Perth, Carnarvon, Canning and Officer Basins have either been completed or are pending. Large areas are currently available for application.

Petroleum tenements current on December 31st 1974 are shown in Figure 17, 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	....	....	Woodside Oil N.L., Shell Development (Aust.) Pty. Ltd., B.O.C. of Australia Ltd.
R1	178	14/11/79	
*WA -2-P	....	....	,, ,, ,, ,,
*WA- 7-P	....	....	,, ,, ,, ,,
WA-13-P	....		West Australian Petroleum Pty. Ltd.
R1 Part 1 110 R1 Part 2 84	194	29/8/79	
WA-14-P			
R1 Part 1 77 R1 Part 2 121	198	29/8/79	,, ,, ,, ,,
WA-15-P	352	20/3/75	Arco Aust. Ltd., Australian Aquitaine Petroleum Pty. Ltd. Esso Exploration & Production Aust. Inc. Alliance Oil Development Aust. N.L.
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	
WA-20-P	....		West Australian Petroleum Pty. Ltd.
R1	15	10/10/79	
*WA-21-P	....	....	
WA-23-P	....	....	
R1	199	3/10/79	
WA-24-P	....	....	
R1	104	17/10/79	
WA-25-P	....	....	
R1	128	16/10/79	
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	Woodside Oil N.L., Shell Development (Aust.) Pty. Ltd., B.O.C. of Australia Ltd.
WA-30-P	400	2/7/75	Woodside Oil N.L., Shell Development (Aust.) Pty. Ltd., B.O.C. of Australia Ltd.
WA-31-P	400	18/5/75	Woodside Oil N.L., Shell Development (Aust.) Pty. Ltd., B.O.C. of Australia Ltd.
WA-32-P	395	2/7/75	Woodside Oil N.L., Shell Development (Aust.) Pty. Ltd., B.O.C. of Australia Ltd.
WA-33-P	389	18/5/75	Woodside Oil N.L., Shell Development (Aust.) Pty. Ltd., B.O.C. of Australia Ltd.
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			
WA-40-P	102	12/3/75	BP Petroleum Development Aust. Pty. Ltd., Abrolhos Oil N.L.
*WA-50-P	....	....	....
*WA-51-P	....	....	....

* Surrender Pending.

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.
H2	100	9/2/88	West Australian Petroleum Pty. Ltd.

PETROLEUM TENEMENTS UNDER THE PETROLEUM ACT, 1967

Exploration Permits

Number	No. of graticular sections	Expiry date of current term	Registered holder or applicant
*EP 3	....	....	....
*EP 5	....	....	West Australian Petroleum Pty. Ltd.
EP 6	199	27/8/75	
EP 7	200	27/8/75	,, ,, ,, ,,
*EP 8	....	....	,, ,, ,, ,,
*EP 9	....	....	,, ,, ,, ,,
EP 13	200	27/8/75	,, ,, ,, ,,
*EP 14	....	....	,, ,, ,, ,,
*EP 15	....	....	,, ,, ,, ,,
EP 17	200	27/8/75	,, ,, ,, ,,
EP 18	86	27/8/75	,, ,, ,, ,,
EP 19	200	27/8/75	,, ,, ,, ,,
*EP 20	....	....	,, ,, ,, ,,
EP 21	90	26/7/75	West Australian Petroleum Pty. Ltd.
EP 23	156	6/8/85	West Australian Petroleum Pty. Ltd.
EP 24	163	6/8/75	West Australian Petroleum Pty. Ltd.
EP 25	96	6/8/75	
EP 26	1	27/8/75	BP Petroleum Development (Aust.) Pty. Ltd.
EP 27	2	19/8/75	
EP 28	4	19/8/75	Abrolhos Oil N.L.
EP 29	7	19/8/75	,, ,, ,, ,,
*EP 31			
EP 32	200	15/4/76	Beach-General Exploration Pty. Ltd., Australian Aquitaine Petroleum Pty. Ltd.
EP 34	1	15/4/76	Woodside Oil N.L., Shell Development (Aust.) Pty. Ltd., B.O.C. of Australia Ltd.
EP 35	1	15/4/76	
EP 36	1	15/4/76	
*EP 37	....	....	....
*EP 38	....	....	....
EP 40	67	26/7/76	West Australian Petroleum Pty. Ltd.
EP 41	180	18/7/76	West Australian Petroleum Pty. Ltd.
EP 42	200	1/9/75	
EP 43	163	1/9/75	,, ,, ,, ,,
EP 44	113	1/9/75	,, ,, ,, ,,
EP 50	110	1/9/75	West Australian Petroleum Pty. Ltd.
EP 54	123	22/9/75	Alliance Oil Development Aust. N.L.
EP 58	200	20/7/76	Associated Australian Resources N.L., Australian Aquitaine Petroleum Pty. Ltd., Abrolhos Oil N.L., Ashburton Oil N.L., Flinders Petroleum N.L., Longreach Oil Ltd., Pursuit Oil N.L.
EP 59	186	18/7/76	
EP 60	2	Appn.	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	Appn.	,, ,, ,, ,,
EP 65	2	19/9/76	,, ,, ,, ,,
EP 66	1	19/9/76	,, ,, ,, ,,
EP 67	29	25/10/76	,, ,, ,, ,,
EP 68	175	27/7/77	W. I. Robinson
*EP 69	...	....	....
EP 70	71	25/9/77	Associated Australian Resources N.L., Australian Aquitaine Petroleum Pty. Ltd., Abrolhos Oil N.L., Ashburton Oil N.L., Flinders Petroleum N.L., Longreach Oil Ltd., Pursuit Oil N.L.
EP 71	81	6/7/77	Coastal Petroleum N.L.
EP 85	4	Appn.	Endeavour Oil Co. N.L., Target Minerals Pty. Ltd., Beaver Exploration N.L., Tricentrol (Aust.) Ltd.
EP 86	118	Appn.	XLX N.L.

* Surrender Pending.

Production Licences

PL 1	5	24/10/92	West Australian Petroleum Pty. Ltd.
PL 2	4	24/10/92	
*PL 3	....	....	....

* Surrender Pending

PETROLEUM TENEMENTS UNDER THE PETROLEUM PIPELINES ACT, 1969

Pipeline Licenses

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	,, ,, ,, ,, ,,

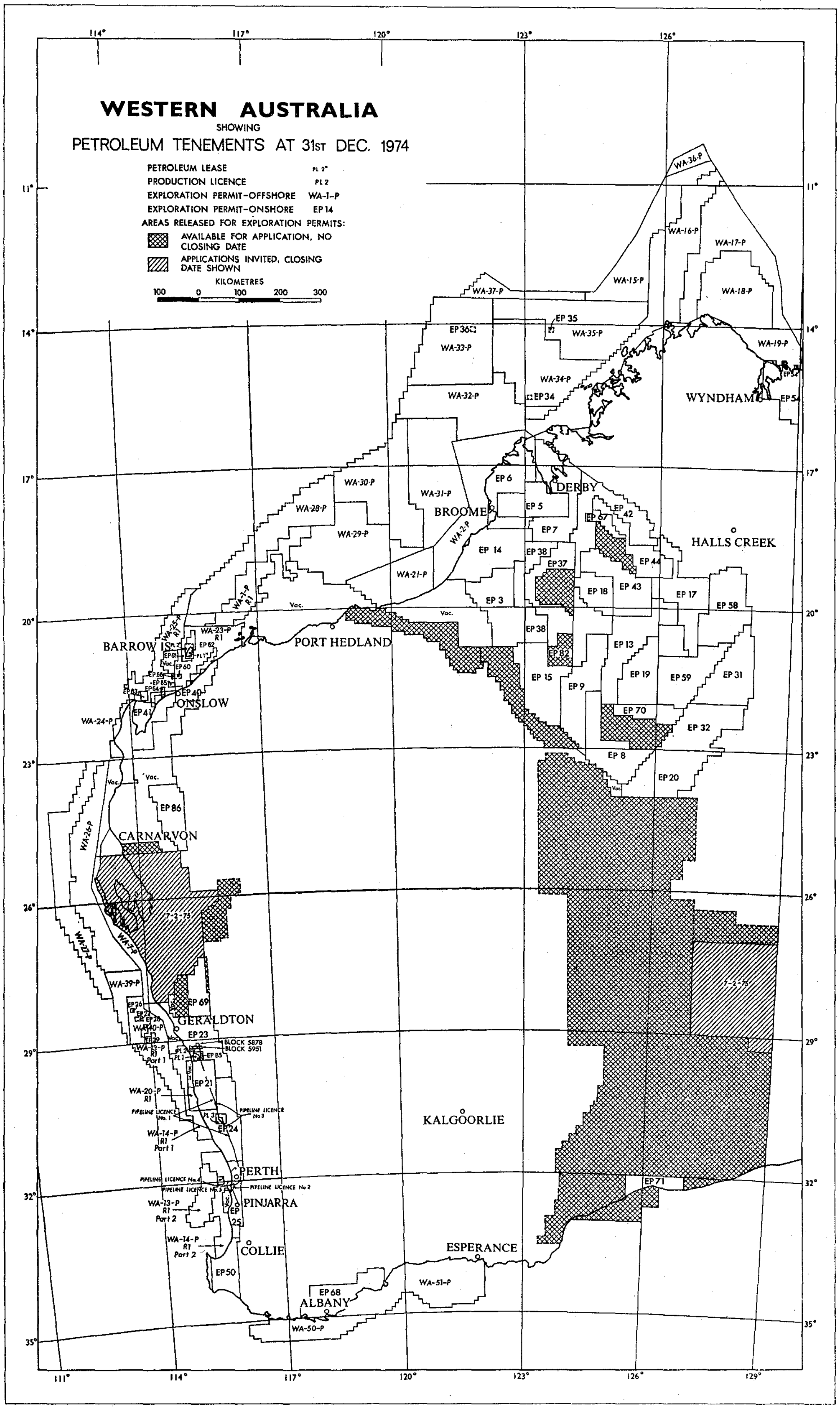

Figure 17. Petroleum tenements at 31st December, 1974.

DRILLING

The positions of wells drilled for petroleum exploration in Western Australia during 1974 are shown in Figures 18 and 19. Details relating to the wells drilled during the year are given in Table 7. All the petroleum exploration wells drilled in Western Australia up to the end of 1974 are listed in Geological Survey Record 1975/1. A summary of the principal results of the drilling in each basin during the year is as follows:

PERTH BASIN

Barragoon No. 1 was located in the central onshore Perth Basin to test an anticlinal closure indicated by seismic data, and to investigate the stratigraphy of a possible onshore extension of a high structural trend from the offshore Vlaming Sub-basin. The well was abandoned as a dry hole after reaching a total depth of 2 335 m in Upper Jurassic Yarragadee Formation. No shows of oil or gas were encountered.

Coomallo No. 1 was drilled to test the potential of an anticlinal fault block on the west flank of the Dandaragan Trough. The well bottomed in the Cattamarra Coal Measures Member of the Lower Jurassic Cockleshell Gully Formation at a total depth of 3 520 m and was abandoned as a dry hole. The small gas shows obtained were confined to coal seams (Fig. 18).

Dongara No. 20 was successfully completed as an in-fill development gas well in the onshore Dongara gas field.

CARNARVON BASIN

Three wells were completed by the B.O.C. group in the Carnarvon Basin during 1974. Lowendal No. 1 and Hampton No. 1 were new-field wildcat tests on the southwestern extension of the Rankin Platform and on the Enderby Trend in the Dampier Sub-basin respectively. No significant hydrocarbon shows were recorded in Lowendal No. 1. A drill-stem test of a gas show in Hampton No. 1, over the interval 535 to 565 m, gave an average flow rate of 3 410 m^3/day accompanied by 46.7 barrels of water per day. Both wells were plugged and abandoned.

Lambert No. 1 was drilled by the B.O.C. group in the northern part of the Dampier Sub-basin, about 17 km west of the Angel gas field and about 32 km northeast of the North Rankin gas field. A drill-stem test conducted over the interval 3 101 to 3 106 m flowed 51° A.P.I. gravity oil, at an average rate of 374 barrels per day, and gas at an average rate of 2 577 m^3/day. The test was carried out through a $\frac{3}{4}$ inch bottom-hole choke. The well is classified as an abandoned oil and gas discovery.

WAPET completed two offshore tests and two onshore stratigraphic wells in 1974. Hilda No. 1A completed the test of a faulted anticlinal structure, about 75 km southwest of the Barrow Island oil field, after the Hilda No. 1 well was abandoned above the target depth because of bad hold conditions. A minor show of oil (A.P.I. gravity 55°) and gas in the basal sand of the Lower Cretaceous Muredong Shale was tested by a formation interval test at 2 669 m. The hole was subsequently plugged and abandoned.

West Tryal Rocks No. 2 was a successful extension test, drilled on the structure discovered in 1973 in the No. 1 well. Two gas and condensate sands were successfully tested by drill-stem tests. The first test over the interval 3 435 to 3 450 m, in a sand that extends between 3 411 and 3 473 m, flowed gas at rates ranging from approximately 255 to 311 x 10^3 m^3/day, with 150 barrels of condensate per day. The second test covered the interval 3 295 to 3 305 m in a sand extending from 3 274 to 3 320 m, and flowed gas at a rate of approximately 436 x 10^3 m^3/day with 221 barrels of condensate per day on a $\frac{1}{2}$ inch choke. The well has been plugged and abandoned.

Onshore in the Robe River area, overlying the Peedamullah Shelf, WAPET drilled twin wells alongside Windoo No. 1 and Mardie No. 1 to obtain cores for more detailed study of gas and oil showings obtained from Lower Cretaceous reservoirs. Both of the twin wells flowed small amounts of gas. Reservoir studies to evaluate the liquid hydrocarbon potential of the area are continuing.

CANNING BASIN

The B.O.C. group drilled three offshore wells in the Canning Basin in 1974, Depuch No. 1, Minilya No. 1 and Poissonnier No. 1. No significant hydrocarbon shows were encountered and the three wells were abandoned as dry holes.

Jones Range No. 1, drilled by WAPET to test an onshore structure on the southwestern flank of the Fitzroy Trough near the edge of the Broome Platform, was also dry and was abandoned.

BROWSE BASIN

The B.O.C. group tested the Heywood, Lombardina, and Prudhoe structures in the Browse Basin with new field wildcat wells during 1974. Heywood No. 1 had minor gas and oil showings but the other two wells were dry. All three wells were abandoned.

BREMER BASIN

Silfar Pty. Ltd. completed two stratigraphic wells (both dry), Kendenup No. 1 and Sunday Swamp No. 1, in the onshore Bremer Basin. Kendenup No. 1 was abandoned and Sunday Swamp No. 1 was completed as a water well.

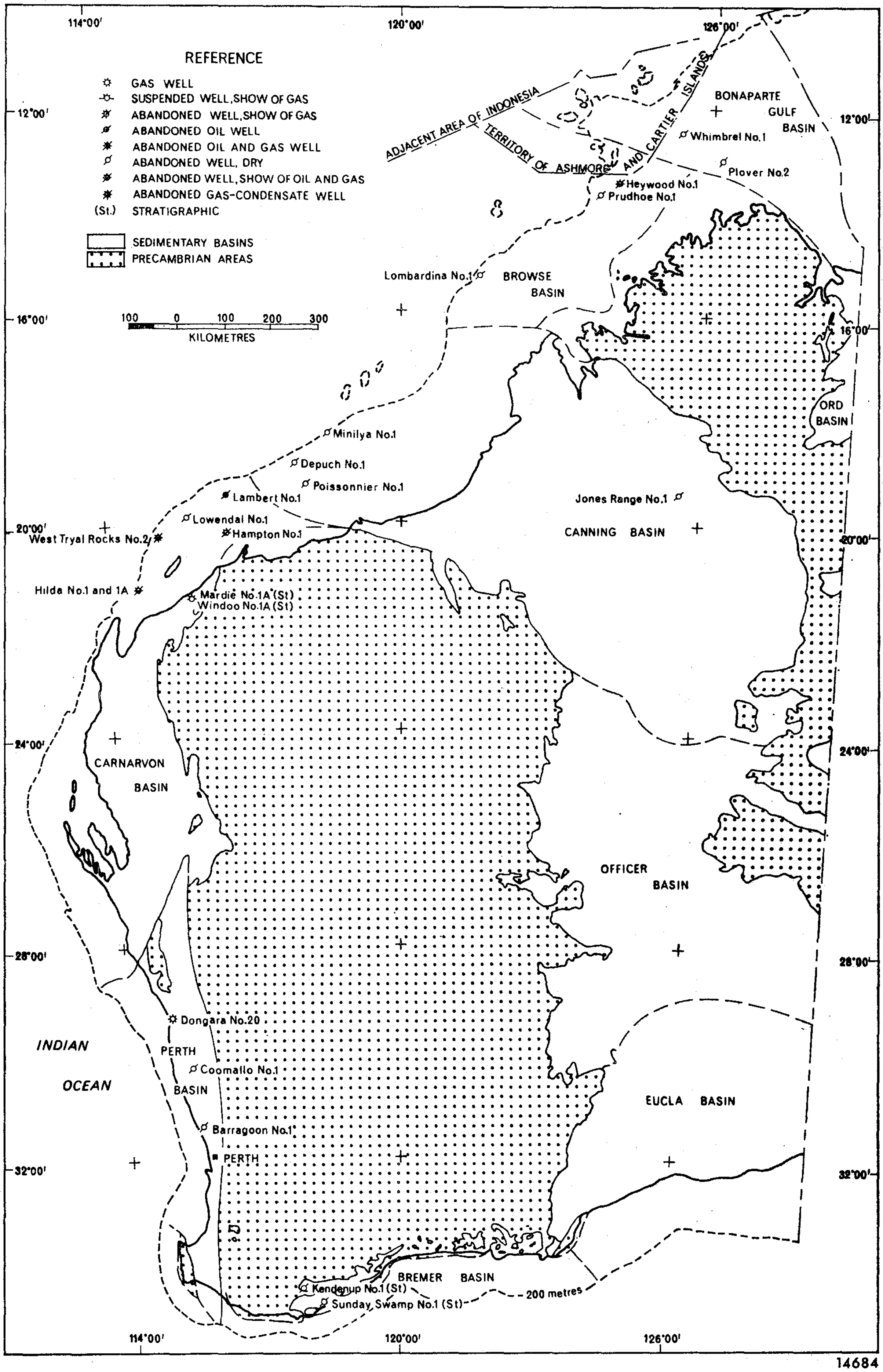

Figure 18. Wells drilled for petroleum exploration in Western Australia during 1974.

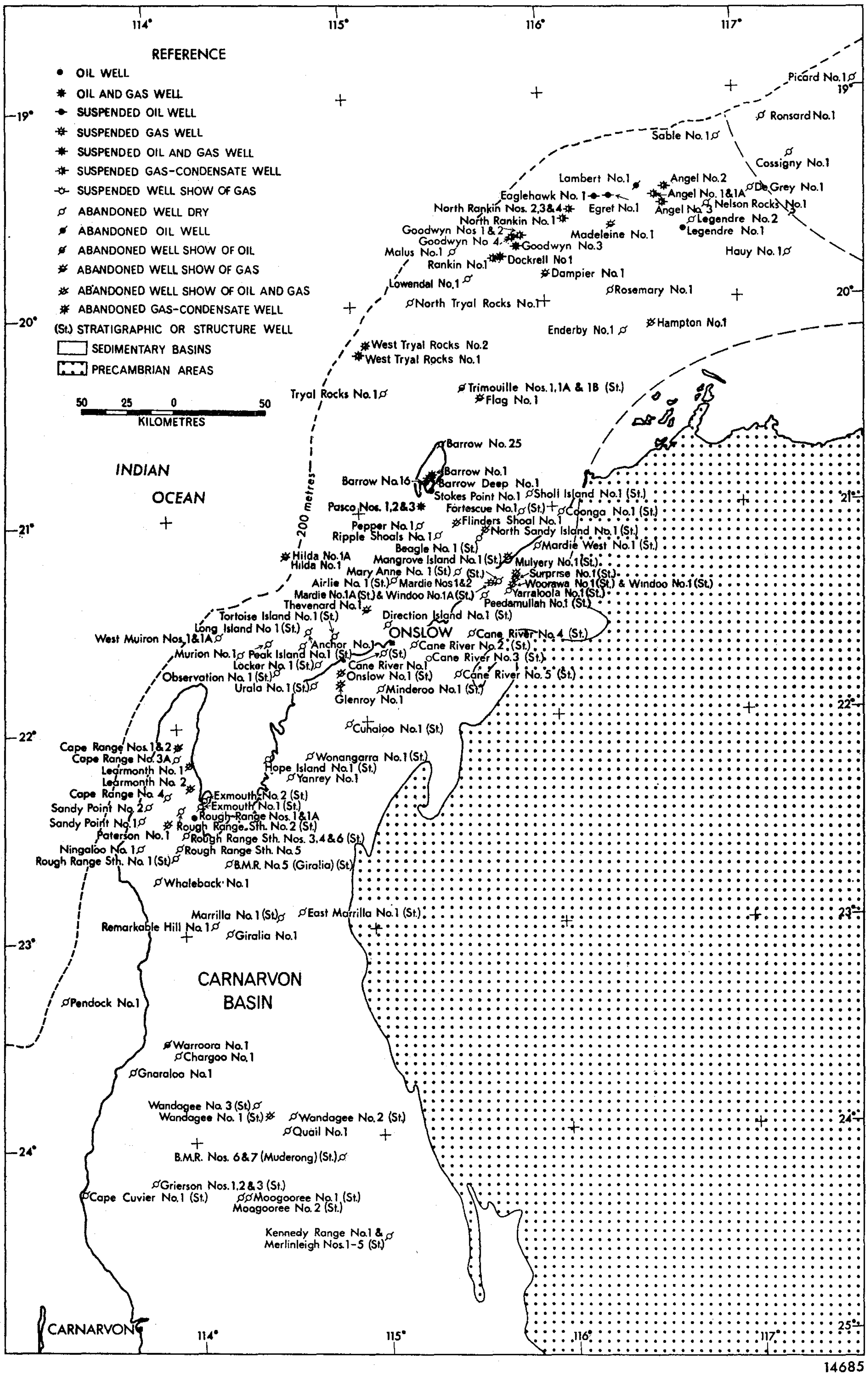

Figure 19. Northern Carnarvon and southwestern Canning Basins showing wells drilled for petroleum to 31st December, 1974.

TABLE 7. WELLS DRILLED FOR PETROLEUM EXPLORATION IN WESTERN AUSTRALIA DURING 1974

Basin	Well	*Subsidized	Concession	Operating Company	Type	Position		Elevation and water depth (metres)			Dates			Total depth (or depth reached) m	Bottomed in	Status on 31 Dec., 1974
						Latitude South ° ′ ″	Longitude East ° ′ ″	G.L.	R.T.	W.D.	Commenced	Reached T.D.	Rig released			
PERTH	Barragoon No. 1	*	EP-24	WAPET	NFW	31 21 40	115 35 09	35·8	39·8	....	31/3/74	20/4/74	22/4/74	2 335	U. Jurassic	Dry, P & A
	Coomallo No. 1	*	EP-21	WAPET	NFW	30 14 55	115 24 57	253·0	258·0	....	17/1/74	25/2/74	28/2/74	3 526	L. Jurassie	Dry, P & A
	Dongara No. 20	....	P.L.1	WAPET	DEV	29 16 03	115 01 18	76·3	80·9	....	7/6/74	12/7/74	20/7/74	1 939	....	Gas well
CARNARVON	Hampton No. 1	....	WA-1-P	B.O.C.	NFW	20 07 04	116 32 47	....	30·0	53·0	22/3/74	17/4/74	24/4/74	2 584	....	Gas show, P & A
	Hilda No. 1	*	WA-25-P	WAPET	NFW	21 12 01	114 38 12	....	12·0	145·0	10/3/74	22/3/74	28/4/74	1 546	Tertiary	Dry, P & A
	Hilda No. 1A	*	WA-25-P	WAPET	NFW	21 11 59	114 38 13	....	12·0	145·0	29/4/74	20/9/74	28/9/74	3 466	U. Triassic	Gas and oil show, P & A
	Lambert No. 1	....	W.A.-28-P	B.O.C.	NFW	19 27 23	116 29 23	....	10·0	125·0	13/11/73	24/1/74	3/2/74	3 700	....	Oil & gas well, P & A
	Lowendal No. 1	....	WA-28-P	B.O.C.	NFW	19 52 48	115 38 02	....	30·0	85·0	31/1/74	15/3/74	21/3/74	3 642	....	Dry, P & A
	Mardie No. 1A	....	EP-40	WAPET	STR	21 21 18	115 14 43	6·8	9·4	....	21/11/74	3/12/74	4/12/74	164	....	Gas show suspended
	West Tryal Rocks No. 2	....	WA-25-P	WAPET	EXT	20 12 56	115 03 56	....	12·0	126·0	1/10/74	24/11/74	18/12/74	3 825	....	G & C well, P & A
	Windoo No. 1A	....	EP-40	WAPET	STR	21 21 20	115 40 55	5·2	7·9	....	7/12/74	15/12/74	15/12/74	174	....	Gas show suspended
CANNING	Depuch No. 1....	*	W.A.-29-P....	B.O.C.	NFW	18 50 07	117 55 19	....	10·0	143·0	4/2/74	30/3/74	3/4/74	4 300	L. Jurassic	Dry, P & A
	Jones Range .... No. 1	....	EP-43	WAPET	NFW	19 21 43	125 40 09	227·3	231·9	....	30/8/74	2/11/74	6/11/74	2 540	....	Dry, P & A
	Minilya No. 1....	....	WA-29-P	B.O.C.	NFW	18 19 29	118 43 57	....	30·0	146·0	4/8/74	30/8/74	5/9/74	2 400	....	Dry, P & A
	Poissonnier No. 1	....	WA-1-P	B.O.C.	NFW	19 18 34	118 09 19	....	30·0	83·0	20/12/73	20/1/74	25/1/74	1 962	....	Dry, P & A
BONAPARTE GULF	Plover No. 2	....	WA-16-P	ARCO	NFW	12 57 29	126 10 28	....	25·3	59·1	10/5/74	19/5/74	23/5/74	1 524	....	Dry, P & A
	Whimbrel No. 1	....	WA-15-P	ARCO	NFW	12 28 59	125 22 40	....	25·3	76·8	5/4/74	4/5/74	8/5/74	2 059	....	Dry, P & A
BREMER	Kendenup No. 1	....	EP-68	SILFAR	STR	34 29 35	117 45 22	159·1	159·4	....	19/12/73	15/1/74	27/1/74	111	....	Dry, P & A
	Sunday Swamp No. 1	....	EP-68	SILFAR	STR	34 45 07	118 17 37	99·0	100·3	....	7/2/74	7/3/74	22/3/74	175	....	Dry; completed as a water well
BROWSE	Heywood No. 1	....	WA-37-P	B.O.C.	NFW	13 27 46	124 04 00	....	10·0	35·0	7/4/74	27/6/74	14/7/74	4 572	....	Gas & oil show, P & A
	Lombardina No. 1	....	WA-32-P	B.O.C.	NFW	15 17 20	121 32 14	....	30·0	175·0	15/5/74	16/7/74	21/7/74	2 855	....	Dry, P & A
	Prudhoe No. 1	....	WA-35-P	B.O.C.	NFW	13 44 56	123 51 51	....	30·0	175·0	13/9/74	1/11/74	12/11/74	3 322	....	Dry, P & A
											Total			52 721		
											Less drilling done in 1973			4 549		
											Total drilling done in 1974			48 172		

ARCO = Arco Australia Ltd.
B.O.C. = B.O.C. of Australia Ltd.
WAPET = West Australian Petroleum Pty. Ltd.
SILFAR = Silfar Pty. Ltd.
DEV = Development well
EXT = Extension test well
G. & C. = Gas and condensate
NFW = New field wildcat well
P. & A. = Plugged and abandoned
STR = Stratigraphic well

GEOPHYSICAL SURVEYS

SEISMIC

During 1974 seismic surveys were conducted in the Perth, Carnarvon, Canning, Browse, and Bonaparte Gulf Basins. Details are as follows:

SEISMIC SURVEYS

Basin	Tenement	Company	Line kilometres	
			Marine	Land
Perth	EP-23	West Australian Petroleum Pty. Ltd.	....	89
,,	EP-24	,, ,, ,,	....	1
,,	PL-1	,, ,, ,,	....	12
,,	WA-12-P	,, ,, ,,	144	....
,,	WA-14-P	,, ,, ,,	268	....
Carnarvon	EP-41	West Australian Petroleum Pty. Ltd.	164	16
,,	PL-1H	,, ,, ,,	....	45
,,	WA-23-P	,, ,, ,,	1 193	....
,,	WA-24-P	,, ,, ,,	588	....
,,	WA-25-P	,, ,, ,,	681	....
,,	PL-2H	,, ,, ,,	12	....
Carnarvon/ Canning	WA-1-P	B.O.C. of Australia Ltd.	1 265	....
	WA-28-P	,, ,, ,,	838	....
Canning	EP-5	West Australian Petroleum Pty. Ltd.	....	11
,,	EP-6	,, ,, ,,	....	142
,,	EP-7	,, ,, ,,	....	8
,,	EP-13	,, ,, ,,	....	81
,,	EP-18	,, ,, ,,	....	54
,,	EP-19	,, ,, ,,	....	81
,,	EP-43	,, ,, ,,	....	2
,,	EP-58/59	Associated Australian Resources N.L.	....	17
,,	WA-29-P	B.O.C. of Australia Ltd.	938	....
,,	WA-30-P	,, ,, ,,	119	....
,,	WA-29-P	Hematite Petroleum Pty. Ltd. (farm-in operator)	683	....
	WA-31-P	Amax Petroleum (Aust) Inc. (farm-in operator)	498	....
Browse	WA-32-P	B.O.C. of Australia Ltd.	465	....
,,	WA-33-P	,, ,, ,,	333	....
,,	WA-34-P	, ,, ,,	1 543	....
,,	WA-35-P	,, ,, ,,	1 010	....
,,	WA-37-P	,, ,, ,,	158	....
Bonaparte Gulf	WA-15-P	Arco Australia Ltd.	213	....
	WA-16-P	,, ,, ,,	247	....
,,	WA-17-P	,, ,, ,,	45	....
,,	WA-19-P	,, ,, ,,	410	....
		Totals	11 815	559

GRAVITY

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

GRAVITY SURVEYS

Basin	Tenement	Company	Party months
Perth	EP-23	West Australian Petroleum Pty. Ltd.	0·2
,,	PL-1	,, ,, ,, ,,	0·1
Canning	EP-6	West Australian Petroleum Pty. Ltd.	0·3
,,	EP-13	,, ,, ,, ,,	0·1
,,	EP-18	,, ,, ,, ,,	0·1
,,	EP-19	,, ,, ,, ,,	0·2
		Total	1·0

MAGNETOMETER

Amax Petroleum (Aust) Inc. conducted 6 373 line kilometres of aeromagnetic survey over part of WA-31-P during 1974.

GEOLOGICAL SURVEYS

West Australia Petroleum Pty. Ltd. carried out surface geological surveys consisting of two geologist-months in the Canning Basin, and one geologist-month in the Carnarvon Basin.

TERTIARY EPEIROGENY IN THE SOUTHERN PART OF WESTERN AUSTRALIA

by R. N. Cope

ABSTRACT

The suggestion that the Darling Plateau has been uplifted since the Eocene was first made 60 years ago, but the relationship of the plateau to surrounding geomorphic units has since received little consideration. It now seems likely that the Darling Plateau surface and its basic drainage pattern were formed during the Cretaceous Period. Evidence from the Blackwood Plateau and the Eucla Basin suggests that uplift took place in at least two main phases, that is, in the Oligocene and the Miocene-Pliocene. There is some evidence that uplift continued into the Quaternary. South of the Darling Plateau the old surface falls regularly to the south coast, and the term Ravensthorpe Ramp is suggested for this geomorphic unit. The hinge line between the two units appears to be a continuation of the Jarrahwood Axis previously described on the Blackwood Plateau; the extension of this term eastwards to cover both areas is therefore proposed. Uplift of the continental interior was accompanied by sagging of the continental margin to form the continental slope. The continental shelf was formed simultaneously by sediment progradation. These events immediately followed the separation of Australia and Antarctica by ocean-floor spreading. A similar history of epeirogenic uplift, development of marginal hinge lines, and peripheral sagging has been reported from South Africa and eastern South America. It is concluded that Cainozoic epeirogeny resulted from forces generated by ocean-floor spreading, although the mechanism is not known.

INTRODUCTION

The hypothesis that the Darling Plateau was uplifted during the Tertiary has been firmly established in the literature for many years (for example, Jutson, 1914, p. 95). However, little consideration has been given to relating the Tertiary tectonic history of the plateau to that of surrounding physiographic provinces such as the Eucla Basin, the south coast area and the Perth Basin. On the west, the Darling Plateau is bounded by the scarp of the Darling Fault. West of the Darling Fault differential erosion has removed all but the youngest geomorphic features so that interpretation of the Tertiary structural history is difficult. To the south, however, there is a gradual transition from the plateau to the continental shelf through the Eucla Basin and what is here termed the Ravensthorpe Ramp.

Interpretation of Western Australian land forms in terms of epeirogeny has been handicapped in the past by the sparsity of elevation control. In recent years, however, partial contoured map coverage has become available at a scale of 1 : 250 000, and since 1970, Royal Australian Survey Corps 1 : 100 000 metric contoured sheets have been published for the western portion of the area under review between Bunbury and Katanning. These data have been assembled to make a generalized contour map representing the plateau surface, if dissection simultaneous with and subsequent to uplift is disregarded (Fig. 20). In compiling this map, use has also been made of the spot heights recorded during the recent B.M.R. helicopter gravity survey (Australia B.M.R., 1969-1972).

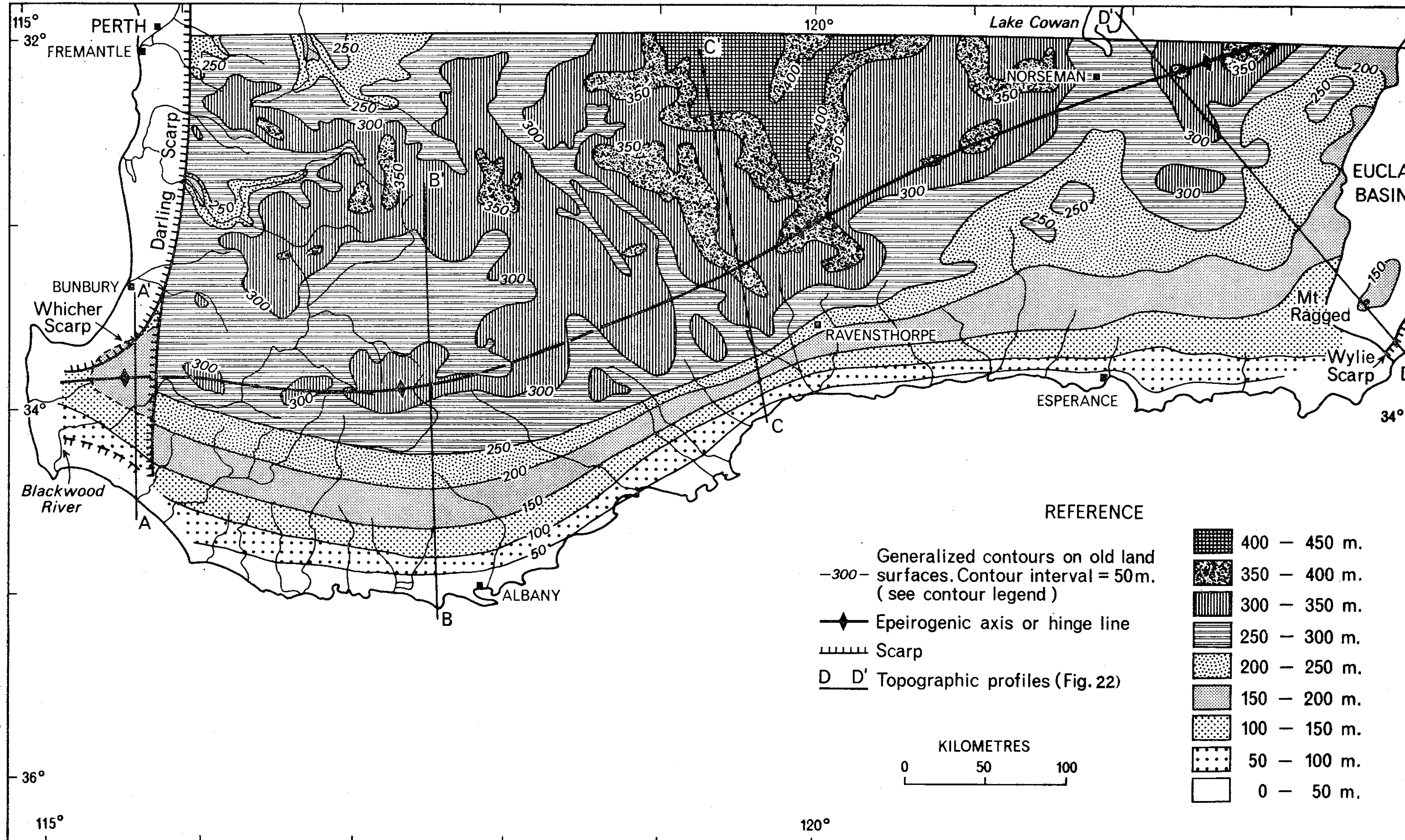

Figure 20. Topographic relief of old land surfaces in the southern part of Western Australia.

The sea floor of the Southern and Indian Oceans has been investigated in recent years. From the magnetic striping and application of the hypothesis of sea-floor spreading it has been suggested that the Antarctic and Australian continents drifted apart in the early Tertiary (McKenzie and Sclater, 1971). In this paper the possible relationship of Tertiary plate movement to epeirogenic uplift is discussed after the evidence from each of the onshore and offshore geomorphic divisions has been reviewed.

ONSHORE GEOMORPHIC SUBDIVISIONS

DARLING PLATEAU

The Darling Plateau in this area and to the north is characterized by a high average elevation, rising from about 300 m in the west to about 400 m in the Eastern Goldfields area (Fig. 20). The highest, and oldest, level is seen in scattered residuals bounded by breakways (Mount Dale level of Woolnough, 1918) while a somewhat lower level forms an extensive undulating plateau (Jutson, 1914). In the southwestern portion of the Darling Plateau, corresponding with an annual rainfall of over 380 mm, the drainage is incised and this becomes marked on the western margin along the Darling Range.

The ages of the uplifted land surfaces forming the Darling Plateau are not known with certainty. Marine Upper Eocene carbonate sediments are present on the plateau around Lake Cowan, near Norseman (Cockbain, 1968a) and Upper Eocene to Oligocene fluviatile and lacustrine sediments have been encountered in a channel 60 m deep at Coolgardie (Balme and Churchill, 1959). Similar sediments of Eocene age have been encountered at Darkan Swamp, 80 km east-southeast of Perth (Playford and others, in press). Fluviatile clastic sediments are also present in the western part of the area as the Kojonup Sandstone (McWhae and others, 1958), the Nakina Formation (Playford and others, in press) and as un-named deposits in the Newlands area (Lowry, 1965). These sediments are not dated, but an Eocene to Oligocene age appears probable by comparison with the Coolgardie and Darkan Swamp occurrences.

The evidence indicates that the Darling Plateau formed prior to the Early Eocene when it was a semi-mature to mature landscape falling and draining to the south and west (Bunting and others, 1974). Johnstone and others (1973) suggest that the present salt lake system is a relic of the Late Jurassic-Early Cretaceous drainage, the good development of which is said to be attested to by the voluminous sediments of that age in the Perth Basin. However, Late Jurassic to earliest Cretaceous rapid sedimentation in the Perth Basin was followed by major intra-Neocomian uplift of the basin and the long period of tectonic stability lasting some 70 million years between the Late Neocomian and the Early Eocene would seem to be a more likely time during which a mature landscape was developed. Subsequently it was lifted by epeirogenic movement to its present position.

RAVENSTHORPE RAMP

The southern boundary of the Darling Plateau can for the most part conveniently be taken along the major divide parallel to the south coast (Fig. 21). This is illustrated in profiles B-B′ and C-C′ of Figure 22, which ignore later dissection of the old land surface corresponding to the main level of the Darling Plateau. The maximum and minimum regional southerly slopes are about 1 in 150 near Ravensthorpe and about 1 in 600 north of Esperance. There are numerous residual hills and mountain masses rising high above the main surface, the highest of which is the Stirling Range (up to 1 097 m). Marine Eocene rocks occupy depressions on the old land surface and are preserved at elevations of 105 m at Neridup and at about 300 m at Ravensthorpe (Cockbain, 1968b). The rivers draining to the south coast are relatively short and are incised into the tilted surface. At the coast the surface is commonly terminated by cliffs, and in the Esperance area it is modified by a series of erosion benches thought to have been formed during the Pleistocene (Morgan and Peers, 1973).

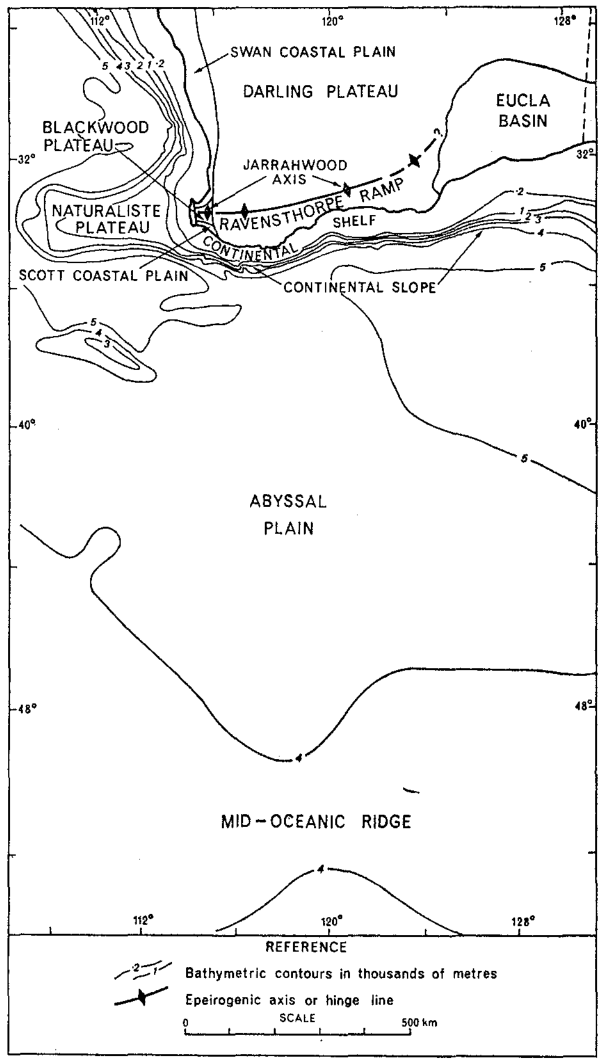

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Figure 21. Geomorphic divisions of the southern part of Western Australia and adjacent offshore areas (after Australia, Bureau of Mineral Resources, 1965).

As can be seen from Figures 20 and 22 the boundary between the Darling Plateau and the Ravensthorpe Ramp is a hinge line or epeirogenic axis. There appears to be a slight reversal of dip to the north of the axis, but the available information is not sufficiently detailed to illustrate this clearly.

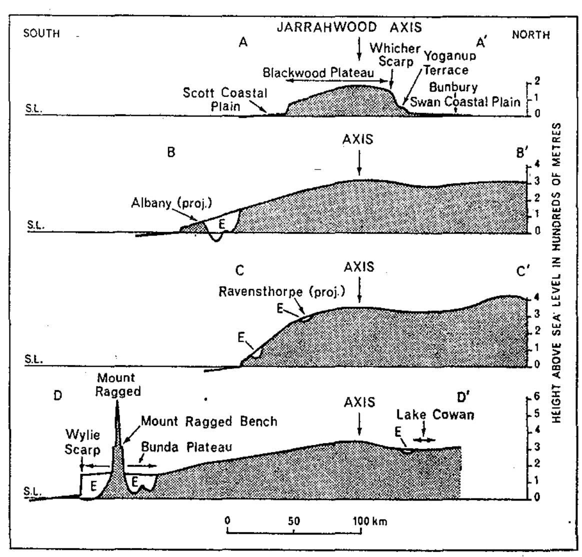

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Figure 22. Generalized topographic profiles approximately perpendicular to the south coast. Vertical exaggeration = x 125. E=Eocene marine deposits. For location of profiles see Figure 20.

EUCLA BASIN

The Eucla Basin contains a relatively thick sequence of dated marine Tertiary rocks and thus may be expected to provide important clues to Tertiary tectonic history (Lowry, 1970). Although the present uplifted land surface (the Bunda Plateau) lies at about 100 to 250 m, the basement surface on which the Eocene rests and with which the Darling Plateau and the Ravensthorpe Ramp are thought to be equivalent, lies between —300 m and +150 m beneath the mainland portion of the basin in Western Australia (Lowry, 1970, p. 17 and 145). Allowing for the depth of deposition below sea level of the Eocene formations, clearly there was subsidence during the Early Miocene to accommodate the Abrakurrie Limestone and later epeirogenic uplift to bring it to the level of the Bunda Plateau.

The approximate history of epeirogenic movement has been suggested by Lowry (1970, Fig. 51), who infers two main phases of uplift, in the Oligocene and Middle Miocene. There is no evidence of Miocene subsidence in the Ravensthorpe Ramp, but the Eucla Basin stratigraphy could be duplicated beneath the continental shelf to the south. By analogy with the Eucla Basin epeirogenic uplift of the Darling Plateau may have taken place in the Oligocene or Middle Miocene or in part during each of these times.

The relationship of the southeastern corner of the Darling Plateau and the Ravensthorpe Ramp to the Eocene sediments of the Eucla Basin is shown in Figure 22, D-D′. This illustrates that Tertiary deposition took place on a highly irregular surface, that uplift is post-Eocene and that the pre-Eocene land surface has been modified by post-Eocene planing, probably during the earlier stages of uplift.

The Mount Ragged Bench at about 300 m is thought by Lowry (1970, p. 156) to mark the Late Eocene sea level. However, the relative elevations would thereby imply deposition of the Toolinna Limestone at Wylie Scarp in water depths of about 150 to 275 m rather than in the range of 46 to 92 m Lowry suggests as being appropriate (p. 76). The Mount Ragged Bench is considered here to be a remnant of an earlier erosion cycle, possibly corresponding to the Mount Dale Level in the Eastern Goldfields.

BLACKWOOD PLATEAU

The nature of the Blackwood Plateau has been outlined in a previous paper (Cope, 1972) where it was concluded that an old semi-mature land surface was uplifted along the east-trending Jarrahwood Axis in the middle to late Tertiary. The southern flank is distinct, with a regional slope of about 1 in 300, but the northern flank is truncated by the Whicher Scarp, formed by Pleistocene erosion. The axis forming the boundary between the Darling Plateau and the Ravensthorpe Ramp appears to be the continuation of the uplift axis on the Blackwood Plateau. It is therefore suggested that the term Jarrahwood Axis might be used for both (Figs. 20 and 21).

Between the Blackwood Plateau on the west and the Darling Plateau and the Ravensthorpe Ramp on the east a dissected scarp 50 m high runs roughly along the line of the Darling Fault. This could have resulted either from movement on the fault after the old land surface was formed, for instance during Tertiary uplift, or by differential erosion during a pause in the uplift of the Darling Plateau.

The major movement on the Darling Fault took place between the Triassic (or earlier) and the Neocomian, when, as discussed under "Darling Plateau", there was a marked phase of uplift. Following this, more stable tectonic conditions prevailed. The intra-Neocomian uplift appears to mark a change in tectonic style from a rift phase preceding continental break-up to a drift phase, when India began to drift northwards (Johnstone and others, 1973, p. 11). Following the intra-Neocomian tectonic event, compaction of the thick Phanerozoic sedimentary column is thought to have accommodated additional Cretaceous sediments in a major portion of the Perth Basin, and some Eocene deposits at Perth (Kings Park Shale). This implies compaction faulting along the Darling Fault and the known faults cutting post-Neocomian sediments may similarly have resulted from differential compaction over quiescent major basement faults. However, the intra-Neocomian unconformity forms a north-south syncline in the Perth area which at its deepest point lies some 650 m below sea level (Allen, A. D., pers. comm.). This depth appears to be rather great to be accounted for by compaction alone and the possibility of movement at basement level on the Darling Fault in this area therefore cannot be ruled out.

The Blackwood Plateau is a distinct geomorphic feature, although now strongly dissected, intermediate in height between the Darling Plateau and the Swan Coastal Plain. If, as already discussed, uplift of the Darling Plateau has taken place since the Eocene, the difference in height of the two surfaces must also have originated since then. Compaction during the Middle and Late Tertiary no doubt resulted in some downward movement of the Blackwood Plateau and basement movement on the Darling Fault at this time is also possible. However, it is thought that the Blackwood Plateau may most reasonably be interpreted as an erosional bench formed during a pause in the uplift of the Darling Plateau and itself later undergoing uplift.

The presence of the scarp between the Darling and Blackwood Plateaux is taken to indicate that the Darling Plateau was uplifted by about 50 m prior to the period of tectonic stillstand. The present elevated position of the Blackwood Plateau and the presence of the Whicher Scarp show that the remainder of the uplift of the Darling Plateau has taken place during a second phase of epeirogenic uplift since the Blackwood Plateau semi-mature surface was formed close to sea level.

SWAN AND SCOTT COASTAL PLAINS

The Swan and Scott Coastal Plains lie relatively close to sea level (generally between 0 and 50 m), and they are still in process of formation today. The superficial deposits covering the plains are of Quaternary age.

One of the most striking geomorphic features of the southern Swan Coastal Plain is the Yoganup Terrace south of Bunbury. It is associated with beach deposits which have been exploited for the heavy minerals contained in them and accurate elevations of the base of the deposits are therefore available. The average level of the terrace falls from about 47 m in the south near Yoganup to about 37 m in the north near Dardanup (Sofoulis, J., written comm.). This represents a northward grade of about 1 : 2 500 compared with an estimated northward slope of 1 : 700 on the northern flank of the Blackwood Plateau to the southeast. No reliable dating of the Yoganup Terrace exists but from regional evidence it is believed to be of early Pleistocene or late Tertiary age. The low northerly gradient may indicate the extent of epeirogenic warping along the Jarrahwood Axis since that time.

The question arises as to why there is no equivalent geomorphic feature to the Ravensthorpe Ramp on the western side of the Darling Plateau. The explanation appears to be that the soft Cretaceous sediments of the Perth Basin were easily bevelled by differential erosion to form the Swan Coastal Plain and the 300 m high Darling Scarp. Although the Darling Plateau land surface is not preserved west of the Darling Fault, down-to-the-west tilting during the Tertiary is demonstrated by the westerly plunge of the Jarrahwood Axis on the Blackwood Plateau (Cope, 1972).

OFFSHORE GEOMORPHIC FEATURES

CONTINENTAL SHELF

The continental shelf is narrowest south of the Ravensthorpe Ramp, with an average grade of 1 : 200, and widest south of the Eucla Basin (average grade, 1 : 400). It is fairly narrow west of the Swan Coastal Plain (average grade, 1 : 225). Recent seismic work in various parts of the world has shown that the continental shelf is built from a sequence of prograded sediments of Tertiary to Recent age (Falvey, 1974; Beck, 1972).

CONTINENTAL SLOPE

As with the continental shelf, there are distinct differences in the average grade of the continental slope which are roughly as follows:

south of Eucla Basin	1 : 20
south of Ravensthorpe Ramp	1 : 10
west of Swan Coastal Plain	1 : 15

The continental slope is formed from the prograded fore-sets of the sediment wedge deposited since continental drift began. The margin of the continental plate has sagged several thousand metres. The base of the continental slope has been taken arbitrarily as about 4 000 m. To the west of Cape Leeuwin the slope is interrupted by the Naturaliste Plateau, which forms a terrace projecting westwards, exactly in line with the Jarrahwood Axis. This feature has apparently been formed from a continental fragment which has foundered to its present level after being left behind by the northward drift of India in the Early Cretaceous and by the relative southward drift of Antarctica in the Early Tertiary.

The lower part of the continental slope is sometimes called the continental rise. This term has not been used here, however, as it is so difficult to define with precision.

ABYSSAL PLAIN AND MID-OCEANIC RIDGE

The abyssal plain in this area lies between 4 000 m and 5 500 m, and the mid-oceanic ridge rises above 4 000 m. According to the theory of ocean-floor spreading, the abyssal plains are floored by new oceanic crust which is created along the mid-oceanic ridge and progressively spreads outwards from it. It has been established that on the western side of the Perth Basin the rift phase was followed by the onset of the drift phase in the Neocomian (Johnstone and others, 1973). To the south, however, Australia and Antarctica did not start to drift apart until the late Eocene (Falvey, 1974). Because drift appears to have been synchronous with the sagging of the southern continental margin and the epeirogenic uplift of the interior, it would seem likely that they are genetically related.

STRUCTURAL HISTORY OF THE CRETACEOUS AND TERTIARY

CONTINENTAL RIFTING OF THE PERTH BASIN

Rifting, which formed the Perth Basin, took place between the Triassic, or earlier, and the early Neocomian. Sediments up to at least 20 000 m thick accumulated in the Perth Basin, but no deposits of this age are known along the southern coast of the State.

NEOCOMIAN UPLIFT

A phase of uplift accompanied by normal faulting affected the Perth Basin in the middle Neocomian. The erosion which followed uplift must have been rapid, because the unconformably overlying basal sediments of the Warnbro Group are also of Neocomian age.

EARLY TO LATE CRETACEOUS DEPOSITION

Upper Neocomian to Upper Senonian sediments were deposited as the Warnbro and Coolyena Groups in the Perth Basin (Cockbain and Playford, 1973). The subsidence which provided space for these sediments in the Dandaragan and Bunbury Troughs is thought to have resulted from compaction of the thick earlier Mesozoic sequence but the possibility of some basement-level continued movement on the Darling Fault cannot be excluded. It was probably during this 50 to 60 million year time interval that the land surface now represented by the Darling Plateau was formed. Sediments of roughly equivalent age were deposited in the Eucla Basin as the Loongana Sandstone and the Madura Formation.

LATE CRETACEOUS TO EARLY TERTIARY EMERGENCE

The Maastrichtian to Paleocene was a time of emergence and erosion in the southern part of the State. This may represent the first pulse of epeirogenic uplift, although it was relatively small.

EARLY TERTIARY SUBSIDENCE AND DEPOSITION

In the Perth Basin late Paleocene to early Eocene subsidence is indicated by the Kings Park Shale which rests in a channel cut into Cretaceous rocks. In the Eucla Basin, the Middle Eocene Hampton Sandstone was laid down on a very irregular surface of Madura Formation (Lowry, 1970). Subsidence continued in the Late Eocene in the Eucla Basin. At this time deposition was initiated along the south coast to the west, where the Plantagenet Group was laid down as a shallow-water marine facies in depressions and valleys of a surface with high relief (Cockbain, 1968b). A shallow-water arm of the sea extended northwards from Esperance towards Kalgoorlie, as is shown by the distribution of the Norseman Limestone, Cowan Dolomite and Princess Royal Spongolite (Cockbain, 1968a).

OLIGOCENE UPLIFT

In the Eucla Basin, the Oligocene was a time of uplift, together with erosion and weathering of the underlying rocks (Lowry, 1970, p. 82). By analogy it is deduced that the Darling Plateau land surface underwent its first appreciable uplift (of about 50 m) at this time and that the Blackwood Plateau was then formed close to Oligocene sea level by differential erosion west of the Darling Fault. The pre-existing drainage system was initially incised also at this time.

EARLY MIOCENE SUBSIDENCE IN THE EUCLA BASIN

Very gentle downwarping in the Eucla Basin was renewed in the Early Miocene with deposition of the shallow-water Abrakurrie Limestone, followed disconformably by the Nullarbor Limestone and its lateral equivalent in the north, the Colville Sandstone. In the Bremer Basin along the south coast Miocene sediments do not occur onshore. The offshore portion of the basin has not, as yet, been tested by drilling. In the Perth Basin, Miocene sediments are known only in offshore wells. These sediments, like the Cretaceous sequence, are thick, and this demonstrates the marked downwarping of the western edge of the continental crust in the Cretaceous and the Miocene (Quilty, 1974).

MIOCENE-PLIOCENE UPLIFT

The only area where post-Early Miocene uplift can be clearly demonstrated is the Eucla Basin, where the top of the Nullarbor Limestone now lies at elevations of up to 250 m above sea level. The total epeirogenic uplift of this horizon comprises the present height above sea level of the eroded top of the formation, plus the thickness removed by erosion and the depth of deposition below sea level. The aggregate of these three figures ranges up to about 280 m in the Eucla Basin. This is roughly the amount of vertical uplift, in addition to the inferred approximately 50 m in the Oligocene, that would be required to bring the Darling

Plateau surface to its present position. It therefore seems reasonable to deduce that the epeirogenic uplift of the Darling Plateau took place mainly between the Middle Miocene and the Late Pliocene. However, uplift apparently continued into the Quaternary. The Perth Basin was also uplifted, decreasing from east to west from a north-south hinge line near the Darling Fault. Differential erosion and compaction have reduced the level of the onshore Perth Basin simultaneously with uplift to near sea level, leaving as erosional remnants the Blackwood Plateau in the south, the Dandaragan Plateau in the central Perth Basin and the Victoria Plateau northeast of Geraldton.

PLIOCENE-QUATERNARY EROSION

Incision of the river systems, which was started in the Late Cretaceous, Oligocene and Late Miocene, took place during the major uplift. The Swan and Scott Coastal Plains were formed by differential erosion of the soft Cretaceous sediments during this time interval. The Blackwood Plateau partly survived erosion owing to its relatively high position, but incision of the lower Blackwood River and its tributaries dissected the central portion of the plateau. During the Pleistocene there were marked climatic variations which resulted in major sea level fluctuations. These resulted in the formation of wave-cut benches at various heights both above and below present sea level, and the covering of the onshore Perth Basin with Quaternary sediments.

COMPARATIVE TECTONICS

The structural history of the area as reconstructed above shows interesting comparisons with that of the continental break-up of Gondwanaland and with certain other segments of the ancient super-continent.

The original formation of the Darling Plateau surface appears to date back to the time immediately following the drift of the Indian plate northwards in the Early Cretaceous (Falvey, 1972). The drifting apart of Australia and Antarctica started in the late Paleocene (Falvey, 1974, p. 105). Following this, phases of subsidence along the south coast in the Late Eocene and Early Miocene alternated with phases of uplift in the Oligocene and the Miocene-Pliocene. Following the latest uplift the Darling Plateau lies at an average height of about 350 m with a hinge line or axis (the Jarrahwood Axis) lying parallel to the south coast.

A very similar geomorphic situation and structural history has been reconstructed for southern Africa and for South America east of the Andes (King, 1956). In southern Africa an upwarped middle Cainozoic surface lies at about 1 000 m and a distinct coastal flexure has been eroded to a scarp by the succeeding denudation cycle (King, 1956, Fig. 1, and p. 463). In eastern Brazil, also, a base-level plain, formed between Late Cretaceous and middle Cainozoic, was lifted up to form tablelands at about 1 000 m which are bent down towards the ocean along the eastern margin of the continent (King, 1956, p. 461).

It appears likely that uplift of the interior plateau in eastern South America, southern Africa and Western Australia is related to the drifting apart of these continents from each other and from Antarctica. It is also now known that the edge of the continental plates have sagged to lie below the offshore continental slope. However, the mechanism by which ocean-floor spreading may have produced these features is not known at present.

CONCLUSIONS

1. The ancient land surface of the Darling Plateau was originally formed during the Cretaceous following an intra-Neocomian uplift. The Cretaceous drainage has, in the main, survived to the present; it is seen in the high-rainfall area of the southwest as an incised river system and as a relict drainage pattern in the arid interior.

2. The Darling Plateau was uplifted during the Cainozoic by several epeirogenic phases, the chief two of which occurred in the Oligocene and the Miocene-Pliocene.

3. Between the Darling Plateau and the south coast a distinct slope can be recognized and for this subdivision a new geomorphic term is proposed, the Ravensthorpe Ramp.

4. Slight warping of the old land surface is recognized as variation in elevation of the Darling Plateau and the Eucla Basin, and as the axis or hinge line between the Darling Plateau and the Ravensthorpe Ramp.

5. It is proposed that the term Jarrahwood Axis be extended from the Blackwood Plateau to cover the Darling Plateau-Ravensthorpe Ramp hinge line.

6. The start of epeirogenic uplift coincided with the separation of Australia and Antarctica by ocean-floor spreading. Simultaneously the margin of the continental plate sagged to form the foundation of the upper continental slope. A fragment of the continental-plate margin foundered to form the Naturaliste Plateau.

7. The continental shelf was formed by the later accumulation of sediments on the upper continental slope.

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THE CLASSIFICATION, GENESIS AND EVOLUTION OF SAND DUNES IN THE GREAT SANDY DESERT

by R. W. A. Crowe

ABSTRACT

Three types of sand dune occur in the Great Sandy Desert, Western Australia: simple and chain longitudinal types and a net-like type. Helicoidal air flow is believed to be responsible for the development of longitudinal dunes in this area. It is postulated that the three types of dune represent stages in an evolutionary sequence that occurs where there is an adequate supply of sand. The most complex (net-like) dunes are shown to occur in depressions and it is suggested that these represent the most evolved type.

INTRODUCTION

The Great Sandy Desert in Western Australia is one of the largest deserts in the world, with an area of approximately 400 000 km^2. It is covered by a remarkable pattern of longitudinal dunes that are now fixed by sparse vegetation. During the last three years, field work in the northeastern part of this area has prompted further study of variations in the dune pattern that cannot always be easily explained. This has involved study of aerial photographs and topographic maps over the rest of the desert and this paper proposes a classification and a theory on the origin of these variations.

CLASSIFICATION

Veevers and Wells (1961, p. 201) classified the longitudinal dunes of the Great Sandy Desert into five categories which they named types A-E, but no attempt was made to explain the significance of the different types. In this report Veevers and Wells' classification is simplified to three types (Figs. 23, 24 and 25) as their types A, B and D are morphologically similar. They are as follows:

Simple longitudinal dunes. Single crest, mainly straight. Wave length 100 m - 2 km (Fig. 23).

Chain longitudinal dunes. Multiple crested, mainly straight. Wave length 400-900 m (Fig. 24).

Net-like dunes. Net-like crest pattern. Not strictly longitudinal dunes although they are elongated parallel to the main wind direction. Wave length <300 m (Fig. 25).

Figure 27 shows the distribution of the different dune types on a topographic map of a representative part of the Great Sandy Desert. The most noticeable trend is that the dunes become increasingly complex towards the centres of depressions. This indicates that the depressions have acted as traps for moving sand, allowing more complex dunes to form in such areas. Thus the morphology of the dunes is related to their topographic position.

The fact that the three categories differentiated are completely gradational from one to another (see Fig. 26) strongly indicates that they have a related origin. Although similar observations on the distribution of dune type have been made by Mabbut (1968) among others, the genesis of these different categories of dunes has not yet been satisfactorily explained.

FORMATION OF LONGITUDINAL DUNES

Bagnold (1952) proposed the theory of helicoidal (Langmuir) air flow for the formation of longitudinal dunes. The theory is that as strong prevailing winds move horizontally across the land surface a thin boundary layer of turbulence develops in response to shearing stresses between the air and the land surface. Within this layer paired vortices form above the land surface, with their axes parallel to the main wind direction. These primary vortices propagate further paired vortices next to them and so on (see Fig. 28).

Other work concerning this subject has been reviewed by Folk (1971a), and Glennie (1970) and Wilson (1973) have described longitudinal dunes on a broader basis with particular reference to Africa and Arabia.

Hanna (1969) has reviewed the literature which shows that helicoidal air flow is restricted to the lowermost atmospheric boundary layer (Fig. 28).

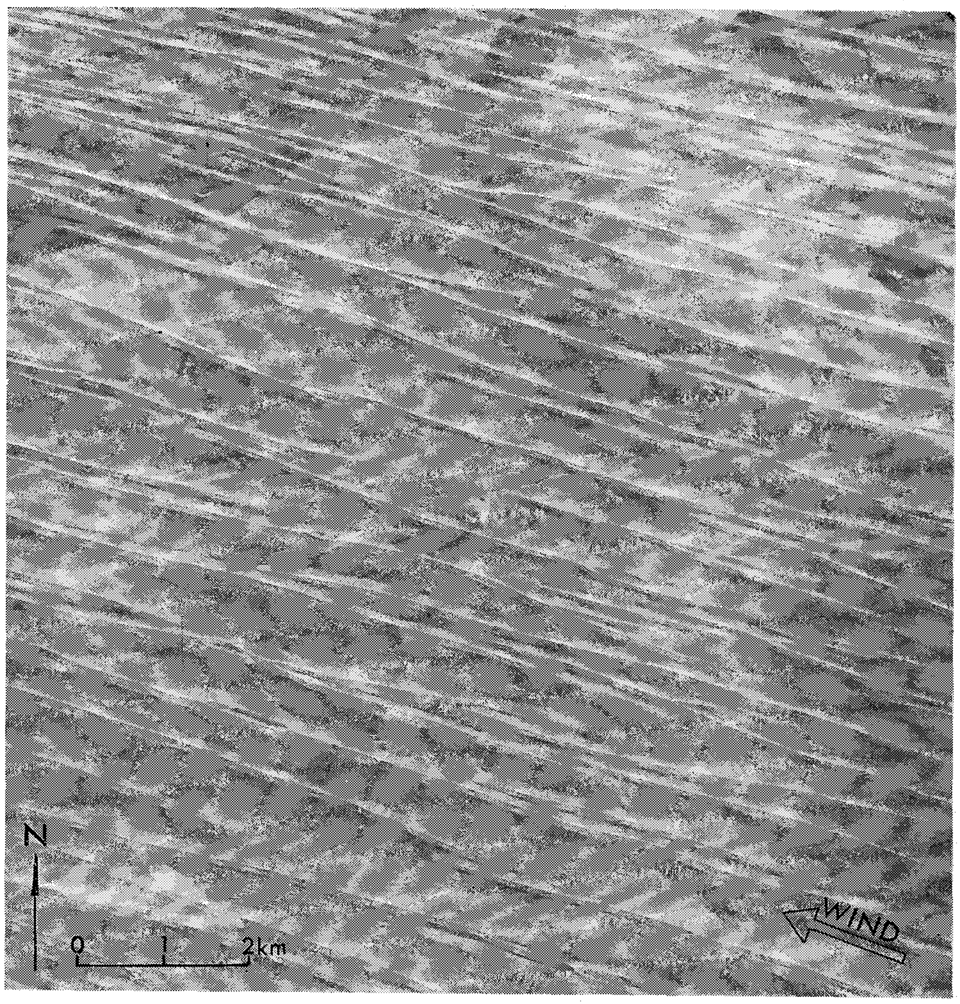

Figure 23. Simple longitudinal dunes. Mount Anderson, Run 6, No. 2132, 1967 photography.

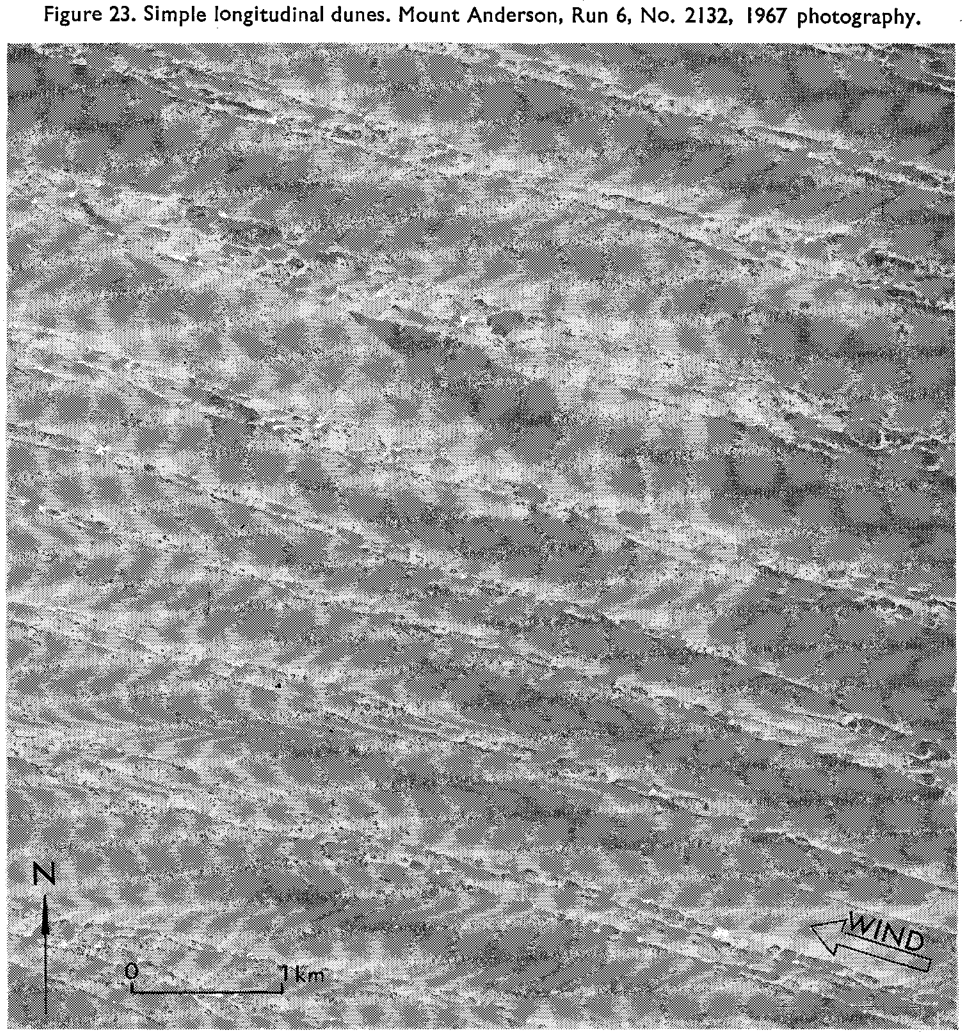

Figure 24. Chain longitudinal dunes. Crossland, Run 14, No. 5955, 1960 photography.

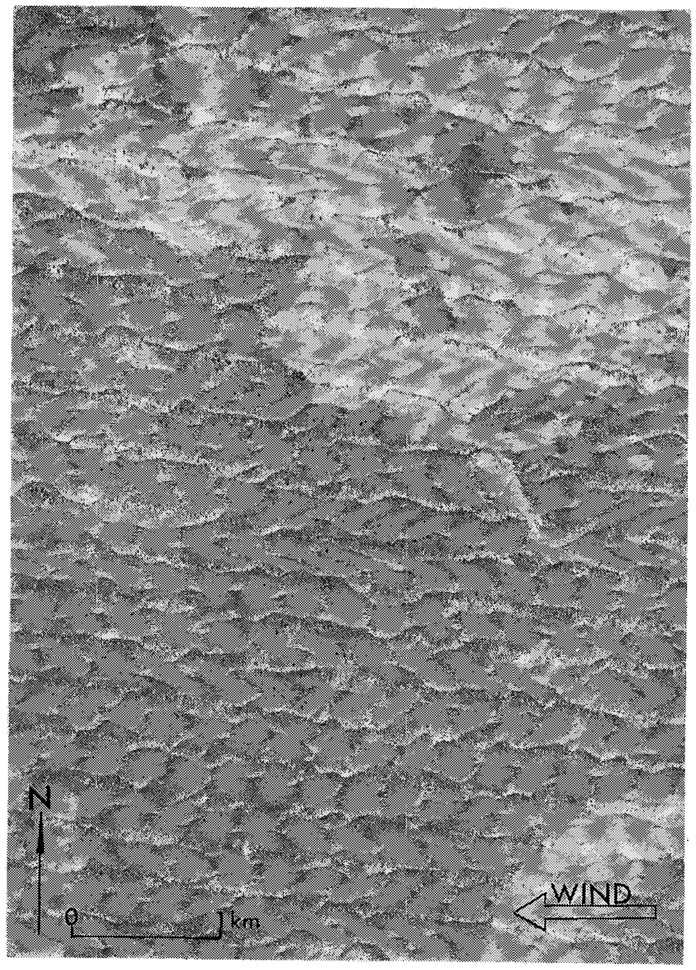

Figure 25. Net-like dunes. Cobb, Run I, No. 5955, 1960 photography.

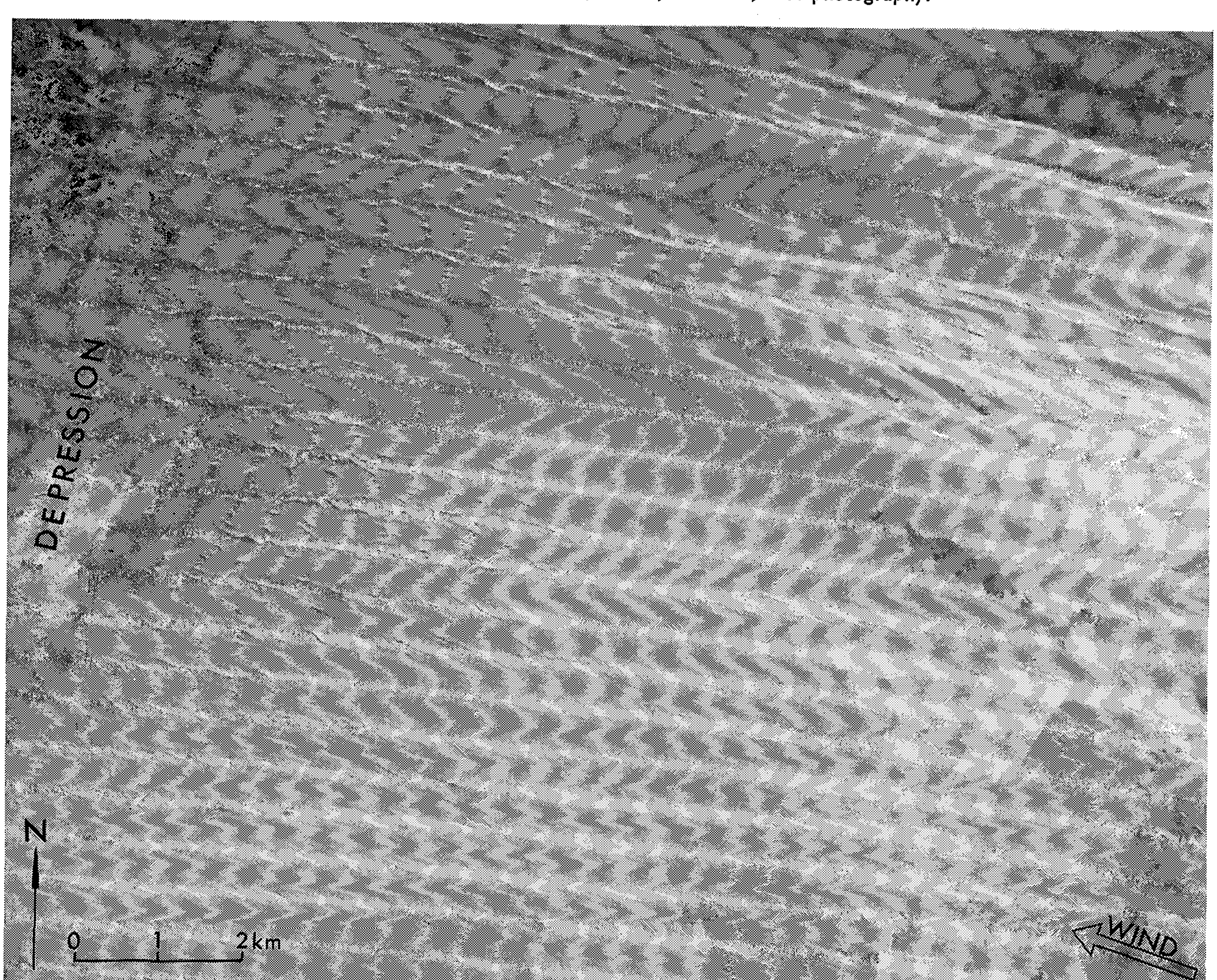

Figure 26. Gradation from simple longitudinal dunes to net-like dunes moving into a depression.
Cobb, Run I, No. 121, 1970 photography

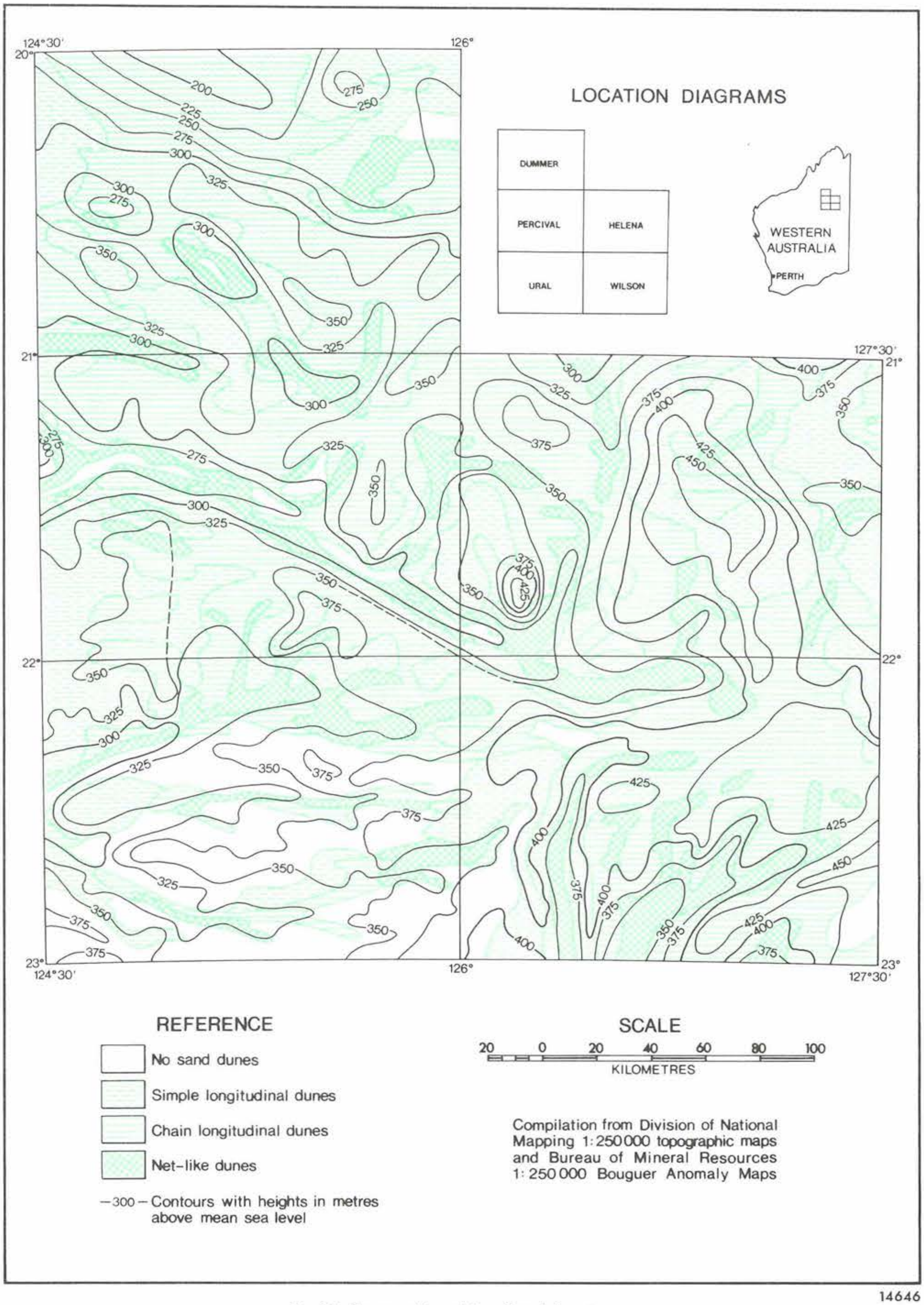

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Fig. 27 Topographic position of sand dune types.

The map shows how the net-like dunes generally occur in depressions. Chain dunes are the predominant type in this part of the desert.

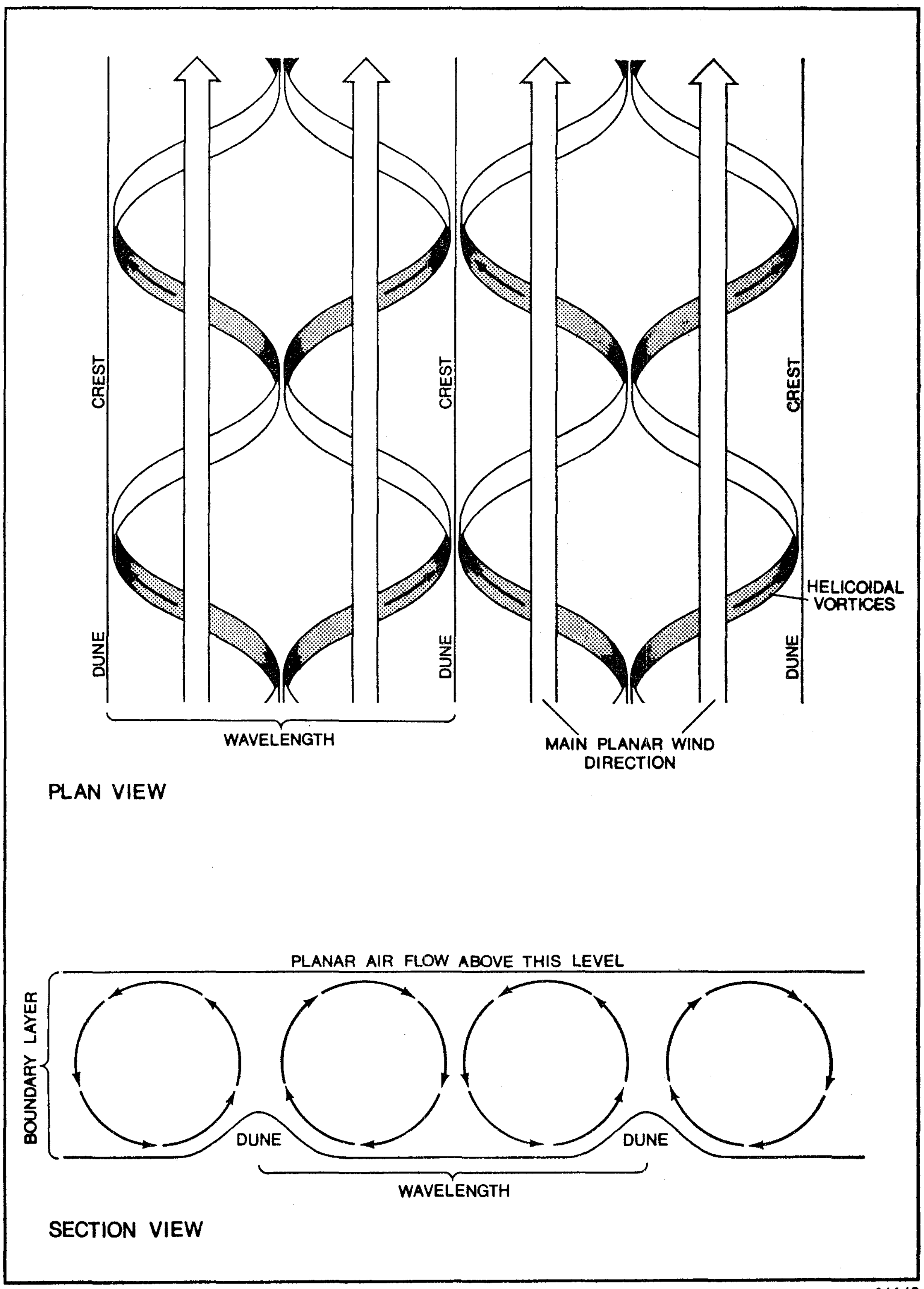

Figure 28. Diagram showing character of helicoidal air flow in dune areas. Note that wave length is related to thickness of boundary layer (adapted from Folk, 1971a).

The helicoidal vortices flow parallel to the main wind direction and produce long ripples or dunes. Above the boundary layer the air flow is essentially planar. It can be seen that the thickness of the boundary layer will govern the size of the vortices and thus the wave lengths of the ripples or dunes. Hanna has also shown that certain conditions are conducive to the formation of such a boundary layer. They are:

(1) Flat underlying terrain

(2) Little direction variation of the wind with height

(3) Wind speed higher than normal

(4) Strong curvature of the wind profile

(5) Unstable lapse rate of temperature near the surface.

He has demonstrated that these conditions are frequently found in desert areas.

Folk (1971b) was the first to find a diagnostic characteristic for this type of air flow. By rolling a cylinder on a greased planar surface he produced patterns identical with longitudinal dune patterns. In both cases "tuning fork junctions", opening upwind or away from the direction of roller movement are present (see Figs. 23 and 24) and Folk believes these are diagnostic features of dunes formed by helicoidal flow. Veevers and Wells (1961, p. 209) showed that the main winds capable of eolian transport in the Great Sandy Desert are winds from the south-southeast to east, in other words the prevailing winds. The tuning-fork junctions opening towards the east indicate that these dunes were formed by helicoidal air flow produced by the prevailing winds.

Application of this information to the variations of dunes, described above, demonstrates that the simple longitudinal dunes have been formed by helicoidal vortices (Fig. 28). The chain-type dunes are more complex and as they grade into simple longitudinal dunes, helicoidal air flow is considered to have also formed the multiple crests of the chain dunes. When the dunes exceed a certain width, a secondary pair of vortices is believed to come into operation, causing a split in the crest. This mechanism is shown in Figure 29.

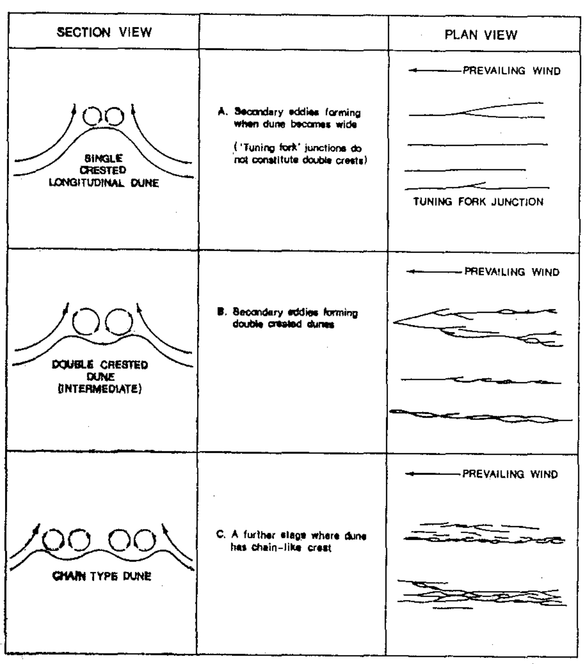

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Figure 29. Diagram showing proposed genesis of chain longitudinal dunes. Once secondary eddies form they become self-perpetuating convection eddies as the double crests are constructed.

The next stage is reached when the chain dunes become still wider. The interdune areas then become too narrow to support the original vortices, and these vortices break down. When this happens the chain dunes coalesce to form the net-like pattern.

One of the critical points about the hypothesis is whether the dunes become wider with time. If the wind was strong enough then the dunes would simply become higher. However, if the climate (wind) is stable, then once the dunes reach their maximum height, and additional sand is available, the dunes can only became wider.

The graduation between the simple longitudinal dunes and the net-like dunes (Fig. 26) shows how the more complex dunes are situated in depressions and, therefore, are in areas where more sand is available. This strongly suggests that the dunes have, in fact, become wider and have coalesced in the way described above.

An alternative hypothesis is that the air flow is modified by topographic highs and lows, and that these modifications cause the variations in dune pattern and are not related to sand supply. However, the increase in complexity of the dunes in depressions cannot be easily explained by this theory because the atmospheric boundary layer would be thicker over depressions, causing wider spaced dunes. Clearly this is not the case (Fig. 28), so it is felt that the increase in complexity is mainly dependent on the supply of sand and is best explained by the theory of dune coalescence where unfiorm helicoidal air flow ceases to have a major effect.

CONCLUSIONS

Over a flat plain, with consistent winds in predominantly one direction, and where high temperatures are conducive to turbulent wind action, helicoidal air flow occurs. This forms simple longitudinal dunes where there is an ample supply of sand suitable for eolian transport. As the dunes get older and the supply of sand is maintained these dunes become wider until they form the chain type. In depressions with still further sand available, the chain longitudinal dunes coalesce to form net-like dunes. In such a situation, convection takes over as the main dune-forming mechanism and helicoidal air flow has a reduced effect. If the supply of sand slows, or ceases, then the increase in complexity will stop. Thus, each of the three variations represents a stage in evolution of longitudinal dunes.

ACKNOWLEDGEMENTS

The aerial photograph of Cobb (Fig. 25) is published with permission of the Surveyor General, Department of Lands and Surveys, Perth. The photographs of Crossland (Fig. 24) Cobb (Fig. 26) and Mount Anderson (Fig. 23) have been made available by courtesy of the Director, Division of National Mapping, Department of Minerals and Energy, Canberra.

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NEW AND REVISED STRATIGRAPHIC NOMENCLATURE, NORTHEAST CANNING BASIN

by A. N. Yeates†, R. W. A. Crowe*, V. L. Passmore†, R. R. Towner†, and L. I. A. Wyborn†

ABSTRACT

It is proposed that the terms Hardman, Condren Sandstone, and Lightjack, previously defined as members of the Liveringa Formation, be given formation status and that the term "Liveringa" be upgraded to group status to include the Hardman Formation, Condren Sandstone, and Lightjack Formation.

New names proposed are:

(1) Knobby Sandstone: Upper Devonian quartzose sandstone, previously recognized and informally named.

(2) Kirkby Range Member, Hicks Range Sandstone Member, and Cherrabun Member for three mappable units comprising the Hardman Formation on the Crossland Sheet area.

(3) Lake Gregory Beds: Cainozoic mud, silt and sand in the Lake Gregory area.

It is also proposed that the term Wolf Gravel be discarded.

For details of the type sections described below see Yeates and others, 1974.

REVISION OF THE LIVERINGA FORMATION

The Liveringa Formation in the Fitzroy Trough was subdivided into the Lightjack, the Middle and the Hardman Members by Guppy and others (1958). The members, however, were not differentiated on their maps. In the Gregory Sub-basin, the southeastern continuation of the Fitzroy Trough (Yeates and others, in prep.), the Liveringa Formation was subdivided into the Balgo, Condren Sandstone, and Hardman Members (Veevers and Wells, 1961; Casey and Wells, 1964). The Balgo Member was recognized as a lateral equivalent of the Lightjack Member, but, at the time, continuity of the units could not be demonstrated between the two widely separated type sections, and two separate names were retained. The term Balgo Member was subsequently discarded by Playford and others (in press. The Condren Sandstone Member is equivalent to the Middle Member of Guppy and others (1958). Casey and Wells (1964) recognized the Hardman Member in the northwestern part of the Mount Bannerman Sheet area. Its only known stratigraphic equivalent to the southeast is probably the Godfrey Beds (Yeates and others, in prep.), which were previously thought to be Lower Cretaceous (Casey and Wells, 1964).

The type sections of the Hardman Formation, Condren Sandstone, and Lightjack Formation remain those described for these units when they were originally assigned member status. The type sections (locations shown in Fig. 30) are at Mount Hardman (Noonkanbah Sheet area), Condren Pinnacles (Lucas Sheet area), and at Lightjack Hill (Noonkanbah Sheet area), and none of them is complete.

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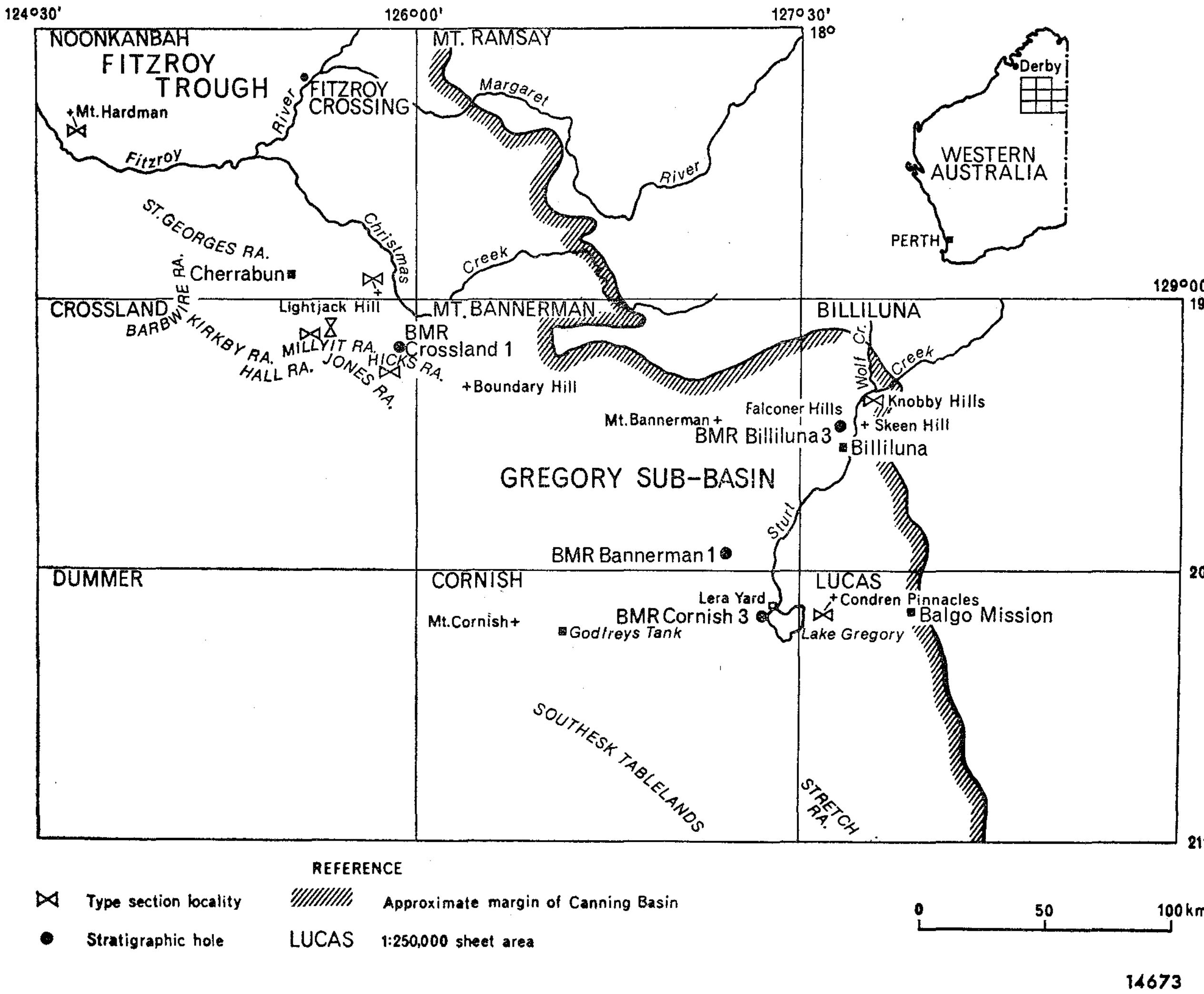

Figure 30. Northeast Canning Basin showing stratigraphic units.

PROPOSED NAME : KNOBBY SANDSTONE

Derivation of name: Knobby Hills, lat. 19° 23′ S, long. 127° 43′ E (Billiluna Sheet area).

Distribution: Crops out in an area of 40 km radius around Knobby Hills.

Lithology: Medium to coarse-grained, cross-bedded quartzose sandstone containing abundant intraformational claystone clasts; quartz granule conglomerate, thin beds of quartz-pebble conglomerate, and rare siltstone.

Type section locality: Lat. 19° 24′ 24″ S, long. 127° 45′ 44″ E, about 2 km east of Sturt Creek and 7 km north of Skeen Hill (Billiluna Sheet area).

Thickness: At the type section (Yeates and others, 1974), 13 m; at Falconer Hills (Billiluna Sheet area), 14.4 m is exposed. A shallow stratigraphic drill hole, BMR Billiluna No. 3, penetrated 170 m at Falconer Hills. The maximum thickness is estimated to be 350 m.

Age: Late Devonian; based on fish fossils.

Fossils: The lycopod *Leptophloem australe* (McCoy, 1874) and placoderm fishes, including undetermined arthrodires (Gilbert-Tomlinson, 1968, p. 210) *Bothriolepis, Asterolepis,* and crossopterygian remains (Young, G. C., pers. comm.). The fish plates, though fragmentary, are widespread, but *Leptophloem* specimens are rarer.

Relationships: The Knobby Sandstone lies unconformably on the Proterozoic Peterson Beds and is probably also unconformable on the Lower Ordovician Carranya Beds. The formation may conformably overlie rocks of possible Silurian-Devonian age in the subsurface. No upper contact is exposed. In the subsurface, the Knobby Sandstone is probably overlain by the Lower Permian Grant Formation in the Billiluna area, and possibly by Carboniferous rocks farther southwest away from the margin of the Canning Basin.

Synonomy or modification of previous nomenclature: Casey and Wells (1964) described the sandstone in the Knobby Hills area but did not formally name it. A Late Devonian to Early Carboniferous age was assigned to it on plant fossil evidence.

Veevers and others (1967) have referred to the "Knobby Sandstone" informally.

PROPOSED NEW MEMBERS OF THE HARDMAN FORMATION

KIRKBY RANGE MEMBER

Derivation of Name: Kirkby Range, lat. 19° 07′ S, long. 125° 13′ E (Crossland Sheet area).

Distribution: The Member occurs in the Millyit Range and Kirkby Range (Crossland Sheet area).

Lithology: Argillaceous siltstone, argillaceous sandstone, minor shale, and calcareous sandstone.

Type section locality: Lat. 19° 09′ 39″ S, long. 125° 34′ 24″ E, 1.5 km west of Spring Creek on the northern scarp of the Millyit Range.

Thickness: At least 52 m at the type section (Yeates and others, 1974), at least 22 m in the southern part of the Millyit Range, at least 75 m in Kirkby Range, and at least 70 m in BMR Crossland No. 1.

Age: Late Permian, based on brachiopods, pelecypods, and a microfloral assemblage.

Relationships: A conformable and gradational contact with the underlying Condren Sandstone; apparent conformity with the overlying Hicks Range Sandstone Member (new name).

Synonomy or modification of previous nomenclature: The member was previously recognized as part of the Hardman Formation.

HICKS RANGE SANDSTONE MEMBER

Derivation of name: Hicks Range, lat. 19° 14′ S, long. 125° 54′ E (Crossland Sheet area).

Distribution: Crops out in a narrow belt extending from Barbwire Range to Hicks Range (Crossland Sheet area).

Lithology: Quartzose sandstone, fine to coarse-grained, cross-bedded; minor quartz granule conglomerate.

Type section locality: The type section is a scarp in the central part of Hicks Range at lat. 19° 13′ 46″ S, long. 125° 53′ 42″ E.

Thickness: 27.9 m at the type section (Yeates and others, 1974), 14.8 m at Spring Creek in the Millyit Range, and at least 10 m in the Kirkby Range.

Age: Late Permian; based on marine faunas above and below the member.

Relationships: Rests with apparent conformity on the Kirkby Range Member (new name) and is conformable beneath the Cherrabun Member (new name).

Synonomy or modification of previous nomenclature: The member was previously recognized as part of the Hardman Formation.

CHERRABUN MEMBER

Derivation of Name: Cherrabun Homestead, lat. 18° 54′ 42″ S, long. 125° 31′ 24″ E (Noonkanbah Sheet area).

Distribution: Millyit Range, Jones Range, and Hicks Range (Crossland Sheet area).

Lithology: Fine-grained micaceous sandstone, fossiliferous sandstone, micaceous and ferruginous siltstone, and shale.

Type section locality: At the source of a tributary of Spring Creek at lat. 19° 11′ 00″ S, long. 125° 33′ 06″ E (Crossland Sheet area).

Thickness: At least 22.2 m at the type section (Yeates and others, 1974) at least 24.6 m in the Hicks Range.

Age: Late Permian based on brachiopods, pelecypods, and gastropods.

Fossils: Brachiopods, pelecypods, gastropods, trace fossils, and a microfloral assemblage.

Relationships: In the Crossland Sheet area the member is conformable on the Hicks Range Sandstone Member (new name) and is overlain with slight angular unconformity by the Lower Triassic Millyit Sandstone.

Synonomy or modification of previous nomenclature: The member was previously recognised as part of the Hardman Formation.

PROPOSED NAME: LAKE GREGORY BEDS

Derivation of name: Lake Gregory, lat. 20 ° 12′ S, long. 127″ 30′ E (Lucas and Cornish Sheet areas).

Distribution: Subcrops beneath eolian sand in the terminal reaches of Sturt Creek. A few exposures occur along the margin of Lake Gregory.

Lithology: Green, brown, and red clay, silt, and fine-grained sand, minor marl and calcrete and rare gravel.

Type section locality: The type section is in BMR Cornish No. 3, a continuously cored hole located at lat. 20° 11′ 05″ S, long. 127° 24′ 15″ E at Lera Yard (Cornish Sheet area).

Thickness: 99.1 m in BMR Cornish No. 3 (Yeates and others, 1974), 64.3 m in BMR Mount Bannerman No. 1.

Age: Cainozoic, based on regional relationships.

Fossils: Indeterminate gastropods; possible plant root casts; indeterminate fish bones.

Relationships: Unconformable on Permian formations; conformable beneath eolian sand.

VALIDITY OF THE TERM WOLF GRAVEL

The Wolf Gravel (Casey and Wells, 1964) was the name given to unconsolidated gravel, conglomerate, and sand of unknown thickness along the banks of Wolf Creek in the Billiluna Sheet area. It is recommended the term be discarded as these deposits are indistinguishable from other alluvial deposits of both Wolf Creek and Sturt Creek.

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SOME PROBABLE LOWER PROTEROZOIC SEDIMENTS IN THE MOUNT PADBURY AREA

by J. C. Barnett

ABSTRACT

A thick sequence of folded sediments on the northern edge of the Yilgarn Block is bounded by the Bangemall Basin to the north, of gneiss and schist, to the west; the gneiss and schist are probably related to the Gascoyne Province. The sediments are of low metamorphic grade and consist mainly of alternating hematite shale and banded iron formation (BIF); some of the BIF in the upper part of the sequence has clastic texture. The sequence includes a thick conglomerate section and there are dolomite beds in the upper part.

The succession is named the Padbury Group: it incorporates three formations, named in descending order the Millidie Creek, Robison Range and Labouchere Formations, and also includes the conformably underlying units, namely the Horseshoe Range and Peak Hill Beds, although these are not yet given formation status.

The boundaries of the Padbury Group are all either faulted or concealed, but the evidence indicates that the sediments are of Lower Proterozoic age; they are possibly contemporaneous with part of the Mount Bruce Supergroup.

INTRODUCTION

This paper discusses a sequence, delineated in the course of regional mapping, on the east side of the Robinson Range 1 : 250 000 Sheet. The area described is between latitudes 25° 05′ S and 25° 50′ S and longitudes 118° 00′ E and 118° 30′ E, about 750 km NNE of Perth, and 100 km north of Meekatharra.

The sequence was mapped on the adjoining Peak Hill 1 : 250 000 Sheet by MacLeod (1970a). The BIF on the Peak Hill and Robinson Range Sheets were subsequently investigated by Sofoulis (1970), and some carbonate intrusions within the sediments were examined by MacLeod (1970b), Lewis (1971) and Lewis and Williams (1971).

MacLeod (1970a) considered that the sequence was probably of Archaean age, but present evidence suggests that it is more likely to be Lower Proterozoic.

The purpose of this paper is to revise the stratigraphic nomenclature, to advocate a Lower Proterozoic age for the sequence, and to describe its lithology.

REGIONAL SETTING

The Padbury Group forms a sequence on the northern edge of the Yilgarn Block. It is unconformably overlain by the Bangemall Basin to the north, and to the west abuts a metamorphic complex of gneiss and schist which is probably related to the Gascoyne Province, a Lower Proterozoic mobile belt. The sequence is strongly deformed but lacks metamorphism; the arenaceous rocks are cleaved, and the finer-grained beds vary from shale to phyllite.

The gneiss and schist contain intrusions of granite and highly metamorphosed remnants of BIF and pelitic and psammitic sediments. The contact is probably faulted; there are air-photo lineaments along the contact and the foliation of the gneiss is discordant with the strike of the sediments. The contact therefore provides no conclusive stratigraphic evidence for the age of the Padbury Group.

It is noteworthy that the metamorphic complex appears to be related to the Gascoyne Province; this suggests that the Province extends farther east than is shown on the 1973 edition of the State Geological Map.

The sediments wrap around the southeastern margin of the gneiss. Between the sediments and gneiss in this area are mafic and ultramafic volcanics which are faulted against the gneiss. The boundary between the volcanics and the Padbury Group is concealed by superficial deposits.

On the north the boundary with the Bangemall Basin is a complex of established faults and probable faults shown by air-photo lineaments, although regionally this can be shown to be an unconformity (MacLeod, 1970a).

To the south the alluvial plain of the Murchison River covers the boundary with the Archaean Yilgarn Block.

Within the sediments in the southeast are a number of carbonate intrusions and a few easterly trending unmetamorphosed dolerite dykes. Laterite in the extreme southeast has a remnant texture suggestive of dolerite which was probably a large stock or sill.

The Padbury Group is folded and faulted. The major fold axes parallel the boundaries of the metamorphic complex, and swing in a broad arc around its convex southeastern margin. Minor folding on several scales is common, and dips are generally steep, vertical or slightly overturned. Faults, and probable faults indicated by air-photo lineaments, are common; the most common trends are north and east, parallel to the fold axes, and there is a subsidiary northwest trend. There is apparently a faulted slice of Labouchere Formation against the eastern margin of the metamorphic complex. Major folds, faults and air-photo lineaments are shown on Figure 31.

STRATIGRAPHY OF THE PADBURY GROUP

MacLeod (1970a) divided the succession into four units, named in ascending order the Peak Hill Beds, Horseshoe Range Beds, Labouchere Beds and Robinson Range Beds. This fourfold division is retained together with the addition of an upper, fifth, unit—the Millidie Creek Formation. The Labouchere and Robinson Range Beds are upgraded to formation status; the Horseshoe Range and Peak Hill Beds, which do not crop out well on the Robinson Range Sheet, are retained at this stage as "Beds".

The Padbury Group is defined as the sequence of BIF, hematitic shale, wacke, siltstone conglomerate and dolomite which occurs in the Mount Padubry (lat. 25° 38′ 30″ S, long. 118° 16′ 30″ E)—Robinson Range—Mount Fraser area, and consists of the Millidie Creek Formation (top), the Robinson Range Formation, the Labouchere Formation, and those units that conformably or disconformably underlie the Labouchere Formation. By implication this includes the Horseshoe Range Beds and the Peak Hill Beds. The Padubry Group is at least 12 500 m thick, and is probably Lower Proterozoic in age.

The sequence on the Robinson Range Sheet is summarized in Table 8.

PEAK HILL BEDS

These are not well exposed on the Robinson Range Sheet, and are not discussed further.

HORSESHOE RANGE BEDS

MacLeod reports that the Horseshoe Range Beds overlie the Peak Hill Beds. These beds crop out in the northeast part of the Robinson Range Sheet, where they consist of siltstone and phyllite with subsidiary BIF, minor wacke, and chert bands up to 150 mm thick. MacLeod (1970a) estimated a thickness of 1 000 m.

The BIF consists of laminated quartz and hematite, with silty and jasper bands. Laminations are 5-10 mm thick, and individual bands of BIF are generally 3-4 m thick. The siliceous

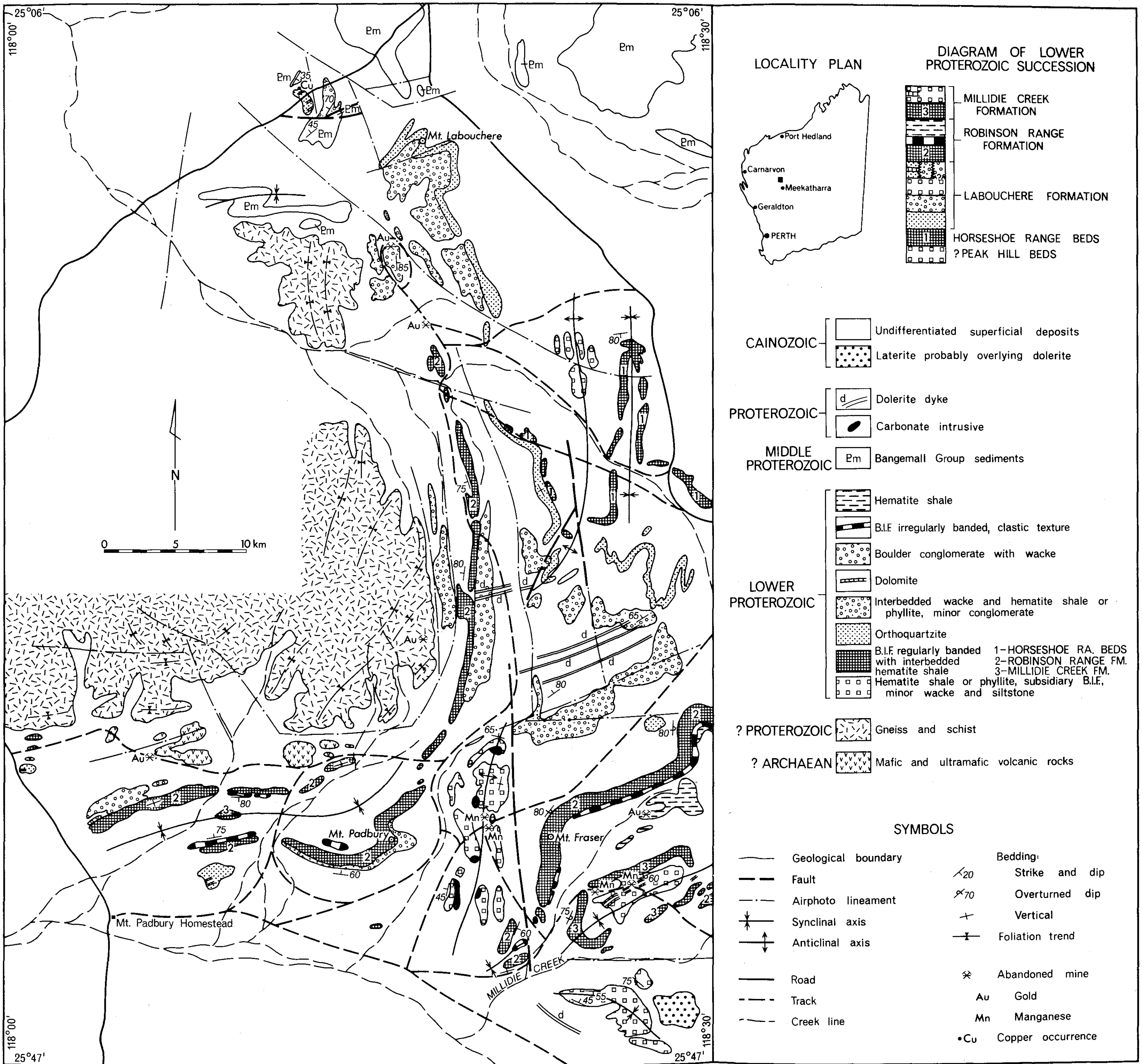

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Fig. 31. Geological map of the Mt Padbury area, Robinson Range sheet.

TABLE 8. PADBURY GROUP

MILLIDIE CREEK FORMATION	*Hematite shale* or *slate* with minor BIF, chert, and feldspathic wacke. Two thin bands of dolomite.
	BIF and *hematite shale*, interbanded. BIF has clastic texture.
ROBINSON RANGE FORMATION	*Hematite shale*, laminated.
	BIF, irregularly banded, clastic texture.
	Hematite shale, minor BIF increasing towards top.
	BIF and *hematite shale* interbedded.
	Hematite shale; laminated, BIF and chert bands towards top.
LABOUCHERE FORMATION	*Wacke, grit, conglomerate, shale, siltstone* and *chert*. Three thin dolomite beds in west. Large lenticular boulder conglomerate in places.
	TYPE AREA
	Feldspathic wacke and *hematite shale* or *phyllite*. Alternating bands; wacke predominants in lower part, hematite shale becomes predominant in top part.
	Orthoquartzite.
	SOUTHERN AREA
	Hematite shale with thin BIF horizons, minor wacke and siltstone.
HORSESHOE RANGE BEDS	*Siltstone, phyllite* and *BIF*, interbanded. Minor wacke.
PEAK HILL BEDS	*Hematite phyllite* with *BIF*. Not well exposed.

laminae are composed of a mosaic of polygonal grains about 0.1 m across, and the hematite laminae are of anhedral to wispy hematite intergrown with minor quartz. In some BIF layers the hematite is more evenly distributed, but lamination is still evident.

The phyllite is usually reddish-purple and hematitic, but more chloritic varieties are dark green. Wacke bands contain quartz and feldspar clasts and some flakes of shale; individual beds are 3-4 m thick. The BIF is manganese stained.

The top portion of the beds is a succession of wacke and siltstone.

LABOUCHERE FORMATION

The Labouchere Formation is defined as that formation of feldspathic wacke, hematitic shale, conglomerate and orthoquartzite which occurs at its type area 5 km south of Mount Labouchere (lat. 25° 11′ 45″ S, long. 118° 17′ 30″ E), and that conformably overlies the Horseshoe Range Beds and underlies the Robinson Range Formation. It is about 5 000 m in thickness.

The base of the formation on the Robinson Range Sheet is an orthoquartzite or silicified arenite, which weathers to a pinkish grey colour. This bed has a distinctive air-photo pattern, and is a useful marker horizon. It forms the prominent strike ridge which includes Mount Labouchere. It is poorly sorted, medium to coarse grained, with small pebbles in places. Feldspar and muscovite clasts are rare.

This orthoquartzite is overlain by a sequence of alternating wacke and phyllitic shale with rare bands of siltstone. The shale proportion is minor at the bottom, but increases through the sequence, to predominant at the top, and the wacke beds are progressively better sorted up the sequence. Minor microconglomerate beds occur, and a coarser conglomerate bed in the north of the area contains pebbles and cobbles of white quartz, purple quartzite and jasper.

The wacke is quartzo-feldspathic with minor muscovite. It is generally red-brown in colour and weathers to pale yellow. Individual beds are usually a few metres thick. Graded bedding and ripple marks are present.

In the southern part of the area, between Mount Fraser and Mount Padbury, and southeast of Mount Fraser, is a sequence of hematite shale with BIF layers, some arkose and wacke, and a little siltstone. The BIF layers are 1-2 m thick and are commonly coated with manganese. This southern sequence is probably a facies change. A less likely possibility is that it is a higher part of the succession, which in the north has been cut out by disconformity.

The top 1 000 metres of the formation is a lithologically variable sequence containing conglomerate. The top beds, in the central and western part of the area, are of thick lenticular boulder, cobble and pebble conglomerate with wacke and shale interbeds. The rudite clasts are well rounded, and are of white quartz and quartzite, with rare black, red and freen fuchsitic quartzite, and reddish sandstone. These clasts have been tectonically elongated and flattened, and are up to 60 cm long; the median size is about 5 cm. The matrix is composed of poorly sorted quartz, feldspar and muscovite sand.

Elswhere the top beds consist of conglomeratic orthoquartzite with pebbles and cobbles up to 8 cm long, interbedded with phyllite or shale, grey chert, and, in the west, three dolomite layers. Each of the dolomite layers is a few metres in thickness.

This is succeeded by interbedded feldspathic wacke, grit, conglomerate, siltstone and shale, each bed being from 0.5-3 m in thickness. The coarser beds are generally graded. Thin white chert beds occur towards the top.

ROBINSON RANGE FORMATION

The Robinson Range Formation is defined as that formation of BIF, hematite shale and chert which occurs at its type section along the range north and west of Mount Padbury. It conformably overlies the Labouchere Formation and conformably underlies the Millidie Creek Formation. It is about 3 500 m thick and is named after the Robinson Range, which runs easterly at about latitude 25° 40′ S, between longitudes 118° 00′ E and 119° 15′ E. The base of the formation is taken as the first appearance of hematite shale with BIF layers.

The basal unit is hematite shale, with bands of BIF up to 15 cm thick, and laminated and nodular chert. The BIF bands become increasingly common up the succession, which passes into interbedded shale and BIF. This main BIF section is shaley in the middle. The BIF is commonly enriched by supergene iron.

Of three samples of BIF examined in thin section, two were of hematite-chert BIF, and one of hematite-quartz BIF. The hematite-chert BIF contains regular bands of massive hematite alternating with chert bands, which include martite octahedra up to 3 mm across. The hematite-quartz BIF is composed of alternating bands, 3-5 mm thick, of fine hematite with martite octahedra, and bands 7-10 mm thick, of quartz grains up to 0.1 mm in diameter.

Above the main BIF section is hematite shale, with minor BIF layers towards the top, and then another BIF unit which is distinguished in the field by irregular and indistinct banding. This higher BIF unit is a quartz-magnetite-hematite rock containing scattered martite or magnetite octahedra, up to 0.3 mm across, with few regular bands of quartz or iron oxide. It may have formed in a higher energy environment than the more regularly banded BIF as it has clastic textures.

Above this horizon is laminated red hematite and green chlorite shale, which is the topmost unit of the formation.

MILLIDIE CREEK FORMATION

The Millidie Creek Formation is defined as that formation of BIF, hematitic shale, feldspathic wacke, chert and dolomite which occurs at its type section 5 km SE of Mount Fraser; it conformably overlies the Robinson Range Formation.

It is at least 1 500 m thick and is named after Millidie Creek, which drains the area south and east of Mount Fraser, and joins the Murchison River at lat. 25° 46′ 00″ S, long. 118° 19′ 00″ E.

The Millidie Creek Formation is the youngest known formation of the Padbury Group and is found in two synclinal cores in the south of the area.

The formation consists of a basal unit of BIF about 300 m thick, succeeded by a shale or slate unit with interbedded feldspathic wacke, BIF, dolomite and chert.

The basal BIF contains thin interbedded hematite shale layers, which become more common higher in the unit. In the lower part, the individual BIF layers have lenticular bands of jasper and white chert. The upper and more shaley section contains chert bands up to 10 cm thick.

The BIF consists of alternating fine-grained quartz-magnetite bands, and coarser clastic textured quartz-magnetite-hematite bands. In thin section one of these coarser bands was seen to contain a lens or nodule of quartzite, which consists of a mosaic of polygonal quartz grains, about 0.05 mm across, with trails of fine-grained iron oxide outlining rounded or irregular to angular shard-like shapes 0.5-1.0 mm across. This BIF has a clastic texture and some of the rounded shapes suggest an original oolitic texture, which was later fragmented. Crystal casts after pyrite occur on some bedding planes.

Above the basal BIF unit is a succession of manganese-stained slate and minor feldspathic wacke, containing two dolomite horizons less than one metre thick near the base. Thin BIF and rare chert horizons occur in the upper part.

The dolomites consist of dolomitic layers and laminae of manganese dioxide. The dolomitic layers are composed of brown dolomite rhombs, about 0.1 mm across, in a matrix of finer-grained quartz, sericite and chlorite.

ECONOMIC GEOLOGY

There are a few small abandoned gold mines in the area, mostly in the sediments within 3 km of the gneiss. They are in or near quartz reefs, and are associated with minor amounts of copper, and less commonly lead. The two largest mines are in a conglomeratic portion of the Labouchere Formation. A costean in the northwest of the area has exposed a quartz vein in dolomite of the Labouchere Formation; the vein contains bornite and malachite.

Manganese has been worked at several localities near Mount Fraser. The ore has formed by replacement in old drainage channels and at the base of scree slopes. Only erosonial remnants of originally more widespread superficial deposits are preserved. The source of the manganese was the nearby BIF and dolomite which are generally stained by manganese.

The BIFs of the Robinson Range Formation contain local concentrations of hematite and goethite, formed by supergene enrichment. No mining has been undertaken but Sofoulis (1970) indicates reserves of 36.6×10^6 tonnes of average grade, ranging from 45 to over 60 per cent iron, for the combined Robinson Range and Peak Hill areas. This estimate assumes an average ore depth of 15.2 m.

The conglomerate at the top of the Labouchere Formation is a potential host for placer gold or uranium, but there has been no reported exploration work on it.

DEPOSITIONAL ENVIRONMENT OF SEDIMENTS

With the exception of the Labouchere Formation the Padbury Group is largely composed of alternating hematite shale and BIF, with lesser amounts of wacke and siltstone. The general pattern is therefore an alternation of chemical and fine clastic sedimentation with occasional contributions of coarser sediment.

The iron in the BIF was originally magnetite so that it was deposited in a mildly oxidising environment. In the upper part of the sequence the BIF often has clastic texture, and one sample suggests a possible oolitic texture. This indicates a higher energy environment than for most chemical sediments. The fine lamination in the associated hematite shale may be non-glacial varves. A possible environment is a shallow marine basin; the chemical sediments and lack of coarser sediments may indicate that adjacent land masses were of low relief.

The Labouchere Formation is coarser grained than the rest of the Padbury Group. The sequence is alternating wacke and shale with conglomerate, common graded bedding, some current bedding and rare ripple marking; it might indicate deposition on the distal margin of a large delta. However, the very coarse conglomerate at the top of the formation suggests a short period of near-shore sedimentation.

AGE OF THE PADBURY GROUP

MacLeod (1970a) assigned these sediments to the Archaean, because of the gold mineralization, presence of BIF, and lithological and structural similarity to Yilgarn Block clastic-volcanic sequences. He mentioned the possibility of a Lower Proterozoic age, perhaps equivalent to the Mount Bruce Supergroup.

The author considers that the sediments are of Lower Proterozoic age, because the succession is more like the Lower Proterozoic sequences of the Hamersley Basin than the Archaean rocks of the Yilgarn Block. The gold and BIF is not diagnostic of Archaean assemblages.

The evidence for a Proterozoic rather than an Archaean age is as follows:

(1) Different structural style to the Archaean of the Yilgarn Block.

(2) Layers of dolomite in upper part of succession.

(3) Common presence of manganese in BIFs and dolomite.

(4) Low grade of metamorphism.

Between the Padbury Group and the metamorphic complex in the southwest are volcanic rocks in faulted contact with the gneiss. The volcanics are mostly metamorphosed mafic rocks with possible pillow structures, but include some altered high-magnesium basalts with quench textures; the high-magnesian basalt implies that the volcanics are more likely to be Archaean rather than Proterozoic. Unfortunately the relationship between the volcanics and the sediments of the Padbury Group is unknown.

The evidence therefore supports a Lower Proterozoic age for the Padbury Group: it is possibly equivalent to part of the Mount Bruce Supergroup in the Hamersley Basin. When mapping of the area across the northern margin of the Yilgarn Block is complete, the relation of the Padbury Group to other Precambrian lithostratigraphic units may be revealed with more clarity.

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THE APPLICATION OF ERTS IMAGERY TO GEOLOGICAL MAPPING IN THE KALGOORLIE AREA

by R. D. Gee and I. R. Williams

ABSTRACT

A comparison of ERTS imagery with both factual and interpretation geological maps of the Kalgoorlie and Kurnalpi 1:250 000 Sheets demonstrates that the greatest potential of the imagery lies in the recognition of faults and lineaments. Strike dislocations, recognizable on the imagery, correspond closely with major strike faults that have been postulated on hitherto negative evidence. Conspicuous imagery lineaments probably represent fracturing late in the crustal evolution. The broad disposition of greenstone belts and granite batholiths is recognizable, although granite is identified mainly by the overlying superficial Cainozoic sediments. The imagery provides a poor guide to lithology. In most cases the imagery strike trends in the greenstone belts relate to gross lithological layering, but in the more structurally isotropic rocks (e.g. metabasalt) dissection along joints gives spurious strike trends. No routine use of ERTS imagery can be envisaged for the systematic production of 1 : 250 000 geological sheets, however, it is a useful data source during the interpretative stage of regional geological studies.

INTRODUCTION

The Earth Resources Technology Satellite (ERTS) programme is an experimental multi-disciplinary study, sponsored by the United States National Aeronautics and Space Administration and the United States Geological Survey, to assess the management of earth resources by remote sensing from spacecraft. The Geological Survey of Western Australia joined the Australian appraisal effort through the Australian Committee for ERTS (ACERTS), and elected to study the "applicability of ERTS imagery to the problems of regional mapping and structural interpretation in poorly exposed Archaean greenstones and metasediments, intruded by granite batholiths and basic dykes". This paper is a modification of a type-III Report of that study, the abstract of which was forwarded via ACERTS to NASA in July, 1974.

The original proposal was to study the area of the main greenstone belt between Kalgoorlie and Norseman. However the lack of coverage in the vicinity of Kambalda, and the cloud covered imagery of the Norseman region required the selection of the Kurnalpi (SH/51-10) and Kalgoorlie (SH/51-9) 1 : 250 000 Sheets. This area is bounded by latitudes 30° S and 31° S, and longitudes 120° E and 123° E.

OBJECTIVES

The broad objective is to evaluate the use of ERTS imagery in the production and interpretation of 1 : 250 000 geological maps. This involves a comparison of the imagery with both "ground truths" and pre-ERTS interpretations. In this study, emphasis is given more to major geological features that relate to Archaean plutonism, vulcanism and crustal deformation, and less to late fracture patterns. Little emphasis is given to Cainozoic weathering sedimentation.

The objective outlined above should be considered in the light of the basic problem of regional geology in the Archaean Yilgarn Block of Western Australia, namely, the difficulty of establishing continuity between small and widely scattered outcrops in strongly lateritized areas.

The objectives that relate to the process of regional mapping present no special problems, because the primary purpose is to systematically document the position and nature of all areas of outcrop. This process should always require ground observation. A related problem involves the attempt to extract the maximum information from areas of laterite. The laterite in this area was an *in situ* blanket development that is now partially dissected and removed by erosion. Commonly vague relict structural patterns can be seen on the ERTS imagery. This investigation also considers whether the multi-spectral overview can "see through" the laterite.

However it is in the interpretive stage where the greatest problem lies. Realistic structural and stratigraphic reconstructions over distance of tens of kilometres are often difficult, and generally require the postulation of large dislocations or faults in areas that are inherently complex. Evidence for these faults is often apparent only after completion of 1 : 250 000 scale mapping or even after synthesis at a scale of 1 : 1 000 000. Mostly these structures have no obvious surface expression, and in many cases the evidence for their existence is based upon the postulate that best fits the data.

IMAGERY AND METHODS

The imagery used is identified by the numbers E-1109-9133 and E-1092-01190. Each ERTS frame covers an area of about 34 000 km^2, compared with about 16 000 km^2 for a 1 : 250 000 sheet. The imagery is not meridionally oriented because the satellite has a heading of 190°. For convenience the imagery analyses are presented here in the standard 1 : 250 000 meridional sheet format, which accounts for the gaps in the Figures 32A and 33A. Coverage is available for the gaps but it is not considered necessary to mosaic the prints for this presentation.

The imagery is available in four spectral bands, namely Multi-spectral Scan (MSS) 4 (0.5-0.6 micrometers, blue-green), MSS 5 (0.6-0.7μ, green-yellow), MSS 6 (0.7-0.8μ, visible red), MSS 7 (0.8-1.1μ, reflected solar infrared). In this study 70 mm negatives, at a scale of 1 : 3.369 million of MSS 4, 5, 6 and 7, were obtained and enlarged to 1 million scale. Preliminary work involved a comparison of the four spectral bands at a scale of 1 : 1 000 000 using annotated transparent overlays. Enlarged prints at a scale of 1 : 250 000 were then made of MSS 7. This enlarged scale provides more data without loss of resolution, enabling the imagery to be directly compared with published 1 : 250 000 maps. However for the purpose of presentation in this paper, the figures have been reduced to 1 : 1 000 000 scale.

The ERTS overlays are reproduced here by superimposed printing on the imagery (Figures 32A and 33A). Three morphological elements are presented on the ERTS overlays:

(1) Major boundaries between contrasting tonal patterns that are not obviously related to drainage features. These boundaries may represent lithological boundaries.

(2) Trends of structural or morphological elements. These may represent traces of planar or curvi-planar structural elements in the bedrock.

(3) Lineaments in excess of 5 km in length, of any morphological expression. These may represent faults, late fractures or master joints.

COMPARISON OF SPECTRAL BANDS

The MSS bands 4 and 5 are totally inadequate for bedrock geological studies. However it is notable that only MSS 4 gives a clear contrast between the Cainozoic sandplain marked by a scrub heath vegetation and the Quaternary alluvial and colluvial sands marked by eucalypt vegetation. In areas of undulating and partly dissected sandplain the Quaternary units mark the small drainage lines that lie on the sandplain unit. Therefore some possible ERTS application for the broader aspects of superficial geology, geomorphology and terrain evaluation are suggested.

Because of the strong reflection near the red end of the visible spectrum, MSS 7 and 6 give a tonal contrast between areas of outcrop (including laterite) and areas of no outcrop.

These two bands are of equal value in bedrock studies, however on MSS 7 the strongly lateritized areas show out more conspicuously as darker grey. Also the intricate dark grey tonal patterns on the surface of the salt lakes, which are well displayed on all spectral bands, are more conspicuous on MSS 7. Black areas, due to the greater reflection (i.e. less penetration) of the layer-wave length, indicate bodies of standing water. For example, the King of the West Lake is represented by the black spot displayed midway on the eastern margin of Figure 32A.

COMPARISON WITH GEOLOGICAL MAPS

Kalgoorlie (Kriewaldt, 1969) and Kurnalpi (Williams, 1970) sheets have been published and are not presented here. Both these are outcrop maps and can reliably be considered as "ground truth" at this scale.

GRANITIC AREAS

The major areas of tonal contrast reflect the gross disposition of the greenstone belts and major granite bodies. Two main tonal patterns are recognized. Firstly, isotropic areas of light grey colour generally represent areas underlain by granite; and secondly, structurally anisotropic areas of dark grey colour generally represent the intervening greenstone belts. Boundaries between the two types have considerable strike extent, and these are shown in Figures 32A and 33A.

However, in detail, the correlation is poor. Many substantial outcrops of granite lie outside the boundary inferred from the overlays. The peripheral portions of the granite masses are, in places, foliated lit-par-lit zones that appear as structurally anisotropic areas and therefore appear as part of the succession. The discrepancy between the ERTS-indicated granite contact and the observed outcrop is particularly evident in the Bulyairdie Dome (Fig. 33B). Usually discrepancies are of the order of 5 km. It is noteworthy that some well-exposed mafic sequences occur within areas of ERTS-indicated granite. Some examples are the greenstone belts at Yangan Hill (location 1, Fig. 33A) and Carr Boyd Mine (location 2, Fig. 33A).

The ERTS imagery does not appear to have provided information on the internal structure of the granite batholiths. Rechecking of imagery in areas of well-exposed granite fail to show any indication of structure. In fact these large areas of outcrop cannot even be distinguished from Cainozoic sand. Very diffuse imagery patterns in the Bulyairdie Dome (location 3, Fig. 33A), having forms remarkably similar to flow-fold geometry, are seen to merge with known lithological traces in the layered sequence around the margin of the dome. Yet these internal traces cannot be matched with any known internal structure, and in fact, occur on large areas of Cainozoic sand. They are the expression of sinuous vegetation patterns that reflect arcuate drainage lines on Quaternary alluvium which is reworked from the older sandplain deposits. Field observations cleary show they are unrelated to bedrock geology.

Similar patterns are apparent in an area of granite on the southern extension of the Bulyardie Anticline (location 4, Fig. 33A). This feature resembles the product of giant-scale strain-slip cleavage, although it is expressed on the ground as arcuate drainage patterns. The area of granite itself is confined by two linear structures that are discussed later. There is no evidence to relate this imagery pattern to bedrock structures.

A distinct imagery pattern is visible in the western part of the granite mass at Lake Owen (location 5, Fig. 32A). Three sets of dark traces seem to indicate remnants of mafic-volcanic rocks within the granite body. Ground inspection has shown these traces are due to sheets of transported ironstone gravel originally derived from the lateritized mafic rocks immediately to the west. These traces probably mark an old sheetwash surface which has now been partly dissected by linear creeks. Although the possibility that mafic-volcanic rocks underlie these traces cannot be discounted, the best evidence is that the underlying rock is granite.

A number of light grey, tonally isotropic, areas on the imagery are not granite. Ground examination demonstrates that they are discrete areas of felsic-volcanic or sedimentary rock within the greenstone sequence. For example the area 3 km east of Kanowna (location 6, Fig. 33A), is a mass of felsic agglomerate and that at Gordons (location 7, Fig. 33A) is an intrusive porphyritic rock. The large area in the Randalls-Mount Belches area (location 8, Fig. 33A) is underlain by greywacke and shale.

Within the greenstone belts at least five small (2-5 km diameter) well exposed granitic plutons, whose presence has been established by ground mapping, are not recognizable on the imagery. These examples include Credo and Mungari on the Kalgoorlie Sheet and Cowarna, Cardunia and Juglah Rocks on the Kurnalpi Sheet. However the outline of one body of granite on the northern extension of the Kunnunalling Anticline has been defined more precisely from the ERTS imagery.

GREENSTONE BELTS

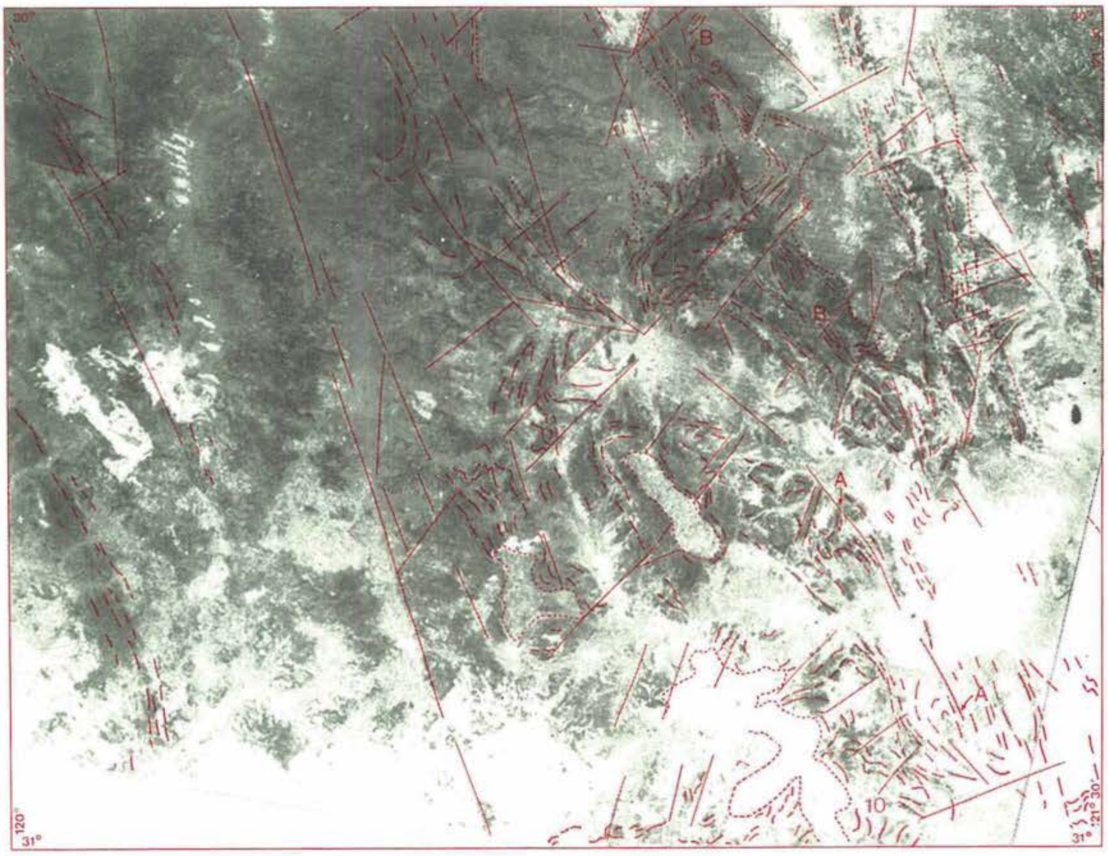
Most imagery trends in the greenstone belts can be related to known geological features. However the individual lithological components, such as conglomerate layers in arenaceous sequences, gabbro sills in metabasalts and interlayering of sediments and volcanics, cannot be distinguished. In fact it is not possible to confidently distinguish between mafic-volcanic, felsic-volcanic and sedimentary rocks. The only possibility of correlation lies in the fact that the mafic-volcanic areas are darker, and are enhanced by the presence of scattered laterite caps.

Structurally anisotropic patterns occur over areas of ferruginous laterite from which no previous structural grain had been recognized. Herein lies a potential use for the imagery. The imagery appears to pick out morphological trends of laterite, having lengths of about 2 km. These trends in many cases correspond with the major structural grain. However in one area of basalt north of the Bulong Anticline (location 9, Fig. 33A), imagery trends are consistently perpendicular to arcuate layering which is defined by gabbro sills recognizable on the ground. This feature may be due to dissection of the laterite along joints, and consequently casts doubts on the general usefulness of using the imagery to determine primary structural trends within the greenstone belts.

The suite of ENE-trending mafic dykes that are clearly represented on aeromagnetic maps and commonly seen in outcrop (Figs. 32B and 33B) are not recognizable on the imagery of this area.

COMPARISON WITH PREVIOUS INTERPRETATION

The pre-ERTS interpretation of Kurnalpi (Fig. 33B) is a modification of one previously published (Williams, 1970), whereas the interpretation for Kalgoorlie (Fig. 32B) is new.

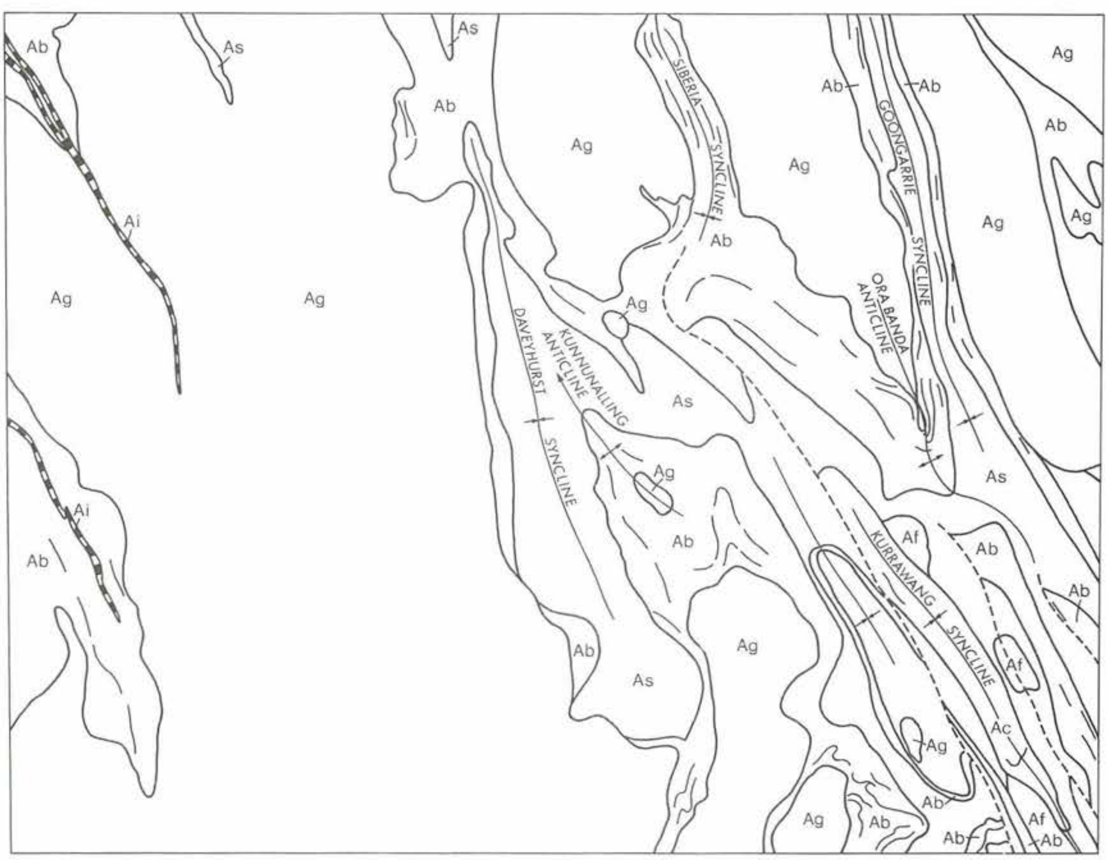


A

······ Boundary between major tonal patterns
– – – – Trends in outcrop areas
——— Imagery lineament
Letters refer to dislocation structures ; numerals refer to location cited in text

0 10 20 30 40 km

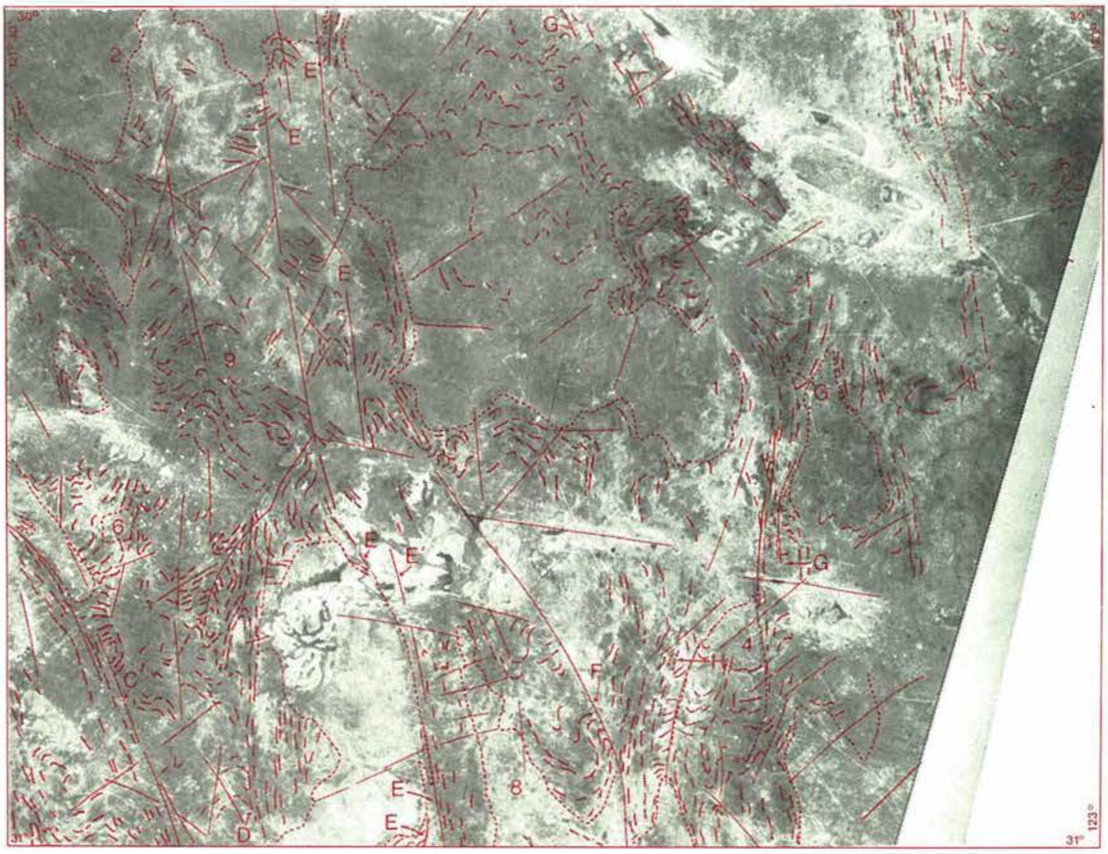
ERTS image of Kalgoorlie Sheet area, at a scale of 1:1 000 000.



B Ag Archaean granitic rocks ; Ab Mafic rocks ; As Sediments ; Ac Conglomerate ; Af Felsic volcanics ;
Ai B.I.F. ; ---- Postulated strike fault ; ++ Fold traces ; —— Lithological trend ;

Pre-ERTS interpretation of Kalgoorlie Sheet.

Figure 32.



A

········ Boundary between major tonal patterns
– – – – Trends in outcrop areas
——— Imagery lineament
Letters refer to dislocation structure ; numerals refer to locations cited in text

0 0 20 30 40 km

ERTS image of Kurnalpi Sheet area, at a scale of 1:1 000 000.

B

Ag Archaean granitic rocks ; Ab Mafic rocks ; As Sediments ; Ac Conglomerate ;
Af Felsic volcanics ; Ai B.I.F. ; ---- Postulated strike fault ; ++ Fold traces ;
— Lithological trend ; o—o Proterozoic mafic dyke

Pre-ERTS interpretation of Kurnalpi Sheet.

Figure 33.

On interpretation maps, it is convenient to represent the Archaean succession by four main units. These are:

(1) A mafic and ultramafic association.

(2) Discrete complexes of felsic volcanic rock.

(3) Fine or medium-grained argillaceous volcanogenic sedimentary rock.

(4) Arenaceous and conglomeratic clastic rock.

Unit 3 occurs peripherally to Unit 2. Unit 1 is thought to form thick sequences that are persistent for long distances along strike. Multi-layering of the mafic-felsic volcanic cycle has previously been demonstrated in the Kalgoorlie region (Williams, 1970). Unit 4 occurs mainly at stratigraphically high levels. Current concepts involve large ovate composite granitic batholiths that intrude the Archaean succession. The interbatholithic areas are in general crumpled synclinal belts.

STRIKE DISLOCATIONS

On the ERTS imagery these features are recognized as the loci of structural discordance that extend for distances of the order of tens of kilometres. They are *not* the most conspicuous features of the imagery and are best revealed once the overlays are made.

They may, or may not, be enhanced by an imagery lineament. Nine strike dislocations are shown on the overlays (labelled A and B on Fig. 32A and C to I on Fig. 33A) and there is evidence for several more. The correlation of these dislocations with previously inferred strike faults is good; several extensions to suspected structures are made, and some new structures are evident. The term "strike fault" is used for a fault that trends parallel with the gross regional strike of the sequence. Strike-slip movement is not implied. Some previously postulated strike faults are shown in Figures 32B and 33B.

Structure A. This structure, which is enhanced by a lineament, relates precisely to a postulated strike fault that lies immediately west of the Kurrawang Syncline. It is manifest on the interpretation map (Fig. 32B) as a line of lithological and structural miss-match, and is known to extend at least 40 km to the south into the Spargoville area. Its northwesterly extension is uncertain, however it may splay into two faults, one into the Siberia Syncline and the other into the Davyhurst Syncline.

Structure B. The nature and significance of this structure is uncertain. In the northern part of the Kalgoorlie sheet it corresponds with the western margin of the major granite body, and has been pointed out previously, the strike discordance may well be related to superficial ferruginous material. However this line of discordance persists to the south-southeast along the western margin of the Ora Banda Anticline and appears to pass to the east of the Kurrawang Syncline, where it can be related to another postulated strike fault.

Structure C. This is the locus of a marked strike discordance that separates northwesterly striking trends to the southwest, from a complex, but generally northerly striking terrain, to the northeast. It nearly fits a line of discordance that Williams (1970) has interpreted as an unconformity. The correlation is not precise and the ERTS-indicated locus disagrees with some ground observations. In view of the possible spurious nature of some of the ERTS trends, this correlation could be considered as significant and supports the interpretation of an unconformity.

Structure D. This corresponds precisely with the Mount Monger Fault which has been recognized in the field as a locus strike discordance, shearing and quartz veining.

Structure E. This structure, which actually consists of two closely adjacent lines of discordance (E and E′), lies immediately to the east of the Bulong Anticline. A major structure has been suspected in this area because it lies between the Bulong and the Belches Anticlines. There is no known syncline separating these two anticlines and a major structural problem exists here.

It is possible that this structure marks a completely faulted out syncline. Structure E can be followed to the northern boundary of Kurnalpi sheet and in fact the aeromagnetic coverage indicates that it extends for hundreds of kilometres to the north and joins with the Keith-Kilkenny Lineament. The Keith-Kilkenny Lineament is very conspicuous on aeromagnetic maps of the Eastern Goldfields and has been shown to be one of the most important tectonic structures of the area (Williams, 1974).

Structure F. This structure appears to dislocate the eastern limb of the Yindalgooda Syncline and does not coincide with any previously recognized strike fault. The imagery gives no indication of its northerly extension. If it continues on the north-northwesterly trend it may merge with Structure E′, as shown on the ERTS overlay. However this would conflict with the position of the trace of the Yindalgooda Syncline which is established from facing evidence in the metabasalts. Alternatively, it could swing to the northeast and join with structures G, H, and I. Known lithological trends support this latter alternative.

The significance of structure F remains uncertain, however it appears to be related to a major system of splay faults that merges into the Keith-Kilkenny Lineament.

Structure G. This relates closely to the southeasterly continuation of the Keith-Kilkenny Lineament. On the geological map (Fig. 33B) it follows closely the Yilgangi Syncline and has a considerable strike extent. To the south it appears to swing from a southeasterly to a southerly direction and becomes involved in a possible splay fault system incorporating structures H and I.

FOLDS

The arcute traces correspond in most cases to previously interpreted folds. The arc around the Ora Banda Anticline between the Siberia and Goongarrie Synclines and the Kurrawang Syncline (Fig. 32A) is clearly depicted on the imagery. Smaller areas of more local crumpling are also recognizable e.g. at Mount Burges (location 10, Fig. 32A). However it has been pointed out that spurious fold patterns can result in areas of lateritized mafic rock due to dissection along cross fractures rather than the bedding. As a qualitative estimate, approximately 60 per cent of the apparent fold traces have geological validity. The balance is either clearly spurious or enigmatic and cannot be resolved with the present data.

In this category is the form of the Yindalgooda Syncline. On the ERTS imagery the Yindalgooda Syncline appears to be a half structure whose eastern limb is completely faulted out by the dislocation F (Fig. 33A).

On the ERTS imagery it apperas that the mafic rocks in the Yindalgooda Syncline are linked over the Belches Anticline to the mafic belt to the west. This reconstruction, however, conflicts with the ground observations because the inferred connecting "mafic rocks" are actually lateritized sedimentary rocks.

IMAGERY LINEAMENTS

Lineaments form two main sets. The most prominent is northeasterly trending, which is roughly perpendicular to the north-northwesterly trending structural grain of the greenstone belts. The second is a set of north-northwesterly trending lineaments that in places enhance known major structural dislocations. Apart from a secondary relationship (for example, following joints that may in some way relate to folds or faults) the lineaments do not appear to show any relationship to the processes of crustal deformation. They appear to be late fractures that are related to master joint patterns or faults. The most conspicuous lineament is that north-northwest trending structure that extends continuously from the southern to the northern edge in the western part of the Kalgoorlie sheet area (Fig. 32A). It lies entirely within granite and has no obvious relationship to bedrock structure.

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DISCUSSION AND CONCLUSIONS

The main attributes of ERTS imagery are:

(1) They are small-scale

(2) They approximate closely to orthophotos

(3) The imagery is multispectral

(4) They present repetitive coverage under constant sun angle and constant image processing.

Factors 1 and 4 enable very large tracts of the earth's surface to be viewed under constant conditions, without the patchwork quilt effect of conventional mosaics. Factor 2 enables imagery to be compared directly with geological maps. However, it should be pointed out that at smaller scales, involving larger areas, projection problems will arise. Factor 3 in itself is not of any advantage for the type of application envisaged here, although it has been noted that certain bands have their individual uses. It is acknowledged here that no attempt has been made to adequately assess the value of the multi-spectral factor by using colour composites. It is concluded that the greatest value of ERTS lies in the overview that the satellite coverage allows.

The most significant contribution lies in demonstrating large strike faults. These structures have previously been postulated, mainly on negative evidence, and only in a few cases has their presence been established. Strike trends which serve to outline these faults are more perceptible on MSS 6 and 7, than on the other two bands. In the context of regional fault and lineament analysis the ERTS data are more useful than conventional photomosaics, especially at the continental scale. In this respect it would be an extra tool of the regional geologist that would complement, rather than replace, photogeology and other forms of remote sensing such as aeromagnetics. The imagery gives only a broad guide to first-order block distribution and at the reconnaissance stage has little to recommend it over the more conventional methods employing areal photomosaics and aeromagnetic maps. No routine day to day use of ERTS imagery can be envisaged at this stage.

These conclusions are intended to apply only to the Kalgoorlie test area; however they do accord with other ACERTS investigations, and other studies, reported in the Weekly Abstracts of the National Technical Information Service of the U.S. Department of Commerce. Examination of other parts of the State indicates a varying potential use for ERTS imagery. For example, in the forested and cultivated areas of the southwestern portion of the Yilgarn Block, no lithological and very little structural information is extractable, whereas in the Pilbara Block the patterns of post-granite mafic dykes, and the shape of the granite domes with their delicately scalloped edges is depicted with superior clarity on the imagery than on small-scale mosaics.

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DEFINITIONS OF NEW AND REVISED STRATIGRAPHIC UNITS OF THE EASTERN PILBARA REGION

by S. L. Lipple

ABSTRACT

New and revised stratigraphic units of the eastern Pilbara region, Western Australia, are formally defined. They are the Archaean Warrawoona Group (mainly a volcanic sequence), its two principal divisions the Talga Talga and Salgash Subgroups, and its formations (Duffer Formation, Marble Bar Chert, Kelly, Panorama and Wyman Formations), the Boobina Porphyry, and the Gorge Creek Group (dominantly a sedimentary sequence) the Soansville Subgroup, and five of the Group's formations (Corboy and Paddy Market Formations, Honeyeater Basalt, Budjan Creek Formation and Lalla Rookh Sandstone); the Lower Proterozoic Tumbiana Formation (Fortescue Group) and two members (Mingah Tuff and Meentheena Carbonate) and the Lower Proterozoic Spinaway Porphyry.

INTRODUCTION

This report describes and formally defines new and revised stratigraphic units in the Archaean and Lower Proterozoic rocks of the eastern Pilbara region, made necessary as a result of regional mapping of the Marble Bar 1 : 250 000 Sheet area. Descriptions of the regional geology, including that of various Archaean granitic plutons named during mapping, but omitted from this report, are given by Hickman and Lipple (1974, see particularly Fig. 3). Although initially defined for the Marble Bar 1 : 250 000 Sheet area, the units are applicable to the eastern Pilbara region generally. Additional stratigraphic and plutonic units occurring only in the Nullagine 1 : 250 000 Sheet area are described by Hickman (in prep.).

Discussion of earlier Archaean stratigraphic nomenclature in the Pilbara region is given by Ryan (1964, 1965). Development of the stratigraphic subdivision of the Pilbara region may be seen by comparison of the earliest scheme presented by Maitland (1908, frontispiece), the subdivision of Noldart and Wyatt (1962, 1 : 500 000 geological structure map of the Pilbara region), and that of this report.

The Archaean layered succession is divided into a lower, dominantly volcanic suite, the Warrawoona Group and an Upper (locally unconformable), mainly clastic sedimentary suite, the Gorge Creek Group. The constituent subdivisions, together with some previous stratigraphic schemes, are given in Table 9. For convenience, an intrusive metamorphosed Archaean porphyry, the Boobina Porphyry, is described with the Warrawoona Group.

TABLE 9. GENERALIZED STRATIGRAPHY OF THE ARCHAEAN LAYERED SUCCESSION

Group	Subgroup	Formation	Maximum Thickness (km)	Lithology
Gorge Creek Group		1 Lalla Rookh Sandstone ? 2 Budjan Creek Formation ? 3 Mosquito Creek Formation*	2–3	1 and 2. Sandstone and conglomerate
			5–10	3. Mainly turbidities, generally schistose, local conglomerate and sandstone near the base
		Honeyeater Basalt	0–1	Pillow Basalt
	Soanesville Subgroup	Paddy Market Formation	1	Banded Iron Formation and ferruginous clastic sedimentary rocks
		Charteris Basalt*	0–1	Pillow Basalt
		Corboy Formation	1–2	Quartzite, sandstone and psammopelitic sedimentary rocks
V	V			
Warrawoona Group	Salgash Subgroup	Wyman Formation	1	Porphyritic, columnar-jointed rhyolite
		V— V — —	2–3	Pillow basalt and chert
		Panorama Formation ⁝ Kelly Formation	1	Dacitic lava tuff and agglomerate and chert with local sandstone and conglomerate
		— — —	3–5	Pillow basalt and chert
		Marble Bar Chert	0·1	Banded Chert
		— — —	0–0·3	Pillow Basalt
		Duffer Formation	5–8	Dacitic agglomerate
	Talga Talga Subgroup	— — —	5–8	Basalt with subordinate ultramafic and chert units

Former Stratigraphic Divisions

Range indicators (arrows spanning the table):

- Pilbara System (Noldart and Wyatt, 1962) (Ryan, 1964, 1965 included granitic rocks also) — whole succession
- Roebourne Group (Ryan, 1964, 1965) — whole succession
- Mosquito Creek Beds (Maitland 1905) — formations 1–3 (Lalla Rookh Sandstone, Budjan Creek Formation, Mosquito Creek Formation)
- Warrawoona Beds (Maitland, 1905, 1908) — Honeyeater Basalt to base
- Cleaverville Formation (Ryan, 1964, 1965) — Honeyeater Basalt to Corboy Formation
- Regal Formation (Ryan, 1964, 1965): — Wyman Formation to base

Gorge Creek Formation of Low (1965) = Lalla Rookh Sandstone and Paddy Market Formation (jaspilites)

Series (Maitland, 1908 ; David, 1950, p. 4 ; Finucane, 1953 ; Ryan, 1964). ' Series ' (Low, 1965) System (Fairbridge, 1953, Chap. I, p. 33, Ryan, 1964)

Succession/succession (Noldart and Wyatt, 1962, p. 14, 47, 100–101, 105–107 ; Ryan, 1964–1965)—Middle Creek Formation ; Eastern Creek Formation = Gorge Creek Formation (Low, 1965, Ryan, 1964, 1965) = Dromedary conglomerate ; Budjan Creek Formation.

Cleaverville Formation of Ryan (1964, 1965) = jaspilite unit (Paddy Market Formation) in Gorge Creek Formation of Low (1965).

Warrawoona Beds (Maitland, 1908—see frontispiece for best illustration of his stratigraphic divisions) ' Series ' (Maitland, 1908 ; Finucane, 1953) ' Series ' (Low, 1965) System (Fairbridge, 1953, Chap. I, p. 33) Succession/succession (Noldart and Wyatt, 1962 ; Ryan, 1964, 1965)

*** Not present in Marble Bar Sheet area.** — — — unnamed units —V—V— unconformity ⁝ **relationship uncertain**

Partly overlying the Warrawoona Group, with a moderate angular unconformity, is the Mosquito Creek Formation which at present is considered to be part of the Gorge Creek Group.

Within the Lower Proterozoic Fortescue Group, the Tumbiana Formation and two members are formally defined. An intrusive Lower Proterozoic porphyry, the Spinaway Porphyry, is described with the other Fortescue Group units because it occurs at a particular stratigraphic level in the group.

ARCHAEAN LAYERED SUCCESSION

A summary of the Archaean stratigraphic units is given in Table 9.

The Charteris Basalt and Mosquito Creek Formation are included in Table 9 for completeness, but are not defined here as they are restricted to the Nullagine Sheet area, and will be described by Hickman (in prep.).

It will be noted that the Talga Talga Subgroup is not divided into formations. Although units of formational status are present in the type area, more work is required to determine whether these can be extrapolated to other parts of the region.

For convenience cosanguinous igneous rocks, within the volcanic piles, are included as part of the units in which they occur.

WARRAWOONA GROUP

Derivation of name: Warrawoona mining centre (latitude South—S, longitude East—E), (21° 20′ 05″ S, 119° 54′ 25″ E), 1 : 250 000 Marble Bar Sheet area.

Definition: The Warrawoona Group consists of the Talga Talga Subgroup; Duffer Formation; Salgash Subgroup includes Marble Bar Chert, Kelly and Panorama Formation; and the Wyman Formation (youngest).

Lithology: It consists mainly of volcanic rocks with subordinate ultramafic rocks, chert and clastic sedimentary rocks.

Thickness: Range, 5-20 km.

Stratigraphic relations: Lower margin intruded by, or faulted against, Archaean granitic rocks. Overlain both conformably and unconformably by the Gorge Creek Group.

Age: Archaean, as intruded by Archaean granitic rocks (dated in the Mooyella area by de Laeter and Blockley (1972) at 3 125 ± 366 m.y.). Felsic porphyry, from Copper Hills mine, dated by de Laeter and Trendall (1970) at 2 880 ± 66 m.y.

Synonymy: The term, Warrawoona Group, supercedes "Warrawoona Succession" of Noldart and Wyatt (1962, p. 14, 47, 100-101, 107-117) and "Warrawoona Beds" of Maitland (1908, p. 155, 156, 161, 162, 284, 286, 287) and "Warrawoona Series" of Maitland (1908, p. 156), Finucane (1953), and Ryan (1964, 1965).

Talga Talga Subgroup

Derivation of name: Talga Talga mining centre (21° 0′ 10″ S, 119° 48′ 15″ E), Marble Bar 1 : 250 000 Sheet area.

Type area: Near Talga Talga mining centre, from the granite contact westwards through the mining centre almost to the Coongan River.

Lithology: In the type area, the Talga Talga Subgroup consists of a lower pillow basalt sequence containing some stratiform and some lensoid ultramafic units, overlain by a thin sequence of intercalated basalt, siltstone and chert. The chert is overlain by a stratiform, ?vesicular brecciated ultramafic layer, then a thick monotonous sequence of pillow basalt with minor thin chert horizons. The basalt may be quite vesicular, even scoriaceous. The upper margin is marked locally by a thin siltstone. Elsewhere the subgroup consists essentially of pillow basalt with associated minor felsic volcanic, ultramafic and sedimentary rocks.

Thickness: Maximum, 5-8 km.

Stratigraphic relations: The Talga Talga Subgroup is the lowest exposed portion of the Warrawoona Group. It is intruded by Archaean granitic rocks along the lower margins and conformably overlain by lavas and pyroclastic rocks of the Duffer Formation.

Duffer Formation

Derivation of name: Duffer Creek (21° 7′ 20″ S, 119° 45′ 35″ E) Marble Bar 1 : 250 000 Sheet area.

Type area: The area north of Marble Bar townsite, extending westwards from the lower reaches of the Duffer Creek, across the Coongan River to the base of the ranges west of the river. The formation is well exposed around Marble Bar townsite and along the banks of the Coongan River.

Lithology: A volcanic pile of predominantly dacite lava, tuff and agglomerate. Pyroclastic rocks are a feature of this formation. Dacite lava is massive to schistose and may be vesicular or porphyritic. Intercalations of pillow basalt, tuff and agglomerate are also present, particularly in the northern portion of the Marble Bar Belt, and some sedimentary rocks are common throughout the sequence. Minor porphyritic intrusions also occur. Thin cherts are present in the upper part of the succession.

Thickness: Maximum, 5-8 km.

Stratigraphic relations: The Duffer Formation conformably overlies pillow basalt of the Talga Talga Subgroup and conformably underlies the pillow basalt and cherts of the Salgash Subgroup. The Marble Bar Chert or Chinaman Pool chert locally form the stratigraphic unit overlying the Duffer Formation.

Synonymy: Noldart and Wyatt (1962, p. 88-89) refer without definition to a series of feldspar porphyry dykes as the "Duffer's Creek Porphyry". They mapped the steeply-dipping Archaean volcanic rocks to the north of the Coongan River—Duffer Creek junction as Proterozoic porphyry flows, suggested that the dykes were feeders, and implied that the flows were also part of the Duffer Creek Porphyry. The porhpyry dykes were noted by Maitland (1908, p. 7, 19 and 205) as intruding Archaean basalt but were not named by him. He described the area west of the Coongan River as agglomerate, not porphyry as shown by Noldart and Wyatt (1962). The nature of rocks on the adjacent Port Hedland 1 : 250 000 Sheet (Low, 1965, p. 10), also mapped as Proterozoic porphyry, is uncertain. These may actually be partly an extension of the Archaean volcanic rocks in the Marble Bar Sheet area, herein defined as belonging to the Duffer Formation, or, more probably, are equivalent to the Lower Proterozoic Bamboo Creek Porphyry exposed on the Nullagine 1 : 250 000 Sheet (Noldart and Wyatt, 1962; and Hickman, in prep.). De la Hunty (1963, p. 26-27, 32; and 1964, p. 13) also used the name for rocks on the Balfour Downs 1 : 250 000 Sheet area.

As the name "Duffer" was previously used without adequate description or definition, it is reapplied to the suite of Archaean volcanic rocks which dominate the area that Noldart and Wyatt incorrectly show as Proterozoic porphyry, and which they imply is the main outcrop area of the "Duffer Creek Porphyry".

Hickman and Lipple (1974) have shown that the rocks in the Copper Hills area referred to, but not strictly defined, by Noldart and Wyatt (1962, p. 108, 192-193, Plate V) as "Copper Hills Porphyry", are actually Archaean felsic rocks of the Duffer Formation.

Salgash Subgroup

Derivation of name: Salgash mining centre (21° 16′ 45″ S, 119° 47′ 35″ E), Marble Bar 1 : 250 000 Sheet area.

Definition: The Salgash Subgroup consists of the Marble Bar Chert, the Chinaman Pool chert (an informal name), the Panorama and Kelly Formations (lithostratigraphically equivalent) and other unassigned volcanic rocks.

Type area: The type area is between Camel Creek and Salgash. The subgroup is also well exposed along Chinaman Creek, west of Marble Bar and in the North Pole Dome, southwest of North Pole.

Lithology: The unit consists of approximately 2 km of lower basalt lavas, commonly pillowed with intercalated chert horizons; 1 km of dacite lava tuff and agglomerate with local sedimentary rocks (Panorama Formation and Kelly Formation); and about 0.5-1 km of upper basalt lavas, commonly pillowed with intercalated chert horizons; and minor felsic volcanic and ultramafic units.

Thickness: The unit has variable thickness, between 1-8 km, due partly to variation in original depositional thickness, and partly to tectonic thinning.

Stratigraphic relations: The subgroup conformably overlies the Duffer Formation and underlies the Wyman Formation. The upper margin is locally unconformable, as in the Kelly Belt. A distinctive association of closely spaced, thick chert units, including the Marble Bar Chert and Chinaman Pool chert within the pillow basalt, occurs at the base of the subgroup. This association has been recognised from the Pilgangoora Syncline to McPhee Dome.

Marble Bar Chert

Derivation of name: The Marble Bar (21° 8′ 50″ S, 119° 42′ 40″ E), Marble Bar 1 : 250 000 Sheet area. This is the popular name given to the chert where it crops out in the Coongan River, and from which the adjacent pool and nearby township derive their names.

Type area: The Marble Bar, in the Coongan River, 5 km southwest of the Marble Bar township.

Lithology: The Marble Bar Chert is a colourful red and white banded chert exhibiting local hydroplastic brecciation with injection veins of massive dark grey chert. The chert is illustrated by Maitland (1908, Figs. 45-48) and Noldart and Wyatt (1962, p. 108-109).

Thickness: 100 m.

Stratigraphic relations: The unit occurs conformably within the Salgash Subgroup at, or near, the contact with the underlying Duffer Formation.

Synonymy: The same unit was referred to by Noldart and Wyatt (1962, p. 114-116) as the Marble Bar Jaspillite. It was also described by Maitland (1908, p. 19, 204).

Panorama Formation

Derivation of name: Panorama Ridge, which is a prominent ridge extending about 22 km west from 21° 15′ 10″ S, 119° 30′ 10″ E to 21° 16′ 0″ S, 119° 17′ 30″ E, Marble Bar 1 : 250 000 Sheet area.

Type area: Panorama ridge, in the area 6 km northeast from North Shaw mining centre.

Lithology: Dacite lava, tuff and agglomerate are dominant in the western portion. The lava is generally massive but may be vesicular or porphyritic. Minor sedimentary rocks including shale, sandstone and conglomerate, are intercalated within the volcanic sequence. Banded cherts including red and white, grey and white, black and white, and green varieties are prominent. In the eastern portion of the formation, sandstone, grit and conglomerate become dominant. The conglomerate contains abundant clasts of chert, dacite, vein quartz and rare basalt. Current stratification is common in the sandstone and grit units.

Thickness: Maximum 1 km.

Stratigraphic relations: The Panorama Formation is a lenticular volcanic-sedimentary rock sequence occurring conformably within unassigned pillow basalt of the Salgash Subgroup. The volcanic and sedimentary rocks exhibit an interfingering contemporary facies relationship with some contribution from the volcanic pile to the adjacent sedimentary deposits. A similar felsic volcanic-conglomerate unit in the North Shaw Belt is correlated with the Panorama Formation. The Panorama and the Kelly Formations are equivalent.

Kelly Formation

Derivation of name: Kelly copper mine (21° 47′ 30″ S, 119° 52′05″ E), Marble Bar 1 : 250 000 Sheet area.

Type area: Three km southwest of Kelly copper mine.

Lithology: The Kelly Formation consists of porphyritic and vesicular dacite lavas, tuff and agglomerate with some porphyritic dacite sills and minor chert horizons. Some of the dacite lavas exhibit columnar jointing.

Thickness: Maximum 1 km.

Stratigraphic relations: The Kelly Formation is a felsic volcanic pile interfingering with the conformably surrounding unassigned pillow basalts of the Salgash Subgroup. It is equivalent to the Panorama Formation, and is overlain unconformably by the Wyman Formation

Wyman Formation

Derivation of name: Wymans Well (21° 17′ 45″ S, 119° 47′ 05″ E), Marble Bar 1 : 250 000 Sheet area.

Type area: The type area is along Camel Creek, south of Wymans Well where the Formation occurs in rugged orange coloured hills, and near Fieldings Gully. The unit is also well exposed in the upper reaches of Budjan Creek.

Lithology: The formation typically consists of massive to schistose, flow banded, porphyritic rhyolite, locally with notable columnar jointing. It also contains felsic tuff and agglomerate and minor basalt lava and agglomerate in the Soanesville Belt. The columnar jointing is well illustrated by photographs in Noldart and Wyatt (1962, p. 108-109).

Thickness: Maximum, about 1 km.

Stratigraphic relations: Conformably overlies the Salgash Subgroup in the Warrawoona Syncline.

Unconformably overlies the Salgash Subgroup in the Kelly Belt and is there unconformably overlain by the Budjan Creek Formation. It is unconformably overlain by the Soanesville Subgroup in the Soanesville Belt.

Synonymy: Rocks of this unit in the Wymans Well and Upper Budjan Creek areas were described by Noldart and Wyatt (1962, p. 108-109, 192 and Fig. 43, 44) as belonging to the "Copper Hills Porphyry".

Boobina Porphyry

Derivation of name: Boobina Creek (21° 41′ 35″ S, 119° 56′ 55″ E), Marble Bar 1 : 250 000 Sheet area.

Type area: The Boobina Porphyry and its relationships with surrounding rocks may be readily observed along the Corunna Downs road 2-3 km Northwest from Copper Hills. It is also well exposed along the road between Copper Hills and Kelly, near 21° 41′ 35″ S, 119° 56′ 55″ E.

Lithology: A weakly metamorphosed dacite porphyry with a dark grey-green, purple or black aphanitic groundmass. Euhedral to subhedral phenocrysts constitute about sixty percent of the rock and are principally plagioclase (An_{30}) and quartz with lesser amounts of biotite. Plagioclase laths often form glomeroporphyritic groups. The larger phenocrysts are the more altered. In the area south of Kelly, instead of biotite, the porphyry contains altered hornblende. The colourless matrix of the rock is too fine for microscopic identification, but is probably a quartzo-feldspathic aggregate. The texture is consistent with devitrification of glass or metamorphic recrystallization of an extremely fine groundmass.

Rock relationships: The Boobina Porphyry intrudes the Talga Talga Subgroup and Duffer and Kelly Formations. It is intruded by the probably late Archaean Mondana Adamellite which contains abundant xenoliths of the porphyry. The porphyry exhibits a low grade regional metamorphism similar to adjacent Archaean layered succession. In the Kelly area the porphyry is intruded by several white, fine-grained, quartz-feldspar porphyry dykes. The unit is faulted against the Duffer Formation and some faults and shears within the porphyry are quartz-filled and contain copper mineralization.

Structure: The two masses cropping out northwest and southwest of Copper Hills may be connected in depth.

Synonymy: The "coarse-grained feldspar porphyry . . . to fine-grained black feldspar porphyry" of Noldart and Wyatt (1962, p. 193 and Plate V), corresponds to the mass herein defined as the Boobina Porphyry.

The material dated at 2 880 ± 66 m.y., by de Laeter and Trendall, 1970, as Copper Hills Porphyry, in thin section closely resembles the Boobina Porphyry.

GORGE CREEK GROUP

Derivation of name: Gorge Creek (20° 51′ 25″ S, 119° 30′ 55″ E) which crosses the Great Northern Highway, about 1 km west of Farrell Well, Port Hedland 1 : 250 000 Sheet area.

Definition: The Gorge Creek Group consists of the Soanesville Subgroup (Corboy Formation, Charteris Basalt and Paddy Market Formations), Honeyeater Basalt, the coequivalent Lalla Rookh Sandstone and Budjan Creek Formation and the Mosquito Creek Formation.

Lithology: It consists mainly of sandstone, grit, conglomerate, argillaceous sedimentary rock, banded iron formation and minor basalt.

Thickness: Maximum, 5-8 km.

Stratigraphic Relations: Conformably (locally unconformably) overlies and folded with the Warrawoona Group. Relationships with the Warrawoona Group often obscured by regional slides. Unconformably overlain by the Lower Proterozoic Fortescue Group. Intruded by Archaean granitic rocks.

Synonymy: The term, Gorge Creek Group, supersedes "Gorge Creek Formation" of Low (1965, p. 8), Kriewaldt and Ryan (1967, Table 2), Noldart and Wyatt (1962, p. 105-106), and Ryan (1964 and 1965).

Soanesville Subgroup

Derivation of name: Soanesville mining centre (21° 31′ 50″ S, 119° 10′ 55″ E), Marble Bar 1 : 250 000 Sheet area.

Definition: The Soanesville Subgroup consists of the Paddy Market Formation (youngest) and the Corboy Formation, and unassigned sedimentary and volcanic rocks in the Soanesville Belt. Southwest of Yandicoogina mining centre, basaltic volcanic rocks (Charteris Basalt) occur between the Paddy Market Formation and the Corboy Formation.

Lithology: The subgroup includes sandstone, siltstone, ferruginous shale, banded iron formation and pillow basalt. Ultramafic and gabbroic sills intrude the formation.

Thickness: Maximum, 5-8 km.

Stratigraphic relations: Conformably overlain by Honeyeater Basalt, and both conformably and unconformably overlies the Wyman Formation, Salgash Subgroup and Talga Talga Subgroup.

In the Soanesville Belt unassigned rocks of the subgroup are unconformably overlain by a thin, flatlying sequence of felsic lavas, centred on 21° 22′ 53″ S, 119° 07′ 20″ E, which have not been assigned to any named unit. The connection of the unassigned Soanesville Subgroup sedimentary rocks with the Corboy Formation, farther north, is obscured by structural complexity and further study is required to elucidate its nature.

Corboy Formation

Derivation of name: Corboy mining centre (21° 44′ 30″ S, 119° 39′ 25″ E), Marble Bar 1 : 250 000 Sheet area.

Type area: Around the Corboy mining centre in the Coongan Syncline.

Lithology: The unit consists mostly of quartzite, sandstone and psammopelitic sedimentary rocks. There are minor felsic volcanics and ultramafic rocks in the southern portion of the formation, and basalt, usually pillowed, in the northern portion.

Thickness: 1-2 km.

Stratigraphic relations: The relationships of the Corboy Formation to the surrounding units is in many places obscured by regional slides. It conformably overlies the Wyman Formation and conformably underlies the Paddy Market Formation.

Paddy Market Formation

Derivation of name: Paddy Market Creek (21° 22′ 55″ S, 119° 15′ 15″ E), Marble Bar 1 : 250 000 Sheet area.

Type area: The unit is well exposed in a gorge cut by Paddy Market Creek through a prominent ridge at 21° 22′ 55″ S, 119° 15′ 15″ E. It is also well exposed east of Split Rock homestead and north of Honeyeater Creek (21° 13′ 30″ S, 119° 14′ 50″ E). Ferruginous shale is prominent in the area north of Honeyeater Creek.

Lithology: Banded iron formation, shale and ferruginous sandstone and siltstone.

Thickness: Maximum, about 1 km.

Stratigraphic relations: Conformably underlies the Honeyeater Basalt and conformably overlies the Corboy Formation.

Synonymy: The Cleaverville Formation of Ryan (1964, 1965) is equivalent to jaspilites of the Gorge Creek Formation of Low (1965) and these are synonymous with the Paddy Market Formation.

Honeyeater Basalt

Derivation of name: Honeyeater Creek (which crosses the unit at 21° 14′ 00″ S, 119° 15′ 55″ E) Marble Bar 1 : 250 000 Sheet area.

Type area: Adjacent to Honeyeater Creek.

Lithology: The Honeyeater Basalt consists of a monetonous sequence of variolitic, amydaloidal and pillowed basalt.

Thickness: 0.5 km.

Stratigraphic relations: Conformably overlies the sedimentary rocks of the Soanesville Syncline and the Paddy Market Formation in the Lalla Rookh Syncline. Conformably overlain by the Lalla Rookh Sandstone.

Lalla Rookh Sandstone

Derivation of name: Lalla Rookh mining centre (21° 03′ 10″ S, 119° 16′ 35″ E), Marble Bar 1 : 250 000 Sheet area.

Type area: In the Lalla Rookh Syncline, southeastwards from near the Lalla Rookh mining centre.

Lithology: Sandstone and conglomerate, usually well bedded and locally showing cross-stratification and ripple marks.

Thickness: Maximum 2-3 km.

Stratigraphic relations: The Lalla Rookh Sandstone conformably overlies the Honeyeater Basalt. Some local unconformities with the other Warrawoona Group are notable. Equivalent to the Budjan Creek Formation.

Budjan Creek Formation

Derivation of name: Budjan Creek (21° 50′ 30″ S, 119° 52′ 05″ E), Marble Bar 1 : 250 000 Sheet area.

Type area: The unit is well exposed in gorges cut by the upper reaches of Budjan Creek.

Lithology: The basal conglomerate, containing chert, vein quartz and dacite clasts, is overlain by shale, siltstone and sandstone units and capped by a thick conglomerate containing angular chert clasts.

Thickness: Exposed thickness is between 1-1.5 km.

Stratigraphic relations: Unconformably overlies Wyman Formation and Salgash Subgroup. Upper margin partly concealed by unconformable cover of Lower Proterozoic Fortescue Group, and partly faulted against divisions of the Warrawoona Group. Equivalent to Lalla Rookh Sandstone.

References: Noldart and Wyatt (1962), Kriewaldt (1964), Low (1965), Ryan (1964, 1965, 1966), Ryan and Kriewaldt, (1964).

LOWER PROTEROZOIC FORTESCUE GROUP

Tumbiana Formation

Derivation of name: Tumbiana Pool in the Nullagine River (21° 14′ 30″ S, 120° 29′ 20″ E), Nullagine 1 : 250 000 Sheet area.

Type area: From Pelican Pool (21° 20′ 25″ S, 120° 21′ 25″ E) to 3 km northeast on the Nullagine River.

Lithology: Upper carbonate member lower tuff member.

Thickness: At Meentheena, about 200 m. In Marble Bar Sheet area about 50 m.

Stratigraphic relations: Part of Lower Proterozoic Fortescue Group. Conformably overlies Kylena Basalt. Conformably overlain by Nymerina Basalt. Subdivided into Meentheena Carbonate Member and Mingah Tuff Member.

Synonymy: Original name, "Tumbiana Pisolite" (Noldart and Wyatt, 1962, p. 80).

Mingah Tuff Member

Derivation of name: Mingah Well, Meentheena Station (21° 18′ 30″ S, 120° 25′ 05″ E), Nullagine 1 : 250 000 Sheet area.

Type area: Pelican Pool (21° 20′ 25″ S, 120° 21′ 25″ E) on the Nullagine River.

Lithology: Basaltic to intermediate tuff. Minor siltstone, mudstone and basalt. Has characteristic pisolitic texture in places, and ripple marks locally. Thin carbonate overlain by basalt (30 m thick) occur near the middle of the sequence.

Thickness: 150 m at Pelican Pool.

Stratigraphic relations: Underlies Meentheena Carbonate Member, conformable overlies Kylena Basalt.

Structure: Sheet-like.

Meentheena Carbonate Member

Derivation of name: Meentheena homestead (21° 18′ 23″ S, 120° 26′ 03″E), Nullagine 1 : 250 000 Sheet area.

Type area: 3 km northeast of Pelican Pool (21° 20′ 25″ S, 120° 21′ 25″ E).

Lithology: Ripple-bedded dark grey siliceous carbonate rocks, containing algal stromatolites and syndepositional slump structures.

Thickness: 20 m.

Stratigraphic relations: Underlies Nymerina Basalt, overlies Mingah Tuff Member.

Structure: Sheet-like (Krynine's classification, 1948). Member extends from the Gregory Range into the Pyramid 1 : 250 000 Sheet area.

Spinaway Porphyry

Derivation of name: Spinaway Well, Nullagine 1 : 250 000 Sheet area (21° 36′ 45″ S, 120° 3′ 20″ E).

Type area: The Spinaway Porphyry is well exposed 18 km south of Spinaway Well near the Great Northern Highway.

Lithology: It is a coarse-grained plagioclase quartz dacite porphyry with abundant euhedral calcic oligoclase phenocrysts and quartz phenocrysts set in a dark blue-black quartzo-feldspathic groundmass. Opaque minerals, secondary sphene and numerous small apatite crystals are associated with chlorite pseudomorphing original pyroxene. There are pleochroic haloes due to ?allanite and zircon. Secondary sericite, calcite and epidote are common. Further description of the Spinaway Porphyry is given by Hickman (in prep.).

Stratigraphic relations: Intrusive sill into the Hardey Sandstone of the Fortescue Group.

Age: Lower Proterozoic, as preliminary geochronological studies indicate an age of 2 124 ± 195 m.y. (Trendall, 1975).

Synonymy: Correlated with the Bamboo Creek Porphyry by Noldart and Wyatt (1962, p. 89).

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LIME RESOURCES OF THE COASTAL LIMESTONE BETWEEN LANCELIN AND MANDURAH

by J. L. Baxter

ABSTRACT

Limestone for industry in the Perth metropolitan area is obtained from quarries in the Coastal Limestone at Spearwood, Coogee, Fremantle and Wanneroo. The resources of high quality limestone (containing more than 75 per cent $CaCO_3$) in the Lancelin-Mandurah area are estimated to be about five hundred million tonnes. Most of this material is within 5 km of the coast and contained on land which is considered prime for urban development. To protect the limestone resources for future industrial purposes steps should be taken immediately to rationalize land development and utilization of the limestone bearing country in the vicinity of the metropolitan area.

INTRODUCTION

The limestone resources in the vicinity of the Perth metropolitan area were first reviewed by the Geological Survey of Western Australia during 1951 and 1952 (McMath, 1952). The present survey was undertaken to assess the current resources of limestone and provide data to assist in planning development in the vicinity of the metropolitan area.

It is apparent that limestone between Wanneroo and Fremantle is effectively sterilized, as most limestone ridges here are subdivided for urban development, and consequently high grade limestone deposits, such as those at Reabold Hill and Mosman Park, are excluded from this survey. This report is a summary of the results presented by Baxter and Rexilius (1974).

GEOLOGY

Coastal limestone is exposed in ridges parallel to the coast and up to 5 km inland. The exposures form reefs and wave cut benches in several places along the coast, e.g. Yanchep, Lancelin, Singleton.

The Coastal Limestone ranges in composition from a calcareous sandstone to a limestone with a quartz component of 1 or 2 per cent, to more than 50 per cent. Variation in composition occurs, both locally and regionally, throughout the unit. The MgO content of limestone in all areas decreases from about 2 per cent along the coast to about 0.5 per cent on the inland margin.

The Coastal Limestone is essentially a series of dunes, but locally beach ridges, lacustrine deposits and reef facies occur. For example reef facies limestone is exposed at Peppermint Grove, Trigg and Cottesloe, while 1 km east of Singleton a cocquina, thought to be a beach deposit, has formed.

The petrography of the Coastal Limestone has been reviewed by Baxter and Rexilius (1974). The calcareous fraction of the unit contains foraminifers and rotaliids with fragments of calcareous algae, echinoids and molluscs, while the terrigenous fraction consists almost entirely of well rounded quartz sand grains with minor feldspar and very rare heavy minerals. Typical chemical analyses of the higher grade areas of limestone are given in Table 10.

LIMESTONE RESOURCES

Five zones of high-grade limestone (greater than 75 per cent $CaCO_3$) outlined by the survey are shown in Figure 34. They are north of Mandurah, between Coogee and Spearwood, west of Lake Pinjar, northwest of Yanchep and south of Ledge Point. The high-grade material is a skeletal grainstone which is usually white, chalky, fine to medium grained and moderately to slightly coherent.

TABLE 10. CHEMICAL ANALYSES OF COASTAL LIMESTONE FROM QUARRIES BETWEEN MANDURAH AND LANCELIN.

Locality	Manduarh	Coogee-Spearwood Thomson Lake	Lake Pinjar		Yanchep Smokebush Hill	Ledge Point		Breton Bay
						Coast	Inland	
G.S.W.A. No.	41320	41197	41107	41176	41113	41159	41160	41152
SiO_2	14·4	7·23	13·1	13·6	8·08	31·0	15·0	9·85
CaO	45·3	49·9	46·8	46·6	49·4	35·0	45·8	49·2
$\equiv CaCO_3$	*80·0*	*89·0*	*83·5*	*83·2*	*88·2*	*62·5*	*81·7*	*87·8*
MgO	0·65	0·75	0·56	0·72	0·67	2·00	0·58	0·56
$\equiv MgCO_3$	*1·36*	*1·57*	*1·17*	*1·51*	*1·40*	*4·18*	*1·21*	*1·17*
Fe_2O_3	0·14	0·18	0·20	0·16	0·14	0·11	0·21	0·07
FeO	0·06	<0·05	<0·05	<0·05	<0·05	0·12	<0·05	0·10
Al_2O_3	0·81	0·53	0·79	0·62	0·48	0·21	0·73	0·12
TiO_2	0·05	0·02	<0·01	0·02	0·03	0·07	0·02	0·07
P_2O_5	0·07	0·08	0·07	0·06	0·07	0·08	0·06	0·05
MnO	<0·005	<0·005	<0·005	<0·005	<0·005	<0·005	<0·005	<0·005
Na_2O	0·10	0·11	0·08	0·11	0·06	0·16	0·15	0·08
K_2O	0·51	0·36	0·39	0·30	0·28	0·23	0·54	0·12
S	0·018	0·045	0·015	0·011	0·009	0·089	0·016	0·017
H_2O^+	1·12	1·05	0·99	0·88	1·05	1·57	0·84	1·14
Total	99·4	100·2	100·3	100·5	99·8	100·3	100·5	100·6

Trace elements (ppm)

Cr_2O_3	20	10	10	15	15	15	15	15
V_2O_5	<10	<10	<10	<10	<10	<10	<10	<10

Analyst: Government Chemical Laboratories.
Note: Analyses percentage on dry basis
$\equiv$ equivalent to

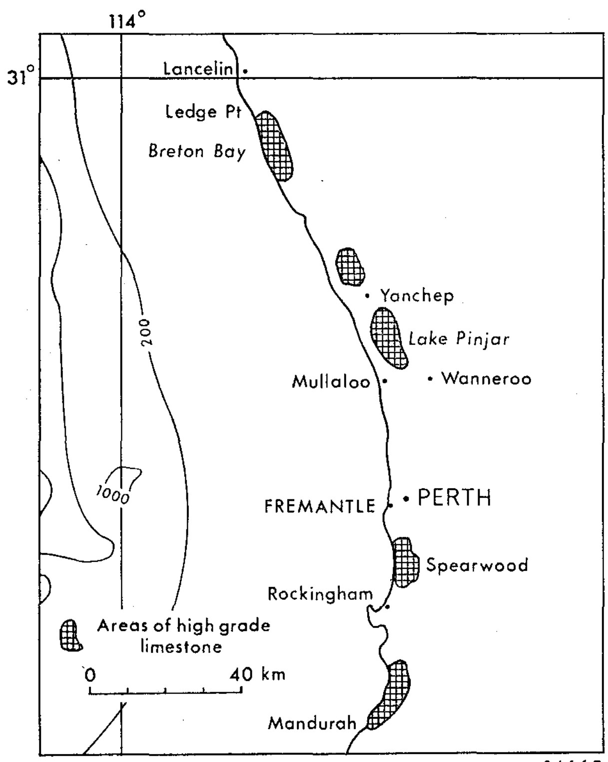

Figure 34. High grade limestone in the vicinity of the Perth metropolitan area.

The deposit north of Mandurah is essentially untested. The limestone occurs east of beach resorts along the coast and contains several zones with greater than 80 per cent $CaCO_3$.

Limestone quarries in the Coogee-Spearwood area have been established for some time, and currently provide most of the lime utilized in the metropolitan area. Large areas are held under various agreements by Swan Portland Cement Ltd and Cockburn Cement Ltd, but smaller areas of high grade limestone are being mined by contractors and government departments for road construction.

West of Lake Pinjar limestone reserves, established by the two portland cement manufacturers, are being held by them to supply their future needs. Several operators are mining in the area to supply lime burning and road construction needs. Most of the limestone here contains more than 80 per cent $CaCO_3$ and less than 1 per cent MgO.

Northwest of Yanchep, adjacent to the Yanchep National Park and within State Forest No. 65, an area of high grade limestone assaying in excess of 85 per cent $CaCO_3$ has been sampled. Isolated areas of this deposit have been quarried to provide material for road construction. This area contains the largest unsecured resources of limestone in the metropolitan area and, if protected, will ensure continued supplies of limestone for industrial purposes for some time.

South of Ledge Point an ill-defined zone of limestone, some of which assays more than 80 per cent $CaCO_3$, has been sampled. The grades of surface exposure vary over short distances and drilling will be required to assess the full potential of this zone.

The inferred resources of these five areas, assuming a mineable depth of ten metres in high-grade limestone, is five hundred million tonnes.

In planning future development of metropolitan Perth the distribution of these important resources should be taken into account and appropriate provision made for their application in the best interests of the community (Baxter and Rexilius, 1974).

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THE MOUNT SEABROOK TALC DEPOSIT

by S. L. Lipple

ABSTRACT

Near Mount Seabrook a white talc deposit, containing 6.8×10^6 t indicated reserves, occurs as a lens within Precambrian metasedimentary schists. The talc was formed at the locus of intense deformation by metamorphism of sandy dolomite. The talc and nearby dolomite have very similar major oxide and trace element compositions. Westside Mines N.L. established a mine in 1972 and total production to the end of 1974 was 14 100 t of lump talc.

INTRODUCTION

The Mount Seabrook talc deposit is located at Trillbar Station, 174 km by road northwest from Meekatharra, lat 25° 36′ 00″ S and long 117° 43′ 17″ E (Fig. 35). The talc was first noted in 1965 by prospector Mr. M. Lalor in the company of an Aboriginal. Mr. Arthur Doust pegged M.C. 190P over the deposit in May, 1969. Adjacent claims were pegged in June, 1969, by Lalor Prospectors Syndicate who later purchased M.C. 190P and carried out geological mapping of the deposit. By May, 1971, Westside Mines N.L., a small public Western Australian company had acquired the whole deposit.

Exploration was concentrated on the northern part of the deposit and included costeaning, diamond and percussion drilling, and shaft-sinking. Following various technical assessments of the talc and market studies, a pilot plant was installed in June, 1972. In August, 1973, a commercial treatment plant was brought into production. By December 1974, 14 000 t of talc had been produced. Of this, 5 062 t were sold realising about $200 000 f.o.b. value.

The mapping on which this report is based was conducted during five days in May, 1974, using 1969, 1 : 40 000 scale air-photographs.

Brief descriptions of the talc deposit were published by Mining Journal (1972, 1973).

REGIONAL GEOLOGY

The Mount Seabrook talc deposit lies near the boundary between the Archaean Yilgarn Block and the Gascoyne Province of Proterozoic metamorphism. The area was mapped by Johnson (1950).

The area about the mine is underlain by metasedimentary rocks with minor gabbro and ultramafic intrusions, metamorphosed generally to greenschist facies, but grading into schists and gneisses. This sequence is probably a continuation of Archaean volcanic and sedimentary rocks, respectively at Mount Maitland (trending northerly) and Mount Taylor-Mount Gould (trending northeasterly), in the adjacent Yilgarn Block. Alternatively, they could be relics of Proterozoic rocks (Pre-Bangemall Group) within gneisses and migmatites of the Gascoyne Province.

In the vicinity of Mount Seabrook (Fig. 35), the metasedimentary rocks strike east-northeast and dip steeply. Evidence provided by a conglomerate, locally truncating and incorporating BIF, suggests that the sequence faces northwards in the vicinity of the mine.

The local base of the succession is a medium-grained granitic gneiss of uncertain origin. This grades northwards through schistose rocks into a sequence which is composed mainly of sandstone, grit and conglomerate, but also includes a useful marker horizon of BIF that makes up the spine of the prominent ridge called Mount Seabrook.

Above these predominantly clastic rocks the sequence contains a large dolomite lens. This is poorly exposed, except near Three Corners Well, and obscured by calcrete and transported soil. The dolomite may be locally unconformable over sandstones 1 km west of the talc mine. The rock is grey, fine grained, poorly bedded, and well crystallized. It consists of interlocking polygonal dolomite, minor quartz and chlorite, all of which are strongly oriented, and traces of intergranular talc. Problematic concentric structures in dolomite north of the talc mine have a poorly defined banding resembling stromatolites, but are probably of liesegang origin. The larger dolomite lens appears to wedge out to the east and to grade into clastic sediments to the west.

Several medium-grained massive to schistose gabbro bodies which intrude the metasedimentary sequence (Fig. 35) have had their igneous texture and mineralogy almost completely destroyed. Some of the gabbro masses are intensely sheared to form dark green mafic schists. Decreasing grain size and increasing feldspar content suggests southward facing of a gabbro sill north of Livingstones. Some ultramafic intrusions occur 2 km west of Four Corner Well.

STRUCTURE AND METAMORPHISM

The metasedimentary rocks are steeply dipping with local overturning. The structural interpretation is shown on Figure 35. The broad symmetry of the sequence, together with scant facing evidence suggest that a synclinal fold trace extends east southwards through the Livingstones Find area, bisecting the dolomite and continuing eastwards through sandstones between Bullock Well and Winga Well. Isoclinal folding probably occurs within the gneisses and schists southwest of Mount Seabrook and in the Four Corner Well-Thomson NE Well area. Mesoscopic folding within individual beds is common throughout the metasedimentary sequence.

Metamorphic grade and degree of schistosity, or gneissosity, diminish from the northern and southern areas towards the central dolomite unit, with concomitant increase in preservation of primary mineralogy and textures, although all rocks exhibit some degree of schistosity and cleavage. Metamorphic assemblages observed, variously including biotite, muscovite, chlorite, albite, talc, chloritoid, tourmaline and dolomite, are all consistent with greenschist or lower greenschist facies metamorphism (Turner, 1968, p. 268-270).

Near Mount Seabrook the metasedimentary rocks are moderately to intensely schistose with the development of talc schist in the mine area.

MINE GEOLOGY

The geology of the mine area, together with the positions of the quarry and the various mine buildings, are shown in the inset to Figure 35.

Near the talc mine the rocks consist of metamorphosed sandstone (local current structures), quartzite, pebble conglomerate, quartz-muscovite (biotite-chlorite) schist, and some psammopelitic schist. Schists exhibit vertical lineation along bedding or schistosity planes. A contorted (steeply plunging chevron folds) schist, containing quartz, green muscovite, and magnetite has a distinctive aerial-photo pattern south of the mine. It may represent a fault or northward-thrust zone extending east-northeast from the truncated end of the Mount Seabrook BIF. The schist passes westwards along strike into well laminated sandstone with green muscovite, and grit.

The talc body is a lens of contorted, steeply dipping, white to light green schist with abundant iron and manganese oxide stained fracture partings. The surface talc weathers to an orange or creamy colour. Small quartz pods and grains are present throughout. In thin section the rock is massive, to weakly foliated, fine-grained (a.g.d. 0.05 mm) talc, with minor rounded or anhedral quartz and tiny (0.02 mm) accessory ?apatite. Veinlets of fine opal, probably formed by wheatering, discolour some talc. Rounded strained quartz, with relatively coarse (0.3 mm) talc wrapped around the grains, form an ocellar texture. Talc has partially replaced the quartz. It is difficult to determine petrographically whether the rounded grains represent original detritial quartz, or whether they have undergone perhaps several phases fo recrystallization accompanied by talc replacement. Discontinuous shear zones of very fine talc are deflected around quartz grains. These zones are partly embayed by coarse talc. Minor subhedral quartz bipyramids (0.2 mm) and plagioclase crystals are also embayed by talc. Fresh talc schist, exposed within the quarry, exhibits a light green vanadate staining along fracture and schistosity planes.

The talc has a lenticular interfingering relationship with surrounding quartzose sediments (Fig. 35, inset). Bands and lenses of sandstone are enclosed by talc, particularly near the margins of the ore body, and individual horizons can be traced from schistose sandstone or quartz-muscovite schist via talcose quartz-muscovite schist into talc schist over short distances.

The relationships between the talc schist and enclosing metasedimentary rocks and schists is further complicated by local folding, possible caused by faulting. Near the mine the strike is markedly discordant to the regional strike (as shown by the Mount Seabrook BIF), but changes direction rapidly along strike towards the northwest and merges north of Mount Seabrook with the regional strike (Fig. 35).

The sequence around the mine is locally obscured by 1-2 m of consolidated scree and colluvium. The talc schist, in particular, is covered by colluvium and by minor development of siliceous breccia capping.

The talc quarry is located on the northern part of the talc schist, excavated into a north-sloping ridge with three production benches each about 4 m high and 5-10 m wide. South of the quarry a quartz band projects into the talc lens and will affect quarry extensions. The quarry is rectilinear in design with surface dimensions of 55 m by 65 m. The floor is about 10 m below the north rim.

ORIGIN OF THE TALC SCHIST

The talc schists were produced by greenschist facies metamorphism of sandy dolomite intercalated with enclosing siliceous metasidementary rocks. Turner (1968, p. 131-151 and p. 282-286) discusses greenschist facies metamorphism of carbonate rocks in detail.

The original sediment at Mount Seabrook probably contained 40 per cent silica if none was added from outside the system. Hydrous metamorphism resulted in the formation of talc at low to moderate temperatures since further recrystallization of talc to actinolite or diopside did not occur. Quartz, in excess of that required to form talc, has recrystallized as lenses and granules of coarse quartz throughout the talc schist. Some siliceous metasedimentary bands are preserved within the talc schist. The margins are transitional and contain sandstone and quartz-muscovite schist which presumably reflect decrease in original carbonate content.

Chemical analyses of several talc schist samples (29627A-D) from Mount Seabrook quarry, dolomite (29626B) from 1.6 km west of the quarry, and a sample of Three Springs talc (29643) are listed in Table 11. The Mount Seabrook talc samples show little variation and their average corresponds closely with the analysis of Three Springs talc, which is derived from the metamorphism of stromatolitic dolomite (Wenham, in press). The trace element content, particularly Ni, V, and Cr, show that formation from one of the igneous ultramafic rocks of the area is improbable. Comparison of the talc analyses, with the nearby dolomite sample, shows that derivation from dolomite is likely.

Fig. 35.

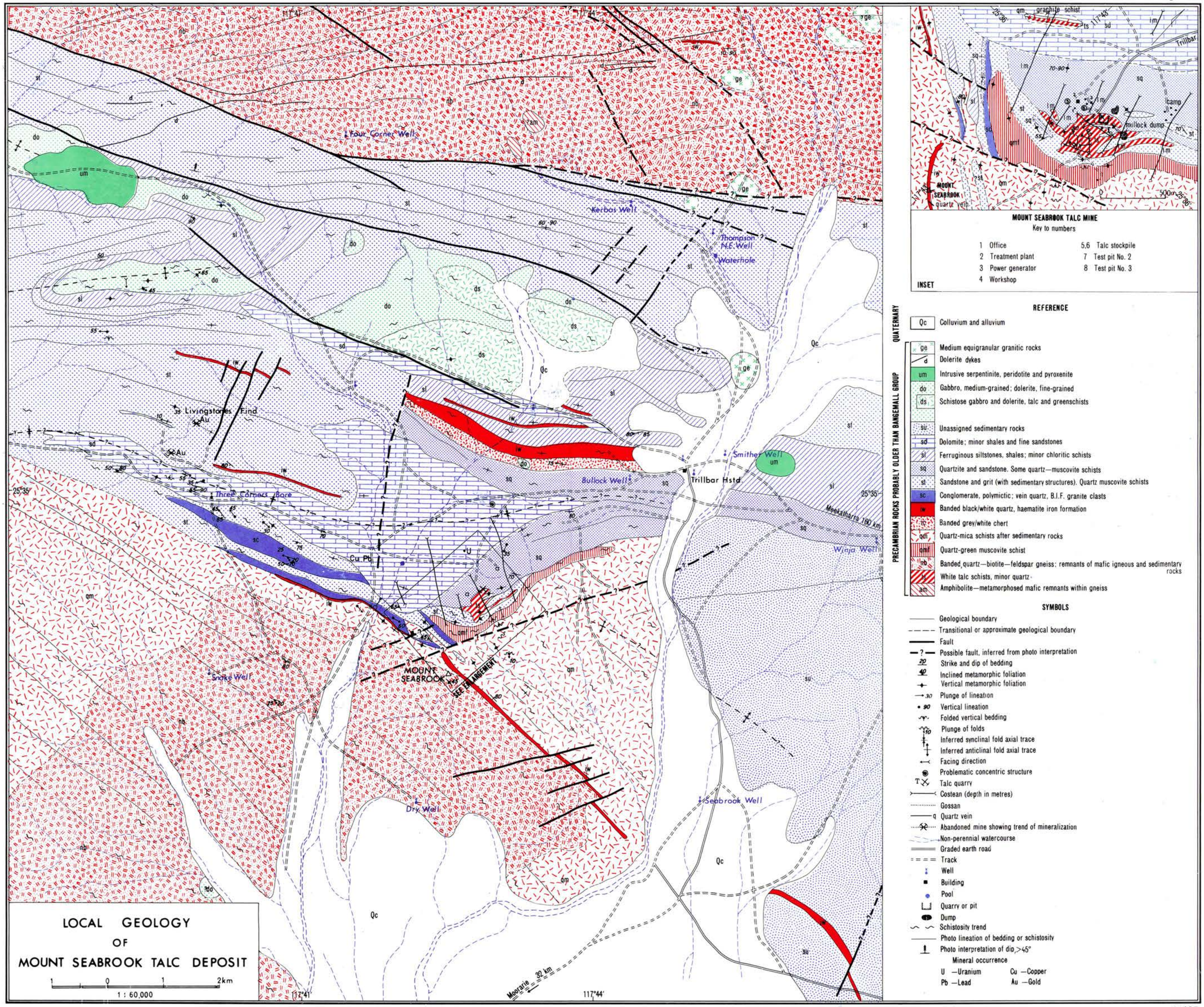

Fig. 35.

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TABLE 11. CHEMICAL ANALYSES OF MT. SEABROOK TALC AND DOLOMITE AND THREE SPRINGS TALC

Sample No.	29626B	29627A	29627B	29627C	29627D	Average 29627A–D	29643
Major oxides per cent							
SiO_2	1·49	63·6	64·3	63·4	64·3	63·9	62·0
Al_2O_3	0·87	0·24	0·25	0·22	0·28	0·25	0·21
FeO	0·44	0·46	0·46	0·57	0·57	0·51	0·75
Fe_2O_3	<0·05	<0·05	<0·05	<0·05	<0·05	<0·05	<0·05
CaO	28·9	0·36	0·26	0·09	0·02	0·18	0·01
MgO	21·3	30·5	30·1	31·3	30·6	30·6	32·3
Na_2O	0·04	0·01	0·02	0·01	0·01	0·01	0·01
K_2O	0·01	0·01	0·01	0·01	0·01	0·01	0·01
MnO	0·05	0·01	0·01	0·01	0·01	0·01	0·01
CO_2	45·0	0·01	0·01	0·01	0·01	0·01	0·01
P_2O_5	0·19	0·01	0·05	0·02	0·02	0·03	0·01
H_2O^+	1·45	4·81	4·58	4·50	4·50	4·59	4·68
H_2O^-	0·02	0·07	0·07	0·26	0·22	0·15	0·23
TiO_2	0·02	0·01	0·01	0·02	0·02	0·02	0·01
Total	99·78	100·05	100·09	100·38	100·53	100·21	100·20
Trace elements ppm							
Cr	24	28	20	54	35	34	57
V	20	<10	<10	<10	<10	<10	<10
Zn	12	13	5	10	7	9	37
Pb	25	11	14	37	19	20	25
Cu	10	16	6	18	11	12	11
Co	5	3	3	14	14	8	12
Ba	340	90	110	120	110	107	130
Zr	<5	<5	<5	<5	<5	<5	<5
Rb	<5	<5	<5	<1	<1	<3	<1
Sr	49	4	5	<1	9	<5	<1
Li	<1	<1	3	<1	<1	<1	<1
Ga	1·1	0·5	0·2	0·2	0·3	0·3	0·3
B	2	2	9	7	7	6	22
Mn	350	14	18	15	14	15	32
Ni	18	19	24	13	21	19	11

Analyses: W.A. Govt. Chem. Labs., Mineral Divison: E. J. Tovey and R. S. Pepper.
29626B: Dolomite 1·6 km west of quarry
29627A–D: Talc from Mt. Seabrook quarry
29643: Talc from Coodawa, 8 km ENE of Three Springs

The main variation, in major oxide content of the dolomite and talc schist, is in silica and lime. The silica differences probably reflect original composition. The silica poor dolomite has only minor chlorite and traces of talc because it contains low silica, together with a much lower degree of deformation. Small pods of talc are reported to occur along its northern margin. The high lime content of dolomite contrasts with that of the talc. This is a problem if the original dolomitic parent, suggested for the talc schist, had similar lime/magnesia ratio to the dolomite analysed. No carbonate veins occur in the fresh talc schists exposed in the quarry. Hence, either the parent rock of the talc schist was low in lime, or calcium carbonate was expelled during recrystallization.

PROPERTIES AND APPLICATIONS OF TALC

The talc is white, platey with a variable hardness between 1.2 and 1.5 (Moh scale). It contains course quartz inclusions. Near surface talc has been silicified by incorporation of excess silica within the crystal lattice. Average brightness of 29627A-D is about 89 (Elrepho, 457μ) and yellowness is 3.7. In general, it is a high grade micaceous talc suitable for paper coating, paint extender, cosmetics and as an industrial filler. About 70 per cent of recent production has been used in paper applications. The talc has been used in Japan as a paint extender and for coating high quality paper. Application in the U.K. and U.S.A. is mostly in cosmetic and pharmaceutical products. In eastern Australia and New Zealand, the talc is used in cosmetics and as a filler in fibro glass, plastics, paints, dusting powders etc.

ORE RESERVES

Total inferred ore reserves for the whole talc deposit are estimated to be 6.8 x 10^6 t to a depth of 35 m. The depth assessment is supported by diamond drilling, proving the presence of good quality talc to a depth of at least 22 m (locally to 35 m) in the northern part of the deposit. The talc is compact and the ore is assumed to have a density of 2.6 t per cubic metre.

In the more closely drilled portion of the deposit, next to the mine, there are 508 000 t measured ore reserves and 356 000 t indicated ore reserves (*Commerce*, July, 1974, p. 9, 11) to a depth of 15 m, lying beneath 2-3 m of overburden. Inferred reserves between 15-30 m are about two million tonnes. Allowing for waste rock, loss during mining, and inferior talc rejected during treatment, the saleable talc present is probably half the reserves given above.

CONCLUSIONS

The talc deposit is a white schistose rock suitable for various commerical applications. It has formed, in a site of strong deformation, by greenschist facies metamorphism of a sandy dolomite intercalated with ?Archaean siliceous metasedimentary rocks. The main dolomite unit overlying the talc schist has been less deformed and less metamorphosed and, because of its low silica content, has only traces of talc. Although chemical analyses support a dolomitic origin of the talc, comparison should also be made with schists formed from mafic and ultramafic intrusions in the region.

ACKNOWLEDGEMENT

The author thanks Westside Mines N.L. for providing detailed drilling information and plans of the quarry site.

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PRECAMBRIAN STRUCTURAL GEOLOGY OF PART OF THE PILBARA REGION

by A. H. Hickman

ABSTRACT

The structural geology of granite-greenstone and Proterozoic terrain in the eastern part of the Pilbara craton is reinterpreted. Regional mapping of 36 000 km^2 of country around the towns of Marble Bar and Nullagine has revealed Archaean and Proterozoic structures belonging to five periods of deformation:

- D1: Interfolding of greenstone and granitic material, granitic intrusion and migmatization. Crustal reworking to produce a granodioritic, partly gneissic, protocrust.

Deposition of a 15-30 km-thick layered succession.

- D2: Diapiric movement (solid-state) of protocrust forming 30-100 km-wide granitic domes and intervening greenstone synclinoria. Greenschist to amphibolite facies metamorphism.
- D3: Conjugate folding and faulting. Dyke intrusion.
- D4: Open recumbent folding. Relations to D3 uncertain.
- D5 (Proterozoic): Open upright folding about northerly trending axes. Tight folding and associated strike faulting on the eastern margin of the craton.

INTRODUCTION

The chief structures of the Pilbara craton are its large granitic domes and intervening greenstone synclinoria, deeply eroded before the deposition of an overlying Lower Proterozoic cover. Between Roebourne and Nullagine the latter has been largely stripped off exposing a 60 000 km^2 area of typical Archaean geology.

This paper describes the structural geology of 36 000 km^2 in the eastern part of the craton and its surrounds using information gained during remapping of the Marble Bar and Nullagine areas (Hickman and Lipple, 1974; Hickman, in prep.). The structural geology of this area was first described by Noldart and Wyatt (1962) who recognized the existence of dome and basin structures but attributed them to cross-folding of an early fold system. Late orogenic granitic batholiths were said to have "tightened the existing fold patterns, further compressing the synclinal belts and accentuating the domal patterns".

STRATIGRAPHY

The Precambrian stratigraphy of the area has been described by Hickman and Lipple (1974) and Hickman (in prep.). Its major subdivisions are:

Middle Proterozoic—conglomerate, sandstone, shale and carbonate.

Unconformity

Lower Proterozoic —dolomite, shale and chert over a predominantly volcanic assemblage.

Unconformity

Archaean—

Gorge Creek Group: sandstone, shale, chert, banded iron formation, conglomerate, turbidites with minor pillow basalt.

Unconformity

Warrawoona Group: pillow basalt, andesite, chert, dacite, ultramafic rocks, pyroclastic rocks and minor clastic sedimentary rocks.

Faulted or intrusive contact

Foliated granodiorite to adamellite complex.

In an accompanying paper Lipple (1975) formally defines the Gorge Creek and Warrawoona Groups, and tabulates the Archaean succession of the Marble Bar area.

Certain evolutionary models proposed by previous workers to explain Archaean greenstone belt developement (e.g. Anhaeusser and others, 1968) postulate deposition of the layered succession (in this case the Warrawoona and Gorge Creek Groups) within isolated elongate basins positioned along the present belts. Such restricted deposition did not take place in the Marble Bar-Nullagine area where stratigraphic sequences can be traced between belts and across major greenstone domes (e.g. the North Pole Dome and McPhee Dome). The Archaean stratigraphic pile of this area is broadly tabular over lateral distances of at least 200 km.

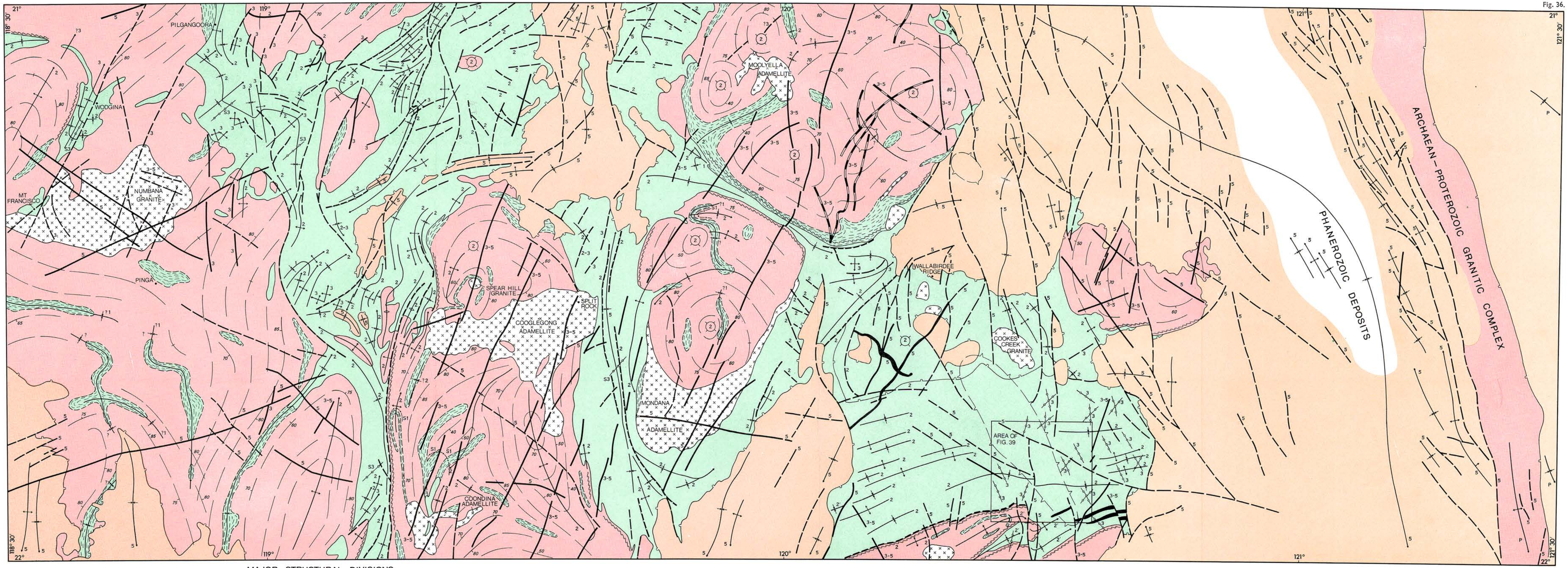
GEOCHRONOLOGY

Table 12 summarizes geochronological data from rocks of the area.

TABLE 12. GEOCHRONOLOGICAL SUMMARY OF THE MARBLE BAR AND NULLAGINE SHEETS

	Rock type and relations	Locality	Age m.y.	Initial Sr^{87}/Sr^{86}	Method and reference
PROTEROZOIC	Spinaway Porphyry. Felsic sill in Fortescue Group	W side Great Northern Highway, 15 km N of Nullagine 21° 46′ S, 120° 05′ E	2 124 ± 195	0·712 6 ± 0·013 9	Rb-Sr Trendall, 1975
	Bamboo Creek Porphyry. Felsic sill in Fortescue Group	Bamboo Creek Mining Centre, 20° 55′ S, 120° 13′ E	2 820 ± 516	0·701 0 ± 0·020 0	Rb-Sr Trendall, 1975
	Black Range Dyke	Cooglegong Creek, 21° 35′ S, 119° 28′ E	2 329 ± 89	0·726 2 ± 0·012	Rb-Sr Lewis, Rosman and de Laeter, 1975
ARCHAEAN	Moolyella Adamellite	Moolyella 20 km east of Marble Bar	2 670 ± 95	0·739 7 ± 0·041 9	Rb-Sr de Laeter and Blockley, 1972
	Cooglegong Adamellite	Shaw River 50 km SE of Marble Bar, 21° 30′ S, 119° 00′ E	2 602 ± 132	0·731 0 ± 0·029	Rb-Sr de Laeter, Lewis and Blockley, 1975
	Cookes Creek Granite	45 km ENE of Nullagine	2 750*		Rb-Sr Trendall (pers. comm.)
	MAIN PERIOD OF DEFORMATION, D2				
	Copper Hills "Porphyry". Felsic tuff in Warrawoona Group	Copper Hills Mine, 21° 39′ S, 119° 58′ E	2 880 ± 66	0·730 3 ± 0·011 9	Rb-Sr de Laeter and Trendall, 1969
	Foliated migmatitic granite	Moolyella, 20 km east of Marble Bar	3 125 ± 366	0·701 6 ± 0·004 7	Rb-Sr de Laeter and Blockley, 1972
	Foliated migmatitic granite	Shaw River, Spear Hill, 21° 30′ S, 119° 00′ E	2 951 ± 83	0·702 0 ± 0·001 0	Rb-Sr de Laeter, Lewis and Blockley, 1975
	Granitic Rock	Pilbara Block	3 050 ± 180		Rb-Sr Compston and Arriens, 1968

* Unpublished provisional value subject to revision by further analyses planned at time of writing.



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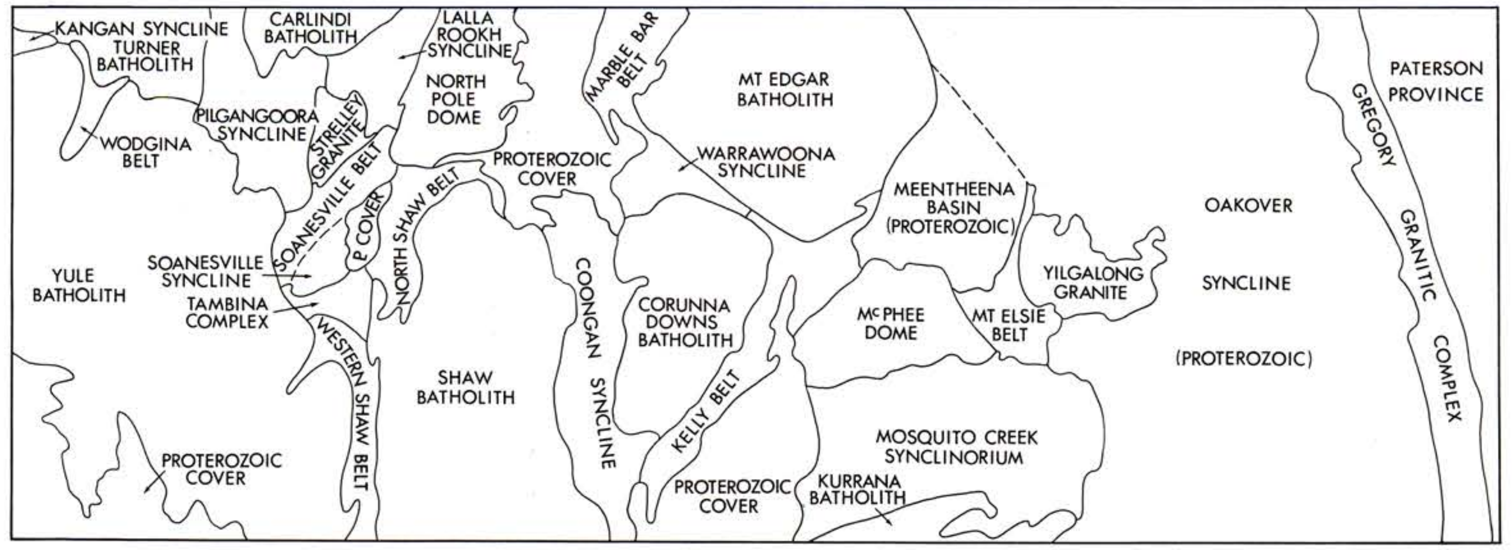
MAJOR STRUCTURAL DIVISIONS



REFERENCE

- Mafic to ultramafic dyke
- Felsic dyke
- Proterozoic rocks
- Unconformity
- Post-tectonic Archaean granite
- Intrusive contact
- Archaean greenstones and metasediments
- Archaean granitic rocks with numerous greenstone xenoliths
- Archaean granitic rocks

SYMBOLS

- 1, 2, 3, 4, 5, P — First, second, third, fourth, fifth and Paterson Province deformation structures
- S1 — D1 foliation (schistosity)
- 80 S2 — D2 foliation (schistosity) with dip locally indicated
- S3 — D3 foliation (strain-slip cleavage)
- Synclinal fold axis
- Anticlinal fold axis
- Synformal anticlinal axis
- Dome
- Tectonic slide
- Shear belt
- Fault
- Unconformity
- Zone of Proterozoic granite stocks

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

STRUCTURAL GEOLOGY OF THE MARBLE BAR AND NULLAGINE SHEET AREAS

SCALE

10 0 10 20 30 KILOMETRES

Fig. 36.

Perhaps the most significant point revealed by Table 12 is that rocks deformed by D2, in effect the greenstones and most of the area's granitic rocks, appear to be aged between 3.2 and 2.8 b.y. whereas the post-tectonic, non-deformed granites ("younger granites") are 2.7-2.6 b.y. old. For reasons advanced by de Laeter and Blockley (1972) it seems probable that the 2.7-2.6 b.y. granites are derived by partial remelting of the migmatitic granites. Such cross-cutting massive granites are commonly generated and emplaced during the later stages of major orogenic episodes; the last such episode in the region was D2. Accordingly it is believed that D2 culminated at about 2.7 b.y.

STRUCTURAL FORMS

Figure 36 shows the position and geological relationships of individual structures and the distribution of major structural units.

GRANITIC DOMES AND GRANITIC SYNCLINES

The granitic domes are broad, steep-sided structures, generally round to ovoid in plan and measuring 30-100 km in diameter. Surface geology and Bouguer anamoly patterns indicate that at depth the domes merge to form a predominantly granitic basement. Each mass typically contains several plutons; composition and texture are extremely varied.

Most of the rocks are foliated. Often, as in marginal areas near the enveloping greenstones, the foliation is extremely pronounced and schistose granitic rocks are common. Towards the centre of each dome this foliation becomes less conspicuous and often only a weak biotite alignment can be detected. Indeed, it is not uncommon to observe what appear to be primary flow structures in such areas. The predominant foliation of the domes is mechanical, a strain effect of vertical shear stress during diapiric movement. On Figure 36 its strong geometrical relationship to the shape of these domes is obvious, and it is superimposed across all internal plutonic boundaries except those of the 2.6-2.7 b.y. granites.

Few of the domes are simple structures; most, especially the larger ones, contain synclines in which the foliation referred to above converges downwards. These intra-domal synclines are characterized by broken trails of greenstone material and, in some cases, by shear belts along their length. Their rocks and structures are similar to those found near contacts with the major greenstone belts and the probability is that many are root zones of now eroded overlying greenstone synclines. This is certainly true at Warrery Gap (Corunna Downs Batholith) and Tambourah (Yule Batholith) where tapering greenstone protuberances pass progressively into intra-domal synclines as deeper structural levels are exposed. Less commonly, greenstone xenolith belts, within the domes, do not lie in D2 synclinal cores and these may represent pre-D2 fold remnants within the plutonic complex (c.f. pre-dome structures of Rhodesian Basement Complex, Stowe, 1968). Alternatively they may mark past granite-greenstone contacts forced apart by later plutons. An example of this type of contact is the northern margin of the Bamboo Springs Adamellite (Hickman and Lipple, 1974).

POST-TECTONIC GRANITES

Unlike the foliated granitic complex, which has been deformed during doming, the post-tectonic granites (Fig. 36) are massive discordant intrusions with sharply defined contacts. The granite and adamellite which comprises them is equigranular unfoliated to poorly foliated, and contains much more microcline, quartz and muscovite than the older granitic rocks. Many of the post-tectonic granites are fringed by associated late-stage pegmatite veins containing economically important minerals, especially cassiterite and tantocolumbite.

The post-tectonic granites form irregular stocks. An absence of marginal disruption of the intruded country rocks and the occurrence of roof pendants and xenoliths of host rock within the bodies suggests "permitted" rather than "forceful" intrusion, probably by a process of magmatic stoping.

The recent mapping has revealed a significant degree of structural control over the emplacement of the post-tectonic granites. The recognition of synclines within the domes has shown that the intrusions tend to occupy D2 synclines, whether these be in granitic or greenstone areas (Fig. 36). Partial remelting of the pre-D2 granitic complex, probably in the high temperature, low confining pressure environment beneath the synclines, must have been followed by upward magmatic intrusion along lithological contacts and shear planes (Fig. 37). High pressure rigid-dome cores were not invaded.

The post-tectonic granites are now exposed at three structural levels:

High level: Granite enclosed by greenstones, e.g. Cookes Creek, Wallabirdee Ridge. Economic minerals of W, Mo, Cu, F, Li and Ba.

Intermediate: Granite at or near greenstone-older granite contacts e.g. Wodgina, Mount Fancisco, Split Rock, Mondana and ?Pilgangoora. Economic minerals of Sn, Ta, Li, Be, and W.

Low level: Granite enclosed by older granite e.g. Moolyella, Spear Hill, Cooglegong, Coondina and ?Pinga (not exposed). Economic minerals of Sn and Ta; others rare.

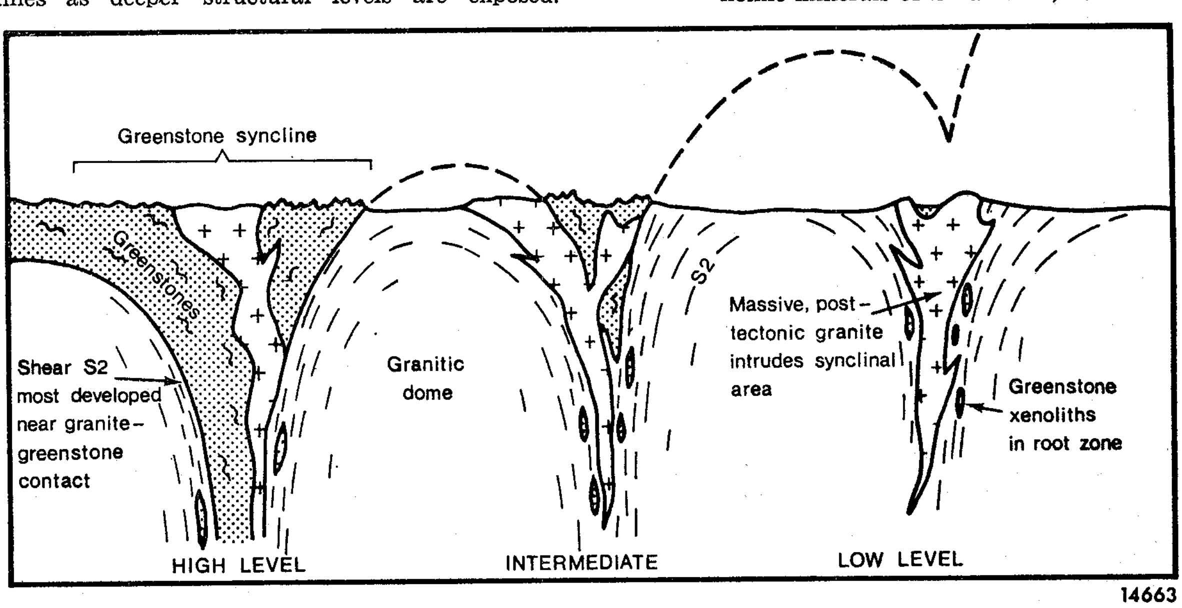


Figure 37. Diagrammatic cross-section showing various structural environments of the post-tectonic granites.

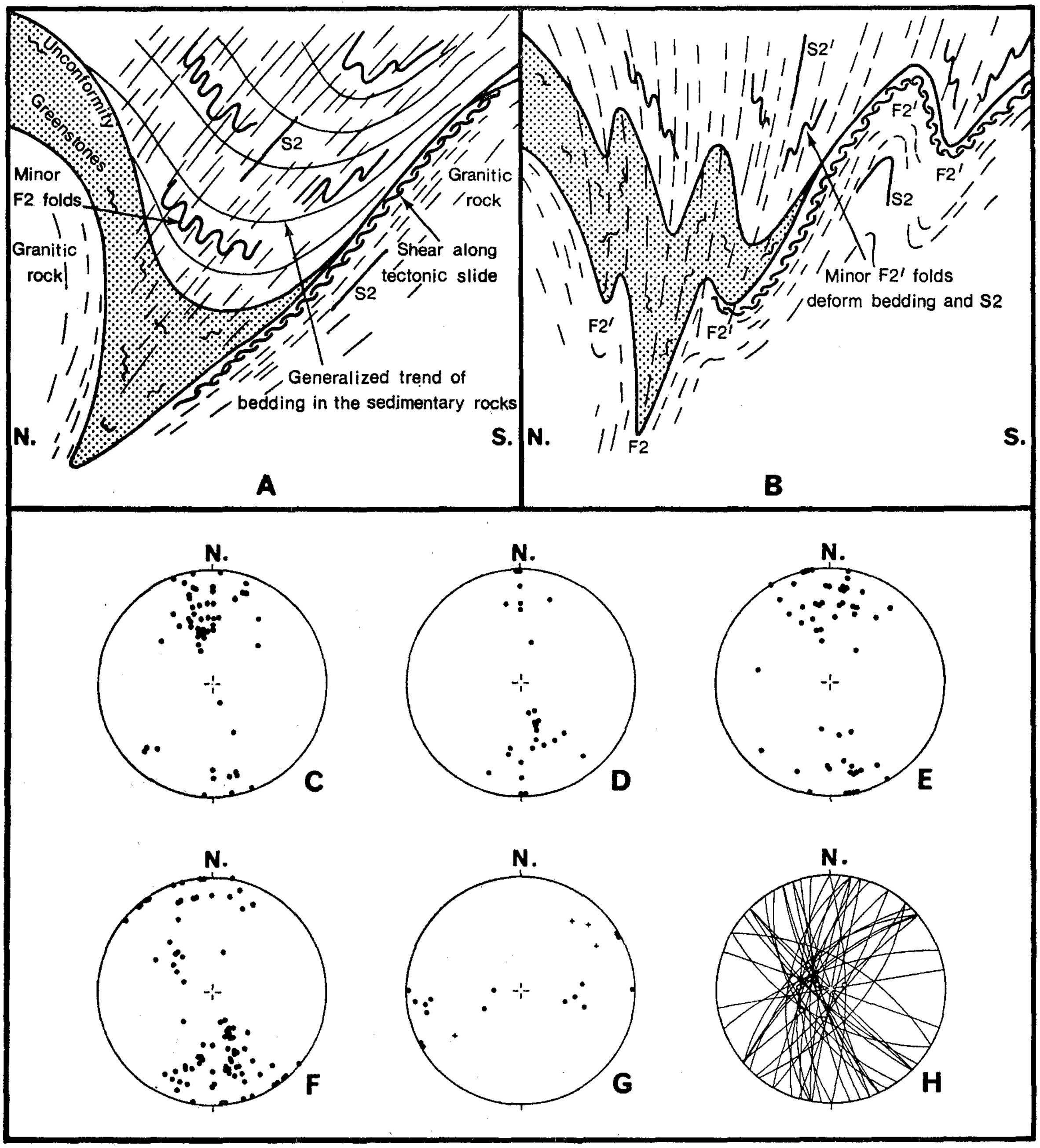


Figure 38. Structural interpretation of the Mosquito Creek Synclinorium. A. Initial form of synclinorium after main D2 folding. B. D2 synclinorium modified by late D2 movements. Includes F2′ folding. C–H: Stereograms of structures in the eastern part of the synclinorium; C, poles to bedding in the northern half of the synclinorium (note prevailing dip is approximately 50° at 170°); D, poles to bedding in the southern half of the synclinorium (prevailing dip is approximately 45° at 350°); E, poles to S2 and S2′ in the northern half of the synclinorium (prevailing steep southerly dip); F, poles to S2 and S2′ in the southern half of the synclinorium (prevailing moderate to steep northerly dip); G, dots, β-points at S:S2 intersection where both measured (approximates to F2 plunge); crosses, F2 plunge measurement; H, S3 great circles. Area of maximum intersection corresponds to regional b-tectonic axis; dots, β-points to conjugate S3 planes.

GRANITE-GREENSTONE CONTACTS

Granite-greenstone contacts are either intrusive or tectonic; in no case has an unconformity been discovered. This situation appears very common in similar terrain elsewhere in the world and has often been cited as evidence that the granite domes are intrusive.

Marginal intrusive relationships do not of course prove that an entire granitic dome is a magmatic intrusion. As excellently demonstrated by the post-tectonic Mondana Adamellite, granite-greenstone contacts are very susceptible to magmatic intrusion. Moreover, without exception, the migmatites of the contact zones are sheared in harmony with neighbouring greenstones. Tectonic foliation can often be traced along strike from greenstone rocks across invading granitic bodies and back into greenstone rocks. Clearly these intrusive structures generally pre-date the marginal shear around the domes. It is possible that the foliated marginal intrusive bodies are syn-orogenic granites generated during deformation of the older granitic complex. Such rocks could have originated as intrusions into the mechanically active contact zone during doming, consolidated and then been sheared by continued deformation. Alternatively, some of the migmatites may have been formed before doming by granitic intrusion along the granitic basement-greenstone boundary.

Sheared contacts commonly accompany steeply dipping, attenuated marginal greenstone units. Attenuation and faulting may be so intense as to tectonically condense or slide out many kilometres of rock at the base of the greenstone succession. In many cases the granites themselves are converted to schist, often with complete destruction of all igneous textures. Such strongly deformed contacts are typical of fairly deep structural levels.

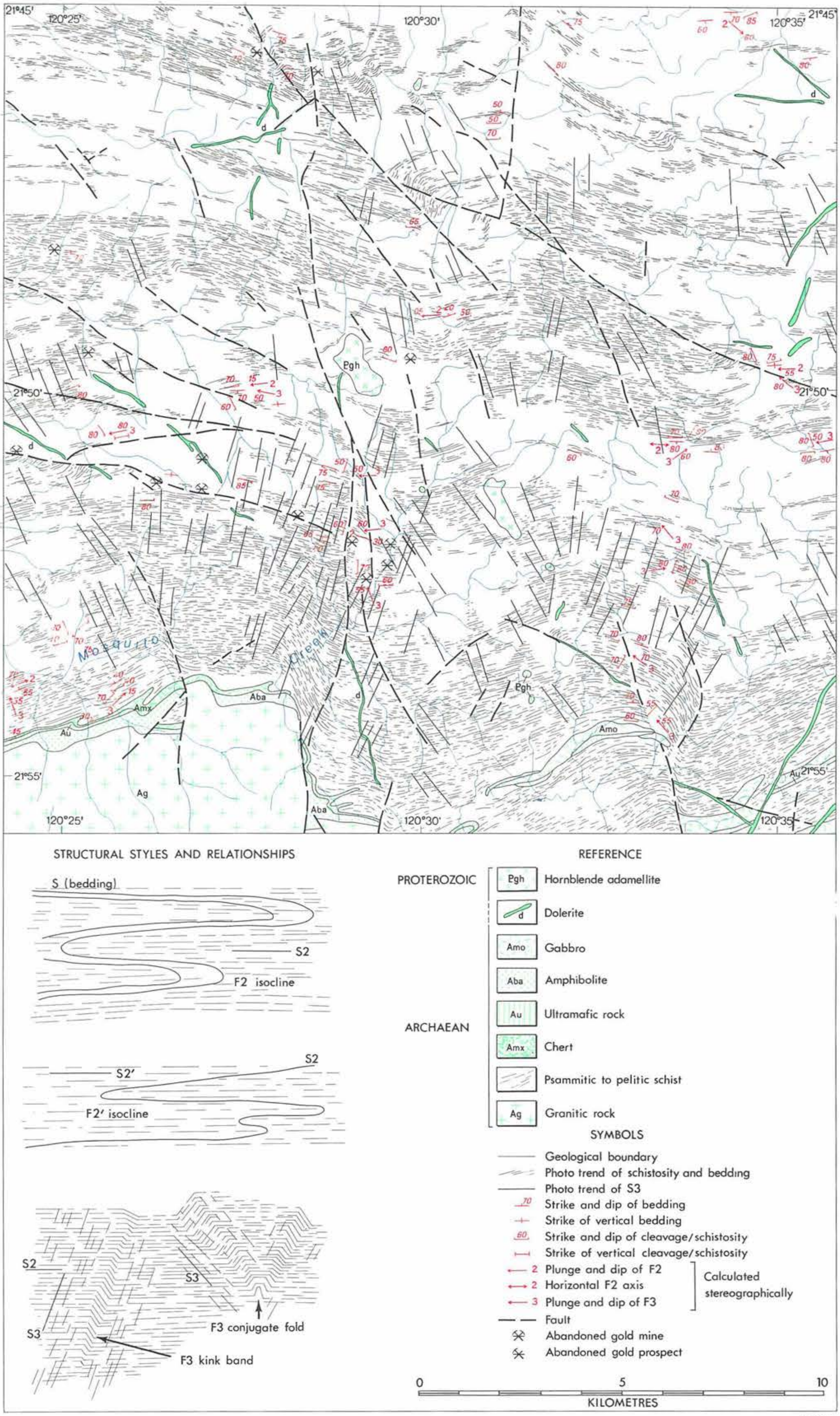


Fig. 39. Structural geology of the Mosquito Creek area.

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GREENSTONE SYNCLINORIA AND GREENSTONE DOMES

Major synclines containing volcanic and sedimentary rocks metamorphosed to greenschist facies lie between the granitic domes. These regionally extensive structures crop out as the "greenstone belts" of the area. Their shapes are controlled by those of adjacent domes, so that not only linear belts but also triangular and four-sided patterns occur. Extrapolations of surface geology indicate that the depth of the synclines ranges to about 30 or 40 km, that is to levels approaching the base of the crust. Dome crestal levels also vary; some of the granitic masses can be projected to about 15 km a.s.l. whereas others culminate at or below present ground level (0.3 km a.s.l.). Examples of the latter type are the North Pole and McPhee Domes where domed greenstone cover is preserved.

It has often been suggested that the arcuate nature of greenstone belts, and their varied orientation within a given region, is the result of cross-folding. In this area there is no evidence of superimposed cross-folding and no interference of minor structures where belts merge. The synclines and their associated second-order folds were produced by differential vertical movements. They complement the domes and are primarily non-cylindrical nonplane folds. Their associated schistosity rims the domes and is continuous between belts of different orientation.

Most of the greenstone belts are composed of upright tight to isoclinal similar folds. Individual limbs of these folds are extremely attenuated in places and slides (longitudinal strike thrusts) are common. One such slide occurs on the eastern margin of the Western Shaw Belt where the normal eastern limb of this major overturned syncline has been completely sheared out against the diapiric Shaw Batholith. In many areas vertically stretched and flattened pillow structures, conglomerate pebbles and agglomerate clasts testify to the degree of strain.

Vertical shear, often parallel or sub-parallel to bedding, has produced a widespread, steeply inclined schistosity in the greenstones. This schistosity is of the same age and origin as the main foliation of the granitic rocks. At relatively high structural levels, in low dipping sequences, such schistosity is very weak or completely absent and primary structures such as pillows, clasts and cross-bedding are not visibly deformed.

At North Pole and McPhee Creek two major greenstone domes occur. The North Pole Dome is 35 km in diameter. Across it a 15 km-thick greenstone succession of pillow basalts, chert and felsic volcanics are inclined at attitudes of 15-45°. Only in the centre is a small core of underlying adamellite exposed. Tensional faults radiate from the centre of the dome but the rocks show no evidence of internal deformation (Hickman, 1973).

About 100 km to the south-east of North Pole lies the McPhee Dome. Some 40 km long and 25 km across, this structure exposes a 7 km-thick succession of pillow basalt, chert and felsic agglomerate. Bedding inclination is very low in the centre of the structure although dips of 40-60° occur in its outer flanks. No granitic core is exposed.

THE MOSQUITO CREEK SYNCLINORIUM

The east-northeast trending Mosquito Creek Synclinorium is about 30 km wide and 60 km long and is unique in the eastern part of the Pilbara craton. Its great thickness of schistose flysch-type sediments and its persistantly east-northeasterly trending sub-isoclinal folds are not repeated elsewhere. Bounded to the north by greenstones, to the south by granite and unconformably overlain by Proterozoic rocks to the east and west, the unit presents interesting stratigraphic and structural problems.

At both the northern and southern contacts the base of the succession includes chert, peridotite, amphibolite, dolerite and gabbro; rock types which are not present at higher stratigraphic levels. Although the igneous rocks could all be interpreted as intrusive the isolated occurrence of chert at this position implies a real stratigraphic equivalence of the two sequences. The northern contact is a locally faulted unconformity inclined southwards at about 60°. The southern contact is a tectonic slide inclined northwards at 30° to 50° and overlies extensively sheared granite. Deformation is greatest in the central and southern parts of the synclinorium and its core lies relatively close to the southern contact. All these features indicate most shear and attenuation on the synclinorium's southern limb.

Graded bedding provides excellent facing evidence across the unit and although fold structures are generally not visible from the air, repeated reversals of facing across strike reveal the existence of major upright isoclines. In all but the most psammitic and psephitic beds the dominant foliation of the rocks is schistosity and it is this, rather than bedding, which is visible on aerial photographs. The synclinorium contains two generations of similarly orientated isoclines, the schistosity being parallel to axial planes to the first folds and folded by the second. The second generation folds possess a steeply inclined axial-plane cleaveage which is quite commonly observed to cross-out both the bedding and the earlier schistosity. As can be seen in Figure 36 an anticline and a syncline of the second generation deform the southern contact of the synclinorium. Figures 38 A and B presents a cross-section through the unit.

Superimposed on the foliations just mentioned are structures belonging to a later phase of deformation. Kink folds, conjugate folds and related strain-slip cleaveage are more conspicuous in this structural unit than elsewhere in the eastern part of the craton. Figure 39 shows that in the vicinity of the Mosquito Creek Mining Centre all these structures are visible from the air. Orientation and plunge of the conjugate kink folds is partly governed by pre-existing structural fabric but the intersection of their axial planes is the b-tectonic axis (Fig. 38H). Micro- and mesoscopic kink bands or joint-drags (Dewey, 1965) are common in the more pelitic beds, especially in the vicinity of northerly striking wrench faults. They are invariably angular in style and generally plunge steeply. The bands commonly occur in conjugate systems where two sets of kink zones, inclined at about 90° to each other, show opposite senses of rotation.

PROTEROZOIC BASINS

As noted elsewhere in the Pilbara (Kriewaldt, 1964; Ryan, 1966) synclines and structural basins in Proterozoic rocks tend to be positioned over Archaean synclines. Four of the five major basins in this area conform to this pattern and the nature of the rocks underlying the fifth, the Oakover Syncline, is largely unknown.

The Proterozoic succession unconformably overlies both Archaean granitic rocks and greenstones but only above the latter are its lower-most formations, the Mount Roe Basalt and Hardey Sandstone, ever present. Over large areas a systematic Proterozoic overlap can be traced from depositional basins underlain by greenstones onto granitic rocks (Hickman and Lipple, 1974; Hickman, in prep.). It may never be known whether the position of these basins was structurally or lithologically controlled. Structural control would have been chiefly responsible had either erosion of Archaean structures been incomplete or had Archaean domes and synclines been reactivated shortly before Proterozoic deposition. Lithological control might have been effective under certain weathering conditions during the late Archaean.

Because synclinal folds in the Proterozoic rocks tend to coincide with those in the basement it has been suggested that the Proterozoic structures may have been formed by slight tightening of the Archaean folds. Proterozoic synclines and structural basins may also have originated partly by gravitational downwarping within depositional basins. It should be noted, however, that anticlines to the northwest and southeast of the Yilgalong Granite deform basin sequences deposited over greenstones and that in the southwestern part of the Marble Bar Sheet area northerly trending synclines and anticlines (very open) occur over granite. It is concluded that structure and topography of the Archaean basement influenced but did not control fully the development of Proterozoic folds. The general northerly axial trend of these structures suggest deformation at least partly in response to a maximum east-west compressive stress.

STRUCTURAL HISTORY

The structural geology of the area is the product of several periods of deformation. Style, orientation and interference of major and minor structures reveal a long and complex history of folding, faulting and dyke intrusion. Mapping at 1 : 250 000 scale does not permit detailed structural analysis. Consequently, certain of the deformation phases may be further subdivided in the future.

In the following account D1, D2 ... refers to first deformation, second deformation ..., F1, F2 ... to folds produced during D1, D2 ..., S to bedding, and S1, S2 ... to foliations produced during D1, D2 ... .

FIRST DEFORMATION D1

All structures formed before the main episode of deformation, D2, are classed as D1 structures. They include early isoclinal folds of greenstone material forming detached structures within the granitic rocks, displaced granite-greenstone contacts, schistose dykes, deformed pegmatite veins, gneissic banding and, on a regional scale, all granitic plutons across which S2 is superimposed. It seems certain that such diverse structures represent deformations of several tectonic and intrusive episodes, but their relationships are generally obscured by D2 structures.

Certain of the megascopic greenstone masses occurring within the granitic domes are deformed by D2 folding and cross-cut by S2. Their contained schistosity, S1, is likewise deformed. Mafic dykes within the granites include folded and foliated bodies which may represent feeders of the greenstone succession. Gneissic banding in the granitic complex is locally deformed by pre-D2 structures, such as interfolial pegmatite veins. The banding was formed by attenuation of migmatite, lit-par-lit injection or possibly by metamorphic differentiation.

MAIN DEFORMATION D2

The dominant structural elements of the area, the granitic domes and greenstone synclinira, were formed during the main episode of deformation. The Mosquito Creek Synclinorium is also a D2 structure, although this preserves evidence of two generations of folding during the same tectonic episode.

Differing competence of the greenstones and granitic rocks has established a regional fold pattern of broad domes and narrow cuspate synclines. Such a pattern is typical of a buckled basement—supracrustal contact in which the basement material is most viscous (Ramsay, 1967, p. 383-386). Internal deformation styles within the two types of rock are, as might be expected, very different. The greenstone synclinoria contain numerous upright tight to isoclinal noncylindrical, nonplane and often conical similar folds. Shearing-out of fold limbs along tectonic slides is quite common.

The granitic domes, on the other hand, are characterized by folding closer to the concentric model with flexural slip along shear planes parallel to the granite-greenstone contacts. Vertical shear, often parallel or sub-parallel to bedding and granite-greenstone contacts has produced the regional schistosity, S2, of the area. Late D2 folds and their associated axial-plane cleavage in the Mosquito Creek Synclinorium are referred to as F2′ and S2′ respectively.

Vertical movement is clearly predominant in the formation of diapiric structures, such as the granitic domes, but the cause of such movement, and the physical state of the material moving is debatable. D1 and D2 structures in the granitic rocks show that these were at least partly domed in the solid-state while preservation of depositional structures in the greenstones leaves no doubt that they were solid. The tabular nature of the greenstone succession rules out down-warping under narrow elongate geosynclinal basins (a model adopted by Anhaeusser and others, 1968, in the Barberton Mountain Land of South Africa). Dome and syncline development was probably a response to "inverted density stratification" (Ramberg, 1967), a low density layer (granitic complex) being overlain by a 15-30 km-thick high density layer (greenstones). Upward movement of the broad viscous granitic domes, over relatively large areas, was complemented by more rapid downward movement of less viscous greenstone material in narrow belts. Ramberg's certifuged models use "low" viscosity, low density bottom layers and consequently produce intrusive salt dome-like diapirs. In model S226 (Ramberg, 1967, p. 174), however, equal viscosities are used to produce structures more closely resembling those of the granitic domes and greenstone synclines.

THIRD DEFORMATION D3

In many areas D2 structures are visibly deformed by folds, faults and cleavage belonging to a later episode of deformation. Structures of this type have been described in the Mosquito Creek Synclinorium, but they also occur in many other areas (Fig. 36). Good examples of D3 folding occur in the Pilgangoora Belt where major F2 axes are deflected several times over a distance of 30 km.

Northeasterly striking, steeply inclined, strain-slip or "crenulation" cleavage, S3, is widespread in schist and phyllite of the greenstone belts. It bears an axial relationship to F3 folds and often produces a steeply plunging microscopic crenulation of S2.

Faults, commonly veined by quartz, are an extremely common D3 structure and fall into two sets, one striking northeast, the other northwest. Most of these faults are wrenches with a tendency for northeast striking fractures to involve sinistral movement, and northwest wrenches to be dextral. This implies a sub-horizontal north-south maximum compressive stress during their formation.

Dolerite dykes have intruded many D3 fractures and are little deformed by later movement. They cross-cut the post-tectonic granites and were probably feeders for the Lower Proterozoic basalt lava succession of the Fortescue Group. Structures grouped under "D3" probably range in age from late Archaean to early Proterozoic.

FOURTH DEFORMATION D4

Sub-horizontal micro and mesoscopic recumbent open crenulations of S2 are tentatively referred to a fourth period of deformation. Their style is distinctive but their relations to D3 have not been established. Axial trend is generally westerly.

FIFTH DEFORMATION D5

Major open folds with northeasterly to northwesterly trending axes deform the area's Proterozoic succession. Although much of the latter once covered the entire area extensive Phanerozoic peneplanation in the centre and west has generally preserved only synclines in shallow basement depressions.

A noteable exception to this D5 style of folding is found in the Gregory Range. Here upright tight to isoclinal folding about north to northwest trending axes is accompanied by a strong steep axial-plane cleavage, S5, and related high angle faults. This belt of deformation is situated on the eastern margin of the craton. It includes Middle Proterozoic rocks (Waltha Woora Formation) and consequently must have formed less than 1 000 m.y. ago.

A conjugate system of wrench faults is developed in the Proterozoic rocks. East-northeasterly striking dextral wrenches, and west-northwesterly sinistral wrenches, testify to a motive east-west maximum compressive stress. Such a stress field is in accord with the regional D5 fold trend. Vertical movement is present on some faults and predominates in the Gregory Range.

It is likely that D5 includes two deformations, an early phase of open folding, perhaps partly syn-depositional, followed by wrench faulting and a later phase of predominantly vertical movements.

CONCLUSIONS

The area's Archaean greenstones were deposited as a 15-30 km-thick tabular succession on a granitic crust. Diapiric movements, culminating at about 2.7 b.y., produced major granitic domes and intervening greenstone synclinoria. Shortly after the culmination of this deformation post-tectonic granites were intruded, chiefly in synclinal areas. Subsequent erosion and minor brittle deformation was followed by the deposition of a thick Proterozoic succession. The final major stage in the structural development of the area was one of widespread open folding about northerly trending axes.

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GRANITE AGES WITHIN THE SHAW BATHOLITH OF THE PILBARA BLOCK

by J. R. de Laeter*, J. D. Lewis and J. G. Blockley

ABSTRACT

Two radiometric ages have been obtained by the Rb-Sr method from granites of the Shaw Batholith, southwest of Marble Bar. The older age, from migmatites and gneissic and foliated, granites of the main portion of the batholith, is 2951 ± 83 m.y., with an initial Sr^{87}/Sr^{86} ratio of 0.7020 ± 0.0010. This is probably a metamorphic age and the low initial ratio suggests a derivation from primary crustal material. The post-tectonic Cooglegong Adamellite, which intrudes the older granite and is associated with a swarm of tin bearing pegmatites, gives an age of 2606 ± 128 m.y. with an initial Sr^{87}/Sr^{86} ratio of $0.730\,3 \pm 0.028$. The initial ratio suggests that the Cooglegong Adamellite consists of reworked material and is probably derived from partial melting of the older granite.

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INTRODUCTION

This paper forms a continuation of work initiated by de Laeter and Blockley (1972) on the geochronology of individual granite batholiths within the Archaean Pilbara block of Western Australia. The earlier paper was concerned with the Moolyella Granite, and its envelope of older gneissic granites, which lies to the east of Marble Bar. The present paper deals with the Shaw Batholith, to the southwest of Marble Bar.

NOMENCLATURE

Certain stratigraphic and structural names are used in this paper concurrently with their first formal definition, revision or appearance, and for clarity these are listed below:

(1) Hickman and Lipple (1974) first define the Moolyella, Cooglegong, Spear Hill and Mulgandinnah Adamellites.

(2) The stratigraphic units Warrawoona Group and Gorge Creek Group are formally revised in Lipple (1975).

(3) The structural names Shaw Batholith and Mount Edgar Batholith first appear in Hickman and Lipple (1974).

In their paper of 1972 de Laeter and Blockley referred to the Moolyella Granite. This intrusion has now been formally defined as the Moolyella Adamellite by Hickman and Lipple (1974). The Moolyella Adamellite and the surrounding older gneissic granites together make up the Mount Edgar Batholith.

PREVIOUS GEOCHRONOLOGICAL WORK

A review of Archaean geochronology in Western Australia has been made by Arriens (1971), and with respect to the Pilbara granites by de Laeter and Blockley (1972). Briefly an age of 3050 ± 180 m.y. was obtained by Compston and Arriens (1968) for 12 samples of gneissic granite collected from localities throughout the Pilbara, and a U-Pb age of 2400 to 2600 m.y. by Greenhalgh and Jeffery (1959) from a pegmatite at Woodstock. For the Mount Edgar Batholith, which is similar to the Shaw Batholith, de Laeter and Blockley (1972) obtained an age of 3125 ± 366 m.y. for the older gneissic granite and 2670 ± 95 m.y. for the Moolyella Adamallite which intrudes it. A younger age limit for igneous activity in the granite batholiths of the Pilbara is provided by an age of 2329 ± 89 m.y., obtained by Lewis and others (1975) for the Black Range dolerite dyke, a member of a dyke swarm which intrudes most units of the Archaean granites.

REGIONAL SETTING

Granitic rocks occupy the greater part of the Pilbara Block (Prider, 1965; Daniels and Horwitz, 1969) and form large dome-like bodies intruded into an older layered series. On a broad scale, however, the granites are concordant with the layered rocks which consist of a lower volcanic sequence, the Warrawoona Group, overlain by sediments of the Gorge Creek Group (Hickman and Lipple, 1974). The layered sequences are now preserved in tight synclines which wrap round and separate the granitic batholiths.

Noldart and Wyatt (1962) noted that the granite batholiths were variable, grading from a central core of homogeneous magmatic granite through an intermediate zone of gneissic granite with pegmatites to a marginal migmatitic granite. Ryan (1965) suggested that the large domes had been intruded by younger granites and Blockley (1970) mapped out several such intrusions and related them to tin mineralization in the Marble Bar area. The most recent mapping by Hickman and Lipple (1974) has shown that the older gneissic granite batholiths are composite, and consist of several mappable units ranging in composition from tonalite to granite.

The present study is confined to the granites of a single gneissic dome, the Shaw Batholith, which is situated 30 km southwest of Marble Bar. For the purpose of this study the dome has been divided into two units only, the younger intrusive Cooglegong Adamellite, one of the "tin" granites of Blockley (1970), and the older gneisses and migmatites which make up the bulk of the batholith.

THE SHAW BATHOLITH

The Shaw Batholith (Fig. 40) is a large oval granitic dome, approximately 80 by 40 km in size, extending southwards from about 30 km southwest of Marble Bar into the northern portion of the adjacent Roy Hill map sheet. The greater part of the dome consists of leucocratic gneissic granite which becomes migmatitic within a few kilometres of the margin. This portion of the batholith forms a flat featureless plain covered by a thin veneer of residual sand and gravel, and only a few isolated outcrops of granite. Intruded into the older granites are the younger "tin" granites which form low rounded hills with large expanses of bare rock.

Older granite

Detailed mapping by Hickman and Lipple (1974) has shown that the older granites of the Shaw Batholith include a number of discreet bodies which form mappable units. The main part of the mass, however, is a medium to coarse-grained, equigranular biotite adamellite gneiss with some granodiorite and tonalite. Foliation throughout the mass is characterized by orientation of feldspar, micas, quartz and hornblende. Towards the margin of the batholith migmatitic varieties become prominent and include nebulitic, stromatic, vein and banded migmatites. For the outermost few kilometres the batholith consists of approximately equal proportions of injected granite and metamorphosed country rock.

Intrusive bodies within the older granites of the Shaw Batholith include tonalite, adamellite and porphyritic adamellite. Some of the major bodies are shown on Figure 40. The Mulgandinnah Adamellite is a fine to medium-grained, well foliated biotite adamellite which occurs as small stocks, having cross-cutting contacts with the enclosing gneisses. The rocks contain xenoliths of the country rock and are thought to be derived by remobilization of the surrounding gneisses. The most prominent of the intrusions, within the older granites of the Shaw Batholith, are the two large irregular masses of porphyritic biotite adamellite. The rocks are easily distinguished by the presence of phenocrysts and although generally well foliated some portions are massive.

The age relationships between the various older granite types present in the Shaw Batholith are uncertain, but for the purposes of this study the various rock units have not been distinguished.

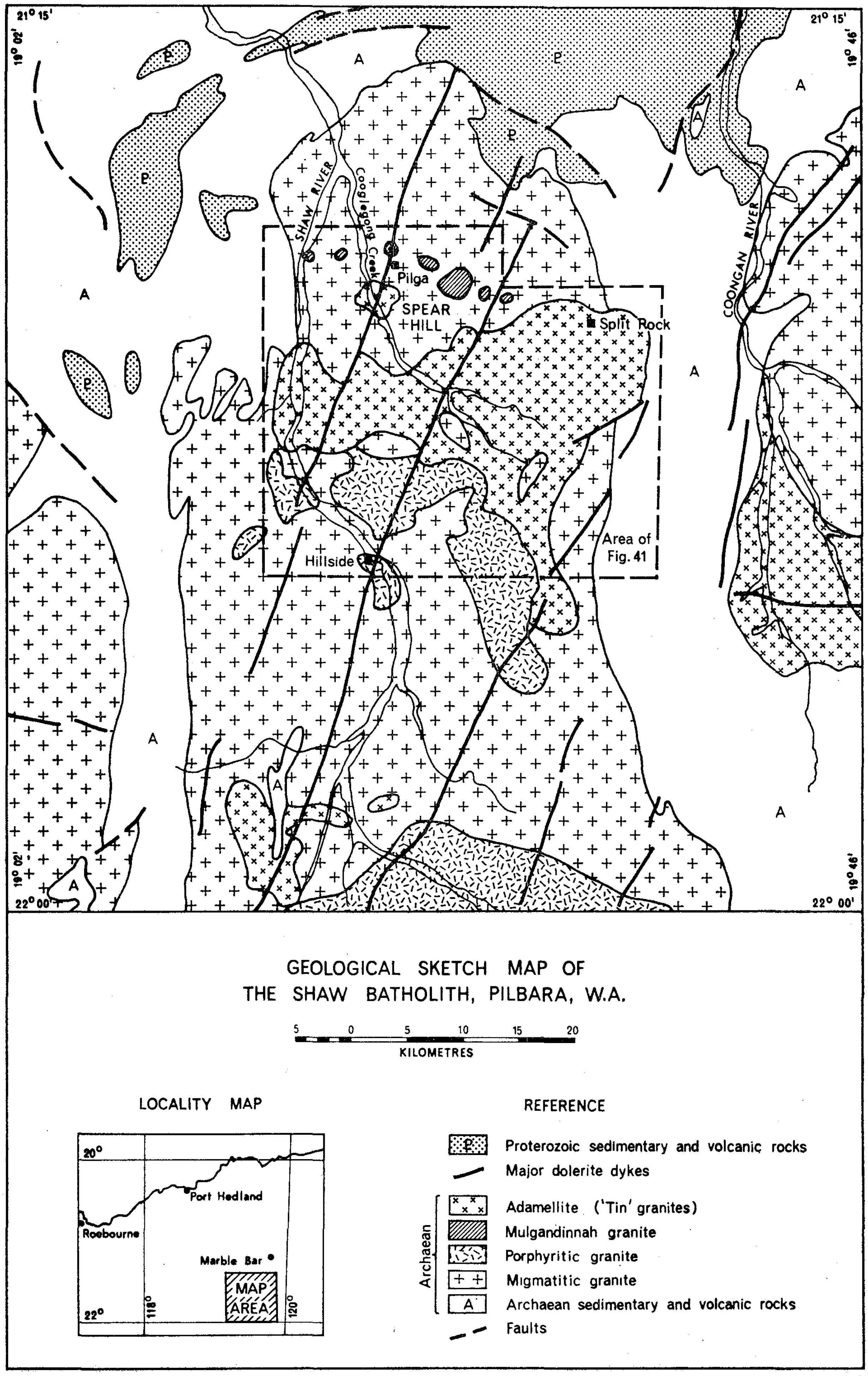

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Figure 40.

Younger granites—the Cooglegong Adamellite

Three stocks of medium to coarse-grained, poorly foliated biotite adamellite intrude the Shaw Batholith (Fig. 40) and constitute the younger, or "tin" granites of Blockley (1970). These granites are associated with cassiterite bearing pegmatites which intrude the older granites and have given rise to extensive tin workings in the district. The largest of the younger granites, named after the Cooglegong tin mining centre, is the Cooglegong Adamellite, which forms an irregular arcuate intrusion with an area of about 400 km² (Fig. 41). The Cooglegong Adamellite outcrops mainly as low tors and boulder fields, but in the area east of the Black Range outcrop is almost continuous over large areas.

The Cooglegong Adamellite intrudes the migmatitic, gneissic and foliated rocks of the older complex and where contacts are seen the relationship is intrusive, with the younger granite clearly transecting foliation and banding in the older rocks. Locally the Cooglegong Adamellite contain xenoliths of the older granite. Along its eastern margin the adamellite intrudes mafic and ultramafic rocks of the Warrawoona Group and the contact zone is marked by extensive pegmatites.

The Cooglegong Adamellite is cut by rhyolite and dolerite dykes and by quartz veins. The rhyolite dykes are restricted to the general vicinity of the Cooglegong and Spear Hill Adamellites and are probably related to the younger granite magma.

MATERIAL USED

Most of the samples of both older and younger granites used in this study were originally collected for geochemical work by J. G. Blockley. The samples proved inadequate to define an isochron for the older granite, and further sampling of the marginal migmatite complex was undertaken. The final choice of samples for geochronology was made on the results of preliminary XRF determination of Rb and Sr. Ten samples of older granite and seven of younger granite were selected and analysed. The location of each specimen is shown on Figure 41.

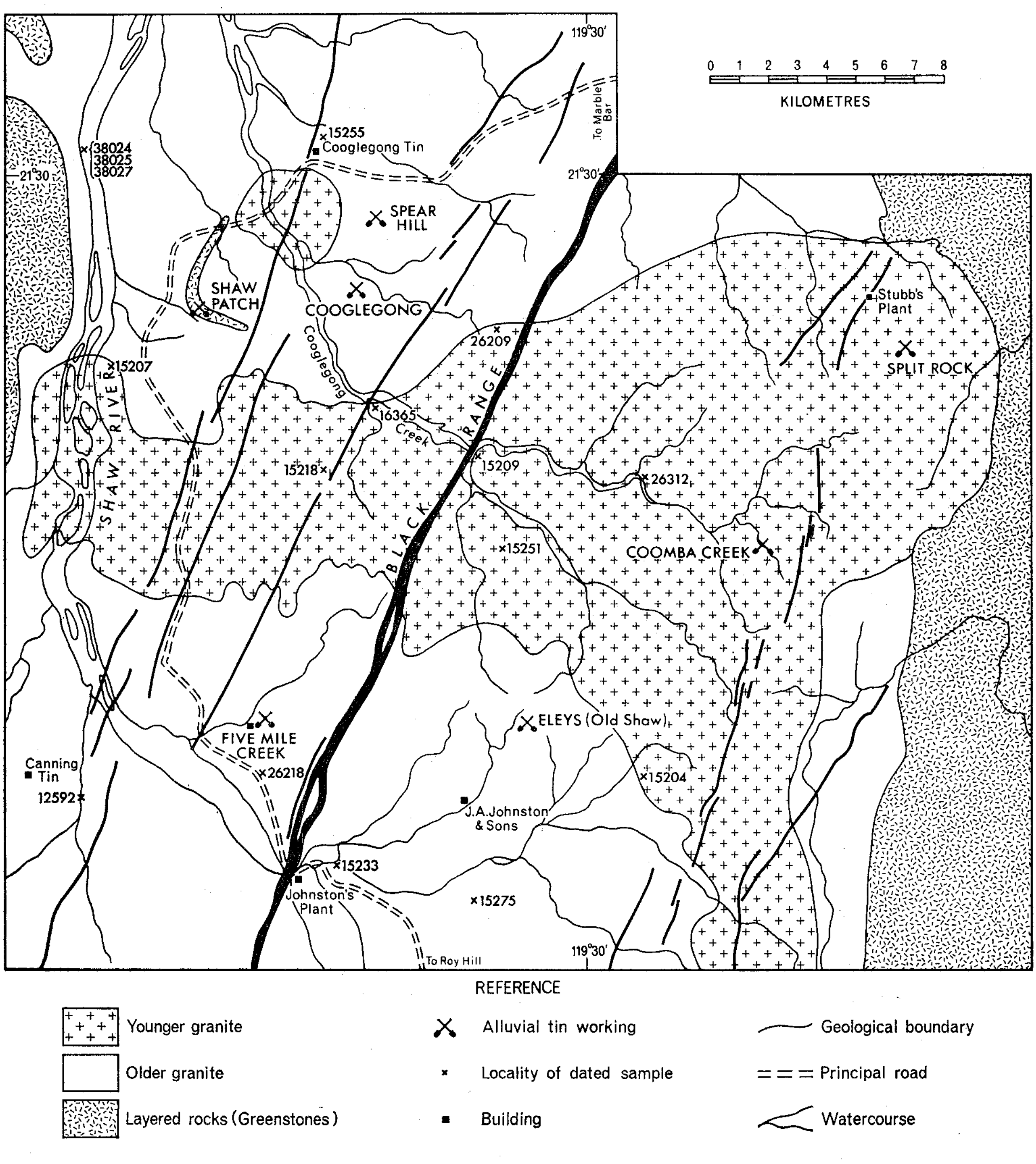

Figure 41. Geological map of the Cooglegong tin field showing localities of samples used in Rb–Sr age determinations.

Older granite

For descriptive purposes the samples can be divided into three groups, five samples of migmatite, three of gneissic granite and two specimens from discreet intrusions within the older granites.

The samples of migmatite were collected from an outcrop measuring about 100 by 200 m in the bed of the Shaw River, to the west of Spear Hill and less than one kilometre from the margin of the Shaw Batholith. The migmatite is a banded complex consisting of a granitic neosome and an amphibolitic palaesome. The amphibolites are the metamorphosed equivalents of the basaltic country rocks.

Specimens 38024A, 38025A, B and C, and 38027C are all from the granitic portion of the migmatite and are course-grained, strongly foliated mylonitic gneisses. The principal minerals in each specimen are quartz, microline and oligoclase, with minor hornblende or chloritized biotite. Secondary epidote, muscovite and carbonate, and accessory apatite, opaques and sphene are present in most specimens. Microcline is always more plentiful than oligoclase, specimens 38024A and 38025C being leucocratic granite, and the remainder hornblende adamellite. The migmatites appear to be derived from a sheared and partially recrystallized igneous rock. Individual feldspar crystals and elongate patches of mosaic quartz are surrounded by narrow zones of fine-grained recrystallized material and there are narrow veins of partially recrystallized material traversing the rock. It is suggested that at least two periods of deformation produced these mylonite gneisses.

Of the gneissic granites both 15255 and 12592 are granodiorites. Specimen 15255 was collected from a dark band in the gneiss and is a strongly foliated, medium-grained, equigranular granoblastic aggregate of sodic oligoclase, quartz and green hornblende, with subordinate microcline and accessory sphene, apatite, zircon and opaques. Secondary minerals present include epidote and chlorite. Specimen 12592 is a coarse-grained leucocratic granodiorite with large subhedral antiperthitic crystals of oligoclase, up to 1 cm long, set in a medium-grained granoblastic aggregate of quartz and oligoclase. A little chlorite and sphene are present as well as secondary epidote and sericite. Biotite adamellite is represented by specimen 26218 which is a coarse-grained, directionless, granoblastic aggregate of quartz, oligoclase and microcline with minor chloritized biotite, accessory, sphene and secondary epidote and sericite.

Specimens 15233 and 15375 were collected from intrusions which form part of the older granite complex, 15233 from a small stock of foliated adamellite, and 15275 from a large irregular intrusion of porphyritic adamellite. Phenocrysts in 15275 are of subhedral microcline, up to 1 cm long, and are set in a coarse-grained matrix of microline, oligoclase and quartz with minor biotite and accessory sphene, allanite, apatite and zircon. Secondary epidote and chlorite are also present. The overall texture of the rock is granitic with only minor modification due to metamorphism. The texture of 15233, a medium-grained biotite adamellite, also remains igneous in character. The sodic oligoclase of this rock has retained a subhedral crystal form and is often zoned to a narrow albitic rim. There are also relicts of a coarse granophyric intergrowth between microcline and quartz. The rock contains large flakes of secondary muscovite and has none of the small, euhedral brown sphenes that are common in the older granite suite. The possibility that 15233 comes from a small stock of younger granite will be discussed later.

Younger granite

Petrographically the samples of Cooglegong Adamellite form a homogeneous group. The rock is medium to coarse grained, directionless, leucocratic and equigranular. One specimen, 15204, however, is of a porphyritic variety. The rock consists essentially of quartz, microcline and plagioclase with minor biotite and chlorite and accessory apatite, zircon and opaques. Secondary minerals, other than chlorite, include epidote, muscovite, sphene and stilpnomelane and rare carbonate and fluorite. The texture of the rock is typically hypidiomorphic granular.

Slightly saussuritized microcline forms about two thirds of the feldspar present. It is commonly poikilitic, enclosing rounded grains of quartz and plagioclase. Perthitic exsolution lamellae of albite are present in most specimens, as is myrmekitic replacement. The microcline phenocrysts of specimen 15204 are up to 1 cm in length, and are mantled by strongly saussuritized plagioclase.

The plagioclase is a calcic oligoclass (An_{20-30}) and is is usually strongly saussuritized. Alteration is to epidote and sericite but in some specimens (15218, 15207) large flakes of muscovite have developed. Narrow zones of unaltered sodic oligoclase surround many crystals.

Most biotite in the Cooglegong Adamellite is altered partly, or completely, to a green chlorite. The chlorite is usually associated with epidote and colourless granular sphene, and sometimes with a little fluorite and carbonate (15207). In one specimen (26312) the biotite is being replaced by muscovite. Accessory apatite and zircon are also commonly associated with the chlorite and biotite.

EXPERIMENTAL PROCEDURES

All instruments and methods used in this study are the same as those described by Lewis and others (this volume p. 84).

RESULTS

The measured Rb/Sr and Sr^{87}/Sr^{86} ratios, as well as the Rb^{87}/Sr^{86} ratios calculated from them, are given in Table 13. The errors accompanying the data are at the 95 per cent confidence level. The data are also plotted in Figures 42 and 43.

TABLE 13. ANALYTICAL DATA FOR GRANITES FROM THE SHAW BATHOLITH

Sample No.	Rb (ppm)	Sr (ppm)	Rb/Sr	Rb^{87}/Sr^{86}	Sr^{87}/Sr^{86}
a. Older gneissic granites					
15255	37	725	0·80 ± 0·002	0·231 ± 0·004	0·711 4 ± 0·000 2
38025A	93	397	0·232 ± 0·003	0·671 ± 0·007	0·730 0 ± 0·000 2
12592	116	306	0·383 ± 0·004	1·110 ± 0·01	0·751 0 ± 0·000 3
38025B	120	296	0·403 ± 0·004	1·168 ± 0·02	0·750 7 ± 0·000 3
26218	158	249	0·637 ± 0·007	1·85 ± 0·02	0·781 3 ± 0·000 3
38027C	183	278	0·654 ± 0·007	1·90 ± 0·02	0·782 8 ± 0·000 2
38025C	197	215	0·90 ± 0·01	2·63 ± 0·03	0·809 7 ± 0·000 4
15275	173	154	1·14 ± 0·01	3·35 ± 0·03	0·339 7 ± 0·000 3
38024A	270	189	1·41 ± 0·02	4·15 ± 0·04	0·869 4 ± 0·000 4
15233	320	73	4·45 ± 0·05	13·5 ± 0·14	1·246 8 ± 0·000 5
b. Younger Cooglegong Adamellite					
26209	326	102	3·22 ± 0·03	0·64 ± 0·1	1·089 2 ± 0·000 4
15204	368	110	3·36 ± 0·04	10·1 ± 0·1	1·106 0 ± 0·000 4
15207	475	82	5·76 ± 0·06	17·7 ± 0·2	1·372 0 ± 0·000 5
15251	574	65	7·87 ± 0·08	24·7 ± 0·2	1·622 5 ± 0·000 5
16365	432	48	9·19 ± 0·1	29·3 ± 0·3	1·780 1 ± 0·000 5
15218	551	50	11·1 ± 0·1	36·4 ± 0·4	2·090 1 ± 0·000 6
26312	638	40	16·2 ± 0·2	56·81 ± 0·6	2·901 2 ± 0·000 6
15209*	480	40	12·0 ± 0·1	39·0 ± 0·4	1·979 1 ± 0·000 5

* This sample not included in the isochron (see text).

Note: The Rb and Sr concentrations have been determined by comparison with a number of standard rocks. Although no assessment of the mass absorption coefficient of individual samples was made we believe the values are accurate to about ±5 per cent. The Rb/Sr ratios do not correspond exactly with the ratios that would be derived from the separate Rb and Sr values shown.

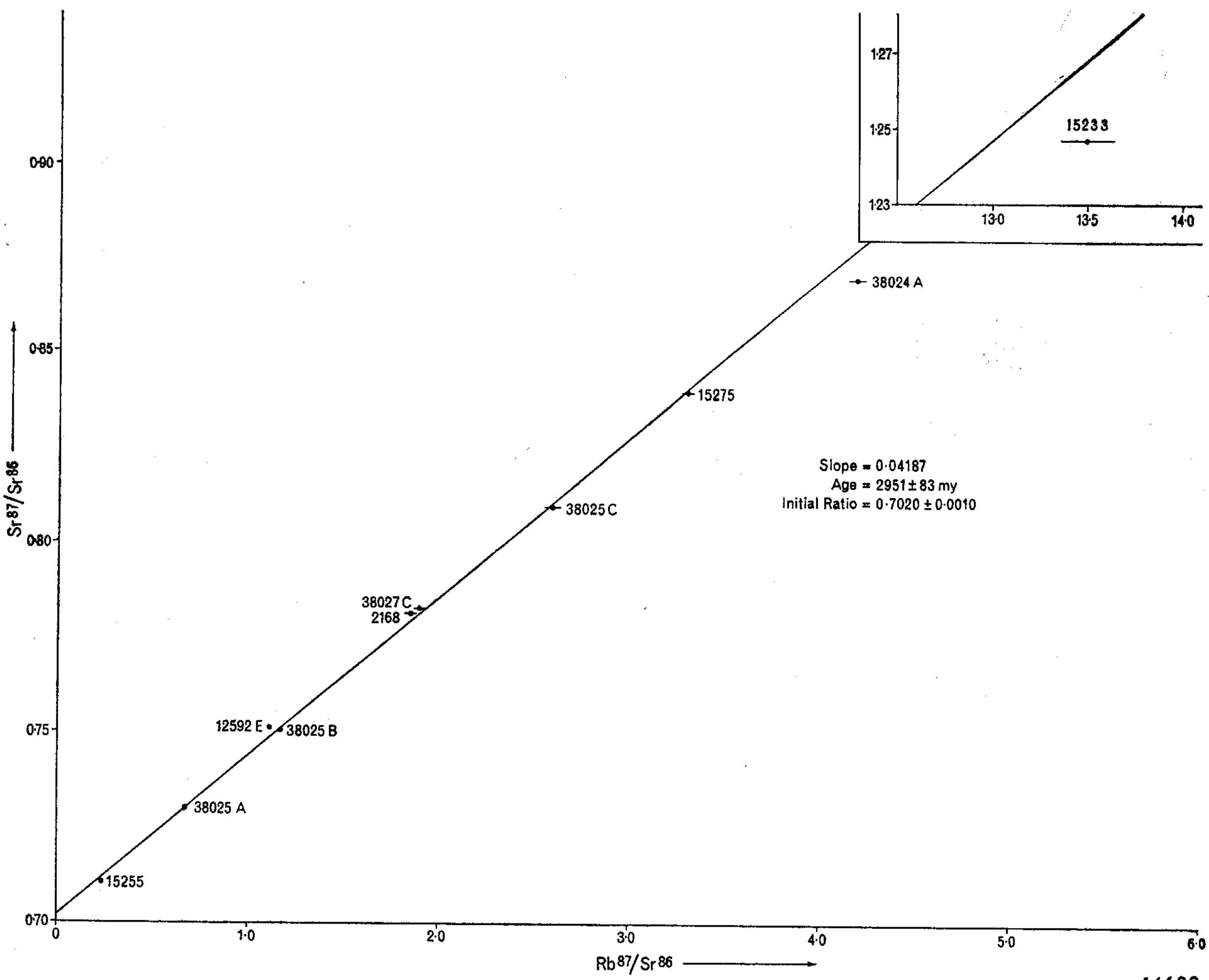

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Figure 42. Isochron plot of granite samples from the older gneissic and migmatitic portions of the Shaw Batholith.

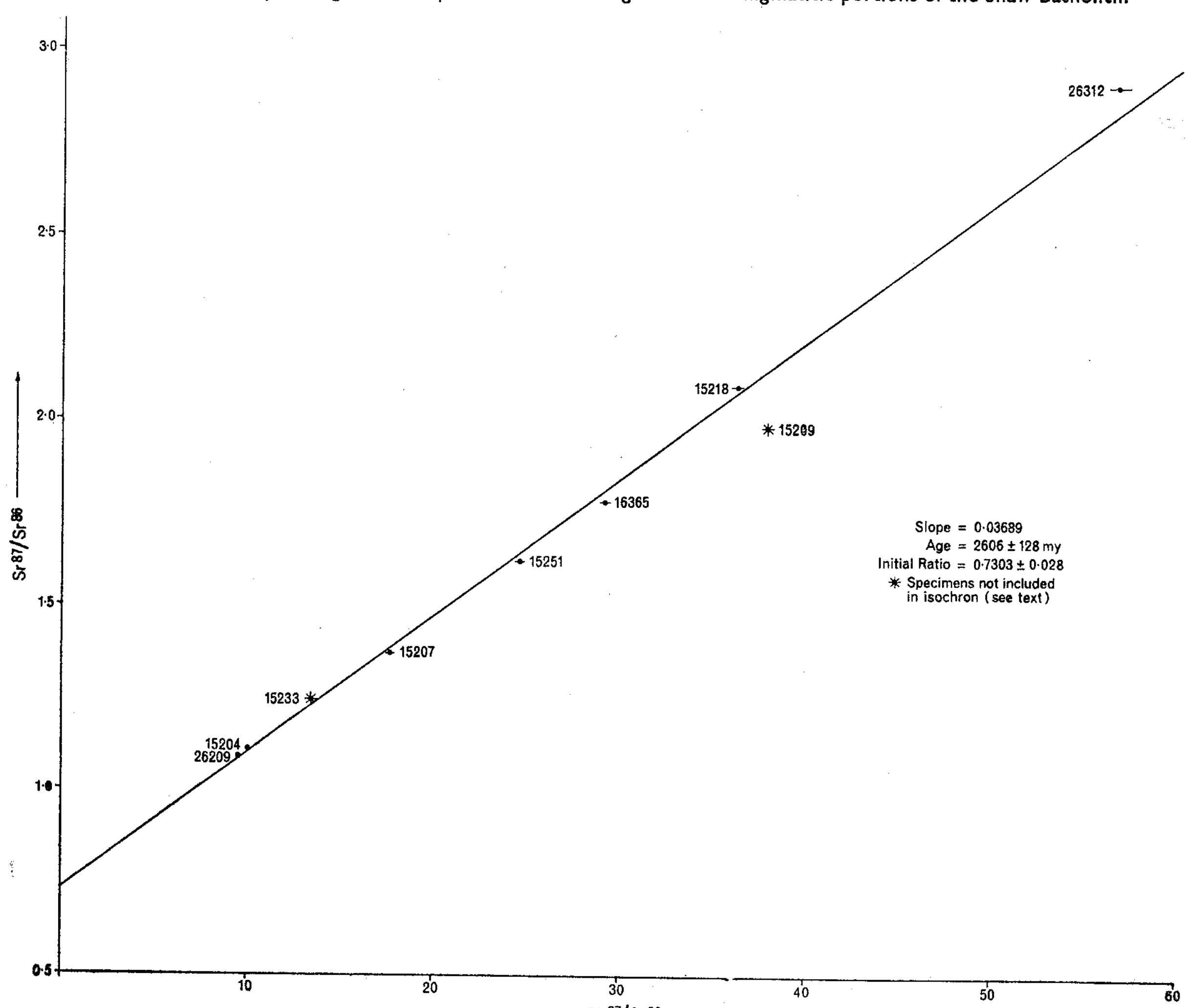

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Figure 43. Isochron plot of samples of the Cooglegong Adamellite.

Regression analyses of the Rb^{87}/Sr^{86} and Sr^{87}/Sr^{86} data were carried out using the programme of McIntyre and others (1966). The ages derived from the data are 2951 ± 83 m.y. for the migmatites and gneisses of the older granitic complex of the Shaw Batholith, and 2606 ± 128 m.y. for the younger Cooglegong Adamellite. The initial Sr^{87}/Sr^{86} ratio calculated for the older samples is 0.7020 ± 0.0010, and for the younger samples 0.7303 ± 0.028.

For both isochrons the mean square of the weighted deviates is greater than unity, implying a scatter in the data points greater than can be expected from experimental uncertainties alone. Either or both of the assumptions that the initial Sr^{78}/Sr^{86} ratios were homogeneous, and that all samples were closed to Rb and Sr, therefore, do not hold for these two suites of samples. The programme has examined each set of data for geological variation and indicated that the rocks within the older isochron probably had slightly different initial Sr^{87}/Sr^{86} ratios and ages, whereas the suite of rocks comprising the younger isochron had the same initial ratios but, slightly different ages.

DISCUSSION

The results of the present study confirm and extend the work of de Laeter and Blockley (1972). Two major periods of granite formation are indicated; an early period at about 3 000 m.y. during which the gneissic and migmatitics granites of the Shaw and Mount Edgar Batholiths were formed, and a later one at 2 700-2 600 m.y. during which the Moolyella and Cooglegong 'tin' granites were emplaced.

The radiometric age of the gneissic granites from the Shaw Batholith, 2951 ± 83 m.y., agrees with the 3050 ± 180 m.y. determined by Compston and Arriens (1968) for a composite sample of all the older Pilbara granites, and is within the error limits of the age found by de Laeter and Blockley (1972) for the Mount Edgar gneissic granites. The interpretation of this age, however, is problematic. Hickman and Lipple (1974) have shown that the older granite complex of the Shaw Batholith is a composite mass containing several distinct ages of intrusion. They have also shown that the main phase of deformation and metamorphism, which gave rise to the gneissic texture, affects the whole of the older granite complex. The isochron of Figure 42 includes two specimens from the intrusive bodies (15233 and 15275), as well as eight from the granites and migmatites into which they are intruded, so that the determined age is, strictly speaking, a metamorphic one. Field evidence, however, suggests that granite intrusion and regional deformation were synchronous in which case the separately mapped intrusions may be only the final phase of formation of the complex. If this is true, then the determined age will be related to the final phase of granite intrusion within the older Shaw granites. Small age differences in the samples, suggested by the statistical examination of the data may reflect an extensive period during which the granites were emplaced, and differences in initial Sr^{87}/Sr^{86} ratios are probably due to varying amounts of country rock assimilated by the marginal migmatite specimens.

As stated earlier the geological affinities of specimen 15233 are uncertain. It was collected from a small intrusion which was presumed to be part of the older granite suite, but has certain petrographic affinities with the younger granites. The specimen plots equally well on either isochron (Figures 42 and 43) and its removal from the older suite raises the calculated age only slightly to 2973 ± 86 m.y., with an initial Sr^{87}/Sr^{86} ratio of 0.7018 ± 0.0010.

The age determined for the younger, post-tectonic Cooglegong Adamellite, 2606 ± 128 m.y. agrees well with that determined for the Moolyella Adamellite. Regional mapping has demonstrated the presence of several similar granites (Blockley, 1970; Hickman and Lipple, 1974) and it seems probable that they were all intruded at about the same time. There is no known geological reason for the scatter of points on the isochron being related to slight age differences within the Cooglegong Adamellite but specimen 15209, which has been excluded from the calculations, has obviously been affected by its proximity to the Black Range dyke. Lewis and others (1975) have examined the adamellite within the contact aureole of the dyke and shown that the rock behaved as an open system with respect to Rb and Sr. Perhaps the intrusion of the dyke swarm had a minor effect on samples collected far from any exposed dyke.

As with the Mount Edgar Batholith the initial Sr^{87}/Sr^{86} ratio of 0.7020 ± 0.0010 for the older Shaw granites suggests an immediate mantle derivation. Similarly the ratio of 0.7303 ± 0.028 for the Cooglegong Adamellite is consistent with the remelting of pre-existing crustal rocks. The wide uncertainty of the latter value is due to the fact that none of the analysed specimens had a very low Rb/Sr ratio. The figure is, however, similar to the 0.7397 ± 0.0419 found by de Laeter and Blockley (1972) for the Moolyella Adamellite.

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THE AGE AND METAMORPHIC EFFECTS OF THE BLACK RANGE DOLERITE DYKE

by J. D. Lewis, K. J. R. Rosman* and J. R. de Laeter*

ABSTRACT

The Black Range dyke is a member of a large north-northeasterly trending basic dyke swarm in the Pilbara district of NW Western Australia. The dyke has been dated by the Rb-Sr method at 2 329 ± 89 m.y. and is shown to be a probable feeder for the overlying Mount Roe Basalt. Where studied the dyke is 120 m wide and has remelted the enclosing granite for a distance of 2 m. Chemical analyses of five samples show that apart from a narrow marginal zone of assimilation the dyke has had no effect on the bulk chemistry of the granite. Within the contact aureole however, microcline has been converted to perthitic orthoclase up to 55 m from the dyke. Within 24 m of the dyke a consideration of isotopic ratios shows that the rock behaved as an open system with respect to radiogenic Sr and that within 10 m of the dyke the granite completely lost its radiogenic Sr and has equilibrated with the dyke. From a consideration of the temperatures required to melt granite and convert microcline to orthoclase it is suggested that a temperature of about 530° C was required to bring about an open system with respect to Sr.

INTRODUCTION

The Black Range dolerite dyke is part of a north-northeast trending dyke swarm which gives rise to prominent topographic features in the Marble Bar district of the northwest of Western Australia. The dark ridge of gabbro, up to 60 m high, which marks the course of the Black Range dyke was remarked upon by the earliest exploration party in the area (Gregory, 1861) and by all subsequent geological parties.

Because cross cutting undeformed basic dykes could be found both in the Archaean rock and superincumbent sediments and lavas of the district, Maitland (1906) grouped the Black Range dyke swarm with his "Newer Greenstones" and assigned a post-Nullagine age. Noldart and Wyatt (1962), however, separated the dyke swarm from a few small dykes which undoubtedly cut the Nullagine succession and assigend a Lower Proterozoic, pre-Nullagine, age to the Black Range dyke.

More recent geological work (summarized by Daniels, 1966) has shown that the former Nullagine System probably spans a period of 1 500 m.y. and can be divided into two groups corresponding to Lower and Middle Proterozoic ages. The Lower Proterozoic Mount Bruce Supergroup has itself been separated into three groups, the Fortescue, Hamersley and Wyloo Groups and Daniels suggests an age of about 2 400 m.y. for the lowermost Fortescue Group, to which all the Proterozoic rocks in the vicinity of the Black Range dyke belong.

With respect to the Black Range dyke swarm the result of this recent work in the Pilbara district has been to narrow the time interval during which the dykes could have been emplaced. Another result has been to give rise to speculation that these very large dykes could be the feeders of the Mount Roe Basalt, which is the oldest stratigraphic unit of the Fortescue Group in the Marble Bar-Nullagine area.

The purpose of this paper, then, is to determine the age of the Black Range dyke and investigate the possibility that this may be the age of the Archaean/Proterozoic unconformity in the Pilbara region. The project was initiated after it was noted that a granite sample (15209), collected near the dyke for the age determination of the Cooglegong Adamellite, gave an anomalously low apparent age. This study will also investigate, therefore, the effect of thermal metamorphism on the isotope ratios of the surrounding granite.

REGIONAL SETTING

The regional geology of the Marble Bar area has been described by Noldart and Wyatt (1962) and more recently by Hickman and Lipple (1974). Essentially a layered sequence of Archaean volcanic rocks, the Warrawoona Group, overlain by sediments of the Gorge Creek Group, have been folded between large masses of intruded granite about 3 000 m.y. old. The volcanic and sedimentary sequences are now preserved in tight synclines which wrap round, and separate, the granites. The large migmatitic and gneissose granite batholiths have themselves been intruded by irregular stocks of equigranular adamellite (the "tin" granites of Blockley, 1970) and the whole is traversed by large basic dykes of the Black Range dyke swarm.

Overlying the Archaean rocks, with a strong angular unconformity, are the gently folded Lower Proterozoic rocks of the Fortescue Group. The succession consists of flood basalts and andesites with thick intercalations of tuff, shale, sandstone, grit and conglomerate and it has a maximum total thickness of 2 500 m in the Marble Bar geological map area. Nowhere is the succession complete. In the immediate vicinity of Marble Bar and overlying the northern margin of the Shaw Batholith only the Mount Roe Basalt, the Hardey Sandstone and the Kylena Basalt are present; that is, the three oldest members of the succession. To the south of the batholith, on the Roy Hill Sheet, the succession begins with the Kylena Basalt and continues up through the remainder of the Fortescue Group, to the lowermost member of the Hamersley Group, before the Cainozoic sediments of the Fortescue River are reached.

THE SHAW BATHOLITH

The Shaw Batholith (Fig. 44) is a large oval granitic dome, approximately 80 by 40 km in size, extending from about 30 km southwest of Marble Bar to a few kilometres south of the sheet margin. The greater part of the dome consists of leucocratic gneissic granite which becomes migmatitic within a few kilometres of the margin. The gneissic granite is variable but is commonly a medium to coarse-grained, equigranular biotite adamellite with some biotite grandiorite and a little biotite tonalite. Foliation in this mass is marked by elongate quartz blebs and the alignment of feldspar, biotite, and where present, hornblende. Marginally the Shaw Batholith has incorporated much basaltic country rock and consists of alternating bands of adamellite and amphibolite.

Extensive areas of foliated porphyritic biotite adamellite near the southern margin of the batholith, and to the northeast of Hillside also form part of the Shaw Batholith and the small stocks of the Mulgandinnah granite, a fine-grained biotite adamellite, probably represent remobilized older granite (Hickman and Lipple, 1974).

The youngest portions of the Shaw Batholith are three bodies of intrusive adamellite which constitute the younger "tin" granites of the area (Blockley, 1970). The largest of these bodies is the Cooglegong Adamellite, an irregular intrusion about 35 km long which divides the Shaw Batholith in two.

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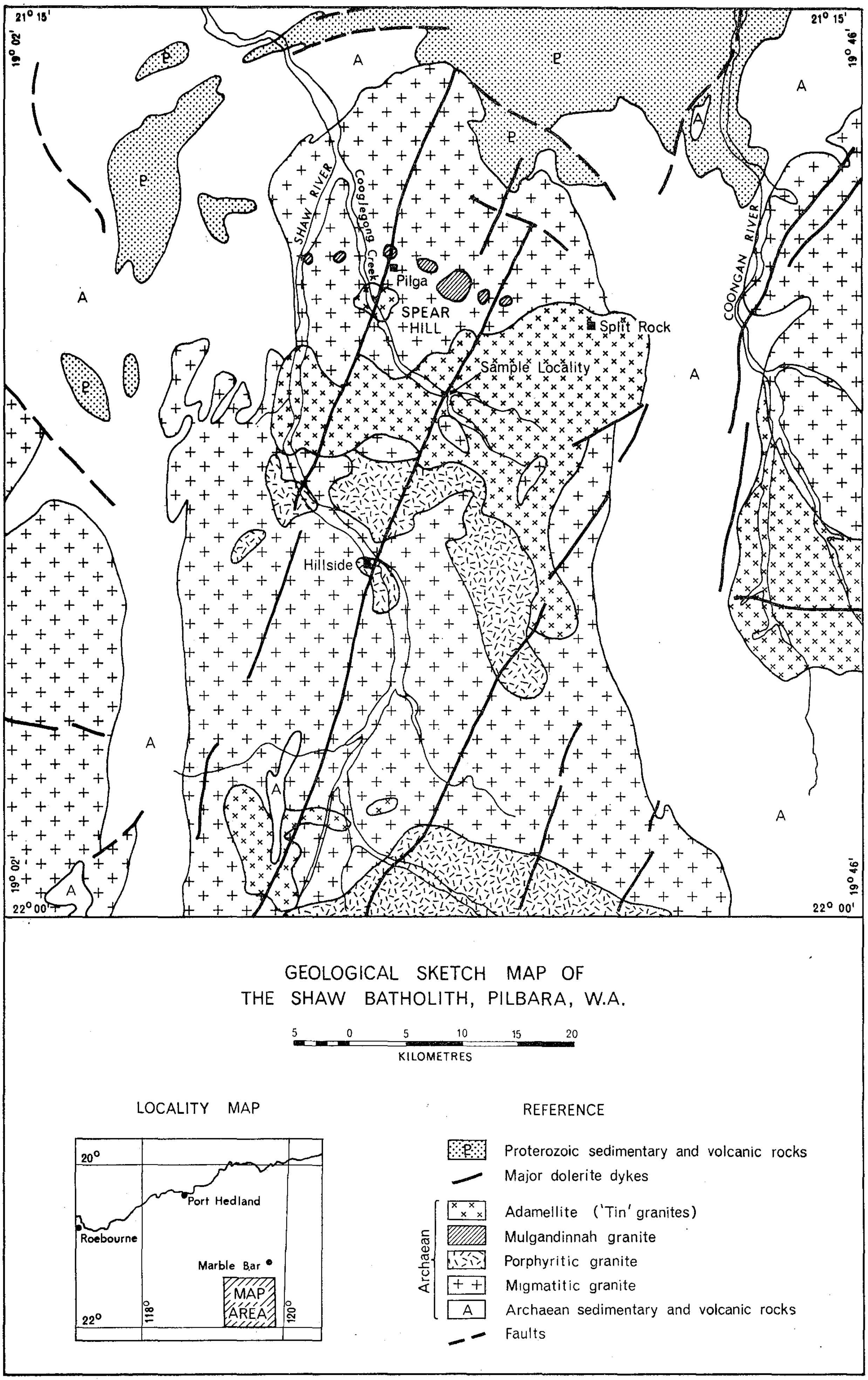
21° 15'
19° 02'
19° 46'
22° 00'
A
P
SHAW RIVER
Cooglegong Creek
Pilga
SPEAR HILL
Split Rock
Sample Locality
Hillside
COONGAN RIVER
GEOLOGICAL SKETCH MAP OF THE SHAW BATHOLITH, PILBARA, W.A.
5 0 5 10 15 20
KILOMETRES
LOCALITY MAP
20°
Port Hedland
Roebourne
Marble Bar
MAP AREA
22°
118°
120°
REFERENCE
Proterozoic sedimentary and volcanic rocks
Major dolerite dykes
Archaean
Adamellite ('Tin' granites)
Mulgandinnah granite
Porphyritic granite
Migmatitic granite
Archaean sedimentary and volcanic rocks
Faults
14688

Figure 44.

Smaller intrusions of similar rock type are found at Spear Hill, to the north of the main mass, and at Coodina to the south of Hillside. These younger granites are poorly foliated, leucocratic, medium to coarse-grained equigranular biotite adamellites.

THE BLACK RANGE DYKE

Throughout most of its area the Shaw Batholith forms a low level plain, with granite covered by a thin veneer of residual sand and gravel. The younger granites, however, form low rounded hills and the Black Range dyke traverses the batholith as a narrow razor-back ridge 60 m high and 70 km long. This ridge is cut at several points by rivers, most notably the Cooglegong Creek and the Shaw River. At these points the relationships between the dyke and the surrounding granites are best displayed, and this report is concerned principally with exposures in the Cooglegong Creek.

The Black Range dyke follows an almost continuous but slightly sinuous course from Coolyia Creek, 15 km northeast of Pilga, to Bootherina Pool on the Western Shaw River, a few kilometres inside the northern boundary of the Roy Hill Sheet. South of Hillside the dyke occupies a series of *en echelon* fractures, with only minor gaps and offsets to the course of the dyke. At Hillside, and again a few kilometres to the north, the dyke occupies a double fracture and encloses slices of granitic country rock a kilometre or so in length and about 100 m wide. The width of the dyke varies up to 150 m and its northern section is usually about 100 m wide. The Black Range dyke is intruded entirely into the granites of the Shaw Batholith; no information is available for its southern termination but at Coolyia Creek the dyke ends abruptly at a west-northwest trending fault. The fault is probably associated with a suite of dacite dykes which are earlier than the Black Range dyke, although movement along the fault continued after the emplacement of the dyke and has led to the preservation of Proterozoic basalts a little to the north.

SAMPLE LOCALITY-COOGLEGONG CREEK

At Cooglegong Creek an excellent section through the Black Range dyke is seen (Fig. 45). The western margin of the dyke is obscured by the same fallen boulders of coarse dolerite which obscure contact relationships throughout much of the dyke length, but it can be seen that the rock texture varies from basaltic near the margin to gabbroic near the centre of the dyke. The dyke is approximately 120 m wide at this point and as it is traversed towards the eastern margin the rock again becomes fine grained and basaltic in character. Whereas the dyke rock is nearly black throughout most of its exposure the marginal metre or so becomes considerably paler, and on examination xenocrysts of quartz and partially digested xenoliths of granite can be seen. This is evidently a zone of contaminated material with a diffuse boundary towards the dyke but with a sharp vertical margin towards a two to three metre wide zone of remelted granite which borders the dyke. Assimilation of granitic material by the basic magma is also well demonstrated by exposures near Hillside Homestead where veins of basalt carrying granitic xenoliths intrude along joints in the granite. Near the dyke margin the vein is of contaminated basalt and the xenoliths are angular and easily distinguished from the enclosing basalt. A few metres away, near the distal end of the vein, the xenoliths have been almost completely assimilated and remain only as ghosts in a porphyry matrix only slightly darker than the granite.

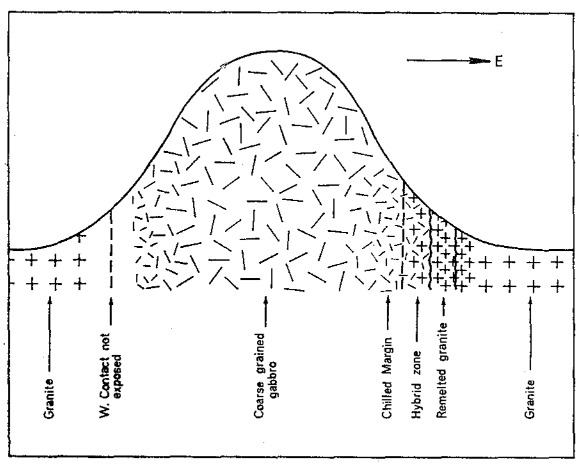

Figure 45. Diagrammatic cross-section of the Black Range dyke.

The zone of remelted granite which borders the dyke is well seen both in the Cooglegong Creek and at Hillside. Elsewhere the scree of gabbro blocks from the dyke effectively obscures this narrow marginal zone.

The remelted granite has the appearance of a coarse grained, pink weathering, quartz feldspar porphyry; towards both dyke and enclosing granite the margin is sharp and vertical but slightly irregular.

The country rock around Cooglegong Creek is the Cooglegong Adamellite, one of the younger "tin" granites of Blockley (1970). In the vicinity of the creek the rock is a medium to coarse grained, pink weathering, directionless granite that is sparsely jointed. A few small pegmatites are present in the granite, including one that carries a small quantity of beryl. Near the margin with the zone of remelted granite the Cooglegong Adamellite has a slightly baked appearance, but elsewhere the rock is uniform and apparently unaltered.

Petrography

Specimens were collected from each of the rock types present but, in particular, a suite of samples was collected from the granite at measured distances from the dyke margin in Cooglegong Creek. The location of each specimen is given in Table 14.

TABLE 14. BLACK RANGE DYKE-SPECIMEN LOCATIONS

Sample No.	Location (distance from dyke margin m)	Rock Type
Dyke Rocks		
15104	Dyke centre	quartz gabbro
15105	6·0	dolerite
15106	0·5	basalt
15107	0·1	contaminated basalt
Country Rocks		
15108	0·22	remelted granite
15109	2·4	partially remelted granite
15135	6·0	
15136	10·5	altered granite
15137	24	
15138	55	
15139	98	fresh granite
15140	189	
15141	305	

The central portion of the dyke is a moderately fresh, medium to coarse-grained gabbro consisting of prismatic labradorite, euhedral to subhedral augite and interstitial micropegmatite. The labradorite prisms are up to 4 mm long and are zoned from a core of composition An_{60-65} to a sodic rim of oligoclase (An_{20}). The plagioclase is fresh except for the development of a little chlorite along some cleavages. Augite crystals up to 3 mm long are commonly rimmed by and sometimes completely altered to a pale green actinolite. The relationship between augite and labradorite crystals indicates that they cristallized simultaneously. A few large patches of chlorite may indicate the former presence of orthopyroxene. The most notable feature of the gabbro is the proportion of interstitial granophyre. Most quartz dolerites contain a small proportion of micropegmatite, but in the Black Range gabbro the proportion rises to about 15 per cent and individual patches can be up to 3 mm across. Labradorite prisms usually form the nucleus about which the granophyre developed and the result is that some plagioclase is almost completely surrounded by granophyric over-growths of quartz and sodic plagioclase. Although the feldspar component of the granophyre is usually a poorly twinned plagioclase there are a few areas of microcline granophyre.

Other minerals present in the gabbro are minor apatite, ilmenite altered to leucoxene and granular sphene, and a little secondary brown hornblende and epidote.

Specimens 15105 and 15106, from the marginal portion of the dyke, are similar to the gabbro from the dyke centre in all except grain size and degree of alteration. In addition, patches of quartz are more common and within the granophyre microcline is more prominent. It is possible that this indicates a small amount of assimilation of granitic rock. In these marginal specimens alteration of pyroxene to actinolite and chlorite is complete and much of the plagioclase is saussuritized.

Hybridization has produced a narrow zone of very variable rock along the dyke margin but essentially the rock is a fine grained hornblende granophyre with corroded xenocrysts of quartz and feldspar. The bulk of the rock consists of saussuritized laths of calcic oligoclase, up to 1 mm long, and acicular actinolite, up to 2 mm long, with an interstitial matrix of very fine-grained granophyre and patches of clear quartz. The granophyre makes up about half the rock and appears to have formed on the oligoclase laths.

Plagioclase xenocrysts are present as ghost crystals and show the effects of assimilation by melt channels which have developed along cleavages, so dividing the original crystal into an orientated group of cleavage rhombs separated by a network of secondary plagioclase. Quartz xenocrysts however, are only attacked at the margins and are found as irregular shaped grains up to 8 mm across with embayed margins. Associated marginally with the quartz xenocrysts are small euhedral prisms of olive green hornblende. Whereas the actinolite of the main mass probably represents altered acicular augite, the green hornblende appears to have developed from mafic minerals associated with the granite xenoliths.

Remelted granite is represented by specimen 15108 which contains about 40 per cent of relict crystals from the original granite and 60 per cent of fine-grained granophyre. The relict material displays all stages of remelting, from patches in which a granitic texture is modified only by highly sutured margins and the development of minor granophyre zones along feldspar/quartz interfaces, through separated relict grains of quartz and feldspar, to ghost crystals of feldspar similar to the xenocrysts of the contaminated dyke margin. The groundmass contains many small prisms, up to 0.5 mm across, of albite and microline and a mass of fine-grained granophyre with larger interstitial quartz patches.

The mineralogy of the rock is similar to the granite mass and includes quartz, microcline and albite in sub-equal proportions, minor biotite and accessory zircon and ilmenite. The biotite, however, forms small olive-brown flakes which crystallized after the remelting and are not relict. Although in the field the boundary between the remelted granite of 15108 and the main mass of the country rock is easily delineated, remelting phenomena can be observed for a further 4 m away from the dyke. Specimen 15109, taken just outside the remelted zone, differs only in degree from 15108. Relict granite makes up about 60 per cent of the rock but granophyre zones up to 0.5 mm wide have developed along grain boundaries and there are large patches of granophyre where all original texture has been destroyed. The biotite in 15109 is the same small olive-brown flakes observed in 15108 but some appear to have recrystallized from larger original flakes. In 15135, 6 m from the dyke margin, granophyre zones between crystals have been developed but chloritized biotite from the original granite remains.

In the zone 10 m to 30 m from the margins of the dyke, the Cooglegong Adamellite has been altered but not reconstituted in any way. The main effects appear to be that microcline has been converted to orthoclase and the margin of some crystals are sutured and granulated.

All feldspars in this zone are slightly turbid and sericitized. These thermal effects diminish noticeably through the zone. Specimen 15136, 10.5 m from the contact, contains only orthoclase and the grain boundaries are highly sutured. Specimen 15137, 24 m from the contact, is similar but 15138, 55 m from the contact, shows no evidence of sutured margins due to contact metamorphism and the microcline is only patchily converted to orthoclase. In contrast to the non-perthitic microcline of the main granite mass in this narrow orthoclase zone, the K-feldspar is perthitic on a very fine scale. As a result of fine scale twinning perpendicular to the length of exsolved albite lamellae, some of the feldspar appears to have a fine microcline twinning pattern but under high power the feldspar is resolved into two components, a slightly sericitized orthoclase, twinned on the Carlsbad law, and exsolved blebs and spindles of plagioclase, twinned on the albite law. In specimen 15138 the conversion to perthitic orthoclase is seen only in zones within the microcline which have close spaced cleaveage. Outside these zones the microcline with normal cross-hatched twinning contains few perthitic lamellae. The granular margins, seen in specimens 15136 and 15137, are observed particularly at the interface of oligoclase and orthoclase crystals and appear to form by small overgrowths on the oligoclase.

In some instances there appears to be a diminution of albite blebs in the perthitic orthoclase over a narrow zone (0.1 mm) adjacent to the oligoclase and it seems that the granular margin has formed by diffusion of albite out of the orthoclase.

At approximately 60 m from the dyke margin, or half the width of the intrusion, the metamorphic effect of the dyke is minimal. Specimens 15139, 40 and 41 collected from 100 to 300 m from the dyke are typical examples of the Cooglegong Adamellite. The rock is coarse grained, leucocratic, directionless, sparsely porphyritic and contains sub-equal amounts of quartz, microcline and plagioclase with minor biotite accessory apatite, zircon and opaques and secondary chlorite, muscovite and epidote. Subhedral phenocrysts of microcline, up to 2 cm across, are sparsely distributed throughout the rock and usually enclose small e/uhedral crystals of sodic oligoclase (An_{16}). Early formed subhedral plagioclase crystals, up to 2 mm across, are also sodic oligoclase but are usually zoned to a narrow rim of albite (An_8). The bulk of the rock, however, is a xenomorphic aggregate of quartz, microcline and albite (An_8), the latter apparently replacing microcline. The plagioclase is usually slightly sericitized and in both feldspars large flakes of muscovite have developed. Small flakes of interstitial brown biotite, usually partially chloritized, are associated with accessory apatite and zircon and secondary epidote.

CHEMISTRY

Table 15 contains analyses and norms of five rocks from the Cooglegong Creek area including the contaminated marginal basalt and the remelted granite.

The gabbro from the dyke centre (15104) is a normal tholeiite except for a higher than usual silica content. The high proportion of micropegmatite in the rock would account for the high silica figure and the 8 per cent quartz of the norm.

Similarly the analysis of 15141 is consistent with the leucocratic adamellite described above, and contact metamorphism of 15135 does not appear to have altered the bulk chemistry of the rock. Almost complete remelting has not changed the major element of chemistry of 15108. This rock, only a few centimetres from the dyke margin, has not lost its more mobile constituents such as Na_2O and K_2O, neither has it assimilated any basaltic material. Assimilation of acid material by the basic dyke, however, is well illustrated by 15107C. Apart from the Al_2O_3 figure, which is inexplicably lower than either the gabbro or the adamellite, a mixture of 60 per cent granitic material and 40 per cent basic gives a good approximation to the actual analysis of the hybrid rock.

TABLE 15. ANALYSES OF SPECIMENS FROM THE BLACK RANGE AND COOGLEGONG GRANITE

Sample No.	15104	15107C	15108	15135	15141
SiO_2	54·19	66·77	75·20	74·56	74·78
Al_2O_3	13·58	12·79	13·21	13·57	13·72
TiO_2	0·62	0·36	0·10	0·05	0·05
Fe_2O_3	1·19	1·09	0·39	0·07	0·16
FeO	8·77	4·59	1·31	0·99	0·99
K_2O	0·64	2·92	4·42	4·69	4·29
Na_2O	1·74	2·34	3·57	3·90	4·00
CaO	9·28	4·44	0·78	0·72	0·77
MgO	7·49	3·24	0·23	0·11	0·14
MnO	0·21	0·10	0·05	0·08	0·05
CO_2	0·04	0·03	0·03	0·04	0·01
P_2O_5	0·09	0·05	0·03	0·02	0·03
H_2O^+	2·15	1·44	0·70	0·45	0·47
H_2O^-	0·07	0·06	0·13	0·12	0·03
Total	100·1	100·2	100·2	99·4	99·5

Trace Elements (ppm)

F	525	545	80	775	825
Li	230	40	40	25	120
Rb	345	165	375	620	510
Sr	130	115	35	20	20
Ba	1 070	800	350	220	200
Zr....	a	a	a	50	90
Sn	b	b	b	b	b
Ni	180	75	15	20	15
Cu	90	55	10	40	40
Zn	110	75	75	50	60
U	b	6	8	6	2

a = less than 10 ppm b = less than 2 ppm

C.I.P.W. Norms

Q	8·34	26·03	34·89	31·59	32·64
C	0·00	0·00	1·29	0·93	1·16
Or	3·55	17·14	26·00	27·78	25·41
Ab	14·72	19·80	30·21	33·00	33·84
An	27·53	15·86	3·48	3·19	3·56
Di	14·50	4·66	0·00	0·00	0·00
Wo	7·38	2·36	0·00	0·00	0·00
En	4·02	1·22	0·00	0·00	0·00
Fs	3·10	1·08	0·00	0·00	0·00
Hy	25·97	12·75	2·48	2·03	1·89
En	14·66	6·75	0·50	0·25	0·25
Fs	11·31	5·99	1·98	1·78	1·64
Mt	1·74	1·59	0·58	0·14	0·29
Il	1·18	0·68	0·19	0·09	0·09
Ap	0·21	0·12	0·07	0·05	0·07
Cc	0·09	0·07	0·07	0·09	0·02

15104: Gabbro, dyke centre.
15107C: Marginal hybrid rock.
15108: Remelted granite.
15135: Partially melted granite 6 m from dyke.
15141: Fresh granite 305 m from dyke.

Analysts: Government Chemical Laboratories; 15104, 15107C, 15108: R.S.Y. Pepper; 15135, 15141: R. W. Lindsey.

Whereas the major element chemistry of these rocks is comparable to normal basic and granitic rocks, the trace elements reveal some striking anomalies when compared with published averages (e.g. Krauskopf, 1967; Vinogradov, 1962). While Ni, Cu and Zn values conform to the published figures Rb is high and Sr low in both gabbro and adamellite. The average Rb/Sr ratio for gabbroic rocks is about 0.1 and for granites about 0.6, but in this study (see Table 16) the ratios are approximately 0.6 and 13 respectively. This suggests that both rocks are highly differentiated and that for the Cooglegong Adamellite the present level of erosion is very near the roof of the intrusion.

The Li values are also high, particularly for the gabbro, but while Ba is high in the gabbro it is low in the adamellite. The low values recorded for Li in the remelted and contact altered adamellite (15108, 15135) might be a reflection of the mobility of this element at an elevated temperature.

EXPERIMENTAL PROCEDURES

About 200 g of each sample was reduced to -200 mesh using a jaw crusher and a Tema mill. Approximately 0.4 g of each powdered sample was then taken into solution using a $HF-HClO_4$ mixture. The solution was then converted to the chloride form with 2.5M HCl. After taking to dryness the residue was dissolved in 1M HCl and centrifuged.

The supernate was transferred to a quartz ion-exchange column containing 2g of Dowex 50W-X8, 200-400 mesh cation-exchange resin. Strontium was eluted using 2.5M HCl 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 12 inch 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 $0.710\,2 \pm 0.000\,1$, normalised to a Sr^{88}/Sr^{86} value of 8.375 2. The Sr^{87}/Sr^{86} values listed in Table 16 have been normalised to a Sr^{88}/Sr^{86} value of 8.375 2. A value of 1.39×10^{-11}/yr 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 analysis, 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.

RESULTS

The measured Rb/Sr and Sr^{87}/Sr^{86} ratios, as well as the Rb^{87}/Sr^{86} calculated from these, are given in Table 16. The errors accompanying the ratios are at the 95 per cent confidence level. The data are also plotted on Figures 46 and 47.

TABLE 16. ANALYTICAL DATA FOR THE BLACK RANGE DOLERITES AND ASSOCIATED ADAMELLITES

Sample No.	Rb ppm	Sr ppm	Rb/Sr	Rb^{87}/Sr^{86}	Sr^{87}/Sr^{86}
(a) Dyke Rocks					
15104	44	120	0·363 ± 0·004	1·05 ± 0·01	7·752 1 ± 0·000 3
15105	106	161	0·655 ± 0·007	1·91 ± 0·02	0·799 1 ± 0·000 3
15106	75	79	0·907 ± 0·009	2·65 ± 0·03	0·818 2 ± 0·000 3
15107	183	140	1·32 ± 0·01	3·83 ± 0·04	0·846 2 ± 0·000 4
(b) Cooglegong Adamellite					
15108	440	61	7·23 ± 0·07	22·4 ± 0·2	1·466 5 ± 0·000 2
15109	661	45	14·6 ± 0·15	49·4 ± 0·5	2·475 2 ± 0·000 4
15135	684	42	16·4 ± 0·16	56·1 ± 0·6	2·605 8 ± 0·000 4
15136	636	48	13·1 ± 0·13	43·3 ± 0·4	2·191 5 ± 0·000 3
15137	576	43	13·3 ± 0·13	44·4 ± 0·5	2·291 7 ± 0·000 4
15138	608	44	13·7 ± 0·14	46·7 ± 0·5	2·567 4 ± 0·000 5
15139	595	48	12·4 ± 0·12	41·0 ± 0·4	2·202 2 ± 0·000 4
15140	535	54	9·9 ± 0·10	32·1 ± 0·3	1·980 6 ± 0·000 4
15141	590	56	10·6 ± 0·11	34·6 ± 0·4	2·052 5 ± 0·000 4
15209*	480	40	12·0 ± 0·12	39·0 ± 0·4	1·979 1 ± 0·000 4

* This sample was analysed as part of the project on the Shaw Batholith (de Laeter and others, 1975).

NOTE: The Rb and Sr concentrations have been determined by comparison with a number of standard rocks. Although no assessment of the mass absorption coefficient of individual samples was made we believe the values are accurate to about ±5 per cent. The Rb/Sr ratios do not correspond exactly with the ratios that would be derived from the separate Rb and Sr values shown.

Regression analysis of the Rb^{87}/Sr^{86} and Sr^{87}/Sr^{86} data were carried out using the programme of McIntyre and others (1966). The data which were fitted to an isochron (Fig. 46) were the four samples from the dyke itself (15104-15107), the remelted granite 15108 and the partially remelted granites 15209 and 15135. The mean square of the weighted deviates for these samples 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 was homogeneous, and that all the samples were subsequently closed to Rb and Sr, therefore do not hold for the suite of samples. The programme has then examined the set of data for geological variation and indicated that the distribution of the residuals suggests that the rocks comprising the isochron probably have slightly different initial Sr^{87}/Sr^{86} ratios and ages. The best estimate of the age of the rocks is 2 329 ± 89 m.y. and the initial Sr^{87}/Sr^{86} ratio 0.7262 ± 0.012.

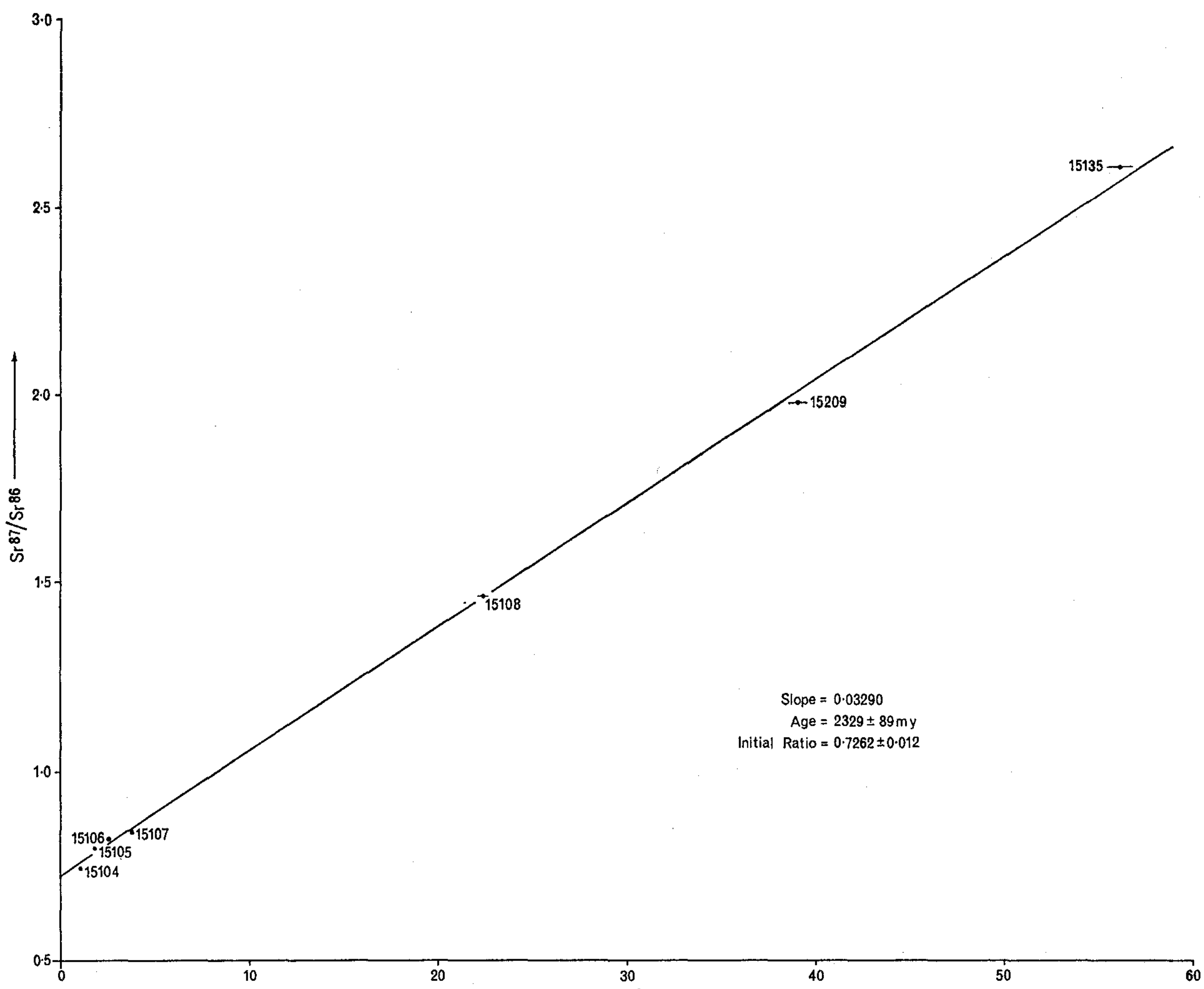

Figure 46. Isochron plot of samples from Black Range dolerite dyke and its metamorphic aureole. 15104–7: dolerite samples; 15108, 15135, 15209: granite samples.

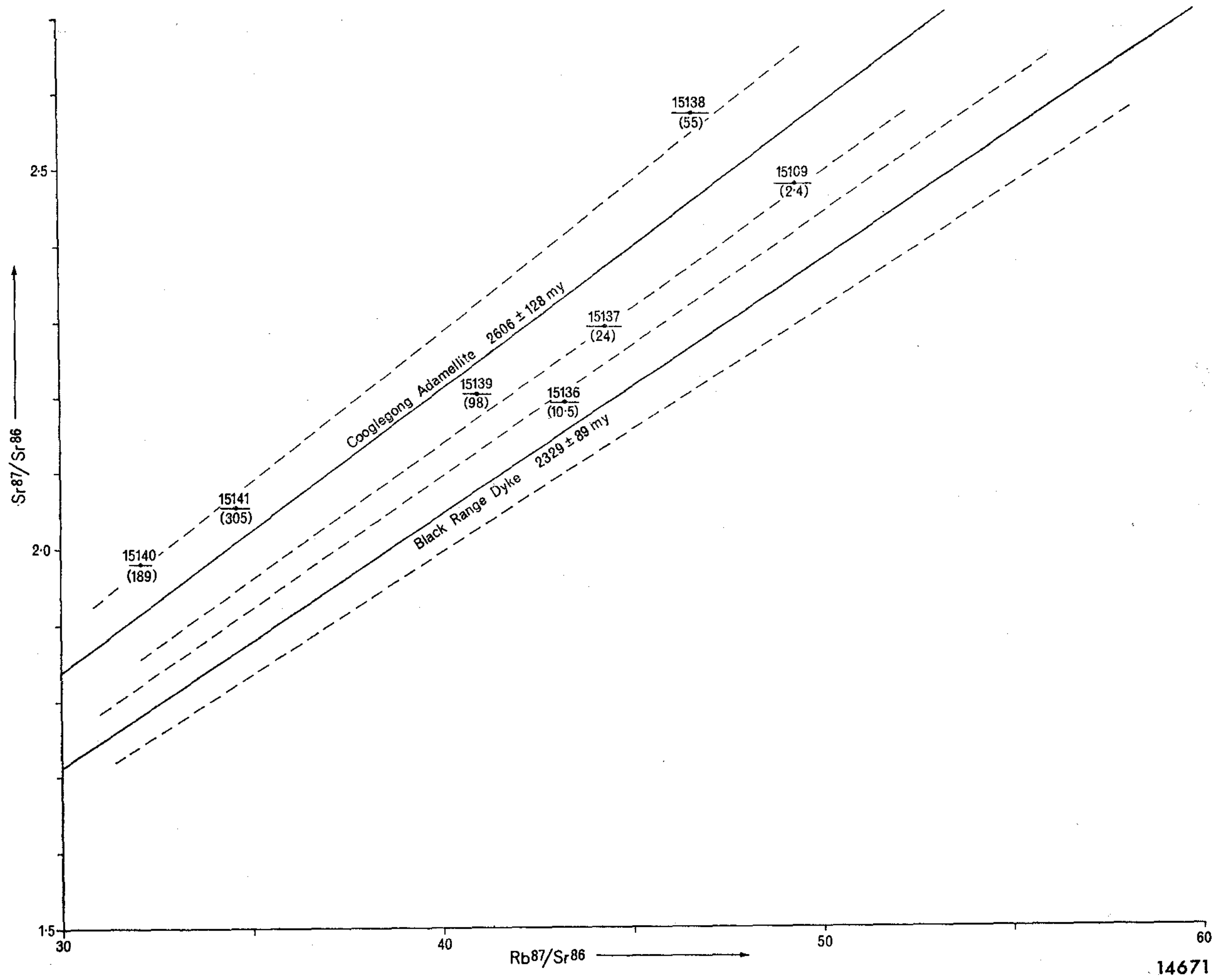

Figure 47. Isochrons of Cooglegong Adamellite (de Laeter and others, 1975) and Black Range dyke, with samples from the contact aureole of the dyke not plotted on Figure 46. Figures in brackets are distance of samples from the dyke in metres.

An isochron comprising only the four samples from within the dyke and the completely remelted granite at the dyke margin (15108) gave an age of 2 340 ± 120 m.y. and an initial $Sr^{87}/^{86}$ ratio of 0.7259 ± 0.016.

DISCUSSION

The age of the Black Range dyke as found in this study is consistent with the geology of the area. The dyke is younger than the Cooglegong Adamellite which has been dated at 2 606 ± 128 m.y. (de Laeter and other, 1975) and is older than the 2 200 m.y. obtained by de Laeter and others (1974) for shales in the Weeli Wolli Formation in the overlying Hamersley Group.

The Mount Roe Basalt, the lowest member of the Fortescue Group, is a highly carbonated and altered basalt and unsuitable for radiometric dating but it is possible that the Black Range dyke at 2 329 ± 89 m.y. could be a feeder for the flows. As stated earlier no direct connection exists between the dyke and the basalt flows as the Fortescue Group, to the north of the Shaw Batholith, is preserved only by the downthrow of the fault against which the dyke terminates. Near the township of Nullagine however, the Cajuput dyke, another member of the Black Range dyke swarm, is overlain by the Hardey Sandstone and cuts basalts believed to be part of the Mount Roe series (Hickman, in prep.).

As the Hardey Sandstone conformably overlies the Mount Roe Basalt it appears reasonable to assume that the age of the Cajuput dyke and the age of the Black Range dyke swarm would be no younger than the age of the youngest flow of the Mount Roe Basalts. The age of these basalts and hence the age of the Archaean/Proterozoic unconformity in the Marble Bar area will, therefore, not be dissimilar to the 2 329 ± 89 m.y. found for the Black Range dyke.

For a dyke as large as the Black Range, part of a swarm covering most of the Pilbara region, it could reasonably be assumed that the magma was derived directly from the mantle. The initial Sr^{87}/Sr^{86} ratio of 0.7262 ± 0.012, however, suggests that the magma was derived by reworking older crustal material. This initial ratio is similar to that found for the Moolyella granite, 0.7397 ± 0.042 and for the Cooglegong Adamellite, 0.7303 ± 0.028 (de Laeter and Blockley, 1972; de Laeter and others, 1975), both of which appear to have been formed by reworking of older granitic material. A possibility exists that the magma has been enriched in radiogenic strontium. Fratta and Shaw (1974) described "residence contamination" of a basic dyke by diffusion of K, Rb, and Li from a granitic country rock but although this might explain the high Rb and Li content of the dyke, the K_2O content has remained normal for a basic magma.

Fratta and Shaw did not find that Sr diffused into the dyke. Neither is contamination a likely source of radiogenic Sr. Various studies have shown that when a basic magma assimilated granitic material potash is preferentially extracted (Lewis, 1970) and again, the potash has remained low in the Black Range dyke. In the absence of an alternative explanation it must be assumed that the Black Range dyke represents reworked Archaean material.

Age determination by the Rb-Sr whole rock method gives the time elapsed since the rock ceased to be an open system. For igneous rocks this will usually be the age of the intrusion. A later period of metamorphism can relatively easily re-equilibrate the minerals within the rock without disturbing the closed system of the whole rock and many examples are available (see Faure and Powell, 1972, p. 98) where, after quite severe metamorphism, the whole rock samples indicate the age of intrusion while mineral separates give the age of metamorphism. The intrusion of a dyke would not normally be considered to cause severe metaporphism of the country rock yet the isochron for the Black Range dyke has been obtained by including several whole-rock analyses of the enclosing Cooglegong Adamellite. It is concluded, therefore, that close to the dyke the adamellite became an open system with respect to Rb and Sr. The adamellite bordering the dyke was almost totally remelted and entirely lost its radiogenic Sr.

It appears that this open system extended into the adamellite at least 24 m from the dyke margin and that for the first 10 m the rock came into nearly complete equilibrium with the dyke. Some portions of the rock closer than 10 m from the dyke, however, did not equilibrate (spec. 15109) and the statistical analysis of the specimens making up the isochron of Figure 46 indicates that the initial Sr^{87}/Sr^{86} ratios were slightly different and probably reflect the diverse origins of the specimens. Beyond 50 m from the dyke, however, the rock appears to retain the age of intrusion of the Cooglegong Adamellite. All specimens from the metamorphic aureole of the dyke not used to calculate the isochron for the dyke are plotted on Figure 47 along with the isochron for the dyke and for the adamellite (from de Laeter and others, 1975). It will be seen from the graph that several specimens lie between the two isochrons, indicating perhaps a partial equilibration, and that the specimens collected furthest from the dyke actually appear to be older than the Cooglegong Adamellite. It is possible that this apparently older age is due to the expulsion of radiogenic Sr^{87} from the aureole of the dyke.

Direct evidence for migration of radiogenic Sr under moderate metamorphic conditions is not common, but Wasserburg and others (1964) have shown that hornblende diorite dykes which intrude augen gneiss, granites and overlying metasediments, all of Precambrian age, have been enriched in Sr^{87} during Mesozoic metamorphism.

In this example, from the Panamint Mountains of California, the dykes have a metamorphic mineral assemblage but the metamorphism has not been sufficient to obliterate the original basaltic textures. Nevertheless, Sr enrichment has occurred on a scale sufficient to give apparent ages which are absurd. The Black Range dyke, in contrast, appears to have caused a depletion of radiogenic Sr within its aureole and to be the first reported example of the open-system behaviour of whole-rock samples due to contact metamorphism.

Several authors, however, have reported the lowering of mineral ages within a contact aureole. Hart (1964) studied the contact zone of the Eldora Stock, Colorado, a small intrusion of adamellite, and found that various minerals responded differently to contact metamorphism but that beyond one intrusion width the ages were unaffected. At distances less than one-tenth the intrusion width, however, the mineral ages of biotite and K-feldspar were severely affected and rapidly approached the age of the intrusive stock. Calk and Naesser (1973) studied the thermal effect of a small basalt intrusion on fission tracks in sphene and apatite from the surrounding adamellite. Again it was shown that beyond one intrusion width there has been no effect and that complete annealing of the apatite took place only within a zone of one-tenth the intrusion width from the basalt.

Despite the difference in methods used the same order of magnitude applies to the metamorphic effect of the Black Range dyke. The dyke is approximately 120 m wide and a sample taken 10.5 m from the dyke has been completely equilibrated while samples beyond 100 m appear to be unaffected.

Insufficient data are available to make an independent estimate of the temperature required to bring about the open-system behaviour of the adamellite with respect to Rb and Sr but, from a consideration of the results of other workers, some estimate of the temperature distribution through the metamorphic aureole can be made.

From regional geological considerations it is unlikely that the present level of erosion is more than 1-2 km below that at the time of intrusion of the dyke. Initial wall rock temperatures, therefore, would be only about 50°C and pH_2O about 500 Kb. Assuming instantaneous injection and an initial temperature of 1 100°C for the basic magma the contact temperature would reach a maximum of 575°C and then decline (Jaeger, 1968). This temperature would be insufficient to melt the adamellite but the presence of a remelted zone 2 m wide, and partial melting up to 6 m from the dyke, indicates that elevated temperatures must have been maintained for a considerable period of time.

Experimental work by Tuttle and Bowen (1958) on the system Q-Or-Ab-H_2O suggests a minimum melting temperature of 770°C at 500 Kb and Piwinskii (1968) obtained a melting temperature of 725°C for granites of the Sierra Nevada Batholith. Such temperatures could be obtained at the margin of the Black Range dyke only by convection or by a flow of magma through the dyke channel. Convection is unlikely because this would lead to homogenization of the contaminated wall rocks with the bulk of the magma. A flow of magma through the dyke channel is consistent with the dyke being a feeder to the Mount Roe Basalts. As partial remelting has affected rocks up to 6 m from the contact, it must be assumed that a temperature of about 750°C was attained for a short while at this distance and that contact temperatures rose somewhat higher.

A second maximum temperature point can be obtained within the contact aureole of the Black Range dyke by considering the transformation of microcline to orthoclase which takes place within 55 m of the dyke. The transition has been investigated by Steiger and Hart (1967) and Wright (1967) for the metamorphic aureole of the Eldora Stock. These authors conclude that the transformation takes place slightly below 400°C, more than 50°C lower than experimental work suggests. (Goldsmith and Laves, 1954; Tomisaka, 1962).

The two temperatures thus obtained for the aureole of the Black Range dyke, 750°C at 6 m and 400°C at 55 m allow an estimation of the temperature at significant points within the aureole. Twenty-four metres from the dyke specimen 15137 has lost a significant proportion of its radiogenic Sr and, assuming an exponential temperature gradient, a temperature of about 530°C is suggested. Similarly 10 m from the dyke, where the Cooglegong Adamellite has behaved as a completely open system with respect to radiogenic Sr, the temperature rose to about 650°C. These temperatures are in agreement with Steiger and Hart (1967), who estimate a temperature of 500-550°C for the regional metamorphism which equilibrated the Sr of the Idaho Springs Formation surrounding the Eldora Stock, and the 500-600°C estimated from Calk and Naesser (1973) to erase fission tracks from apatite and sphene. The temperatures produced in the aureole of the Black Range dyke are also in excess of the 350-400°C required to reset mineral ages in the aureole of the Eldora Stock (Steiger and Hart 1967).

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A GEOCHEMICAL STUDY OF A DOLOMITE-BIF TRANSITION IN THE LOWER PART OF THE HAMERSLEY GROUP

by R. Davy

ABSTRACT

Partial chemical analyses are reported on approximately 50 samples taken from the lower part of the Millstream No. 9 drill core to cover the transition between iron formation and the overlying dolomite unit of the Wittenoom Dolomite. The iron formation contains less iron (22.6 per cent Fe) and more calcium (6.6 per cent CaO) than other magnetite-bearing iron formations from Western Australia and other parts of the world. A transition zone, 2.2 m thick, separates the iron formation from the dolomite. This zone has a high iron content with magnetite-rich bands, but otherwise is similar in lithology to the overlying rocks. The dolomite unit is characterized by a mixture of very uniform dolomites, carrying up to 1.1 per cent MnO, with thin bands of intercalated carbonaceous shale. The latter contain up to 11.9 per cent K_2O which occurs as authigenic low-sodium adularia. Origins of the rocks are obscured by diagenesis which, by recrystallization, has destroyed many of the primary features of the rocks. However, the high carbon content and vestigial textures suggest fossil remains at some levels, and the rocks are believed to have been formed as chemical precipitates in shallow water, with relatively rare deposition/superimposition of clastic shales. The feldspar is believed to have been formed from illite with potassium extracted from sea water and, possibly, tuffaceous material.

INTRODUCTION

The central Hamersley Group of the Proterozoic Hamersley Basin of northwest Western Australia is characterized by the presence of numerous banded iron formation units.

Within the Hamersley Group, the Brockman Iron Formation (in particular the Dales Gorge Member) is the locus for the bulk of the known hematite deposits and is the host for all the Precambrian iron ore currently being mined in the Hamersley Range area; its stratigraphy is well known and is thoroughly documented.

Over the last few years intense exploration activity has been focussed on the Marra Mamba Iron Formation, which also occurs within the Hamersley Group, stratigraphically below the Brockman Iron Formation. Ore in the Marra Mamba Iron Formation occurs near the top of the formation, close to its contact with the overlying Wittenoom Dolomite; this part of the Hamersley Group is less well documented stratigraphically.

This paper describes, geochemically and petrographically, a section through the lower part of the Wittenoom Dolomite, intersected in an exploratory hole drilled by the G.S.W.A. in 1972 as part of a programme to test and to evaluate water-bearing potential, in the hope that it will have direct application in current iron ore exploration.

There is still some confusion concerning the passage of Wittenoom Dolomite downwards into Marra Mamba Iron Formation and it is not yet certain that the iron formation discussed in this paper is part of the Marra Mamba Iron Formation. Some geologists consider, that elsewhere in the area, the Wittenoom Dolomite contains iron formation near its base. The problem will only be resolved when additional exposures, or drill intersections, of the contact are found and examined.

The Millstream No. 9 hole, sited in the Fortescue Valley (Pyramid 1 : 250 000 Sheet, SF/50-7; co-ordinates 515.299; lat. 21°37'S, long. 117°01'E) was drilled to test the water-bearing capacity of the surficial calcrete and underlying Wittenoom Dolomite. The geology of the general area is given in MacLeod (1966) and Kriewaldt and Ryan (1967). The hole was extended below its original intended depth and core has been recovered over a distance of 167.75 m in the interval 61.5 m to 229.25 m (the bottom of the hole). The core largely consists of dolomite unit in the lower part of the Wittenoom Dolomite, but, at 223.5 m, a magnetic band is present and the remainder of the core is iron rich and passes into a siliceous iron formation unit. The whole of the core has been logged by geologist W. A. Davidson of the Western Australian Geological Survey (unpublished file report) but this study was restricted to the lower portion of the hole from 177.6 m to the end (approximately 50 m).

The dolomite unit in the core consists of massive to thinly laminated dark grey dolomite with black, carbonaceous partings and thin interbedded zones of black carbonaceous shale. These shale bands are commonly 2 mm to 2 cm thick. A large proportion of the upper and middle (unsampled) portions of the core consists of intraformational dolomite breccia, and minor brecciation (both intraformational and compactional or diagenetic) occurs elsewhere. It was noted that dolomite, with associated shale bands, extends below the first magnetic band to 225.2 m at which point the core becomes noticeably more siliceous. The zone from 223.0 m to 225.2 m is considered a transition zone between iron formation and the dolomite unit. A log of the core is given with Figure 48.

The iron formation found in the Millstream 9 core is a mixture of siliceous material with magnetite-rich bands and with subordinate carbonate. It grades upwards into dolomite and shales as noted earlier. Below this band of siliceous iron formation manganiferous shales are believed to occur (A. F. Trendall, pers. comm.) though these were not reached in this core.

Samples were chosen as far as possible to be representative of the various rock types (Table 17). A disproportionately large number of the shales was sampled, in that the great majority of the shales which exceeded 2 mm were chosen. Dolomite samples were chosen to be as representative of this type of rock as possible. The length of dolomite core selected was a standard 5 cm. The thicknesses of the remaining samples are given in Table 17.

TABLE 17. SAMPLES ANALYSED FROM THE MILLSTREAM 9 DRILL CORE WITH HAND SPECIMEN DESCRIPTION.

GSWA Sample Number	Depth (m)	Description
42301	177·6	Dark grey dolomite with incipient bedding. Two very thin (1 mm) zones of lighter carbonate
42302	177·9	Massive black cavity infilling associated with white carbonate vein, thin (2 mm) layer of shale at bottom
42303	178·5	Dark grey rock ' oozing ' oily hydrocarbons
42304	184·4	Massive dark grey dolomite
42305	186·2	Black shale (5 mm)
42306	190·2	Black shale (2 cm)
42307	190·5	Black shale (2–3 mm)
42308	191·5	Black shale, 5 mm thick, splitting into two sections 2 mm and 3 mm thick with veinlet 0·5–1 mm of intercalated dolomite
42309	191·7	Black shale (4 mm)
42310	192·0	Black shale (4–6 mm)
42311	192·1	Massive dark grey dolomite with indications o bedding
42312	193·5	Black shale (2 cm)
42313	195·7	Black shale with dolomite intercalations (6–7 mm)
42314	198·7	Shaly dolomite
42315	198·8	Massive dark grey dolomite
42316	201·9	Black dolomitic shale (3–4 mm)
42317	204·4	Black dolomitic shale (4–6 mm)
42318	206·6	Finely banded, grey-black dolomitic shale with rare lighter zones
42319	206·9	Dark grey dolomite
42320	207·85	Dark grey-black dolomite with oily smears
42321	208·6	Black shaly dolomite (2-5 mm), irregularly surfaced
42322	209·3	Dark grey, bituminous dolomite
42323	209·6	Dark grey dolomite
42324	210·5	Dark grey, finely banded dolomite
42325	210·7	Brecciated, blotchy dolomite with shale ' bands (1–2 mm) and dark streaks
42326	212·5	Black shale (1–2 mm)
42327	213·3	Black shale (2–4 mm)
42328	214·4	Massive dark grey dolomite
42329	216·1	Thinly bedded dark grey dolomite
42330	216·7	Black shale (2 cm)
42331	218·1	Dark grey massive dolomite
42332	218·8	Black shale (1·5 cm)
42333	219·3	Black shale (1 cm)
42334	222·5	Dark grey dolomite
42335	223·0	Black shale (2 cm)
42336	223·35	Dolomite, adjacent to contact with magnetite-rich rock. Dolomite, rather leached-looking, variably dark to light grey
42337	223·4	Black magnetite-rich rock (3 cm)
42338	224·85	Black shale (2–3 cm)
42339	225·1	Dark grey dolomite, with carbonaceous partings
42340A	225·2	Carbonate rock adjacent to first main magnetic band
42340B	225·2	Magnetite-dolomite-silicate rock (2 cm)
42340X		Composite of iron formation from 225·2 m to 229·2 m
42341D	225·7	Magnetite rock (5 mm)
42341L	225·7	Chert dolomite zone (1·5 cm)—8 mm below 42341D Part of swell zone of a pod
42342	225·8	Magnetite-rich zone (4 mm)
42343D	226·3	Magnetite-rich zone (4mm) adjacent to siliceous pod
42343L	226·3	Siliceous pod (2 cm)
42344	226·7	Siliceous zone with carbonate; irregular shape (2 cm)
42345D	226·8	Thinly bedded magnetite-rich rock (3 mm)
42345L	226·8	Chert-carbonate rock (2 cm) immediately above 42345D
42346	227·2	Rather featureless silica-phyllosilicate rock with rare opaques (1 cm)
42347	227·3	Magnetite band (3 mm)
42348D	228·3	Magnetite band (1·2–1·5 cm) with fine, lighter layers
42348L	228·3	Siliceous (chert) zone with rare riebeckite (7 mm), 2·5 mm above 42348D
42349D	228·9	Thinly banded magnetite rock (1·4 cm)
42349L	228·9	Siliceous zone with carbonate (1cm)
42350	229·25	Riebeckite-carbonate rock (1 cm)

N.B. The normal thickness of sample is 5 cm. Other thicknesses used are listed. The fissility of the shales enabled collection of relatively clean shale samples. However, the iron formation zones were less fissile, with, in some cases, gradational zones. As clean zones as possible were chosen by careful selection of the samples

Other samples from the dolomite unit were chosen because of their particular interest, and included a portion of rock which was oozing hydrocarbons (178.4 m, 42303), and one which was a cavity infilling (177.9 m, 42302).

48396—(9)

The shale samples were split to give as pure specimens as possible, and their fissibility made separation from adjoining dolomite relatively easy. However thin sections showed, in some cases, that intercalations of dolomite were present. The surfaces of the shales are quite undulatory, and the thicknesses of the shales vary by several millimetres even in the width of the core.

A composite sample was taken from the iron formation. A thin sliver of uniform thickness was cut from the side of the core from 225.2 m to the end of the hole at 229.25 m. This was bulked. Because of the wide variation of rock types, the extreme thinness of some layers, and the presence of pod-like structures in some places it was not possible to choose representative small portions of the rock. Instead, samples were cut from some of the thicker layers (mesobands) to give an indication of the composition of the "purer" members of the various phases. Many zones showing transitional mineral changes were not sampled because of their innate variability.

PREPARATIONAL AND ANALYTICAL TECHNIQUES

The samples were divided into four portions. One part was used for thin section preparation, one part for atomic absorption analysis, one part for wet chemical and X-ray diffraction analysis (where applicable), and one part was retained for reference purposes.

The samples for analysis were passed through a jaw-crusher and then ground in a Tema ring-mill using chrome-steel grinding heads.

Determinations were restricted to the following elements: Na, K, Ca, Mg, Mn, C, Cu, Pb, Zn, Ni, Ba, Sr, and V, together with carbonate (as CO_2) and phosphorus (as P_2O_5). Hydrocarbon or non-carbonate carbon was measured separately from carbonate carbon. All components except C, CO_2 and P_2O_5 were determined by atomic absorption spectrometry and the choice of elements was restricted to those relevant elements for which suitable analytical equipment was available. Three digestion methods were used in the AAS determinations, partly for comparative purposes, but also because of difficulties in the determination of various elements.

A description of the methodology is given in Davy (1975).

The analysis for free (non-carbonate) carbon, carbon dioxide and phosphorus (expressed as the pentoxide) was carried out by the Government Chemical Laboratories.

The thin sections were half-stained with Alizarin-Red-S solution after being dipped into dilute hydrochloric acid. A red stain on grains of carbonate indicated the presence of calcite. No attempt was made to discriminate, by any staining technique, between dolomite and iron-bearing carbonate.

X-ray diffraction analysis was carried out by the Government Chemical Laboratories.

PETROGRAPHY

An approximate mineralogical composition of the samples analysed is given in Figure 48.

DOLOMITE UNIT

The dolomite unit can best be considered in terms of two end phases: dolomite and shale. Mixtures of the two and a few variants containing chert occur in places.

The *dolomite phase* consists, charcteristically, of a mosaic of recrystallized dolomite which shows evidence of its former (primary) structures only in the disposition of some of the contained opaques. The dolomite is dark grey and massive. The bedding is more apparent in hand specimen than in thin section though the thin sections reveal that it is the dispersed trains of opaques which define the bedding. The dolomite shows no sign of lineation and/or foliation, and in many samples, grains of secondary dolomite enclose the trains of opaques. The size of the dolomite grains varies from about 0.03 mm to 0.35 mm with the most common size range being 0.07 to 0.1 mm. There is some small variation in size from specimen to specimen and, in general, late stage veins, wherever found, contain the largest (0.30-0.35 mm) grains.

Primary textures are not easy to deduce. The trains of opaques show slight irregularities and in 42324 (210.5 m)* an overturned fold is indicated. The opaques commonly appear more abundant than the analyses would suggest and consist of carbonaceous material (organic carbon, hydrocarbons or graphite), together with pyrite and possibly hematite. Their grain size (except for pyrite) is of the order of 0.001 mm, though irregular, larger aggregates up to 0.01 mm in diameter are relatively common.

The opaques are commonly collected into diffuse aggregates up to 0.1 mm in diameter, which define the bedding (e.g. 42322). These aggregates may have sufficient lateral width as to suggest former pellets (42311, 42319), and elsewhere similarities with algal structures are possible.

Pyrite occurs in nearly all samples as small cubes or pyritohedra, as well as in irregular grains. All pyrite is of the order of 0.01 to 0.02 mm in diameter. Sample 42302 is unusual in the amount of pyrite present. In this sample it appears as loose aggregates (interspersed with dolomite) of ?framboids with the aggregates reaching 3 to 4 mm in diameter. There is no indication of the time of formation of the greater part of the pyrite except in 42302 where it is clearly secondary.

Post-depositional changes include the recrystallization of dolomite. There is no indication whether dolomite was the primary mineral. In some samples the dolomite has a tendency to form discrete rhombs, which still contain some dispersed opaques, but which, in many cases (e.g. 42303, 21, 25 and 34) appear to have pushed the brownish-black hydrocarbon material into the interstitial zones between the rhombs. Other post-depositional features are shown by the presence of incipient stylolites (42319, 24) or definite stylolites (42328, 29, 31). These are in general parallel with the bedding with the amplitude varying up to 2.5 mm. Late-stage veins of dolomite are present in 42315, 24 and in 42329 where they appear to cement fine cracks.

The mineralogy of *the shales* is very uniform. All are fine grained with only dolomite (or calcite), and traces of quartz, mica, and, rarely pyrite, being readily identified in thin section. The overall grain size is less than 0.01 mm, in many cases less than 0.002 mm. Optical identification is rendered very difficult because of the all-pervasive opaques, which, in thin section, appear to be very abundant (especially in 42312, 30). The opaque grains, however, largely hydrocarbon or graphite, are usually quite small but conceal transparent minerals above or below them. The shales are all thinly laminated with bedding traces no more than 0.01 to 0.1 mm apart.

* Subsequently the G.S.W.A. sample number only is given. The depth from which the sample were taken will be found by referring to either Table 17 or to Figure 48.

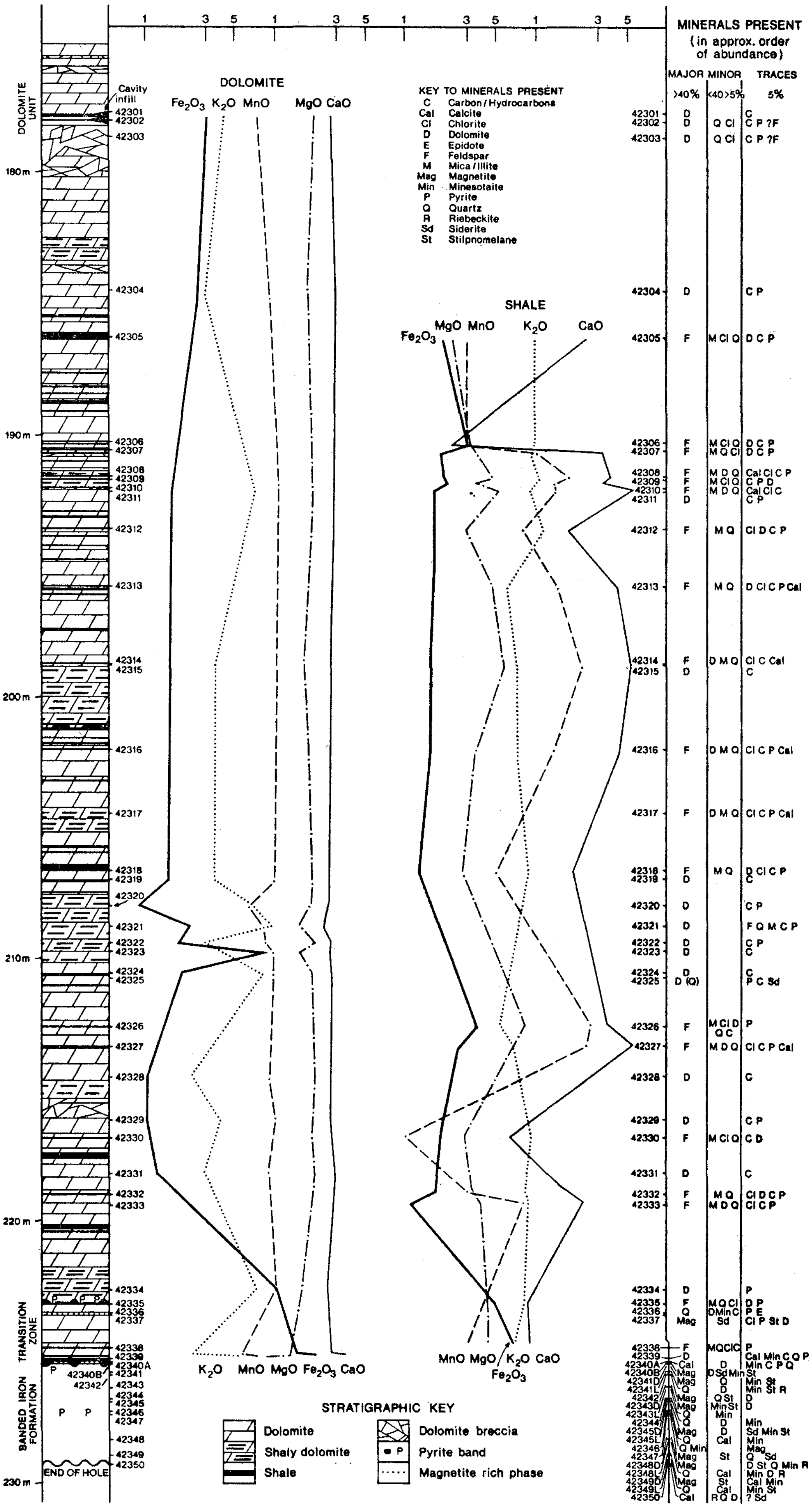

Figure 48. Down-hole profilesf or selected major oxides in the two main phases of the dolomite unit of Millstream No. 9 drill core. The profiles are drawn for clarity. The true values may be gauged from the mean values below:

	dolomite (per cent)	shale (per cent)
CaO	27·7	2·96
MgO	19·1	4·21
MnO	0·95	0·11
K_2O	0·50	8·74
Fe_2O_3	2·9	2·1

Left hand: stratigraphic log. Right hand: essential mineralogy of samples analysed.

The bedding is defined by the parallelism of the phyllosilicates and differences in the opaque content. The mineralogy of the majority of shale samples has been determined by X-ray diffraction analysis which revealed that the bulk of the non-opaque material was a low-temperature, largely monoclinic K-feldspar—considered to be adularia.

Careful examination of the thin sections revealed traces of cross-hatch twinning on two grains only (42333), suggesting the presence of some microcline. A few small (0.05 mm) detrital grains of quartz, including one rutilated quartz grain (42306), and of white mica were noted, the remainder was so fine grained that its origin is in doubt. The shale sections, in particular, were examined for evidence of volcanic material, but none was found.

The shales contain dolomite and/or calcite. Calcite was recognized in thin section by the pink stain taken with Alizarin-Red-S solution. Grains of calcite and dolomite were larger than other components of the shale, ranging up to 0.5 mm in a few grains. Calcite has irregular outlines with no crystal forms, but dolomite occurs both as irregular grains and as "blastic" rhombs.

A few samples contain negligible carbonate (42306, 30, 35, 38). Several contain dolomite which appears to have penetrated into the shale from both above and below (e.g. 42307, 16). Others are impregnated with carbonate throughout (e.g. 42309, 26) but have a tendency for the carbonate to be concentrated in specific layers. A few consist of alternations of shale and dolomitic shale (e.g. 42313, 27).

Quartz is recognizable in the thin section in layers and in veins in 42328.

Several of the samples chosen were found to be breccias. These included 42302, 03, 25 and 33. Of these, the first three are dominantly dolomitic, the last is a shale. Sample 42302 was chosen as a black, apparently massive, cross-cutting cavity infilling (initially suspected of carrying manganese dioxide) whilst 42303 was oozing hydrocarbons. Sample 42325 was chosen because of dark streaks which were considered possibly manganiferous, and 42333 appeared in hand specimen to be a normal shale.

The cavity infilling (42302) is a mixture of chert, dolomite and shale and has components of all three except that no K-feldspar was detected by X-ray diffraction (indicating that less than 5-10 per cent of the mineral was present). The thin section shows several zones with apparent gradational bedding. Dolomite at the base of each zone passes through dolomitic carbonaceous shale to carbonaceous shale in a regular fashion over 5 to 8 mm, with the dolomite grains, even at the base, separated by carbonaceous films. Later dolomite infilling of translayering cracks contains aggregates of pyrite (with interstitial dolomite). The pyrite in aggregate reaches 3 mm in diameter though individual grains are rarely more than 0.03 mm across.

The bituminous rock 42303 proved to be largely dolomite with subordinate shale, small amounts of chert, and again, negligible K-feldspar. The brecciation of 42325 was more obvious in hand specimen than in thin section. In the section all the dolomite occurred as rhombs, in places discrete, with brown interstitial material. Elsewhere the dolomite rhombs were so abundant as to form a mosaic with the interstitial material absent.

TRANSITION ZONE

The first optically recognizable sign of the top of the iron formation is seen in 42336 (223.35 m) which is a rock composed largely of granular chert impregnated with minnesotaite, dolomite and carbon/hydrocarbons. The opaques are unusual in that they are composed of little "rings" of ?carbon 0.01 mm in diameter. These rings have small (0.001 to 0.005 mm) protruberences on them. They occur singly or in aggregate (giving the rock a well marked banding), and appear to be organic in origin. The minnesotaite occurs (as in the iron formation proper) in single arcuate fibres or plates and in sheaves of plates up to 0.15 mm long and, cumulatively, with a similar width.

Immediately below the last sample there is a prominent magnetite-rich band some 3 cm thick but for the next 1.8 m there is a reversion to the dolomite unit type of rock with both dolomite (42339) and shale (42338).

The main features of difference from the corresponding rock above are the presence of calcite with the dolomite in the carbonate facies rock, and the presence of small amounts of minnesotaite in the carbonate. The shale contains visible quartz in thin layers and veins.

IRON FORMATION

At 225.2 m there is a distinct facies change to more siliceous iron formation, with reduction of the carbonate content of the rock. In lower zones carbonate is more variable, with calcite quite prominent, and with siderite accompanying or replacing dolomite. The iron formation contains an abundance of thin bands (mesobands) of quite markedly variable lithology. Some zones are magnetite rich (with accessory siderite, dolomite, or stilpnomelane), some are chert rich (with subordinate carbonate and minnesotaite), others are carbonate rich (with subordinate chert, riebeckite, magnetite) and others are phyllosilicate rich (mainly ferrostilpnomelane). Some of the bands appear homogeneous and have sharp boundaries, others are gradational and merge into a mesoband of different type. In a few places minnesotaite and pale to olive green ferrostilpnomelane occur together, but, for the most part, these minerals seem to be mutually exclusive. Megascopic features of the bands include pod structures, and possible compactional features with tension cracks infilled by overlying layers. The overall grain size of the minerals is small. Opaques reach 0.1 mm, but the greater part of all other minerals except carbonates are much smaller than this. Carbonates, particularly those in veins, or those which have rhombic outlines can be as large as 0.3 mm, and, in one zone 0.6 mm. Quartz in veins can also reach 0.1 to 0.3 mm in diameter, though most approach chert-size grains. Minnesotaite plates and fibres can reach 0.1 to 0.5 mm. There is some suggestion of a later recrystallization of at least part of the carbonate.

On the basis of the chemistry of the rock (see later section) certain of the calcites of the iron formation are considered to be ferroan calcite (or ankerite) though no separation and analysis has been made. The lowest refraction index determined in oil on crushed rock is about 1.52 and the highest about 1.69.

RESULTS

ANALYTICAL

Condensed results of analysis are presented in Table 18. A complete set of results, including values given by both geochemical (HCl/HNO_3) and "total" (HF based) attacks, is given in an unpublished Geological Survey report (Davy, 1975).

The samples have been grouped by lithological type in Table 18 to facilitate comparisons between the groups.

The means and standard deviations of the composition for dolomite and shale (from the dolomite unit), and for the magnetite-rich phases of the iron formation, and iron formation/transition zone, are given in Table 19.

DOLOMITE UNIT

The dolomite unit, with its contained shales, is dark grey to black. In thin section the proportions of minerals in the shales are very hard to estimate for the proportion of opaques appears grossly in excess of those reported in the analyses. The opaque minerals present are pyrite, carbon (or hydrocarbons) and hematite. The organic grains are finely divided, though the iron minerals are slightly larger. Samples were deliberately chosen to get "pure" shales, and typical dolomites. The feature of the samples analysed is the prominence of the "end members" of dolomite and shale (see Fig. 49). Other samples can, for the most part, be considered as simple mixtures of shale material with dolomite. In a few places (42321) there is dilution by silica.

Because of the fundamental difference in composition between the dolomites and the shales separate down-hole profiles have been drawn for selected elements for these phases (see Fig. 48). The close correlation of manganese with calcium ($r = 0.93$) shows that this element is present in the carbonate phase and not in the opaques. The manganese values are exceptionally high for dolomite. Barium is also relatively high in the dolomites, showing close correlation with calcium ($r = 0.87$).

The sodium and potassium values of dolomites are rarely reported. However the sodium values appear about normal whereas the potassium values are slightly elevated (e.g. Pettijohn, 1957, p. 418).

Iron values are approximately the same in both shales and dolomites, away from the contact with the iron formation, with the exception of a dolomitic rock at 209.6 m (42323). With this one possible exception, iron has no particular affinity with carbonate and the prominence of fine opaques suggests that, despite the presence of traces of visible pyrite, some of the iron may be present as finely dispersed hematite.

Comparison with the analyses of dolomites reported by Pettijohn (1957, p. 418) and with dolomites reported by Deer, Howie and Zussman (1962, v. 5, p. 280) shows that most of the dolomites approximate to the composition of pure dolomite, with the molecular ratio of calcium to magnesium approximately 1 : 1. In general the dolomite phase is not calcitic though calcite appears in the carbonate rocks in the transition zone with the iron formation.

Trace element values are low in the dolomite and are comparable with those reported from unmineralized dolomites in other parts of the world. However, barium values are well above those suggested by Turekian and Wedepohl (1961), Hawkes and Webb (1962) and Krauskopf (1967) for carbonate rocks. The base metals all appear marginally higher than the averages given by these authors. There are traces of carbon, and the phosphate content, with the exception of sample 42323, is very low.

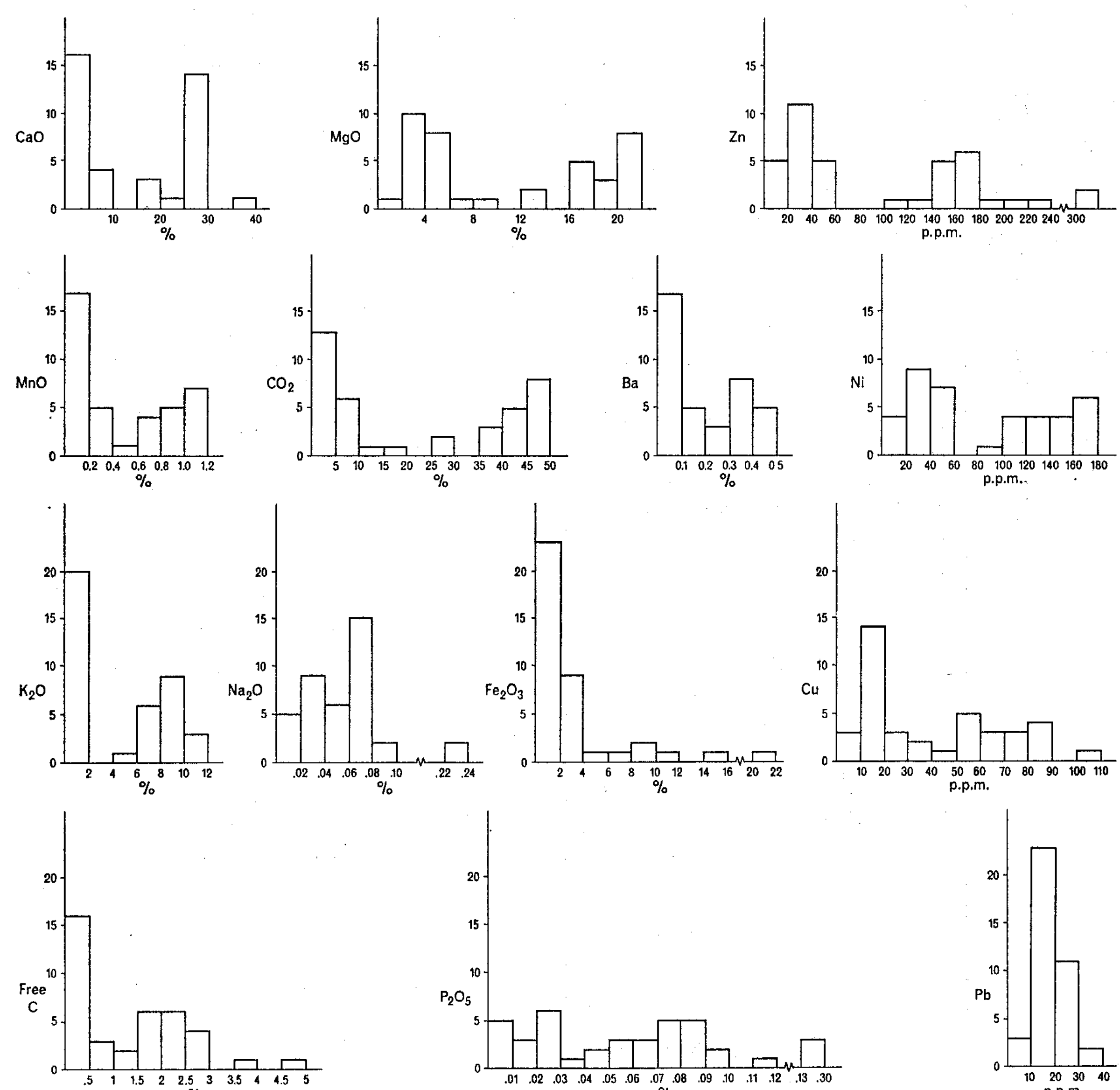

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Figure 49. Histograms of the distribution of elements and oxides in the dolomite unit.

TABLE 18. PARTIAL ANALYSIS OF ROCKS FROM MILLSTREAM 9

1. DOLOMITES

	Sample	42301	42304	42311	42315	42319	42320	42321	42322	42323	42324	42328	42329	42331	42334	42339 (Transition Zone)	42340A (Transition Zone)
	Depth (m)	177·6	184·4	192·1	198·8	206·9	207·85	208·6	209·3	209·6	210·5	214·4	216·1	218·1	222·5	225·1	225·2
	Digestion																
Fe_2O_3 %	$HF/HClO_4$	3·0	2·6	1·7	1·7	1·6	0·9	2·3	1·9	8·7	2·0	1·1	1·1	1·3	10·6	14·7	21·7
MnO %	$HF/HClO_4$	0·75	0·93	1·11	1·08	1·05	0·67	0·85	0·88	1·01	1·02	0·94	1·06	0·93	1·08	0·57	0·70
MgO %	$HF/HClO_4$	20·4	18·4	20·1	17·2	20·2	19·7	16·2	20·1	16·4	19·7	21·2	20·1	20·9	16·2	13·3	5·30
CaO %	$HF/HClO_4$	27·1	29·7	29·2	27·4	27·7	26·9	24·8	28·0	27·7	28·1	28·4	27·7	29·5	25·7	27·1	35·3
Na_2O %	$HF/HClO_4$	0·02	0·02	0·03	0·03	0·05	0·02	0·06	0·03	0·05	0·03	0·04	0·04	0·04	0·08	0·08	0·07
K_2O %	HF/H_2SO_4	0·42	0·30	0·72	0·36	0·36	0·72	0·96	0·30	0·42	0·84	0·24	0·39	0·30	0·73	0·24	0·54
Cu ppm	$HF/HCl/HClO_4$	10	10	20	10	20	20	30	20	20	20	20	20	20	30	20	25
Pb ppm	$HF/HCl/HClO_4$	40	20	30	15	20	20	20	20	20	20	20	20	25	25	20	25
Zn ppm	$HF/HCl/HClO_4$	45	40	55	30	60	30	140	30	20	15	20	30	35	30	40	30
Ni ppm	$HF/HCl/HClO_4$	30	15	45	30	60	45	135	30	30	15	15	30	30	60	30	45
V ppm	HCl/HNO_3	<12	12	12	12	100	<12	<12	<12	<12	12	<12	<12	12	40	<12	<12
Ba %	HCl/HNO_3	0·40	0·35	0·40	0·35	0·50	0·35	0·30	0·50	0·35	0·40	0·47	0·50	0·40	0·30	0·45	0·47
Sr ppm	HCl/HNO_3	10	10	20	12	20	20	25	5	15	10	15	20	15	18	10	25
†CO_2 %	See text	45·4	46·2	45·1	41·6	45·0	43·5	38·2	45·5	43·0	45·9	46·7	46·0	46·1	37·9	40·8	36·8
†Free C %	See text	0·03	0·1	0·2	0·3	0·3	0·2	0·7	0·2	0·3	N.D.	0·05	0·1	0·1	0·9	0·1	0·3
†P_2O_5 %	See text	0·001	0·012	0·052	0·028	0·026	0·022	0·063	0·034	0·304	0·011	0·008	0·009	0·010	0·036	0·014	0·096
Fe as metal %	....	2·1	1·8	1·2	1·2	1·1	0·6	1·6	1·3	6·1	1·4	0·8	0·8	0·9	7·4	10·3	15·2

2. SHALES

	Sample	42305	42306	42307	42308	42309	42310	42312	42313	42314	42316	42318	42326	42327	42330	42332	42333
	Depth (m)	186·2	190·2	190·5	191·5	191·7	192·0	193·5	195·7	198·7	201·9	206·6	212·5	213·3	216·7	218·8	219·3
	Digestion																
Fe_2O_3 %	$HF/HClO_4$	2·0	3·0	1·9	2·0	2·1	1·7	1·7	1·7	1·6	1·6	1·3	3·6	2·6	1·9	1·7	1·1
MnO %	$HF/HClO_4$	0·03	0·03	0·10	0·17	0·14	0·14	0·08	0·15	0·23	0·14	0·05	0·27	0·25	0·01	0·03	0·08
MgO %	$HF/HClO_4$	2·32	3·15	3·48	4·64	3·48	5·10	2·98	4·97	5·80	3·48	2·82	8·32	6·80	2·82	3·32	3·81
CaO %	$HF/HClO_4$	2·24	0·13	3·22	3·65	3·20	5·04	1·80	4·26	5·44	4·62	1·96	3·56	5·56	0·64	1·68	2·50
Na_2O %	$HF/HClO_4$	0·07	0·07	0·07	0·08	0·08	0·08	0·08	0·06	0·06	0·07	0·08	0·06	0·07	0·08	0·09	0·20
K_2O %	HF/H_2SO_4	10·1	9·76	9·52	10·8	10·0	9·27	11·9	6·38	7·35	7·47	8·91	5·54	6·87	9·28	8·43	8·79
Cu ppm	$HF/HCl/HClO_4$	60	80	110	70	65	60	60	50	40	60	85	70	75	80	90	40
Pb ppm	$HF/HCl/HClO_4$	<10	40	25	25	30	30	20	20	10	15	20	20	25	20	20	15
Zn ppm	$HF/HCl/HClO_4$	160	300	180	160	180	175	180	150	185	145	205	40	165	170	225	20
Ni ppm	$HF/HCl/HClO_4$	150	165	165	150	150	135	180	135	90	135	105	120	120	180	180	30
V ppm	HCl/HNO_3	100	160	100	85	100	60	75	25	25	12	100	150	60	100	100	25
Ba %	HCl/HNO_3	0·05	0·05	0·12	0·10	0·05	0·05	0·02	0·07	0·10	0·07	0·05	0·20	0·05	0·05	0·05	0·02
Sr ppm	HCl/HNO_3	5	5	12	8	10	20	20	20	5	<5	10	12	10	20	5	8
CO_2 %	See text	2·2	0·3	2·6	5·5	3·7	6·9	2·8	5·6	6·6	7·3	2·8	4·1	7·1	0·8	1·7	3·2
Free C %	See text	2·1	2·5	1·7	1·8	1·9	1·6	2·6	2·1	1·4	1·7	2·7	4·6	2·9	2·6	2·3	2·3
P_2O_5 %	See text	0·082	0·064	0·082	0·146	0·092	0·089	0·051	0·083	0·074	0·119	0·080	0·148	0·090	0·050	0·075	0·078
Fe as metal %	....	1·4	2·1	1·3	1·4	1·5	1·2	1·2	1·2	1·1	1·1	0·9	2·5	1·8	1·3	1·2	0·8

3. MISCELLANEOUS ROCK FROM THE DOLOMITE UNIT

		Impure Dolomites			Dolomitic Shale	Siliceous Contact Rock	Transition Zone Shales	
	Sample	42302	42303	42325	42317	42336	42335	42338
	Depth (m)	177·9	178·5	210·7	204·4	223·35	223·0	224·85
	Digestion							
Fe_2O_3 %	$HF/HClO_4$	2·3	2·6	1·9	1·7	9·6	4·7	6·7
MnO %	$HF/HClO_4$	0·34	0·35	0·62	0·21	0·06	0·04	0·03
MgO %	$HF/HClO_4$	20·9	16·4	12·8	5·47	1·49	4·30	4·31
CaO %	$HF/HClO_4$	16·2	15·8	15·8	7·6	2·10	0·86	0·90
Na_2O %	$HF/HClO_4$	0·02	0·03	0·04	0·07	0·01	0·08	0·24
K_2O %	HF/H_2SO_4	0·12	0·30	0·42	7·11	0·24	8·19	6·87
Cu ppm	$HF/HCl/HClO_4$	20	20	20	85	20	60	85
Pb ppm	$HF/HCl/HClO_4$	25	20	15	10	20	20	25
Zn ppm	$HF/HCl/HClO_4$	45	55	20	165	25	110	330
Ni ppm	$HF/HCl/HClO_4$	45	60	10	180	30	105	150
V ppm	HCl/HNO_3	25	25	12	75	125	125	175
Ba %	HCl/HNO_3	0·20	0·15	0·33	0·13	0·02	0·05	0·02
Sr ppm	HCl/HNO_3	5	10	22	10	5	15	10
CO_2 %	See text	19·0	25·4	28·0	11·1	2·8	1·0	0·8
Free C %	See text	1·2	1·0	0·5	2·0	0·2	2·3	3·7
P_2O_5	See text	0·021	0·050	0·022	0·059	0·003	0·068	0·076
Fe as metal		1·6	1·8	1·3	1·2	6·7	3·3	4·7

4. IRON FORMATION

		MAGNETITE—RICH PHASES									SILICEOUS PHASES							Carbonate Riebeckite Phase	Composite Sample
		Transition Zone																	
	Sample	42337	42340B	42341D	42342	42343D	42345D	42347	42348D	42349D	42341L	42343L	42344	42345L	42346*	42348L	42349L	42350	42340X
	Depth (m)	223·4	225·2	225·7	225·8	226·3	226·8	227·3	228·3	228·9	225·7	226·3	226·7	226·8	227·2	228·3	228·9	229·2	225·2–229·25
	Digestion																		
Fe_2O_3 %	$HF/HClO_4$	68·6	56·0	72·3	76·9	70·5	83·4	77·3	83·2	78·2	9·8	2·7	2·9	6·0	22·3	8·3	8·8	13·7	32·3
MnO %	$HF/HClO_4$	0·28	0·41	0·03	0·02	0·01	0·01	0·02	0·01	0·01	0·16	0·01	0·06	0·03	0·03	0·12	0·54	0·30	0·13
MgO %	$HF/HClO_4$	3·48	4·97	0·91	0·48	0·99	0·56	0·86	0·53	0·80	4·06	0·06	2·24	1·57	3·98	2·40	3·05	3·16	2·57
CaO %	$HF/HClO_4$	3·22	13·6	1·72	0·77	0·70	0·62	0·96	0·41	0·34	6·65	0·04	2·81	0·95	0·15	4·73	32·2	21·4	6·58
Na_2O %	$HF/HClO_4$	0·02	0·05	0·20	0·30	0·05	0·07	0·24	0·28	0·34	0·17	<0·01	<0·01	0·01	0·01	0·51	0·67	2·36	0·13
K_2O %	HF/H_2SO_4	0·60	0·60	0·34	0·32	0·27	0·25	0·23	0·25	0·24	0·22	0·06	0·05	0·25	0·20	0·04	0·24	0·12	0·24
Cu ppm	$HF/HClO_4$	25	20	10	10	20	10	5	5	5	10	5	5	5	12	10	5	10	10
Pb ppm	HCl/HNO_3	20	20	65	60	70	60	55	55	55	20	<5	55	55	10	15	40	40	40
Zn ppm	$HF/HClO_4$	30	30	13	15	40	20	15	15	10	10	10	10	13	30	10	10	10	20
Ni ppm	$HF/HClO_4$	60	60	45	40	50	55	30	35	30	30	15	20	20	25	20	30	20	25
Ba ppm	HCl/HNO_3	500	1700	ND	175	ND	ND	150	125	ND	100	100	200	250	ND	250	300	125	(100)
Sr ppm	HCl/HNO_3	20	10	10	ND	5	75	5	70	ND	20	ND	460	370	ND	30	75	50	20
CO_2		13·3	26·6	2·63	1·00	0·84	0·87	1·34	0·46	0·44	11·1	0·03	4·00	1·10	0·14	6·70	30·5	18·3	8·2
Free C %	See Text	0·8	0·2	0·05	0·03	0·04	0·04	0·06	0·02	0·07	0·06	0·04	0·03	0·04	0·02	0·12	0·06	0·07	0·03
P_2O_5	See Text	0·059	0·068	0·043	0·040	0·043	0·056	0·027	0·075	0·047	0·13	0·014	0·008	0·020	0·010	0·033	0·14	0·021	0·060
Fe as metal	See Text	48·0	39·2	50·6	53·8	49·3	58·3	54·1	58·2	54·7	6·9	1·9	2·0	4·2	15·6	5·8	6·2	9·6	22·6

ND = Not detected

* = Chert-minnesotaite rock

† = In this, and subsequent tables, analyses of CO_2, free C and P_2O_5 by Government Chemical Laboratories

The shales are unusual in their high potassium content. This potassium is not recognizable in thin section except by staining. (A yellow stain is given with sodium cobaltinitrite). The potassium content is comparable with that in shales reported from Minnesota (Weiss, 1954), Scotland (Bowie and others, 1966), Mount Isa (Croxford, 1964-5) and the Rhodesian Copperbelt (Darnley, 1959-60) but exceeds the world Clarke figure by a factor of 2 to 3 (see later discussion).

The non-carbonate carbon also exceeds that suggested by Pettijohn (1957, p. 344) for the average shale by a factor in excess of 3, though the value is much lower than that reported for other black shales e.g. 13.1 per cent in shales at Dry Gap, Georgia (Pettijohn, 1957, p. 362).

The shales contain variable amounts of carbonate. In many cases this is dolomite, but in some samples the carbonate is mainly calcite (e.g. 42306, 42310, 42316, 42332). In all cases magnesium is present in excess of that required for the carbonate mineral. This magnesium represents that present in the phyllosilicates illite and chlorite. Iron is probably present both in the phyllosilicates and in the opaques. Trace elements have higher values than the dolomites with the exception of manganese and barium. The values for Cu, Pb, Ni, V and Zn fall within the ranges suggested by Turekian and Wedepohl (1961), Hawkes and Webb (1962) and Krauskopf (1967). The phosphate is overall slightly higher in the shales than in the dolomites (see Fig. 49) but is not of major significance. Strontium values are very low.

The dolomites proper show relative uniformity over the extent of the core sampled (Fig. 48). There are no major trends apparent except at the bottom near the iron formation where there is an increase in iron, and some depletion of magnesium. An exception occurs at 209.6 m where the dolomite contains appreciable iron and a higher phosphate content. The increase in iron is matched by some depletion of magnesium.

The shales have a more variable composition though whether the differences in composition reflect genuine trends is not certain. A possible trend is that shown in Figure 48 for K_2O.

TRANSITION ZONE

A transition zone is considered to extend between the iron formation and the dolomite unit from 223.0 m to 225.2 m (approximately). This zone contains two bands with high magnetite content at 223.4 m (42337) and 225.2 m (42340B) but is characterized by the relative abundance of carbonate and the presence of high-potassium shales as in the dolomite unit. In the magnetite-rich bands the iron content, expressed as Fe_2O_3, reaches over 55 per cent but even in other layers, compared with the dolomite unit, the overall iron content is high with a minimum value (of Fe_2O_3) of about 5 per cent. Chert with minnesotaite, and ferrostilpnomelane also become evident (223.35 m and 224.85 m) respectively, indicating the close relationship of this phase with the underlying iron formation proper. Compared with the overlying rocks this zone is distinguished by the presence of calcite (and/or siderite) as well as dolomite in the carbonate-rich samples. Alkali metals and the trace elements determined fit well into the pattern of the shale or carbonate facies of the dolomite unit as appropriate, and the trace metal values of the two iron-rich bands are more similar to values in the overlying rocks than they are to the magnetite-rich bands in the iron formation proper.

IRON FORMATION

Examination of the analyses for the various bands of the iron formation reveals the massive inherent variability between adjacent mesobands. For this reason, and for other comparative purposes, a composite taken from the whole of the core from 225.2 m to the end of the core at 229.25 m is presented (42340X). This analysis (the average of duplicate samples) shows moderate to high Fe_2O_3, CaO and MgO values with appreciable carbon dioxide, and low overall concentrations of alkali metals. The trace element content, including the free carbon and the phosphate content, is also low.

The bulk chemistry scarcely reflects the composition of any single band. The magnetite-rich bands show high iron values, but differences in the nature of the associated minor minerals have caused moderate variations in calcium, magnesium and carbon dioxide values. Sodium and potassium are universally low, though there seems to be some tendency for Na_2O values to rise with depth (this is reflected not only in the magnetite-rich phases, but also in the silicate-rich phases). Of interest is the relatively high value of lead in the magnetite-rich phase. Presumably lead (and nickel) can be found in the magnetite. Both lead and nickel are present in lower concentrations in the siliceous phases and the copper and zinc values are very low indeed. Barium and strontium appear very variable and related neither to iron nor to carbonate minerals. The phosphate content of these magnetite-rich phases is quite low.

The composition of the siliceous phases is more variable than that of the magnetite phases, reflecting the changes in mineralogy. There is a variable iron content, mainly in minnesotaite and stilpnomelane, more rarely in magnetite (42346) or riebeckite. There is a very variable carbonate, calcium and magnesium content and both dolomite and calcite co-exist.

Barium is more abundant in this phase than in the magnetite phase, and so, overall, is strontium, though the amount of this element is very variable and it seems to behave independently of any particular mineral. Sodium varies from very low (?absent) to 2.36 per cent Na_2O in phases containing riebeckite.

Potassium values are quite low indicating that K-bearing phyllosilicates are absent. The presence of appreciable magnesium in the chert-minnesotaite phase (227.2 m, 42346) indicates that it might be appropriate to consider the minnesotaite as an iron-rich talc some distance from the end member.

DISCUSSION

IRON FORMATION

It is quite rare to get adequate samples of unmineralized iron formation from the Hamersley Range area which are fresh enough for an analytical evaluation. Such samples as have been analysed have been derived mainly from drill cores, and from the walls of steep-sided or overhanging gorges. Until recently the greater part of the economic interest in the area has lain with the Brockman Iron Formation which occurs stratigraphically above the Marra Mamba Iron Formation in the Hamersley Group of rocks. Between these two iron formations lie (oldest first) of the order of 300 m of varied dolomite (the Wittenoon Dolomite), iron formation and shale (the Mount Sylvia Formation) and further shale, dolomite and chert (the Mount McRae Formation). Within the Brockman Iron Formation the most studied portion has been the Dales Gorge Member. Analyses of the Brockman Iron Formation and the Boolgeeda Iron Formation (which occurs at the top of the Hamersley Group, 100 to 1 000 m above the Brockman Iron Formation) are presented in Trendall and Blockley (1970, p. 134). These authors also present the results of analysis (as composites) of selected mesoband types from the Dales Gorge Member.

The complete analysis 42340X, when compared with the Brockman and Boolgeeda Iron Formations, shows that the iron formation in the Millstream No. 9 drill core contains rather less iron than either of the other two formations. It is also richer in carbon dioxide (i.e. in carbonate content) than most of the samples analysed and reported in Trendall and Blockley (1970, p. 134, 5), though the wide fluctuation of carbon dioxide reported for the various samples may mean that all these iron formations have very variable compositions. The calcium content of 42340X (6.6 per cent CaO) exceeds the published calcium values of the other iron formations by a factor of 2 to 3. Magnesium figures are similar for all analyses. Sodium and potassium values given by Trendall and Blockley for the Dales Gorge Member of the Brockman Iron Formation are essentially similar to the present analysis, but the Joffre Member of the Brockman

Iron Formation, and the Boolgeeda Iron Formation are richer in potassium than either the Dales Gorge Member, or the present iron formation analysis. Trendall and Blockley postulate (1970, p. 138) that the higher potassium values of the Joffre Member and the Boolgeeda Iron Formation may be caused by the presence of sericitic phyllosilicates in these rocks. In the light of the mineralogy of the shales of the dolomite unit it appears possible that their higher K_2O values may be represented by fine-grained feldspar.

The phosphorus content of this iron formation is lower than that of the Dales Gorge Member and the Boolgeeda Iron Formation. Iron ore from the Marra Mamba Iron Formation is known to be lower in P_2O_5 than that from the Brockman Iron Formation (Mining Magazine, Aug. 1974, p. 87); it appears that this is a fundamental property of the Marra Mamba Iron Formation, and may assist in the stratigraphic siting of the iron formation investigated here.

Trendall and Blockley did not publish any analyses of magnetite-rich bands though they have given various complete and partial analyses (1970, p. 139 ff) of various individual mesoband types. Their analyses are a mixture of composites of mesoband types and individual mesobands, which collectively can be grouped into composites. Their analyses contrast with the analyses presented here which are all from single mesobands within the core. There are widely differing proportions of carbon dioxide, and its related cations, but comparable analyses can be found in the Brockman Iron Formation.

Trendall and Blockley present no trace element determinations.

The iron formation composite is compared with published analyses of other magnetite-rich iron formations in Tables 20 (major elements) and 21 (trace elements). This core of iron formation contains less iron than most other iron formations and more calcium. It contains slightly more carbon dioxide than most of the other iron formations (the Temiscamie Iron Formation being a notable exception). The iron contents are only slightly lower than values reported for the Biwabik Iron Formation and the Pongola beds. By contrast, as noted during the comparison with other West Australian iron formations, the calcium values are appreciably higher, by factors varying between 1.5 and 3. The number of analyses is limited and the inferences drawn are therefore somewhat tentative, but it does appear that this iron formation is unique in its calcium content (in magnetite facies rocks). Values of other major elements are comparable with those of other deposits. Some analysts do not report values for Na_2O and K_2O; whether these oxides were not determined or not detected is not always clear. The phosphorus value is slightly lower than most of the other analyses.

Very few trace element values appear in the literature and Table 21 shows those which have been found. However, even these determinations are scarcely comparable since most of them have been derived from rocks which contain either dominant, or, at least, appreciable hematite. The nickel and barium values of the examined iron formation are comparable with the other published figures, however copper, zinc and strontium are possibly low. No firm conclusions can be inferred from this comparison.

The origins of iron formation are discussed by Trendall and Blockley (1970, chapter 9) and no evidence is revealed by the present chemical study to disprove their general hypotheses.

THE TRANSITION ZONE

Transition zones from iron formation to adjoining rocks are not well recorded in the literature, possibly because the main interest has lain in the potentialities of the iron formations for the location of iron ore bodies and possibly because near-surface weathering and alteration has masked many of the effects.

It is clear, however, that in this drill core there is an approximate 2.2 m band of overlap between the iron formation below and the dolomite unit above.

The iron content remains high but the dominantly siliceous phase of the iron formation is replaced by carbonate (with minor shale). Apart from their iron values, the retention of a little free silica (e.g. at 223.35 m 42336) and the presence of calcite with dolomite, the remainder of the lithology is like that of the overlying dolomite unit. However, the last traces of the iron formation may be weakly represented by sample 42323 at 209.6 m. This specimen contains much higher iron than the remaining samples from the dolomite suite.

THE DOLOMITE UNIT

The two major items of interest are the presence of high potassium in the shale layers and the high manganese in the dolomite proper.

Average shale contains 3 to 4 per cent K_20 (Krauskopf, 1967) but high potassium shales are not particularly rare. Examples of such shales are noted by Berg (1952) in Minnesota and Wisconsin; Bowie and others (1966), in Scotland; Croxford (1964-5), at Mount Isa; Darnley (1959-60), in Rhodesia; Granger and Raup (1964), in Arizona; Schmitt (1924) and Weiss (1954) in Minnesota; Shearer (1918), in Georgia; and Tester and Atwater (1934) in various places. Trendall and Blockley (1970, p. 148) record the presence of high potassium shales occurring in the Brockman Iron Formation but do not remark on the high values.

The above authors are divided about the origin of the potassium in these shales. Croxford (1964-65) reports the presence of volcanic shards in shales at Mount Isa, and a mineralogy for the rock of K-feldspar 70-80 per cent, ferroan dolomite 10 per cent, quartz 5 per cent, accessories 1-2 per cent. The K-feldspar has the composition $Or_{98.3}$ $Ab_{1.7}$ An_0 and is believed by Croxford to have once been a low-temperature orthoclase phase (?adularia), though it is largely microcline in its present state. Croxford considered that the potassium was derived from connate water and reacted with volcanic glass to form the orthoclase. He reports the highest values of all authors for K_2O in shales, 12.45 to 13.42 per cent in four samples.

Darnley (1959-60) showed that argillites of the Roan sediments of Rhodesia contained from about 6 per cent K_20 to over 11 per cent K_20. In some cases the potassium was present in biotite/sericite, in others in K-feldspar. He believed the origin of this potassium to be metasomatic.

The greater part of the remaining authors believe that K-feldspar has ultimately formed from clay minerals following collection of potassium from sea or interstitial water by the clays. A sequence of montmorillonite-illite (with chlorite)-K-feldspar is postulated. The mechanisms of K-fixation by montmorillonite in alkaline environments have been reasonably established (Reitemeier, 1951; Nanz, 1953; Grim and Johns, 1954, and Whitehouse and McCarter, 1958—reference cited by Bowie and others, 1966) and are believed to occur by diagenesis. In the process sodium is given up to surrounding waters/solutions. Berg (1952) and Gruner and Thiel (1937) directly, and Bowie and others (1966) indirectly, argue the additional step to K-feldspar without demonstrating the mechanism. The origin of the potassium remains a problem.

Conway (1943) believed that the rate of removal of potassium from the ocean reached a peak in or around the late Precambrian. Many of the potassic shales and rocks cited above are from this general period. Granger and Raup (1964) identify K-rich siltstones of the Dripping Springs Quartzite with 6 to 7 per cent low-sodium K-feldspar as Proterozoic. Berg's (1952) illustration is from the Upper Cambrian Franconia Formation. The Minnesota specimens (Weiss 1954; Schmitt, 1924) are Ordovician. The Scottish "fucoid" beds are Cambrian (Bowie and others, 1966). The Mount Isa rocks are Lower Proterozoic. The present sediments are Lower Proterozoic. There is thus some tenuous support for Conway, however, the origin of the potassium remains unclear.

Trendall and Blockley (1970, p. 112) illustrate in photomicrographs the presence of volcanic shards in the shales of the Dales Gorge Member of the Brockman Iron Formation. Petrological

TABLE 19. SUMMARY VALUES FOR THE TWO MAIN PHASES IN THE DOLOMITE UNIT, AND FOR MAGNETITE-RICH MESOBANDS IN THE IRON FORMATION

	Dolomite (n = 14)		Shale (n = 17)		Magnetite-Rich Bands A(n = 7)		Magnetite-Rich Bands B(n = 9)	
	χ	σ	χ	σ	χ	σ	χ	σ
Fe_2O_3 %	2·89	2·95	2·13	0·90	77·40	4·90	74·04	8·50
MnO %	0·95	0·13	0·11	0·08	0·02	0·01	0·09	0·15
MgO %	19·06	1·81	4·21	1·59	0·73	0·21	1·51	1·59
CaO %	27·71	1·35	2·96	1·68	0·79	0·46	2·48	4·26
Na_2O %	0·04	0·02	0·08	0·03	0·21	0·11	0·17	0·12
K_2O %	0·50	0·24	8·74	1·64	0·27	0·04	0·34	0·15
Cu ppm	19	6	68	18	9	5	12	8
Pb ppm	22	6	21	8	60	5	51	18
Zn ppm	41	31	161	63	18	10	21	10
Ni ppm	40	30	135	39	41	9	45	12
V ppm	17	25	82	44	....	....	....	....
Ba ppm	3 980	710	680	430	64	81	294	551
Sr ppm	15	5	11	6	23	34	22	29
CO_2 %	44·01	2·89	3·78	2·33	1·08	0·75	5·28	8·98
Free C %	0·23	0·26	2·30	0·73	0·04	0·02	0·14	0·25
P_2O_5 %	0·04	0·08	0·09	0·03	0·05	0·01	0·05	0·01

χ = mean; σ = standard deviation;
n = number of samples

N.B. Samples from the transition zone 223·0 to 225·2 m have been excluded from the calculations because of their evidently changed nature, except that the two magnetite bands in the transition zone have been included in the calculation for the last two columns

TABLE 20. COMPARISON OF THE MAJOR ELEMENT CHEMISTRY OF THE IRON FORMATION WITH OTHER PUBLISHED VALUES (NON-AUSTRALIAN)

%	1	2	3	4	5	6	7	8	9	10	11
SiO_2		34·44	35·86	45·66	39·50	22·70	50·90	46·40	40·71	41·83	43·28
Al_2O_3		0·85	1·57	0·28	0·44	0·31	6·25	0·90	2·32	0·92	0·08
Fe_2O_3	32·3	30·54	38·56	19·16	29·21	22·07	20·00	18·70	21·04	33·21	36·14
FeO	*	22·06	20·26	21·28	18·51	23·20	14·40	19·71	20·10	14·66	16·54
MgO	2·57	2·30	1·74	2·73	2·00	3·88	2·00	2·98	3·15	1·96	1·33
CaO	6·58	1·72	0·51	1·04	2·71	4·49	0·85	1·60	2·63	1·90	0·62
Na_2O	0·13	0·0	}0·02					0·04	1·05		0·13
K_2O	0·24	0·13						0·13	0·57		trace
H_2O+		0·44	0·60	1·54			}1·30	1·60	0·91		0·09
H_2O-		0·17	0·06					0·32	0·07		
TiO_2		0·02	0·04		0·040	0·014	0·30	0·04	0·12	0·21	0·22
P_2O_5	0·060	0·07	0·14	0·085			0·05		0·25	0·072	0·14
MnO	0·13	0·21	0·16		0·12	1·06	1·85	0·63	0·29	0·07	0·04
CO_2	8·2	7·36	0·60	7·54	6·22	21·88	1·10	6·90	6·56	0·12	1·84 (L.O.I.)
C	0·03	0·04		0·12	0·017	0·016		0·17			
Fe (total)	22·6							28·36		34·59	38·15

* Iron expressed as Fe_2O_3; FeO not determined

L.O.I. indicates loss on ignition

Blank spaces indicate lack of (published) analyses

1. Iron formation. Composite 42340X, this study
2. Magnetite iron-formation. Ironwood iron-formation; quoted in James, 1966, p.w21
3. Magnetite-quartz rock. Sakasogan (Krivoi Rog) Series, Ukraine ; quoted in James, 1966, p.w. 21.
4. Magnetite chert. Biwabik Iron Formation, Mesabi, Minnesota; quoted in James, 1966, p.w21

5. & 6. Magnetite chert rock, Temiscamie Iron Formation, Quebec; quoted in James, 1966, p.w21

7. Magnetite-siderite slate. Pongola beds, Swaziland System, southeast Transvaal; quoted in James, 1966, p.w21
8. Weighted mean, Biwabik Iron-formation, Mesabi, Minnesota. Bayley and James, 1973, p.942
9. Kuruman Iron Formation, S. Africa.Average of nine analyses. Quoted in Beukes, 1973, p.989
10. Magnetite quartzite, Kursk Magnetic Anomaly, USSR. Plaksenko and others, 1973, p.92
11. Magnetite quartzite, Tarikhan deposit, Aldan Shield USSR. Vorona and others, 1973, p.246

TABLE 21. COMPARISON OF TRACE ELEMENT COMPOSITIONS OF THE IRON FORMATION WITH OTHER PUBLISHED TRACE ELEMENT DATA

	1	2	3	4	5
Cu ppm	10	34	22(6–50)	*(6–8)	30–50
Pb ppm	40				30–80
Zn ppm	20				40–60
Ni ppm	25	23	21(7–170)	*(10–20)	10–20
Ba ppm	100	53	179(34–1000)	27(10–46)	
Sr ppm	20	72			

1. Iron formation; present study. Composite 42340X
2. Magnetite quartzite, Kursk Magnetic Anomaly; Plaksenko and others, 1973. p.93
3. Itabirite (hematite-rich), Casa de Pedra deposit, Minas Gerais, Brazil; Dorr 1973, p.1012. Values given are means, figures in brackets the range. Eighty-nine samples were analysed
4. Dolomite Itabirite; Dorr, 1973, p.1012. Figures have same significance as item 3. Six samples analysed. * Mean values not given
5. Iron Formation (Hematite, magnetite, martite) Bel Park Dala, Kazakhstan; Alexandrov, 1973, p.1050. Spectrographic analyses—ranges only

examination of the present suite of samples has revealed no traces of shards, however, the possibility of a volcanic source cannot be ruled out. The shales are relatively rich in carbon (or hydrocarbons) and some features in the adjoining dolomites suggest the presence of fossil material. It is possible that the shale bands represent "sudden death" sedimentation with volcanic activity not only contributing debris but also killing the then living organisms. The junctions of shale with dolomite are commonly sharp, if somewhat undulatory, and the shales vary from very thin (1-5 mm) to thin (1-2 cm), indicating the abrupt changes which took place in what must have been a relatively short period of time. It is possible that carbonate sedimentation took place at a uniform rate. The sudden bursts of clastic material represented by the shales may have produced local, more rapid deposition. The carbonate content of the shales may therefore reflect carbonate precipitation at a standard rate, overprinted (or diluted) by the clastic components. The low sodium content precludes against the feldspar being normal igneous feldspar. The identification of adularia (by X-ray diffraction) in the present investigation and the absence of visible detrital K-feldspar suggest that at least the greater part of the K-feldspar in these shales is of authigenic origin with a volcanic (tuffaceous) component and, possibly, a sea water component.

Turning to the dolomitic rock proper, the main points of interest are the consistent overall composition and the presence of high manganese values throughout the entire length of the column analysed. The high magnesium content renders the dolomite in this area unsuitable as a metallurgical flux.

The high manganese content is of greater interest, for the levels are high enough for the rock to have potential as a source of manganese ores. The lateral equivalent of the Wittenoom Dolomite in the Oakover River Basin is the Carawine Dolomite, which is known to be appreciably manganiferous (de la Hunty 1963, 1965; Campana and others, 1972), and acts as host ("enclosing rock", Campana and others' terminology) for manganese mineralization—Woodie Woodie, Ripon Hills. The origins of this mineralization are not absolutely clear, though, ultimately, the manganese is believed to have been derived from the Carawine Dolomite (de la Hunty, 1963; A. Hickman, pers. comm.). Rocks of comparable age and lithology in the Kuruman District of South Africa are also manganiferous and are the hosts of manganese mineralization (Frankel, 1958). In the dolomite unit the manganese is evidently an inherent feature of the rock as its close relationship with calcium and magnesium must mean that the manganese is a component of the carbonate. It was therefore present at or before the crystallization of the dolomite. A comparable situation, with comparable manganese values, occurs in the "deep Bangombé" borehole in the manganiferous deposit of Moanda, Gabon (Weber, 1973).

It was stated earlier that certain relict features in the dolomite and in the transition zone are reminiscent of fossil material. Trendall and Blockley (1970, p. 85) note that algal structures have been recognized in the Carawine Dolomite at Woodie Woodie. If the features in the rocks of the Millstream core are demonstrated to be of organic origin, they will be among the few known fossils of this age from the Hamersley area.

A major problem is that the greater part of the minerals have been transformed by diagenesis, and very little non-recrystallized material has been recognized. Evidence of recrystallization and diagenesis is found in the rhombic growth of dolomite (and siderite), the presence of abundant stylolites at certain intervals, the presence of authigenic feldspars, the random growth of riebeckite and the late development of pyrite. Other features include the infilling of apparent compaction cracks, the growth of carbonate grains across, and including, trains of opaque grains and late stage veining by dolomite and, rarely, quartz. Not all these features were noted in any one specimen but there is no reason to exclude any part of the sequence from the recrystallization process.

Original features of the rock are believed to include primary disposition of opaques, particularly the carbonaceous opaques, and the intraformational breccias which, though not sampled, are present near the top of the column.

There is no evidence from this core to show whether the rock before recrystallization was dolomitic or not. The presence of calcite within the shales suggests that calcite might have been the primary carbonate, though the reverse has been postulated by Trendall and Blockley for the Brockman Iron Formation. These authors (1970, p. 129) consider that calcite which is associated with some of the shales is secondary.

Chemical conditions, since diagenesis at least, have been reducing as is shown by the retention of the organic carbon, and by the presence of pyrite and magnetite. The presence of intraformational breccias, of varying thicknesses of shale, and of possible organic, ?planktonic and algal remains, suggests a shallow water environment of deposition possibly with subsidence occurring at a rate corresponding with the rate of deposition. The lack of large clastic grains indicates generally quiet conditions with a general absence of detritus.

CONCLUSIONS

This study has consisted of an investigation of the transition from an iron formation unit to an overlying dolomite unit of the Wittenoom Dolomite.

The main features shown by the study are:

(i) The tremendous variability of composition of the various mesobands of the iron formation.

(ii) The close similarity of composition of the iron formation to other magnetite-rich, Precambrian banded iron formations throughout the world. The main differences lie not in the mineralogy, but in the proportion of iron, which at 22.6 per cent Fe is lower and in the proportion of calcium (6.6 per cent CaO) which is higher than in most other iron formations.

(iii) The presence of a distinct transition zone between the iron formation and the dolomite unit has been recognized. This zone, which is approximately 2.2 m thick, has, for the most part, the dolomite unit facies of dolomite with shales, but additionally contains two magnetite-rich bands and rare chert with minnesotaite. This zone is richer in iron and is also probably richer in calcium than the overlying part of the Wittenoom Dolomite.

(iv) The lower part of the dolomite unit consists of rather featureless dolomite punctuated by thin (2 mm-2 cm) bands of shale. The dolomite is dark in colour and contains visible oily hydrocarbons at 179.5 m. Contacts between shale and dolomite are normally abrupt though much of the dolomite has shaly partings.

(v) The dolomite of the dolomite unit approximates to the theoretical composition for the mineral dolomite with some substitution of manganese for magnesium. The manganese content is high compared with normal dolomite (averaging 0.95 per cent MnO) but is similar to that in dolomites of similar age in the Oakover River area, W.A., in Gabon and in South Africa.

(vi) The shales in the dolomite unit are abnormally high in potassium which is present as adularia, a low-sodium, K-feldspar. This feldspar is believed to have developed authigenically from illite. The origin of the potassium is unknown, but a tuffaceous source is suspected.

(vii) The conditions of formation of the various rocks/phases are uncertain because of extensive diagenesis and recrystallization. However it appears likely that all phases, except the shales, were once chemical precipitates. Shallow water sedimentation is suggested and the reducing conditions may have developed concurrently with diagenesis. The shales are considered to be transformed products of vulcanism (volcanic ash) possibly with other clastic components.

ACKNOWLEDGEMENTS

The help and advice of members of the Government Chemical Laboratories, in particular Messrs D. Burns, M. Costello (chemical analysis) and R. Clarke and L. Bastian (X-ray diffraction) is gratefully acknowledged.

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THE NULLAGINE METEORITE

by J. D. Lewis

ABSTRACT

A small meteorite recovered in 1973 near the township of Nullagine (21° 52′ S, 120° 07′ E), Western Australia, weighed 102 g and is an almost complete stone. The Nullagine meteorite is a moderately metamorphosed bronzite chondrite and contains rare chromite chondrules. The meteorite contains approximately 11 per cent iron and 8 per cent sulphides. Neumann bands are prominent in the iron and some of the sulphide has been remobilized by shock veins.

INTRODUCTION

During the regional mapping of the Nullagine Sheet in 1973 by the Geological Survey of W.A., a small stony meteorite was recovered by Mr. R. Thom. It was found 5 km north of Nullagine township, by the side of the Great Northern Highway, (approx: 21° 52′ S, 120° 07′ E), in the Pilbara district of N.W. Western Australia. A brief search of the area did not reveal further finds or evidence of an impact crater in the surrounding surface rubble of weathered Archean sediments.

The meteorite has been designated the Nullagine meteorite after the township near which it was found. The name has been approved by West Australian Meteorite Committee.

GENERAL DESCRIPTION AND MORPHOLOGY

The meteorite, as collected, weighed 102.25 g and apart from a chip on one corner is a complete stone (Fig. 50A and B). The stone is irregular in shape with maximum dimensions of about 5 x 4 x 3 cms and a "kite" shaped cross section. A very thin (ca. 0.1 mm) matt brown oxidised fusion crust covers the whole meteorite except for the small broken section which reveals an oxidised chondritic core. Depressions on two of the larger faces probably represent the original shape of the stone rather than regmaglypts. No features due to orientation in flight can be seen.

STRUCTURE AND PETROGRAPHY

On a cut surface the chondritic nature of the meteorite is obscured by a general oxidation which extends uniformly throughout the mass. Metal and sulphide particles are visible however, and a thin section reveals that oxidation has not extended beyond formation of a thin film of hydrated iron oxides on the original minerals.

Modal analysis of a polished mount of the Nullagine meteorite gave the following analysis:

Mineral	*Per cent*
Silicates	77.6
Kamacite	11.1
Troilite	6.0
Taenite	2.2
Chromite	1.1
"Iron oxides"	2.0

The silicate phase is predominantly chondritic with probably only 10 per cent as interstitial olivine and pyroxene grains. The opaque minerals form a large part of the interchondrule material but troilite is also found marginally in many chondrules and a few chondrules consists predominantly of chromite. "Iron oxides" noted in the modal analysis are the weathered products of the kamacite and troilite; their probable composition is goethite. They could probably be distributed proportionately to determine the original metal and sulphide content of the unweathered meteorite.

Chondrules

A wide variety of chondrules is present (Fig. 50E), ranging in size from about 0.2 mm to 2 mm in diameter. The chondrules are commonly spherical or ovoid but some are polygonal and perhaps one third of the chondrules are broken.

Fine-grained excentroradial orthopyroxene chondrules are the most prominent type and include the largest and the smallest chondrules. These chondrules are typically spherical and the degree of crystallization varies from devitrified glass through feathery fans of orthopyroxene to stout radiating prisms of orthopyroxene. Variations include chondrules which crystalized about a small central euhedral pyroxene crystal and a few containing small acicular orthopyroxene crystals arranged to form a "spherulite".

Porphyritic chondrules, containing euhedral to subhedral olivine and orthopyroxene in a devitrified groundmass, are the commonest type. Individual olivine crystals vary from about 0.01 mm to 1 mm long. Most porphyritic chondrules contain only olivine crystals and the proportion of olivine varies from chondrules of packed anhedral olivine grains with minimal interstitial material to those in which the olivines are euhedral and the devitrified groundmass contains abundant needles of orthopyroxene.

Few porphyritic chondrules contain only orthopyroxene but there are a number in which orthopyroxene predominates, either as euhedral prisms 0.2-0.5 mm long or as more acicular prisms up to 1 mm long (Fig. 50D).

A distinctive type of porphyritic chondrule are those which contain a high proportion of interstitial devitrified glass. In these chondrules olivine may form small outline skeletal crystals only, or skeletal additions to earlier formed euhedral olivines, while orthopyroxene forms randomly orientated, small, ghost crystals. Occasionally small skeletal olivines have nucleated on the surface of the chondrules and the crystallites are directed inwards (Fig. 50D). The textures shown by these chondrules are probably quench textures but with cooling taking place more rapidly than for the barred chondrules.

Barred chondrules are not uncommon in the Nullagine meteorite but the most distinctive form (Fig. 50E), consisting of a small number of broad parallel olivine bars in optical continuity with a granular olivine rim, is the least common. In the example illustrated the interstitial material consists of fine grained acicular needles of orthopyroxene. More commonly the barred olivine chrondrules are polygonal and consist of one or more sets of narrow olivine plates, with up to 30 plates per set and no rim (Fig. 50C). Despite the apparent regularity of the arrangement of the sets of olivine plates, Dodd and Calef (1971) have shown that the olivines are probably randomly orientated rather than twinned.

Barred chondrules of orthopyroxene are also found although some are probably fortuitous sections through coarsely crystaline excentroradial chondrules. Olivine bars can also be seen traversing some orthopyroxene rich chondrules and in a few there appear to be alternate bars of olivine and orthopyroxene, sometimes on such a fine scale that the chondrule appears to be an excentroradial chondrule of olivine.

As an intermediate type between the barred and porphyritic chondrules many chondrules contain individual, large porphyritic olivines which have grown from a skeletal barred crystal and now enclose small blebs and trains of devitritified glass.

Chromite rich chondrules will be described later but mention must be made of a few small chondrules which contain diopside. The two such chondrules observed are small, about 0.2 mm across, polygonal and contain a few acicular diopside crystals in a devitrified glassy matrix. Diopside is also plentiful however as an exsolution product of orthopyroxene where it occurs most commonly as marginal lamellae parallel to the 100 polysynthetic twinning. Less well defined lamellae and zones of diopside are also present internally in some of the larger orthopyroxene crystals. Exsolution blebs of diopside are common in the fine-grained excentroradial chondrules.

The orthopyroxene of the Nullagine meteorite is commonly homogeneous and has straight extinction but a few crystals show well defined polysynthetic twinning and a small extinction angle, indicating inversion from clino-bronzite (Binns 1970). Frequently the homogenization is incomplete and the crystal has the appearance of a strained orthopyroxene.

Small low relief and low birefringance patches within the groundmass of some chondrules are probably plagioclase but nowhere have they developed into well shaped crystals.

Opaque Minerals.

Kamacite and troilite are the principal opaque minerals of the Nullagine meteorite and together they constitute more than half of the interchondrule mesostasis. Both form large cuspate grains up to 1 mm across, and are moulded onto the chondrules and interstitial silicates.

Throughout most of the meteorite the individual grains of kamacite and troilite are single crystals but within a few millimetres of the fusion crust the grains have been partly or completely recrystallized to an aggregate of small equiaxed crystals usually less than 0.1 mm across. Troilite has always been more completely recrystallized than adjacent kamacite grains. Except near the fusion crust kamacite shows well developed Neumann bands (Fig. 51E) and some of the troilite shows a strained extinction.

Kamacite is almost entirely moulded onto the chrondules but troilite also occurs as small spherical droplets in the marginal parts of chondrules and occasionally as small droplets within chondrules.

Kamacite and troilite are never intergrown in the Nullagine meteorite but occasionally a large subhedral crystal of troilite is enclosed by kamacite. Taenite is only present to the extent of 2 per cent and forms small irregular grains often intergrown with troilite (Fig. 51C). More rarely taenite is found in association with kamacite. Etch patterns indicate a high nickel content for the taenite. Some taenite crystals have a spongy internal structure (Fig. 51D) which appears to be a myrmekitic style intergrowth between high and low nickel taenite.

According to Ramdohr (1973) chromite is the most variable mineral in stoney meteorites. This is true of the Nullagine meteorite where chromite can be found as individual large subhedral crystals, up to 0.1 mm across, as anhedral interstitial crystals, as irregular aggregates and as a major or minor component of chondrules. Two generations of chromite are probably present. Early formed chromite is found as small euhedral crystals in chondrules and possibly in the irregular aggregates.

A later chromite phase is moulded on the silicates of the interstitial material but is euhedral towards kamacite and troilite. This later phase is the commonest and appears to be preferentially associated with troilite and taenite (Fig. 51C). Being a brittle mineral chromite is easily fractured and several crystals now consist of aggregates of shard-like fragments.

Chromite aggregates range up to about 0.2 mm across, are irregularly shaped and appear to consist of a number of small octahedra welded together. Centrally the chromite has often aggregated to a degree that excludes silicates but marginally small laths of silicate minerals form a considerable proportion of the aggregate.

In chondrules chromite varies from a few small euhedral grains in a normal chondrule, to chondrules which consist principally of chromite. Scattered chromite grains in chondrules are fairly common, making up 20 per cent in one example. Chromite rich chondrules, however, are small, usually about 0.2 mm across, and contain about 60-70 per cent chromite. In the few samples located in the Nullagine meteorite the chromite forms predominantly as octahedra which appear to have matted together, but occasionally the crystals are prismatic (Fig. 51A). The silicate material in such chondrules is, according to Ramdohr (1967), mainly plagioclase but in the Nullagine meteorite it has not been identified. One chromite chondrule contains many small blebs of troilite (Fig. 51B).

Metamorphism.

Both thermal and shock metamorphic effects are visible in the meteorite. Thermal metamorphism is evidenced by the turbidity of former glassy portions of the meteorite, the almost complete elimination of low-Ca clinopyroxene and the presence of a little interstitial plagioclase. The chondrules, however, are strongly delineated which suggests that the temperature of metamorphism did not reach extreme values (van Schmuss and Wood 1967).

Low grade shock metamorphism is shown by the presence of strained extinction and, more rarely, twinning in the troilite and Neumann bands in the kamacite (Fig. 51E). Strain in the troilite is not common but Neumann bands are almost universal in the iron phase except near the fusion crust; their presence indicates that the meteorite was subjected to high energy shock after it had cooled down (Uhlig 1955). A few shock veins are also present and these usually contain a dark glass, crystal fragments and sometimes anastomosing veins of secondary troilite (Fig. 51E). Iron is only rarely found in these shock veins but adjacent to the vein it is sometimes recrystallized to a very fine-grained polycrystalline aggregate which truncates the Neumann bands in the main mass.

The history of the Nullagine meteorite, as revealed by its metamorphism, indicates that the original mass was first metamorphosed at temperatures above 550° C (van Schmuss and Wood 1967) and probably near 900° C (Binns 1967). At a temperature probably below 300° C (Uhlig 1955) the mass exploded, causing the shock metamorphism and the angular shape of the present specimen. Passage through the atmosphere then gave rise to the fusion crust and marginal recrystallization of the metal and sulphide fractions.

CLASSIFICATION

Olivine from the Nullagine meteorite, determined by the Weissenberg X-ray method of Pryce (1970), has the following cell dimensions: $a = 4.767 \pm 0.002$ Å, $b = 10.249 \pm 0.003$ Å, $c = 6.001 \pm 0.0025$ Å which correspond to a composition of $Fa\ 19 \pm 1$. The meteorite is therefore an H group or olivine bronzite chrondrite according to the data of van Schmuss and Wood (1967, p. 750, table 1). Petrographically the Nullagine meteorite falls in either type 4 or 5 of the above author's classification. The presence of turbid glass in some chondrules and the well defined outlines of the chondrules suggest type 4, whereas the structural state of the low-Ca pyroxene and the recrystallized nature of the matrix suggest type 5.

Using the classification of Binns (1967) the presence of diopside in association with the orthopyroxene indicates an olivine bronzite chondrite of the transitional group.

The Nullagine meteorite is, then, an H5 or transitional group olivine-bronzite chondrite.

ACKNOWLEDGEMENTS

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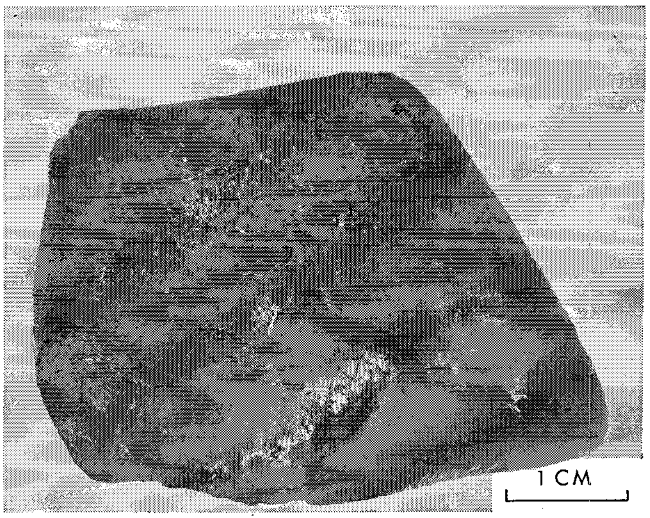
Figure 50. (opposite)
A and B. Two views of the Nullagine meteorite.
C. Small barred olivine chondrule.
D. Porphyritic chondrule containing only orthopyroxene (upper), and spherical, glassy chondrule with small skeletal olivines nucleated on the surface of the chondrule (lower).
E. Photomicrograph showing the variety of chondrules present in the Nullagine meteorite.



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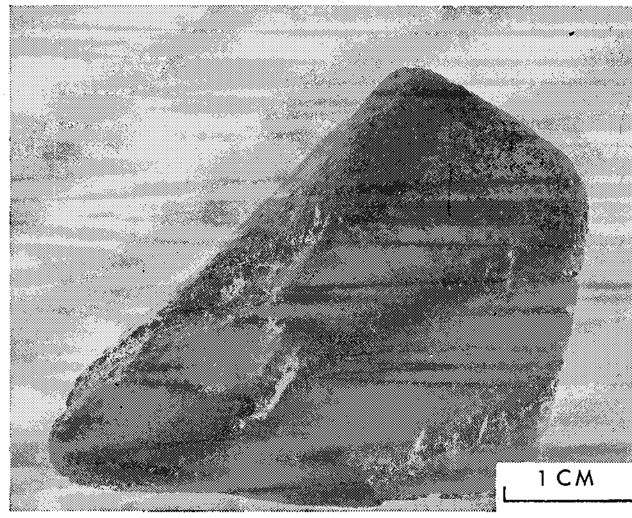

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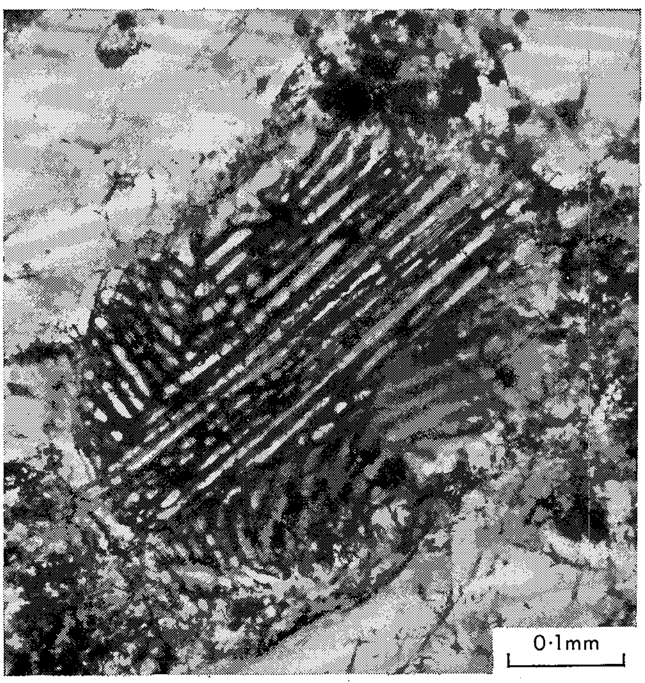

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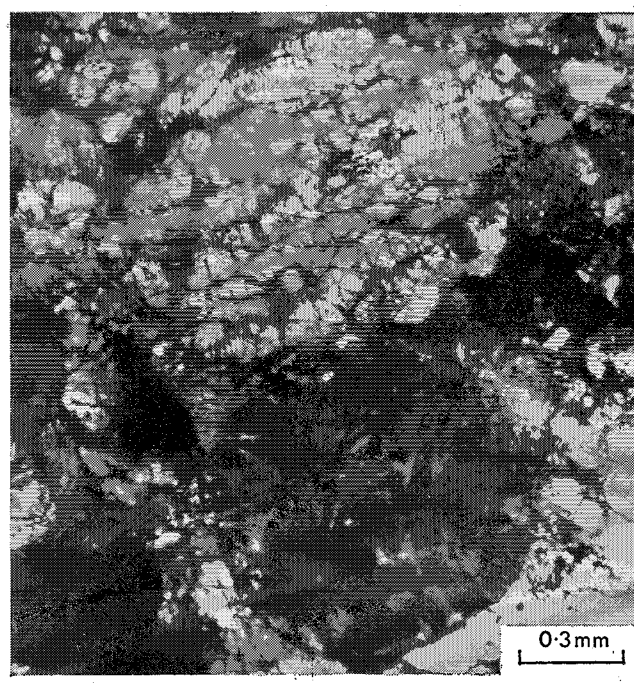

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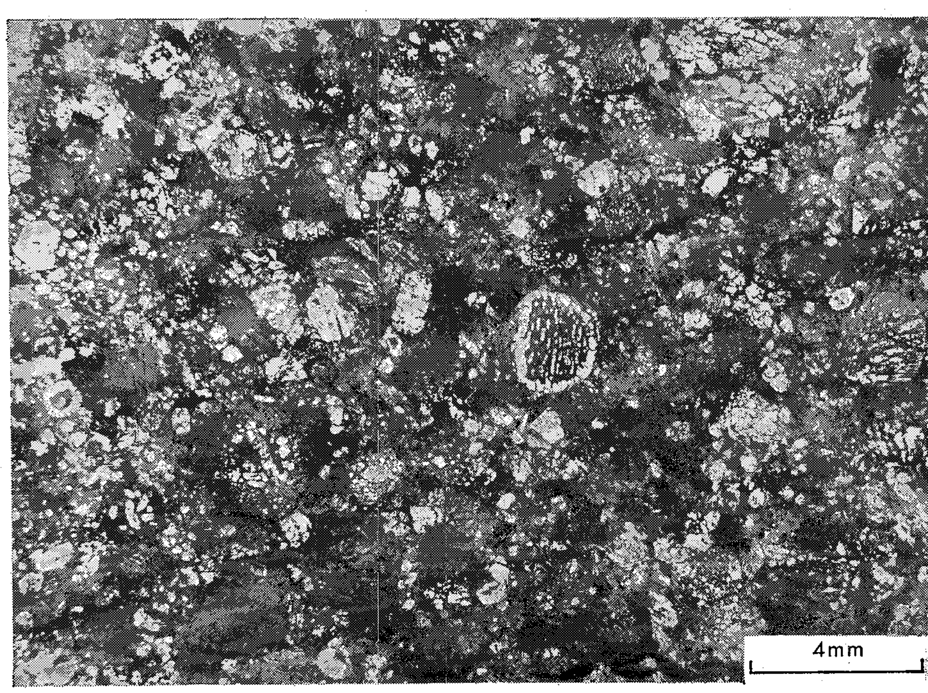

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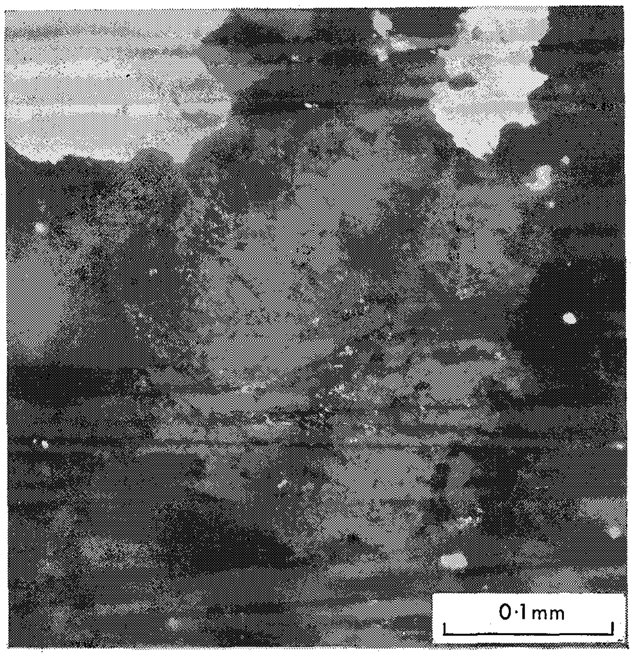

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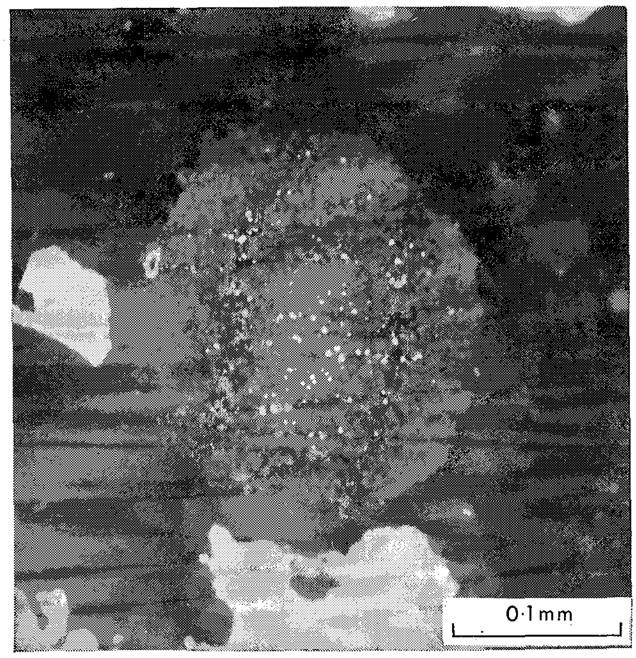

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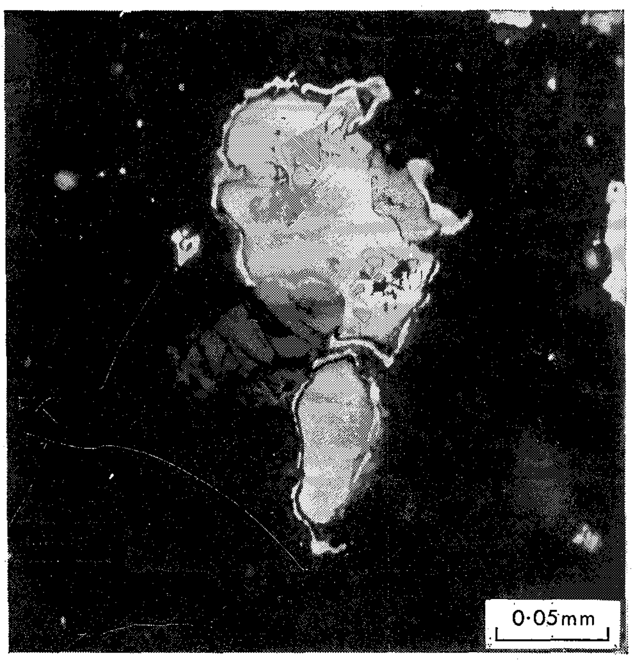

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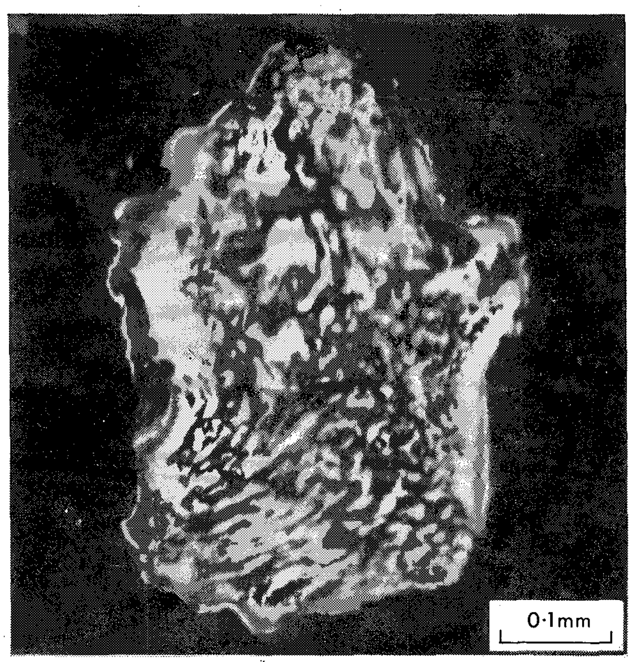

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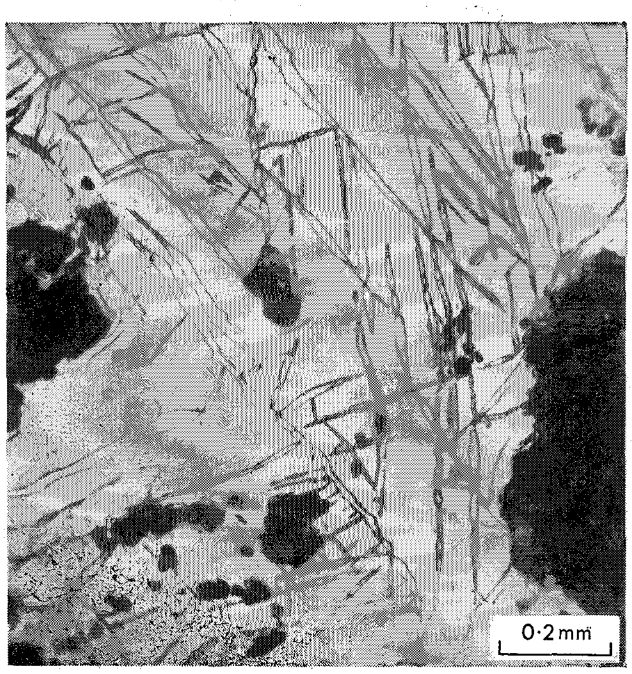

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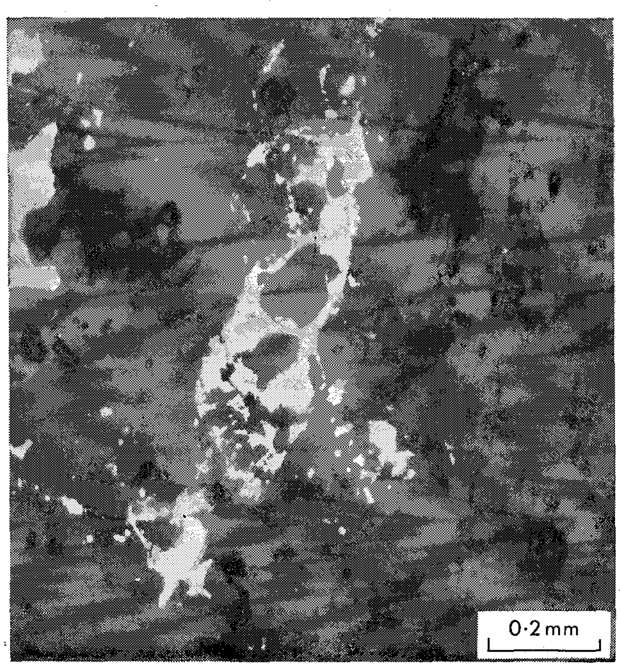

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Figure 51. (opposite).
A. Chromite rich chrondrule with prismatic chromite.
B. Chromite rich chondrule containing small blebs of troilite. In this example the original chromite euhedra have been partly fused together.
C. Taenite (nital etched) intergrown with troilite and moulded onto a large chromite grain.
D. Taenite (nital etched) showing myrmekitic style intergrowth of high and low Ni varieties.
E. Neumann bands in kamacite (nital etched).
F. Remobilization of troilite along a shock vein. Small angular fragments of silicate minerals set in a network of troilite.

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PRELIMINARY GEOCHRONOLOGICAL RESULTS FROM TWO PILBARA PORPHYRY BODIES

by A. F. Trendall

ABSTRACT

The Bamboo Creek Porphyry and the Spinaway Porphyry are two stratiform bodies of porphyry within the Hardey Sandstone (Fortescue Group) in two separate parts of its outcrop in the eastern Pilbara area of Western Australia. Similarity of petrography and intrusion shape, as well as stratigraphic equivalence, suggest correlation of the two porphyry bodies. However, Rb/Sr isotopic analyses of nine samples of Spinaway Porphyry, and of ten samples of Bamboo Creek Porphyry, give computed isochrons of 2 124 ± 195 m.y. and 2 820 ± 516 m.y. respectively. A large age difference cannot be satisfactorily reconciled with the geological evidence. On the other hand, if the two porphyries are accepted from geological evidence as closely coeval, and the age of both, on regional grounds, is accepted to be close to that of the Spinaway Porphyry isochron, the isotopic analyses of the Bamboo Creek Porphyry samples are not easily reconciled with their petrography and chemistry. Nevertheless, this second course appears to be the most reasonable one, pending further evidence.

INTRODUCTION

The purposes of this paper are to report and discuss the results of Rb/Sr isotopic analyses of 19 whole-rock samples from two stratiform bodies of felsic porphyry near the base of the Fortescue Group in the eastern Pilbara area of Western Australia; specifically, these results are relevant to the geological history of an area roughly enclosed between latitudes 21° and 22° S and longitudes 119° 30′ and 120° 30′ E, representing the eastern and western parts respectively of the Marble Bar and Nullagine 1:250 000 Sheet areas.

Although the data reported are consistent with more than one hypothesis concerning the age and emplacement of the porphyry, they are nevertheless significant, and as there is no immediate prospect of further work a published record is desirable.

GEOLOGICAL SETTING AND NOMENCLATURE

The broad regional tectonic and geochronological significance of both the porphyry bodies, under the single name Bamboo Creek Porphyry, were discussed by de Laeter and Trendall (1971); the following brief outline supplies only enough background to allow this paper to be read and understood in isolation.

During the early Proterozoic, steady sinking of a land surface eroded across Archaean rocks led to the development of an ovoid depositional basin—the Hamersley Basin—over an area of some 150 000 km^2 of what is now the northwestern part of Western Australia. The material which accumulated within it was at first volcanic and volcanoclastic, then largely chemically precipitated, and finally clastic, and this sequence broadly corresponds with the three divisions—Fortescue Group, Hamersley Group, and Wyloo Group—into which the remaining part of its contents are now stratigraphically subdivided. Later uplift led to the removal of much of this material, and the present northern edge of the basin is marked by a regional unconformity in which the negligibly disturbed Fortescue Group dips very gently southwards off the Archaean rocks of the Pilbara Block.

This great unconformity runs sinuously but consistently east-southeastwards from the coast for some 400 km before its course becomes more irregular, swinging northwards and back towards the west. As a result, in the area under immediate attention, two lobes of the unconformity, one from the northeast and the other from the south, are opposed across a gap about 20 km wide in which the Archaean floor of the basin is re-exposed. Within a clastic unit clearly identifiable as equivalent in the lower part of the Fortescue Group of both lobes there is present also in each lobe a stratiform body of similar porphyry.

Noldart and Wyatt (1962) mapped and described the southern and northern outcrops of porphyry as part of a single, presumably originally continuous, body called the Bamboo Creek Porphyry. They noted earlier divergence of opinion as to whether it was intrusive or extrusive, and also described some new evidence for both types of origin.

Hickman (in prep.), as a result of recent re-mapping of the Nullagine 1 : 250 000 Sheet area by himself and Mr. R. Thom, proposes to retain the name Bamboo Creek Porphyry for the porphyry north of the exposure gap, and to apply the name Spinaway Porphyry (Lipple, 1975) to that south of it. Both form stratiform bodies within the Hardey Sandstone of the Fortescue Group, probably up to about 100 m thick. Hickman (in prep.) records local evidence that the Bamboo Creek Porphyry is at least in part extrusive, and that the Spinaway Porphyry is intrusive. He nevertheless appreciates that the evident similarity in lithology and intrusion shape, as well as the stratigraphic continuity of the host sandstone, make a supposition of original direct continuity attractive.

MATERIAL USED

The samples analysed were collected by Dr. A. H. Hickman. Nine were taken from the Spinaway Porphyry and ten from the Bamboo Creek Porphyry.

Samples 32559 A-I (9), from the Spinaway Porphyry were collected at lat.21° 46′ S, long.120° 05′ E, 15 km north of Nullagine from cliffs 100 m west of Great Northern Highway.

The individual samples, each weighing about 2 kg, were collected from the central part of the sheet over an exposure area of about 0.5 ha to give a variable sample separation of about 5 to 25 m.

These nine samples are not distinguishable from one another in macroscopic appearance, and consist of massive, fresh, homogeneous, felsic porphyry. Abundant greyish yellow-green (5 GY 7/2) plagioclase phenocrysts mostly between 2 and 10 mm in longest diameter, less abundant and slightly smaller rounded phenocrysts of pink (5 RP 8/2) potassium feldspar, and corroded phenocrysts of quartz about the same size as the plagioclase phenocrysts, are set in a bluish-grey (5 B/6/1) aphanitic matrix. Darker and more coarsely granular patches in this matrix may represent digested xenoliths.

Thin section examination shows clearly that the shapes of all three phenocryst types are those characteristic of late modification, including resorption. The quartzes are well rounded and in places deeply embayed, the plagioclase (albite) has slightly rounded and corroded subhedral outlines, while the potassic feldspar is deeply embayed and irregular. Lamellar twinning and glomerocryst structure is typical of the albite phenocrysts, whose green colour is due to abundant inclusions of fibrous pumpellyite and chlorite; epidote, fluorite and carbonate are less abundant. The potassic feldspar is untwinned, with highly irregular patchy extinction, and is charged with exsolved hematite dust.

The matrix consists of a random mesh of slender "laths", about 0.5 mm long, which consist of quartz which is optically continuous in a pattern independent of the lath forms. The laths are assumed to be quartz paramorphs after tridymite. The interstitial areas contain either finely fibrous brownish-green chlorite or a fine (0.02-0.05 mm) mosaic of potassic feldspar, or a mixture of both. There are wide variations in textural detail in the matrix, which has a locally variable minor content of opaque mineral, carbonate, sphene and epidote. Larger concentrations of chlorite may be pseudomorphous after pyroxene.

Samples 32995 A-J (10), from the Bamboo Creek Porphyry were collected at Bamboo Creek (120° 13′ 30″ E; 20° 55′ 30″ S). They were collected over an area of about 0.25 ha within 30 m of the lower contact of the porphyry; approximate sample separation was 5 to 10 m.

Like the porphyry material from the Spinaway Porphyry, each sample weighed about 2 kg; the ten samples are not distinguishable from each other in macroscopic appearance and consist of massive, fresh, homogeneous, felsic porphyry. While these rocks are closely similar to those from the Spinaway Porphyry in that they contain both green and pink feldspar phenocrysts as well as quartz in a fine-grained grey matrix, there are macroscopic differences in colour and relative abundance of these constituents which are related to significant differences apparent in thin section.

The matrix is a darker bluish-grey (5 B 4/1) than in the Spinaway Porphyry samples, as also are the dusky yellow-green (5 GY 5/2) plagioclase phenocrysts; the phenocrysts of potassic feldspar are of the same pink (5 RP 8/2) colour. All three phenocryst types are of roughly equal size (2-10 mm), and also of approximately equal abundance.

In thin section the plagioclase phenocrysts of these rocks are so abundantly sericitized that their composition cannot be accurately determined; in addition they appear more corroded than those in the Spinaway Porphyry. The potassic feldspar phenocrysts show the same patchy extinction and irregular forms as their possible southern counterparts, but differ in having abundant carbonate alteration.

The matrix of these rocks from the Bamboo Creek Porphyry shows no sign of the lath-like quartz texture, but is a very fine-grained aggregate of quartz, feldspar and sericite. Chlorite and opaque minerals are also present in irregular scattered aggregates in the matrix.

In summary, while the analysed samples from the Spinaway Porphyry and Bamboo Creek Porphyry are distinctively different in both macroscopic and thin section appearance, the differences would be accepted by most petrographers as those to be expected within a single igneous rock body.

ANALYTICAL PROCEDURES

With one exception, all instruments and methods used were the same as those described by de Laeter and others (1974). The exception is that the Sr^{87}/Sr^{86} values of Table 22 were normalized 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 normalizing value has now been adopted.

RESULTS

The measured Rb/Sr (XRFS) and Sr^{87}/Sr^{86} ratios are shown in Table 22 together with the calculated Rb^{87}/Sr^{86} values. All errors are at the 95 per cent confidence level. The data also appear in Figure 52 together with two isochrons computed from them by the programme of McIntyre and others (1966). The 2 124 ± 195 m.y. age derived from the nine analyses of samples 32559 A-I, from the southern area, is a Model 4 age; the age of 2 820 ± 516 m.y. computed from the ten results of sample 32995 A-J, from the north, is a Model 3 age. The mean squares of weighted deviates (MSWD) for Model 1 ages of these two groups were 13.2 and 16.1 respectively, indicating that the scatter of points is well beyond experimental error, and is due to some "geological effect".

TABLE 22. ANALYTICAL DATA FOR NINE WHOLE-ROCK SAMPLES FROM THE SPINAWAY PORPHYRY (32559) AND TEN WHOLE-ROCK SAMPLES FROM THE BAMBOO CREEK PORPHYRY (32995)

Sample No.	Rb (ppm)	Sr (ppm)	Rb/Sr	Rb^{87}/Sr^{86}	Sr^{87}/Sr^{86}
32559 A	167	92	1·68 ± 0·02	4·93 ± 0·05	0·863 9 ± 0·001 0
32559 B	170	72	2·24 ± 0·02	6·60 ± 0·07	0·913 0 ± 0·004 0
32559 C	156	94	1·62 ± 0·02	4·74 ± 0·05	0·854 5 ± 0·005 0
32559 D	159	116	1·31 ± 0·01	3·80 ± 0·04	0·829 6 ± 0·001 9
32559 E	164	77	2·09 ± 0·02	6·14 ± 0·06	0·894 2 ± 0·001 5
32559 F	167	110	1·45 ± 0·01	4·24 ± 0·04	0·836 5 ± 0·002 0
32559 G	156	101	1·50 ± 0·02	4·39 ± 0·04	0·842 2 ± 0·002 6
32559 H	178	94	1·81 ± 0·02	5·31 ± 0·05	0·873 6 ± 0·010 0
32559 I	170	87	1·93 ± 0·02	5·67 ± 0·06	0·879 3 ± 0·006 3
32995 A	198	185	1·06 ± 0·01	3·10 ± 0·03	0·826 6 ± 0·001 5
32995 B	166	159	1·04 ± 0·01	3·04 ± 0·03	0·819 7 ± 0·001 3
32995 C	158	157	0·95 ± 0·01	2·77 ± 0·03	0·816 4 ± 0·002 1
32995 D	156	202	0·77 ± 0·01	2·24 ± 0·02	0·792 8 ± 0·001 0
32995 E	156	152	1·05 ± 0·01	3·06 ± 0·03	0·823 8 ± 0·001 3
32995 F	174	185	0·94 ± 0·01	2·68 ± 0·03	0·806 6 ± 0·002 8
32995 G	161	176	0·91 ± 0·01	2·64 ± 0·03	0·804 8 ± 0·003 4
32995 H	187	183	1·02 ± 0·01	3·01 ± 0·03	0·822 4 ± 0·001 4
32995 I	174	204	0·85 ± 0·01	2·79 ± 0·03	0·811 8 ± 0·000 4
32995 J	156	176	0·89 ± 0·01	2·54 ± 0·03	0·799 8 ± 0·000 7

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.

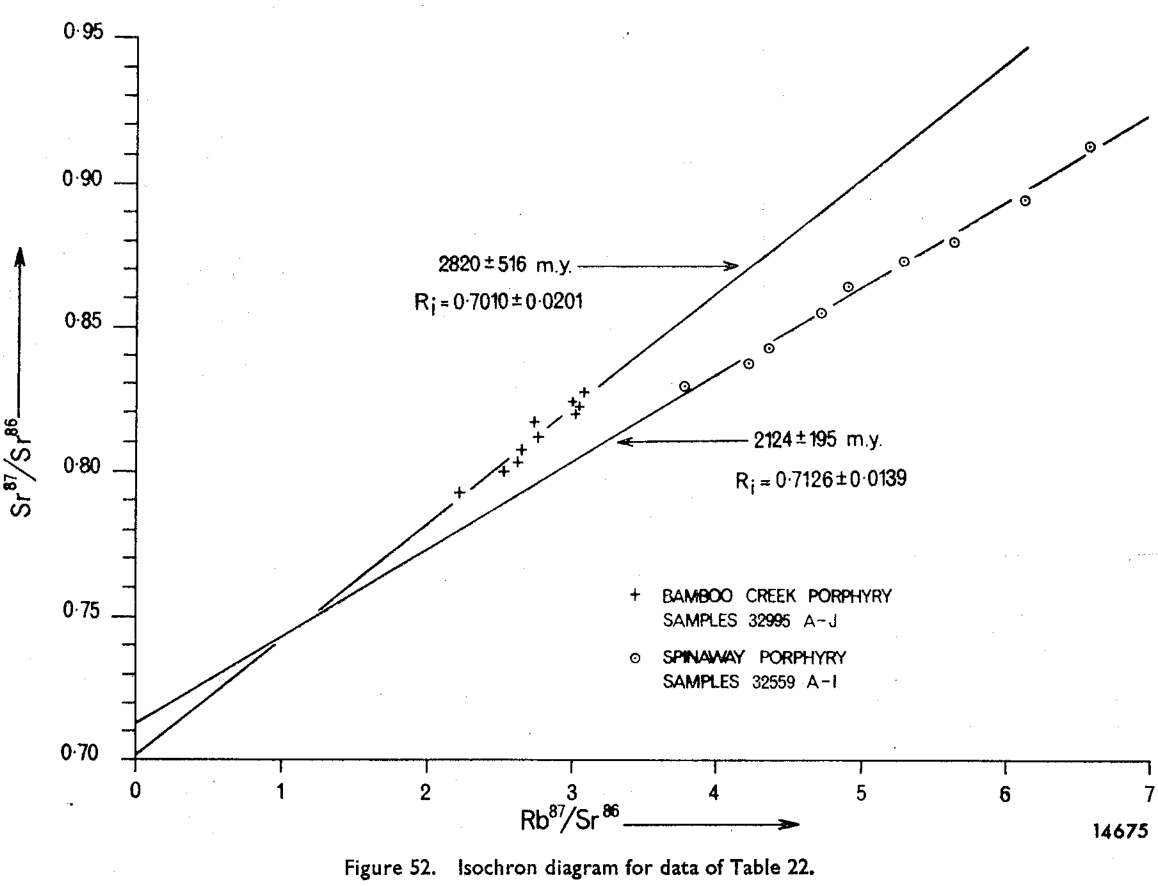

Figure 52. Isochron diagram for data of Table 22.

DISCUSSION

From Table 22 it is clear that, in respect to Rb and Sr chemistry, both porphyry bodies, as samples, have a comparable Rb content, but a Sr content differing by a factor of about 2. The means for samples 32559 and 32995 are, for Rb, 165 and 199 respectively, with an overlap in range of values, and for Sr, 94 and 178, with a gap of 36 ppm between the highest value (D) for 32559 and the lowest (E) for 32995. It is noteworthy that the samples with more abundant potassic feldspar phenocrysts (32995) unexpectedly have higher Sr values. The range of values for both Rb and Sr for both sets of samples is small. These features result in the lack of overlap between their Rb^{87}/Sr^{86} values, evident in Figure 52, and the comparatively narrow range in this ratio for each set.

It was evident from visual assessment of Figure 52 that the analyses of the two sets of samples did not define a single isochron, and separate isochrons for the two sets were therefore computed. The computed age for the Spinaway Porphyry, 2 124 ± 195 m.y., is consistent with its supposed intrusive relationship into the Hardey Sandstone, the best available younger and older limits on the age of which are 2 200 m.y. (de Laeter and others, 1974) and either 2 606 ± 128 m.y. or 2 329 ± 89 m.y. according to preferences in regional interpretation (Lewis and others, 1975). It is also consistent with its broad correlation with a number of other stratiform felsic bodies within the Fortescue Group and overlying Hamersley and Wyloo Groups (Fig. 53), as representatives of a regional igneous event at about 2 200 to 2 000 m.y.

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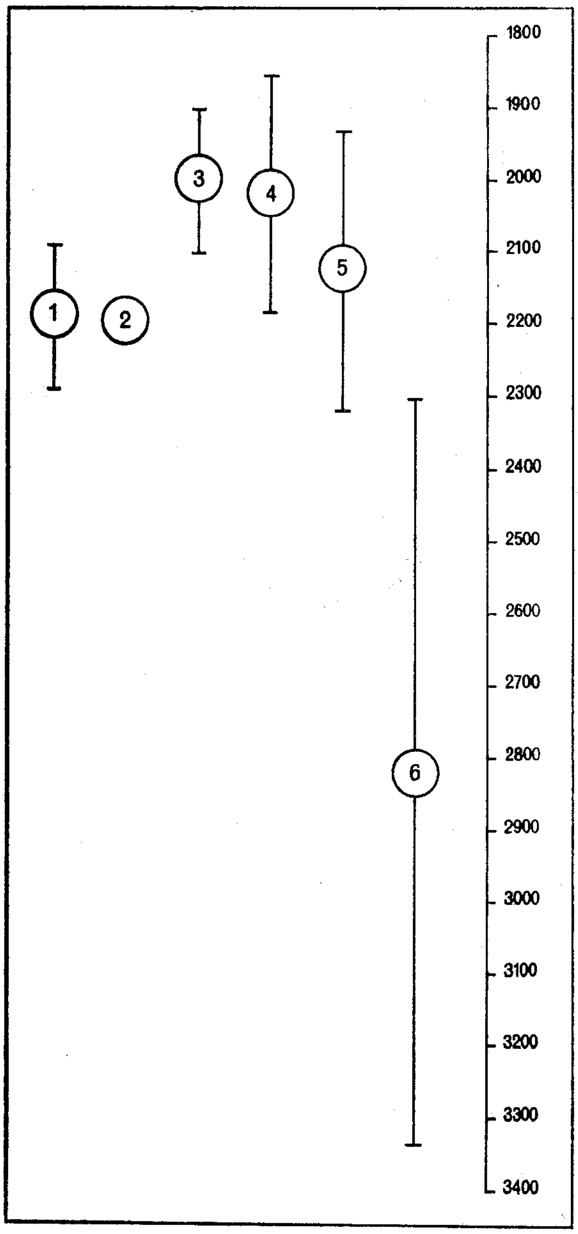

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Figure 53. Graphic comparison of age determinations from six stratiform bodies of felsic rock in the Pilbara and Hamersley Range areas:

1. 2 190 ± 100 m.y.; interbedded layers of acid igneous rocks in Fortescue Group (Compston and Arriens, 1968).
2. 2 196 ± 26 m.y.; granophyre intruded along basal unconformity of Fortescue Group (de Laeter and Trendall, 1971).
3. 2 000 ± 100 m.y.; Woongarra Volcanics (Compston and Arriens, 1968).
4. 2 020 ± 165 m.y.; layered acid igneous rocks interbedded in the Wyloo Group (Compston and Arriens, 1968).
5. 2 124 ± 195 m.y.; Spinaway Porphyry (this paper).
6. 2 820 ± 516 m.y.; Bamboo Creek Porphyry (this paper).

Further discussion of the regional relationship of determinations 1–4 above are given by de Laeter, Peers and Trendall (1974), in whose Figure 58 they are numbered 5, 6, 9 and 12 respectively.

The computed age for the Bamboo Creek Porphyry, of 2 820 ± 516 m.y., also represented in Figure 53, raises problems not presently capable of solution. If this order of age difference between the two porphyry bodies is real then it is remarkable, but not impossible, that two stratiform bodies of such similar rock were emplaced at the same stratigraphic level at times several hundreds of millions of years apart. The possible extrusive origin of the Bamboo Creek Porphyry, contrasted with the intrusion of the Spinaway Porphyry, is not a satisfying explanation of the age difference, since it would do little to reduce the coincidence involved, it would push the age of the initiation of the Hamersley Basin beyond the oldest limit of present credibility, and it would require a highly variable time-depression relationship for the basin. If, on the other hand, the older age of the Bamboo Creek Porphyry is dismissed as meaningless, it would be necessary to suppose that the analyses of Figure 52 fall, in fact, on a cluster of younger isochrons, parallel to each other and to that of the Spinaway Porphyry, or perhaps to an isochron of about 2 300 m.y. representing the overlap of error limits for both sets. In this case it would be necessary to explain why different subsets of closely spaced samples of Bamboo Creek Porphyry should have acquired different initial Sr^{87}/Sr^{86} ratios at the time of emplacement. Different proportions of ingested older potassic material would be the conventional explanation, but neither the very small spread in Rb/Sr ratios, nor the indistinguishable petrographies of the different samples, make this attractive.

Until more data are available the provisional acceptance of the Spinaway Porphyry age, and the rejection of that for the Bamboo Creek Porphyry, on grounds which cannot be convincingly argued, seems to involve least mental stress, but does not provide a satisfying reconciliation of the data presented.

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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 XRFS procedures.

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PALYNOLOGY OF THE YARRAGADEE FORMATION IN THE ENEABBA LINE BOREHOLES

by J. Backhouse

ABSTRACT

The Late Jurassic and Early Cretaceous *Dampieri, Baculatisporites* and *Cicatricosisporites* Zones recognized in the Watheroo Line boreholes are present in the Eneabba Line boreholes, but the highest zone (*Concavus* Zone) is absent. In addition, a distinctive microflora with contemporaneous microplankton and diverse remainé forms is recorded from the Otorowiri Siltstone Member in five boreholes. This unit occurs at the base of the *Cicatricosisporites* Zone. The overall composition of the palynogolical assemblages in each zone does not differ significantly from the Watheroo Line.

INTRODUCTION

The Eneabba Line boreholes (referred to as E.L. in this report) are located just north of latitude 30° S and extend from south of Carnamah to the coast north of Snag Island (Fig. 54). Drilling commenced in 1972 and was completed towards the end of 1974.

The Late Jurassic and Early Cretaceous Yarragadee Formation was intersected in boreholes E.L. 1 to 7 and also in Dathagnoorarra No. 1 borehole. Side-wall cores were obtained from all boreholes except Dathagnoorarra No. 1 from which ditch cutting samples were processed. A few conventional cores were cut in shallow subsidiary boreholes on the same sites as the main boreholes.

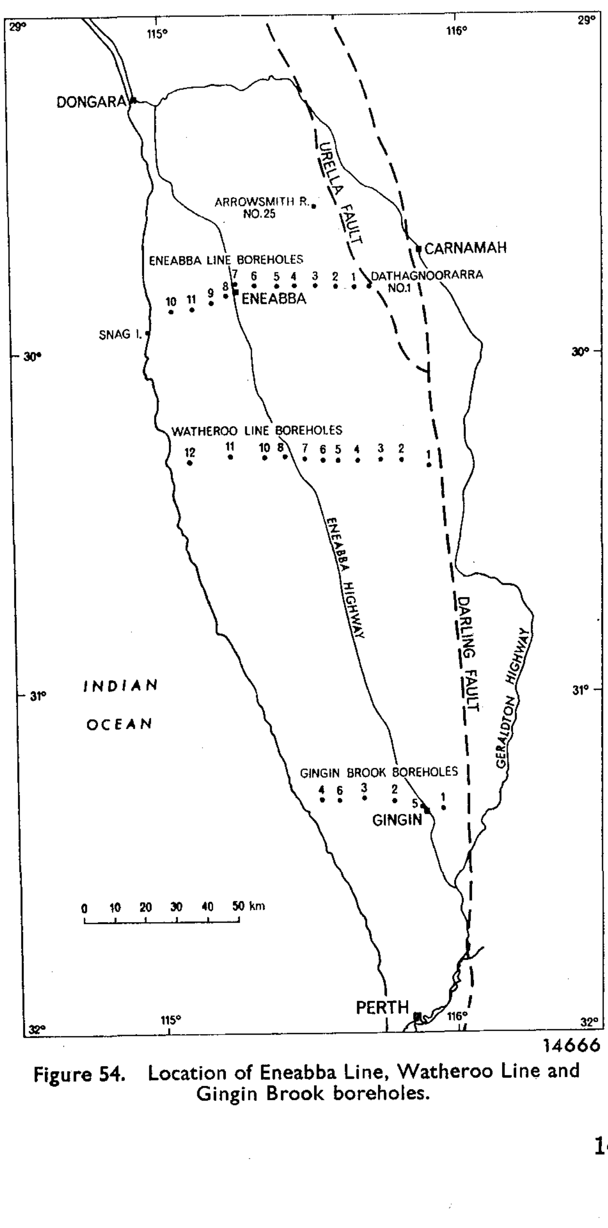

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Figure 54. Location of Eneabba Line, Watheroo Line and Gingin Brook boreholes.

The position of the samples is shown in Figure 54, and the distribution of palynomorphs from the samples is set out in Table 23.

The microflora of the Yarragadee Formation in the Eneabba Line boreholes is comparable with the previously described microfloras from the same formation in the Gingin Brook and Watheroo Line boreholes (Ingram 1967a, Backhouse 1974). A major difference is the occurrence in the Eneabba Line of the characteristic microflora associated with the Otorowiri Siltstone Member in the Arrowsmith River boreholes (Ingram. 1967b). This microflora forms a prominent marker zone in the five eastern boreholes.

ZONATION

Three of the zones described in the Watheroo Line, the Late Jurassic *Dampieri* and *Baculatisporites* Zones and the Early Cretaceous *Cicatricosisporites* Zone can be recognised in the Eneabba Line. The uppermost zone, the *Concavus Zone*, is not represented in any sample so far examined. Spores and pollen grains, characteristic of these zones, are illustrated in Backhouse (1974).

DAMPIERI ZONE

Palynomorph assemblages from E.L. 6 and E.L. 7 belong to the *Dampieri* Zone. As in the Watheroo Line, samples from this zone are dominated by *Araucariacites australis* Cookson, *Zonalapollenites* spp. and bisaccate pollen grains, and *Cyathidites* spp. are common.

However, unlike the samples from the Watheroo Line, *Klukisporites* spp. are sometimes very common and *Classopollis* type pollen is rare. The following forms occur which were not recorded from the *Dampieri* Zone in the Watheroo Line:

Concavisporites jurienensis Balme
Contignisporites cooksonii (Balme)
C. multimuratus Dettmann
Coronatispora telata (Balme)
Dictyophyllidites sp.
Ischyosporites crateris Balme
Inaperturopollenites turbatus Balme

BACULATISPORITES ZONE

This assemblage zone occurs above the *Dampieri* Zone and below the first appearance of *Cicatricosisporites australiensis* (Cookson) which marks the *Cicatricosisporites* Zone. In the Eneabba Line many samples from this zone are barren or yielded only sparse assemblages. As in the Watheroo Line *Baculatisporites comaumensis* (Cookson) and *Osmundacidites wellmanii* Couper are more abundant in this zone and *Microcachryidites antarcticus* Cookson occurs for the first time. Other forms to occur for the first time are:

Aequitriradites acusus (Balme)
A. hispidus Dettmann and Playford
Cyathidites concavus Balme
Lycopodiumsporites facetus Dettmann
L. nodosus Dettmann
Trilobosporites sp.

CICATRICOSISPORITES ZONE

The *Cicatricosisporites* Zone starts with the first occurrence of *C. australiensis* which in the Eneabba Line first appears in the Otorowiri Siltstone Member and then is recorded sporadically throughout this zone. One species, *Pilosisporites notensis* Cookson and Dettmann, which first occurs in this zone in the Watheroo Line also first occurs in this zone in the Eneabba Line. However, *C. concavus*, which first occurs in this zone in the Watheroo Line, is known from the *Baculatisporites* Zone in the Eneabba Line. *M. antarcticus* is noticeably more common in this zone in the Eneabba Line.

TABLE 23. PALYNOMORPHS FROM THE ENEABBA LINE BOREHOLES

PALYNOMORPHS	E.L.7						E.L.6				E.L.5					E.L.4							E.L.3					E.L.2								E.L.1					
	645	589.5	446	315	247	120	393.5	380.5	264	154	688	631.5	556.5	421.5	375	643	404	296	282	267	238	156.5	490.8	490	450	323	151	598	515	479	433	384	366	277	206	694	684	345	294	278	197
Aequitriradites spp.															X				X		X		X	X	X		X	X	X	X	X	X	X	X			X	X	X	X	X
Araucariacites australis	X	X	X	X	X	X	X	X	X	X				X	X			X	X	X	X		X	X	X	X		X		X	X	X	X	X	X	X	X	X	X	X	X
Baculatisporites comaumensis			X												X		X	X		X	X	X	X	X	X	X	X			X	X	X	X	X	X		X	X	X	X	X
Ceratosporites equalis															X			X						X	X		X	X					X	X	X			X	X		X
Cicatricosisporites australiensis																							X	X			X			X	X	X			X				X		X
Classopollis spp.	X	X	X	X			X							X					X	X	X		X	X	X	X	X	X		X	X	X	X				X	X		X	X
Concavisporites jurienensis	X				X				X	X					X					X		X	X	X		X	X					X			X						
Contignisporites cooksonii	X	X	X			X		X	X	X				X	X				X	X	X		X	X	X	X	X	X	X	X	X	X	X					X	X	X	X
C. multimuratus					X			X	X	X					X			X	X	X	X	X	X	X	X	X	X	X		X	X		X	X	X		X	X		X	X
Coronatispora perforata																								X	X		X				X			X					X	X	
C. telata			X												X					X		X						X	X	X	X	X	X		X	X	X	X	X	X	X
Cyathidites australis	X							X							X		X	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X
C. concavus																												X	X		X		X					X			X
C. minor	X	X		X	X	X	X		X	X			X				X	X		X	X	X	X	X	X	X	X	X	X		X	X	X	X	X		X	X	X	X	X
Densoisporites velatus																			X	X				X	X	X	X						X						X	X	
Dictyophyllidites sp.	X	X	X	X	X		X		X	X							X			X	X				X		X	X					X						X	X	X
Dictyotosporites complex																									X	X	X				X		X	X	X						
Foraminisporis dailyi																											X	X													
Foveosporites canalis									X											X		X	X		X		X	X	X	X			X		X		X			X	X
Foveotriletes parviretus																										X	X	X	X		X	X	X	X	X	X				X	X
Ginkgocycadophytus nitidus																		X		X	X				X		X				X	X	X				X	X		X	
Gleicheniidites senonicus	X	X		X	X		X		X								X	X		X	X	X		X		X		X	X	X	X	X	X		X		X	X	X	X	
Inaperturopollenites turbatus	X	X		X						X													X	X																	
Ischyosporites crateris		X						X	X	X		X					X				X	X	X	X	X	X	X	X	X	X	X	X	X	X				X	X	X	X
Januasporites spinulosus																																X							X		
Klukisporites scaberis	X	X	X	X			X	X		X			X		X					X	X	X		X	X	X	X	X	X	X	X		X	X	X	X		X	X	X	X
K. sp.		X		X	X	X			X	X									X																						X
Laevigatosporites spp.					X																							X	X						X						X
Leptolepidites major		X													X							X			X	X					X		X		X		X			X	
L. verrucatus			X								X				X				X	X	X	X			X		X	X		X		X	X	X	X		X	X	X	X	X
Lycopodiacidites asperatus	X	X		X	X			X	X	X										X	X	X	X			X	X	X	X	X			X		X	X	X				X
Lycopodiumsporites austroclavatidites	X	X	X				X				X	X	X	X	X				X	X		X	X	X	X	X	X	X	X	X	X				X	X	X	X	X	X	X
L. circolumenus												X		X	X				X	X		X		X	X	X	X			X		X	X	X	X	X	X	X		X	X
L. eminulus																		X			X			X	X	X	X		X	X		X	X			X	X	X		X	X
L. facetus																X									X			X					X		X		X			X	
L. nodosus														X			X									X										X		X			
Matonisporites crassiangulatus									X																X	X		X				X	X		X					X	X
M. sp.							X		X																																
Microcachryidites antarcticus															X		X	X	X	X	X		X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
Murospora florida	X							X		X	X			X	X		X		X			X		X	X	X	X	X	X	X	X	X	X	X			X	X	X	X	X
Neoraistrickia truncata		X	X					X					X	X	X			X	X	X	X	X	X	X	X	X	X	X			X	X	X		X			X	X	X	
Nevesisporites vallatus																									X	X					X		X					X		X	X
N. sp.																					X				X	X	X				X	X	X					X	X	X	X
Obtusisporites sp.	X	X						X	X	X							X								X	X	X	X	X				X								
Osmundacidites wellmanii						X	X	X			X	X	X		X	X	X	X	X	X	X	X	X	X	X		X	X	X		X		X	X	X	X	X	X	X	X	X
Pilosisporites notensis																										X															X
Polypodiidites sp.																							X	X	X	X		X		X	X	X	X						X		X
Staplinisporites caminus					X		X	X	X	X			X							X		X															X				X
Stereisporites antiquasporites																								X	X																
Trilobosporites sp.									X									X					X	X	X	X	X	X			X	X	X	X	X		X	X	X	X	X
Zonalapollenites dampieri	X	X	X	X	X	X	X		X	X				X	X		X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Z. segmentatus			X	X			X		X												X		X		X	X	X	X		X		X							X		
Z. trilobatus	X	X		X			X		X	X									X					X	X		X			X	X	X						X	X	X	
bisaccate pollen	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
remanié forms				X						X				X					X	X	X	X	X	X	X					X								X			
microplankton																																									
Chytroeisphaeridia sp.																			X	X			X															X			
Komewuia sp.																			X	X			X	X																	
Meiourogonyaulax sp.																			X				X		X													X			
Micrhystridium spp.																					X									X										X	
Veryhachium spp.																		X	X	X			X	X	X			X		X						X		X	X		

X = present Depths in metres

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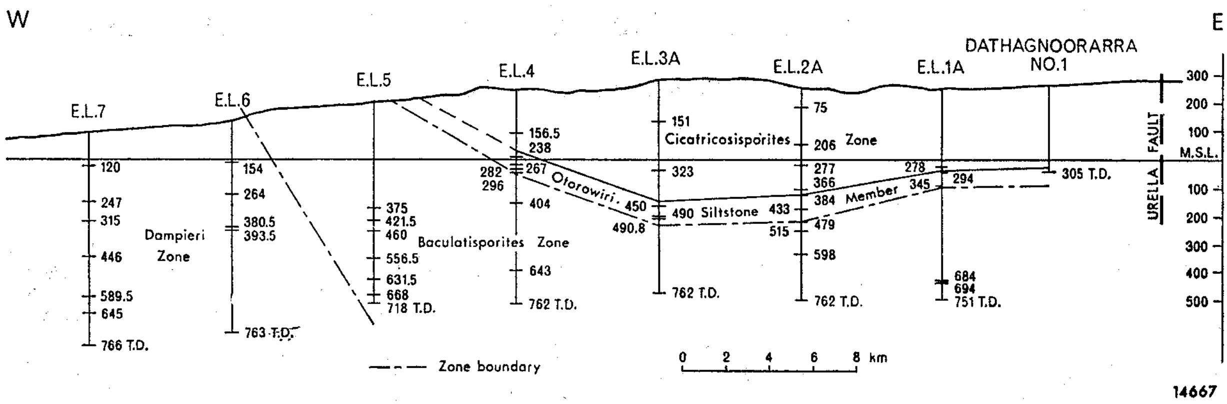

Figure 55. Palynological correlation of Eneabba Line boreholes.

OTOROWIRI SILTSTONE MEMBER

The type section of the Otorowiri Siltstone Member was defined by Ingram (1967b) in Arrowsmith River No. 25 borehole, approximately 27 km north of E.L. 3. During the Eneabba Line drilling the member was encountered in Dathagnoorarra No. 1 and E.L. 1-4 boreholes, and it crops out between E.L. 4 and E.L. 5 (D.P. Commander pers. comm.). It occurs in a syncline, becoming thicker in the centre and reaching a maximum intersected thickness of 99 m in E.L. 2 (Fig. 55).

In the Arrowsmith River area the Otorowiri Siltstone Member is characterized by a rich and diverse association of remanié palynomorphs. Spores and pollen of Devonian, Early and Late Permian, Early Triassic and Middle to Late Triassic age, and dinoflagellates of Late Jurassic age were identified by Ingram (1967b). In the Eneabba Line boreholes spores and pollen of Early Triassic and Permian age are common but there is only one definite occurrence of a remanié Devonian spore—a single specimen of *Hymenozonotriletes lepidophytus* Kedo from E.L. 2A at 479 m. This is of particular interest as this species has a very restricted age range of late Famennian to early Tournaisian. Several samples contain remanié Late Jurassic microplankton including *Adnatosphaeridium aemulum* (Deflandre), *Gonyaulacysta perforans* (Cookson and Eisenack), *Leiofusa jurassica* Cookson and Eisenack and *Wanaea clathrata* Cookson and Eisenack.

Thin walled dinoflagellates and a few acritarchs are present in small numbers in some samples. The dinoflagellates are tentatively referred to the genera *Meiourogonyaulax, Komewuia* and *Chytroeisphaeridia*. These are not considered to be remanié forms.

Komewuia sp. and other microplankton have been recorded from the Quinns Shale Member of the Yarragadee Formation in offshore wells drilled by West. Australian Petroleum Pty. Ltd. (Williams in Moyes, 1971), and *C. australiensis* seems to first appear at about the same stratigraphic level. There is also a similarity between gamma-ray logs of the Otorowiri Siltstone Member in the Eneabba Line boreholes and the Quinns Shale Member in offshore wells. It seems likely that both the Otorowiri Siltstone Member and the Quinns Shale Member occur at the base of the *Cicatricosisporites* Zone and are of the same age. This is contrary to the opinion of Cockbain and Playford (1973), who suggested that the Quinns Shale Member was slightly older than the Otorowiri Siltstone Member.

CONCLUSIONS

The biostratigraphy of the Yarragadee Formation in the Eneabba Line boreholes differs significantly from that in the Watheroo Line in two ways:

(1) The Otorowiri Siltstone Member microflora is present in the Eneabba Line at the base of the *Cicatricosisporites* Zone. The Eneabba Line is closer to the Arrowsmith River area, where the Otorowiri Siltstone Member microflora was first recognized, and the member appears to lens out between the Eneabba and Watheroo Lines of boreholes.

(2) The *Concavus* Zone of the Watheroo Line zonation was not encountered in any borehole on the Eneabba Line. This is probably because sediments from a higher stratigraphic level were sampled in the Watheroo Line.

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MACROFOSSILS FROM THE CRETACEOUS OF THE PERTH BASIN

by K. Grey and A. E. Cockbain

ABSTRACT.

The bivalve *Maccoyella* Etheridge 1892 is recorded for the first time from the Early Cretaceous Leederville Formation. A probable trigoniid bivalve, tentatively identified as *Pterotrigonia* van Hoepen 1929, and the desmoceratid ammonite *Puzosia* Bayle 1878 are illustrated from the mid-Cretaceous Osborne Formation. The discovery of these specimens extends their known geographical occurrence to the Perth Basin, and confirms the ages assigned to these formations on palynological evidence.

INTRODUCTION

Cretaceous sediments in the Perth Basin have only sparse outcrops and are known mainly from borehole sampling. Macrofossils are rarely encountered in such material, and even fragmentary and poorly preserved specimens assume substantial significance in any consideration of the faunal elements of the associated sediments.

Two boreholes and a shallow quarry in the Perth Basin (Fig. 56) have recently yielded fragments of macrofossils. These discoveries extend the known geographical occurrence of these fossils, and provide further evidence for the Cretaceous age assigned to the sediments on the basis of spore and microplankton dating.

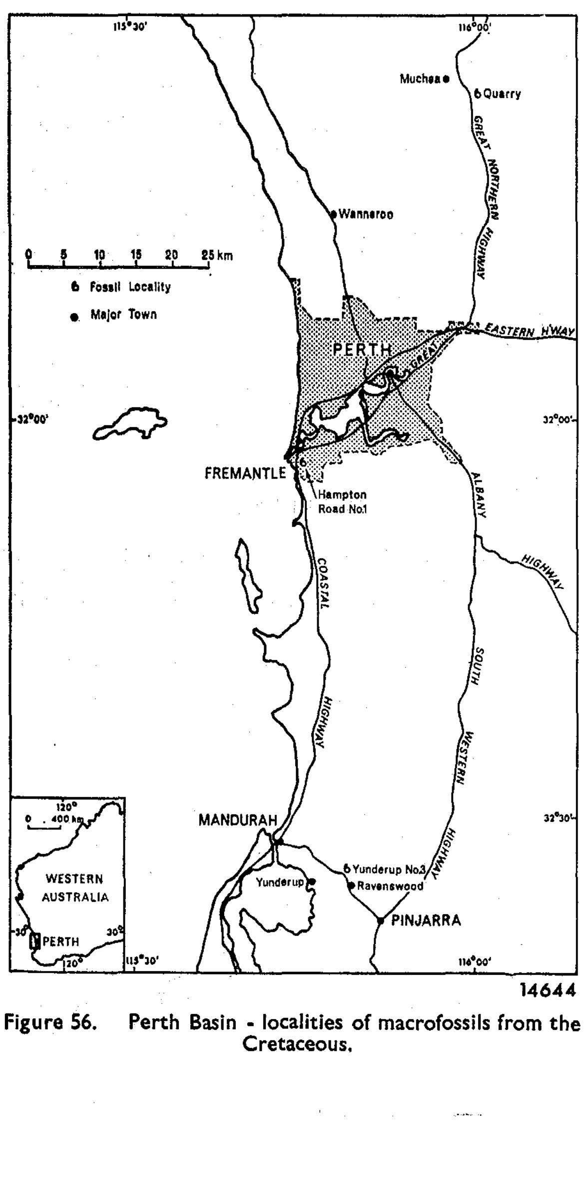

Figure 56. Perth Basin - localities of macrofossils from the Cretaceous.

STRATIGRAPHY

Cockbain and Playford (1973) revised the nomenclature of the Cretaceous rocks of the Perth Basin. The succession is summarized in Figure 57. The bivalve *Maccoyella* Etheridge 1892 is recorded from the Leederville Formation, a unit of the Warnbro Group, and the probable trigoniid bivalve ?*Pterotrigonia* van Hoepen 1929 and the desmoceratid ammonite *Puzosia* Bayle 1878 are recorded from the Osborne Formation, a unit of the Coolyena Group. Detailed descriptions of these formations are given by Cockbain and Playford (1973). Details of the localities and lithologies of each of the specimens are given with the specimen descriptions.

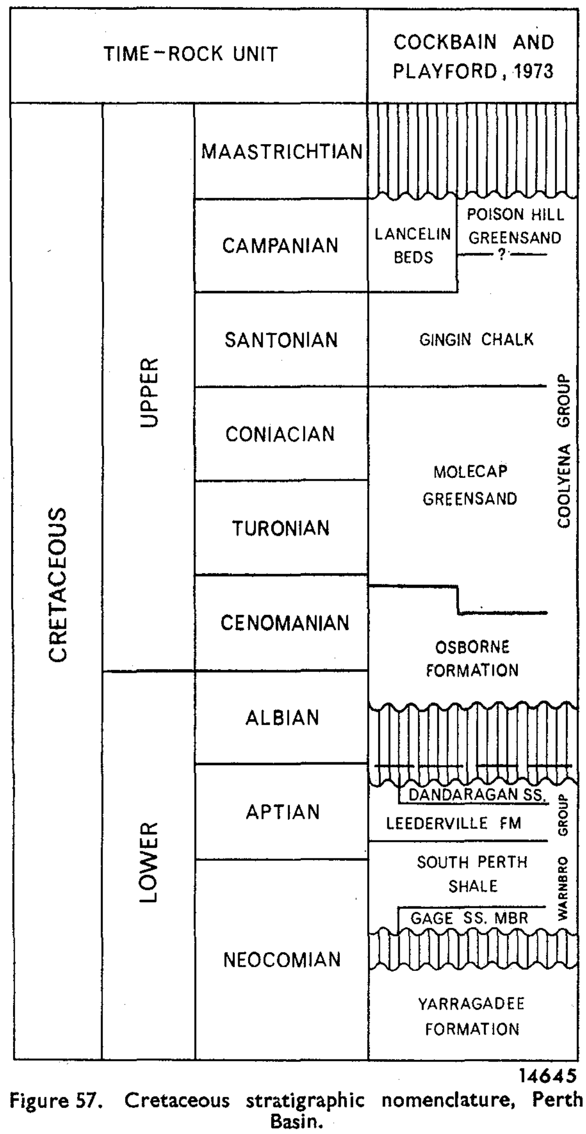

Figure 57. Cretaceous stratigraphic nomenclature, Perth Basin.

THE BIVALVE *MACCOYELLA* FROM THE LEEDERVILLE FORMATION

Yunderup No. 3 borehole is situated north of the Mandurah to Pinjarra road, near Ravenswood, lat. 32° 35′ S, long. 115° 50′ E. The borehole was drilled to a total depth of 115 m and passed through a sequence of sands and clays which are considered to be part of the Leederville Formation (D. P. Commander, pers. comm. 1973). A cuttings sample from a depth of 46 m consists of coarse sand with shale and fragments of the bivalve *Maccoyella* (G.S.W.A. registered No. F8470).

SYSTEMATIC PALAEONTOLGY

Phylum	MOLLUSCA
Class	BIVALVIA
Subclass	PTERIOMORPHIA
Order	PTERIOIDA
Suborder	PTERIINA
Superfamily	PECTINACEA
Family	OXYTOMIDAE
Genus	MACCOYELLA Etheridge 1892

Maccoyella sp. cf. *M. barklyi* (Moore)
Figure 58A-D

cf. 1870 *Avicular barklyi* Moore; p. 245, pl. 11, fig. 1, 2.

cf. 1902 *Maccoyella barklyi* (Moore); Etheridge Jr.: p. 17, pl. 2, figs. 3-5, pl. 3, figs. 4-5, pl. 4, figs. 3-4.

1961 *Maccoyella* aff. *barklyi* (Moore); Cox: p. 16, pl. 1, fig. 14.

cf. 1966 *Maccoyella barklyi* (Moore); Ludbrook: p. 150, pl. 5, figs. 1-7.

Description: The material consists of about 30 shell fragments of the umbonal region. The largest fragment is 8.5 mm in length and 6.5 mm in height; most fragments are of left valves, a few are right valves.

The left valve is inflated with a slightly overhanging umbo. There are about 14 primary ribs which are fairly widely spaced and are crossed by prominent growth lines; where ribs and growth lines intersect a weak spine may be developed. Secondary ribs are inserted between the primaries. The right valve is somewhat flatter, with a posterior ear and a prominent anterior byssal notch. Most right valves are either smooth or weakly ribbed.

Remarks: On the basis of the degree of inflation and the rib count, the Yunderup specimens are compared with *M. barklyi*, which however is a much larger form.

Age: The sample is dated as Early Cretaceous on the basis of palynomorphs. The sample contains the microplankton: *Dingodinium cerviculum, Wetzeliella* sp., *Ascodinium* sp.; the spores *Gleicheniidites* sp. and *Contignisporites cooksonii:* the foraminifer *Marginulina;* plant fragments and fish teeth. Stratigraphically the sample comes from the Leederville Formation. Although fragmentary bivalve remains have long been known from the Leederville Formation and South Perth Shale, this is the first record of *Maccoyella* from these beds.

Distribution: This is the first record of *Maccoyella* from the Perth Basin, although the genus is widely known from Australia and has been recorded from the following places in Western Australia:

Carnarvon Basin: Cox (1961) records *M.* sp. aff. *M. barklyi, M.* sp. aff. *M. corbiensis, M.* sp. aff. *M. moorei* and *M.* sp. from the Nanutarra Formation.

Canning Basin: No undoubted record of *Maccoyella* has been found from the Canning Basin. Brunnschweiler (1954) records *Maccoyella* 'almost indistinguishable from *Maccoyella corbiensis*' from the Alexander Formation which is now believed to be Oxfordian in age. Cox (1961) identifies specimens from the Alexander Formation as 'indistinguishable from *M. barklyi*'. However, Brunnschweiler (1960) describes *Meleagrinella maccoyelloides* from the same formation, and Dickins (in Veevers and Wells, 1961, Appendix 4) refers to '*Meleagrinella maccoyelloides* Brunnschweiler, 1960 (previously referred to as Maccoyella sp.)'. It is probable that the Alexander Formation *Maccoyella* in fact is a species of *Meleagrinella.*

Officer Basin: The following species are recorded by Skwarko (1967) from the Samuel Formation and the Bejah Claystone: *M.* sp. cf. *M. barklyi, M.* sp. aff. *M. corbiensis, M.* sp, cf. *M. reflecta* and *M.* sp.

Eucla Basin: In a review of earlier work, Lowry (1970) notes the presence of *M. corbiensis* in the Madura Formation.

Maccoyella is essentially an Early Cretaceous genus. As shown above, the Late Jurassic record from the Alexander Formation is probably due to misidentification. Ludbrook (1966) gives the stratigraphic range of *M. barklyi, M. corbiensis, M. reflecta* and *M. umbonalis* as Aptian, and the range of *M. rockwoodensis* as Albian. The presence of *M.* sp. cf. *M. barklyi* in the Leederville Formation of Yunderup No. 3 borehole would suggest that the unit is of Aptian age. This is in agreement with the Neocomian-Aptian age for the unit established on palynological grounds.

A PROBABLE TRIGONIID FROM THE OSBORNE FORMATION

The specimen (Western Australian Museum Registered No. 74.528) was supplied by Mr. G. W. Kendrick of the Western Australian Museum. The sample is a dark grey siltstone from a shallow quarry at the east side of the road, 4.5 km south-east of Muchea, lat. 31° 35′ S, long. 116° 01′ E. The material was collected from strata that were formerly mapped as the Bullsbrook Beds but are now considered to belong to the Osborne Formation.

SYSTEMATIC PALAEONTOLOGY

Phylum	MOLLUSCA
Class	BIVALVIA
Subclass	PALAEOHETERODONTA
Order	TRIGONIOIDA
Superfamily	TRIGONIACEA
Family	TRIGONIIDAE
Subfamily	PTEROTRIGONIINAE
Genus	PTEROTRIGONIA van Hoepen 1929

?Pterotrigonia sp. indet.

Fig. 58E

Description: The specimen is a poorly preserved external mould of the right valve of a bivalve mollusc. The impression was illuminated so as to bring it into positive relief on the accompanying photograph; hence the impression appears to be a left valve.

The specimen is almost certainly a trigoniid and probably belongs to the genus *Pterotrigonia.* However, the preservation is such that the identification is tentative.

Age: Microplankton and foraminifers have been recovered from the same formation in nearby drillholes and indicate an Albian to Cenomanian age.

Distribution: Trigoniids are quite common in Lower Cretaceous rocks in Australia (and indeed in other circum-Indian Ocean countries). The only other Cretaceous record from the Perth Basin is of *Pterotrigonia* from the Maxicar Beds (Cockbain and Playford 1973, p. 29).

A DESMOCERATID AMMONITE FROM THE OSBORNE FORMATION

An ammonite fragment (G.S.W.A. registered No. F8651) was recovered from a core sample of the Hampton Road No. 2 borehole during palynological sampling. The borehole is sited near the junction of Hampton Road and Knutsford Street, Fremantle, lat. 32° 03′ S, long. 115° 46′ E. Details of the borehole are on file at the Geological Survey of Western Australia.

The core sample, taken between a depth of 121 and 131 m, consists of a dark grey siltstone with grains of glauconite and is from the Osborne Formation. The specimen was identified as an indeterminate species of *Puzosia* by Dr. M. K. Howarth of the British Museum (Natural History).

SYSTEMATIC PALAEONTOLOGY

Phylum MOLLUSCA
Class CEPHALOPODA
Order AMMONOIDEA
Family DESMOCERATIDAE
Genus PUZOSIA Bayle 1878

Puzosia sp. indet.

Fig. 58 F, G.

Description: The fossil is a poorly preserved fragment of the last whorl with the aperture missing. The specimen has a rounded whorl with flattened sides; weak ribs are present but are distinct only on the outer part; sinuous constrictions are present and are separated by approximately four ribs.

Remarks: The extremely poor preservation of the specimen precludes identification at species level.

Age: The genus *Puzosia* ranges from the Early Albian to Late Turonian and therefore confirms a mid-Cretaceous age for the Osborne Formation. Few macrofossils have been recorded from this formation, but an Albian to Cenomanian age is indicated by microplankton.

Distribution: This is the first record of *Puzosia* from the Perth Basin. Cretaceous ammonites have previously been described from Western Australia by Etheridge (1913), Spath (1926, 1940) and Brunnschweiler (1959, 1966). Etheridge described specimens from the Gingin Chalk and these were later reassessed by Spath (1926), who noted a resemblance of some of the specimens to *Parapuzosia*. Spath (1940) described ammonites from the Maastrichtian of the Carnarvon Basin including the puzosiid *Kitchinites*.

CONCLUSIONS.

The discovery of the macrofossils described above has increased our knowledge of the faunas of the Perth Basin. *Maccoyella* is indicative of paralic sediments and shallow marine basins (Skwarko 1967), a conclusion also indicated by the sporadic occurrence of microplankton in onshore sections of the Leederville Formation. The Osborne Formation contains abundant microplankton and the marine nature of these sediments is further emphasized by the presence of *Puzosia* and ?*Pterotrigonia*. Skwarko (1963, p. 9) regards the presence of various trigoniids in Western Australia as indicative of "widespread though marginal marine incursions of the Australian continent".

Figure 58. opposite).

A, B, C, D, *Maccoyella* sp. cf. *M. barklyi*. — all x 6.
A. Exterior, left valve.
B. Interior, left valve.
C. Exterior, right valve.
D. Interior, right valve
E. ?*Pterotrigonia* sp. indet., external mould of right valve x 4.
F, G. *Puzosia* sp. indet. F. lateral view, G. ventral view x 2.

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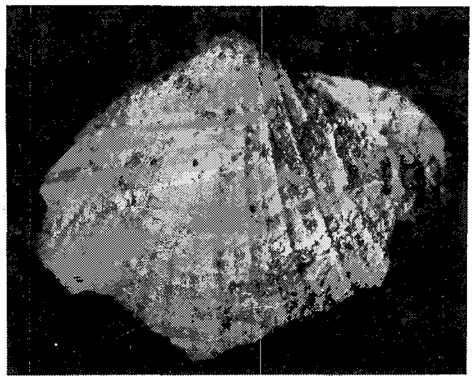
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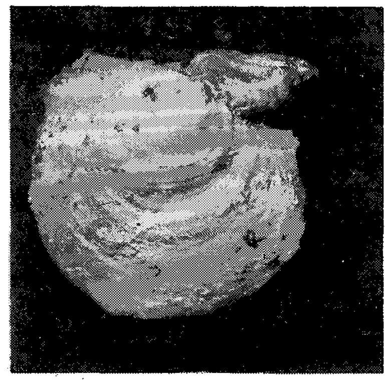
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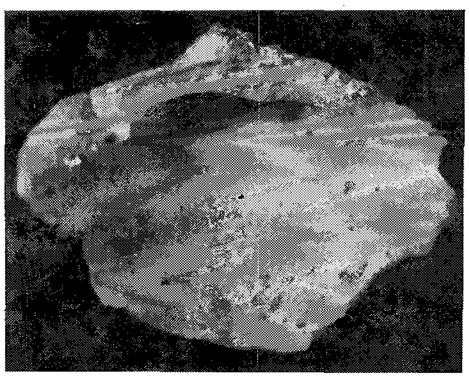
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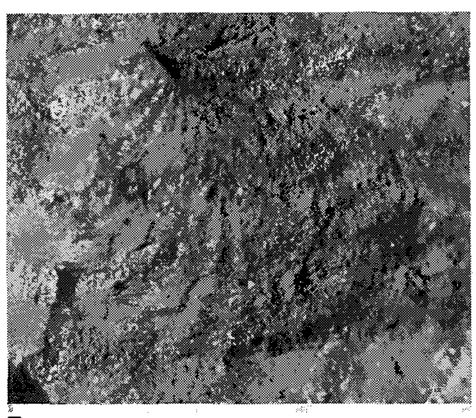
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DIVISION V

Report of the Head of The Petroleum Branch for the Year 1974

Under Secretary for Mines:

I hereby submit the 1974 Annual Report for the Petroleum Branch.

PETROLEUM EXPLORATION OPERATIONS

Petroleum exploration operations in 1974 were at a greatly reduced level. Onshore drilling activity, expressed in rig months, declined by 62 per cent from 20 rig months in 1973 to 7.5 rig months in 1974. Offshore drilling activity declined by 35 per cent from 40 rig months in 1973 to 26 rig months in 1974. Land seismic line kilometres surveyed declined from 1 776 in 1973 to 559 in 1974 and marine seismic survey declined from 14 904 line kilometres to 11 815 line kilometres.

Two new offshore drilling vessels operated in West Australian waters during the year namely M.V. "Dalmahoy" (Salvesen Offshore Company) and the semi-submersible "Margie" (Atwood Oceanics). M.V. "Glomar Tasman" (Global Marine Co.), semi-submersible "Ocean Digger" (ODECO) and the "Margie" all moved out of the West Australian adjacent area after completing contracts leaving only the M.V. "Dalmahoy" in the State at the end of the year (Figure C). Four different rigs operated for portions of the year drilling land wells (Figure C).

All rigs, onshore and offshore, were inspected in order to appraise their conformance to the standards specified by the petroleum legislation.

Drilling operations on the Northwest Shelf are particularly vulnerable to tropical cyclones during the summer. There were three cyclone warnings issued and these interrupted the drilling of the wells Lambert No. 1, Depuch No. 1, Poissonier No. 1 and Lowendal No. 1. There was no loss of life or injury and no reported structural damage to rigs resulting from cyclones.

Details of petroleum exploration activity during 1974 are given in the report by G. H. Low in the Sedimentary Division Section of the Annual Report of the Geological Survey Branch.

PETROLEUM DEVELOPMENT AND PRODUCTION

Barrow Island Field

(Operators—West Australian Petroleum Pty. Limited.)

The Barrow Island Field (Fig. D) is the sole oil producing field in Western Australia. The production of liquids and gas from the various reservoirs during 1974 and the cumulative production are shown in Table C while the status of wells with respect to the "Windalia Sand" reservoir, from which 98 per cent of the oil production came using a water flood secondary recovery scheme, is illustrated in Figure D. The 510 wells on Barrow Island (excluding those which have been abandoned) are classified according to status and reservoir in Table D. Limited quantities of the gas produced are used for field-fuel and gas-lift. There is no commercial outlet for the 93 per cent which remains after stripping. The statistics relating to field-fuel gas, crude oil disposal and royalty paid are given in Table E. After reaching a maximum average daily production rate of almost 50 000 BD in September 1970 the field has continued to decline (Figure E), the December 1974 daily average being 36 675 BD. The low production in July and August was caused by industrial disputes which restricted tanker movements. The proved crude oil reserves remaining in the Barrow Island Field on 31st December, 1974 are 22.74 x $10^6 m^3$ (Table F). This means that 42 per cent of the original recoverable reserves have been produced so far.

A comprehensive inspection was made, during the year, of the WAPET facilities on Barrow Island. During October an accidental oil spill of about 12 barrels occurred at the main loading terminal when replacing 16" and 12" flexible oil loading hoses at the end of the 5 miles long concrete-coated steel oil pipeline used for loading ocean going tankers. The oil spill was fully investigated as to the causes, magnitude, remedial action taken, and the possible means of preventing a recurrence.

North Rankin, Goodwyn and Angel Fields

(Operator—B.O.C. of Australia Ltd.)

On 4th January, 1974 the Designated Authority declared Locations covering the Angel, North Rankin and Goodwyn gas fields (ref. Table F, Figure B). This represents the first step towards application for a Production Licence. The Petroleum (Submerged Lands) Act, 1967 provides that an application for a Production Licence may be made within two years or, under special circumstances, within four years of the declaration of a location.

BOCAL as operator for the North West Shelf Venture group of companies has submitted to the State Government a Deliverability and Feasibility Study covering platforms, pipelines and onshore processing facilities.

West Tryal Rocks Field

(Operator—West Australian Petroleum Pty. Limited)

West Tryal Rocks No. 2 was drilled as an extension test some 3.6 km northeast of West Tryal Rocks No. 1. The well was programmed to evaluate hydrocarbon zones of possible commercial significance which for mechanical reasons could not be tested in the discovery well. A preliminary evaluation of data obtained indicates the presence of considerable reserves of gas. However, further evaluation will be necessary before the commercial viability of the field can be ascertained.

Principle test results were:—

Test	Perforated Interval (m)	Choke Size Inches	Gas Flow 10^3 m^3/d	Fluid Recovery	
					Rate m^3/d
DST 1	3530–3538	½	....	water	437
2	3435–3450	½	300·1	condensate	17
3	3305–3295	½	438·9	condensate	33

Onshore Northern Carnarvon Basin

In EP-40 two twin wells, Mardie 1A and Windoo 1A, were drilled by Hematite under a farm-in agreement with the permittee WAPET. The object was to test the hydrocarbon-bearing Mardie Greensand (equivalent to the Muderong Shale) without interference from the high water pressures of the underlying Yarraloola Conglomerate. Mardie 1A was drilled to 164 metres and on test produced about 15 MCF gas per day and no liquid. Windoo 1A (174 metres) flowed about 265 MCF gas per day and little or no formation liquid. Both wells were shut in pending complete core analysis and engineering evaluation.

Dongara and Mondarra Fields

(Operator—West Australia Petroleum Pty. Limited)

In the Dongara Field well No. 20 was drilled by WAPET in Production Licence No. 1 to a total depth of 1 939 metres. (Figure F). Subsequent testing produced 67 MCFD from the interval 1 833-1 853.8 m in the Irwin River Coal Measures. Provisional testing of a higher interval (1 710-1 716 m) in the Dongara/Wagina Sandstone produced a flow of 8 MMCFD on a ½" choke. The well is to be connected to the gathering system as a gas producer.

A proposal to carry out extensive production tests of a thin oil column which occurs beneath the main gas zone at Dongara was submitted. These tests are expected to commence early in 1975 and are necessary to evaluate the potential of the oil zone for commercial production.

Gas production continued to be from 10 wells in the Dongara Field and one well in the Mondarra Field (Figure F) and the combined production in 1974 was 808 827 $\times$ 10^{3}m^3 (Table G). Cumulative combined production to end 1974 was 2 276 978 $\times$ 10^{3}m^3 and the remaining reserve of the Dongara and Mondarra Fields is estimated to be 11.29 $\times$ 10^{9}m^3 (Table F). The monthly gas production was maintained at a fairly constant level (Figure G) and during December 1974 amounted to 2 143 $\times$ 10^{3}m^3.

Gingin and Walyering Fields

(Operator — West Australian Petroleum Pty. Limited)

The Gingin No. 1 well remained on standby throughout the year as a back-up in the event of interruption to the Dongara/Mondarra gas supply north of Gingin. Approval for the surrender of the Walyering Licence Area did not take place in 1974 owing to delays in the restoration of drilling and production sites.

PETROLEUM PIPELINES

The natural gas pipeline facilities, operated by West Australian Natural Gas Pty. Ltd., between Dongara and Pinjarra, were inspected several times during the year. New condensate collection and storage facilities were installed at Stations 1 and 2. Bund walls around existing condensate storage at the City Gate Station (Caversham) and at the ALCOA sales outlet station were installed.

Pipeline patrol proposals submitted to the Branch were also reviewed during the year. Three incidents of encroachment on the natural gas pipeline were investigated, one of which involved physical damage to the pipeline, and the pipeline had to be repaired under elaborate safety and control arrangements, including a reduction of gas pressures and throughput. As a result of these encroachments an arrangement was instituted with members of the Public Utilities Committee whereby the Mines Department is notified of all proposed works. The system, basiclly that of liaison, is working smoothly.

SAFETY

A complete statement of all accidents reported from the petroleum exploration, production and pipelines industry during 1974 is presented in Table H. No fatalities occurred. The frequency rate and the severity rate variations by quarter are graphed in Figures H and I respectively. These rates are calculated as recommended by the Standards Association of Australia (Australian Standard CZ6-1966).

Special attention was devoted to safe procedures during inspection of all operations and sites. On all offshore operations, opportunities were taken to attend safety meetings and to witness emergency fire and abandon-ship drills, some of which were specifically requested.

Particular attention has been paid to diving operations from offshore rigs in relation to safe diving practices, equipment standards and safety, and the accurate measurement of diving depths, pressures, and air or breathing medium mixtures.

A near-fatal-accident occurred on the drilling vessel "Dalmahoy" as a result of a load falling from cargo handling slings. Direction No. 5 relating to cargo handling operations was served on the permittee.

TITLES

Offshore

No new permits were granted during the year. Seven permits were renewed, having reached the expiry date of the first term (Table A and Figure A). There was one part-surrender and two permits were cancelled. Four access authoriies were issued and three locations were declared (Figure B). In the case of the renewal of WA-20-P Direction No. 4 was issued to WAPET allowing the renewal of 15 blocks.

Onshore

Onshore (under the Petroleum Act 1967) there were nine full-permit surrenders and one partial surrender (Table B and Figure A). Two permits were cancelled. Applications were invited with a closing date for a total of 2 164 blocks, comprising 12 surrendered exploration permits and the two secondary entitlement areas of Locations 1 (Mondarra) and 2 (Dongara) which had not been taken up. In the cases of these two location areas re-advertisement extended the closing date owing to an unavoidable delay in being able to make the existing data available to prospective applicants. The three-block Dongara secondary entitlement area was subsequently advertised as available for application without a closing date. Four applications for exploration permits were received of which two were refused and two were pending at the end of the year.

GENERAL

The Petroleum Branch was formed in May 1974. Prior to May 1974 the responsibility for the technical administration of petroleum legislation was divided between the State Mining Engineer's Branch and the Geological Survey Branch. In view of the major petroleum discoveries on the North West Shelf and the level of petroleum activity in the State it was considered that the technical petroleum responsibilities should eventually be combined into one Branch and in order to commence this integration the Petroleum Branch was established. The Branch was staffed during 1974 as follows:—

A. J. Sharp—Senior Petroleum Engineer (Level 5) and Acting Head of the Petroleum Branch—transferred from State Mining Engineer's Branch, 27th May, 1974.

A. H. Pippet—Reservoir Engineer (Level 4)—appointed 27th August, 1974.

P. H. J. Hammett—Petroleum Engineer (Operations) (Level 4)—transferred from State Mining Engineer's Branch, 27th May, 1974.

R. N. Cope—Production Geologist (Level 4)—transferred from Geological Survey Branch, 27th May, 1974.

T. D. Tanner—Typist/Receptionist (C-V) seconded from Adminstrative Branch, 27th May, 1974.

Two conferences relevant to the petroleum industry were held in Perth during the year. The Australian Petroleum Exploration Association 1974 Conference was held between 25th and 27th March, 1974.

Between 28th September and 2nd October a Symposium on the Impact of Tropical Cyclones on Oil and Mineral Development in North West Australia was held. The Petroleum Branch assisted in the organisation of the Symposium in collaboration with the Department of Science, Burmah Oil Co. of Australia Limited, Global Marine Australasia Pty. Ltd., Hamersley Iron Pty. Limited and West Australian Petroleum Pty. Limited.

The object of this conference was to achieve a better understanding of tropical cyclones by industry and government and to discuss measures to lessen the impact of this natural phenomenon on development in the Northwest.

LIST OF TABLES

TABLE A

CHANGES AFFECTING TITLES UNDER THE PETROLEUM (SUBMERGED LANDS) ACT, 1967 DURING 1974

PERMIT RENEWALS

Permit Number	Permittee	Date Renewed	Original No. of Blocks	No. of Blocks Renewed
WA-1-P	West Australian Petroleum Pty. Limited	13/12/74	364	178
WA-13-P	Shell Development (Aust.) Pty. Ltd., BOCAL PTY. LTD., Woodside Oil N.L.	6/11/74	387	194
WA-14-P	,, ,, ,, ,, ...	6/11/74	396	198
WA-20-P	,, ,, ,, ,, ...	6/11/74	29	15
WA-23-P	,, ,, ,, ,, ...	6/11/74	398	199
WA-24-P	,, ,, ,, ,, ...	6/11/74	208	104
WA-25-P	,, ,, ,, ,, ...	6/11/74	256	128
			2 038	1 016

PERMIT SURRENDER

Permit Number	Permittee	Original Blocks Held	Surrendered Blocks	Surrender Date
WA-20-P	West Australian Petroleum Pty. Limited	34	5	28/6/74

PERMIT CANCELLATIONS

Permit Number	Permittee	No. of Blocks	Cancellation Date
WA-43-P	Planet Exploration Co. Pty. Ltd.	241	31/5/74
WA-44-P	,, ,, ,, ...	400	31/5/74
		641	

ACCESS AUTHORITIES

Access Authority No.	Permittee/Applicant	Permit or Locality	Duration	Operating Permit
26SL	West Australian Petroleum Pty. Limited	Vacant Areas	20/8/74 to 19/11/74	WA-25-P
27SL	,, ,, ,, ,, ...	WA-1-P .... Vacant Areas	20/8/74 to 19/11/74	WA-23-P
28SL	B.O.C. of Australia Limited	WA-2-P	5/3/74 to 4/6/74	WA-31-P
29SL	,, ,, ,, ...	WA-2-P	17/4/74 to 16/7/74	WA-31-P and WA-32-P
4				

LOCATIONS DECLARED

Location Number	Permit Number	No. of Blocks	Permittee	Discovery Block/Nom. Block	Date Declared
1SL	WA-1-P	9	B.O.C. of Australia Ltd.	Cape Keraudren 2984	4/1/74
2SL	WA-28-P	9	,, ,, ,, ...	Cape Keraudren 3122	4/1/74
3SL	WA-28-P	9	,, ,, ,, ...	Cape Keraudren 3191	4/1/74
3		27			

TABLE B

CHANGES AFFECTING TITLES UNDER THE PETROLEUM ACT. 1967 DURING 1974

PERMIT SURRENDERS

Permit No.	Permittee	Original Blocks Held	Surrendered Blocks	Surrender Date
18	West Australian Petroleum Pty. Limited	200	114	25/10/74
33	Beach-General Exploration Pty. Ltd., Australian Aquitaine Petroleum Pty. Limited	197	197	30/8/74
45	Continental Oil Company of Australia Ltd., Australian Sun Oil Co. Ltd.	199	199	16/8/74
46	(as above)	199	199	16/8/74
47	(as above)	199	199	16/8/74
48	(as above)	199	199	16/8/74
72	Planet Exploration Co. Pty. Ltd.	198	198	16/8/74
73	(as above)	198	198	16/8/74
75	(as above)	198	198	16/8/74
76	Genoa Oil N.L., Hartog Oil N.L., Olympus Petroleum N.L., Pexa Oil N.L., Omega Oil N.L., Kambalda Petroleum N.L.	188	188	24/12/74
		1 975	1 889	

PERMIT CANCELLATIONS

Permit No.	Permittee	No. of Blocks	Date Cancelled
51	Lennard Oil N.L.	17	26/7/74
52	Lennard Oil N.L.	18	26/7/74
		35	

ADVERTISEMENTS INVITING APPLICATIONS FOR EXPLORATION PERMITS WITH A CLOSING DATE

Former Permit Number	No. of Blocks	Gazettal Date	Closing Date	Section
E.P. 16	200	10/5/74	19/8/74	30 (1)
E.P. 53	49	„	„	„
E.P. 39	160	„	„	„
E.P. 55	178	„	„	„
E.P. 12	182	„	„	„
E.P. 45	197	13/12/74	7/2/75	„
E.P. 46	199	„	„	„
E,P. 47	199	„	„	„
E.P. 48	199	„	„	„
E.P. 72	198	„	„	„
E.P. 73	198	„	„	„
E.P. 75	198	„	„	„
E.P. 23 Loc. I (Sec. Entitlement)	4	22/3/74 10/5/74	20/5/74 22/7/74	33 (1)
Loc. 2 (Sec. Entitlement)	3	22/3/74 10/5/74	20/5/74 22/7/74	33 (1)
	2 164			

ADVERTISEMENTS MAKING AREAS AVAILABLE FOR APPLICATION WITHOUT A CLOSING DATE

Former Permit Number	No. of Blocks	Gazettal Date	Section
E.P. 23 Loc. 2 (Sec. Entitlement)	3	25/10/74	33 (2)

PERMIT APPLICATIONS

Permit Number	Applicant	Applied For	No. of Blocks	Status
83	Australian Gold Development N.L.	22/2/74	200	Refused 7/8/74
84	„ „ „	22/2/74	200	Refused 7/8/74
85	Endeavour Oil Company N.L., Target Minerals Pty. Ltd., Associated Australian Resources N.L., I.O.L. Petroleum Ltd., Alliance Minerals N.L.	18/7/74	4	Pending
86	XLX N.L.	8/8/74	118	Pending
			522	

TABLE C
BARROW ISLAND FIELD PETROLEUM PRODUCTION DURING 1974

Reservoir	Average daily prod. oil in m^3 and (bbls) during December 1974	Production for year 1974					Cumulative production				
		Oil in m^3 and (bbls)	L.P.G. in m^3 and (bbls)	N.G. in m^3 and (bbls)	Water in m^3 and (bbls)	Gas $10^3 m^3$	Oil in m^3 and (bbls)	L.P.G. in m^3 and (bbls)	N.G. in m^3 and (bbls)	Water in m^3 and (bbls)	Gas $10^3 m^3$
Windalia	5 735 (36 073)	2 140 642 (13 464 213)	5 101 (32 084)	5 748 (36 155)	795 408 (5 002 961)	133 452	16 361 302 (102 909 320)	9 897 (62 253)	10 832 (68 133)	3 544 508 (22 357 143)	1 632 512 ....
Muderong	55 (348)	19 932 (125 371)	.... (0)	.... (0)	9 407 (59 169)	2 904	174 605 (1 098 233)	.... (0)	.... (0)	44 366 (279 053)	26 375 ....
Jurassic 5 500′	.... (0)	.... (0)	.... (0)	.... (0)	.... (0)	0	*2 477 (15 580)	.... (0)	.... (0)	16 157 (101 628)	14 626 ....
Jurassic 6 200′	.... (0)	.... (0)	.... (0)	.... (0)	.... (0)	0	9 140 (57 489)	.... (0)	.... (0)	19 650 (123 592)	80 926 ....
Jurassic 6 600′	13 (81)	11 844 (74 498)	.... (0)	.... (0)	22 260 (140 008)	1 760	59 390 (373 551)	.... (0)	.... (0)	107 147 (673 931)	22 435 ....
Jurassic 6 700′	28 (173)	8 089 (50 882)	.... (0)	.... (0)	7 323 (46 059)	8 879	185 859 (1 169 010)	.... (0)	.... (0)	57 688 (362 851)	103 835 ....
Jurassic 10 600′	.... (0)	*212 (1 334)	.... (0)	.... (0)	18 (113)	1 805	*212 (1 334)	.... (0)	.... (0)	18 (113)	1 805 ....
Jurassic 10 900′	.... (0)	*180 (1 131)	.... (0)	.... (0)	120 (754)	1 085	*180 (1 131)	.... (0)	.... (0)	120 (754)	1 085 ....
Jurassic 11 250′	.... (0)	*219 (1 379)	.... (0)	.... (0)	101 (635)	10 260	*219 (1 379)	.... (0)	.... (0)	101 (635)	10 260 ....
Total Field	5 831 (36 675)	2 181 120 (13 718 808)	5 101 (32 084)	5 748 (36 155)	834 637 (5 249 699)	160 145	16 793 384 (105 627 027)	9 897 (62 253)	10 832 (68 133)	3 799 755 (23 899 700)	1 893 859 ....

Water injected during 1974 : 5 022 231 m^3 (31 588 830 bbls). Cumulative water injected : 33 117 853 m^3 (208 304 669 bbls)

NOTES :
1. *Denotes condensate which is blended with crude for sale.
2. Production for Jurassic 10 600′, 10 900′, and 11 250′ Sands includes **total** production to end '74 as these zones were not included in this report last year.
3. Metric standard conditions for both gas and oil are 15°C and 101·325 kPa.
4. Where oil is expressed in barrels, imperial standard conditions are used, i.e. 60°F and 14·73 psia.

TABLE D

BARROW ISLAND FIELD WELL STATUS BY RESERVOIRS AT 31st DECEMBER, 1974

Reservoir	Flowing	Pumping	Gas Lift	Closed in	Water Injection	Water Source	Water Disposal	Total
Windalia	9	173	102	29	163	9	7	492
Muderong	3	2	3	0	0	0	0	8
Jurassic 5 500′	0	0	0	1	0	0	0	1
Jurassic 6 200′	0	0	0	2	0	0	0	2
Jurassic 6 600′	1	0	0	0	0	0	0	1
Jurassic 6 700′	2	1	0	2	0	0	0	5
Jurassic 11 250′	0	0	0	1	0	0	0	1
Total	15	176	105	35	163	9	7	510

NOTES :
1. Metric standard conditions for both oil and gas are 15°C and 101·325 kPa.
2. Where oil is expressed in barrels imperial standard conditions are used, i.e. 60°F and 14·73 psia.

TABLE E

BARROW ISLAND FIELD OIL AND GAS DISPOSAL DURING 1974

	Oil m³ (bbls)	Gas m³ x 10³
Total Production	2 181 120 (13 718 808)	160 145 ....
Field Fuel	0 (0)	17 209 ....
Oil Shipments	2 207 720 (13 886 118)	....

Royalty paid : $1 247 008

TABLE F

ESTIMATE OF PROVED AND PROBABLE RECOVERABLE PETROLEUM RESERVES (UNDISCOUNTED IN WESTERN AUSTRALIA AS AT 31/12/74)
(See footnote 1)

Company	Area and Field	Oil $m^3 \times 10^6$	N.G.L. $m^3 \times 10^6$	Raw Gas $m^3 \times 10^9$
	CARNARVON			
BOCAL	Angel	....	8·31	35·4
BOCAL	Goodwyn	neg.	14·94	71·9
BOCAL	N. Rankin	....	29·17	243·7
WAPET	Barrow Island	22·74	·33	1·7
	Sub Total	22·74	52·75	352·7
	PERTH BASIN			
WAPET	Dongara	0·23	·05	10·90
WAPET	Mondarra	....	·01	·41
WAPET	Yardarino	....	neg.	·04
WAPET	Gingin	....	neg.	·02
	Sub Total	0·23	·06	11·37
	Grand Total	22·97	52·81	364·07

NOTE :
1. Significant gas condensate discoveries, awaiting further evaluation, have also been made by BOCAL at Scott Reef and WAPET at West Tryal Rocks.

TABLE G

DONGARA AND MONDARRA FIELDS PETROLEUM PRODUCTION DURING 1974

Field	Number of producing wells at 31/12/74	Average daily production during December, 1974		Production for year 1974			Cumulative production		
		Gas 10^3m^3	Condensate m^3 and (bbls)	Gas 10^3m^3	Condensate m^3 and (bbls)	Water m^3 and (bbls)	Gas 10^3m^3	Condensate m^3 and (bbls)	Water m^3 and (bbls)
Dongara	10	1 907·5	9·8 (62)	743 421	4 086 (25 694)	3 170 (19 932)	2 108 751	11 690 (73 528)	8 810 (55 413)
Mondarra	1	241·2	3·5 (22)	65 406	1 161 (7 297)	223 (1 405)	168 227	3 313 (20 838)	710 (4 466)
Total	11	2 148·7	13·3 (84)	808 827	5 247 (32 991)	3 393 (21 337)	2 276 978	15 003 (94 366)	9 520 (59 879)

Total gas sold in 1974 = 814 842 x 10^3m^3 Total royalties paid = A$274 968

NOTES :

1. Condensate and water Production for 1974 was calculated by differences of December 1973 cumulative and December 1974 cumulative.
2. Metric standard conditions for both gas and oil are 15°C and 101·325 kPa.
3. Where oil is expressed in barrels, imperial standard conditions are used, i.e. 60°F and 14·73 psia.

TABLE H

ACCIDENT STATISTICS RELATING TO THE PETROLEUM EXPLORATION, PRODUCTION AND PIPELINE INDUSTRY DURING 1974

DESCRIPTION OF INJURY	Drilling Activities		Barrow Island Oil-Field	Dongara Gas Field	Natural Gas Transmission Pipeline	Seismic Activities		Totals
	Onshore	Offshore				Onshore	Offshore	
Head	3	17	2	....	....	1	....	23
Eye	1	21	7	....	....	....	....	29
Trunk	4	37	18	....	1	....	....	60
Arm	3	12	12	....	....	1	....	28
Hand	12	47	15	....	....	1	....	75
Leg	2	27	15	....	....	....	....	44
Foot	2	17	9	....	....	1	....	29
Occupational Diseases	....	1	3	....	....	....	....	4
Other Injuries and Shock	....	2	2	....	....	3	....	7
AGENCY OF INJURY								
Machinery in Operation	....	14	....	....	....	....	....	14
Vehicles	....	2	3	....	....	3	....	8
Tools—Hand	1	5	4	....	....	....	....	10
Tools—Power	....	5	....	....	....	1	....	6
Manual Handling	7	48	25	....	1	1	....	82
Harmful Contacts	3	23	25	....	....	....	....	51
Persons Falling or Striking	8	35	14	....	....	....	....	57
Objects Flying or Falling	5	42	3	....	....	....	....	50
Other	3	2	....	....	....	....	....	5
MAGNITUDE OF INJURY								
Minor	6	92	31	....	....	1	....	130
Serious	21	75	46	....	1	4	....	147
Fatal	....	....	....	....	....	....	....	....
TIME FACTOR								
Days Lost	131	1 266	322	....	29	269	....	2 017
Manhours Exposure	90 577	794 186	219 989	13 369	18 109	131 899	....	1 268 129

48396—(11)

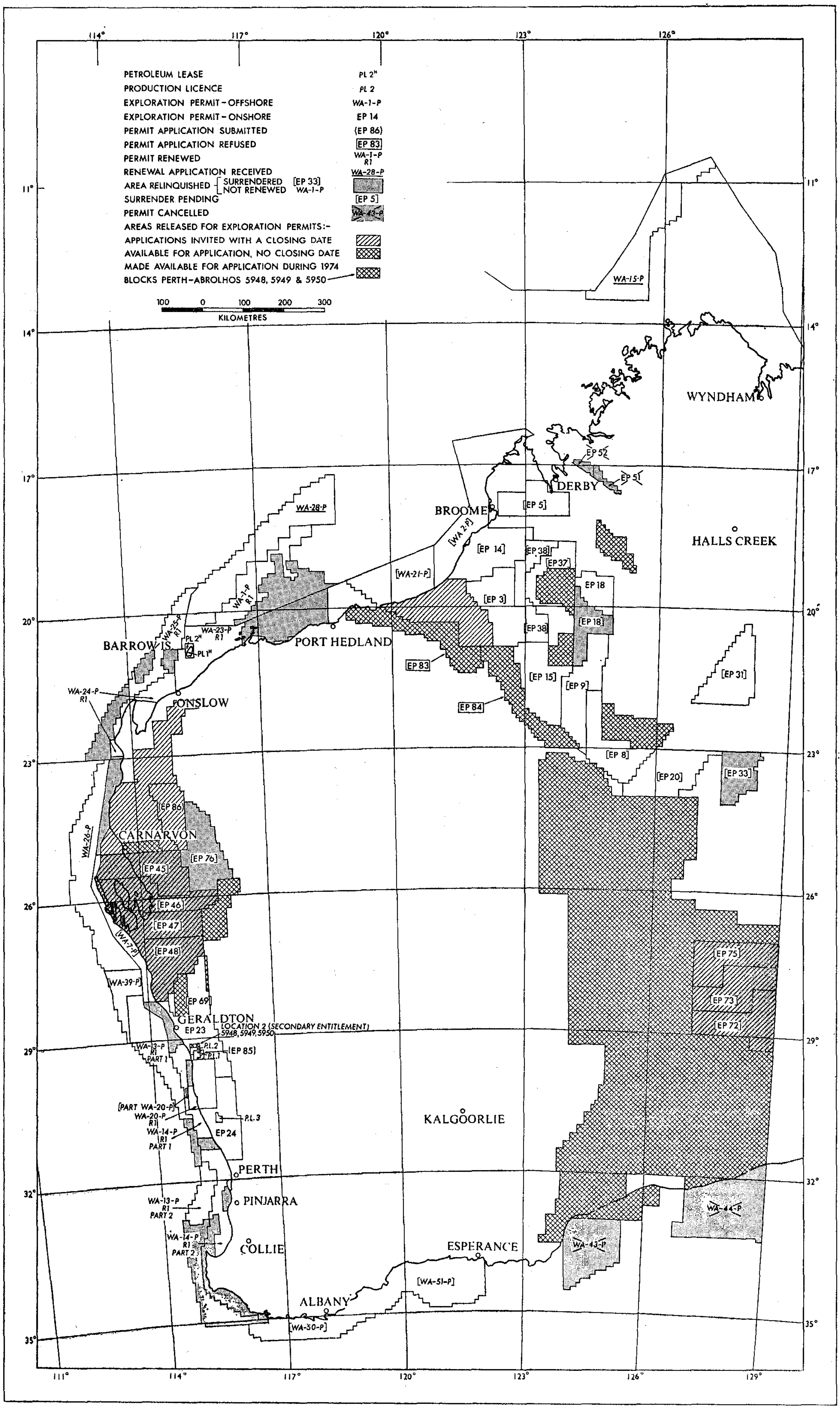

Figure A. Changes in the status of petroleum tenements and areas advertised for petroleum exploration during 1974.

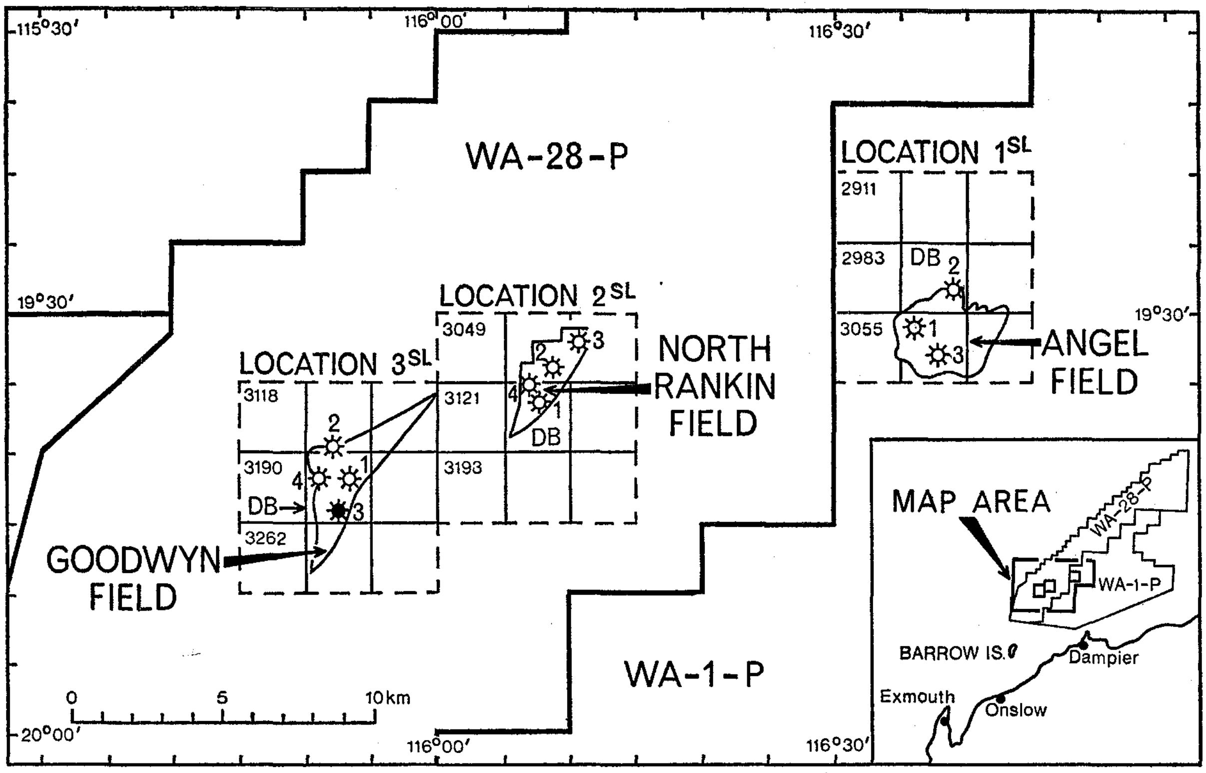

Figure B. Locations 1SL, 2SL and 3SL. DB—Discovery Block. 2911—Graticular block number on Cape Keraudren Sheet 1:1 000 000 Map Series. Inset map shows situation on Northwest Shelf.

1974 OFFSHORE DRILLING OPERATIONS

OPERATOR	CONTRACTOR	RIG	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
BOCAL	GLOBAL MARINE	'GLOMAR TASMAN'	LAMBERT No.1 3700 m OIL & GAS WELL P&A	DEPUCH No.1 4300 m PLUGGED and ABANDONED		HEYWOOD No.1 4572 m OIL & GAS SHOW PLUGGED and ABANDONED								
BOCAL	ODECO	'OCEAN DIGGER'	POISSONIER No.1 1962 m P&A	LOWENDAL No.1 3642 m PLUGGED and ABANDONED	HAMPTON No.1 2584 m GAS SHOW P&A		LOMBARDINA No.1 2855 m PLUGGED and ABANDONED			MINILYA No.1 2400 m P&A	PRUDHOE No.1 3322 m PLUGGED and ABANDONED			
ARCO	ATWOOD OCEANICS	'MARGIE'				WHIMBREL No.1 2059 m P&A	PLOVER No.2 1524 m P&A							
WAPET	SALVESEN OFFSHORE	'DALMAHOY'			HILDA No.1 1546 m PLUGGED and ABANDONED	HILDA No.1A 3466 m OIL & GAS SHOW PLUGGED and ABANDONED						WEST TRYAL ROCKS No.2 3825 m GAS & CONDENSATE WELL PLUGGED and ABANDONED		

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1974 LAND DRILLING OPERATIONS

OPERATOR	CONTRACTOR	RIG	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
WAPET	O. D. & E	IDECO 7-11 JUNIOR	COOMALLO No.1 3526 m P&A			BARRAGOON No.1 2335 m P&A		DONGARA No.20 1939 m GAS WELL						
WAPET	O. D. & E	IDECO SUPER 7-11									JONES RANGE No.1 2540 m PLUGGED and ABANDONED			
WAPET - HEMATITE	INTAIRDRILL	GARDENER - DENVER 15W											MARDIE No.1A 164 m GAS SHOW SUSPENDED	WINDOO No.1A 174 m GAS SHOW SUSPENDED
ROBINSON	DRILLING AND PROSPECTING SERVICES	LONGYEAR 44	KENDENUP No.1 111 m P&A	SUNDAY SWAMP No.1 175 m PLUGGED and ABANDONED										

Figure C. Drilling rig operations during 1974.

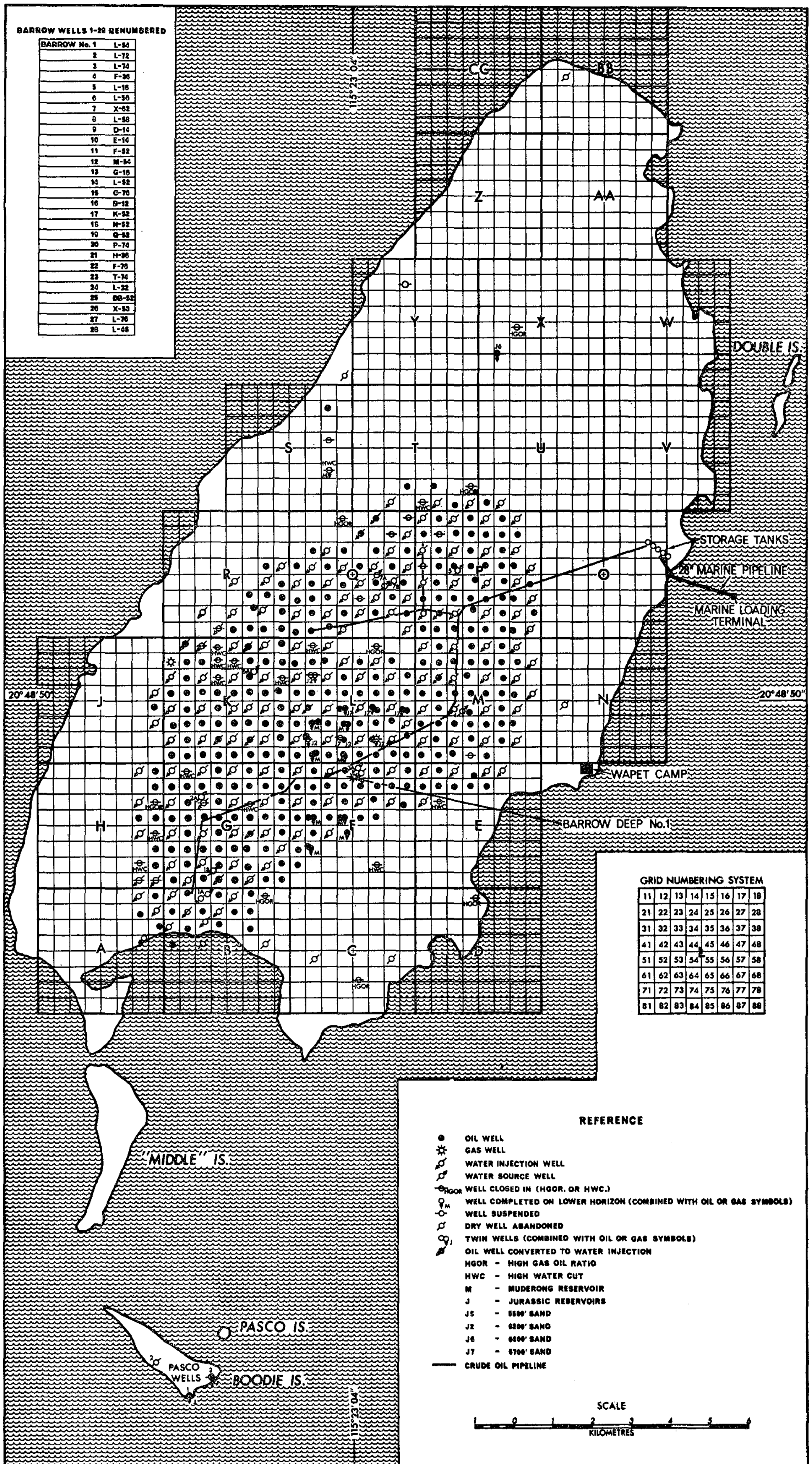


Figure D. Barrow Island Field, northern Carnarvon Basin. Status of wells with respect to the "Windalia Sand" reservoir on 31st December, 1974.

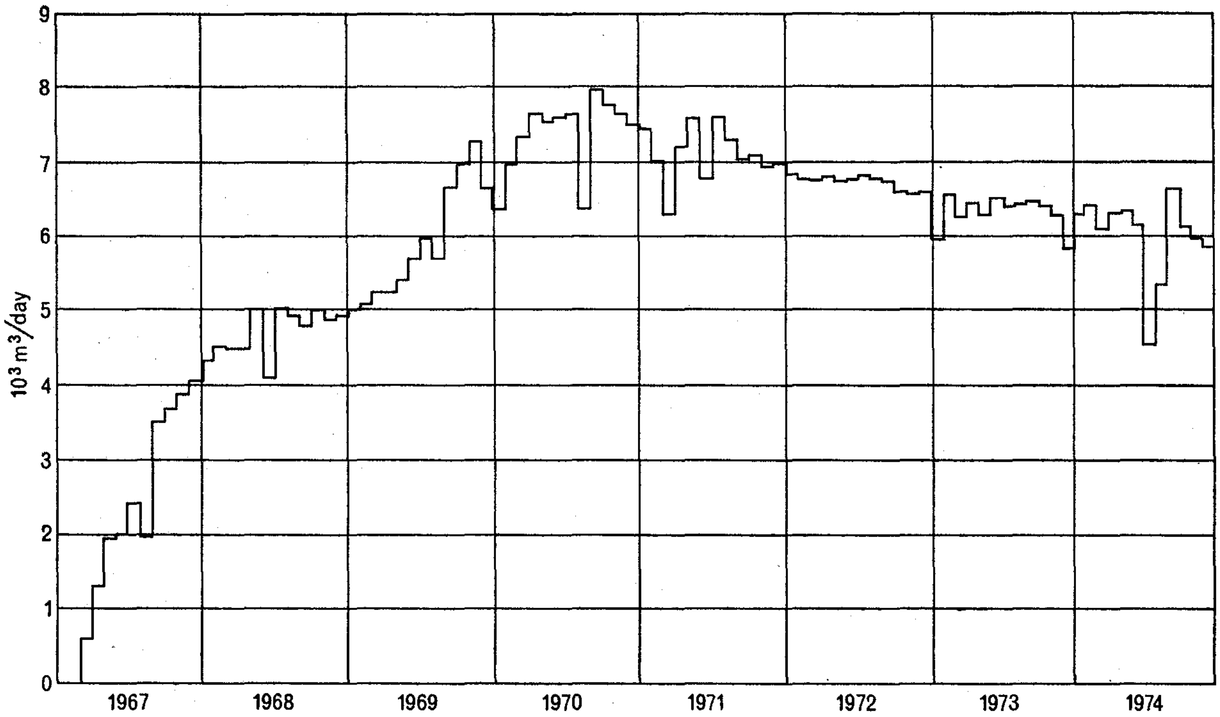


Figure E. Barrow Island Field (Petroleum Lease 1H), northern Carnarvon Basin. Average daily production per month of crude oil between March 1967 and 31st December, 1974.

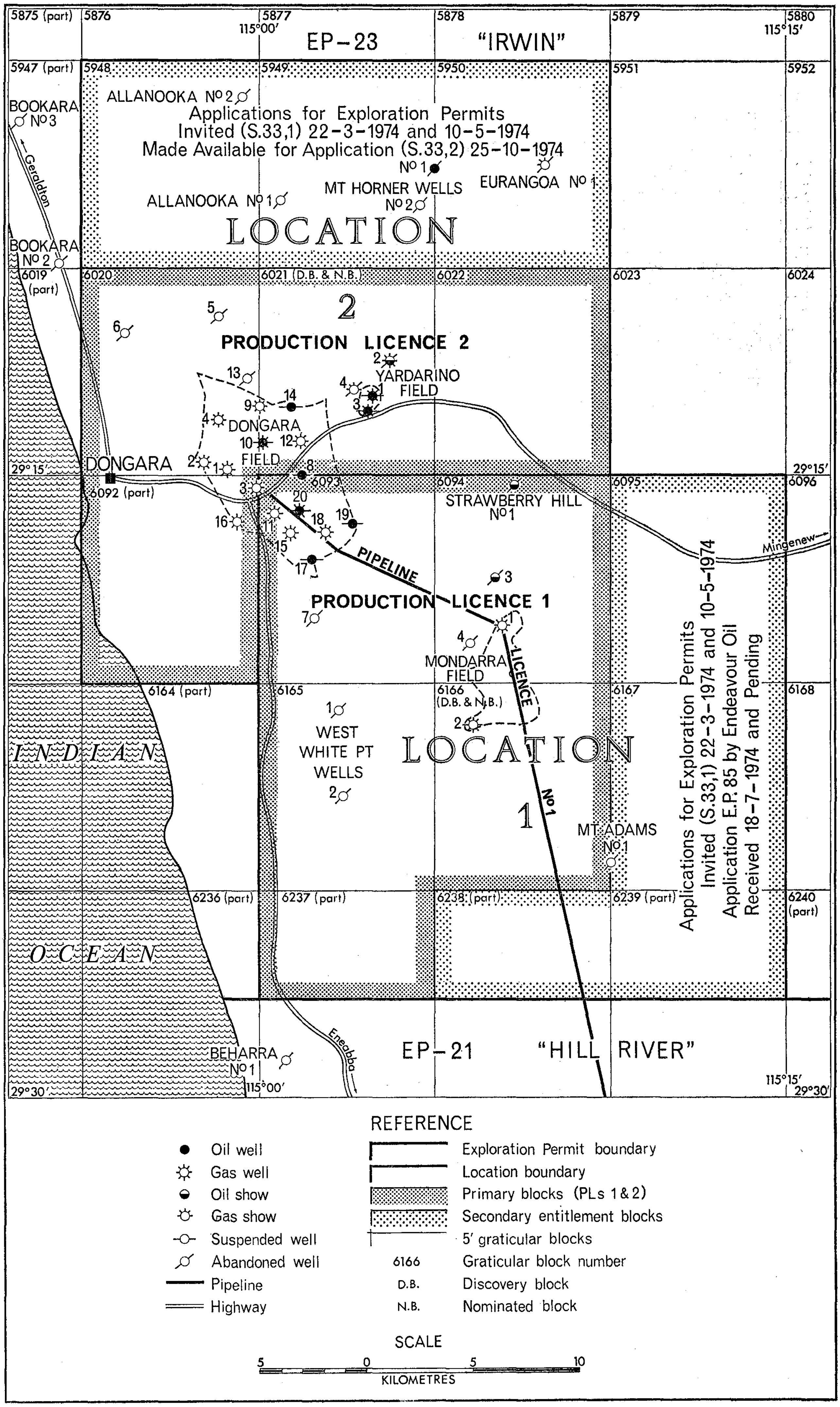


Figure F. Dongara area, northern Perth Basin. Status of petroleum tenements and wells at 31st December, 1974 (Perth Sheet 1:1 000 000 Map Series).

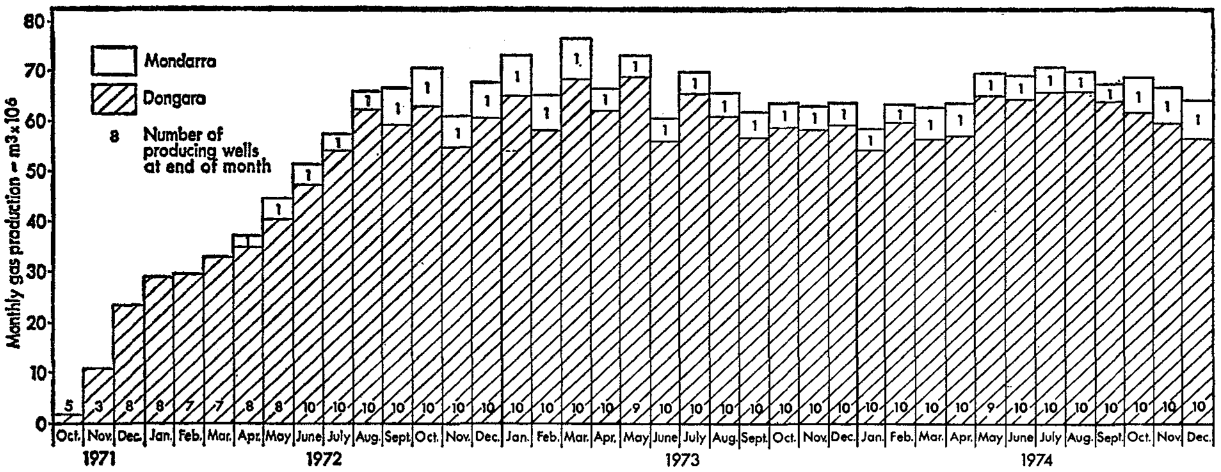


Figure G. Mondarra and Dongara Fields (Production Licences 1 and 2), northern Perth Basin. Monthly gas production between 25th October, 1971 and 31st December, 1974.

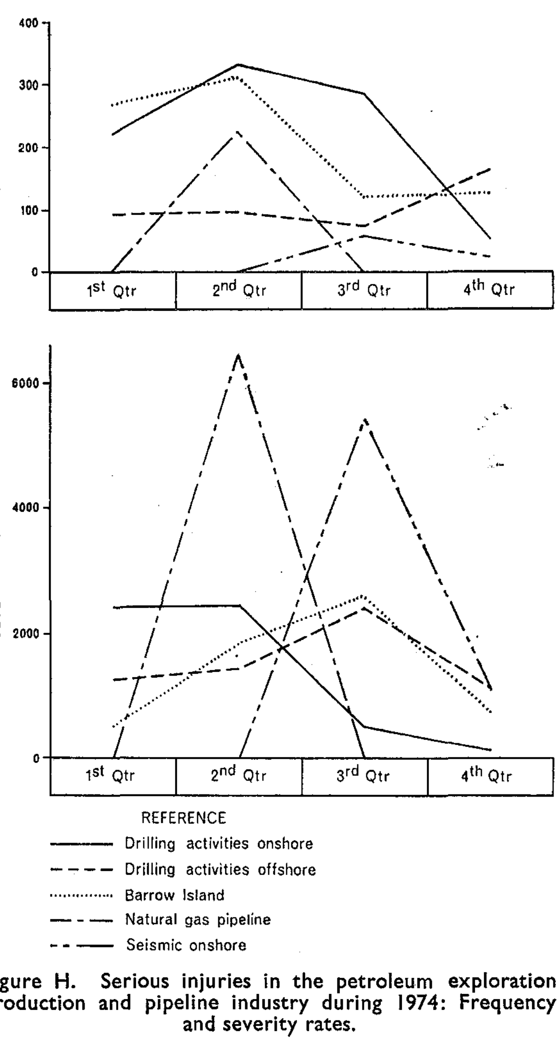


Figure H. Serious injuries in the petroleum exploration production and pipeline industry during 1974: Frequency and severity rates.

DIVISION VI

Report of the Superintendent Surveys and Mapping for the Year 1974

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, 1974.

STAFF

The membership of the staff now totals 125 officers comprising 105 males and 20 females in the following categories:

Professional	55
Clerical	12
General	31
Technical	5
Cadet Cartographers	18
Trainee Draftsmen	4
	125

Cadet Cartographers, Messrs. Maloney, Martin, Ridley, Sadlier and Stevens qualified in the Diploma of Cartography and were appointed to the Level 1 Career Range as Cartographic Draftsmen.

Five Cadets qualified in the latter part of the year, and are eligible for appointment to the Level 1 Cartographic range in the new year.

The number of surveyors authorised by the Hon. Minister to perform cadastral surveys for the Department now stands at 72.

The accumulated balance of deposited survey fees which stood at $3 497 600 at the beginning of the year was reduced to $2 327 874 as at 31st December.

There was a further falling off, of the value of surveys performed. This year's figure was $370 411 as against $400 501 for 1973. (see graph).

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 divisions of the Branch are appended hereto.

A. A. HALL,
Superintendent Surveys and Mapping.

SURVEY SECTION

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 the Department and in accordance with its regulations and requirements. Survey work done is summarised in the following tables:—

Table A

Number of Surveyors	26
Number of survey field parties used (est.)	32
Number of tenements surveyed	1 764
Number of field books lodged	217
Number of connection stations established	48
Total boundary line run	3 678·232 km
Total traverse line run	103·632 km
Total area delineated by survey	141 974 ha
Total distance travelled	92 108 km
Total value of boundary survey	$345 297
Total value of "connection" survey	$ 25 113
Total	$370 411

Table B

Surveyor	Field Books	Surveys	Hectares
McKimmie, Jamieson and Partners Pty. Ltd.—			
J. A. Jamieson	32	247	13 602
T. L. Markey	3	21	377
M. J. McKimmie	3*	18	1 316
Benetti Croghan & Associates—			
R. J. Benetti	16	114	9 618
P. D. Heyhoe	9	85	8 152
K. J. Croghan	3	31	3 492
M. M. Fisher and Associates—			
M. M. Fisher	22*	259	13 540
F. R. Rodda Pty. Ltd.—			
F. R. Rodda	10	123	10 389
P. R. Blackadder	9	84	9 268
D. F. V. Wilson & Associates—			
D. F. V. Wilson	14	138	9 127
K. F. Patterson	13	123	12 916
J. Ranieri	16	95	9 405
McCarthy, Smirk and Associates—			
D. H. Stewart	10	91	9 131
M. J. Byrne and Associates—			
M. J. Byrne	17	81	8 398
Associated Surveys Pty. Ltd.—			
G. E. Roughan	3	22	2 303
D. H. Thompson	1*	....	....
W. Berryman & Associates—			
W. A. Berryman	9	68	7 611
A. C. Watson	1	5	530
Hille and Thompson—			
A. G. Thompson	7	71	8 242
A. K. King	7	72	3 757
Australian Aerial Mapping (W.A.) Pty. Ltd.—			
A. Quinn	6*	....	....
I. M. Gordon	2	8	65
W. F. Johnson Pty. Ltd.—			
K. Amsuss	1	6	695
L. J. Burkett	1	1	1
G. C. Callaghan	1	1	39
H. Denton	1	....	....
	217	1 764	141 974

* Includes connection surveys.

Boundary surveys of claims and leases were carried out in all areas of the State from Kununurra in the North, Paterson Range on the edge of the Great Sandy Desert and the Metropolitan area. In some cases considerable large concentrations of tenements were involved, but the trend is to smaller and more discrete groupings of tenements.

Special Projects

Shay Gap Connections

A total of five station points were selected and marked and now await measurement and computation. The surveys of ML 249 SA will be tied to these positions.

Paterson Range Connections

The final observations were made to the stations established in this area. The survey of the remaining main block of leases was completed. Final computations are awaited.

North Pole—Normay Connections

The claims for the North Pole Barite Mine were tied in to one central station. This is to be subsequently connected onto the main geodetic network.

Coolgardie Connections

The field work for this survey was completed in May. The purpose of the survey was to establish connection points in the area centred on the town of Coolgardie and with an areal extent of some 980 km^2 to facilitate the co-ordination and integration of cadastral surveys into a standard traverse system with subsequent accurate base map plots. Considerable plan error was known to exist in this area, the existing plans having their origins in surveys at the turn of the century.

The survey was based on 2 major existing stations, Bullabulling and Mt. Burges, with one supplementary station, Mt. Comet, being upgraded in the subsequent adjustment.

In all, nine major connection points were established with standard departmental survey plaques emplaced and with connections to the existing cadastral surveys made. An additional fourteen radiated points were accurately located to serve as starting points for future cadastral traversing.

The measurements were computed using the National Mapping programme VARYCORD, the summary of results being:—

Azimuth Adjustment (per Angle)—Average 0.82"—Max. 2.58"

Length Adjustment (per line)—Average 0.025 m—Max. 0.164 m.

Agnew-Leinster Downs Connections

The field work for this control was completed in October, including reconnaisance and observations. A total of nine stations were established.

All connection stations established are monumented with standard Departmental brass plaques set in concrete, stamped with the appropriate numbers, and witnessed with a red and white painted star-iron post. Reference marks were placed at all new stations. This stage of the marking was actually carried out during the stage 2 of the survey to enable two marks to be placed on line to adjacent stations. The reference marks are 40 cm iron spikes set in concrete or driven to ground level surrounded by a rock circle.

The survey is designed to connect onto the existing National Mapping Stations, Mt. Adamson, Agnew Bluff, Mt. White, Mt. Goode and Mt. Bryan.

No computational adjustment has as yet been carried out but preliminary calculations indicate that the specified standard errors of 1.5 seconds for angles and 10 cm for distances have been achieved.

Bulong-Kanowna Connections

The operation for location and placement of stations to link existing cadastral surveys in this area into the National control network was carried out in November. In all a total of 13 stations have been selected and marked. Observation survey is programmed for 1975.

Staff Required

Field activity on these projects is performed by private consultants. However, due to the lack of suitable professional office staff caused by resignation of key officers much of this geodetic computation awaits completion. If additional staff can be recruited in the new year this situation can be resolved.

Field Inspections

During the year, field inspections were carried out by senior officers in this Branch.

(a) South Yilgarn and Eastern Goldfields. The purpose was threefold; to inspect and evaluate the survey marking and applicants claim marking; to evaluate vegetation and terrain categories for assessment of loading factors to the scale of survey fees; and to photograph typical vegetation types.

(b) Kalgoorlie-Eastwards. This was to assist in the reconnaisance for selection of connection stations and to provide an on the spot evaluation.

(c) Golden Grove. This was to inspect the cently establishment claim surveys, evaluate vegetation categories and check the possibility of future connection surveys.

(d) Port Hedland and Pilbara generally. This was a general appraisal of the survey problems in this area and to enable the Department to be aware that its survey involvement is achieving the optimum effect. A feature of this was the opportunity to inspect the Paterson Range area—250 kilometres South-east of Marble Bar—and to evaluate the large amount of lease and connection surveys in this area.

Conference with Practitioner Surveyors

A new scale of survey fees was gazetted under the Land Act, operative from 1st January 1974. Our regulations require conformity to this scale and our charges have been adjusted accordingly. The new scale introduced some new innovations which are desirable. However, some divergence of opinion regarding interpretation became apparent. In addition, some matters arising from our field inspections were considered to need further emphasis and accordingly a full statement of departmental policy was prepared. This was presented to a full gathering, in conference, of all practitioner surveyors registered with the department. Matters discussed were: survey instructions, field activity, survey camps, drafting, accounts and estimates.

A new procedure introduced at this conference was that of estimating. The introduction of this new action is revolutionary and breaks a lot of new ground. It is being phased in progressively and indications are that it will be successful and become confirmed practise during 1975.

Map Control and Computer Systems

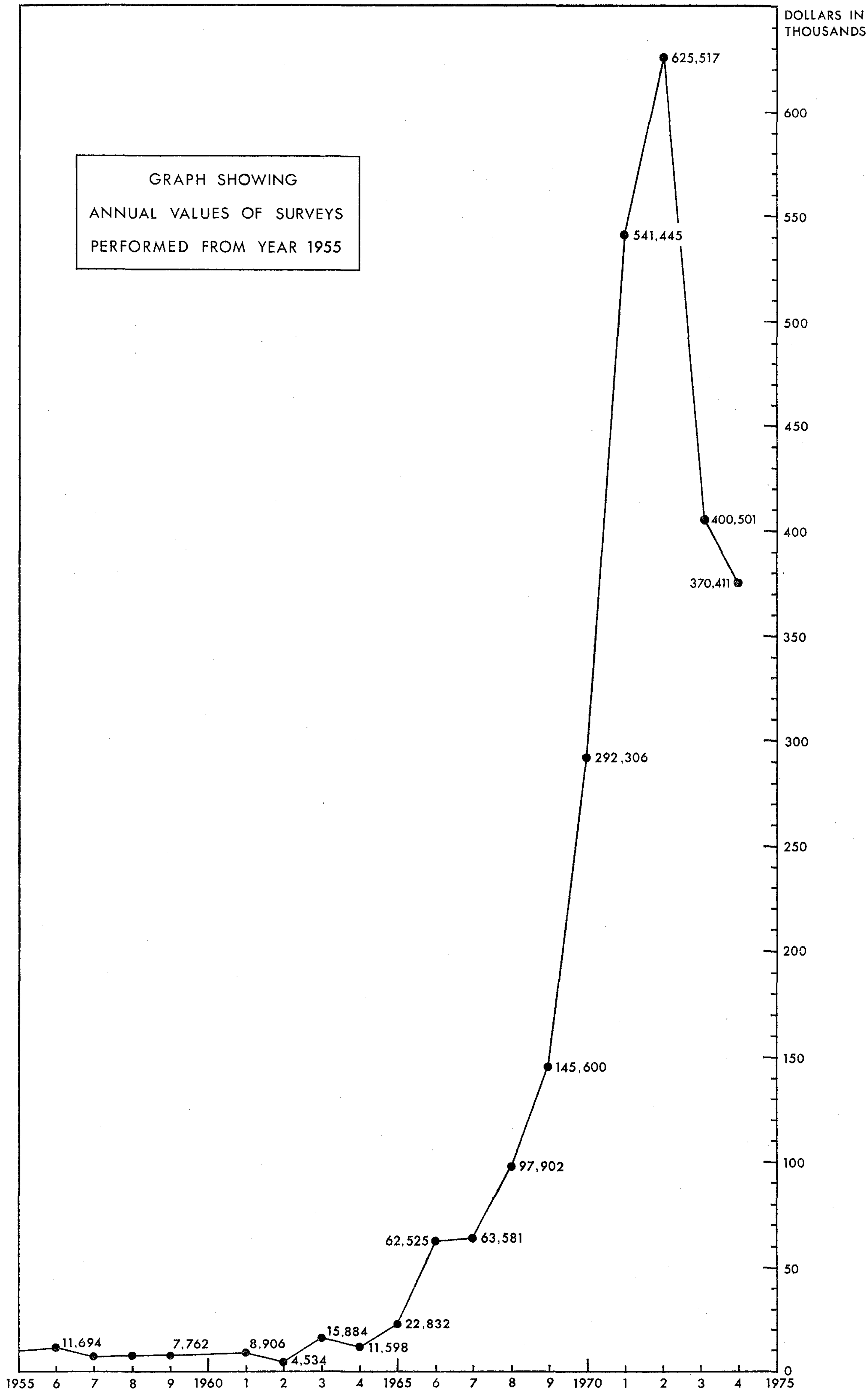
Work progressed during the year when more standard traverse work was done in the Coolgardie and Barrambie areas. Also the system of standard traverses has been successfully used for standard plan update procedures and the imposition of an AMG onto these plans in the Pilbara region.

It is hoped, in the new year, to commence operations for storeage of this type of data on the "CADMAPS" system developed by the Department of Lands and Surveys.

Petroleum

The latter half of the year saw an influx of "offshore" Exploration Permit renewals. A total of 3 065 Blocks expired, making 1 532 Blocks eligible for first renewal. Only 1 016 Blocks representing seven Permits are being negotiated for renewal.

There has been considerable demand for maps showing relinquished areas as well as the standard tenement map. A revised edition of the tenement map at scale 1 : 4 000 000 was produced incorportaing additional data relating to interest holders in individual permits.


GRAPH SHOWING
ANNUAL VALUES OF SURVEYS
PERFORMED FROM YEAR 1955
DOLLARS IN THOUSANDS
625,517
541,445
400,501
370,411
292,306
145,600
97,902
63,581
62,525
22,832
15,884
11,598
11,694
7,762
8,906
4,534
600
550
500
450
400
350
300
250
200
150
100
50
0
1955
6
7
8
9
1960
1
2
3
4
1965
6
7
8
9
1970
1
2
3
4
1975
YEARS

MAPPING BRANCH

A heavy programme of general drafting and mapping work was completed during the year. The details of each subsection was as follows:—

Cadastral Mapping

A total of 24 new provisional maps at a scale of 1 : 50 000 were prepared in the Pilbara covering Edmund and 32 new plans were redrawn on the Australian Map Grid of Yarraloola and Pyramid. There were 42 new A.M.G. sheets started to replace the provisional plans of Dampier, Roebourne and Port Hedland.

Revision was completed covering Balfour Downs, Nullagine, Yarrie, Robertson in the Pilbara and Peak Hill Robinson Range in the Murchison.

A further six plans were completed at a scale of 1 : 100 000 on the Australian Map Grid and six more commenced.

Geological Mapping—1 : 250 000 Series.

This series forms a major part of our mapping programme and during the year, the following sheets were completed and sent to Hobart for printing:—

1st Edition
- Dongara-Hill River
- Mason
- Seemore
- Edjudina
- Lake Johnston
- Ravensthorpe

Preliminary Edition
- Cundeelee

The following sheets were published during the year:—

1st Edition
- Balladonia
- Zanthus
- Cue
- Norseman
- Esperance-Mondrain Island

Preliminary Edition
- Leonora
- Laverton
- Mason
- Rason
- Plumridge
- Vernon
- Minigwal
- Marble Bar
- Nullagine
- Perth
- Seemore

Work continued on the sheets of Yalgoo, Leonora, Laverton and Perth and the First Editions of Marble Bar and Nullagine were commenced.

Other Work

Over 500 drawings were prepared for various publications such as Bulletins, Reports and Overseas Papers. Other requirements were drawings for projection slides both colour and black and white and overhead projector slides for lectures.

Bulletins were in progress for the following:—

Tin, Mineral Sands, Perth Basin and Carboniferous areas. Various information pamphlets were prepared or reprinted for issue through G.S.W.A.

A new geological series was commenced at a scale of 1 : 1 000 000, the first two sheets being Kalgoorlie and Esperance.

A new edition of the State Geological Map completed in 1973, was published early in the year.

Microfilming

Microfilming of "S" reports, "M" series plans and reports and Petroleum Permit relinquishment packages became a major project. Other work to be filmed comprised the old mining tenement registers of the Registration Branch, Survey Field Books and Mineral Claim files.

An estimate of at least three years work has been made for microfilming and the acquisition of our own camera is essential.

The preparation of Microforms for S.G.I.O., the Metropolitan Water Board and Education Department Certificates for use on the COM90 unit at the Treasury A.D.P. centre was a new task for the Branch.

Photographic Section

As in previous years, this section was under heavy pressure to meet the increasing demand for process work and overtime was frequently worked.

There was a big increase in the number of items prepared on the Process Camera, the total being 2 822 comprising reductions, enlargements and same size copy.

Processing of items on the Vacuum Frames numbered 1 437 plus 110 A. B. Dick Metal Plates. This was a decrease from the previous year due to new films being used on the camera not requiring a negative stage.

Both the enlargers were in constant use with 144 rolls of 35 mm film being processed and printed from both colour and black and white.

529 colour slides were processed and 464 colour prints were made ranging from 6 in x 4 in up to 40 in x 30 in size. 3 152 black and white prints were made making a total of 4 289 items in all for processing.

Various items of equipment were purchased to assist with the changing films and processes and it is obvious that there is a marked trend toward more colour work which will require additional equipment to meet the need.

Plan Printing

The Plan Printing Section produced 34 865 paper and film prints as well as 1 127 photo copies of various sizes.

Mounting of plans was down from the previous year with 2 151 being the total.

APPLICATIONS AND PUBLIC PLANS

The following applications were received during 1974:—

Mineral Claims	**4 833**
Mineral Leases	**119**
Gold Mining Leases	**576**
Licenses to Treat Tailings	**185**
Prospecting Areas	**417**
Coal Mining Leases	**329**
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.	148
TOTAL	6 607

One hundred and thirty eight applications for new Temporary Reserves were received and 135 processed.

T.R. Applications were for:—

Iron	**60**
Gold	**8**
Coal	**5**
Other Minerals	**62**
Rejected on receipt	**3**

No overtime has been worked and no abnormal backlogs have occurred.

Enquiry into areas of interest for Gold continues.

Head Office Plans sales total **$7 598.93** for the sale of:—

Dyelines	7 274
Transparencies	**338**
Photo Copies	**3 116**
T.R. Iron List	**31**
T.R. Other Minerals List	**26**
State Maps	**173**
Gazetteers	**134**
Mineral Occurrence Map	**132**
Gold Bearing Areas Map	**73**

DIVISION VII

Government Chemical Laboratories Annual Report—1974

Under Secretary for Mines:

I submit a summarised Annual Report on the operations of the Government Chemical Laboratories for the calendar year 1974.

Administration

At 31 December, 1974, 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., F.R.A.C.I.

Deputy Director—H. C. Hughes, B.Sc., M.A.I.A.S., A.R.A.C.I.

Agriculture Division—J. Jago, B.Sc., A.R.A.C.I., Chief of Division.

Engineering Chemistry Division—B. A. Goodheart, B.Sc., M.I.E. Aust., A.R.A.C.I., A.M. Aust. I.M.M., Chief of Division.

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—J. Bryant, B.Sc., Dip. Ed., Dip. Lib.

The close association of these Laboratories with other Government Departments and kindred associations was maintained and extended during 1974. Special effort was continued during the year to extend our assistance to other departments beyond that of purely supplying an analytical service, by providing a practical professional service.

Various members of the staff served as members of the following Committees during the year:

Australian Coal Industrial Research Laboratories Ltd.

Australian Water Resources 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.

Gasification of W.A. Coal Committee.

Government Paint Committee.

Laboratory Safety Committee.

Laporte Effluent Disposal Committee.

Laporte Industrial Factory Agreement, Review Committee.

Lupin Technology Committee.

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.

W.A.I.T. Advisory Committee on Applied Chemistry.

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 the study of the Laporte effluent problem, particularly to examining the technical and economic feasibility of various chemical treatments and to the Pesticide Sampling Study Group of the Ord River Ecology Committee.

During the year flexible working hours were introduced as a trial. This has turned out to be an outstanding success. All staff have appreciated and responded to the advantages of flexible working hours. Any disadvantages of the system are greatly outweighed by the definite advantages shown by staff accepting greater responsibility for their own working time.

Staff

As of 31 December, 1974 the establishment of the Laboratories was as follows:

Professional	78
General	45
Clerical	11
Wages	2
Total	136

Tentative approval has been received for only 3 of the 13 additional staff requested for 1974-75. Even if this approval is now confirmed it is unlikely that any of these 3 would start before July 1975 or even later.

The position with respect to additional staff has become serious. We have no direct control over our work load or the volume of work submitted to us from any Department. The very great increase in work received in 1974 and the restrictions on staff increases to handle the work, has meant delays in many cases of urgent police, health and environmental work. The need to sort priorities out for work requested has meant a lag of over 12 months in the reporting of some samples. This delay is retarding the work of other professional officers in client departments as their work is dependent on availability of our results in a reasonable time.

It is again emphasised that restrictions on additional scientific staff in these Laboratories is resulting in client departments employing their own analytical chemists. This results in no saving of salaries, probable duplication of work in some areas and an overall inefficiency of scientific services to Departments.

For many years the Laboratories provided about the only consultant and analytical chemistry service to the public and private industry in the State. With the growth of private consultant laboratories and the large increase in Government work it has been necessary to further restrict the amount of private work accepted because staff cannot be obtained to handle the Government work.

During the year Mr. H. C. Hughes was promoted to the position of Deputy Director and Mr. J. Jago was promoted to the resulting vacancy of Chief Agriculture Division.

In October Miss D. E. Henderson retired from the position of Senior Clerk after over 35 years of loyal and very valuable service to these Laboratories.

During the year Messrs. Brennan and McKinnon were seconded for five months to the Pilbara Study Group. Because of the importance of this project to the State and because of the major contribution these two officers could make through their chemical engineering training and experience, the inconvenience of their absence was accepted. Mr. Brennan was seconded again in September for a period of seven months to the Department of Environmental Protection. He was to act as the Ecology Officer to set up the environmental planning required with respect to the Jumbo Steel Plant Feasibility Study. Again the inconvenience of the absence of a senior valuable officer was accepted because of the magnitude of the project and the ultimate important impact it would have on the future of the State.

Many staff members have continued to actively participate, many in executive capacities, in a range of learned societies covering the activities of the Laboratories. Such participation is actively encouraged because of the value to the individuals and the benefits gained by the Laboratories.

During the year several staff members were again required to act as laboratory assessors for the National Association of Testing Authorities.

Library

The Library has continued to grow and serves a very essential back-up to each of the Divisions.

During the year 2 747 items were added to the Library consisting of 277 monographs, 2 082 periodicals and 388 reports.

Equipment

Major equipment received during the year includes a Technicon dual channel flame photometer, a Dynavac freeze drier, a Techtron atomic absorption spectrophotometer Model AA6 with carbon rod atomiser, a Technicon dual channel autoanalyser, a Monroe calculator, a Brookfield Synchro-Lectric viscometer, a Carl-Zeiss-Elrepho photoelectric reflectometer and additional laboratory flotation cells.

Buildings

The changes required to the Plain Street site for the Network Survey of the Australian Water Resources Council did not develop because confirmation of the project from the Commonwealth Government to the Public Works Department was not received. However subsequent receipt of this approval means that these building alterations will be necessary early in 1975.

Approval for further pilot plant space and additional storage space at Bentley has still not been received and this is now seriously handcapping the efficiency of the Engineering Chemistry Division at Bentley.

No final decision has been made on the re-building of the Kalgoorlie Metallurgical Laboratory. While the time for the School of Mines use of the present Kalgoorlie Metallurgical Laboratory site has not been given a definite date, the Kalgoorlie Metallurgical Laboratory continues to function in the present very old buildings. As soon as the School of Mines future plans and timetables are known, there is going to be an urgent need for replacement by a new laboratory either on a new site or partly within the School of Mines on the present site.

General

1974 has been a year unprecedented in the increase in the number of samples received for examination. An additional 6 400 or 27 per cent more samples were received in 1974 than in 1973. This increase has been mainly in the Agriculture Division from samples forwarded by the Department of Agriculture. This has meant an increase in this Division of 89 per cent over that in 1973. We had no prior indication of such a large increase in work and with no increase in staff this has meant that many samples in the Agriculture Division will have to be delayed up to 12 months depending on priorities allocated.

Although the increase in sample numbers in other Divisions have not been as spectacular, the variety and range of determinations has increased the work load far more than is indicated by sample numbers. For example in the Mineral Division 95 mineral samples were received for an average of 23 different determinations or a total 2 160 analyses on this one batch of samples.

The numbers and source of samples and their allocation in various Divisions is given in Table 1.

TABLE 1

SOURCE AND ALLOCATION OF SAMPLES RECEIVED DURING 1974

Source	Division						Total
	Agriculture	Engineering Chemistry	Food and Drug	Industrial Chemistry	Mineral	Water	
STATE—							
Aboriginal Affairs Authority	....	....	1	....	18	5	24
Agriculture Department	13 475	9	547	....	6	17	14 054
Community Welfare Department	....	....	1	....	1	....	2
Consumer Protection Bureau	....	....	4	6	1	5	16
Department of Industrial Development	....	....	....	....	1	2	3
Department of Motor Vehicles	....	....	1	1	....	....	2
Education Department	....	....	1	....	....	....	1
Environmental Protection Department	30	....	9	....	73	10	122
Fisheries and Fauna Department	....	....	474	....	4	130	608
Geological Survey	....	....	....	....	855	235	1 090
Government Chemical Laboratories	6	128	58	1	273	13	479
Government Printing Office	....	....	....	1	....	....	1
Government Stores Department	....	....	....	....	3	3	6
Harbour and Lights Department	....	....	....	16	....	....	16
Hospitals	1	....	81	....	....	1	83
Labour Department	1	....	135	1	1	....	138
Main Roads Department	2	....	....	....	2	....	4
Medical Department	....	....	....	1	....	4	5
Metropolitan Water Board	....	5	2	1	7	2 677	2 692
Milk Board of W.A.	....	....	53	....	....	....	53
Mines Department	....	....	27	....	366	....	393
Office of the North West	....	....	....	....	1	....	1
Peel Inlet Advisory Committee	....	....	....	....	....	65	65
Police Department	....	....	2 534	....	77	....	2 611
Public Health Department	198	....	1 374	1	1 267	68	2 908
Public Works Department	....	1	212	23	62	1 707	2 005
State Housing Commission	....	....	....	....	12	1	13
Swan River Conservation Board	....	....	....	....	....	728	728
Tender Board	....	....	....	89	....	....	89
W.A. Fire Brigades Board	....	....	4	....	....	....	4
W.A. Government Railways	....	....	1	....	....	....	1
W.A. Museum	....	....	....	....	2	....	2
COMMONWEALTH—							
Various Departments	6	....	5	....	1	....	12
PUBLIC—							
Free	....	....	....	1	50	....	51
Pay	91	106	671	101	466	441	1 876
TOTAL	13 810	249	6 195	243	3 549	6 112	30 158

The total numbers shown in Table 1 is less than that given in the sum of the various Divisions given in their individual reports, as in many cases samples are allocated to more than one Division but are only registered once within the Laboratories. This is because samples and problems presented to us do not always clearly define themselves within the ability and experience of specialists within any one Division or in many cases within the scientific discipline of chemistry, mineralogy or physics the basic sciences of the professional staff.

The number of samples received gives 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 with 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 summarised reports of the individual Divisions which follow, emphasise the range of subjects dealt with by the Laboratories. They also show their increasing involvement in ecological, environmental and consumer protection matters in addition to the more traditional subjects. As a consequence of this, officers of the Laboratories are making a fuller professional contribution to these fields rather than purely a service one of supplying analytical data. The greater involvement by staff in the entire problem presented to us and the direct contribution they are making is resulting in far greater job satisfaction besides providing a more valuable and useful scientific service to the State.

R. C. GORMAN,
Director.

AGRICULTURE DIVISION

Staff

Mr. Jago was appointed Chief of Division in June after continuing to act in that capacity for the first part of the year. The Division, because of various acting positions and leave, was compelled to operate for the whole year with one senior staff position vacant and for five months below strength by two senior officers.

A Level 1 position created at the end of 1973 was filled in February. However, the overall staff position remained unsatisfactory and unable to cope with the increase in quantity and variety of work received. The curtailment of research work noted in the 1973 report was, of necessity, continued in 1974, apart from the most essential investigations such as commissioning of new equipment and introduction of methods relating to completely novel work. It is important that this situation be corrected by provision of extra staff as soon as possible.

Staff members have adapted readily to the system of flexible working hours which was introduced for a trial period.

Professional

Mr. Jago completed his term as President, W.A. Branch of the Australian Society of Soil Science in May. He attended a symposium on "Sulphur in Australasian Agriculture" in Canberra and the Australian Soil Science Conference in Melbourne in February-March.

Mr. Rowley attended the centenary celebrations of the Society for Analytical Chemistry while in London.

Mr. Codling joined the committee of the Analytical Group (W.A. Branch) of the Royal Australian Chemical Institute.

Mr. Williams joined the committee (W.A. Branch) of the Australian Society of Soil Science.

Equipment

A Technicon dual channel flame photometer, compatible with existing Auto Analyser equipment was received. We are again indebted to the Commonwealth Extension Services' Grant for provision of funds to purchase this equipment.

Other major items of equipment received were a Dynavac freeze drier with heated chamber accessory, and a Varian Techtron Model AA6 atomic absorption spectrophotometer with a carbon rod atomiser Model CRA 63.

Amino Acid Analyser. The Beckman Model 118 instrument received in 1973 was commissioned during 1974. The range of components in mixed feeds awaiting analysis has necessitated development work on sample preparation and extensive calibration procedures. Seventeen amino acids are presently determined automatically on each sample. Tryptophan is not determined since it requires a separate alkaline hydrolysis of the sample. A spectrophotometric method for the determination of tryptophan is being investigated.

Nature of Samples

Table 2 shows the sources, types and numbers of samples received during the year.

TABLE 2

AGRICULTURE DIVISION

	Agriculture Department	Environmental Protection	Public—Pay	Public Health Department	Other	Total
Animal—						
Blood	78	....	....	....	....	78
Liver	69	....	....	....	....	69
Minced meat	336	....	1	....	2	339
Pig excreta	36	....	....	....	....	36
Tissue	178	....	2	....	....	180
Urine	50	....	....	....	....	50
Various	9	....	....	....	....	9
Cereal—						
Barley	43	....	4	....	....	47
Oats	310	....	2	....	....	312
Wheat	939	....	....	....	....	939
Fertiliser—						
Fertiliser	17	....	....	....	....	17
Fertiliser Act	116	....	....	....	....	116
Horticulture—						
Apple tree parts	923	....	....	....	....	923
Bean leaves	40	....	....	....	....	40
Cabbage leaves	165	....	....	....	....	165
Citrus	43	....	....	....	....	43
Peach leaves	32	....	....	....	....	32
Pine leaves	15	....	....	....	1	16
Vine leaves	202	....	....	....	....	202
Various	20	....	....	....	....	20
Miscellaneous—						
Filter paper	....	....	....	140	....	140
Human viscera	....	....	....	58	....	58
Rapeseed	22	....	....	....	....	22
Weeds	96	....	....	....	....	96
Various	12	....	31	2	7	52
Pasture and Fodder—						
Clover	594	....	....	....	....	594
Feed residue	18	....	....	....	....	18
Feeding stuffs	177	....	19	....	6	202
Feeding Stuffs Act	134	....	....	....	....	134
Grass	204	....	....	....	....	204
Hay	584	....	1	....	....	585
Kikuyu	52	....	....	....	....	52
Lucerne	314	....	2	....	....	316
Lupins	934	....	6	....	....	940
Native vegetation	160	....	....	....	....	160
Pangola grass	60	....	....	....	....	60
Pasture	4 204	....	4	....	....	4 208
Pig feed	26	....	....	....	....	26
Silage	60	....	....	....	....	60
Stubble	24	....	....	....	....	24
Various	5	....	17	....	5	27
Soil—						
Soil	2 198	30	24	....	....	2 252
	13 499	30	113	200	21	13 863

Thirteen thousand, eight hundred and sixty-three samples were received. This was a large and unexpected increase, being 6 513 more than in 1973 and well above the average receivals (7 300) for the previous five years 1969 to 1973. The Division was unable to cope with this influx of samples and at the end of the year 7 286 samples remained to be dealt with compared with 2 864 at the end of 1973. This back log of work remained despite a sample output almost 30 per cent over the number of samples dealt with in the previous year. This very creditable achievement was mainly due to a continuation of an excellent work effort by all members of the Division.

The increase in receivals, compared with 1973, was almost entirely due to increased activity by the Department of Agriculture in the evaluation of the quality of animal feeding stuffs. Pasture and fodder samples numbered 7 610 compared with 2 202 the previous year. Notable among these was a more than tenfold increase in the number of samples of lupin plants. There was a decrease in number of citrus leaf samples but this was more than countered by a large increase in the numbers of apple tree parts received. Fewer samples of native vegetation from air pollution work, was compensated for by an increase in samples of filter paper from air pollution monitoring by the Department of Public

Health. The number of soil samples received from the Department of Agriculture was double that of last year.

Soils

Two thousand, two hundred and fifty-two samples were received.

Soil Testing

Potassium

(a) Work on calibration trials, commenced in 1972 to evaluate the potassium status of soils in the South-West supporting clover based pastures, continued. Chemical work on 157 samples received in 1973 and on 112 samples received in 1974 from the third and final year of the trials was completed. Each sample was analysed for 25 parameters including: total, organic, exchangeable, extractable and water soluble potassium; total, exchangeable and water soluble calcium, magnesium and sodium; extractable aluminium, iron and manganese. Statistical analysis of the data by the Department of Agriculture computer is awaiting further analyses of samples of pasture components harvested from selected plots of the trials.

(b) 0.5 M Sodium Bicarbonate Extractable Potassium. The use of this soil test in assisting district advisers to make recommendations for potassium fertiliser dressings was demonstrated on samples submitted from the dairying districts of the State. One hundred and twenty-two samples were collected by advisers in January and February and analyses were reported in March. Half of the samples tested were potassium deficient (less than 80 p.p.m. extractable K). One quarter had adequate potassium (greater than 160 p.p.m. extractable K) and the remainder (90-160 p.p.m. K) were classed as intermediate. Lighter textured soils were generally lower in K status than heavier loams and clays. A conclusion of interest was that potassium fertiliser history may not always be a valid basis for making fertiliser recommendations.

The test was used to estimate the potassium status of 85 soils from other sources.

Iron

Some sites in the potassium status calibration trials described above produced clover with symptoms of iron deficiency. Further investigation of the simple soil test for iron deficiency reported in last year's Annual Report, showed promising correlation with symptoms observed in the field. The results indicated that iron deficiency could be expected when the iron extracted by shaking overnight with 1 M ammonium acetate at pH 4.8 was below 1.5 to 2 p.p.m. of the soil. Table 3 illustrates this correlation.

TABLE 3

IRON DEFICIENCY IN CLOVER
AMMONIUM ACETATE EXTRACTABLEE
SOIL IRON

Iron, Fe	Visual Symptoms		
	severe	mild	none
p.p.m.	number of sites		
0-1·0	8	nil	nil
1·1-2·0	3	2	2
2·0-10·0	nil	nil	7
over 10	nil	nil	10

The mean value of extractable iron from sites with deficiency symptoms was 0.8 p.p.m., and without symptoms 19.5 p.p.m.

Phosphorus

The sodium bicarbonate test (0.5 M, pH 8.5) for phosphorus has continued to be of assistance in predicting requirements of fertiliser phosphorus for pastures.

The test was also extended to evaluation of the fertility of soils at Kununurra. One hundred and eight samples taken across the slope of irrigated cotton plots (channel, centre, drain) were analysed for total and extractable phosphorus. There was no indication of vertical or lateral leaching of phosphate at 0-15 or 15-30 cm depths. The critical limit of soil phosphorus for cotton appeared to be associated with a sodium bicarbonate extractable figure of 15 p.p.m. P.

Analysis of 465 samples of soils was commenced as part of a study aimed at incorporating a phosphate sorption parameter (Ozanne and Shaw (1967) A.J. Agric. Res., 18, 601) as an adjunct to the rapid bicarbonate test for extractable soil P in predicting superphosphate requirements.

Nitrogen

(a) Nitrate. In connection with a study of nitrogen fertiliser usage on pastures, the changes in soil nitrogen fractions under established pasture were followed by sampling throughout the year, of an experiment in the Armadale district. The soils had previously been treated with ammonium nitrate at rates of 0, 25, 50 and 100 kg N per ha. Samples were taken initially at weekly intervals, commencing immediately after the first rains and continuing for a period of six weeks. Subsequent samples were taken at monthly intervals.

Analysis of a total of 404 samples was carried out on freshly extracted soil, to avoid changes in the nitrogen fractions which might have been induced by drying.

Soils were extracted with 1 M potassium chloride, and ammonia determined by the indophenol blue method. Nitrate was determined by U-V spectrophotometry directly on the extract. Incubatable nitrogen was determined by measurement of ammonia before and after anaerobic incubation.

Results showed that nitrate nitrogen was rapidly lost from the plant root zone in the first three weeks, during which 86 mm of rain was recorded. Ammonium nitrogen was retained for about one week longer. Analyses of pasture samples to measure the amounts of total and nitrate nitrogen taken up by the various components of the pasture are not yet complete.

(b) Total. Three hundred and forty samples of top soils from sites under wheat in three areas centred on Merredin, Three Springs-Morawa,or Narrogin were analysed for total nitrogen. No relationship was evident between soil nitrogen and wheat grain protein particularly in the Three Springs-Morawa region. However, the survey revealed that while low protein biscuit wheats could be grown on a range of soil types under higher rainfall conditions, certain soils would not grow them in low rainfall regions.

Trace Elements

Forty-eight samples were analysed for copper in continuation of a long-term experiment at Newdegate investigating the residual effectiveness of copper fertiliser dressings on wheat yields. Previous work was reported fully in 1973. The 1974 results indicated that no response to copper would be obtained on the Newdegate soil if copper extracted by 0.2 M ammonium oxalate was greater than 2.0 p.p.m. of the soil. As reported in the Annual Report for 1973, 0.1 M hydrochloric acid extracted from 70 to 90 per cent of the copper extracted by ammonium oxalate solution, which in turn extracted from 10 to 70 per cent of the total copper in the soil.

Other samples from research stations or farmers properties were analysed for aluminium, manganese and zinc, extracted by various reagents such as EDTA, ammonium acetate, ammonium carbonate—EDTA or potassium chloride.

pH Measurements

The measurement of soil pH in a 1 : 5 soil : water suspension is common practice in Australia and is used by this Division. Some workers and organisations, particularly in other countries, use electrolyte solutions such as potassium chloride, calcium chloride or sodium nitrate at various soil: solution ratios, in order to minimise salinity and suspension effects. These effects were examined in 17 Western Australian soils having a range of pH values (5.3 to 9.0) and salinities (0.01 to 2.22 per cent sodium chloride).

The results confirmed the effects reported in the literature that pH measured in electrolyte solutions is lower than in water and that the measured pH decreases as the concentration of neutral salts

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in the suspension increases. This salt effect was most noticeable in a group of acid soils. The results also showed that there is no justification for changing the existing practice, except for saline alkaline soils where an electrolyte solution could replace water with advantage. It is considered that correction for the suspension effect is too tedious for most work and, in the soils examined, the effect was small enough to be ignored.

Other

Apart from the customary analyses for monitoring of fertility in long-term trials, some unusual work included:

(a) the analysis of four soils from Libya in order to provide basic data for planning of an experimental programme in which the Department of Agriculture is participating;

(b) determination of the alkalinity of samples of red mud and soil filling from a disposal "lake" near Kwinana at the request of the Department of Environmental Protection;

(c) analysis of soils from the Kalgoorlie district for salinity and nutrients in relation to establishment and persistence of native pasture species.

Fertilisers Act

One hundred and sixteen samples of fertilisers were received, 38 fewer than in 1973. Certificates of Analysis were issued for 115 samples examined including 35 brought forward from 1973. Deficiencies were found in 52 (45 per cent) of the samples examined. The number of individual deficiencies (86) was, as usual in recent years, found mainly in products intended for home gardeners.

Potassium was deficient in 20 cases, nitrogen in 14, copper in 12 and phosphorus in nine.

Feeding Stuffs Act

One hundred and thirty-four samples were received. Certificates of Analysis were issued for 116 samples, 38 of which were brought forward from 1973. Excesses or deficiencies were found in 102 (88 per cent) of the samples examined. Deficiencies were due to crude protein (31 cases), sodium chloride (22 cases), phosphorus (18 cases) and calcium (16 cases). Excesses were mainly due to phosphorus (28 cases), sodium chloride (27 cases), calcium (25 cases) and crude fat (24 cases).

Animal Tissues

(a) Total mercury was determined in 130 samples of porcine tissues in a continuation of the assessment of the effect of feeding whale products as protein supplements in pig rations. The results confirmed the trends shown in our Annual Report for 1973 and showed (Table 4) that addition to the standard ration of 4.5 per cent by weight of dried whale solubles (91 per cent crude protein, 2.2 p.p.m. mercury) or 1 per cent by weight of whalemeal (65 per cent crude protein, 7.7 p.p.m. mercury) resulted in the production of flesh which contained approximately 0.03 p.p.m. of mercury. This is the maximum concentration permitted by the National Health and Medical Research Council for foods other than fish.

TABLE 4

TOTAL MERCURY IN PIG TISSUE

Ration	Standard (no whale product)	plus 4·5% whale solubles	plus 1% whalemeal
	Mercury, Hg, parts per million as received		
Kidney	less than 0·02	0·13	0·05
Liver	less than 0·02	0·07	....
Muscle	less than 0·02	0·03	0·02
Fat	less than 0·02	less than 0·02	....

Samples of flesh from a group of animals which had received 5 per cent of dried whale solubles in the ration contained 0.08 p.p.m. mercury, slightly above the limit, but well below the allowance for fish (0.5 p.p.m.).

In order to limit the uptake of mercury by stock from these feed supplements it seems necessary to restrict the amount which may be added to rations to such an extent that manufacturers would find it an unattractive proposition to use these materials.

(b) The removal of mercury from fish protein concentrates by chemical methods has been successful overseas and in Victoria. One successful method is an extraction of the material with acidified isopropanol. This was applied on a laboratory scale to whalemeal and fresh whale meat. Results of extraction with isopropanol acidified with 16 per cent of hydrochloric acid are shown in Table 5.

TABLE 5

REMOVAL OF MERCURY FROM WHALE PRODUCTS

	Whalemeal	Whale meat fresh	Whale meat dried at 105° C
	Mercury, Hg, parts per million		
Before extraction	7·3	2·0	2·0
After extraction .... (16% HCl–Isopropanol)	6·7	0·7	1·5
		per cent	
Mercury removed	8	65	25

The method was ineffective for whalemeal but was reasonably successful for the fresh meat. The inhibiting effect of drying the meat at 105° C on the subsequent removal of mercury may explain the ineffectiveness of the extractant in removing mercury from whalemeal since the manufacture of this product involves steam digestion and drying in a hot air stream.

(c) Minced lamb carcasses were examined in relation to a series of trials aimed at prediction of body composition for marketing purposes, from measurements made on the live animal.

Chemical composition of the carcasses, in terms of moisture, ash, crude protein and crude fat content was obtained by analysis of 336 samples. The correlation of these values with measurements of fasted live weight and tritiated water space by officers of the Sheep & Wool Branch, Department of Agriculture was good, although different to that of other workers who used analysed samples of whole sheep rather than a commercially prepared carcass.

(d) Other samples examined included blood for selenium content from ewes in an investigation of reproductive wastage in clover areas of the State. Values of selenium ranged from 0.02 to 0.29 milligrams per litre.

Cobalt and copper were determined in bovine livers in a survey of the status of these elements in the nutrition of stock in the South-West.

Urine samples were examined for fluoride content as part of a study of the effects of feeding rock phosphate supplements to pigs.

Minced meat prepared from bone scrapings was checked for calcium content as an indication of the amount of bone included.

An unusual request was for the analysis of brains of two calves in order to obtain "normal" levels of a number of elements. The results, together with the results for the livers of each animal are shown in Table 6.

TABLE 6

ANALYSIS OF BRAIN AND LIVER OF TWO CALVES

Sample	Brain		Liver	
Animal	1	2		2
	parts per million dry basis			
Calcium	1080	2 220	440	450
Magnesium	780	780	530	740
Cobalt	0·03	0·04	0·08	0·10
Copper	10	12	400	550
Iron	190	94	900	370
Manganese	1·4	1·5	8·1	5·3
Zinc	70	68	120	210

Human Tissues

Determination of selenium for the Department of Public Health in specimens relating to the investigation of the cot death syndrome, was continued. Five specimens of biopsy tissue from metal implant problems were analysed to determine the nature and quantity of metals present in the region of the implants.

Pasture, Hay and Fodder Crops

(a) Analysis of pasture, hay and fodder crop samples occupied a large part of the Division's facilities for automatic analysis. In previous years this work was confined mainly to nitrogen, phosphorus and potassium determinations. In 1974 more staff were involved with this type of sample following requests for extension of the analyses to include calcium, magnesium and sodium determinations.

The sodium analyses were requested after reports that, in the Eastern States, responses to sodium supplements in the diet of animals grazing on kikuyu had led to increased milk yields in dairy cows and weight gains in steers. The suggested critical level in pasture feed was 0.25 per cent sodium, on a dry basis. The survey of feeds in 1974 showed that sodium content varied widely below and above the suggested critical level, and will need evaluation in conjunction with the levels of sodium in stock waters in the areas covered by the survey.

Sodium levels in samples of irrigated pangola, kikuyu and paspalum grass which had received up to 800 kg N per ha as ammonium nitrate showed some unexpected results. Kikuyu is usually considered to have a high potassium and a low sodium content, to the extent that a sodium supplement may be required by cattle feeding on this grass. Contrary to expectations, sodium levels in the kikuyu samples ranged from 0.8 per cent without ammonium nitrate to 1.18 per cent with fertiliser. On the other hand, sodium levels in paspalum remained fairly constant at about 0.4 per cent, and for pangola grass levels fell from 0.4 per cent with no fertiliser to 0.3 per cent for 400 kg N per ha and even further for 600 and 800 kg N per ha, to 0.14 and 0.18 per cent respectively, well below the critical level mentioned above. Some of the irrigation water used in the experiment was from Wellington dam and a check on the randomisation of the treatments with respect to the source of water is to be made as a result of sodium analyses obtained.

(b) Most of the other work in relation to pasture evaluation was in connection with studies of cutting, baling and storage of hay on Research Stations or analysis of clover, lucerne or grass pastures from individual farmer's properties as part of an extension service designed to inform farmers by practical demonstration, of best methods for improving yields and quality of pastures and hay. Samples of native plants mainly from northern pastoral districts were tested for nitrogen, ash and chloride content.

(c) Lupin seed production is already an important part of the State's agriculture and increasing farmer interest and research activity was indicated by the large number of samples received in 1974. Most of these awaited analysis at the end of the year, mainly for manganese content in relation to the study of the problem of split seeds.

Measurement of crude protein in 119 seed samples was from an experiment with inoculation techniques. The most significant result was a marked increase in protein content of Unicrop seed with inoculation either with gum slurry or lime pelleting (33 per cent crude protein), compared with 27 per cent for controls.

(d) Silage. The use of formic acid in silage production is reported to preserve carbohydrate and protein from conversion to lactic acid. However, acetic acid may increase at the same time, an undesirable side effect.

Comparison of dry matter, pH, crude protein and volatile fatty acids content for two batches of silage from dairying areas, in which formic acid treatment was compared with conventional methods of preparation is shown in Table 7. Apart from a marked reduction in lactic acid content the formic acid treatment produced little effect. There was no increase in acetic acid content.

TABLE 7
EFFECT OF FORMIC ACID ON SILAGE COMPOSITION

(Means of 3 replicates of each treatment)

Treatment	Batch 1 Conventional	Batch 1 Formic acid	Batch 2 Conventional	Batch 2 Formic acid
pH	3·9	3·9	4·8	4·5
	per cent as received			
Dry matter	20·8	22·9	19·3	20·6
	per cent dry basis			
Crude protein	11·8	11·2	12·9	12·8
Acetic acid	2·8	2·2	0·8	0·4
Lactic acid	8·2	4·6	3·4	2·2

Lactic acid was determined colorimetrically with p-hydroxy diphenyl following reduction by sulphuric acid to acetaldehyde after the procedures of Barker & Summerson (1941) J. Biol. Chem. 138, 535 and Pennington & Sutherland (1956) Biochem. J. 63, 353.

Gas chromatography was used for the determination of the other volatile fatty acids. An internal standard, isovaleric acid, was added to aqueous extracts of the silage samples and 5 per cent formic acid was used to reduce tailing and ghosting. A Packard chromatograph coupled to an Infotronics CRS-208 automatic digital integrator was used.

(e) Other. A range of materials analysed for feed value included meatmeal, whale products, peanut kernels, peanut shells, peanut hay and dock root.

Dock root (Rumex spp.) had the following composition:

	per cent as received
Moisture	7.1
Ash	1.6
Crude protein (N x 6.25)	9.4
Crude fat	3.5
Crude fibre	1.0
Nitrogen free extractives	77.4

Numerous mixed feeds were checked for quality in relation to nutritional disorders in livestock including leg weakness in poultry and posterior paresis in pigs which may involve calcium : phosphorus ratio imbalance. The practice of substituting lupin meal for meatmeal as a protein source required checks on the calcium content of feeds.

Cereals

Effects of soil fumigation on yield and quality of wheat were investigated at Wongan Hills Research Station. Soil samples from the experiment analysed in 1973 showed an increase in ammonia nitrogen in samples taken soon after the fumigation treatments, but no effects on nitrate nitrogen were apparent. Grain samples from the experiment showed very marked benefit from fumigation in terms of nitrogen content, as shown in Table 8.

TABLE 8.
SOIL FUMIGATION AND WHEAT GRAIN NITROGEN

Treatment	Mean Nitrogen Level per cent dry basis
Nil	2·14
Fungafume 400 kg/ha	2·73

A large number of samples of wheat and oat plants were analysed as part of investigations of:

(a) effect of seeding rates on grain protein,

(b) uptake of nitrogen from different rates of urea,

(c) uptake of nitrogen from urea and effect of cutting and grazing of cereals for hay production,

(d) effect on nitrogen uptake of the time of application of ammonium nitrate,

(e) residual value of copper fertiliser for cereal production,

(f) reduced yields of wheat on soils treated annually for 10 years with high rates of sulphate of ammonia.

Other samples were analysed to provide information on quality of grain used in experimental rations; certificates of analysis were issued for export shipments of wheat and barley; samples of Standard Oats were analysed for the Grain Pool.

Horticulture

Apple Trees

Chemical composition of leaves from Granny Smith apple trees from an experiment at Stoneville Research Station showed some interesting effects of fertiliser placement and irrigation practice. Fertiliser mixture (N, P and K with or without trace elements Cu, Mn and Zn) was placed either below the tree or on the surface of the soil around the tree in a single application of 1 500 g per tree or three split applications of 500g. Flood irrigation was applied at either frequent or infrequent intervals. Under the latter treatment the soil dried out intermittently.

Results of analysis of leaves sampled in March showed marked differences in nutrient content.

Frequent irrigation produced:

(a) higher levels of leaf potassium than infrequent watering and this was most pronounced for above ground applications of fertiliser;

(b) higher levels of phosphorus, but only for split surface application of fertiliser;

(c) lower levels of magnesium for all methods of application of the fertiliser.

Surface applications of fertiliser produced:

(a) higher levels of nitrogen than below ground treatment;

(b) higher phosphorus levels, especially for the split dressings.

Levels of trace elements were not affected by the method of watering but methods of application produced:

(a) slightly higher levels of copper from 15 g copper sulphate per tree applied to the surface in a single dressing;

(b) a five-fold increase in zinc from 40 g of zinc sulphate applied to the surface compared with a two-fold increase if placed below the tree;

(c) a two-fold increase in manganese from 65 g of manganese sulphate for each method of application.

Unusually high levels of manganese in the leaves (700 p.p.m.) appeared to be related to planting of the trees in a peat-soil mixture, and approached toxic levels which may have complicated the responses to fertilisers.

Analysis of leaves sampled in May showed almost identical effects of fertiliser treatment on levels of nitrogen, phosphorus, copper, manganese and zinc. The effect of the irrigation treatments, which were continued into April, were still evident with respect to potassium, in that leaves from the trees receiving frequent watering were higher in potassium than the others, and there was no difference in leaf potassium due to method of application of the fertiliser. On the other hand, the infrequent watering gave a markedly lower level of potassium in the leaves, and below ground placement of the fertiliser gave a higher level of leaf potassium than surface applications.

Zinc Nutrition

Study of the translocation in apple trees of zinc applied as a foliar spray necessitates removal of spray residues from samples of leaf material before chemical analysis. Two procedures for washing of leaves were compared:

(a) Agitated: Fifty leaves of sub-sample were agitated together for 10 sec. in a dilute acid-detergent solution, followed by rinsing for 10 sec. in tap water and 10 sec. in distilled water.

(b) Scrubbed: Fifty leaves of another sub-sample were scrubbed individually followed by the rinsing steps.

Both methods were effective in removing zinc, as shown in Table 9 and it was obvious that the additional work involved in the scrubbing method was not necessary.

TABLE 9.
WASHING OF APPLE LEAVES

	Unwashed	Agitated	Scrubbed
		Zinc, Zn	
		parts per mullion	
		dry basis	
Range	120–360	90–210	80–210
Mean	270	170	160

The results of the washing experiment indicated that zinc was absorbed by the leaves. However, sprayed trees can develop zinc deficiency symptoms in the following year and this would not be expected at the high levels of zinc in the leaves shown in Table 9. It is apparent that the level of zinc in washed leaves is not a measure of the zinc status of the tree as a whole, because either the washing does not remove all the spray residue or the zinc is fixed in the leaf tissue and unavailable for translocation within the tree. For subsequent experiments on translocation of zinc, shoots were sealed in polythene bags, if in the leaf stage, or in aluminium pipe if dormant, during spraying operations, to provide unsprayed leaf material for sampling later in the season.

Leaf samples were obtained in this way from a trial to compare methods of improving zinc uptake by Granny Smith and Yates varieties. The only effective method was a foliage spray in spring as shown in Table 10.

TABLE 10.
ZINC UPTAKE BY APPLE TREES

Treatment	Granny Smith	Yates
	Zinc, Zn parts per million dry basis	
Spring spray	23	20
Dormancy spray	13	13
Dormancy spray (covered)	15	18
Autumn spray	13	14
Soil application	14	15
Control	12	14

Other work included

(i) analysis of 180 samples from trees which had been fertilised with a N, P, K and trace element mixture, and separated into leaves, new and old shoots, stumps, large roots and fine roots for analysis of N, P, K, Cu, Mn and Zn. Results showed a large uptake of manganese and zinc but not of copper, for all portions of the trees.

(ii) determination of N, P, K, Ca, Mg, Cu, Mn and Zn in 333 samples of leaves from fertiliser experiments at Manjimup to examine responses in terms of leaf nutrient levels to fertiliser practices. Chemical analysis showed:

(a) N fertiliser produced increases in leaf nitrogen.

(b) K fertiliser produced increases in leaf potassium.

(c) P fertiliser had no effect on leaf phosphorus.

(d) lime fertiliser had no effect on calcium, manganese or zinc in the leaf.

(e) fertilisers produced no changes in calcium, magnesium or trace elements in the leaves.

(f) zinc levels in leaves from two experiments were below 10 p.p.m. suggesting a situation of incipient deficiency.

(iii) analysis of 215 leaf samples for N, P, K, Ca, Mg, Cu, Mn an Zn from experiments at Stoneville and Manjimup to follow effects of cultivation methods and fertiliser usage.

Other

Analysis of grapefruit leaves from Kununurra indicated deficiencies of copper, molybdenum, zinc and possibly boron and manganese. Copper and zinc deficiencies were evident in samples from Carnarvon.

Orange leaves from trials at Stoneville Research Station were analysed for zinc to assess its uptake from applications of zinc sulphate sprays.

Peach and pear leaf samples from growers' properties in the Manjimup area were analysed to assist in diagnosis of causes of poor growth.

Viticulture

Leaves from Grenache and Pedro varieties of grapevines at Muchea which have suffered from a temporary leaf necrosis each year were analysed in an attempt to define the problem as either nutritional or due to virus disease or mite damage. There were very marked differences between the phosphorus, potassium and sodium contents of leaf blades from healthy and affected vines (Table 11) and, in addition, leaf petioles showed large differences in magnesium content. Whether the nutrient imbalances are the cause or the effect of the disorder has not been resolved.

TABLE 11.
NUTRIENTS IN GRAPEVINE LEAF BLADES

	Grenache		Pedro	
	healthy	affected	healthy	affected
		per cent dry basis		
Phosphorus, P	0·40	0·15	0·30	0·11
Potassium, K	1·02	0·77	1·44	0·92
Sodium, Na	0·03	0·10	0·04	0·09

Leaf analysis was of no assistance in diagnosis of a suspected deficiency of potassium in vines at a property in Wanneroo.

Oilseeds

Thirty-six samples of safflower seeds from a variety trial in the Ord River irrigation area were analysed for oil and protein. Rapeseed samples from the breeding programme at Mt. Barker were analysed for oil and fatty acid composition and the results were used in calibration of the Department of Agriculture's instrument for determination of oil content of seeds by nuclear magnetic resonance.

Vegetables

Carrot tops harvested at the end of a rates of fertiliser x frequency of application experiment were analysed for N, P, K, Ca, Mg, Na and Cl. Treatments were combinations of three rates each of sulphate of ammonia, superphosphate and potassium chloride, the same total amount of fertiliser mixture being applied at frequencies of every 3½, 7, 14 or 28 days.

Condensed results are shown in Table 12 and show the very wide ranges of concentrations of the nutrients in the tops induced by the fertiliser treatments. Values in tops from control (nil) treatments, the range with the fertiliser treatments, and values reported in leaves from a recent overseas experiment (Bishop et al) are shown for comparison.

TABLE 12.
ANALYSIS OF CARROT TOPS

	Control	Range	Bishop et al*
		per cent dry basis	
Nitrogen, N	1·8	1·2 –1·9	2·9
Phosphorus, P	0·46	0·14–0·61	0·24
Potassium, K	3·1	0·31–5·4	4·8
Calcium, Ca	3·2	1·6 –3·3	1·6
Magnesium, Mg	0·32	0·10–0·32	0·6
Sodium, Na	0·68	0·25–3·0	....
Chloride, Cl	1·9	1·7 –3·1	....

* R. F. Bishop et al, (1973) Comm. in Soil Science and Plant Analysis, 4(6), 467.

The most marked effects of the fertilisers on concentration of elements in the tops were:

(a) Sulphate of ammonia alone increased Cl, markedly increased Na, markedly decreased K and caused decreases in P and Mg.

(b) Superphosphate alone increased P and decreased Cl. In the presence of sulphate of ammonia, superphosphate decreased values for Ca, Mg, N and P. In the presence of both sulphate of ammonia and potassium chloride P was increased but Ca and K decreased.

(c) Potassium chloride alone increased K but decreased Mg and Na. Applied with sulphate of ammonia, potassium levels were increased but Mg, Na, N and P were decreased. In combination with superphosphate, potassium chloride increased K and Cl and decreased Mg and Na. The three fertilisers applied together increased K, but decreased Mg, Na, N and P.

(d) As K content increased from 0.3 per cent (N + P fertiliser) to 4.5 per cent (high K fertiliser rate), the corresponding concentrations of Na decreased from 3.0 per cent to 0.25 per cent.

(e) Mg concentrations fell from 0.3 per cent in tops from control samples to 0.1 per cent in tops from plants receiving the three fertilisers together. A curious effect was the increase in chloride content in the presence of sulphate of ammonia fertiliser. Yield data have not been examined, but the chemical analyses indicate that potassium and possibly magnesium were limiting nutrients.

Other

Samples of cauliflower leaves were analysed to assist in diagnosis of a leaf scorch problem but no clear picture was gained, except that leaves with severe scorch had high nitrogen content.

Bean leaves from an irrigation and soil amelioration experiment at Gascoyne Research Station were examined to assist in comparing results of flood irrigation and low sprinkling rates. Leaf composition was not affected by the method of applying water, although irrigation lowered chloride content.

Air Pollution

Filter papers, clay and leaves from a variety of vegetation were analysed for fluoride in continuation of the monitoring of emissions from brickworks, in collaboration with the Public Health Department and the Department of Agriculture.

Pine leaves and leaves of blackboy, banksia and eucalyptus were analysed for aluminium, chloride and sulphur in conclusion of the survey of air pollution in the Kwinana area.

Miscellaneous

A sample of seaweed extract claimed to have fertiliser value was shown to have no value at the rates of application advised by the producers.

Standard samples of plant material exchanged with laboratories in New South Wales and Queensland were analysed as part of a collaborative study of accuracy of methods of analysis.

Molasses was analysed for moisture and ash content following a complaint from a consumer that the product was below standard.

A sample of rock phosphate from Venezuela contained 2.2 per cent of fluoride.

ENGINEERING CHEMISTRY DIVISION

As in recent years, the main effort was directed to a limited number of projects, each of which required extensive investigational work. The demand from industry for the undertaking of test programmes continued to be satisfied and progress was maintained on Departmental projects, which were selected because of significant current or long term interest to the State.

Staff and General

For much of the year, Divisional output suffered due to the absence of key personnel.

Senior Chemist and Research Officer Mr. L. Brennan was appointed to the Pilbara Study Group from February until late June and then again from September 10th 1974 until April 1975 has been seconded to the Department of Environmental Protection to act as Ecology Officer for the Jumbo Steel Plant Feasibility Study.

Chemist and Research Officer, Mr. R. Marshall departed in mid August to undertake a 12 month post-graduate course in Mineral Process Design at the University of London, and will resume duty late in 1975.

The vacancy that had been created by the resignation of a Research Officer late in 1973 remained unfilled until December of 1974 when Dr. W. R. Fitzgerald commenced duty.

Messrs. R. Couche and K. Henrick were appointed to fill temporary professional vacancies late in the year.

Mr. L. Brennan continued to serve as a member of the Scientific Advisory Committee as constituted under the Clean Air Act and was appointed to the newly formed Committee (under the direction of the Fuel and Power Commission) to study the gasification of Western Australian coals.

Mr. B. Goodheart assumed full member status on the Board of Management of the Australian Coal Industry Research Laboratories, late in the year and will continue as Western Australia's representative for a period of three years.

Chief of Division, Mr. B. Goodheart attended the Second National Chemical Engineering Conference, which was held in Queensland during July, and in association visited industrial plants and C.S.I.R.O. Research Groups in both Sydney and Melbourne.

Mr. L. Brennan attended the Conference conducted by the Institute of Fuel in Adelaide in November—the topic being "The Changing Technology of Fuel".

Equipment and Buildings

The submission made during 1973 for extensions to the main pilot plant building to assist preparation (crushing, classifying, pelletising, etc.) work has not yet materialised and pilot plant operations were handicapped accordingly. When completed, these extensions will also enable the installation of the pilot scale flotation circuit, which was transferred from another Division during the year.

The rotary kiln continues to be an important unit in many of the Division's projects, and special attention has been directed to upgrading the ancillary instrumental control system. A refined, more accurate, temperature sensing system has been incorporated and modifications made to the feed and sampling devices and provision made for both oil and gas firing of the kiln.

The small (15 cm × 25 cm) stainless steel reactor vessel, which has been fabricated to enable small scale simulation of rotary kiln processing, was commissioned during the year and effectively used in several projects.

A laboratory type flotation machine was acquired for mineral separation testwork. The unit is flexible and can be used for flotation, agitation and attrition.

The addition of a binocular microscope with zoom lens facility has assisted mineral identification work.

Investigational Projects

Utilisation of Western Australian Diatomites

Public interest in the potential utilisation of Western Australian diatomites was maintained during the year and the Departmental research project on this topic was advanced to the stage of preparation for pilot plant assessment. A major Australian Company, which has indicated an intention to erect a pilot plant in Western Australia for feasibility study purposes, has studied the research findings of the Division and considerable interaction has occurred.

Earlier experimental indications that local diatomites could be processed to products of similar quality to top grade imported materials have been verified. A laboratory pressure filtration test unit has been used to provide a direct comparative measure of the flowrate characteristics of both laboratory prepared test products and commercial samples.

The initial test programme indicated that wet processing was accompanied by dewatering difficulties and most effort has been directed towards developing a dry, pneumatic system for diatomite treatment. Special consideration must be given to the necessity for dispersion of the diatomite prior to separation and to recovery of the ultrafines exhausted from the classifying system.

Further calcination testwork has verified the need to achieve thorough pre-cleaning and presizing of the local diatomites to achieve maximum filter aid capacity of final products. The failure of several of the local samples to respond to treatment was largely due to the difficulty of removing contaminants that had particle settling velocities equivalent to that of the diatom frustules. Investigation suggested that part of this contamination was due to overburden, which had been introduced during sampling, and emphasised that it is likely that extremely selective mining techniques will need to be employed to avoid contamination when mining the relatively thin, lens shaped, lake bed deposits that are normal in Western Australia.

Physical parameters such as particle size distribution, air permeability and bulk density in addition to microscopic examination have been found to be useful guides to quality assessment for the preparation of high quality products. X-ray Diffraction scans of typical flux calcined products, prepared from local diatomites, have confirmed the preferred structural composition to be a minimum of 90 per cent of ordered cristobalite and a maximum of 2 per cent of quartz.

Full pilot scale processing trials based on rotary kiln calcination combined with pre and post treatment circuits will be carried out early in 1975. These tests will be aimed at confirming laboratory batch results and obtaining sufficient data to enable complete commercial process design and costings.

Copper Processing

The investigational programme aimed at assessing the potential application of hydrometallurgical extraction methods to copper processing with regard to Western Australian conditions was expanded during the year.

Work continued on the ethylenediaminetetraacetic acid (EDTA) leaching method for oxidised ores, and a new project was initiated to evaluate the acetonitrile-leach-recycle method in conjunction with the newly established Metals Research Group of Murdoch University.

Acetonitrile Processing

Development of this technique of processing copper (in a variety of forms) via cuprous sulphate in acetonitrile-water solutions had been originated by Professor A. J. Parker at the Australian National University. Professor Parker's appointment to Murdoch University provided a stimulus to further researching of these techniques for possible applications in Western Australia.

The chemistry of the process had been thoroughly defined and comprehensive theoretical appraisals made, but there had been little examination of chemical engineering aspects and minimal testwork done on a continuous operation basis or on scaling up to pilot plant level. The Engineering Chemistry Division has agreed to mount a joint study with Professor Parker's Group to examine these aspects with the overall aim of assessing the economic viability of these treatment methods under Western Australian conditions.

An initial period of familiarisation was necessary, but by the year's end, batch and continuous testing on the laboratory bench scale was well under way.

Basically the process involves the dissolution of copper in an acetonitrile-water mixture via the oxidation—reduction reaction $Cu^{\circ} + Cu^{2+} \rightarrow 2Cu^{+}$ where the reductant may be a range of copper types such as metal, mineral or scrap.

This reaction, which is unfavourable in water, is based upon the highly selective stabilisation of the cuprous ion in the presence of nitrile. This dissolution step is followed by filtration of insoluble impurities, copper recovery and final recycling of the mother liquor to dissolve further copper. Where the nitrile is volatile, distillation reverses the reaction to produce a pure copper powder.

Distillation costs can be high and optimisation of this part of the process will receive maximum attention in the research programme. The key to the total process is inherently tied to effective distillation of acetonitrile. Subsequent to this, effective leaching with the recycled solutions must be maintained as well as control of the build up of any impurities and of copper sulphate.

Promising leaching kinetics have been obtained in early trials and it is already evident that efficient leaching will depend on the following desirable process conditions:

(a) high nitrile concentration.
(b) high cupric ion concentration in feed liquor.
(c) low sulphuric acid concentration.
(d) Operating temperature of 60°C minimum (despite enhancement of hydrolysis of nitrile).

EDTA Processing

The majority of Western Australia's copper deposits are of modest size and occur in isolated areas. The need to define economically attractive and perhaps novel methods of treatment of copper from these deposits persists and work continued during the year to confirm the applicability of EDTA leaching.

Extraction of copper from oxidised ores from two areas—Peak Hill District (Thaduna deposit) and Yalgoo District (Warriedar deposit)—was investigated. Laboratory leaching trials determined the optimum leaching conditions, while a small batch recycling system was used to verify the stability of the EDTA anion through a wide range of conditions. After ten complete cycles little decrease in leaching efficiency was detected.

Methods for recovery of copper from the leach solutions were also investigated and a high purity copper oxide obtained when aldehydes were used as the reducing agent. Copper oxide of 84 per cent Cu purity was obtained in trials with glucose as the reductant.

A very generalized costing of the process has been made to assess economic viability.

The trials have shown that reagent cost rather than process chemistry is likely to be the most serious disadvantage of the process. Using a mole ratio of 1.5:1 EDTA-copper and assuming a 70 per cent extraction, the weight of EDTA required to extract one kilogram of copper is 9.9 kg. At current prices 8-9 cycles would be necessary from each mole of EDTA for economical leaching. The system has been proven over 10 cycles on a laboratory scale. Reagent losses during filtration, etc. would obviously have to be minimised.

A Report of Investigation, which details the investigational work carried out on this process, has been prepared for publication.

Beneficiation of Primary Iron Deposits

Western Australia is a major exporter of high grade iron ores of the hematite (mainly) and limonite types and these ores generally contain over 60 per cent Fe.

In addition vast occurrences of unenriched iron exist in the form of banded ironstone deposits. These deposits are similar to the taconites of the U.S.A. and Canada, which are being extensively mined and concentrated to furnish a large proportion of the iron requirements of these countries.

These unenriched iron formations of the Hamersley Range contain of the order of 30 per cent Fe in the raw state and the reserves have been conservatively estimated at 100 000 million tonnes. Such material, if readily amenable to concentrating processes could prove to be of significant long term potential both from the aspect of vastly increasing mineable reserves and also for blending with lower grade ores to enhance iron, phosphorus and other values. In conjunction with the Geological Survey, an investigation was undertaken to evaluate the broad prospects of beneficiation of the Hamersley Range banded iron material, with drill core samples from the Junction Gorge area providing the initial sample.

Testwork to date has defined that the degree of liberation necessary to produce a high grade concentrate requires size reduction down to the order of 50 microns. This restricts beneficiation methods to those applicable to sub sieve size materials such as magnetic separation and flotation.

Wet magnetic separation has been shown to be effective on a laboratory scale and capable of producing iron concentrates in the 66-69 per cent Fe range. The applicability of flotation methods is currently being evaluated along with further wet magnetic testing and comprehensive assessments of the product concentrates will be made.

Blast Furnace Reductants

A local Company, faced with the need to prove an alternative blast furnace burden material to satisfy increasing output requirements, commissioned the Division to investigate methods of processing a waste dump material as a possible source of reductant.

A comprehensive test programme examined the briquettability of the material under a range of conditions with various bonding agents. Work was continuing at the end of the year.

Gold Recovery

The renewed interest in the processing of low grade ore deposits and tailings materials for gold recovery was maintained during 1974 and the Division received many enquiries and undertook several investigations in this area.

Further trials were carried out in the gold recovery programme based on volatilisation processing which had begun in 1972. The Sponsor Company is anxious to proceed to commercial development and requested further continuous pilot plant trials in the search to confirm a reliable and economical recovery method. The most recent tests were carried out in conjunction with an international chemical engineering company, and for this trial specialised test equipment was integrated with the Division's rotary kiln.

A Divisional study of the chemistry of gold volatilisation processes has been initiated. In volatilisation processes, the metal is separated from the gangue by use of alkali or alkaline earth halides in a suitably designed furnace at temperatures high enough to form and vaporise the chlorides of the metal. In the case of gold the volatilised halides are involved in complex equilibria between $AuCl$ - $AuCl_3$ - Au_2Cl_6 - Au_2Cl_2 and Au metallic. The volatilised gold, which is sub micron in size, has long been recognised to be in a form not easily condensible. It is anticipated that the study of the chemistry of the process will assist in defining optimum treatment conditions of Western Australian type materials and verify suitable collection methods.

In response to another request, tests were carried out to examine the feasibility of recovery of both gold and arsenic from an ore deposit of the Yilgarn region.

Other Sponsored Work

Typical of the test programmes carried out during the year at the request of various mining and industrial companies and individuals—the results of which must remain confidential—are the following:

(i) At the request of a leading mining company, a pilot plant scale controlled roasting trial was carried out on several tonnes of uranium bearing ore.
(ii) Methods of producing a marketable oxide pigment by calcination of an upgrading process "by product" were investigated at the request of a Perth company.
(iii) An exploration company requested gravity separation trials to ascertain the efficiency of concentration of reconnaissance stream sediment samples.
(iv) Several requests for determination of physical properties of coals, chars and dusts

were satisfied. These included the determination of ignition temperature, ash characteristics and full proximate and ultimate analyses.

(v) Eighty-seven samples of a wide range of feeding materials—mainly agricultural stock foods—were analysed for calorific value and a variety of potential fuels (for example, sewage materials for incineration) were analysed for appropriate properties.

Consultative and Advisory

The Division continued its function of providing information on all matters relevant to its sphere of activities. Examples of such topics were energy conversions including coal gasification and pulverised coal firing; manufacture of calcium carbide from Western Australian raw materials; instrumental control of a rotary kiln for adaptation to the production unit of a local cement company; costings and feasibility of ilmenite upgrading processes.

A Senior Research Officer of the Division made two trips to a north-coastal salt harvesting and processing operation and spent several days assisting in an advisory capacity on pilot plant (Government Chemical Laboratories equipment) flotation trials aimed at recovery of a refined product.

Among the visitors to the Division during the year were:

Mr. C. Rodriguez—Metallurgical Consultant, California, U.S.A.

Mr. K. Sullivan—Senior Research Officer, Australian Coal Industry Research Laboratories, Sydney.

Dr. R. W. Killick—Development Manager, J. Kitchen Ltd., Port Melbourne.

Mr. T. Marshall—Deputy Director, Chemistry Division, Department of Scientific and Industrial Research, New Zealand.

Dr. R. A. Durie—Assistant Chief of C.S.I.R.O., Division of Mineral Chemistry, Sydney.

Mr. H. Kurita—Assistant Manager, Nichimen Co. Ltd., Tokyo, Japan.

Dr. G. Foyer—Research Consultant, Johannesburg, South Africa.

Mr. R. Galleon—Development Manager, Simon Carves Ltd., Sydney.

FOODS, DRUGS, TOXICOLOGY AND INDUSTRIAL HYGIENE DIVISION

As in recent years nearly eighty per cent of the analytical work of the Division was concerned with samples submitted by the Departments of Police, Public Health, Agriculture and Fisheries and Fauna. 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 forwarded through the Public Health Department, and are included in the figure of 1 374 samples from that Department.

Six thousand two hundred and ninety-one samples were received during 1974, a decrease of fifty on the number for 1973. This was due largely to the much smaller numbers of shark tissues analysed for mercury, and to the cessation of the W.A. Milk Board's programme of "legal" sampling at the end of February, 1974.

Table 13 shows the source and condensed description of samples received during 1974.

TABLE 13

FOODS, DRUGS, TOXICOLOGY AND INDUSTRIAL HYGIENE DIVISION

	Agriculture Department	Environmental Protection	Fisheries and Fauna Department	Hospitals	Labour Department	Metropolitan Water Board	Milk Board of W.A.	Mines Department	Pay—Public	Police Department	Public Health Department	Public Works Department	Western Australian Trotting Association	Other	Total
FOODS—															
Fish	....	....	38	....	....	....	....	....	....	....	280	....	....	....	318
Fruit Juice	24	....	....	....	....	....	....	....	....	....	67	....	....	....	91
Liquor	....	....	....	....	....	....	....	....	....	2	45	....	....	....	47
Meat	....	....	....	....	....	....	....	....	....	....	30	....	....	3	33
Milk	18	....	....	....	....	....	53	....	....	....	38	....	....	....	109
Oysters	....	....	....	....	....	....	....	....	....	....	39	....	....	....	39
Prawns	....	....	....	....	....	....	....	....	....	....	127	....	....	....	127
Rock lobster tails	....	....	....	....	....	....	....	....	....	....	103	....	....	....	103
Shark	....	....	....	....	....	....	....	....	....	....	155	....	....	....	155
Tripe	....	....	....	....	....	....	....	....	....	....	21	....	....	....	21
Vinegar	....	....	....	....	....	....	....	....	....	....	15	....	....	....	15
Various	....	....	6	....	4	....	....	....	4	....	133	....	....	3	150
INDUSTRIAL HYGIENE—															
Air	....	....	....	....	....	....	....	....	....	....	18	....	....	....	18
Inspections	....	....	....	....	....	....	....	....	....	....	16	....	....	....	16
Urine	....	....	....	....	130	....	....	3	84	....	52	....	....	1	270
Various	....	....	....	....	....	....	....	1	....	....	4	....	....	....	5
MISCELLANEOUS—															
Animal tissue	....	....	89	....	....	....	....	....	....	....	....	....	....	....	89
Bait	37	....	....	....	....	....	....	....	2	3	3	....	....	....	45
Benthic fauna	....	....	40	....	....	....	....	....	....	....	....	....	....	....	40
Criminal	....	....	....	....	....	....	....	....	....	156	....	....	....	....	156
Detergents	....	....	....	1	....	....	....	22	....	....	3	....	....	....	26
Drugs	....	....	....	6	....	....	....	....	....	230	....	....	....	....	236
Eggs	....	....	39	....	....	....	....	....	....	....	....	....	....	....	39
Fat	296	....	....	....	....	....	....	5	....	....	....	....	....	....	301
Filter	....	....	....	....	....	....	....	....	....	....	21	....	....	....	21
Fish tissue	....	....	186	....	....	....	....	....	....	....	....	....	....	....	186
Horse urine	....	....	....	....	....	....	....	....	1	....	....	....	296	....	297
Human Milk	....	....	....	1	....	....	....	....	....	....	52	....	....	....	53
Liquid	....	....	....	....	1	....	....	....	....	....	13	....	....	1	15
Lupins	40	....	....	....	....	....	....	....	....	....	....	....	....	....	40
Magpie tissue	....	....	57	....	....	....	....	....	....	....	....	....	....	....	57
Mussel tissue	....	....	10	....	....	....	....	....	....	....	....	....	....	....	10
Maritime pollution	....	....	....	....	....	....	....	....	....	23	....	....	....	....	23
Miscellaneous solutions	....	....	....	....	....	....	....	38	....	....	....	....	....	....	38
Pasture	52	....	....	....	....	....	....	....	....	....	....	....	....	....	52
Pesticides	10	....	....	....	....	....	....	....	10	....	8	3	....	....	31
Silt	....	....	....	....	....	....	....	....	....	....	....	68	....	....	68
Water	3	....	....	....	....	22	....	16	11	....	1	151	....	1	205
Whale specimens	....	....	....	....	....	....	....	....	....	....	14	....	....	....	14
Various	31	9	9	6	....	....	....	38	23	1	77	7	....	18	219
TOXICOLOGY—															
Animal	42	....	....	....	....	....	....	....	6	4	1	....	....	....	53
Human	....	....	....	10	....	....	....	....	....	1 078	....	....	....	....	1 088
Sobriety	....	....	....	....	....	....	....	....	189	583	1	....	....	....	773
Specimens from patients	....	....	....	57	....	....	....	....	50	....	37	....	....	1	145
Traffic death	....	....	....	....	....	....	....	....	....	454	....	....	....	....	454
TOTAL	553	9	474	81	135	22	53	123	380	2 534	1 374	229	296	28	6 291

The variation in the number of samples received during 1971-74 from the four Departments mentioned above is indicated in Table 14.

TABLE 14

Year	1971	1972	1973	1974
	No. of Samples			
Police Department	2 391	2 169	2 276	2 534
Public Health Department	798	973	1 825	1 374
Agriculture Department	985	737	604	553
Fisheries and Fauna Department	374	136	288	474
All other sources	1 270	1 266	1 348	1 356
Total	5 818	5 281	6 341	6 291

Foods

The number of samples of food received during the year was approximately 400 less than in 1973, but still higher than in any previous year.

The survey of sharks from around the coast of Western Australia was continued by the Departments of Public Health, and Fisheries and Fauna, and 155 samples of shark tissue were analysed for mercury content.

One hundred and ninety-four samples of local fish and 124 samples of imported fish were also analysed for mercury. Analyses for arsenic were carried out on 131 samples, while 33 samples were analysed for cadmium, 20 for lead and 19 for zinc.

Twenty samples of imported fish were received for identification of colouring matter, while 56 local fish products and 150 imported fish samples were analysed for total volatile bases as a measure of incipient deterioration.

Only fifty "legal" 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. These samples were submitted during January and February prior to the new Dairy Industry Act coming into operation.

It was found that 4 per cent of these "legal" samples contained less than the prescribed minimum (3.2 per cent) for fat content, 78 per cent contained less than the prescribed minimum (8.5 per cent) of solids not fat, and 80 per cent failed to comply with the standard for freezing point (0.54 degree C below zero). It is emphasised, however that these were legal samples taken by Inspectors because of *prima facie* evidence of non-compliance with prescribed standards.

Samples of bottled milk from country and metropolitan treatment plants were also analysed in a programme of regular monthly "screening" for organo-chlorine insecticide residues.

Investigations were continued by the Horticultural Division of the Department of Agriculture into the residues of ethylene dibromide following fumigation of citrus fruits, and 24 samples of lemon, orange and mandarin juice from experimental treatments were received and analysed for ethylene dibromide.

Fourteen samples of commercial orange juice were examined for compliance with Food and Drug Regulations; only three complied with requirements for orange juice content.

Of six samples of concentrate used for making commercial orange juice only two produced a product of satisfactory juice content, when diluted in accordance with instructions.

Other samples of orange concentrate and juice were examined for the presence of artificial colouring, and 42 samples of varied fruit juice cordials were analysed for the Public Health Department in a survey to establish the general level of juice content of such cordials.

Oysters received for sale on the local market were also investigated for "trace metal" content by the Public Health Department. Of imported samples, one was analysed for arsenic, eleven were examined for cadmium, nine for lead, fourteen for mercury, and eleven for zinc. Of Australian oysters, twelve were analysed for arsenic, thirty three for cadmium, thirteen for mercury, and thirty three for zinc. It was obvious that the zinc content of Australian oysters was related to the location of the oyster beds, and that the higher zinc concentrations were also associated with the higher levels of cadmium although the latter did not exceed the N.H.M.R.C. tentative maximum for cadmium in oysters.

Twenty-five samples of spirits were received for analysis for alcohol content; only five of these complied with the standards prescribed under the Health Act.

Twenty-one samples of tripe were examined for pH and the presence of formaldehyde; all were found to be satisfactory.

Five samples of vinegar analysed for copper, lead and zinc content were all found to be satisfactory, but of another ten samples examined for quality standards, seven failed to comply with prescribed standards in respect of labelling provisions.

Nine samples of meat pies were received for analysis for meat content; four failed to meet the required standard of 18 per cent fat-free (i.e. lean) meat. Other meat products analysed for meat content were found to be satisfactory, as were a number of canned and corned meats analysed for nitrate and nitrite contents.

A sample of ham, suspected of containing fragments of glass, was found to contain numerous "crystals" of disodium hydrogen phosphate. These were quite hard, and "glassy" in appearance, and varied in size up to ten millimetres long by five millimetres wide and 2 millimetres thick. Their distribution in the piece of ham was uneven, but in some sections a normal serving would have contained approximately 20 per cent of these crystals.

Six samples of icecream submitted by the Public Health Department for examination were all found to comply with the chemical standards prescribed by the Health Act.

Quite a number of cases of canned foods, local and imported, were found to show evidence of deterioration and/or corrosion of the can. In most cases where the internal surface was partly lacquered the corrosion was confined to the metal surface, but in one sample of imported tomato paste where fermentation had taken place the lacquer had "lifted" away, allowing corrosion to extend to the underlying metal.

Human Toxicology

Exhibits were received from approximately 555 cases of sudden death which were the subject of police investigation. Of this number, 215 cases comprising 917 exhibits as registered, were submitted for examination for poisons or drugs.

In 108 cases no evidence of any poison or drug was established, but in 107 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 of the drugs and poisons detected are listed in Table 15.

TABLE 15
Drug and Poison Cases

Drug or Poison	No. of Cases
Carbon monoxide	35
Pentobarbitone	18
Phenobarbitone	7
Amitriptyline	6
Amylobarbitone	6
Methaqualone	6
Chlorpromazine	3
Dextropropoxyphene	3
Diphenhydramine	3
Glutethimide	3
Chlorbutol	2
Codeine	2
Diazepam	2
Imipramine	2
Nortriptyline	2
Paracetamol	2
Phenytoin	2
Quinalbarbitone	2
Salicylamide	2
Salicylate	2
*Various (one of each)	19
Negative	108

* Acetone, arsenic, barbitone, barbiturate (unidentified), butobarbitone, chloral, chlordiazepoxide, chloroquine, digitalis, ephedrine, ethopropazine, metasystox, methanol, methapyrilene, mineral turpentine, pentazocine, pethidine, strychnine, trimipramine.

In 188 of these cases a sample of blood was available for alcohol determination; 111 cases were negative and in 32 cases the alcohol concentration was 0.150 per cent or more.

One hundred and sixty-one exhibits of post-morten blood and urine were also received from ninety-six cases of "sudden death" where full toxicological examination was not considered necessary by the pathologist. Of these 96 cases, 42 per cent were negative, (i.e. blood alcohol was nil) while in 36.5 per cent of cases the blood alcohol was 0.150 per cent or more, and in 48 per cent it was 0.080 per cent or more. In 12 cases (12.5 per cent) the figure was greater than 0.300 per cent.

Blood Alcohol (Traffic Deaths)

Four hundred and fifty-four samples of blood and/or urine were received from the Police Department in connection with investigations into fatal traffic accidents. Two hundred and thirty-nine of these were post mortem blood samples which were analysed for alcohol, although it was noted that the "road toll" for Western Australia in 1974 was 339.

The distribution of blood alcohol figures for the various categories of persons killed in traffic accidents is shown in Table 16.

TABLE 16

TRAFFIC DEATHS—BLOOD ALCOHOL LEVELS

Alcohol per cent	Motor vehicle drivers	Passengers	Pedestrians	*Motor cycle riders	Pillion passengers	Unknown
	Number involved					
Negative	43	33	13	9	....	....
0·050 and less	5	2	3	....	....	....
0·051–0·079	1	2	1	1	1	....
0·080–0·099	5	3	1	2	1	....
0·100–0·149	6	9	1	5	....	3
0·150–0·200	18	3	6	7	....	1
0·201–0·250	9	6	6	3	....	....
0·251–0·300	8	....	10	2	1	....
More than 0·300	3	3	3	....	....	....
Total	98	61	44	29	3	4

* Includes motor-scooters

Table 16 shows that 39 per cent of fatally injured drivers, whose blood was analysed, had a blood-alcohol figure of 0.150 per cent or more, while the corresponding figure for passengers and pedestrians was 20 per cent and 57 per cent respectively and that for motor-cycle riders was 41 per cent.

Blood-alcohol levels of 0.08 per cent or more were recorded for 50 per cent of motor vehicle drivers, 39 per cent of passengers, 61 per cent of pedestrians and 66 per cent of motor-cycle riders.

Negative results (i.e. no blood-alcohol) were recorded for 44 per cent of motor vehicle drivers, 54 per cent of passengers, 30 per cent of pedestrians, and 31 per cent of motor-cycle riders.

As a matter of interest, the figures for the four years 1971-1974 are tabulated below, the figure in each table being the percentage of that category of person killed in fatal traffic accidents during the year.

Blood-Alcohol of 0·150 per cent or more

Year	1971	1972	1973	1974
	per cent of category killed			
Motor vehicle drivers	21	32	50	39
Passengers	14·5	24·5	29	20
Pedestrians	44	36	30	57
Motor cycle riders	....	....	5	41

Blood-Alcohol of 0·080 per cent or more

Year	1971	1972	1973	1974
	per cent of category killed			
Motor vehicle drivers	35	50	62	50
Passengers	29	41	38	39
Pedestrians	50	53	38	61
Motor cycle riders	....	....	16	66

Blood-Alcohol : Nil

Year	1971	1972	1973	1974
	per cent of category killed			
Motor vehicle drivers	57	43	30	44
Passengers	54	45	48	54
Pedestrians	42	20	32	30
Motor cycle riders	....	....	68	31

It is emphasised that the above figures apply only to the samples of post-mortem blood received for analysis at these Laboratories. The proportion of these relative to the actual number of "traffic deaths" for the years 1971-74 is shown in the following table:

Year	Bloods received	Traffic deaths
1971	219	338
1972	217	349
1973	243	371
1974	239	339

Blood Alcohol (Traffic Act)

Seven hundred and seventy-one samples of blood were submitted by Police and Local Traffic Authorities under Section 32 BB of the Traffic Act, which provides for samples of blood to be analysed for alcohol in connection with suspected breaches of the Traffic Act, e.g.

(1) Under Section 32 AA 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 32 C (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 17, the figure being the alcohol content at the "time of occurrence of event", calculated as prescribed in Regulation 12 of the Blood Sampling and Analyses Regulations, 1966.

As a matter of interest the results of the 4 005 Breathalyser tests conducted by the Police Department are also set out in comparable form in Table 17.

TABLE 17
Traffic Act—Blood Alcohol Levels

Alcohol, per cent	Blood Analyses No. of Cases	Blood Analyses Per cent of Cases	Breathalyzer Tests No. of Cases	Breathalyzer Tests Per cent of Cases
0·050–and less	33	4·3	113	2·8
0·051–0·079	38	4·9	241	6·0
0·080–0·099	32	4·2	320	8·0
0·100–0·149	144	18·7	1 171	29·3
0·150–0·200	222	26·8	1 226	30·6
0·201–0·250	186	24·1	654	16·3
0·251–0·300	82	10·6	240	6·0
More than 0·300	34	4·4	40	1·0
	771	100·0	4 005	100·0

In accordance with normal practice, each blood analysis was repeated independently by another chemist.

Table 17 shows that of those who had a blood analysis 524 persons, or 67.9 per cent of the total, had a blood-alcohol figure of 0.150 per cent or more; 668 persons or 86.6 per cent had a blood-alcohol concentration of 0.100 per cent or more; 700 persons, or 90.8 per cent, had a blood-alcohol of 0.08 per cent or more, and that 738 persons, or 95.7 per cent, had a blood-alcohol greater than 0.05 per cent.

Of those who had a breathalyser test, 2 160 persons, or 53.9 per cent of the total had a blood-alcohol figure of 0.150 per cent or more; 3 331 persons, or 83.2 per cent had a blood-alcohol of 0.100 per cent or more; 3 651 persons or 91.2 per cent had a blood-alcohol of 0.080 per cent or more, and that 3 892 persons or 97.2 per cent had a blood-alcohol greater than 0.05 per cent.

Specimens from Patients

One hundred and forty-five samples were received for examination. 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 18.

TABLE 18
Specimens from patients—Analyses

Analysis	Number
Arsenic	39
Lead	39
Zinc	17
Mercury	8
Thallium	8
Copper	5
Drugs (general)	5
Silver	4
Amphetamines	3
Tin	3
Chromate	2
*Various (one of each)	6

*Barbiturates, cadmium, ethanol, fluoride, methanol, organo-chlorine insecticides.

Animal Toxicology

There was a slight decrease in the number of exhibits in connection with deaths of animals, but a marked increase in the proportion of cases where strychnine was detected.

Fifty-two exhibits were received from 31 post-mortem examinations. Of these, 17 were negative, strychnine was detected in 13 cases, and D.D.T. and dieldrin in one case.

The variations in findings of animal post-mortem cases over the past four years is indicated in Table 19.

TABLE 19
Animal Post-Mortem Analyses

Year	Number of cases	Negative cases	Strychnine detected
	per cent of total		
1971	26	46	32
1972	17	71	29
1973	23	60	29
1974	31	55	42

Eleven samples of suspected poison baits were received from veterinary surgeons, the Police and the Department of Agriculture. Cyanide was detected in one bait, but no common poisons were detected in the remainder. In a case with non-fatal results, several cats exhibited symptoms of being heavily "tranquillised" following ingestion of "heart" meat sold as pet food. Examination of the meat showed that it contained pentobarbitone to the extent of 10.6 mg per 100 grams. The matter was pursued further by the Department of Public Health.

Industrial Hygiene

Three hundred and nine samples were registered during the year in connection with industrial hygiene investigations. The greatest proportion of these were samples of urine from workers in situations where exposure to a potential hazard, in particular lead, was suspected. Analyses were carried out to assist clinical diagnosis or to provide "screening" to exclude the possibility of undue exposure.

On these samples of urine there were 233 analyses for lead, 29 for mercury, 15 for thallium, 14 for fluoride, 3 for arsenic and one for copper, tin and zinc.

Analyses of the 233 samples examined for lead revealed that 61.4 per cent contained not more than 0.08 mg per litre of lead (as Pb), 29.6 per cent contained 0.09-0.15 mg per litre, 6.5 per cent contained 0.16-0.20 mg per litre, and 2.5 per cent contained more than 0.20 mg per litre.

Analyses for mercury were made on eight samples of urine from workers using mercury in assay laboratories, and 21 samples of urine and 3 of air were analysed in a survey of exposure to possible mercury hazard in dental surgeries.

Following discovery of a case of thallium poisoning, blood and urine samples from 15 employees of a commercial firm were analysed in a "screening" programme to check that there were no additional cases.

Fourteen samples of urine were analysed for fluoride in connection with fluoridation of public water supplies, and three from workers exposed to potential arsenic hazard.

Examinations were made of working conditions in a number of factories, and samples of air were analysed for vinyl chloride, D.D.V.P., manganese, fluorine, iron and zinc.

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 leakage from containers of chemicals 2,4-D, M.C.P.A., methyldithiocarbamic acid, ethylene thiourea, furfuraldehyde, Desmodur (methylene bisphenyl isocyanate), isophorone, maleic anhydride, hydrofluoric acid, xylene, and carbide; from the use of cyanide and maldison as fumigants; and complaints of irritant fumes resulting from the use of fork-life trucks during loading and discharge of cargo.

"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 safety measures necessary to ensure safe working conditions.

Of some interest was a "Self Rescuer" canister submitted for testing by the Mines Department. A mixture of one per cent carbon monoxide in air (10 000 parts per million) was drawn through the canister at the rate of 32 litres per minute and the exhaust gas monitored for carbon monoxide content. No carbon monoxide was detected during the first eighty minutes of operation, but the level rose to 100 parts per million at 89 minutes, to 200 parts per million at 107 minutes, and to 500 parts per million at 148 minutes.

Miscellaneous

Maritime Pollution—There was a marked decrease in the number of samples received in connection with maritime pollution, 23 samples from 7 cases of oil spillage, as compared with 43 samples in 1973. In 2 cases the only work required was that the material was in fact oil, in 5 cases it was possible to establish the probable source of the spillage and in one of those cases it was possible to eliminate one vessel as the cause of the pollution. The matter of identifying the specific source of a spillage in cases of maritime pollution is still a problem. The high degree of uniformity of bunker oils gives few characteristic features which can be used to identify their source. The techniques currently employed include U.V. ratios, fluorescence ratios at different dilutions in hexane, and where necessary, nickel/vanadium ratios. Emission spectrography has also been applied to this problem. A suitable quantity of the oil sample is ashed with sulphur and then "arc-ed". The resulting spectrogram is compared with those of similarly treated oils from "suspect" vessels. Due to the limited number of pollution incidents this technique has yet to be evaluated for bunker oils although present indications are that it would be successful in identifying the source of crude oil spillages.

Pesticides—There was a decrease also in the number of pesticides as such, received for analysis, 40 samples as compared with 60 in 1973. The types of pesticide are listed in Table 20.

TABLE 20
Pesticide—Examinations

Concentrates and Emulsions	No. of Samples
Aldrin	4
Dieldrin	2
Heptachlor	6
Maldison	8
2,4-D ester	7
Various	5
Formulations	8

Samples of aldrin and heptachlor 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, and samples of aldrin, dieldrin and heptachlor were analysed for the Public Health Department in connection with their surveillance of the quality of service provided by pest control operators. In one case a sample of soil, which from calculation should have contained not less than 400 parts per million of aldrin, was found to contain only 2 parts per million of aldrin and 20 parts per million of dieldrin. Following proper application of the pesticide a "repeat" sample of the soil contained 500 parts per million of aldrin.

Samples of heptachlor concentrate were assayed for the Entomology Branch of the Department of Agriculture for their programme of Argentine Ant Control, and samples of protein hydrolysate fruit bait were analysed for protein, salt, solids, ammonium chloride and pH (acidity) in connection with an interstate investigation into the causes of injury to fruit tree foliage on which the bait had been applied.

A sample of "dust" which had accidentally contaminated a number of foods during transport was found to contain benzene hexachloride (B.H.C.), and a sample of fumigant gas, alleged to be ineffective against test insects, was found to contain only one-third of its correct concentration of ethylene oxide.

Samples of maldison dust were assayed for a commercial firm for conformity to trade specification, and samples of maldison emulsion were examined for stability as prescribed by W.H.O. specifications.

Criminal—One hundred and fifty-six exhibits were examined for the Police Department in connection with enquiries by the Criminal Investigation Branch. These included 52 exhibits taken from 36 cases of suspected arson; in 2 cases only, a flammable material kerosene was identified in the exhibits as received for examination.

There were 20 exhibits in connection with assault of persons, 18 with theft etc., 10 with wilful damage to property, 15 with motor vehicle accidents, 27 with alleged attempted murder, 3 with food suspected of containing poison, and a number of miscellaneous examinations.

Drugs—Again there was a marked increase in the number of exhibits received from the Police Drug Squad in connection with suspected possession of drugs—230 exhibits from 130 cases under investigation. As in previous years the most common drug detected was cannabis which was found in 131 exhibits (from 47 cases). Details are listed in Table 21.

TABLE 21
DRUGS—POLICE DRUG SQUAD

Type of drug	No. of Cases
Cannabis	47
L.S.D.	9
Morphine	9
Heroin	4
Pethidine	3
Cocaine	2
Dextromoramide	2
Methadone	2
Various	26
Negative	26
	130

Horse doping tests—There was a slight decrease in the number of urine samples received from the Western Australian Trotting Association in connection with the "swabbing" of winners and place-getters of trotting races. 296 samples were examined as compared with 344 in 1973; only two positive cases were detected, one of caffeine from Pinjarra and one of oxyphenbutazone from Gloucester Park.

Late in the year greyhound racing commenced in Western Australia and six samples of dog urine were similarly examined for the Greyhound Racing Control Board; all were negative.

Detergents—Samples of detergents were submitted by the Government Tender Board in connection with 113 tenders to the 15 items of the Schedule for the supply of detergents for use in Government institutions. A considerable amount of work was entailed in assessing 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 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 no diminution in the field of pesticide residue work, nearly 1 200 samples being received for examination during the year. Some indication of the variety of this work is given in Table 22.

TABLE 22
PESTICIDE RESIDUE ANALYSES

Sample (and analyses)	Number
Water, Ord area (O.C's, O.P's herbicides)	128
Water, S.W. rivers (O.C's and herbicides)	12
Silt, Ord area (O.C's, O.P's)	37
Silt, S.W. rivers (O.C's, herbicides)	18
Fish, Ord area (O.C's, O.P's)	224
Soil, Ord area (O.C's, O.P's)	15
Fat, bovine Kununurra (O.C's)	218
Pasture, Kununurra (O.C's)	39
Bird tissue (O.C's)	146
Feedstuffs, K.R.S. (O.C's, O.P's)	6
Water, Swan River (O.C's, O.P's)	16
Fat, ovine (O.C's)	78
Birds eggs (O.C's)	39
Human milk (O.C's)	51
Bore water (O.C's)	10
Lupin seed and stubble (O.C's)	48
Milk ex treatment plants (O.C's)	33
Respirator filters (O.C's)	19
Various	44

During the year the Laboratories initiated a programme to monitor levels of organo-chlorine and organo-phosphorus pesticides in the Swan River. Two sampling points were selected, at the Causeway, Perth, and at the Fremantle Traffic Bridge, and samples of river water were collected and analysed monthly, commencing in mid-May, 1974.

Details of the pesticides detected during the programme May-December are listed in Table 23.

TABLE 23

PESTICIDE RESIDUES SWAN RIVER
MONTHLY SAMPLES MAY-DECEMBER 1974

Pesticide	Causeway Perth		Traffic Bridge Fremantle		Drinking Water* maximum level mg/l	Marine and Estuarine Waters* maximum level mg/l
	No. of times found	Range mg/l	No. of times found	Range mg/l		
Aldrin	2	0·00002–0·00017	1	0·000002	0·017	0·00005
D.D.T. and Metabolites	4	0·000003–0·000005	3	0·000003–0·000005	0·042	0·00005
Dieldrin	6	0·000007–0·00004	6	0·000002–0·000017	0·017	0·00005
Lindane	1	0·00002	1	0·000001	0·056	0·00005
Fenchlorphos	1	0·0001	0	....	0·1	0·00005

* Water Quality Criteria, Federal Water Pollution Control Administration, Washington 1968.

Although these figures indicate that low levels of pesticides are finding their way into the river, the concentrations detected are well below the maximum levels recommended for drinking water. With respect to marine and estuarine organisms the maximum recommended levels vary considerably between references and the figures quoted in Table 23 probably are on the high side. However to put these levels in their right perspective it must be realised that the levels found in the river are very low and are near or below the limit of determination in most cases. Also rain water in London has been found to contain up to 0.000 14 mg/l DDT and metabolites, 0.000 07 mg/l dieldrin and 0.000 15 mg/l of lindane.

Miscellaneous samples received and examined during the year included:

- Five samples of air analysed for possible carbon dioxide "build-up" around heads of infants in neo-natal cribs.
- Eight samples of mine air analysed for carbon monoxide and oxides of nitrogen in connection with underground trials of blasting agents conducted by the Mines Department, Kalgoorlie.
- Nine "Streamer Bombs" examined for the Explosives Branch as a check on the presence of the prohibited substances arsenic and antimony.
- Childrens toys for colouring matter, lead and identification of liquids in novelty toys.
- Cleaning fluids for identification of solvents and presence of benzene.
- Plant materials for presence of fluoroacetate.
- A deodorant toilet block, chewed by a detained person, for its effect on a Breathalyzer test.
- Examination of the fragments of a pressure gauge from an explosion; mineral oil was found to be present.
- Explosives analysed for the Explosives Branch to determine composition.
- Grass for ascorbic acid, feedstuff for aflatoxins, soap and glue for cause of irritation, Sikes Hydrometers for calibration, tallows for examination to trade specifications, and ceramic ware for "leachable" lead and cadmium.

Numerous enquiries for technical information and advice were received and dealt with 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 held at Melbourne in February.

Mr. G. F. Ebell attended the Conference of Residue Chemists held at Adelaide in August.

Mr. V. J. McLinden attended the Annual Conference of Forensic Toxicologists, followed by the inaugural Conference on Illicit Drugs, both of which were held at Hobart in October-November.

INDUSTRIAL CHEMISTRY DIVISION

The Division continues to receive enquiries covering a wide range of subjects from Government, private companies and the general public. This involved short literature searches in order to answer many of these enquiries and interest in plastics continues to be considerable.

Staff

Dr. Smith again delivered the final lecture of the annual "Know Your Plastics" series organised by the Plastics Institute of Australia. He also acted as Chairman of a seminar on Protective Coatings organised by the Australasian Corrosion Association. Both Dr. Smith and Mr. Kippo delivered lectures at a seminar on the behaviour of plastics in fires.

Mr. R. I. McKinnon was seconded for four months to the Pilbara Study Group to assist in the preparation of their report. Dr. Smith accompanied the Controller of Stores to Melbourne to attend a seminar on paint testing and approval, organised by the Victorian State Paint Group and the Australian Government Paint Committee. Representatives of all States attended, the purpose being to persuade all States other than Victoria, who are already members, to join the Government Paint Committee scheme for paint approvals.

Details of Work

1. Routine.
   (a) Paint.

The State is now a member of the Government Paint Committee, and all States except New South Wales have now joined. It is expected that New South Wales will become a member in 1975. A State Paint Group will be formed to represent as wide a range of Government Departments and Instrumentalities as possible. The Government Paint Committee was originally established as a service to Commonwealth Government Departments.

Our membership will give us access to the expertise built up over many years by the Government Paint Committee Secretariat and in particular to use their wide range of paint specifications and their systems of paint approvals. In return we will be expected to carry out work for the Government Paint Committee from time to time and to provide copies of paint test results. The existing Paint Advisory Committee will continue to act for the Government Tender Board in considering paint tenders. However, in future, only those paint manufacturers who are approved by the Government Paint Committee will be allowed to tender and then only for those products which are also approved.

We have again tested many samples of paint mostly for Government Tender Board. During the year 26 samples were supplied from Government Stores and State Housing Commission stocks for testing to compare results obtained with the reference samples supplied for the 1974 tender. Generally the samples compared well with the reference samples. There were, however, four samples in which property variations exceeded those allowed in the appropriate standard.

Fifty-five samples of paint were examined for the 1975 tender. On this occasion a different procedure was adopted. All paint companies asked to supply paint samples were also requested to provide a certificate of analysis for each sample. The amount of our testing was therefore reduced and our report was completed in time for consideration by the Paint Advisory Committee.

Two samples of paint film from the Perth Medical Centre supposed to be alkyd enamels, but suspected to be PVA-acrylic, were found in fact to be alkyds.

Warren District Hospital complained to Government Stores of poor hiding power in a batch of PVA Suede paint supplied by a particular manufacturer, one of the successful tenderers for the 1974 tender. The undercoat was found to have a wet hiding power 22 per cent below that of the reference sample which was well outside the variation allowed. It was also observed that the dry hiding power of the PVA paint samples was rather poor and worse than samples of this paint tested in previous years.

A second complaint concerning paints supplied by the same paint manufacturer was reported by the State Housing Commission. Three samples were submitted, one pink primer, one undercoat and one PVA Suede latex paint. The pink primer had a wet hiding power less than half that of the reference sample and the undercoat a wet hiding power 18 per cent lower. The PVA paint was wrongly labelled as white, whereas in fact it was tinted blue. As a result of the colour the wet hiding power was substantially higher than the white reference sample but dry hiding power was still not very good.

Another small sample of paint from the Police Headquarters Building was submitted for confirmation that it was a chlorinated rubber-based paint.

A report prepared by an outside laboratory on a range of paints made by a new company was submitted by Public Works Department for comment. Insufficient information was provided in the report for us to make adequate comment and it is likely that samples of these paints will be submitted for testing.

(b) Building Materials

Continuing work on carpet testing for the Furniture Section, Public Works Department, three samples of carpet were submitted to the tests described in previous Annual Reports. Results were generally similar to previous tests particularly in stain resistance and dimensional stability.

Two samples of carpet and one sample of carpet underlay were submitted for identification of materials by the Consumer Protection Bureau.

Some samples of cement which had failed in extensions to a hospital were analysed for lignosulphonate content. The quantity determined was within the normal range and is therefore unlikely to have contributed to the failure.

One sample of concrete underlay was found to consist of a black woven polyethylene fabric. Its properties were generally similar to other samples of this type of material tested previously, although it failed the hydrostatic pressure test and its water vapour transmission was very high.

The Public Works Department submitted two samples of super six asbestos roofing, spray coated with about one inch of polyurethane foam. In both samples the foam itself was found to be self-extinguishing under the conditions of ASTM D1692-68. Both panels failed the standard fire resistivity test, with coefficients of resistivity well below 0.5 and would therefore not be acceptable for use in public buildings.

The fire resistance test was perhaps not very fair to the two surface coatings. The actual surface of the sprayed foam was extremely uneven and most of the coating material had flowed into the "valleys", leaving a very thin coating on the "hills". Even so, both coatings behaved quite well and appeared to be self-extinguishing under the conditions of the test.

In our report it was suggested that an intumescent paint might upgrade the coefficient of resistivity to an acceptable level. Subsequently, we received another sample panel with the foam coated with such a paint. Although the coating appeared of reasonably even thickness the foam surface was still extremely rough, as is usually expected with sprayed foam. The coefficient of resistivity was found to be a little higher but still below 0.5.

In another test on a flat reinforced plastic panel the same intumescent paint had raised the coefficient of resistivity to an acceptable level.

The sealing of the wall to floor joint in a large reinforced concrete water storage tank at Port Hedland had failed at the bond between the polysulphide rubber sealant and the concrete floor.

We were asked by Country Water Supply to determine the cause of failure. Samples of a number of possible contaminants were supplied together with a section of floor with partly attached sealant.

No contamination of the concrete surface was detected and it was suggested that faulty application of the sealant was to blame for the failure. The sealant was deposited by gun into a U-shaped trough about 2.5 cm wide and the operator could not have been able to see the vertical face of the trough on the floor side. There were indications that application of primer to this face was uneven and it was noted that the sealant was only bonded to the lip of the trough on this side. Air entrapment below the lip between the sealant and vertical face probably explains the patchy adhesion experienced in the trough.

A sample of lime slurry was submitted by Metropolitan Water Board for determination of viscosity to aid selection of a suitable pump.

(c) Plastics

A sample of composite panel with a white foam core was submitted by the Department of Public Health for identification of foam and facing materials and the hardness of the surfaces. The foam was found to be polystyrene and the two facing sheets were both polyurethane. The hardness of the facing sheets was determined with a Barcol Hardness Tester. This sample was similar to two samples reported on in 1973 and burned equally well.

Two reinforced plastic tanks had been installed in the Perth Medical Centre for special effluent treatment. During use both tanks cracked, mainly around the domed base and finally one tank failed catastrophically. Public Works Department asked for identification of the resins used and the glass content, together with comments on the strength of reinforced plastic materials and suggestions as to why failure had occurred.

The tanks were designed to operate at a maximum temperature of 95°C. Subsequent tests after the failure indicated that actual operating temperatures could have greatly exceeded the design figure. Gross thermal overload seems likely to be the major cause of the failure.

A sample of "plastic marble" was submitted by Consumer Protection Bureau who had received a complaint concerning the term used to describe it. The product was found to be a talc-filled polyester resin and some comments were made concerning the descriptive terms used.

The Harbour and Light Department submitted 15 samples of reinforced plastics for determination of resin/glass ratios and glass content.

The same Department also submitted a sample of polyethylene foam for tests to establish its suitability as a buoyancy material in boats. In all respects except fire resistance the material was satisfactory. However, when tested in accordance with ASTM D1692-68 the sample continued to burn after the flame was removed.

Medical Department submitted a sample of reinforced plastic sheet which the local manufacturer claimed to be fire resistant. It behaved well in all tests and had a coefficient of resistivity of 4.9 and is therefore suitable for use in public buildings.

Plastic printing plates are used frequently in printing now and the Government Printer asked for advice on a cleaning preparation which could be used to remove accumulations of fibres and ink which become embedded in and around small lettering on the plates such as is used for the telephone directory. A solvent composition based on an ethylene glycol ether was suggested for trial.

The Midland Junction Abattoirs Board submitted six samples of composite panels for physical testing. The panels were being considered for floors and walls in cold rooms. They were composed of a core of polystyrene foam with facing sheets of epoxy resin of different thicknesses reinforced with sand or fibre glass or both. Extensive compression and impact testing was carried out which showed that the panels had generally satisfactory properties.

(d) Miscellaneous.

Wundowie Charcoal Iron and Steel Works submitted three samples of wood tar for analysis according to the Australian Standard for Creosote Oil, K55-1965. Two of the samples included additions of another solvent to improve penetration into timber.

The results showed some discrepancies in the specific gravity of the three samples and it was found there was an error in the formula in the Standard for calculating specific gravity. When this was corrected the specific gravity figures were of the right order of magnitude.

A dark brown stain on a sheet supplied by the Home of Peace was identified as a brown floor wax and suggestions were made for removing it.

The Department of Labour and Industry submitted a leather jacket with a fleecy lining labelled "All Cotton". It was thought that the label was wrong. It was in fact found that the lining was composed of 100 per cent acrylic fibre, no cotton or polyester fibres being present. Incidently the "leather" of the jacket was a vinyl coated fabric.

The Home Economics Department, W.A. Institute of Technology, submitted two lots of 16 samples of curtain material for exposure for 100 hours in our UV weatherometer.

The Consumer Protection Bureau submitted two samples of curtain fabric claimed to be rayon, but which differed in physical appearance although well-matched in colour. The materials were both acetate rayon but differed in weave, thus explaining the difference in appearance.

A sample of trimming fringe was submitted by Public Health Department. It was thought to be causing some irritation to two machinists using it. The material was identified as a chemically treated cotton.

As a result of a fatal fire in a car some work was done for the Department of Motor Vehicles on the combustibility of some materials sampled from a similar car.

2. Assistance to Industry

(a) Peat Wax

Two companies submitted samples of peaty soil. One company supplied only one sample and this was found to be very low in wax and of no economic interest. The second company supplied 7 samples for determination of total organic matter and, where thought necessary, wax content and water holding capacity. Four samples were very low in organic matter. The one sample high in organic matter was used for determination of wax and water holding capacity, neither result being of commercial significance.

(b) Dust Suppressants

One of the iron ore mining companies had been using a product to control dust on their ore stock piles. They were unable to obtain further supplies and we were asked to identify the material. It was found to be a dispersion of polyvinyl alcohol containing some plasticiser and wetting agent and we were able to suggest other suppliers of similar materials.

(c) Solvent Extraction

We have continued our pilot plant work using the Cavsol process for the production of protein concentrates. Further quantities of fish have been processed and also poultry offal, bone meal and soybeans.

(d) Vinyl Floor Tiles

Samples of tiles were submitted to determine the reason for adhesion failure to a concrete floor. The tiles were found to be quite moist and the water had a high pH. It was therefore suggested that the concrete floor had not dried out and that this was the cause of the failure.

(e) Plastic Coated Metal

At the request of a local company developing a plastic coated metal panel for exterior use, we submitted samples to accelerated weathering in our UV weatherometer.

(f) Marble

A mining company developing a local deposit of high quality marble submitted samples for determination of abrasion resistance in comparison with imported Italian marble.

(g) Plastic Carry Bags

These imported bags consist of thin polyethylene film with a moulded plastic handle heat sealed to the top. The handle is in two halves which clip together. In a shipment of such bags from Singapore some handles had torn away from the bag after use. We submitted a batch of bags to two tests. Both tests caused a high proportion of failures and a visual inspection of the heat seals showed that the work had been done very carelessly.

(h) Roofing Tiles.

A local company producing tiles submitted several samples with various coatings for accelerated weathering in our UV weatherometer.

3. Investigational

(a) Work was continued during the year as time allowed on painting of karri timber, production of printers rollers, formulation for polyester drafting film, rust treatment, clear lacquers for timber, wood waste utilisation, enzyme chemistry and testing of polishes.

(b) Laporte Effluent

As part of a Government study on this problem we have investigated some aspects of the chemistry of this effluent on a small scale.

4. Other Activities

Scaevola spinescens. Supply of an extract of this plant to a few cancer sufferers was continued. A collecting trip was necessary during the year to replenish supplies.

5. Consultative

A large range of consultative work was undertaken and a selection from enquiries received is given below:

- Gas producing materials for fuse gear to kill arcing.
- Materials of construction for fume cupboards.
- Acoustic and heat insulation of tractor cabins.
- Use of plastic foam for air conditioning ducting.
- Formulation of dental paste acrylics.
- Formulation of bronze darkening solutions.
- Information on testing of glass reinforced plastics.
- Advice to Perth City Council on repair of the Council House pools.
- Use of plastics in solar energy equipment.
- Prevention of felting of hair in wigs.
- Disposal or utilisation of yeast wastes.
- Cleaning of headstones.
- Embedding wildflowers in clear plastic.
- Properties and handling of liquid ammonia.
- Utilisation of scrap rubber in tyres.
- Production of UF foams for home insulation.

KALGOORLIE METALLURGICAL LABORATORIES

General

Three hundred and one Certificates of testing or analysis were issued during the year, an increase of four over the previous year and included a number of lengthy certificates issued to Mining Companies who did not want their results made public owing to the time between receiving the information and investigating and installing equipment for a production plant.

Work on three C.S.I.R.O. reports were completed (No. 778-780). Clients who requested the reports will be contacted to see when their report can be released, as C.S.I.R.O. reports can be confidential up to a period of two years, most clients are satisfied with a period of six months.

Companies and prospectors during the year were actively engaged in assessing old gold mine dumps, with the prospectors leading the way in examining old mines to see what can be achieved, but are handicapped through lack of capital to open a mine which has been abandoned for many years. More bullion bars are also being brought in for assay and reflects the growing interest in gold.

The most difficult ore we have found to handle by fire assay methods is material containing 2 or more per cent of chromium which prevents the lead produced in the assay charge from forming into a coherent lead button.

To overcome this difficulty a low chrome ore was extracted with sulphuric acid and it was found necessary to recover gold from the filtrate solution to obtain agreement with the original head assay.

The above procedure was cumbersome and for an ore high in chromium, we anticipate precipitating the gold from the acid leach solution by adding sodium sulphite whilst the residue is still in contact, thereby using the solids to help collect the precipitated gold and the pulp will then be filtered, washed, dried and assayed.

During the year some time was spent tracking down the unusual effect that colloidal slime in some ores can absorb gold from a cyanide solution and then release it when a large volume of water dilutes the cyanided pulp. In searching for an answer as to why the cyanide residue and gold in filtrate assay did not check (as the gold above was lost in the filtrate washings and was not taken into account until later) some test work was carried out into the assay solution methods.

The evaporation of cyanide solutions containing soluble gold with Chiddy's and Canadian methods was checked and it was found that all the methods were reliable, with the Canadian method better suited to handling large volumes of solution.

In several instances the retreatment of residue dumps, have presented considerable difficulty in that sulphides oxidise to give a pH of 4 or less. This has reacted with the tailing itself and which have become slimy and colloidal, sealing the material off from outside aeration and leaching and this had allowed ferrous and magnesium salts to form which could consume a considerable quantity of lime and cyanide in their treatment. By adding lime to the dump surface and scarifying the area the quantity of ferrous sulphate and the magnesium sulphate will be reduced so that leaching and tailing will not be a major problem and the porosity of the material to be leached should be improved.

Table 24 gives the summary of samples reported in 1974.

Equipment

A new Wilfley concentrating table was installed during the year to replace an old table which had been used for about 30 years. The new unit has a fibre glass deck and it will be of interest to see how this surface compares with the linoleum covered table which has served for so long.

A new Agitair flotation cell was received and this will extend our flotation facilities.

TABLE 24.

KALGOORLIE METALLURGICAL LABORATORY SAMPLES REPORTED 1974

Ore and Minerals	Mines Department	State Batteries	Police	School of Mines	Public		Total
					Free	Pay	
Gold ore	16	2	10	14	1	1 143	1 186
tails	....	8	2	....	....	590	600
bullion	....	....	....	....	....	20	20
Nickel	....	....	....	....	1	78	79
Copper	1	....	4	....	1	82	88
Tungstic oxide	....	....	....	....	....	3	3
Arsenic	2	4	....	....	....	1	7
Antimony	....	....	....	....	....	1	1
Cobalt	....	....	....	....	....	1	1
Silver	....	2	4	....	1	92	99
Lead	....	....	....	....	....	62	62
Zinc	....	....	....	....	....	10	10
Calcium fluoride	....	....	....	....	....	6	6
Other....	....	....	....	....	1	5	6
TOTAL	19	16	20	14	5	2 094	2 168

MINERAL DIVISION

General

The total number of samples received in the Division during 1974 was 3 877. Generally speaking samples were submitted for a greater number of individual determinations than usual, 95 samples from the Geological Survey alone requiring 2 160 determinations or an average of 23 per sample. Analyses have been made for about 60 of the 103 known elements.

The number of dusts showed an increase of 7 per cent over the previous year while 29 per cent more gold samples were received. This continues the trend in recent years following respectively the growing pollution consciousness and the rise in the price of gold.

There was a large increase in complete analyses and a falling off in geochemical samples. However, large batches from the previous year are still in hand for geochemical determinations and further samples can be expected following the reappointment in June of a geochemist in the Geological Survey of Western Australia. The big increase in limesand and limestone analyses was due mainly to samples taken during the Survey's review of limestone deposits.

About 85 per cent of the total samples received were from Government sources: of those from Government sources 49 per cent were from branches of the Mines Department and 39 per cent from Public Health.

Details of the source and type of samples handled are listed in Table 25.

TABLE 25
MINERAL DIVISION

	Aboriginal Affairs Planning Authority	Agriculture Depart-ment	Environ-mental Protection Authority	Geological Survey	Govern-ment Chemical Labora-tories	Mines Depart-ment	Police Depart-ment	Public Health Depart-ment	Public Works Depart-ment	State Housing Com-mission	Other	Public			Total
												Pay	Concession	Free	
Building Materials	....	....	....	1	....	....	....	....	16	12	3	8	....	....	40
Complete Analyses	....	....	....	169	1	....	....	....	....	....	2	13	....	2	187
Dusts	....	....	....	....	....	283	....	1 255	....	....	1	1	....	....	1 540
Geochemistry	....	....	....	331	....	....	....	....	....	....	....	....	....	....	331
Mineral Identifications	18	1	....	90	238	2	....	1	3	....	2	59	39	10	463
Police Exhibits	....	....	....	....	....	....	51	....	....	....	....	....	....	....	51
Thermometer Calibrations	....	....	....	....	....	....	44	....	....	....	....	....	....	....	44
Miscellaneous	....	5	73	....	1	14	....	16	15	....	23	104	5	....	256
Ores and Minerals—															
Clay	....	115	....	36	3	....	....	3	29	....	....	5	1	....	192
Copper	....	....	....	....	17	....	....	....	....	....	....	5	1	1	24
Diatomite	....	....	....	....	12	....	....	....	....	....	....	....	....	....	12
Gold Ores	....	....	....	3	17	....	....	....	....	....	....	164	79	27	290
Gold Tailings	....	....	....	....	....	65	....	....	....	....	....	53	....	....	118
Heavy Sands	....	....	....	....	....	....	....	1	....	....	....	5	7	9	22
Iron	....	....	....	34	71	....	....	....	....	....	....	2	....	....	107
Lime-Limesands	....	....	....	150	1	....	....	....	....	....	....	1	....	....	152
Magnesite	....	....	....	12	....	....	....	....	....	....	....	....	....	....	12
Various Others	....	....	....	29	6	....	....	....	....	....	....	....	....	1	36
Total	18	121	73	855	367	364	95	1 276	63	12	31	420	132	50	3 877

Field Trips

Greenbushes Tin N.L., the major tin-tantalum miner at Greenbushes, currently engaged in mining new exposures, co-operated generously in a trip to Greenbushes by Messrs. M. Pryce and P. Bridge. A detailed examination was made of the extensive fresh exposures in the several deep pit mining operations in both the pegmatite kaolinised zone and also some old alluvial workings. A comprehensive suite of specimens was collected, also some of historical value from the recently discovered remnants of the phenomenally tin-rich alluvial "wash" and lateritised alluvial thought to have been completely worked out last century. The assistance given by the Company staff is gratefully acknowleged.

Material exposed during dredging activities in the Bunbury harbour was examined at Bunbury and some interesting specimens obtained.

Inspections and Interstate Visits

Meetings of the Standards Association of Australia sub-committee dealing with iron ore analysis were separately attended by Mr. G. Payne and Mr. M. Costello in Adelaide and Melbourne respectively.

Mr. Costello carried out a re-assessment of a private laboratory at the request of the National Association of Testing Authorities.

Mr. A. G. Thomas attended an Australian Mineral Foundation workshop course in Adelaide covering basic analytical techniques involved in direct reading instrumental analysis. Mr. N. L. Marsh represented the Laboratories at the Second Australian Conference on X-ray analysis in Canberra which covered subjects ranging from microprobe analysis through X-ray fluorescence to X-ray diffractometry.

Publications

The following lists publications by Divisional Staff during 1974:

Magnesian collinsite from Milgun Station, Western Australia. Bridge, P. J. and Pryce, M. W., MIN. MAG., 39, 577 (1974).

Glaukosphaerite, a new nickel analogue of rosasite. Pryce, M. W. and Just, J.,* MIN. MAG., 39, 737 (1974).

* Australian Selection Pty. Ltd., Perth, W.A.

Guanine and uricite, two new organic minerals from Peru and Western Australia. Bridge, P. J., MIN. MAG., 39, 889 (1974).

Clinobisvanite, monoclinic $BiVO_4$, a new mineral from Yinnietharra, Western Australia. Bridge, P. J. and Pryce, M. W., MIN. MAG., 39, 847 (1974).

Avian-derived phosphate from inland Western Australia. Bridge, P. J., W.A. NATURALIST, 13, 24 (1974).

Crystal structure of collinsite. Brotherton,* P. D., Maslen,* E. N., Pryce, M. W. and White,* A. H., AUST. J. CHEM., 27, 653 (1974).

* University of Western Australia.

Crystal structure of "calcium sulphosilicate", $Ca_5(SiO_4)_2SO_4$. Brotherton,* P. D., Epstein,* J. M., Pryce, M. W. and White,* A. H., AUST. J. CHEM., 27, 657 (1974).

* University of Western Australia.

Coincidence was associated with the naming of both new minerals glaukosphaerite and clinobisvanite.

A secondary nickel mineral, submitted in 1967, could not be identified and in the nickel boom years that followed material having the same properties was received from widespread areas of the Central goldfields. As time permitted, further work was carried out and in 1972 the name glaukosphaerite was submitted to and accepted by the Commission on New Minerals and Mineral Names, International Mineralogical Association. In 1973, a Belgian mineralogist, M. Deliens, submitted a paper for publication entitled "Kasompite a new carbonate of copper and nickel" in which he described a mineral from Zaire. The mineral was identical with the W.A. glaukosphaerite which name was given preference over kasompite because of the formers earlier submission to International Mineralogical Association.

Similarly, in the case of clinobisvanite, overseas workers had been accumulating data on the same mineral and published a paper in 1973 describing this monoclinic bismuth vanadate from the Mutala Pegmatite in Mozambique (von Knorring, Sahama, Lehtinen, Rehtijarvi and Siivola, CONTR. MIN. PETR., 41, 325 (1973). However no name had been suggested and so clinobisvanite as proposed in our later paper has been accepted.

The two crystal structure analyses were carried out as a joint project with the Departments of Chemistry and Physics of the University of W.A. whose contributions of automatic intensity measurement, computer programmes and expertise are gratefully acknowledged. Co-operation of the Surveys and Mapping Branch of the Mines Department in production of a suitable diagram of the complex collinsite structure is appreciated.

These crystal analyses provided one of the authors (M.W. Pryce) with the rare opportunity of following through from the initial descriptions of the rare mineral and the new artificial compound to their characterisation as exemplified in their detailed crystal structures.

Equipment

The ability of the Division to assess kaolin clays was improved by the acquisition of a Brookfield Synchro-Lectric RVT viscometer and a Carl Zeiss-Elrepho photoelectric reflectometer.

General laboratory equipment was upgraded by replacement purchases of a Carbolite muffle furnace and a Sartorius 2474 analytical balance.

Other additions were an automatic dilutor, a compensating planimeter, a ring-flash for specimen photography and a detente spindle stage for microscopic manipulation and orientation of crystals.

Two Leitz Dialux microscopes were renovated.

The safety of the X-ray diffraction equipment was improved and all units made compatible by the replacement of a leaking shield with a Philips PW 1316/10 vertical shield. The unit is now simpler to use and more versatile.

Computing

The year saw considerable activity in the computing field.

The Division was represented on the Laboratories computer study group by Mr. A. G. Thomas. The group made a study of individual divisional requirements and submitted a recommendation for the acquisition of an "in-house" computer to serve most of the needs of the Divisions for on-line data collection and collation. Such an installation would remove most of the data preparation bottleneck at present seriously slowing down the issue of reports on complete and geochemical analyses by X-ray fluorescence.

It is such analyses that at present make the greatest demand within the Mineral Division on computer time. The first large group of geochemical samples submitted by Geological Survey of Western Australia was completed during the year, involving 756 samples for 17 determinations each. The throughput of geochemical samples has been slower than hoped, due mainly to the need to set up new calibration procedures and the inevitable interruptions caused by occasional demand for more urgent silicate analyses or other investigations.

A second group of 483 geochemical samples is being processed at a rate of about 140 determinations per working day on a routine basis which will be considerably improved with the anticipated provision of an automatic 10 head sample changer and the replacement by "in-house" computing facilities of the present manual method of data transfer between spectrometer and the Regional Computing Centre.

Cost of the addition of further hardware to the X-ray spectrometry equipment (multiple sample changer, tabulator control units, etc.), would be offset by the release of staff for other work: under present arrangements the spectrometer calls for the full time attention of a technician, whereas if fully automated the demand for technician attention would be reduced by about 75 per cent. Further work would be handled, including many silicate analyses, at present being carried out by classical methods by chemists who would then become available for investigational and other work not suited to X-ray fluorescence techniques.

Further developmental work has been carried out to assist in the interpretation and analysis of geochemical data.

Programmes have been developed whereby selected data may be abstracted from data files and presented in a variety of numerical and/or graphical forms. Numerical presentations consist of general statistical parameters and correlation matrices. Graphical forms are histograms scatter plots and contour plots.

In the field of X-ray diffraction, Mr. M. Pryce was engaged in small-scale computing of unit cell refinements from X-ray measurements of organic compounds, olivine, garnet and tourmalines on the C.D.C. 6200 computer at the W.A. Regional Centre. The timely upgrading of the old PDP-6 computer to a PDP-10 by the Centre enabled the recompilation and use of the Laboratories INDEX programme which had lapsed while the PDP-6 was off-line for upgrading.

INDEX, an X-ray powder pattern indexing programme written by Dr. B. Roof and adapted to PDP machines, would otherwise have required major changes for use on the C.D.C. 6200 computer.

At the same time all the laboratory X-ray diffraction programmes in use on the C.D.C. 6200 were also compiled on the new PDP-10 tape with INDEX. The mineralogists now have two independent compiled copies of each programme and the choice of computer in the event of breakdowns and delays.

Mineral Collections

Addition of 189 new specimens during the year brought the number of specimens in the Mineral Division reference collection to 5 343.

About 90 per cent of the additions originated from within the State. Those from overseas were chosen mainly because of their association with species of commercial significance within W.A. or with current projects being undertaken internally within the Division; such additions include three nickel sulphide ores from Canada, and the phosphates crandallite, rockbridgeite, laueite, wardite, englishite, sterrettite and diadochite from U.S.A. and hannayite and brushite from Sarawak.

Specimens were added of all species recorded for the first time in Western Australia in addition to all those from new localities within the State. These are listed elsewhere under New Mineral Localities.

A very comprehensive suite of secondary silver-lead-zinc ores from a mine near Kununurra was donated by the mine owner, Mr. P. G. Costeo. As well as spectacular specimens of common minerals, several rare species are present and the whole suite, after detailed description, will be a valued addition to the Mineral Division reference collection.

Data from this latter collection has been transferred to magnetic tape file at the W.A. Regional Computing Centre. Programmes have been written to produce a three-way index to the collection. The index is ordered on MDC No., mineral name and locality. New entries will be added annually to update the file and work is in hand to similarly index the Simpson collection.

The merging of these two ordered indexes will provide a very comprehensive index of W.A. mineral occurrences as recorded in these Laboratories.

New Mineral Localities

Localities from which specific minerals were recorded for the first time in these Laboratories during 1974 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

aurichalcite	Kununurra
chalcopyrite	Karunjie
huntite	Carson River
mottramite	Kununurra
rosasite	Kununurra

(b) North West Division

alunite	Uaroo
aragonite	Gregory Gorge
baryte	Mt Sandiman
*bobierrite	Wodgina
cacoxenite	Nullagine
cassiterite	Tabba Tabba Creek
chromite	Gorge Range
chrysoberyl	Wodgina
cinnabar	Mt Sandiman
corondum	Marble Bar
lithiophorite	Brumby Creek
monazite	Prairie Downs
paratacamite	Brumby Creek
pyrophyllite	Yinnietharrra
sphalerite	Mt Sandiman
sphalerite	Prairie Downs
tapiolite	Tabba Tabba Creek
thorogummite	McPhees Range
triphylite	Yinnietharra
turquoise	Nullagine
wodginite	McPhees Range
wodginite	Pilgangoora
zircon	Prairie Downs

(c) Murchison Division

aphthitalite	Wilgiemia
biphosphammite	Wilgiemia
chrysocolla	Gregg Well
urea	Wilgiemia
variscite	Yarlarweelor

(d) South West Division

apatite	Jerdacuttup River
chabazite	Boyup Brook
chalcocite	West River
chalcopyrite	West River
chalcopyrite	Paynes Find
clinobisvanite	Paynes Find
clinozoisite	Rothsay
corondum	Munglinup
covellite	West River
gahnite	West River
galena	Paynes Find
holmquistite	Greenbushes
ilmenite	Morawa
molybdenite	Paynes Find
nontronite	Rothsay
plattnerite	Paynes Find
pucherite	Paynes Find
pyrite	West River
scheelite	Danberrin Hill
scheelite	South Burracoppin
sphalerite	West River
tapiolite	Paynes Find
wodginite	Greenbushes
zircon	Morawa

(e) Central Division

azurite	Mt Pleasant
*chalconatronite	Carr Boyd
chalcopyrite	Nepean
clinobisvanite	Try Again Bore
danalite	Coolgardie
dolomite	Windarra
garnierite	Scotia
grossular	Nepean
ixiolite	Coolgardie
kyanite	Woolibar
malachite	Mt Pleasant
marcasite	Agnew
opal	Cowarna
paratacamite	Scotia
pecoraite	Scotia
pyrochlore	Coolgardie
*retgersite	Mt Keith
rutile	Woolibar
siderite	Windarra
sphalerite	Mt Celia
*stichtite	Mt Keith
takovite	Agnew
thenardite	Carr Boyd
trona	Carr Boyd
wulfenite	Kanowna

(f) Eucla Division

biphosphammite	Madura
clinozoisite	Bellinger Lake
grossular	Bellinger Lake
*rhodochrosite	Cape Pasley
rhodonite	Cape Pasley
spessartite	Cape Pasley
syngenite	Madura
taylorite	Madura
tephroite	Cape Pasley
*uricite	Madura

Specimens of all the above minerals have been added to the Departmental reference collection.

Complete Analyses

Requests for 194 complete analyses were received during the year. Ninety-five such analyses were reported, involving 2 159 determinations, an average of 23 determinations on each sample.

Most samples originated from the Geological Survey.

As the X-ray fluorescence unit was in full-time operation, mainly on large batches of geochemical samples, an appreciable proportion of these complete analyses were carried out by classical methods.

Two complete analyses of interest are tabulated below:

	orthopyroxene* per cent	feldspar† per cent
SiO_2	49·26	66·49
Al_2O_3	1·49	21·09
Fe_2O_3	2·12	0·12
FeO	35·70	<0·02
MgO	9·77	0·02
CaO	0·69	0·96
Na_2O	0·01	9·85
K_2O	0·02	0·92
H_2O+	0·46	0·19
H_2O-	0·13	0·18
TiO_2	0·12	<0·01
P_2O_5	0·04	<0·01
Cr_2O_3	<0·01	
MnO	0·52	<0·01
Rb_2O	....	0·004
Total	100·3	99·8

< less than

* An orthopyroxene extracted from a quartz-orthopyroxene granulite near Toodyay, analysed to determine relationship to metamorphism of banded iron formation. Analyst J. R. Gamble.

† Snowstone Wialki feldspar of commercial potential. Analysis indicates approximately 84 per cent albite, 6 per cent microcline. Analyst K. J. Renton.

Analysis of a sulphide mineral posed some interesting problems and gave the following results:

	per cent
SiO_2	7.36
Al_2O_3	0.09
Fe	37.47
CaO	0.18
MgO	9.61
H_2O^+	3.48
H_2O^-	0.14
CO_2	0.50
Ni	12.23
Co	0.28
Cu	0.06
S	27.97
Total	99.37

Analyst J. R. Gamble.

Ferrous iron could not be determined due to the reducing effect of hydrogen sulphide evolved during acid attack on the pyrrhotite present.

Because of the variable iron to sulphur ratios in pyrrhotite (and pentlandite), iron present in excess of that required to balance the sulphur content cannot be calculated and allotted to any possible iron oxide present.

Analysis of the material remaining after removing the hydrochloric acid soluble fraction (mainly pyrrhotite) gave Fe 11.3, Ni 11.0, S 12.3 per cent in which the three elements are in molecular proportions close to the theoretical pentlandite formula. Most of the nickel is thus present as pentlandite.

Samples representing the Mt. Margaret and the Jeedamya meteorites were analysed for the Museum Meteorite Advisory Committee using the fractionation and chlorination process designed to give added meaning to such analyses.

Talc samples from Mt. Seabrook and Three Springs were analysed at the request of the Geological Survey. As well as the usual major constituents, 15 trace elements were also determined. One analysis from each source is listed below, neither of which is related to commercial parcels.

	Mt. Seabrook per cent	Three Springs per cent
SiO_2	64·34	61·96
Al_2O_3	0·25	0·21
FeO	0·46	0·75
Fe_2O_3	<0·05	<0·05
CaO	0·26	0·01
MgO	30·10	32·26
Na_2O	0·02	<0·01
K_2O	<0·01	<0·01
CO_2	<0·01	<0·01
P_2O_5	0·05	0·01
H_2O+	4·58	4·68
H_2O-	0·07	0·23
TiO_2	<0·01	0·01
Total	100·1	100·1
	ppm	ppm
Cr	20	57
V	<10	<10
Zn	5	37
Pb	14	25
Cu	6	11
Co	3	12
Ba	110	130
Zr	<5	<5
Rb	<5	<5
Sr	5	<1
Li	3	<1
Ga	0·2	0·3
B	9	22
Mn	18	32
Ni	24	11

Analysts : E. J. Tovey (Mt. Seabrook)
R. S. Pepper (Three Springs)

	per cent	per cent
Brightness	90·7	84·2
Yellowness	3·2	5·8

Brightness expressed as a percentage relative to MgO, was measured at wavelength 570 nm. Yellowness is defined as the difference between brightnesses measured at 570 nm and 457 nm.

Mineral Identifications and Analyses

Items are considered under this heading roughly in the order of Hey's mineral indexing, namely native elements, sulphides, oxides, carbonates, silicates through to vanadates, sulphates and tungstates.

A small grain of zinc found in a specimen of copper ore from the Odin mine at Mt. Pleasant has yet to be authenticated as a natural mineral occurrence. Noted for its abundance of native copper, the ore from this mine also contains native silver.

One of the most interesting sulphide minerals received was cinnabar which, with baryte, was identified in samples from the vicinity of Mt. Sandiman.

Specimens from the Ark Gold Mine at Paynes Find contained molybdenite, chalcopyrite, galena, pyrrhotite, pyrite and gold. They represented the first recorded occurrence of molybdenite and chalcopyrite from this locality.

Corundum crystals were received from Yandeearra, some with small inclusions of rutile and thin crusts of mica. A corundum specimen from Byro, weighing over 11 kg, showed inclusions of margarite.

Precious opal was received from a deposit eight miles east of Cowarna homestead but the commercial significance of the deposit is as yet unproven.

Fluorite was contained in a copper-stained rock from the Koolyanobbing area, associated with epidote, quartz, altered hornblende and a little nontronite.

Analyses of a great many limestones were carried out in connection with a review by the Geological Survey of limestone reserves adjacent to the Metropolitan area.

Fifty-six drill hole samples from the Wittenoom dolomite were also analysed for carbonate and non-carbonate carbon and phosphorus. Ba, Ca, Fe, Mn, Mg, Cu, K, Na, Pb, Sr and Zn were also determined on a selected number. Nineteen of the samples were further examined by diffractometry and a semi-quantitative estimate was made of the quartz, feldspar, clay (illite-muscovite), dolomite and chlorite contents.

A primitive white mineral pigment from the Carson River Station was identified as huntite, an uncommon form of calcium magnesium carbonate.

A sample taken for damsite evaluation in the Gregory Gorge area was found to be aragonite. Materials from another dam site on Moochalabra Creek were submitted for determination of percentage quartz, nature of clay minerals and their cation exchange capacity.

Among the many silicate minerals examined, the rare green chromium garnet, uvarovite, was identified in a diopside rock from Heaneys, near Southern Cross. This species is usually found in ultrabasic serpentinite, sometimes also with chromite deposits and is of considerable geochemical interest. This particular sample had a density of 3.82, refractive index 1.825 and an a cell dimension of 11.928Å. Its molecular composition approximated 3 uvarovite: 1 grossular.

Other samples containing garnets came from the Eucla Division. One from Cape Pasley, consisted of spessartite with rhodonite, rhodochrosite and tephroite: a second, from Bellinger Lake was essentially clinozoisite with grossular and hornblende. Grossular was also present as a wide vein in Nepean sulphide ore containing chalcopyrite, pyrrhotite and pentlandite, with calcite and epidote.

A generous supply of the lithium-bearing amphibole, holmquistite, was donated by Greenbushes Tin N.L. from their mining site in Floyd's Gully, Greenbushes. It was associated with quartz and a little stibiotantalite, columbite and cassiterite, and represented only the second occurrence of the mineral in W.A. recorded by us. Pure material is being prepared to allow of a complete chemical analysis of this uncommon mineral.

Partially metamict allanite was identified in a syenite rock from the margins of Lake Shaster, about 50 km east of Hopetoun.

A specimen from the Nullagine area, pseudomorphous after a mineral of good cleavage, proved to be an intergrowth of quartz and pale green muscovite. Though believed to be pseudomorphous after spodumene, the lithium content was only 100 ppm.

A few crystals from the heavy fraction of a mineral sand from an unknown W.A. locality were identified from their X-ray powder pattern as the rare-earth-bearing mineral kemmlitzite. The higher refractive indices of the crystals as compared to the type mineral from Kemmlitz in Saxony probably indicate greater substitution of rare-earths for strontium.

A specimen from the Pilbara area was reported in 1972 as being an aggregate of fine-grained illite and pyrophyllite. A sample received in 1974 from another locality in the Pilbara (11 km S.S.W. of Mt. Olive) appeared very similar in hand specimen but gave a diffraction pattern similar to muscovite $2M_1$ polymorph. For confirmation, diffraction patterns of both samples were repeated, using the 11.4 cm diameter camera in place of the smaller 5.73 cm one, whereby the diagnostic differences were amplified, the low angle line of muscovite clearly showing at about 10Å while that of pyrophyllite occurs at about 9Å. Chemical analysis of the 1972 sample showed 4.82 per cent K_2O, while the K_2O content of the 1974 sample was 8.13 per cent. This gave further confirmation of the X-ray diagnosis, as published K_2O figures for the relevant minerals are pyrophyllite trace to 0.2, muscovite 8 to 10, illite 5 to 10 per cent.

A rock from Lionel, thought to have commercial potential as a jade substitute, was composed of antigorite. No jadeite or nephrite was present.

Biotite concentrates from 20 granites in the North West Division showed tin concentrations ranging from less than 10 ppm up to a maximum of 220 ppm.

A black tourmaline was collected from a vicinity on Yinnietharra close to that from which particularly fine crystals of dravite had previously been recorded (for complete analysis of this dravite see G.C.L., A.R. 1973). Partial analysis of the black tourmaline showed FeO less than 0.1, Fe_2O_3 4.43, MgO 9.85 per cent. These figures are much lower in iron and higher in magnesium than in any published analysis of schorl, and high-iron dravite seems the logical classification for this black tourmaline which occurs in crystals fully as spectacular as those of the dravite.

Both varieties occur in a matrix of phlogopite which was examined to test its potential as a commercial expanding mica. However, it showed only a fourfold maximum volume expansion, compared with increases from 12 to 26 by industrial vermiculites.

An investigation at bench level was carried out to examine the feasibility of producing a commercial kyanite concentrate from heavy mineral concentrates similar to those produced in the Bunbury-Busselton area. In the normal treatment of these heavy sands the relatively small amounts of kyanite usually report in the zircon fraction and present separation problems.

The material examined was a concentrate consisting of zircon and kyanite, with lesser amounts of garnet, spinel, monazite, rutile and corundum. It was subjected to magnetic separation on a Frantz electromagnet and the non-magnetic fraction further split by gravity separation in Clerici solution. The light fraction of the non-magnetics contained most of the kyanite, together with some corundum and minor amounts of spinel and other accessories.

An analysis of this kyanite-rich fraction (representing about 60 per cent of the original sample) gave the figures tabulated below (U.S. National Stockpile Specifications for refractory grades of kyanite are tabulated for comparison).

	W.A. sample per cent	U.S. Specification Grade A per cent	Grade B per cent	Grade C per cent
Al_2O_3	63·9	min 59·0	60·0	59·0
SiO_2	34·6	max 39·0	37·5	38·0
Fe_2O_3	0·47	max 0·75	1·50	1·25
TiO_2	0·21	max 1·25	2·00	2·00
CaO	0·10	(a) 0·20	0·20	0·20
MgO	0·46	....	....	....
Na_2O	0·01	(b) 0·20	0·20	0·50
K_2O	0·05	....	....	....

(a) CaO + MgO, max.
(b) Na_2O + K_2O, max.

The sample meets specification requirements except with respect to (CaO + MgO). The excessive MgO figure is due mainly to trace amounts of spinel, which may possibly be reduced by further electrostatic treatment. The differential between the electrostatic susceptibilities of kyanite and spinel are poorly documented and could no doubt vary with the type of spinel, a mineral having many isomorphous replacements.

Interesting pegmatite minerals were received from Yinnietharra. One, from near White Well, was a radioactive hard glassy metamict mineral, with a thick crust of pale brown earthy material, containing inclusions of tantalite/columbite. Secondary cavity infillings contained a white powdery mineral whose X-ray diffraction pattern resembled that of pyrochlore, while the glassy portion, optically inhomogeneous, after heating to 750°C also gave a pattern resembling pyrochlore plus another phase or phases.

The glassy material was shown by electronprobe analysis to contain uranium 13 per cent, niobium 12 per cent, iron 1 per cent, titanium and tantalum each 0.2 per cent. From the imperfect data available it seems that the sample in its unaltered form would have been considered essentially a uranium-bearing pyrochlore-type mineral.

A second resinous metamict mineral from the same pegmatite was also optically inhomogeneous varying in colour from greenish-yellow to brown. After heating to 750°C its X-ray pattern suggested a mixture of pyrochlore and betafite.

A vuggy pegmatite sample from the Barbara mine at Coolgardie contained an interesting series of minerals, including clear platy crystals of albite, blue-grey apatite, black ixiolite, yellow-brown danalite, soft black pyrochlore and siderite.

Wodginite was identified for the first time in this Division in the Greenbushes area in a suite of samples received through Greenbushes Tin N.L.

Specimens of doubtful identity from the Simpson Collection were examined by X-ray techniques and some interesting species confirmed, amongst them being thorogummite and wodginite from McPhees Range, clinozoisite from Wodgina, columbite, wodginite, microlite from Pilgangoora, tanteuxenite, pyrochlore, monazite, columbite from Eleys and a range of minerals from Greenbushes, including stibiotantalite, gahnite, topaz and wodginite.

Work has continued on the suite of essentially phosphate minerals from Milgun Station briefly referred to in our 1973 Annual Report. The paper on collinsite has been published in which the minerals identified at that stage are listed. Since that time, further identifications have been made, including goyazite, mitridatite, jarosite, opal and an alunite-like mineral.

Work by Professor P. Moore of the University of Chicago on pegmatite phosphates has revealed new minerals which also occur in the Milgun deposit. One of these is jahnsite, another an as yet unnamed basic phosphate of calcium and aluminium. Work on the latter is being carried out in co-operation with the British Museum.

A radioactive sandstone from Prairie Downs station owed its radioactivity to its monazite content. Other heavy minerals present were zircon, magnetite, epidote and tourmaline.

Six commercial monazite concentrates were analysed for total rare earths, thorium, titanium and insoluble material.

A spectacular specimen from Winning Pool consisted of a 2 cm diameter central core of gypsum surrounded by concentric crusts of radiating baryte and thin laminae of gypsum building up to a pineapple-shaped specimen about 12 cm in diameter.

Sulphate minerals received from 14 km east of Kalgoorlie included pickeringite, halotrichite, copiapite, jarosite and alunogen, while jarosite was identified as a powdery mineral in veins in a rock from 26 km SSE of Cowarna station.

Shale samples from Glen Ross Creek on the Mt Vernon station were encrusted or stained by sulphate minerals, including copiapite, pickeringite, alunogen, epsomite, and possibly melanterite. An efflorescence of epsomite occurred on a shale from Brumby Creek which also showed green encrustations of paratacamite and black stains of lithiophorite.

The bulk of a rock specimen from Uaroo consisted of very fine-grained quartz and a small amount of muscovite and carbonaceous matter. Throughout the body of the rock small white spots occurred which were found to consist of a fine-grained mixture of alunite and quartz, unexpected ingredients in what had been considered an unmetamorphosed rock. Later samples, also from the Bangemall Basin, contained infillings of alunite in cavities originally occupied by a mineral of cubic form, probably pyrite.

Scheelite-bearing samples were received from Danberrin Hill and South Burracoppin.

Three batches of samples were received at intervals from Geological Survey in connection with a proposed Bulletin on molybdenum, tungsten, chromium and vanadium. In the first batch, two samples, from Callie Soak and Yandhanoo Hill, each contained wolframite while four samples of a later batch from Tallanalla contained vanadium ranging in concentration from 0.2 to 1.1. per cent V_2O_5. The latter samples were composed mainly of ilmenite and martite (in some cases with relict magnetite) and some weathering products.

Analyses of two tungsten-bearing minerals, from Cookes Creek and Callie Soak respectively, gave the following results

	Cookes Creek	Callie Soak
Fe, per cent	10.6	12.9
Mn, per cent	6.06	3.54
Fe: Mn ratio	1.75	3.6

From Hey's classification of the iron manganese tungstates, viz:

Fe: Mn	Species
greater than 4	ferberite
4 to 0.25	wolframite
less than 0.25	hubnerite

these two minerals would both be classified as wolframite.

Other material from Cookes Creek contained a manganese mineral isostructural with the hollandite group which includes also the lead-bearing coronadite and the barium-rich cryptomelane.

Nickel minerals were examined from most of the recognised nickel developments, including Scotia, Windarra, Agnew and Mt Keith.

Of the sulphides, pentlandite, violarite, phyrrhotite, pyrite and chalcopyrite were common to most, with some valleriite from Scotia and marcasite from Agnew (nickel hexahydrate had formed on the surface of some Agnew samples).

A specimen from a shaft dump at Mt. Keith consisted of magnetite, pyrite and magnesite crystals on a serpentinite containing magnesite, morenosite ($NiSO_4 . 7H_2O$) and stichtite. This represents the first W.A. occurrence recorded by us of the basic magnesium chromium carbonate, stichtite. The mineral is sometimes so highly ferriferous that Fe may exceed Cr. Partial analysis of a small fragment of stichtite from Mt Keith showed Cr_2O_3 14.5, Fe_2O_3 6.42 per cent giving a Cr_2O_3 to Fe_2O_3 ratio of 2.3. Ratios of 3.5 and 1..2 in stichtites from Dundas (Tasmania) and Transvaal respectively show the variable composition of this species.

Takovite, $Ni_5Al_4O_2(OH)_{18}$ $6H_2O$, was identified in samples from the Perseverance Mine at Agnew as was nickel hexahydrate occurring as a surface coating.

Work has been carried out on a new mineral from Carr Boyd Rocks. It is a sulphate-bearing hydroxide of nickel and aluminium and a paper describing the mineral (carrboydite) is being prepared jointly with an officer of the C.S.I.R.O.

From the Lionel area a rock was received composed mainly of serpentine polymorphs, including apple green nickel lizardite, light green nickel chlorite and dark green pecoraite. Minor minerals present were magnetite, opal and manganese oxides.

A specimen of manganese mineral from 1.3 km southeast of Mt Walter gave rather poor X-ray diffraction patterns having some resemblance to those of todorokite and lithiophorite but would most safely be described as a cobaltiferous and nickeliferous wad. Chemical analysis showed Mn 30.6, Fe 0.17, Ni 1.16, Co 0.52 per cent.

Work on lead minerals included an ore from the Kimberley area assaying 39.6 per cent lead and which contained also 1.08 per cent antimony, 5 per cent copper and 20 and 620 grams per tonne of gold and silver respectively.

Dump material from the Devonian Lead Mine showed a bulk density between 1 480 and 1 540 kg per cubic metre and a roughly 2 to 1 zinc lead ratio. It showed a very much higher silver content relative to lead concentration than did a high-grade galena sample from the Ashburton area.

A study of samples from the various mine dumps in the Northampton area was made to determine the forms in which the lead, zinc and copper minerals occur.

Germanium, indium and arsenic were determined on products resulting from experimental work by Murdoch University staff on recovery of rare elements from baghouse dusts.

Sodium, potassium and strontium were determined in 45 rock samples from the Rason, Neale and Plumridge areas to enable a suitable selection to be made for Rb/Sr radiometric dating purposes. The sodium range was mostly between 1 and 3 per cent but potassium and strontium covered considerably wider proportional ranges. An isolated strontium figure of 710 ppm was obtained but the majority were less than 300 ppm.

Three samples of salt were analysed for potassium and bromine contents, the latter ranging from 60 to 110 ppm.

Gallium, rubidium and strontium were determined on fifty shale samples taken in connection with the geochronology and paleo-environmental analysis by the Geological Survey of the lower Proterozoic shale of the Hardey Sandstone in the Nullagine area. Selected composite samples were also analysed for their potassium contents.

The composition of the olivine in the Nullagine meteorite was determined so that the meteorite could be accurately classified. A single crystal study by Weissenberg camera of olivine grains gave the following refined unit cell:

a 4.767±0.002Å

b 10.249±0.003Å

c 6.001±0.0025Å

From this b dimension and the known values of b for pure forsterite (Mg_2SiO_4) and pure fayalite (Fe_2SiO_4), the fayalite content of the meteorite olivine is calculated as 19±1 per cent, placing the meteorite in the group characterised by low fayalite content of the olivine component.

A study of Hamersley Range iron ores was commenced during the year, the main objective being to produce evidence for the time and nature of ore genesis. A preliminary suite of iron ore specimens collected from the region displayed a number of noteworthy features, which point to ore development in the Precambrian. Among these were the pressure solution of martitised magnetite crystals where they adjoin microband boundaries, and pronounced dimensional orientation of hematite grains in recrystallised martite ore. The latter is regarded as strong evidence for ore development during an orogenic period.

Future work will be directed to studying the conversion of specific types of BIF to ore, the search for more cases of hematite fabric, and analysis of the fabrics by use of the X-ray diffractometer.

Building Materials

1. Aggregates

A number of mortar bar tests, commenced during 1973 were completed in 1974. The results are summarised below together with potential alkali reactivity figures obtained by the short chemical method on the same aggregates.

	Mortar Bar test		Chemical test	
Aggregate No.	Maximum expansion* parts/100 000	Cement alkalinity Na_2O%	Reduction in alkalinity Rc	Dissolved silica Sc
1	12	0·51	28	21
2	6	0·51	108	27
3	8	0·45	47	5
4	3	0·51	50	33
5	6	0·55	2	19
6	8	0·55	6	25
7	8	0·55	36	41
8	13	0·55	9	21

* After at least 6 months curing.

An aggregate is considered potentially reactive if—

(a) expansion of mortar bars after 6 months curing exceeds 100 parts per 100 000;

(b) Sc is greater than $35+\frac{1}{2}$Rc (when Rc is less than 70);

(c) Sc is greater than Rc (when Rc is greater than 70).

The mortar bar tests thus confirmed the chemical results indicating that none of these aggregates would be reactive towards the alkalies of cement.

The cement used in all cases was local cement commercially available at the time, the total alkalinity of which ranged from 0.45 to 0.55 per cent expressed as Na_2O. Mortar bar specifications recommend in general a cement of alkalinity in excess of 0.60 per cent but none such was available.

Aggregate Nos. 1, 2 and 4 were sand or shingle from rivers in the Pilbara, devoid of obvious chert or opal, No. 3 was a blast furnace slag and Nos. 5 to 8 were material from near-metropolitan quarries consisting essentially of weathered and fresh granite, with one schist.

A majority of the aggregates examined were for the State Housing Commission and were in connection with native housing schemes in the Kimberley area, namely the One Arm Point settlement at the mouth of King Sound and the Looma village near Camballin.

Eight samples were submitted from the One Arm Point-Lombardina area, all being sands consisting essentially of quartz, some containing appreciable shell material and accessory minerals. In some cases, organic matter was excessive while one contained an undesirable concentration of soluble salts, but samples were submitted that met every requirement specified for fine aggregate in concrete used for normal housing purposes.

A river sand and a coarse aggregate were examined in connection with proposed construction work at Looma village. Both were from the bed of the Fitzroy River. The sand, composed of quartz with minor feldspar and trace accessories, gave the rather unusual potential alkali reactivity figures of Rc = O and Sc = 32 millimoles per litre. These figures, by specification interpretation, indicate an aggregate borderline between innocuous and deleterious. However, a mineralogically similar material from another reach of the same river, showing Rc = O, Sc = 39, had some time previously caused no expansion in mortar bars after 54 weeks storage, and so the present sample could be regarded as safe for use in ordinary domestic construction.

A fine-grained rock from the Gregory Gorge dam site on the Fortescue river gave a potentially deleterious reaction (Rc 115, Sc 135). It was composed of chert and clay with some calcite as grains and minor quartz fragments.

2. Other.

Locally manufactured wire-cut bricks had been used in building a country hospital and were showing evidence of deterioration. Examination was requested of old bricks and bricks of more recent but still local manufacture for comparison purposes and to ascertain the reason for crumbling of the earlier batches.

The bricks were sectioned and examined visually, microscopically and by X-ray diffraction. Examination revealed a number of characteristics which would have an unfavourable influence on weather resistance. The presence of concentrations of ingredients with fluxing properties led to local fusion and the production of cavities up to a centimetre in diameter.

Poor mixing of ingredients was exemplified by pellets of pure white clay (now reconstituted as mullite and cristobalite) which had not bonded with the red clay matrix. Some surface fracturing related to bloating was evident and a very high porosity had resulted from the large number of sub-parallel fractures 0.5 mm wide and up to 1 cm long originating probably from excessive stress during shaping of the raw mix.

The more recently manufactured bricks still showed evidence of poor mixing and surface and internal fracturing.

Samples were submitted by Public Works Department in connection with problems being experienced with poor adhesion of render to brickwork in extensions to a district hospital. Mortars, render, raw materials and various brick types were examined.

Tests were made for original mix (on mortar and render), mineralogy and sizing (on mortar raw materials), surface characteristics, permeability and absorption (on bricks). The conclusion reached was that poor adhesion could have been due to excessively high lime content of the render and/or the highly glazed surface of the bricks.

State Housing Commission submitted a sample of unusual building material. It was a block stated to be made 70 to 80 years ago near the Beagle Bay Mission by kiln firing of a local material. The sample proved to be spongolite rock composed essentially of sponge spicules with associated diatoms and some detrital quartz grains.

This type of rock constitutes a considerable part of the Plantagenet Beds extending along the south coast from Albany eastwards beyond Esperance, but had not previously been recorded from the Kimberley area. The Kimberley rock differs from the Plantagenet spongolites in the lack of variety in the sponge spicules and in the presence of diatoms.

Along the south coast the compacted silicified form of spongolite has been used direct from quarries as a building stone in places such as Albany, Ravensthorpe and Esperance. The deposit from which the Beagle Bay sample originated has not been located.

Examination of a cement sample for a Government Department showed that it met specification requirements as regards chemical composition but not as regards the fineness index, falling beyond the specified range of 280 to 420 square metres per kilogram.

A proprietary cement-like material was submitted by the Public Works Department for identification. It was stated to be a concrete repair material. Examination by X-ray diffractometry showed its main components to be monocalcium aluminate and tetracalcium aluminoferrate with lesser amounts of tricalcium silicate. It was thus a high-alumina cement, similar to "Ciment-Fondu" and fulfilling much the same function as this fast-setting aluminous cement.

Dusts

Of the 1 547 dust samples received, the big majority originated from the Department of Public Health, mainly from various dust monitoring programmes initiated by that Department. Major sources of samples were—Perth (475 samples for lead, mainly from exhaust fume), Port Hedland (256 samples for iron and manganese), Rivervale (144 for lime), Esperance (140 for nickel, iron, copper), Kwinana area (90 for iron and alumina) and the Dampier-Roebourne area (72 for iron and copper).

Samples received from the same Department but having an emphasis on the health hazards associated with the dust rather than its polluting effects required determinations mainly of free quartz and asbestos fibres. A review by the State Mining Engineer of health conditions in gold assaying laboratories has led to a number of dust samples being analysed for lead originating from the litharge universally used in fire assaying for precious metals.

Owing to the health hazards associated with sand blasting using quartz sand, consideration is being given to alternative materials. Materials proposed to the Public Health authorities include nickel slag and ilmenite. Carefully sized fractions of the samples submitted for examination, together with a control sample of quartz, were subjected to identical conditions designed to produce measurable abrasion of the grains. At the end of an arbitrary four hour period, the percentages of the grains reduced to fines were nickel slag 1.5, ilmenite 2.0, quartz 0.12. It is concluded that the slag and ilmenite would be less effective than quartz as sand blasting agents and would, in addition, produce more dust. However, the free quartz content of the dusts would be extremely low, the slag containing less than 0.2 per cent of quartz and the ilmenite about 0.3 per cent.

Corrosion

An examination was made of a white deposit forming on a PVC insulated cable which had been laid in a galvanised duct suspended below a concrete roof. It had an alkaline reaction and proved to be essentially calcium carbonate and contained also traces of zinc carbonate. Such deposit would have no deleterious effect on the PVC but its alkalinity would lead to corrosion of the galvanised ductwork.

A corrosion product associated with deterioration of copper piping from a domestic hot water system was shown from its X-ray diffraction patterns to consist of chrysocolla ($CuSiO_3.2H_2O$) and, less predictably, deweylite ($MgSiO_3.2H_2O$).

The main corrosion product formed from a metal box recovered from the wreck of the Batavia was pseudoboleite ($Pb_5Cu_4Cl_{10}(OH)_8.2H_2O$) or the closely related compound having a similar X-ray diffraction pattern, boleite ($Pb_9Cu_8Ag_3Cl_{21}(OH)_{16}.H_2O$). Surface corrosion products included cotunnite ($PbCl_2$), anglesite ($PbSO_4$), phosgenite ($Pb_2CO_3Cl_2$) and chalcocite (Cu_2S).

A hard black stalactitic boiler deposit was shown by X-ray examination to contain dahllite (calcium phosphate), basic magnesium phosphate and serpentine (basic magnesium silicate), a well-documented type of scale common in boilers using phosphate-conditioned feed water.

Nickel hexahydrate was identified as an efflorescence on specimens of ore on permanent display in Stirling Gardens, Perth.

Metals, Alloys and Artificial Minerals

Work was carried out for the Consumer Protection Bureau on ferrous metal parts claimed to have been surface hardened by special treatment. The treatment gave the parts a copper-coloured finish.

Polished and etched sections of one of the samples (a metal sprocket) were examined microscopically and physically. No significant hard coating was observed, nor were any variations in grain structure or impact hardness.

Chemical examination of the surface layer indicated that the steel sprocket had been coated, probably electrolytically, with a coating of copper less than 50 nanometres thick.

Two out of three stainless steel safety treads for ladders were found to be deficient in specification requirements for molybdenum.

Among the spurious minerals received was an unusual sample from an unexpected site which proved to be massive calcium chloride. It had been found among seaweed above water level on a metropolitan beach. Its extreme solubility precluded its origin as flotsam and it is assumed it had been dumped from the land for disposal.

Fragments of zinc metal were retrieved from the coast near Lombardina Mission and from tin workings in the Port Hedland hinterland, while specimens proving to be metallurgical products were submitted from various localities.

Police Exhibits

A number of examinations were made at the request of the Criminal Investigation Branch of samples taken in connection with various criminal cases.

Soil samples taken from the scene of an alleged murder showed close similarities with mineral grains taken from a car suspected of being the vehicle involved.

Loose metal from the teeth of a hacksaw blade was found to be similar to that of the barrels of sawn-off shot guns used in an armed robbery but was of a type too common to provide indisputable connection between the two.

Glass from two different vehicles connected with the same hold-up had identical refractive indices but here again the indices were within the range shown by many common glasses.

Mineralogical comparisons were made between soil stains on clothing of the accused and soil from the scene of an alleged assault and rape.

Samples of soiled footwear and burnt residues were submitted for comparison for possible court evidence in connection with alleged arson at Dampier. A definite correlation was established between the burnt residues and material adhering to the footwear.

Samples of debris from the scene of an explosion were examined for the presence of significant remnants but none were detected.

Comparison was requested of samples from the mud flaps of a vehicle and from skid marks at the scene of an offence. In both cases the samples were quartz sands with minor mineral and organic accessories, most of which were common in the metropolitan area. However, the presence among the accessories in each case of relatively uncommon diatoms and sponge spicules, together with overall similarity in shape and size distribution of the quartz particles, provided evidence consistent with the two samples having a common source.

In other police cases, similarity was shown between paint flakes from different sources, and dissimilarity was established between metal from a rifled safe and metal fragments found on a car seat.

An investigation for the Motor Vehicle Inspections Branch was carried out in conjunction with the Industrial Chemistry Division to examine the cause of a fatality resulting from fire in a motor vehicle. The temperature distribution in a vehicle similar to that involved in the fatality, and fitted with the latters faulty muffler, was measured after subjecting the vehicle to various driving conditions.

The vehicles insulating materials, foam plastic and fibre, were subjected to thermal decomposition by D.T.A. and a visual burning test in air and oxygen.

The results of the investigation indicated that the temperatures so observed would not have been sufficient to cause combustion.

Miscellaneous

Work has continued, in conjunction with the Department of Agriculture, on extracts from urinary calculi and urinary sediments from sheep pastured on subterranean clover. It is hoped ultimately to publish the full optical and X-ray diffraction properties of the three compounds involved.

Examination, by chemical analysis and X-ray diffraction, of material taken at the outfall in Cockburn Sound of the effluent from a fertilizer plant showed it to consist of gypsum (in excess of 90 per cent) with lesser amounts of apatite, halite, fluorite and magnesium sulphate.

Samples from the seabed and from the mound formed by this effluent were analysed for trace amounts of the toxic elements mercury, cadmium, lead and arsenic and a report prepared for the Environmental Protection Authority. The work led to an investigation of the enhancement of trace cadmium figures when determined by atomic absorption in the presence of high calcium contents.

Work for the Explosives Branch was limited to determination of total oxidisable material and oil absorption on 6 samples of ammonium nitrate prills and sizing analysis of an aluminium powder. The oxidisable material in the nitrate prills was uniformly low, varying only within the range 0.007 to 0.017 per cent.

WATER DIVISION

General

Sample receivals during 1974 of 6 113 were 10 per cent higher than for 1973 and this is to be compared with annual increases since 1970 which have consistently been between 1 and 3 per cent. As in previous years the increases have been mainly the result of environmental aspects with perhaps some slight reduction in other areas. Environmental samples generally require more components per sample and the effective output has therefore increased by more than the 10 per cent indicated by sample numbers. This increased output has not been obtained without some detriment to other areas of equal importance.

Major items of equipment purchased during 1974 included a dual channel autoanalyser, which is intended for streamlining of present sample flow, but whose capacity for handling the intended components of the impending Australian Water Resources Council Network Survey samples will need to be assessed. A calculator, Monroe Model 1830, was also obtained and this has already given service well in excess of that intended at the time of its purchase, resulting in the saving of hundreds of man-hours per annum.

A definite commitment in relation to the Australian Water Resources Council Network Survey samples was anticipated during 1974, but this did not eventuate. Planning for staff and equipment for this activity has therefore not advanced beyond the preliminary stage.

Mr. P. Jack attended the Sixth Federal Convention of the Australian Water and Wastewater Association in Melbourne and spent several days visiting kindred organisations in fruitful attempts to help solve some of our immediate pressing problems.

Mr. K. Browne attended the one week's course provided by Technicon in Sydney for the operation of the Autoanalyser and while interstate, visited the Engineering and Water Supply Department of Adelaide at Bolivar. Their Laboratories are well advanced in relation to Network Survey sampling and analysis at both the State and Federal level.

Mr. J. Weir's attachment to the Metropolitan Water Board's Laboratory at Leederville, where increases in analytical staff have already and will continue to occur, is proving a satisfactory arrangement for both Departments concerned. His liaison with officers of the Water Division continues.

Mainly because of our increasing role of an advisory nature in swimming pool practices to manufacturers, retailers, operators and householders, Mr. N. Platell addressed the Fifth Annual Conference of the Australian Institute of Pool Management at Fremantle.

Table 26 shows the source, type and number of samples received during the year. Increases with respect to environmental monitoring and surveys are obvious with Swan River Conservation Board and Peel Inlet Advisory Committee samples, but less obvious are the increases contributed by the Public Works Dept., the Metropolitan Water Board and Department of Environmental Protection.

TABLE 26

WATER DIVISION

	Agriculture Department	Consumer Protection Bureau	Environmental Protection Department	Fisheries and Fauna Department	Geological Survey	Metropolitan Water Board	Mines Department	Peel Inlet Advisory Committee	Public—Pay	Public Health Department	Public Works Department	Other State Departments	Swan River Conservation Board	Total
Corrosion	....	1	....	....	....	2	....	....	4	....	2	1	....	10
Deposits and Scales	....	....	....	....	....	3	....	....	2	....	9	....	1	15
Effluents	....	....	....	....	....	....	6	....	29	10	22	....	14	81
Investigations	....	1	....	....	....	....	1	....	3	....	3	....	....	8
Treatment Chemicals	....	1	....	....	....	20	....	....	1	....	1	....	....	23
Water—														
Fluoridated	....	....	....	....	....	796	....	....	....	1	680	....	....	1 477
General	17	1	10	128	235	1 855	5	....	396	56	950	11	....	3 664
Environmental Monitoring and Surveys—														
Leschenault Inlet	....	....	....	....	....	....	....	....	....	....	38	....	....	38
Peel Inlet and Harvey Estuary	....	....	....	....	....	....	....	65	....	....	....	....	....	65
Swan River	....	....	....	....	....	....	....	....	....	....	....	....	713	713
Various	....	1	....	2	....	1	1	....	6	1	2	5	....	19
TOTAL	17	5	10	130	235	2 677	13	65	441	68	1 707	17	728	6 113

Public Water Supplies

(a) Hills source reservoirs salinities: Wellington dam was the only Major "Hills" reservoir in the South West providing water for town supply, that did not respond to higher than average rainfall during 1973 and the increased clearing of the catchment area over the past several decades was considered to contribute to the cause. Results for 1974, with another higher than average rainfall now tend to reduce the emphasis of this clearing aspect because the salinity of the water in Wellington dam at the end of 1974 was only marginally higher than that of Mundaring weir and both had dropped to what are considered average salinity levels. Table 27 below lists years and levels of maximum and minimum mean annual salinity for the major Hills reservoirs since 1964.

TABLE 27.
SALINITY OF HILLS RESERVOIRS. 1964-1974.

Reservoir	Salinity as NaCl Annual Mean Maximum year	mg/l	Minimum year	mg/l	December, 1974 mg/l
Canning	1972	265	1964	140	180
Churchmans†	1972	110	1974	100	90
Mundaring	1972	445	1964	120	210
Nth Dandalup*	1972	140	1974	105	130
Serpentine	1972	190	1964	120	135
Victoria†	1972	235	1974	170	165
Wellington	1973	490	1964	140	225
Wungong*	1972	145	1974	125	135

* These are pipehead dams and reported figures are average for only winter and spring flow.

† Reliable records of annual mean salinities for these reservoirs do not go back as far as 1964.

(b) Fluoridated Waters: Table 28 below shows the number of samples received and the arithmetic mean of the levels of fluoride in fluoridated waters from the various centres practising fluoridation. The results show that Perth Metropolitan is being dosed exactly as intended, with four other centres being within the range intended. Samples from Mundaring and Wellington are marginally outside the range intended while those from Albany are significantly outside the range intended. These low results are again mainly due to poor feedability of the sodium silicofluoride used. The responsible shipment has now apparently been all used at the centres involved and higher mean values are anticipated during 1975.

TABLE 28.
FLUORIDATION OF WATER SUPPLIES

Supply	No. of samples	Mean level Fluoride, F mg/l	Intended level Fluoride, F mg/l
Perth Metropolitan	769	0·79	0·8±0·1
Mundaring Weir	101	0·68	0·8±0·1
Wellington	38	0·67	0·8±0·1
Albany	130	0·67	0·9±0·1
Collie*	76	0·72	0·8±0·1
Esperance	109	0·81	0·9±0·1
Geraldton	84	0·72	0·8±0·1
Manjimup	120	0·83	0·9±0·1

* Representing fluoridated water from both Mungallup and Wellington dams.

Samples of sodium silicofluoride submitted for analysis and which possess a high "feedability index", rated on screen analysis and moisture, nevertheless appear to have varied feedability based on visual free flowing characteristics and a more meaningful test than "feedability index" is therefore required.

A sample of insoluble material associated with feeding of sodium silicofluoride and which subsequently caused blockage problems was expected and shown to be insoluble calcium fluoride. Recommendations for its removal included the use of a 10 per cent alum solution.

(c) Depth samples from South Dandalup dam: Water from the South Dandalup dam is the least saline of all major source reservoirs serving the metropolitan area and depth sampling during 1974 confirmed the suspected deterioration of hypolimnion water during summer. Whether this deterioration will become less significant over a number of years, as has occurred at Canning, Mundaring and Serpentine will only be shown by future monitoring. South Dandalup winter run off water is frequently coloured at approximately 20 units and contains approximately 0.3 mg per litre of iron and therefore has a potential for continuing hypolimnion problems. The hypolimnion water is never reticulated as such. During late autumn and early winter mixing, the iron and manganese in the hypolimnion are significantly diluted and precipitated to give the figures indicated in the October sampling in Table 29. In summer part of this is redissolved in the hypolimnion but with present requirements of water this hypolimnion water is always more than 10 metres below the surface.

(d) Ord River Dam (Lake Argyle): Depth profile sampling has not been conducted at the Ord River dam but monthly samples representing the surface and depth have been submitted for analysis. The depth sample sometimes shows levels of iron and manganese approaching 1 mg per litre and this can be interpreted that layering exists. Climatic conditions at the Ord River are markedly different to those in the South West and stratification at the dam should be studied along with other already commenced studies associated with environmental aspects.

TABLE 29.
SOUTH DANDALUP DEPTH SAMPLES

Date	pH		Temperature		Dissolved oxygen		Sodium chloride, NaCl		Iron Fe		Manganese, Mn	
			°C		%		milligrams per litre					
	E*	H†	E	H	E	H	E	H	E	H	E	H
29/3/74	7·3	6·6	21·8	16·6	84	4	134	121	0·37	5·0	0·05	0·90
9/5/74	7·2	6·9	17·1	15·7	62	4	133	121	0·51	7·4	0·07	1·0
10/10/74	7·0	7·0	14·5	14·5	68	68	105	105	0·05	0·05	<0·05	<0·05
19/12/74	7·4	6·6	23·0	15·8	85	27	111	108	0·09	0·15	<0·05	0·12

* Mean values for samples in the epilimnion profile.

† Mean values for samples in the hypolimnion profile.

(e) Moora town supply: A new bore at Moora with a production of approximately 100 Kilo litres per hour and with markedly reduced salinity and hardness values compared to that already serving the town supply contained levels of iron and manganese at 5.0 and 0.15 mg per litre respectively. Field testing incorporating aeration, pH adjustment, chlorination and sand filtration showed a number of alternate procedures for reducing iron and manganese levels below 0.1 and 0.05 mg per litre respectively, levels which are considered maximum for satisfactory chlorination and reticulation procedures.

Shallow Ground Waters for Metropolitan Supply

Waters from all bores serving metropolitan treatment plants are comprehensively analysed, involving at least 22 components and fluctuations in levels of pertinent components are regularly checked. These shallow ground waters include the Mirrabooka and Gwelup series which are already serving their respective treatment plants; the Wanneroo series which is intended for its treatment plant to be completed in 1975 and other series at Gingin, Pinjar and Lake Thompson which are intended for use in the near future.

(a) Mirrabooka: Laboratory, pilot plant and full scale plant trials have again been carried out during the year. Bentonite addition at economical rates of 5 to 8 mg per litre was shown to be of no benefit although higher dosage rates indicated some slight improvement. Trials with chlorinated ferrous sulphate at full scale plant level were not decisive; and although laboratory and pilot plant trials indicated satisfactory performance at upflows of 1.5 metres per hour a wide variety of problems prevented a balanced full scale trial. The need for persistent chlorine levels throughout the slurry pool of the full scale plant was dramatically demonstrated when the chlorine dosage was raised to give a positive residual at the clarifier outlet. The chlorine requirement to breakpoint for 20 mg per litre of iron, added as ferrous sulphate, to the raw Mirrabooka water was 18 mg per litre, but was expected to be significantly lower because of the time lapse between aeration of the ferrous ion and the point of chlorine addition. A positive chlorine residual did not appear at the clarifier outlet until the chlorine dose had been increased to 35 mg per litre. Apparently the organic matter associated with the raw water colour and attached to the hydrated iron oxide in the slurry pool where it had a contact time with the chlorine for more than 24 hours, had appreciably raised the calculated chlorine requirement of the raw water (based on ½ hour contact).

Sludge recycling, at laboratory level, using preformed sludge from the full scale plant, indicated an economical advantage in a slight reduction of alum requirement and pilot plant trials completed during 1974 and planned for 1975 should enable an assessment of its likely economical advantage.

A recommendation to chlorinate to breakpoint at the Mirrabooka works outlet, to be supported by occasional shock dosing of the treatment plant was made in 1974. This chlorination practice was to replace the former practice of continual marginal chlorination at both the inlet and outlet of the treatment plant, which was apparently unsuccessful in keeping algal counts in the holding reservoir at adequate levels. The new chlorination treatment was implemented with a nett result in chlorine saving and significantly reduced algal counts in the holding reservoir.

(b) Gwelup: The raw water, which required only iron removal, commenced treatment at the Gwelup plant in December, 1974. The treatment does not involve a coagulant aid, the raw water containing 5 to 10 mg per litre of iron requires alum only as a primary coagulant. Although a less complex treatment system than an upflow clarifier could be used, the inbuilt safety factor associated with moderate alum dosages to a shallow unconfined water closely associated with suburban activity is desirable.

(c) Wanneroo: The raw water for treatment is very similar to that at Mirrabooka, i.e. a colour removal problem, and the proposed plant, although of a significantly different design, is anticipated to require similar levels of treatment chemicals.

Environmental

With the exception of the study of farm dam contamination in the Narrogin area, all other studies for contamination and pollution that were carried out in 1973 were continued during 1974.

Additional areas and factors during 1974 include:

(a) Laporte Effluent: The present effluent disposal from Laporte is by pumping the raw effluent into limesand dunes between Leschenault Inlet and the Indian ocean, the neutralised effluent entering the ocean only by seepage over a broad area beyond the line of the breakers. In a new disposal area the neutralised effluent entering the ocean is mainly sulphates and bicarbonate of calcium but as time progresses, increasing quantities of iron are also present. A series of boreholes at predetermined sites and depths in a new disposal area are being regularly sampled to observe the flow pattern of the neutralised effluent. Although the neutralised effluent runs only into the ocean, some contamination of the natural aquifer adjacent to the Leschenault Inlet near an old disposal site is evident. Its flow into the estuary has been prevented by a natural impervious layer. Regular samples from such sites show varying degrees of contamination with a seasonal variation. The levels of sulphate and bicarbonate of calcium and magnesium reach as high as 5 000 mg per litre but iron levels have not exceeded 60 mg per litre.

Apart from iron, its most troublesome component at levels of 5 000 mg per litre, other metal determinations on the effluent included arsenic, beryllium, cadmium and mercury which are present at concentrations of less than 0.1 mg per litre, lead which is present in concentrates varying between 0.1 and 1.0 mg per litre, and chromium, copper, nickel, zinc and vanadium which are present in the concentration range 1 to 10 mg per litre.

(b) Swan River depth sampling: As a result of numerous fish deaths in an area extending several miles upstream of the Narrows during early May, for which oxygen deficiency was responsible, a monthly survey of depth samples from eleven selected sites to as far upstream as Ashfield was commenced in July. Four samples are collected at each site and analysed for dissolved oxygen, chloride, nitrogen fractions and phosphorus. The monitoring is intended for a 12 month period at the end of which the results will be published. The results of testing to date, from sites downstream of "the Narrows", are in agreement with earlier published reports; namely that a "sill" exists at the mouth of the Swan causing an oxygen depleted saline layer to develop at depth as winter progresses into spring. This oxygen depleted layer is gradually re-oxygenated by sea water as summer progresses. There have apparently been no previous reports on samples upstream of "the Narrows" and here the effect is in direct contrast to that downstream. There is no oxygen depletion at depth during winter but oxygen levels deteriorate as summer progresses. The cause of this deterioration is considered to be decomposition of organic material being in the river or contamination from local drains during periods of comparatively low river water movement.

(c) Effluents into the Swan River: Regular 3 monthly surface sampling of the Swan River from 49 sites is undertaken primarily to detect unusual changes in the river and sampling sites are accordingly located close to discharge drains etc. The results of analyses of these regular samples have led to detailed inspection of some factory sites to locate the source and quantify the extent of the contamination. Two such inspections included a brewery and a fertiliser works. The brewery problem was due to excessive spillage during beer transfer within the factory, the B.O.D. of beer being 90 000 mg per litre. The problem at the fertiliser works was due to seepage of scrubber water from a holding pond together with additional seepage from underground water leaching of "spent" pyrites used for sulphuric acid production during the 1940's. The scrubber water appears to be responsible for acid, fluoride and phosphorus and the "spent" pyrites for acid, iron and sulphate. The main items of concern to the river water are the increased phosphorus level which promotes organic growths and also the iron which is deposited as a brown deposit close to the point of discharge. The other mentioned components do not significantly alter the levels of components already in the river water.

(d) Peel Inlet and Harvey Estuary: During the normal 3 monthly surface sampling of this area, additional depth samples have been collected from those sites where layering or stratification could be predicted. A salinity layer developed at the comparatively deep Mandurah bridge site during winter and spring but had disappeared by mid-summer. Oxygen depletion was not associated with this saline layer. The Murray River at Ravenswood began to develop at depth a warmer more saline layer with oxygen depletion by mid-summer. Other sites in the system had only marginal differences in chloride levels between the surface and depth samples.

An algal bloom, more prolific than that experienced in 1973, again developed during 1974 and was persistent for at least several weeks during October. The species was the same as 1973, "Nodularia Spumigena", and apart from a "soupy" appearance of the water its main effect was to raise the pH value to more than 9, raise the dissolved oxygen level up to 150 per cent saturation and also raise the albuminoid plus free ammonia and total phosphorus values to an abnormally high level. The nutrients considered responsible for the bloom are derived mainly from the Harvey River with some contribution also from the Murray and are considered to be the result of normal farming practises.

(e) Sewage effluent—metal levels: Samples of raw and treated sewage from Perth metropolitan and Albany sewage works were analysed for a variety of components to give the following results. The levels reported are total and include all suspended material.

TABLE 30
METALS IN SEWAGE EFFLUENT

Component		Raw	Primary effluent	Secondary effluent
			range of values milligrams per litre	
Arsenic	As	<0·02	<0·02	<0·02
Barium,	Ba	0·14 –0·49	0·10 –0·21	0·10 –0·18
Cadmium,	Cd	<0·02	<0·02	<0·02
Chromium,	Cr	0·01 –0·74	0·01 –0·04	<0·01 –0·05
Copper,	Cu	0·21 –0·53	<0·05 –0·12	0·05 –0·14
Fluoride,	F	0·8 –1·2	0·5 –1·1	0·6 –0·8
Iron,	Fe	1·2 –1·8	0·06 –0·81	0·80 –1·2
Lead,	Pb	0·19 –0·29	0·02 –0·10	0·19 –0·24
Manganese,	Mn	0·06 –0·13	0·03 –0·08	0·01 –0·04
Nickel,	Ni	0·02 –0·04	<0·02	0·02 –0·04
Selenium,	Se	<0·001–0·001	<0·001	<0·001–0·001
Silver,	Ag	<0·02 –0·06	0·02	<0·02 –0·03
Tin,	Sn	<0·1	<0·1	<0·1
Zinc,	Zn ..	0·37 –0·75	0·20 –0·40	0·13 –0·36

(f) Hertha Road Rubbish Disposal: Three additional boreholes were sited in this area to obtain a clearer picture of the effects of the rubbish tip on the underground water. Because of the complexity of water movement in the area the quantitative assessment is still continuing but obvious contaminants to the water are bicarbonate, ammonia, calcium, iron, manganese and colour.

Corrosion, Scales and Water Treatment

The experience and expertise gained by staff members through years of continued involvement in both the practical and theoretical aspects of corrosion and water treatment has led to increasing involvement in consultation in both the government and private sector. Some inspections and recommendations for private industry were undertaken and brief summaries of these and other interesting activities in this sphere are listed below.

(a) Carbon Dioxide Attack on Gear Pumps: A firm, using cast iron and stainless steel gear pumps for pressurising spent boiler flue gases, from which the oxides of sulphur had been scrubbed, was experiencing severe corrosion. The lubricant used for the cast iron pump was sodium carbonate solution and for the stainless steel was oil. The failure of the cast iron was considered due to inadequate strength of sodium carbonate to keep free carbon dioxide levels low, and of the stainless steel was considered due to lack of oxygen penetration through the film of oil to passivate the stainless steel surface. The recommendation involved a series of trials with the cast iron, the pH of the lubricant solution to be initially controlled above 8 and then gradually lowered until the corrosion being experienced was tolerable. For the stainless steel the same series of trials were suggested but it was considered likely that water lubrication would be adequate.

(b) Scale Deposition in 3 000 Kilo-pascal Boiler Tubes: The presence of 16 per cent silica in the boiler scale indicated a role for this component in the scale formation which subsequently led to tube failure. Examination of the analytical records for the boiler and demineraliser water indicated that a silica "slip" equilavent to 2 mg per litre was occurring during normal demineralisation practices. The raw water for demineralisation was presumed to have contained 4 to 5 mg per litre of silica but the actual supply used contained 9 mg per litre. Recommendations included use of a purer demineralised water and maintenance of silica/alkalinity ratios in the boiler water below 0.15. Trials were also suggested to compare the economics of maintaining this ratio by the alternative processes of adding alkalinity to the demineralised water or by increasing the resin's capacity for silica removal by regenerating with caustic soda to a higher level.

(c) Demineralised Water—Silica Slip: Samples of demineralised water taken from towards the end of a run, although indicating a satisfactory product with a specific conductivity between 10 and 20 microsiemens per cm at 25° C contained between 110 and 120 mg per litre of silica. It is not normal, in low silica content waters, for the silica slip in the product water to exceed that in the raw water, but in this instance with the raw water silica of 47 mg per litre the silica concentration had increased two to three fold until its concentration had almost reached the saturation level of 120 to 140 mg per litre.

(d) Ultrasonics for Boiler Scale Control: An inspection of a boiler equipped with an ultrasonic device for scale removal and control was carried out. While such control appears feasible and of possible benefit, the supporting evidence from staff operating the boiler proved unreliable upon examination of samples collected. Our recommendation included installation of the device in a boiler where a specific chemical dosage had been planned and where it could be controlled by regular analysis.

Corrosion of Copper Hot Water Services—Silica Role

The role of silica in general corrosion of copper pipes in New Zealand with cold water has already been recognised with the recent publication of several papers but its role in pitting corrosion of copper in hot water systems was not recognised till 1974. Partly because of a major reduction in the corrosion of copper hot water cylinders by the use of sacrificial anodes of aluminium, the role of silica has been overlooked. Where sacrificial anodes cannot be used, such as in recirculating ring mains, corrosion of copper by hot water is still a problem.

(a) Ring Mains: A recommendation for raising the pH value of the hot water by caustic soda injection to give the water a significant positive Langelier index at 70° C has been implemented at two country hospitals, namely Albany and Geraldton with somewhat unexpected results. Deposits in the inside of the pipe were expected to be mainly calcium carbonate, but were not.

Table 31 shows typical raw and treated water analyses for both Albany and Geraldton, together with an analysis of the uniform layer on the inside of the copper tubes of the ring mains.

TABLE 31.

WATER AND DEPOSITS IN COPPER HOT WATER SYSTEMS

WATER

	Albany untreated	Albany treated	Geraldton untreated	Geraldton treated	Derby untreated
pH	7·4	8·2	6·8	8·2	7·2
Saturation index .... (Langelier at 70°C)	+0·4	+0·9	—0·4	+0·6	—1·3
			milligrams per litre		
Total dissolved solids	480	500	600	620	510
Chloride, Cl	125	125	300	300	233
Total alkalinity .... (as $CaCO_3$)	220	240	65	85	30
Calcium, Ca	20	20	12	12	5
Magnesium, Mg	3	3	13	13	....
Silica, SiO_2	12	12	18	18	88

DEPOSITS

		per cent dry basis	
Calcium, Ca	5·5	<1	<1
Magnesium, Mg	10·4	3·9	<1
Silica, SiO_2	43·0	26·7	36·0
Copper, Cu	1·5	25·7	34·8
Loss on ignition	19·7	30·0	17·3

Carbonates, chlorides and sulphates were not detected in these deposits, the limits of detection being of the order of 1 per cent.

For Albany the deposit is apparently protective because there have been no leakages in the system since caustic dosage was implemented several years ago, nor has there been any evidence of pitting attack beneath the layer.

At Geraldton the caustic soda dosage has been implemented for only one year and there has already been one leakage of the copper pipe in the ring mains due to pitting attack. It is not certain whether the perforation was due to an old site where attack was not arrested by the caustic soda treatment, but the level of copper in the uniform layer suggests that the deposited layer of mainly basic copper silicate is not impervious to water and hence is not protective. Laboratory controlled tests of several days' duration with Geraldton water dosed with caustic soda and in contact with copper at 70° C were carried out. When the caustic soda dose was adequate to give a pH value of 9, magnesium silicate was deposited but there were no dramatic changes to indicate the cause of an apparently rapid pitting corrosion attack. It is intended to pursue this aspect further during 1975.

(b) Hot Water Cylinders Without Anodes: A solar hot water cylinder at the Derby Leprosarium was also badly corroded within a period of less than one year. The pitting attack had proceeded to perforation but there was also general uniform attack. Analysis of the raw water and the deposit on the cylinder surface are also included in Table 31. Apart from recommendations for alteration to the design of the cylinder, the installation of sacrificial anodes was also advised.

Swimming Pools

The involvement at consultative and analytical level in this area did not diminish during 1974.

(a) Black Spot or Stain: Although there has not been any further scientific confirmation that the oxidation by chlorine of the cobaltous hydroxide to the insoluble cobaltic hydroxide is the cause of this observed phenomenon in glass fibre reinforced plastic pools, there has been additional circumstantial evidence to support the argument.

Tests at laboratory level supported the predicted reduction in cobaltic hydroxide formation at lower pH values and many pool manufacturers who have recommended lower pH control of the pool water between 6.5 and 7.0 have also reputedly effected an 80 per cent reduction in incidence of black spot formation.

A steriliser unit, based on the formation of silver and copper ions by electrolysis with electrodes of the same material, has reputedly been used in 100 fibre glass reinforced plastic pools without a single case of black spot. The ions, at the concentrations added, would not be adequate to oxidise the soluble cobaltous to the insoluble cobaltic hydroxide.

The addition of a complexing agent, such as sodium hexametaphosphate, "Calgon", to the pool water significantly reduced the intensity of the colour from chlorine oxidation of cobaltous salts at normal pH values, and pool chemical suppliers are claiming similar success in practice.

(b) Role of Isocyanurates: Investigations on the role of isocyanurates as chlorine stabilisers was carried out in 1974 and areas of uncertainty from the 1973 investigations are now more clearly defined.

Manufacturers and suppliers of isocyanurates have argued that the addition of isocyanurates, while enhancing the stability of chlorine, do not have any marked effects on its sterilising capacity. This argument was supported by chemical analysis with recognised analytical methods for free chlorine such as ortho-tolidine and diethyl-p-phenylene-diamine (D.P.D.) which showed no variation after isocyanurate addition to free chlorine solutions. Bacterial evidence supporting this was contentious but it was generally accepted that isocyanurates at levels below 50 to 100 mg per litre did not significantly reduce bactericidal effect. Recent literature studies have indicated that less than 1 per cent of the free chlorine originally present in the pool water prior to isocyanurate addition exists as free chlorine after isocyanurate addition, but that equilibrium attainment is rapid after removal of the free chlorine. The net effect is close to that of chlorine without isocyanurate addition. It was confirmed by amperometric analysis in these Laboratories with chlorine and isocyanurate at normal pool levels, that less than 1 per cent of the free chlorine originally present now existed after isocyanurate addition.

There are a number of arguments supporting control of swimming pool pH values marginally below 7 and these arguments are based mainly on bactericidal value. Corrosion aspects with metallic components and the difficulty of controlling the pH at this value in a system controlled only by the bicarbonate buffer have led most health authorities to recommend pH values for pool water between 7 and 8. An addition of 10 mg per litre of sulphuric acid to pool water controlled only by bicarbonate at pH 7.0 will reduce the pH to less than 5. The presence of isocyanurates has no effect on the alkalinity determination and the results in Table 32 support the contention by these Laboratories that the isocyanurate ion in conjunction with the bicarbonate ion will allow the pool pH to be safely controlled at values between 6.5 and 7.0. With corrosion resistant material, generally plastic, there now appears to be no need for setting a lower limit on pH of 7.2.

If public swimming pool regulations are to be applied to private pools, favourable consideration should be given to alteration of the pH range to include values down to 6.5. Not only is this likely to give better bactericidal action but it would also reduce the likelihood of formation of black spot in glass fibre reinforced plastic pools.

TABLE 32

CYANURATE-BICARBONATE BUFFER IN AERATED WATER

Isocyanuric Acid mg per litre	Alkalinity (as $CaCO_3$) mg per litre 0	5	10	15	25	35
	pH					
0	5	7·0	7·0	7·1	7·3	7·8
50	5	6·5	6·6	6·7	6·9	7·2
100	5	6·3	6·5	6·5	6·8	6·9

(c) Alternative Bactericidal Procedures: Methods for sterilisation, other than hypochlorite, for private pools have been investigated. A packaged unit, whose operating principles involve the electrolysis by inert electrodes of a pool water made saline by the addition of 6 000 mg per litre of salt NaCl, should be capable of providing an equal bactericidal condition to that using hypochlorite. It has the advantage of being able to maintain a continuous dose by placing it in circuit with the recirculating pump but also has the disagreeable effect of swimming in a brackish water.

A similar packaged unit already referred to, which operates on fresh water, but which relies on electrolysis of electrodes comprised of mainly copper with about 3 per cent of silver, still needs additional investigation in its bactericidal properties and its ability to maintain the generally considered bactericidal level for silver of 0.05 mg per litre. Perth water has high chlorides by world standards and based on the solubility of silver chloride being only 2 mg per litre at pool water temperature, the equilibrium level of silver cannot reach 0.05 mg per litre unless the chloride level is below 15 mg per litre. With the average chloride level in Perth water nearer to 150 mg per litre, the equilibrium silver level in solution is not likely to exceed 0.005 mg per litre.

Miscellaneous

(a) International Co-operative Study: The Division participated in the International Association of Geochemistry and Cosmochemistry International Co-operative Study. Five correctly taken and stored water samples from a variety of selected sources were analysed for a number of selected components by regular analytical methods and the results of each participating Laboratory were evaluated in regard to both the result obtained and the analytical method used. More than 90 per cent of the reported results were within one standard deviation of the mean values reported and all results were within two standard deviations. The nett result is that the methods used and the reliability of the analysts is of a comparatively high order.

(b) Fluoride Analytical Method: The colorimetric method for fluoride, using SPADNS reagent had been preferred by these Laboratories because of its rapidity compared to that of the fluoride electrode. During the year it was discovered that the interference due to polyphosphate is positive and quantitative, 10 mg per litre of $(NaPO_3)_6$ giving the same reading as 1.0 mg per litre of fluoride. Waters from experimental drilling are frequently contaminated with drilling mud containing polyphosphate and the SPADNS colorimetric method has now been abandoned in favour of the fluoride electrode which is not subject to such interference.

(c) Polyphosphate Addition to Rainwater Galvanised Tanks: A sample of rain water from a galvanised tank which had been treated with a commercial product composed mainly of metaphosphates of zinc and calcium and which is recommended by the suppliers to prevent corrosion, was found to contain an anticipated level of zinc and phosphorus based on the quantities of materials dosed. The zinc level of 23 mg per litre was in excess of the maximum recommended for a drinking water, namely 15 mg per litre, but does not represent a toxic hazard. The suppliers who have been recommending this treatment method since 1964 were notified of the implication of their treatment and are now giving the matter additional consideration.

(d) Potassium in Natural Water: An artesian water from the Busselton area with a total dissolved solids of 240 mg per litre contained 10 mg per litre of potassium. The ratio of potassium/chloride at 0.10 is higher than that of sea water 0.02 and shallow underground water in the South West which is usually less than 0.05. A number of bores serving the Bunbury town water supply and an artesian water in Mount Hawthorn, serving the Metropolitan water supply, have similar high ratios of potassium/chloride and also contain similar levels of iron. The fertiliser value of the water is equivalent to 190 kilograms of potassium per hectare metre.

(e) Discolouration of Tea due to Iron: The presence of iron in water at levels of 2 mg per litre or higher, either in true solution or as a fine suspension was shown to cause a deeper discolouration of the tea after brewing and after addition of milk discoloured the tea to varying hues of blue or purple.

DIVISION VIII

Annual Report of the Chief Inspector of Explosives for the Year 1974

The Under Secretary for Mines:

In accordance with Section 10 of the Explosives and Dangerous Goods Act, 1961-1974, I submit for the information of the Hon. Minister for Mines this report on the administration of the Act for the year ended 31st December, 1974.

STAFF

Mr. G. A. Greaves, Chief Inspector of Explosives since 6th March, 1968, retired on 1st November, 1974, at the age of 63. The staff of the Explosives Branch wish him a long and happy retirement.

On 12th December the Deputy Chief Inspector, Mr. H. Douglas, was appointed Chief Inspector of Explosives.

Mr. D. J. Quayle, Bsc., A.R.A.C.I., was appointed to the newly created position of Inspector and Research Officer on 3rd May, 1974.

After several months illness, the Officer in Charge of Woodman Point Explosives Reserve, Mr. C. M. Kerr, died at Fremantle Hospital. Mr. W. E. Bennett was appointed to the vacant position on 13th December.

At 31st December the staff of the Explosives Branch totalled 20 and consisted of:—

- Inspectorate—7
- Clerical—5
- Explosives Reserve—8 (including 6 wages staff).

LEGISLATION

The following amendments to the Act and Regulations were prepared and gazetted throughout the year:—

Explosives and Dangerous Goods Act, 1961:—

- (i) Amendments to effect metric conversion of the Second and Third Schedules to the Act were authorised on 26th April.
- (ii) The Explosives Amendment Act, 1974 was assented to on 16th October.

Explosives Regulations, 1963:—

- (i) The Explosives (Metric Conversion Amendments) Regulations, 1974 were published to take effect on and from 12th July.

Flammable Liquids Regulations, 1967:—

- (i) The Flammable Liquids (Metric Conversion Amendment) Regulations, 1974 were published to take effect on and from 12th July.
- (ii) Regulation 128 was amended to allow the use of steel drums of type suitable for flammable liquids and of size conforming to the metric capacities to be specified at a future date.

AUTHORISATION OF EXPLOSIVES

Thirteen samples of explosives were submitted for authorisation throughout the year and in each case the composition, quality and character of the explosive were examined.

One, of European manufacture, was refused authorisation because of a lack of sensitivity and another, a two pack system explosive, of American manufacture, was refused authorisation because of undesirable toxic and flammable characteristics.

Four of the explosives were approved under previously authorised general definitions. Those were:—

Lo-Noise Primacord, approved under the classification Class 6—Ammunition—Division 2
- Detonating Fuse (ZZ)

Union Rio Tinto Detonators, Electric Detonators and Delay Detonators, approved under the classification Class 6—Ammunition—Division 3
- Detonators (Z)
- Electric Detonators (Z)
- Delay Detonators (Z)

The following explosives were classified and officially authorised in accordance with Section 14 of the Act for use throughout Western Australia:—

Class 6—Ammunition—Division 1
- Asahi CCR Electric Igniters (X)

Class 6—Ammunition—Division 2
- Asahi CCR Explosive Charges (Y)
- Union Rio Tinto Detonating Fuse (ZZ)

At the end of the year, definitive tests were still being conducted on the remaining four explosives submitted for authorisation.

MANUFACTURE OF EXPLOSIVES

The manufacture of Class 2—Nitrate Mixture explosives under factory controlled conditions was approved at five licensed locations throughout the State. These allowed the production of proprietary mixtures based on ammonium nitrate with minimal conveyance to the points of use.

The total production of Class 2 type explosives during 1974 (including that manufactured on site) was 78 400 tonnes, and though ammonium nitrate-fuel oil (ANFO) explosive continued to be the most popular blend, the aluminized ANFO and slurry explosives were increasingly used where high density, high seismic strength explosive was required. In this regard, some 1 200 tonnes of aluminium powder were used throughout the year.

Fireworks continued to be produced in factories owned by the two licensed manufacturers in Western Australia, but on a reduced scale to previous years. Both manufacturers conduct organised displays of their fireworks throughout the State but find it more economical to buy the larger display pieces from overseas manufacturers.

IMPORTATION OF EXPLOSIVES

Only seven licences to import explosives were issued in 1974, however, the quantity of imported explosives remained similar to the previous year. Nitroglycerine type explosives are gradually being replaced as greater developments take place in local production and in the cartridging and packaging of slurry and water gel explosives. It is expected that these will replace N.G. explosives completely. In this event the main imported explosives will be the primary initiating detonators and detonating relay elements together with primer or booster charges, detonating fuse and accessories.

Twenty-seven Entry Permits and Certificates of Release were issued to cover the importation of small quantities of unauthorised explosives throughout the year. These included items such as Christmas crackers, whaling explosives, snaps for bon-bons, display fireworks and specialised explosives for the oil industry.

One application for an Entry Permit was refused because the quantity of explosives exceeded that which could have been recommended for entry to Fremantle Harbour, and though lightering facilities were made available to off-load the explosives at the Woodman Point Explosives Reserve Jetty, the offer was refused and the explosives, consisting of 500 kilograms of detonating fuse, were dumped at sea rather than risk delay of the vessel.

Another application for Entry Permit to import novelty fireworks was refused after tests showed that these joke items could cause injury to the unsuspecting user.

Total Consumption of Explosives for 1974—

The following summary shows the total quantity of explosives used throughout Western Australia during the year ended 31st December, 1974:—

	Tonnes
Blasting Powders (Class 1—Gunpowder)	0.5
Nitrate Explosives (Class 2—Nitrate Mixtures)	78 400.0
Dynamite Explosives (Class 3—Nitro Compounds, Div. 1)	1 315.0
Boosters, primers and seismic explosives (Class 3—Nitro Compounds, Div. 2)	489.8
(7.06×10^6m) Detonating fuse (Class 6—Ammunition, Div. 2)	155.3
Total quantity	80 360.6

The above quantity does not include some several hundred thousand primary initiators or accessories such as safety fuse and fuse lighters. It is, however, of interest to note that the 80 360 tonnes of explosives used throughout 1974 is greater than the total quantity of explosives used in Western Australia in the sixty years from 1892 to 1951.

LICENCES AND INSPECTIONS

There was a total of 417 licences for explosives current at the end of 1974, these were:—

Licence to Import	7
Licence to Manufacture Explosives	5
Licence to Manufacture Blasting Agents	97
Licence to Manufacture Fireworks	2
Licence to Store, Mode A (50 kg)	29
Licence to Store, Mode B (150 kg)	18
Magazine Licence, Type One (Not more than 1 000 kg)	79
Magazine Licence, Type Two (1 001 to 5 000 kg)	39
Magazine Licence, Type Three (more than 5 000 kg)	47
Licence to Sell Explosives	52
Licence to Convey Explosives	42

All of those licences involved Clerical and Inspectorate staff to ensure that the requirements of the regulations were maintained. The number of inspections for 1974 continued at a level comparable with the preceding years. Some 254 inspections of explosives in storage, conveyance, etc. were made throughout the year—61 per cent of the licences issued.

The conveyance of explosives required particular attention from the Inspectorate throughout the year to ensure that safe conditions prevailed and that approved routes were adhered to by all drivers. All vehicles loaded from the Woodman Point Explosives Reserve were checked before the vehicle was allowed to proceed on public roads.

EXPLOSIVES RESERVES

The Woodman Point Explosives Reserve continued to be the main storage and distribution centre for explosives imported to Western Australia. The main difference in the operation of the Reserve during 1974 from previous years was that the explosives arrived by rail and road rather than by ship.

The Kalgoorlie Explosives Reserve at Parkeston was increasingly used throughout 1974 and interest in the storage facilities there was expressed by several importers. Approval was given to store bagged ammonium nitrate within the factory building licensed for the manufacture of explosives, however the total storage of AN and manufactured explosives within this building was limited to that which would not cause sympathetic detonation of the neighbouring magazines should an explosion occur during the process of manufacture.

As all railed imports of explosives to Western Australia pass through Kalgoorlie it is expected that more use will be made of the Kalgoorlie Explosives Reserve for storage and distribution to the surrounding mine sites. Two new sites were chosen within the Reserve during 1974 for the location of 50 tonne capacity magazines, one of which is proposed for use for the storage of explosives imported from overseas.

The feasibility of importing overseas explosives through Esperance was considered, however, there is no Explosive Reserve in the Town of Esperance that can be used even as a holding area for explosives awaiting transport to other magazine areas—apparently the former Reserve was surrendered in order that it could be used as a recreational area. Investigation of possible reserve sites in Esperance for the temporary storage of imported explosives was initiated during 1974.

Explosives magazines on Reserves at Geraldton, Meekatharra, Southern Cross and Port Hedland were stocked to capacity throughout 1974 and special approval had to be given for the temporary storage of some 400 tonnes of a marine seismic explosive in the open on one of the Port Hedland reserve areas. The majority of this explosive was used during the year and the remainder transferred to storage magazines. A second explosives magazine and a detonator magazine were constructed within the Geraldton Reserve.

EXPLOSIVES STOLEN AND DESTROYED

Eleven instances of theft were reported during 1974 involving various quantities of explosives the maximum of which was 57 kilograms of gelignite and 1 000 detonators. The Explosives Inspectorate examined the magazine storage after each theft to ensure that security continued to conform to the standard required by the regulations.

Though it is true that determined thieves may breach the highest security, it was pleasing to note that in the above cases the thieves experienced considerable trouble in obtaining their explosives. In one instance the thief used oxy-acetylene (at peril of his life) to gain entrance to a magazine containing, amongst other explosives, an open box of blasting powder.

The services of the Explosives Inspectorate were required on fifty occasions throughout 1974 to destroy deteriorated and unwanted explosives. These explosives ranged in quantity from one No. 6 plain detonator to 680 kilograms of badly exuding gelignite. In all, some 1 780 kilograms of explosives and 3 600 plain and electric detontators were destroyed by the inspectorate. Some of the explosives destroyed were those recovered by Police from thefts from licensed and non-licensed storages.

DISPLAY OF FIREWORKS

Throughout the year a total of twenty-eight Permits for Display of Fireworks was issued by the Chief Inspector of Explosives, who, before issuing the permit, required to be satisfied that the display would be organised with due regard to the safety of the public and had the approval of the Police Department, the Fire Brigade and the Council of the Shire in which the display was held.

One injury resulted from fireworks in 1974—a child sustained severe burns to his upper leg when a fireworks piece ignited in his pocket. Apparently the child found the firework during an organised display and later attempted to light the firework by sheltering if from the wind in his pocket.

Injuries resulting from fireworks have certainly decreased since sale to the public has been prohibited—for example, the Princess Margaret Hospital for Children has had no fireworks caused eye injury cases since 1967 whereas prior to the ban that hospital had up to six such cases every year.

Several requests for approval to use small fireworks items under regulation 131 (3) of the Explosives Regulations were received throughout the year. These items included solid fuel for toy rockets, flare cartridges for toy guns and explosive inserts for joke cigarettes. The latter item was imported into the State without a permit but was confiscated by the Customs Department and returned to the country of origin when the application for an Entry Permit was refused because the inserts were shown to be potentially dangerous to the unsuspecting user.

ANALYSIS AND TESTING

The nine samples of explosives for which authorisation work was completed throughout the year were each analysed and tested to determine its composition, character and quantity. Chemical analyses were conducted by the Department's Laboratory staff and the physical testing, for example, impact, heat, double cartridge gap sensitivity, stability and velocity of detonation were determined by the Branch Inspectorate.

A total of 446 samples of nitroglycerine type explosives was tested for N.G. stability by the Abel Heat Test at the Woodman Point Explosives Reserve—all samples showed satisfactory stability. Also at the Woodman Point Explosives Reserve, following a complaint that imported safety fuse showed discrepancy in burning rate of samples taken from the beginning and those taken from the end of a reel of safety fuse, thirty cartons of safety fuse were tested by burning a sample of fuse from both ends of each reel. The results showed a difference of up to 10 seconds per metre within some of the reels. All samples, however, burned within the prescribed rates of 90-110 seconds per metre.

Six samples of locally manufactured prilled ammonium nitrate were submitted for analysis throughout the year to check that organic content and prill porosity were satisfactory. Those analyses showed that the prilled ammonium nitrate was completely acceptable for transport and for use in explosives manufacture in Western Australia. The average values were 0.010 per cent total oxidisable matter and 8.2 per cent oil absorption. Also submitted were four samples of flammable liquids for flash point determination to assist in classification for storage, and fifteen samples of streamer bombs and snaps for bon-bons were tested for check on the pyrotechnic composition in order that Entry Permits could be issued.

Considerable work was completed during 1974 on the testing of electric firing equipment. A total of 169 photo-electric and 105 battery operated circuit testers was shown to have a maximum current output less than 10 milliamps and therefore quite safe to be used for testing the continuity of electric detonator circuits. Also, three condenser type exploders were submitted and after suitable modification were approved for use throughout Western Australia—these were:—

Nitro Nobel Blasting Machine, type C1-100
Nitro Nobel Blasting Machine, type C1-15
Asahi Blasting Machine A.50R

An application for approval of a ground current leakage tester of European manufacture was not granted because use of the instrument as recommended by the manufacturer was considered capable of causing a premature explosion of the detonator circuit under certain circumstances.

USE OF EXPLOSIVES

A total of twenty-three complaints of alleged misuse of explosives was received in 1974 and each complaint was investigated. In most cases the shotfirer had neglected public relations and had failed to advise all persons in the vicinity, or had failed to give an audible signal before blasting. A few shotfirers required admonishment because of failure to halt traffic and two shotfirers were warned of the possibility of causing damage or danger from flying rock or other material projected from the blast. All persons concerned took heed of, and indeed welcomed, advice from the Inspectorate and in no instance was prosecution necessary.

The Branch involvement in the use of explosives has increased and can be expected to continue to increase, particularly when the provisions of the Explosives Amendment Act, 1974 are effected. The amendment to Section 34 of the Act, affecting the use of explosives by State Department of Works, alone will cause considerable increase in Branch involvement in this sphere of activity.

Two major Public Works projects required Branch attention throughout the year, these were the Canning Dam tunnel and the deepening of Bunbury Harbour. Both projects involved not only the customary inspections associated with licensed storage of explosives but also the examination and testing of personnel for issue of a Shotfirer's Permit and the regular inspection of working practice to ensure compliance with the Explosives Regulations. Considerable time was spent with personnel of the Bunbury Harbour project to ensure that safe procedures would be used for blasting operations from barges within the harbour.

Only two accidents involving the use of explosives at places other than mines were reported throughout 1974. In both instances the accident was caused by failure to follow prescribed blasting procedure and these incidents are reported in a later section of this report. Generally, however, since the introduction of Shotfirer training in 1972 the standard of blasting practice has increased considerably.

TRAINING OF SHOTFIRERS

Three inservice training courses, each of five days' duration, were conducted for Governmennt employees during 1974 and, of the 56 persons attending the courses, 48 qualified for a Shotfirer's Permit.

The Branch Inspectorate also conducted, under the auspices of Technical Education, five evening courses for Shotfirers. Each course consisted of 17 two hour lectures and two weekends of practical work. Of the 79 persons enrolled in these courses throughout the year, 75 passed the examination at the end of the course for issue of a Shotfirer's Permit.

In all, including individuals who considered themselves to be sufficiently experienced or who had studied the course notes privately, 283 candidates sat the examination for a Shotfirer's Permit and 234 passed. Since the introduction of the permit system 387 candidates have been issued with a Shotfirer's Permit.

ACCIDENTS AND EXPLOSIONS

Unauthorised Use of Explosives

Premises in Maddington were damaged through the misuse of explosives in a neighbouring block by a person unauthorised to use explosives. Civil action may be taken against the person to recover damages.

Explosives Outrages

The rear of Perth premises used as an escort agency was severely damaged by a bomb explosion which was believed to have contained 4 kilograms of nitroglycerine type explosive. Examination of the wreckage showed some 25 metres of burned safety fuse which was identified as a type not normally used in Western Australia but available in the Eastern States of Australia.

Three youths were charged with the theft of explosives, detonators and safety fuse. The youths used those explosives to demolish two telephone booths, one at Wundowie and the other at Bakers Hill.

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Stump Blasting Accident

A blasting contractor lost an arm and his sight in one eye when the charge for removal of a tree stump fired prematurely. Examination of the remaining primers which had been prepared by the contractor showed the use of safety fuse of length not greater than 150 mm. The regulations required that not less than 1 metre of safety fuse be used for any blasting operation. Burning tests on the fuse showed that it burned within the prescribed rate of 90-110 seconds per metre.

Drilling Into Butt-holes

Investigation of an explosion which occurred whilst a man was using a pneumatic drill showed that he was completely untrained in explosives work and frequently used old butt-holes when drilling "to save time". The man though hospitalised for a few days was soon able to return to work no doubt wiser in the first-hand knowledge that butt-holes sometimes contain percussion sensitive explosives.

Safe Blowers at Work

A man was reported to have lost his right arm and eye when a cartridge of gelignite he had picked up in a disused quarry at Gosnells exploded in his hand. It was learned that the man was in fact practising the use of explosives with short lengths of safety fuse and further enquiry by the Police led to the preferment of safe blowing charges against him.

Fireworks Accidents

A 13 year old boy suffered severe injuries to his right thigh due to the explosion of a sub-section of a demonstration firework. He had placed the firework piece in his pocket to shelter from the wind whilst lighting the fuse but it burned more rapidly than he expected and the piece exploded before it could be withdrawn from his pocket.

Home Made Bomb

A twelve year old boy lost his right hand and part of his left hand when a home made bomb exploded in his home at Boodarockin. Apparently he had loaded a device with explosives from two 0.22 calibre bullets plus two shotgun cartridges and matchheads from six boxes of matches. The explosion occurred when the device was being screwed together.

Spontaneous Combustion

A fire in a furniture factory in Bayswater started within an enclosed paint spray cabinet. Though the unit had been in use for several months without any mishap, it was learned that the paint system sprayed for the first time twelve hours before the fire was an oxidisable oil/catalyst system. This fact, along with the charred remains of a cleaning rag, and the absence of any other causation factors led to the conclusion that the origin of the fire was probably spontaneous combustion.

Ammonium Nitrate Fire

A fire in a bulk ammonium nitrate store at Dampier was allowed to burn itself out only after action had been taken to evacuate the area within 1 kilometre of the blaze. Approximately 200 tonnes of bagged ammonium nitrate was destroyed along with the storage shed and it appeared that the fire was started intentionally. Police are investigating the matter.

Liquefied Petroleum Gas Explosion

Seven employees suffered burns, two severely, and the premises were damaged when an explosion of LP Gas occurred in a depot of the Metropolitan Water Board at Leederville. Apparently an LP Gas cyclinder was accidentally knocked over causing the valve to break. The escaping gas was most probably ignited by a nearby electric fan.

FLAMMABLE LIQUIDS REGULATIONS

Most of the 4 588 premises relicensed during 1974 for the storage of flammable liquids continued to show "on file" improvement in storage conditions. However, the only reliable indicator of satisfactory storage is an inspection report verifying that conditions conform to the requirements of the regulations.

Unfortunately, not more than two-thirds of all the licensed premises could be inspected throughout the year, and though experience has shown that failure to discuss storage requirements at least once per year leads to neglect by the licensee of important safety features, the Branch Inspectorate is just not sufficient in number to give the attention that is required for every flammable liquids storage.

Some 3 500 inspections for flammable liquids were made by the Inspectorate and these included not only storages at bulk depots and factory premises but also vehicles for the conveyance of flammable liquids. Advice was given in 149 instances to the owners of tank vehicles with regard to modifications needed by the vehicle for the safe conveyance of flammable liquids. Special approval was given in three instances for the conveyance of quantities of flammable liquids greater than is normally allowed by the regulations. Those special approvals were subject to stringent safety precautions, suitable vehicle modification and to the conveyance being confined to a remote area of the State, *viz.* Esperance to Ceduna, Kalgoorlie to Laverton and Port Hedland to Karratha. In one instance a request for approval to convey bulk flammable liquids together with bulk liquefied petroleum gas on triple bottom trailer units was refused.

The bulk storage of flammable liquids within agency depots showed considerable improvement throughout the year, though on many premises the fire fighting system was reported as being inadequate. When the regulations were introduced five years ago it was agreed that the Inspectorate would tolerate certain deficiencies under a provisional license subject to the Petroleum Company budgeting for satisfactory upgrading of the premises over a period of several years. After five years of operation it is considered that all depots should by now conform to the prescribed standards.

Throughout the year was seen the introduction of "tank-tainers" for the containerised transport of bulk inflammable liquid products such as acetone and polyester resins. These tank-tainers were approved as demountable tanks for conveyance by road in Western Australia and as such are limited in capacity to not more than 18.2 kilolitres and are subject to all other regulations for the conveyance of flammable liquids. It is expected that many licensed premises currently storing drums of flammable liquid products will eventually change to safe underground tank storage gravity filled from a tank-tainer.

ACCIDENTS—FLAMMABLE LIQUIDS

Incorrect Labelling of Fuel

An employee of the Main Roads Department suffered burns to his leg after fuel, which was accidentally sprayed on his overalls, was ignited by a nearby flame. The fuel which was labelled "Power Kero" was considered to have been petrol instead. The matter of incorrect labelling was taken up with the company supplying the fuel.

Domestic Heater Explosion

Although the fuel supplied to a domestic heating unit in South Perth was shown by flash point determination to be the more flammable kerosine instead of heating oil, the cause of a minor explosion within the unit was attributed to faulty ignition rather than the wrong fuel.

Highly Flammable Adhesive

A fire occurred in a Perth bowling premises soon after an adhesive compound was used to position floor tiles. Analysis of the vapours from the adhesive showed the presence of highly flammable toluene which together with the use of non-flameproofed electrical equipment was considered to have caused the fire.

Service Station Fire

A fire which destroyed the offices of a roadhouse service station at Marchagee burned without involving the underground storage tanks and without injuring anyone. The cause of the fire could not be determined and, as the premises were not rebuilt, the licence to store flammable liquids was cancelled and the underground storage tanks made safe by filling with water and sealing off all openings.

Swimming Pool Factory Fire

A fire at a Maddington factory for plastic swimming pools was considered to have been caused through ignition of flammable vapours by a static electrical spark. Recommendations were made to improve ventilation and to increase the rate of dissipation of static electricity.

Domestic Fuel Tank Collapse

A 450 litre domestic heating oil tank which was located in the laundry of a Nedlands duplex unit collapsed spilling its contents over the wooden floor. Prompt action was taken to clear the spilled oil and no ignition of the fuel occurred. The owner of the premises was instructed to relocate the fuel tank outside of the building.

COMMITTEES AND LECTURES

SAA Committee, ME/17

The workings of the above committee, of which the Chief Inspector is a member, culminated in the circulation for public review of a draft Australian Standard "The Storage and Handling of Flammable and Combustible Liquids". Much work has been done by the Committee on the preparation of this draft which will be used to supplement the Flammable Liquids Regulations, 1967 as a guide in those matters not fully covered by the regulations.

Petroleum Marketing Engineers Advisory Committee

The Chief Inspector in company with two senior members of the WA Fire Brigades Board attended a meeting of the above Committee in Perth. The main topic of discussion was the Branch requirements for additional water supplies to the petroleum terminals at North Fremantle. It was agreed that terminals with adequate foam facilities fixed to every storage tank for flammable liquids shall be exempt from the requirement to provide additional water supplies.

CONCLUSION

The successful control of explosives and flammable liquids throughout the year was due largely to the efficiency and high standard of work maintained by all members of the staff. The loss of working time through sickness and injuries aggravated a chronic shortage of inspectors which prevented much work required in the field of dangerous goods.

Appreciation is recorded of the co-operation received from officers of the Fire Brigades Board and of other Government Departments, including the various Branches of the Mines Department, who have assisted with the work of the Explosives Branch.

H. DOUGLAS,
Chief Inspector of Explosives.

DIVISION IX

Report of Superintendent, Mine Workers' Relief Act, and Chairman, Miners' Phthisis Board 1974

Annual Report 1974—Mine Workers Relief Act 1932 and Miners Phthisis Act 1922.

Under Secretary for Mines:

1. This Report is submitted for the information of the Honourable Minister for Mines, on the above Acts for the year ended 31st December, 1974.

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:—

Dumbleyung, Esperance, Norseman, Redross, Kambalda, Southern Cross, Merredin, Bullfinch, Koolyanobbing, Coolgardie, Nepean, Kalgoorlie, Scotia, Leonora, Wiluna, Meekatharra, Laverton, Mt. Windarra, Warburton, Cunderlee, Westonia, Northam, Mundijong, Whitby Falls, Pinjarra, Karnet, Jarradale, Bunbury, Gelorup, Capel, Yoganup, Wonnerup, Greenbushes and Mt. Barker.

3. *Mine Workers' Relief Act*

3.1. *Total Examinations*

The examinations made under the Mine Workers' Relief Act during the year totalled 5 164 and compared with 5 330 for the previous year; a decrease of 166. The results of examinations are as follows:—

Normal	4 803
Silicosis early, previously normal	31
Silicosis early, previously silicosis early	310
Silicosis advanced, previously normal	—
Silicosis advanced, previously silicosis early	4
Silicosis advanced, previously silicosis advanced	4
Silico-tubercolosis, previously normal	—
Silico-tubercolosis, previously silicosis early	2
Silico-tubercolosis, previously silicosis advanced	—
Silico-tubercolosis, previously tubercolosis	—
Tubercolosis, previously normal	—
Asbestosis early, previously normal	—
Asbestosis early, previously asbestosis early	—
Asbestosis advanced, previously normal	—
Asbestosis advanced, previously asbestosis early	—
Silico-asbestosis early, previously normal	1
Silico-asbestosis early, previously asbestosis early	7
Silico-asbestosis early, previously silicosis early	2
Silico-asbestosis early, previously silico-asbestosis early	—
Silico-asbestosis advanced, previously silicosis early	—
Silico-asbestosis plus tubercolosis, previously normal	—
Silico-asbestosis advanced plus tubercolosis, previously silico-asbestosis early	—
Total	5 164

The 1974 figures, together with figures for previous years are shown on the table annexted hereto. Graphs are also attached illustrating the trend of examinations since 1940.

3.2. *Analyses of Examinations*

In explanation of the examination figures, I desire to make the following comments:—

3.2.1. *Normal, etc.*

These numbered 4 803 or 93.02 per cent of the men examined and include men having first class lives or suffering from fibrosis only. The figures for the previous year being 5 078 or 95.27 per cent of the men examined.

3.2.2. *Early Silicosis*

These numbered 341 of which 31 were new cases and 310 had previously been reported; the figures for 1973 being 236 and 21 respectively. Early silicotics represent 6.60 per cent of the men examined, the percentage for the previous year was 4.54 per cent.

3.2.3. *Advanced Silicosis*

There were 8 cases reported 4 of which advanced from early silicosis. Advanced silicotics represent 0.15 per cent of the men examined, the percentage for the previous year being 0.13 per cent.

3.2.4. *Silicosis Plus Tuberculosis*

There were 2 cases reported. This compares with none for the previous year.

3.2.5. *Tuberculosis Only*

There were no new cases reported in 1974 compared with 2 in 1973.

3.2.6. *Asbestosis*

There were three cases of early asbestosis reported during the year.

3.2.7. *Silicosis-Asbestosis*

Ten cases of early silicosis-asbestosis were reported during the year, only one being a new case. This category represents 0.19 per cent of the men examined.

4. *Mines Regulation Act*

4.1. *Total Examinations*

Examinations under the Mines Regulation Act totalled 9 362. There was an increase of 1 229 under this Act in 1974 as compared with 1973.

Of the total of 9 362 examined, 8 838 were new applicants and 524 were re-examinees. In addition, Provisional Certificates were issued to 1 162 persons in isolated country areas.

4.2. *Analyses of Examinations*

Particulars of examinations are as follows:—

4.2.1. *New Applicants*

Normal	8 833
Silicosis early	—
Silicosis early with tuberculosis	—
Tuberculosis	—
Other conditions	5
Total	8 838

4.2.2. *Re-Examinees*

Normal	524
Silicosis early	—
Silicosis early with tuberculosis	—
Tuberculosis	—
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 Certificates (Form 2)	9 305
Temporary Rejection Certificates (Form 3)	—
Rejection Certificates (Form 4)	9
Re-Admission Certificates (Form 5)	48
Special Certificates (Form 9)	—
Total	9 362

5. *Miners' Phthisis Act*

The amount of compensation paid during the year was $6 201.88 compared with $7 121.00 for the previous year.

The number of beneficiaries under the Act as on 31/12/1974 was 29 being 2 ex-miners and 27 widows.

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	Per Cent.	Previously reported as Normal etc.	Previously reported as Silicosis Early	Total	Per Cent.	Previously reported as Normal etc.	Previously reported as Silicosis Early	Previously reported as Silicosis Advanced	Total	Per Cent.	Previously reported as Normal etc.	Previously reported as Silicosis Early	Previously reported as Silicosis Advanced	Total	Per Cent.	Total	Per Cent.	Asbestosis early previously normal	Asbestosis early previously asbestosis early	Asbestosis advanced previously normal	Asbestosis advanced previously asbestosis early	Asbestosis advanced previously asbestosis advanced	Asbestosis plus tuberculosis previously normal	Asbestosis plus tuberculosis previously asbestosis	Total	Per Cent.	Total
1925 } 1926 }	3 239	80·5	....	....	459	11·4	....	....	....	183	4·5	....	....	....	131	3·3	11	0·3	....	....	....	....	....	....	....	....	....	4 023
1927	3 116	83·6	33	348	381	10·2	8	....	85	93	2·5	39	27	62	128	3·4	10	0·3	....	....	....	....	....	....	....	....	....	3 728
1928	2 977	85·5	59	303	362	10·4	3	16	79	98	2·8	18	14	10	42	1·2	4	0·1	....	....	....	....	....	....	....	....	....	3 483
1929	2 120	81·9	102	224	326	12·6	....	34	60	94	3·6	8	14	19	41	1·6	7	0·3	....	....	....	....	....	....	....	....	....	2 588
1930	2 785	81·9	136	247	383	11·3	2	22	43	67	2·0	8	60	46	114	3·3	50	1·5	....	....	....	....	....	....	....	....	....	3 399
1931	2 530	84·0	94	252	346	11·5	....	18	35	53	1·8	4	35	19	58	1·9	25	·8	....	....	....	....	....	....	....	....	....	3 012
1932	3 835	89·5	35	338	373	8·7	....	6	47	53	1·2	3	9	4	16	·4	8	·2	....	....	....	....	....	....	....	....	....	4 285
1933	2 920	86·5	57	322	379	11·2	1	15	44	60	1·8	2	9	4	15	·4	3	·1	....	....	....	....	....	....	....	....	....	3 377
1934	5 140	92·4	54	315	369	6·6	1	24	12	37	·7	6	6	....	12	·2	5	·1	....	....	....	....	....	....	....	....	....	5 563
1935	4 437	92·3	35	303	338	7·0	....	24	2	26	·6	....	5	....	5	·1	2	·0	....	....	....	....	....	....	....	....	....	4 808
1936	6 972	94·7	29	323	352	4·8	1	15	4	20	·3	3	8	....	11	·1	8	·1	....	....	....	....	....	....	....	....	....	7 363
1937	7'487	95·4	15	319	334	4·3	....	14	4	18	·2	1	10	....	11	·1	2	·0	....	....	....	....	....	....	....	....	....	7 852
1938	6 833	95·7	13	266	279	3·9	....	15	2	17	·2	1	8	....	9	·1	3	·0	....	....	....	....	....	....	....	....	....	7 141
1939	6 670	95·6	18	264	282	4·0	....	7	3	10	·1	1	9	1	11	·2	2	·0	....	....	....	....	....	....	....	....	....	6 975
1940	7 023	96·2	12	245	257	3·5	....	10	1	11	·2	....	4	....	4	·0	4	·0	....	....	....	....	....	....	....	....	....	7 299
1941	6 840	95·8	32	248	280	3·9	....	11	3	14	·2	....	....	....	....	....	7	·1	....	....	....	....	....	....	....	....	....	7 141
1942	5 469	93·9	61	264	325	5·6	....	20	5	25	·4	....	2	....	2	·0	3	·1	....	....	....	....	....	....	....	....	....	5 824
1943	3 932	91·5	63	262	325	7·6	....	25	7	32	·7	....	5	....	5	·1	4	·1	....	....	....	....	....	....	....	....	....	4 298
1944	4 079	91·5	70	270	340	7·5	....	21	14	35	·8	1	7	....	8	·2	6	·1	....	....	....	....	....	....	....	....	....	4 468
1945	3 071	92·1	54	166	220	6·6	....	26	10	36	1·1	3	2	....	5	·2	2	·1	....	....	....	....	....	....	....	....	....	3 334
1946	5 294	94·4	89	172	261	4·7	1	36	2	39	·7	3	1	2	6	·1	6	·1	....	....	....	....	....	....	....	....	....	5 606
1947	6 021	93·3	101	237	338	5·2	....	49	9	58	1·0	13	11	1	25	·3	8	·1	....	....	....	....	....	....	....	....	....	6 450
1948	4 827	94·0	24	239	263	5·1	....	18	17	35	·7	1	3	....	4	·1	5	·1	....	....	....	....	....	....	....	....	....	5 134
1949	5 162	94·0	24	239	263	4·8	....	20	31	51	1·0	3	2	1	6	·1	7	·1	....	....	....	....	....	....	....	....	....	5 489
1950	5 077	93·6	14	269	283	5·2	....	14	41	55	1·0	....	1	2	3	·1	8	·2	....	....	....	....	....	....	....	....	....	5 426
1951	4 642	93·9	13	248	261	5·3	....	9	20	29	·6	....	4	2	6	·1	4	·1	....	....	....	....	....	....	....	....	....	4 942
1952	5 073	94·6	8	234	242	4·5	....	4	31	35	·6	....	2	....	2	·1	7	·1	....	....	....	....	....	....	....	....	....	5 359
1953	4 474	93·03	74	225	299	6·22	....	8	24	32	·6	....	2	....	2	·1	2	·1	....	....	....	....	....	....	....	....	....	4 809
1954	5 142	91·33	154	275	429	7·62	....	22	21	43	·76	1	6	2	9	·1	7	·1	....	....	....	....	....	....	....	....	....	5 630
1955	4 559	90·40	63	286	449	8·90	....	9	22	31	·62	1	1	1	3	·06	1	·02	Segregation of asbestosis diagnoses commenced in 1959									5 043
1956	4 600	90·78	25	401	426	8·41	....	8	25	33	·65	1	3	....	4	·08	4	·08	....	....	....	....	....	....	....	....	....	5 067
1957	3 925	89·08	30	424	454	10·30	....	8	10	18	·41	1	4	....	5	·12	4	·09	....	....	....	....	....	....	....	....	....	4 406
1958	5 154	90·20	46	483	529	9·26	....	15	9	24	·42	....	6	....	6	·10	1	·02	....	....	....	....	....	....	....	....	....	5 714
1959	5 242	90·10	66	485	551	9·47	....	9	....	....	·15	1	5	1	7	·12	3	·05	6	....	....	....	....	....	....	6	....	5 818
1960	5 214	90·54	50	473	523	9·08	....	5	....	5	·09	2	9	....	11	·19	3	·05	2	....	....	....	....	1	....	3	....	5 759
1961	5 188	90·18	54	479	533	9·26	....	13	....	13	·23	2	3	....	5	·09	3	·05	5	5	....	1	....	....	....	11	·19	5 753
1962	5 183	89·98	50	499	549	9·53	1	10	....	11	·19	1	5	....	6	·10	1	·02	2	7	....	1	....	....	....	10	·18	5 760
1963	4 795	87·21	188	451	639	11·62	....	22	....	22	·40	7	6	....	13	·24	3	·05	10	11	....	4	....	1	....	26	·47	5 498
1964	3 484	83·85	64	561	625	15·04	....	9	1	10	·24	....	1	....	1	·02	2	·05	13	17	....	2	....	....	1	33	·80	4 155
1965	3 770	87·39	53	459	512	11·87	....	6	....	6	·14	....	1	....	1	·02	5	·12	5	15	....	....	....	....	....	20	.46	4 314
1966	3 411	86·56	26	469	495	12·56	....	14	....	14	·36	3	1	....	4	·10	1	·02	4	12	....	....	....	....	....	16	·40	3 941
1967	1 644	81·03	19	332	351	17·30	....	7	1	8	·39	....	2	....	2	·10	5	·24	8	6	....	5	....	....	....	19	·94	2 029
1968	3 364	86·93	39	431	470	12·14	....	18	3	21	·54	....	1	1	2	·05	1	·03	5	4	....	3	....	....	....	12	·31	3 870
1969	3 406	87·77	36	412	448	11·55	....	13	1	14	·36	....	1	....	1	·03	1	·01	2	7	....	2	....	....	....	11	·28	3 881
1970	3 841	89·73	30	400	430	10·04	....	6	....	6	·14	....	1	....	1	·02	3	·07	....	....	....	....	....	....	....	....	....	4 281
1971	3 915	91·80	15	327	342	8·02	....	5	2	7	·16	....	....	....	....	....	1	·02	....	....	....	....	....	....	....	....	....	4 265
1972	4 647	93·30	20	308	328	6·55	....	5	2	7	·15	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	4 982
1973	5 078	95·27	27	215	242	4·54	....	4	3	7	·13	....	....	....	....	....	2	·04	....	1	....	....	....	....	....	1	·02	5 330
1974	48 03	93·02	31	310	341	6·60	....	4	4	8	·15	....	2	....	2	·04	....	....	3	7	....	....	....	....	....	10	·19	5 164

MINING STATISTICS

to 31st December, 1974

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TABLE I

PRODUCTION OF GOLD AND SILVER AS REPORTED TO THE MINES DEPARTMENT DURING 1974.

(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.)

Mining Centre	Number of Lease	Registered Name of Company or Lease	Total for 1974					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	....	....	523·00	7·533	....	....	....	2 848·22	85·787	·110
	1203	Mt. Prophecy	....	....	56·00	·287	....	....	....	5 628·76	82·920	3·536
Marble Bar	1450	Betty Boo	....	....	605·00	1·256	....	....	....	605·00	1·256	....
	1473	Big Schist	....	....	53·00	·085	....	....	....	53·00	·085	....
	927	Halley's Comet	....	....	....	22·008	2·333	....	....	6 462·06	238·563	25·802
	1209	Ironclad	....	....	757·00	1·508	....	....	....	1 240·23	2·687	·006
	1332	Just in Time	·871	....	198·00	·179	·008	....	·871	198·00	·179	·008
	1458	Kangaroo	....	....	28·00	1·820	....	....	....	61·99	2·607	....
	1330	Kerry	....	....	52·00	·021	....	....	....	52·00	·021	....
	1334	Levers Hill	....	....	53·00	·245	....	....	....	53·00	·245	....
	1390	Nick	....	....	42·00	·291	....	....	....	42·00	·291	....
	1192	Talga Blink	....	....	85·00	·118	....	....	....	85·00	·118	....
	1331	General	....	....	193·00	·352	....	....	....	239·18	·574	....
	1474	Three Weight	....	....	200·00	·198	....	....	....	200·00	·198	....
	1321	Tricia	....	....	163·00	·236	....	....	....	163·00	·236	....
		Sundry Claims	....	·113	196·00	·484	....	2·086	8·052	22 851·39	407·098	·341
North Shaw	1468	Sponduelux	....	....	68·00	1·855	....	....	....	68·00	1·855	....
		L.T.T. 45/12 (2297H)—Dorph-Petersen, C.V.	....	....	343·00	1·018	....	....	....	343·00	1·018	....
NULLAGINE DISTRICT.												
Nullagine	....	Sundry Claims	....	....	12·00	·226	....	9·995	21·649	7 009·72	331·045	·583
		Reported by Banks and Gold Dealers	·066	....				315·119	4·588	....	1·494	·190
West Pilbara Goldfield												
Yule River	M.C. 305 W.P.	Yule River Mining Pty. Ltd.	3·381	....			·004	3·381	....	....	1·439	·004
Peak Hill Goldfield.												
Mt. Seabrook	....	Sundry Claims	....	....	7·00	·104	....	....	....	1 113·83	25·084	....
Peak Hill	G.M.L. 621P	Atlantic North....	....	·246	....	....	....	....	·626	....	....	....
	609P	Morning Star	....	....	....	·038	....	....	....	....	·038	....
	611P	Mount Pleasant	....	....	28·00	·090	....	....	....	28·00	·090	....

East Murchison Goldfield.

LAWLERS DISTRICT.

Lawlers	....	Sundry Claims	....	....	26·00	·081	....	12·494	14·047	18 117·71	304·927	8·566

BLACK RANGE DISTRICT.

Barrambie	G.M.L. 1117B	Scheelite Leases	....	....	70·00	1·439	....	....	....	1 869·77	35·766	·610
Sandstone	....	Sundry Claims	....	....	8·00	·067	....	1·464	44·200	1 6690·17	216·374	....
		L.T.T. 57/5 (2116H)—Murchison Gold Mines Pty. Ltd.	....	....	1 172·50	1·300	....	....	....	1 172·50	1·300	....

Murchison Goldfield.

CUE DISTRICT.

Tuckanarra	G.M.L. (2333)	Lady Annie	....	....	364·00	·763	....	....	....	364·00	·763	....
		Sundry Claims	....	....	8·00	·018	....	3·584	24·817	10 368·45	320·795	·004
		Reported by Banks and Gold Dealers	....	·371	....	....	....	107·772	3·795	....	·703	·065

MEEKATHARRA DISTRICT.

Garden Gully	G.M.L. 2150N	White Horse	....	....	25·00	·043	....	....	....	25·00	·043	....
Meekatharra	2016N	Commodore	....	....	31·00	·394	....	....	....	83·17	1·044	....
	2015N	Haveluck	....	....	1 288·00	2·490	....	....	....	11 153·51	21·418	....
	2119N	Two Way	....	....	63·00	·094	....	....	....	63·00	·094	....
		Sundry Claims	....	....	8·00	·563	....	8·704	43·303	33 183·41	366·405	·407
Nannine	2122N	Nannine South	....	....	13·00	·050	....	....	....	13·00	·050	....
		Reported by Bank and Bold Dealers	·022	....	....	....	....	383·076	9·267	458·74	3·039	·328

DAY DAWN DISTRICT.

		L.T.T. 21/8 (2209H)—Sears, E. L.	....	1·117	....	....	....	....	1·117	....	....	....

MOUNT MAGNET DISTRICT.

Lennonville	....	Sundry Claims	....	....	120·00	·153	....	·808	3·638	16 267·54	189·331	·344
Mt. Magnet	G.M.L. 1670M	Black Cat	....	....	89·00	·080	....	....	....	336·71	·532	....
	1696M	Edward Carson	....	....	49·00	·009	....	....	....	49·00	·009	....
	1455M	Evening Star	....	....	53·00	·050	....	....	....	1 153·63	3·918	....
	1282M etc.	Hill 50 Gold Mine N.L.	....	....	21 493·00	187·067	9·603	....	....	3 219 720·49	42 173·967	2 144·184
	1444M	Late Comer	....	....	56·00	·306	....	....	·079	575·20	12·477	....
		Sundry Claims	....	·130	141·00	·219	....	4·913	81·909	63 681·70	943·593	·918
		L.T.T. 58/6 (2170H)—Murchison Gold Mines Pty. Ltd.	....	....	156·00	·091	....	....	....	156·00	·091	....
		L.T.T. 58/18 (2239H)— do. do.	....	....	58·00	·039	....	....	....	58·00	·039	....

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 1974 Alluvial	Total for 1974 Dollied and Specimens	Total for 1974 Ore treated	Total for 1974 Gold therefrom	Total for 1974 Silver	Total Production Alluvial	Total Production Dollied and Specimens	Total Production Ore treated	Total Production Gold therefrom	Total Production Silver
			kg	kg	Tonnes	kg	kg	kg	kg	Tonnes	kg	kg
Yalgoo Goldfield.												
Goodingnow	G.M.L. 1063	Ark	....	....	454·00	20·349	....	....	·388	3 240·91	92·218	....
	1313	Gulya	....	....	29·00	·107	....	....	....	29·00	·107	....
	1324	Lucky Strike	....	....	129·50	·451	....	....	....	129·50	·451	....
	1244	Sweet William Extended	....	....	25·00	·221	....	....	....	55·48	·327	....
Rothsay	....	Sundry Claims	....	....	17·00	·037	....	....	·023	6 590·31	79·725	....
Yalgoo	1308	Last Chance	....	....	600·00	·122	....	....	....	600·00	·122	....
Mt. Margaret Goldfield.												
MT. MORGANS DISTRICT.												
Linden	G.M.L. 615F	Coronation	....	....	275·00	·247	....	....	....	275·00	·247	....
	668F	May Prince	....	....	2·00	·020	....	....	....	2·00	·020	....
Redcastle	....	Sundry Claims	....	....	8·00	·050	....	....	3·541	1 335·54	20·081	....
		L.T.T. 39/5 (2074H)—Reid, R.	....	....	107·00	·196	....	....	....	107·00	·196	....
		L.T.T. 39/4 (2054H)—Reid, R.	....	....	389·00	·756	....	....	....	389·00	·756	....
		Reported by Banks and Gold Dealers	....	....	....	·203	....	98·329	4·412	10·46	3·181	·021
MOUNT MALCOLM DISTRICT.												
Leonora	G.M.L. 1897C	Bon Boo	....	....	290·00	·265	....	....	....	2 278·45	21·538	....
	2031C	Forgotten	....	....	101·00	·278	....	....	....	101·00	·278	....
	2015C	Island	....	....	160·00	1·949	....	....	....	205·72	4·194	....
	2030C	Narroo Two	....	....	100·00	·120	....	....	....	100·00	·120	....
	1982C	Puddin Lease	....	....	26·00	·070	....	....	....	26·00	·070	....
	1762C	Sons of Gwalia....	....	....	1 018·30	1·791	....	....	·213	2 308·07	5·347	....
	1906C	Two Glads	....	....	2 247·00	10·984	....	....	....	4 259·28	30·146	....
	1860C	Tower Hill	....	....	320·00	1·089	....	....	....	1 308·61	3·917	....
		Sundry Claims	·034	....	843·00	1·863	....	1·207	12·211	25 338·52	411·247	·833
Mertondale	....	Sundry Claims	....	....	36·00	·013	....	....	....	36·00	·013	....
		State Battery—Lake Darlot	....	....	....	*·086	....	....	....	18·29	*134·742	·155
		State Battery—Leonora	....	....	....	*8·942	·077	....	....	92·46	*61·910	1·511
		L.T.T. 37/18 (2358H)—Leaver & Hadfield	....	....	305·00	·265	....	....	....	305·00	·265	....
		L.T.T. 37/22 (2413H)—Sceghi, P.	....	....	150·00	·148	....	....	....	150·00	·148	....
MOUNT MARGARET DISTRICT.												
Laverton	G.M.L. 2679T	Bulldog	....	....	619·80	·534	....	....	....	991·67	·894	....
	2750T	Falcon	....	....	50·00	·022	....	....	....	50·00	·022	....

North Coolgardie Goldfield.

MENZIES DISTRICT.

Comet Vale	G.M.L. 5964Z	Mardall	....	....	350·40	·355	....	....	....	350·40	·355	....
Goongarrie	....	Sundry Claims	....	....	10·00	·119	....	1·445	66·699	3 105·84	107·375	....
Menzies	5815Z	Espacia	....	....	129·00	·914	....	....	....	230·60	1·982	....
	5812Z	Kirwans Reward	....	....	280·00	·318	....	....	....	280·00	·318	....
		Sundry Claims	....	....	124·00	·069	....	1·769	19·419	43 901·79	827·546	25·311

ULARRING DISTRICT.

Davyhurst	....	Sundry Claims	....	....	104·50	·711	....	....	6·484	14 544·75	180·790	....
Morleys	G.M.L. 1221U	Emerald	....	....	178·20	1·476	....	....	....	178·20	1·476	....
	1089U	Paramount	....	....	77·00	·517	....	....	·046	4 697·47	119·095	....
Mulwarrie	1113U	Oakley	....	....	100·00	·323	....	....	....	5 802·05	283·036	10·387

NIAGARA DISTRICT.

Kookynie	G.M.L. 973G	Hose Shoe	....	....	18·80	·225	....	....	....	18·80	·225	....
	968G	Littlest Prospector	....	....	46·20	·114	....	....	....	46·20	·114	....
		Sundry Claims	....	....	25·00	·206	....	1·895	3·370	10 294·49	219·723	·130
Niagara	969G	Pine Lodge	....	....	67·60	·590	....	....	....	67·60	·590	....

YERILLA DISTRICT.

Edjudina	....	Sundry Claims	....	....	11·50	·025	....	....	·887	7 090·89	150·248	·021
Yarri	G.M.L. 1349R	Blue Duck	....	....	20·00	·054	....	....	....	20·00	·054	....
	1418R	Pinola	....	....	20·00	·073	....	....	....	84·47	·188	....
	1126R	Porphyry (1939) G.M. N.L.	....	....	358·00	·961	....	....	....	70 564·91	316·704	8·147
	etc.	Prior to Transfer to Present Holders	....	....	....	....	....	....	....	30 831·44	169·477	15·785
	1339R	Yilgangie	....	....	15·00	·264	....	....	....	958·91	12·698	·293
		Sundry Claims	....	....	228·00	·505	....	·027	·184	19 089·94	200·695	·043
Yilgangie	....	Sundry Claims	....	....	138·00	·169	....	3·784	3·054	3 598·96	65·571	·019
		State Battery, Yarri	....	....	....	*·667	·044	....	....	280·94	*283·927	·452

Broad Arrow Goldfield.

Bardoc	....	Sundry Claims	....	....	81·00	·069	....	1·709	37·887	19 791·17	267·735	....
Black Flag	....	Sundry Claims	....	....	81·20	·220	....	22·174	8·645	8 622·76	156·819	....
Broad Arrow	G.M.L. 2406W	Arinder Line	....	....	983·00	1·546	....	....	....	983·00	1·546	....
	2341W	Chancelot	....	....	314·00	1·056	....	....	....	1 733·42	2·999	....
		Sundry Claims	....	....	77·60	·164	....	31·370	98·832	41 684·87	554·483	·044
Grants Patch	2311W	Bent Tree	....	....	404·60	·456	....	....	....	2 073·76	7·568	....
	2417W	Lady Beatrice	....	....	174·00	·124	....	....	....	174·00	·124	....
	2407W	Sand Queen Extended	....	....	29·00	·040	....	....	....	29·00	·040	....
		Sundry Claims	....	....	36·50	1·562	....	·137	15·912	7 991·76	107·403	·

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 1974 Alluvial	Total for 1974 Dollied and Specimens	Total for 1974 Ore treated	Total for 1974 Gold therefrom	Total for 1974 Silver	Total Production Alluvial	Total Production Dollied and Specimens	Total Production Ore treated	Total Production Gold therefrom	Total Production Silver
			kg	kg	Tonnes	kg	kg	kg	kg	Tonnes	kg	kg
Broad Arrow Goldfield—cont.												
Ora Banda	(2414W)	Argonaut	....	....	24·40	·033	....	....	....	24·40	·033	....
	2412W	Ora Banda South	....	1·444	....	....	....	....	1·444	....	....	....
	2351W	Sand King	....	....	12·20	·168	....	....	....	28·46	1·669	....
	2300W	Sleeping Beauty	....	....	396·00	·801	....	....	....	6 129·96	37·516	·035
		Sundry Claims	....	....	480·80	·640	....	....	14·531	18 410·83	164·336	....
Paddington	2339W	Paddington Consols South	....	....	26·00	·118	....	....	....	315·57	5·199	....
Riches Find	2366W	Cave Hill Extended	....	....	28·00	·031	....	....	....	28·00	·031	....
Siberia	....	Sundry Claims	....	....	92·00	·158	....	8·991	39·903	21 994·25	416·117	....
Smithfield	....	Sundry Claims	....	....	69·60	·066	....	....	3·866	4 522·26	44·025	·003
		L.T.T. 24/40 (1872H)—Aurex Pty. Ltd.	....	·079	....	....	....	....	·079	....	....	....
North-East Coolgardie Goldfield.												
KANOWNA DISTRICT.												
Gindalbie	....	Sundry Claims	....	....	37·00	·104	....	....	22·286	6 124·41	103·817	....
Kalpini	G.M.L. 1599X	Kalpini Main Lode	....	....	103·60	·471	....	....	....	1 682·79	7·433	....
	1597X	Kalpini North East	....	....	204·00	·872	....	....	....	757·75	2·890	....
Kanowna	1586X	Kanowna Red Hill	....	....	30·50	·963	....	....	....	10 251·68	47·231	·060
	1585X	New Kanowna	....	....	187·30	·525	....	....	....	557·60	7·095	....
		Sundry Claims	....	....	90·30	·353	....	3·898	67·465	29 503·40	384·496	·053
KURNALPI DISTRICT.												
Karonie	479K	Stanhovell	....	....	22·10	·066	....	....	....	22·10	·066	....
Kurnalpi	....	Sundry Claims	....	·260	....	....	....	10·081	22·884	4 752·16	74·245	....
Mulgabbie....	488K	Jenny	....	....	212·00	·704	....	....	....	212·00	·704	....
	482K	Pinnacles	....	....	162·60	·143	....	....	....	162·60	·143	....

East Coolgardie Goldfield.

EAST COOLGARDIE DISTRICT.

Boorara	G.M.L. 6671E	Waterfall North	....	....	71·40	·464	....	....	....	378·75	7·196	....
Boulder	5345E etc.	Kalgoorlie Lake View Pty. Ltd.	....	....	469 049·00	2 389·200	846·485	....	....	653 264·40	3 475·559	1 206·020
		Prior to Transfer to present holders	....	....	....	....	....	....	26·700	62 162 730·32	732 838·733	106 492·417
	5700E etc.	North Kalgurli Mines Ltd.	....	....	35 265·00	161·095	22·638	....	3·967	9 981 512·95	74 498·880	22 896·945
Feysville	6791E	Butterfly	....	....	10·10	·026	....	....	....	10·10	·026	....
	6833E	Suzanne	....	....	159·00	1·268	....	....	....	159·00	1·268	....
		Sundry Claims	....	....	161·82	1·204	....	....	6·189	1 709·00	22·590	....
Hampton Plains	P.P.L. 277 Loc. 50	Kalgoorlie Lake View Pty. Ltd. (Pernatty)	....	....	1 883·00	11·424	....	....	....	2 508·88	14·723	....
		Prior to transfer to present holders	....	....	....	....	....	....	....	50 452·01	149·695	·064
	P.P.L. 9 Loc. 50	Walters, R.D.	....	....	1 321·50	1·562	....	....	....	1 321·50	1·562	....
Kalgoorlie....	G.M.L. 6591E	Kalgoorlie Lake View Pty. Ltd. (Kalgoorlie Star)	....	....	430·00	·416	....	....	....	11 313·89	26·291	....
		Prior to transfer to present holders	....	....	....	....	....	....	....	52·33	·568	·018
	6537E	Golden Key	....	....	30·40	·502	....	....	....	199·57	6·275	....
	6630E	Golden Star	....	....	42·10	·133	....	....	....	1 388·87	1·613	....
	6563E etc.	Kalgoorlie Lake View Pty. Ltd. (Mt. Charlotte)	....	....	690 537·00	2 605·008	....	....	....	973 526·38	3 547·381	....
		Prior to transfer to present holders	....	....	....	....	....	....	·178	4 947 601·36	21 751·229	5·336
	6569E	Kapai	....	....	507·41	·656	....	....	....	507·41	·656	....
	6693E	Mary Rose	....	....	55·10	·231	....	....	....	55·10	·231	....
	6485E	Maritana Hill	....	....	301·20	·500	....	....	....	6 727·95	20·980	....
	6639E	Old Hinchcliffe	....	....	344·62	·529	....	....	....	2 299·75	7·288	....
Wombola	6709E	Big Bull	....	....	122·90	·296	....	....	....	122·90	·296	....
	5497E 5500E	Daisy Leases	....	·082	694·00	15·520	....	....	·082	27 768·50	817·249	27·519
	5497E	Daisy	....	....	....	....	....	....	....	6 383·06	156·511	....
	5500E	Happy-Go-Lucky	....	....	....	....	....	....	....	2 108·55	52·125	....
	6811E	Leslie West	....	....	264·30	·606	....	....	....	264·30	·606	....
	6614E	Logan's Gold Mine	....	....	1 116·05	5·312	....	....	5·227	7 296·20	42·758	·039
	6834E	Residues	....	....	190·00	·249	....	....	....	190·00	·249	....
	6828E	Western Jerk	....	....	262·85	·600	....	....	....	267·85	·600	....
		Sundry Claims	....	....	170·24	·623	....	....	22·336	28 928·31	485·837	·006
		State Battery—Kalgoorlie	....	....	....	*7·466	·750	....	....	396·97	*1 316·411	24·863
		Reported by Banks and Gold Dealers	·049	....	....	....	....	529·544	313·497	437·59	237·615	1 080·656

BULONG DISTRICT.

Balagundi	....	Sundry Claims	....	....	48·00	·045	....	·109	10·158	945·43	17·021	....
Randalls	G.M.L. 1364Y	Wanderers Find	....	....	654·60	1·043	....	....	....	654·60	1·043	....
	1365Y	Wanderers Find South	....	·068	213·60	·285	....	....	·068	213·60	·285	....

Table I.—*Production of Gold and Silver from all sources, etc.*—continued.

Mining Centre	Number of Lease	Registered Name of Company or Lease	Total for 1974					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.										
		COOLGARDIE DISTRICT.										
Bonnievale	G.M.L. 6151	Melva Maie	....	·009	8·90	·068	....	....	·046	1 068·08	3·111	....
	6174	Mystery	....	....	84·30	·509	....	....	....	105·64	·656	....
	5890	Rayjay	....	....	15·20	·642	....	....	1·030	1 245·89	54·029	·159
		Sundry Claims	....	....	302·30	·462	....	....	12·075	12 153·09	183·013	·034
Burbanks	6160	Belgium Queen	....	....	62·40	·853	....	....	....	62·40	·853	....
	6267	Grosmont	....	....	233·00	·148	....	....	....	233·00	·148	....
		Sundry Claims	....	....	1 202·80	3·101	....	1·712	15·475	19 994·74	298·886	·030
Coolgardie	6260	El Paso	....	....	89·50	·145	....	....	....	89·50	·145	....
	6199	Fly Flat	....	·559	....	....	....	....	·559	....	....	....
	5884	Lone Hand	....	....	144·70	·123	....	....	·617	651·71	2·762	....
	6154	Monkani	....	....	2 096·92	2·630	....	....	....	2 096·92	2·630	....
	6195	Rose Hill	....	....	405·20	·216	....	....	....	522·04	·328	....
	(6243)	Tantom	....	....	67·80	·109	....	....	....	67·80	·109	....
		Sundry Claims	....	....	127·30	·460	....	7·345	95·544	92 828·92	941·30	·059
Gibraltar	....	Sundry Claims	....	....	51·80	·096	....	0·43	1·579	3 804·67	45·264	....
Hampton Plains	P.P.L. 484 Loc. 59	Baker, T. R.	....	....	634·20	1·112	....	....	....	1 389·63	3·375	....
	P.P.L. 486 Loc. 59	Boucher, H.	....	....	19·90	·141	....	....	....	463·66	3·386	....
Higginsville	G.M.L. 5647	Fair Play Gold Mine	....	....	1 422·40	1·430	....	·137	1·950	32 232·24	105·002	·001
	6061	Two Boys	....	....	1 509·70	3·847	....	....	9·074	3 301·24	29·541	....
Kambalda	M.C.s. 152 etc.	Western Mining Corporation	....	10·929	32·00	60·561	114·140	....	10·929	32·00	60·561	114·140
		Sundry Claims	....	....	72·50	·333	....	....	....	72·50	·333	....
		L.T.T.s 15/35-36 (2356H, 2360H) Bray., FC.	....	....	312·70	·195	....	....	....	312·70	·195	....
		KUNANALLING DISTRICT.										
Carbine	G.M.L. 1072S	Leisa	....	....	333·50	1·231	....	....	....	333·50	1·231	....
	(1081S)	Nuts	....	....	99·00	·095	....	....	....	99·00	·095	....
	(1086S)	Suzanne	....	....	353·00	·155	....	....	....	353·00	·155	....
		Sundry Claims	....	·263	152·00	·283	....	4·238	3·279	7 127·04	75·891	....
Dunnsville	1060S	West Carolina	....	....	10·80	·829	....	....	....	10·80	·829	....
		Sundry Claims	....	....	52·50	·171	....	·653	32·163	3 233·29	66·241	....
Kintore	1059S	New Haven	....	·155	63·90	·172	....	....	·155	2 591·57	9·706	....
Kunanalling	1052S	Catherwood	....	....	300·00	·819	....	....	....	873·30	2·163	....
		Sundry Claims	....	....	73·70	·094	....	6·735	30·928	18 194·66	322·242	·674

4396—(15)

Yilgarn Goldfield.

Bullfinch	G.M.L. 4535	Casas	....	....	649·30	1·394	....	....	....	1 591·43	9·531	·069
	4607	Open Cut	....	....	67·00	·410	....	....	....	398·49	1·464	....
		Sundry Claims	....	....	49·60	·563	....	·263	1·741	7 963·48	134·500	·755
Golden Valley	4728	Little Suzy	....	....	44·00	·113	....	....	....	44·00	·113	....
	4427	W.A. Gold Development N.L.	....	....	1 063·00	17·456	....	....	....	9 883·15	127·272	1·400
Kennyville	(4722)	Battler	....	·092	115·00	·126	....	....	·092	115·00	·126	....
	4724	Dorothy Leslie....	....	....	130·00	·139	....	....	....	130·00	·139	....
Marvel Loch	4637	Elcipse	....	....	149·00	·366	....	....	....	149·00	·366	....
	4694	Scorpio	....	....	100·00	·144	....	....	....	100·00	·144	....
		Sundry Claims	....	....	130·20	1·139	....	·353	25·172	39 685·25	434·434	2·675
Mt. Rankin	4462	Golden View	....	....	52·00	·008	....	....	9·857	196·28	8·868	·074
Parkers Range	4508	Buffalo	....	....	159·00	·299	....	....	·322	1 536·50	7·822	·175
	4626	The Australia	....	·111	....	....	....	....	·111	....	....	....
		Sundry Claims	....	....	49·00	·301	....	·205	9·453	14 724·83	178·412	·101
Southern Cross	4634	Frasers	....	·309	3 424·00	28·387	....	....	·309	7 386·58	153·318	....
		Sundry Claims	....	....	172·00	·492	....	2·983	20·218	9 088·74	86·248	·298
		State Battery—Marvel Loch	....	....	....	*4·463	·323	....	....	149·36	*176·277	82·789
		L.T.T. 77/27 (2112H)—Casas, B.	....	....	8·00	·061	....	....	....	8·00	·061	....
		(L.T.T. 3/68) (1680H)—Congdon, E.	....	....	....	·319	....	....	....	....	·319	....
		L.T.T. 77/57–59 (2397H–99H)—Oetiger, F.	....	....	90·00	·380	....	....	....	90·00	·380	....
		L.T.T. 77/73—Wright, L.	....	....	19·00	·273	....	....	....	19·00	1·201	....

Dundas Goldfield.

Beete	G.M.L. 2044	Beete	....	....	32·50	1·634	....	....	6·106	318·01	10·433	1·710
Dundas	....	Sundry Claims	....	....	61·00	·026	....	·024	12·872	2 459·63	37·022	·747
Norseman	1936 etc.	Central Norseman Gold Corporation N.L.	....	....	114 199·00	900·312	653·552	....	....	5 468 691·18	74 789·548	51 507·754
		Prior to transfer to present holders	....	....	....	....	....	....	51·735	70 940·22	1 489·610	513·482
		State Battery, Norseman	....	....	....	*2·769	·266	....	....	434·76	*824·970	36·140

Phillips River Goldfield.

Kundip	G.M.L. 277	Western Gem	....	....	23·00	·275	....	....	....	740·33	7·292	·001

South West Mineral Field

Burracoppin		Sundry Claims	....	....	50·80	·043	....	....	·030	462·55	8·446	....

State Generally

		Reported by Banks and Gold Dealers	....	3·865	....	3·069	....	37·351	38·447	....	41·381	35·487

TABLE II

Production of Gold and Silver from all Sources, as reported to the Mines Department during the year 1974.

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	....	....	....	....	....	....	....	3·381	....	....	....	3·381	·004
Pilbara	Marble Bar	·871	·113	3 615·00	39·494	40·478	2·341	·937	·113	3 627·00	39·720	40·770	2·341
	Nullagine	·066	....	12·00	·226	·292	....						
Ashburton	....	....	....	....	....	....	....	....	....	....	....	....	....
Gascoyne	....	....	....	....	....	....	....	....	....	....	....	....	....
Peak Hill	....	....	....	....	....	....	....	....	·246	35·00	·232	·478	....
East Murchison	Lawlers	....	....	26·00	·081	·081	....	....	....	1 276·50	2·887	2·887	....
	Wiluna	....	....	....	....	....	....						
	Black Range	....	....	1 250·50	2·806	2·806	....						
Murchison	Cue	....	·371	372·00	·781	1·152	....	·022	1·618	24 015·00	192·429	194·069	9·603
	Meekatharra	·022	....	1 428·00	3·634	3·656	....						
	Day Dawn	....	1·117	....	....	1·117	....						
	Mt. Magnet	....	·130	22 215·00	188·014	188·144	9·603						
Yalgoo	....	....	....	....	....	....	....	....	....	1 254·50	21·287	21·287	....
Mt. Margaret	Mt. Morgans	....	....	781·00	1·472	1·472	....	·034	....	7 047·10	29·891	29·925	·077
	Mt. Malcolm	·034	....	5 596·30	27·863	27·897	·077						
	Mt. Margaret	....	....	669·80	·556	·556	....						
North Coolgardie	Menzies	....	....	893·40	1·775	1·775	....	....	....	2 301·20	8·655	8·655	·044
	Ularring	....	....	459·70	3·027	3·027	....						
	Niagara	....	....	157·60	1·135	1·135	....						
	Yerilla	....	....	790·50	2·718	2·718	·044						
Broad Arrow	....	....	....	....	....	....	....	....	1·523	3 309·90	7·252	8·775	....
North-East Coolgardie	Kanowna	....	....	652·70	3·288	3·288	....	....	·260	1 049·40	4·201	4·461	....
	Kurnalpi	....	·260	396·70	·913	1·173	....						
East Coolgardie	East Coolgardie	·049	·082	1 202 988·99	5 204·890	5 205·021	869·873	·049	·150	1 203 905·19	5 206·263	5 206·462	869·873
	Bulong	....	·068	916·20	1·373	1·441	....						
Coolgardie	Coolgardie	....	11·497	8 895·52	77·181	88·678	114·140	....	11·915	10 334·02	81·030	92·945	114·140
	Kunanalling	....	·418	1 438·50	3·849	4·267	....						
Yilgarn	....	....	....	....	....	....	....	....	·512	6 470·10	56·833	57·345	·323
Dundas	....	....	....	....	....	....	....	....	....	114 292·50	904·741	904·741	653·818
Phillips River	....	....	....	....	....	....	....	....	....	23·00	·275	·275	....
South-West Mineral Field	....	....	....	....	....	....	....	....	....	50·80	·043	·043	....
Northampton Mineral Field	....	....	....	....	....	....	....	....	....	....	....	....	....
State Generally	....	....	....	....	....	....	....	....	3·865	....	3·069	6·934	....
Outside Proclaimed Goldfield	....	....	....	....	....	....	....	....	....	....	....	....	....
Total	....							4·423	20·202	1 378 991·21	6 558·808	6 583·433	1 650·223

TABLE III

Return showing total production reported to the Mines Department to 31st December, 1974.

Goldfield	District	District: Alluvial	District: Dollied and Specimens	District: Ore Treated	District: Gold Therefrom	District: Total Gold	District: Silver	Goldfield: Alluvial	Goldfield: Dollied and Specimens	Goldfield: Ore Treated	Goldfield: Gold Therefrom	Goldfield: Total Gold	Goldfield: Silver
		kg	kg	Tonnes	kg	kg	kg	kg	kg	Tonnes	kg	kg	kg
West Kimberley	....	....	....	....	....	....	....	·040	·768	1·02	·077	·885	1 160·705
Kimberley	....	....	....	....	....	....	....	282·614	94·412	23 299·89	537·841	914·867	4·005
West Pilbara	....	....	....	....	....	....	....	201·170	11·655	25 300·54	759·720	972·545	59·432
Pilbara	Marble Bar	483·933	142·619	362 810·47	10 604·466	11 231·018	1 048·102	811·004	233·317	515 526·42	14 819·956	15 864·277	1 081·722
	Nullagine	327·071	90·698	152 715·95	4 215·490	4 633·259	33·620						
Ashburton	....	....	....	....	....	....	....	288·283	15·006	6 916·33	90·617	393·906	1 305·455
Gascoyne	....	....	....	....	....	....	....	21·725	3·860	4 271·21	197·266	222·851	3·973
Peak Hill	....	....	....	....	....	....	....	105·372	171·421	795 671·62	10 038·516	10 315·309	118·009
East Murchison	Lawlers	221·544	73·823	2 055 172·12	25 750·065	26 045·432	848·153	280·939	691·665	12 833 320·81	113 719·810	114 692·414	1 876·298
	Wiluna	7·355	39·007	9 016 048·65	58 235·757	58 282·119	321·060						
	Black Range	52·040	578·835	1 762 100·04	29 733·988	30 364·863	707·085						
Murchison	Cue	160·036	283·723	6 925 726·34	43 658·485	44 102·244	8 548·605	802·163	1 858·171	15 779 094·67	188 796·311	191 456·645	16 340·866
	Meekatharra	457·427	583·467	2 380 522·85	40 828·575	41 869·469	164·191						
	Day Dawn	102·381	353·886	2 070 636·73	42 787·477	43 243·744	5 270·404						
	Mt. Magnet	82·319	637·095	4 402 208·75	61 521·774	62 241·188	2 357·666						
Yalgoo	....	....	....	....	....	....	....	56·477	101·502	453 919·04	8 257·470	8 415·449	47·372
Mt. Margaret	Mt. Morgans	111·191	292·434	1 239 224·67	22 335·381	22 739·006	181·374	366·763	1 103·921	11 708 707·70	154 610·887	156 081·571	8 175·879
	Mt. Malcolm	126·552	520·533	7 899 147·88	95 756·977	96 404·062	5 935·744						
	Mt. Margaret	129·020	290·954	2 570 335·15	36 518·529	36 938·503	2 058·761						
North Coolgardie	Menzies	52·773	219·168	1 988 157·93	44 625·578	44 897·519	1 218·623	151·123	621·652	3 803 618·87	80 576·692	81 349·467	2 255·948
	Ularring	4·033	227·041	548 684·03	13 935·355	14 166·429	693·202						
	Niagara	53·451	56·717	960 353·06	16 444·377	16 554·545	177·793						
	Yerilla	40·866	118·726	306 423·85	5 571·382	5 730·974	166·330						
Broad Arrow	....	....	....	....	....	....	....	684·367	883·238	1 463 827·95	23 532·965	25 100·570	177·393
North-East Coolgardie	Kanowna	3 314·052	424·115	1 057 828·73	19 653·013	23 391·180	94·903	3 713·342	682·751	1 073 367·90	20 252·767	24 648·860	95·298
	Kurnalpi	399·290	258·636	15 539·17	599·754	1 257·680	·395						
East Coolgardie	East Coolgardie	1 049·527	1 295·245	104 496 568·68	1 222 371·516	1 224 716·288	206 239·690	1 901·934	1 795·072	104 690 976·59	1 226 539·073	1 230 236·079	206 242·793
	Bulong	852·407	499·827	194 407·91	4 167·557	5 519·791	3·103						
Coolgardie	Coolgardie	535·383	708·210	3 087 041·61	48 333·874	49 577·467	1 808·626	582·719	891·635	3 466 264·59	56 253·511	57 727·865	1 832·671
	Kunanalling	47·336	183·425	379 222·98	7 919·637	8 150·398	24·045						
Yilgarn	....	....	....	....	....	....	....	68·389	200·340	8 455 300·37	76 424·774	76 693·503	6 734·631
Dundas	....	....	....	....	....	....	....	70·176	519·883	7 549 063·66	105 059·045	105 649·104	64 510·111
Phillips River	....	....	....	....	....	....	....	18·883	25·608	133 523·68	3 916·102	3 960·593	2 520·036
South-West Mineral Field	....	....	....	....	....	....	....	9·738	1·513	5 068·38	78·493	89·744	·472
Northampton Mineral Field	....	....	....	....	....	....	....	....	....	....	....	....	164·423
State Generally	....	....	....	....	....	....	....	37·351	38·447	27·43	321·615	397·413	1 015·922
Outside Proclaimed Goldfield	....	....	....	....	....	....	....	....	....	....	....	....	39·177
Total	....	....	....	....	....	....	....	10 454·572	9 945·837	172 787 068·67	2 084 783·508	2 105 183·917	3 157 62·591

TABLE IV

Total output of Gold Bullion, Concentrates, etc., entered for export and received at the Perth Mint from 1st January, 1886.

Year	Export	Mint	Total	Estimated Value
	kg	kg	kg	$A
1886	8·403	....	8·403	2 294
1887	135·592	....	135·592	37 036
1888	97·193	....	97·193	26 546
1889	431·079	....	431·079	117 742
1890	634·586	....	634·586	173 328
1891	843·406	....	843·406	230 364
1892	1 656·933	....	1 656·933	452 568
1893	3 085·543	....	3 085·543	842 770
1894	5 763·435	....	5 763·435	1 574 198
1895	6 441·847	....	6 441·847	1 759 498
1896	7 826·216	....	7 826·216	2 137 616
1897	18 781·724	....	18 781·724	5 129 954
1898	29 221·390	....	29 221·390	7 981 394
1899	39 916·966	5 823·952	45 740·918	12 493 464
1900	27 818·554	16 171·431	43 989·985	12 015 220
1901	28 729·876	24 252·300	52 982·176	14 471 308
1902	21 991·394	36 204·372	58 195·766	15 895 322
1903	25 930·526	38 291·976	64 222·502	17 541 438
1904	25 212·977	36 472·373	61 685·350	16 848 452
1905	20 375·573	40 441·549	60 817·122	16 611 308
1906	17 487·948	38 328·690	55 816·638	15 245 498
1907	13 430·579	39 369·240	52 799·819	14 421 500
1908	11 083·847	40 171·918	51 255·765	13 999 762
1909	12 017.468	37 600.957	49 618·425	13 552 548
1910	7 277·291	38 464·478	45 741·769	12 493 696
1911	4 989·691	37 649·055	42 638·746	11 646 150
1912	2 599·539	37 295·584	39 895·123	10 896 770
1913	2 682·834	38 188·480	40 871·314	11 163 402
1914	1 600·419	36 749·447	38 349·866	10 474 704
1915	539·349	37 099·332	37 638·681	10 280 456
1916	831·774	32 181·395	33 013·169	9 017 064
1917	280·631	29 899·606	30 180·237	8 243 292
1918	486·586	26 775·958	27 262·544	7 446 366
1919	200·490	22 631·509	22 831·999	7 237 018
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	15 507·496	15 692·058	4 464 372
1924	80·409	15 005·866	15 086·275	4 511 854
1925	121·633	13 602·843	13 724·476	3 748 640
1926	99·165	13 503·729	13 602·894	3 715 430
1927	104·480	12 596·703	12 701·183	3 469 144
1928	103·864	12 132·508	12 236·372	3 342 186
1929	94·465	11 637·022	11 731·487	3 204 284
1930	54·527	12 931·737	12 986·264	3 728 884
1931	53·705	15 826·860	15 880·565	5 996 274
1932	120·901	18 714·164	18 835·065	8 807 284
1933	76·109	19 743·255	19 819·364	9 772 508
1934	109·497	20 149·391	20 258·888	11 117 746
1935	306·951	19 880·732	20 187·683	11 404 298
1936	1 711·456	24 608·549	26 320·005	14 747 078
1937	2 228·468	28 895·125	31 123·593	17 487 510
1938	3 533·979	32 788·387	36 322·366	20 726 046
1939	3 071·154	34 695·859	37 767·013	23 685 928
1940	2 229·512	34 829·707	37 059·219	25 393 006
1941	2 050·526	32 453·118	34 503·644	23 702 890
1942	487·593	25 893·768	26 381·361	17 730 990
1943	199·322	16 797·964	16 997·286	11 421 338
1944	56·764	14 445·691	14 502·455	9 799 994
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	25 458·683	25 626·527	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	26 882·327	26 954·549	27 083 858
1960	64·343	26 552·728	26 617·071	26 743 322
1961	91·524	27 025·885	27 117·409	27 413 780
1962	141·179	26 588·160	26 729·339	26 871 460
1963	145·109	24 744·257	24 889·366	25 035 372
1964	95·516	22 076·504	22 172·020	22 299 886
1965	93·204	20 417·579	20 510·783	20 722 164
1966	45·475	19 511·667	19 557·142	19 765 287
1967	85·325	17 830·932	17 916·257	18 071 924
1968	28·580	15 887·164	15 915·744	16 785 723
1969	43·951	14 431·968	14 475·919	17 707 219
1970	49·089	10 576·110	10 625·199	11 069 049
1971	29·183	10 795·117	10 824·300	11 921 570
1972	....	10 850·502	10 850·502	16 042 688
1973	6·098	7 934·406	7 940·504	18 326 747
1974	60·504	6 570·454	6 630·958	22 324 330
	361 062·598	1 792 164·019	2 153 226·617	1 161 701 447

	1973	1974
	$A	$A
Estimated Mint value of above production	1 109 600 296	1 115 914 563
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	24 597 617	40 607 680
Estimated Total	$A1 139 377 117	$A1 161 701 447
Bonus paid by Commonwealth Government under Commonwealth Bounty Act, 1930	322 896	322 896
Subsidy paid by Commonwealth Government under Gold Mining Industry Assistance Act, 1954, from 1955	29 200 611	29 200 611
Gross estimated value of gold won	$A1 168 900 624	$A1 191 224 954

TABLE V

Quantity and Value of Minerals, other than Gold, Reported during the year 1974

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.	1 192 188·00	....	75 098 200·00
M.L. 1SA	South-West	Alcoa of Australia (W.A.) Ltd.	789 017·00	....	49 701 800·00
			1 981 205·00	....	124 800 000·00 (*l*)
		BENTONITE (See Clays)			
		BERYL (*g*) (*h*)			
				BeO Units	
M.C. 4958	Yalgoo	Baker G. S. & Pearson K. J.	8·00	93·00	1 312·00
M.C. 4958	Yalgoo	Mineral By-Products Pty. Ltd.	2·00	29·20	410·00
M.C. 2146	Murchison	Baker G. S.	1·00	11·00	150·00
M.C. 874	Yalgoo	Seleka Mining & Investments Ltd.	68·00	797·40	12 251·76
			79·00	930·60	(*b*) 14 123·76
		BUILDING STONE			
		Quartz Crystal			
M.C. 1110H	South-West	Snowstone Pty. Ltd.	70·00	....	3 467·00
		Quartz			
M.C. 1110H	South-West	Snowstone Pty. Ltd.	2 537·39	....	109 121·96
		Quartzite			
M.C.'s 1158H, 1159H	South-West	House R.P.	608·07	....	5 850·00
		Spongolite			
M.C. 1062H	South-West	Worth, H.	79·25	....	1 092·00
		Quartz			
M.C. 1921H	South-West	Cutts, J. E.	1 669·08	....	1 643·00
		Lepidolite			
M.L. 80	Coolgardie	A.C.I. Minerals Pty. Ltd.	75·67	....	567·18
			5 039·46	....	121 741·14 (*a*) (*c*)
		CLAYS			
		Bentonite			
M.C. 1042H etc.	South-West	Scott, M. E., W. T. and R. J.	328·47	....	4 314·00
M.C. 1055H	South-West	Scott. J. W.	240·52	....	3 555·00
		*Brick Pipe and Tile Clay			
M.C. 1438H	South-West	Concrete Industries (Monier) Ltd.	33 762·00	....	33 229·00
	South-West	†Unspecified Producers	277 130·85	....	276 634·00
		Cement Clay			
M.C. 788H	South-West	Bell Bros. Pty. Ltd.	25 731·00	....	72 929·52
M.C. 483H etc.	South-West	Cockburn Cement Pty. Ltd.	9 244·00	....	22 740·24
		Fireclay			
M.L. 436H, 437H	South-West	Midland Brick Co. Pty. Ltd.	157 463·86	....	38 741·00
M.L. 435H	South-West	Midland Brick Co. Pty. Ltd.	19 426·49	....	4 779·00
M.C. 304H	South-West	Clackline Refractories Ltd.	1 727·63	....	3 400·00
M.C. 1302H	South-West	Bridge, J. S.	16 017·48	....	15 764·50
M.C. 522H, 523H	South-West	Bridge, J. S. and T. D.	26 307·86	....	25 892·00
		White Clay-Ball Clay			
M.C. 109H	South-West	H. L. Brisbane & Wunderlich Ltd.	718·65	....	6 881·00
			568 098·81	....	508 859·26 (*a*) (*c*)

* 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.	742 638·01	....	3 873 677·99
C.M.L. 437 etc.	Collie	Western Collieries Ltd.	703 409·92	....	5 271 304·47
			1 446 047·93	....	9 144 982·46 (*e*)

TABLE V.—*Quantity and Value of Minerals, other than Gold, Reported during the Year* 1974—*continued*

COBALT (Metallic By-Product of Nickel Mining)

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonnes	Metallic Content	Value $A
				Cobalt Tonne	
M.L. 150 etc.	Coolgardie	Western Mining Corporation Ltd.	....	135·00	(*f*) 608 308·00

COPPER (Metallic By-Product of Nickel Mining)

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonnes	Metallic Content	Value $A
				Copper Tonne	
M.L. 150 etc.	Coolgardie	Western Mining Corporation Ltd.	....	267·00	(*f*) 341 520·00

EMERALDS

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonnes	Metallic Content	Value $A
				Carats	
M.L. 116, M.C. 2131	Murchison	Bellairs, R. D.	....	19	1 400·00

FELSPAR

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonnes	Metallic Content	Value $A
M.L. 80 etc.	Coolgardie	Australian Consolidated Industries	856·54	....	16 811·93
M.C. 874	Yalgoo	Seleka Mining & Investments Ltd.	18·00	....	410·00
M.C. 14521H	South-West	O'Neil, C. K. and Watkins, A. H.	5·89	....	265·05
			880·43	....	17 486·98 (*a*)

GLASS SAND

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonnes	Metallic Content	Value $A
M.C. 417H, 418H etc.	South-West	Australian Glass Manufacturers Co.	12 484·00	....	16 589·59
M.C. 521H	South-West	Bell Bros. Pty. Ltd.	121 530·00	....	198 977·00
M.C. 1074H	South-West	Ready Mix Group (W.A.)	28 643·03	....	N.A.
M.C. 1191H	South-West	Silicon Quarries Pty. Ltd.	117 988·45	....	90 498·64
M.C. 6056H	South-West	Zaninovich, L. V.	24·39	....	9·60
			280 669·87	....	(*c*) 306 074·83

GYPSUM

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonnes	Metallic Content	Value $A
M.C. 30 etc.	Yilgarn	Ajax Plaster Co. Pty. Ltd.	3 558·50	....	7 555·06
M.C. 50 etc.	Yilgarn	H. B. Brady & Co. Pty. Ltd.	17 736·27	....	43 685·00
M.C. 9 etc.	Yilgarn	West Australian Plaster Mills	19 920·00	....	40 154·73
M.C. 43 etc.	Gascoyne	Garrick Agnew Pty. Ltd.	74 609·00	....	258 853·46
M.C. 612H etc.	South-West	Gypsum Industries of Aust. Pty. Ltd.	46 190·30	....	110 179·00
M.C. 1419H	South-West	Forsyth, V.	20·32	....	40·00
M.C. 1115H, 1116H	South West	McAndrew, R. W.	101·60	....	200·00
			162 135·99	....	(*a*) 460 667·25

Plaster of Paris reported as manufactured during the year 30 412·50 tonnes from 43 601·28 tonnes of gypsum by three companies.

IRON ORE

Pig Iron

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonnes	Metallic Content	Value $A
			Ore treated Tonne	Pig Iron Recovered Tonne	
M.L. 2SA	Yilgarn	Charcoal Iron and Steel Industry....	86 936·00	53 378·00	3 906 401·00 (*c*) (*d*)

Ore Railed to Kwinana

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonnes	Metallic Content	Value $A
				Av. Assay Fe%	
M.L. 2SA	Yilgarn	Dampier Mining Co. Ltd.	*2 245 106·00	63·00	15 452 738·60 (*n*)

Ore Shipped to Eastern States

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonnes	Metallic Content	Value $A
M.L. 10 etc.	West Kimberley	Dampier Mining Co. Ltd.	194 601·00	67·18 }	1 513 406·00
M.L. 50/60	West Kimberley	Dampier Mining Co. Ltd.	25 083·00	67·80 }	(*n*)
M.L. 244SA	Peak Hill	Mt. Newman Mining Co. Pty. Ltd.	4 035 930·00	64·00	22 167 180·00 (*b*)

Ore Exported Overseas

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonnes	Metallic Content	Value $A
M.L. 50/60	West Kimberley	Dampier Mining Co. Ltd.	2 550 962·00	67·26	19 071 411·60 (*b*)
M.L. 10 etc.	West Kimberley	Dampier Mining Co. Ltd.	534 254·00	68·90	4 416 443·17 (*b*)
T.R. 2401H	West Pilbara	Cliffs W.A. Mining Co. Pty. Ltd.	6 688 564·00	59·49	34 228 567·00 (*b*)
M.L. 4SA	West Pilbara	Hamersley Iron Pty. Ltd.	30 343 465·00	63·78	201 099 168·00 (*b*)
M.L. 235SA	Pilbara	Goldsworthy Mining Ltd.	7 762 307·00	63·35	54 759 149·00 (*b*)
M.L. 244SA	Peak Hill	Mt. Newman Mining Co. Pty. Ltd.	26 534 197·00	63·00	178 707 933·00 (*b*)
M.C. 876H etc.	South-West	Western Mining Corporation Ltd.	527 601·00	59·89	3 580 424·00 (*b*)
			81 442 070·00	....	534 996 420·37

* Includes 1 251 469 Wet tonnes shipped to Eastern States and 103 638 Wet tonnes shipped overseas.

TABLE V.—*Quantity and Value of Minerals, other than Gold, Reported during the Year 1974—continued*

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonnes	Metallic Content	Value $A
		Pellets (Exported Overseas)			
T.R. 2401H	West Pilbara	Cliffs W.A. Mining Co. Pty. Ltd.	3 970 929·00	62·68	38 909 515·00
M.L. 4SA	West Pilbara	Hamersley Iron Pty. Ltd.	1 587 813·00	63·80	15 239 260·00
			5 558 742·00	....	54 148 775·00
		* LIMESTONE (For Building. Burning Purposes etc.)			
M.C. 692H	South-West	Bell Bros. Pty. Ltd.	21 399·60	....	18 831·12
M.C. 1662H	South-West	Bell Bros. Pty. Ltd.	12 584·00	....	11 100·48
M.C. 1290H	South-West	Bellombra, V.	3 413·87	....	9 743·67
M.C. 1988H, 1989H	South-West	Cockburn Cement Ltd.	3 730·00	....	3 707·60
M.C. 1542H	South-West	Caroleo, R. D.	301·00	....	296·63
M.C. 14211H	South-West	Gibbs, C. E.	30·00	....	120·00
M.C. 14072H	South-West	G. Korsunski Pty. Ltd.	42 434·16	....	20 601·99
M.C. 1227H	South-West	Korsunski, G.	138 402·23	....	68 107·89
M.C. 1093H	South-West	Piper Walker Pty. Ltd.	98·56	....	97·00
M.C. 1093H	South-West	Menchetti, E. N.	113·81	....	113·00
M.C. 1105H, 1702H	South-West	Moore, F. W. and E. M.	2 431·62	....	4 786·00
M.C. 1456H	South-West	Ready Lime Putty Pty. Ltd.	1 000·00	....	1 000·00
M.C. 1660H	South-West	Swan Portland Cement Ltd. ...	257 379·90	....	477 565·95
M.C. 727H	South-West	Thiess Bros. Pty. Ltd.	1 625·67	....	480·00
M.C. 709H	South-West	Snader, R.	32 127·94	....	15 933·50
M.C. 713H	South-West	Steel Bros. Transport Pty. Ltd.	83·00	....	53·30
M.C. 1284H	South-West	W. A. Limestone Co. Pty. Ltd.	13 378·52	....	19 789·35
M.C. 513WP	West Pilbara	Specified Services Pty. Ltd.	47 552·00	....	47 552·00
M.L. 267WP etc.	West Pilbara	Hamersley Iron Pty. Ltd.	223 962·30	....	165 399·25
Q.L. 61	Pilbara	J. C. Chandler and E. Praznovszky	13 940·00	....	13 719·50
	South-West	†Unspecified Producers	340 934·49	....	394 518·00
		(For Agricultural Purposes)			
M.C. 50	Dundas	Esperance Lime Supply	393·06	....	1 548·10
			1 157 315·73	....	1 275 064·33 (*c*)

* 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) (*h*)			
M.L. 80 etc.	Coolgardie	Australian Glass Manufacturers Co. Pty. Ltd.	1·00	Li20 Units 420·00	(*a*) 15·65
		MANGANESE (Metallurgical Grade)			
M.C. 487 etc.	Pilbara	Westralian Ores Pty. Ltd.	18 107·04	Av. Assay Mn% 46·41	(*b*) 336 655·00
		MICA			
M.C. 1309	Yilgarn	Mineral By-Products Pty. Ltd.	34·00	....	(*a*) 418·30
		MINERAL BEACH SANDS Ilmenite (*g*)		Av. Assay TiO2%	
Sussex Loc. 7	South-West	Cable Sands Pty. Ltd.	50 002·77	54·98	N.A.
M.C. 746H	South-West	Cable Sands Pty. Ltd.	149 995·33	54·97	N.A.
M.C. 7062H etc.	South-West	Allied Eneabba Pty. Ltd.	3 137·55	61·00	N.A.
M.C. 7556H etc.	South-West	Jennings Mining Ltd.	27 041·00	59·59	N.A.
M.C. 389H etc.	South-West	Western Mineral Sands Pty. Ltd.	194 594·00	54·00	N.A.
M.C. 619H etc.	South-West	Westralian Sands Pty. Ltd.	148 634·00	56·68	N.A.
M.C. 516H etc.	South-West	Western Titanium N.L.	280 259·00	54·59	N.A.
			853 663·65	55·09	11 237 931·58 (*b*)
		Upgraded Ilmenite (*g*)		Av. Assay TiO 2%	
M.C. 516H etc.	South-West	Western Titanium N.L.	12 068·00	91·79	N.A.
M.C. 619H etc.	South-West	Westralian Sands Pty. Ltd.	2 058·00	67·90	N.A.
			14 126·00	88·32	N.A.
		Reduced Ilmenite (*g*)			
M.C. 516H etc.	South-West	Western Titanium N.L.	907·00	67·64	N.A.

TABLE V.—*Quantity and Value of Minerals, other than Gold, Reported during the Year 1974—continued*

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonnes	Metallic Content	Value $A
		Rutile (g) (h)		TiO2 Tonne	
M.C. 516H etc.	South-West	Western Titanium N.L.	3 813·00	3 657·81	513 380·35
M.C. 7062H etc.	South-West	Allied Eneabba Pty. Ltd.	337·02	323·53	62 178·60
M.C. 7556H etc.	South-West	Jennings Mining Ltd.	7 125·00	6 763·16	939 637·00
			11 275·02	10 744·50	1 515 195·95 (b)
		Leucoxene (g) (h)		TiO2 Tonne	
Sussex Loc. 7	South-West	Cable Sands Pty. Ltd.	3 925·42	3 437·55	484 366·37
M.C. 877H etc.	South-West	Cable Sands Pty. Ltd.	1 308·48	1 145·86	161 455·45
M.C. 516H etc.	South-West	Western Titanium N.L.	1 198·00	1 057·54	107 820·00
M.C. 7556H etc.	South-West	Jennings Mining Ltd.	325·00	282·75	65 026·00
M.C. 619H etc.	South-West	Westralian Sands Pty. Ltd.	8 910·90	7 862·96	817 237·00
			15 667·80	13 786·66	1 635 904·82 (b)
		Monazite (g) (h)		ThO2 Units	
Sussex Loc. 7	South-West	Cable Sands Pty. Ltd.	411·50	2 950·31	6 883·92
M.C. 877H etc.	South-West	Cable Sands Pty. Ltd.	137·16	983·43	22 961·31
M.C. 516H etc.	South-West	Western Titanium N.L.	1 789·00	10 782·62	231 285·19
M.C. 619H etc.	South-West	Westralian Sands Pty. Ltd.	324·00	2 106·00	63 331·00
			2 661·66	16 822·36	(b)386 461·42
		Zircon (g) (h)		ZrO2 Tonne	
Sussex Loc. 7	South-West	Cable Sands Pty. Ltd.	3 348·11	2 183·29	241 091·25
M.C. 877H etc.	South-West	Cable Sands Pty. Ltd.	10 045·38	6 551·89	723 276·75
M.C. 7062H etc.	South-West	Allied Eneabba Pty. Ltd.	207·78	137·14	13 770·96
M.C. 7556H etc.	South-West	Jennings Mining Ltd.	4 627·00	3 007·55	241 256·00
M.C. 619H etc.	South-West	Westralian Sands Pty. Ltd.....	32 128·00	21 044·01	2 407 644·00
M.C. 516H etc.	South-West	Western Titanium N.L.	23 325·00	15 195·19	1 395 071·55
			73 681·27	48 119·07	5 022 110·51 (b)
		Xenotime (g) (h)		Y203 kg	
M.C. 516H etc.	South-West	Western Titanium N.L.	26·00	7 874·40	(b) 21 036·63
		NICKEL CONCENTRATES		Av. Assay Ni%	
M.C. 150 etc.	Coolgardie	Western Mining Corporation Ltd.	*337 339·00	12·26	109 956 965·00
M.C. 39W	Broad Arrow	Great Boulder Mines Ltd. and North Kalgurli Mines Ltd.	8 665·88	16·01	3 677 000·00
M.C. 41Z	North Coolgardie	Great Boulder Mines Ltd. and North Kalgurli Mines Ltd.	11 593·43	9·36	3 006 200·00
M.C. 246, 283	Coolgardie	Anaconda Australia Inc.	10 659·30	16·07	4 818 194·00
			368 257·61	....	121 458 359·00 (o)
		NICKEL ORE		Av. Assay Ni%	
M.C. 1288. M.L. 248	Coolgardie	Metals Exploration N.L.	68 791·00	3·36	4 833 775·21 (c)
		PALLADIUM (h) (Metallic By-Product Nickel Mining)		kg	
M.C. 150 etc.	Coolgardie	Western Mining Corporation Ltd.	....	163·717	428 700·00
		PLATINUM (h) (Metallic By-Product Nickel Mining)		kg	
M.C. 150 etc.	Coolgardie	Western Mining Corporation Ltd.	....	59·537	227 200·00
		RUTHENIUM (h) (Metallic By-Product Nickel Mining)		kg	
M.C. 150 etc.	Coolgardie	Western Mining Corporation Ltd.	....	5·281	7 300·00

* Contained Gold 60·504 kg, Silver 114·140 kg. Transferred to Gold and Silver Items.

TABLE V.—*Quantity and Value of Minerals, other than Gold, Reported during the Year 1974—continued*

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonnes	Metallic Content	Value $A
		PETROLEUM			
		Crude Oil			
1H	Ashburton	West Australian Petroleum Pty. Ltd.	Barrels 13 801·191	....	31 257 311·62 (m)
		Natural Gas			
Lic. 1	South-West	West Australian Petroleum Pty. Ltd.	m^310^3 831 604·36	....	5 285 737·76 (p)
		Condensate			
Lic. 1	South-West	West Australian Petroleum Pty. Ltd.	tonne 4 283·89	....	N.A.
		SALT			
		State Total as Reported to Mines Dept.	3 906 492·38	....	11 576 831·00 (b)
		SEMI-PRECIOUS STONES			
		Amethyst			
M.C. 444	Gascoyne	Soklich, F.	kg 1 466·270	....	2 249·95
		Chalcedony			
M.C. 498 etc.	Gascoyne	Soklich, F.	2 636·800	....	1 757·40
		Green Beryl			
M.L. 116, M.C. 2131	Murchison	Bellairs, R. D.	5·000	....	104·00
		Moss opal			
M.C. 60	Dundas	Soklich, F.	17 762·960	....	7 614·28
		Opal			
M.C. 392K	North East Coolgardie	Russgar Minerals N.L.	4·323	....	16 994·00
		Opalite			
M.C. 11F	Mt. Margaret	Downie, R.	1 020·000	....	400·00
		Quartz			
P.A. 395	Pilbara	Soklich, F.	4 850·710	....	1 755·75
					30 875·38
		SILVER			
		By-Product of Gold Mining....	kg 1 604·213	....	118 457·55
		By-Product of Nickel Mining	114·140	....	11 256·00
			1 718·353	....	129 713·55
		TALC			
M.L. 433H	South-West	Three Springs Talc Pty. Ltd.	56 985·00	....	N.A.
M.C. 190P....	Peak Hill	Westside Mines N.L.	4 668·00	....	N.A.
			61 653·00	....	N.A.
		TANTO-COLUMBITE ORES AND CONCENTRATES (g) (h)			
				Ta205 Units	
M.L. 660 etc.	Greenbushes	Greenbushes Tin N.L.	88·20	4 112·00	560 392·37
M.C. 647 etc.	Greenbushes	Vultan Minerals Limited	49·81	1 799·86	168 771·00
			138·01	5 911·86	(b) 729 163·37

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonnes	Metallic Content	Value $A
		TIN CONCENTRATES (*g*) (*h*)		Sn Tonnes	
M.C. 647 etc.	Greenbushes	Vultan Minerals Limited	138·58	85·36	330 612·00
M.L. 660 etc.	Greenbushes	Greenbushes Tin N.L.	611·09	430·78	2 167 495·30
D.C. 195 etc.	Pilbara	Pilbara Tin Pty. Ltd.	37·96	25·31	121 752·00
M.C. 700	Pilbara	Edwards, M. R.	3·00	2·00	7 761·65
M.C. 1348, 1349	Pilbara	Johnston J. A. and Sons Pty. Ltd.	22·09	15·86	77 675·77
D.C. 700	Pilbara	Henderson J. M. and Sons	1·71	1·23	4 787·59
D.C. 53 etc.	Pilbara	Marshall, W.	3·60	2·45	8 414·52
	Pilbara	Crown Lands—District Generally	13·78	9·58	42 528·74
M.C. 305 WP	West Pilbara	Yule River Mining Pty. Ltd.	10·08	6·97	40 181·12
M.C. 3134/5 WP	West Pilbara	Yule River Mining Pty. Ltd.	38·23	26·50	116 492·81
	West Pilbara	Crown Lands—Sundry Persons	·33	·23	1 217·85
			880·45	606·27	2 918 919·35 (b)
		VERMICULITE			
M.C. 965	Yilgarn	Mineral By-Products Pty. Ltd.	225·00	....	(*a*) 2 767·50

REFERENCES

N.A. Not available for publication.

(a) Estimated F.O.R. Value.

(b) Estimated F.O.B. Value.

(c) Value at Works.

(d) Value of Mineral Recovered.

(e) Value at Pit Head.

(f) Estimated value based on current published prices.

(g) Only results of sales realised during the period under review.

(h) Metallic content calculated on assay basis.

(i) Concentrates.

(j) By-Product of Gold Mining.

(k) By-Product of Tin Mining.

(l) Value computed by the Department of Mines based on the price of Alumina F.O.B. Jamaica.

(m) Value based on the price per barrel as assessed by the Industries Assistance Commission for Barrow Island Crude Oil at Kwinana.

(n) Nominal Value.

(o) Estimated F.O.B. Value based on the current price for Nickel Cathodes.

(p) Nominal Value at Well-Head.

NOTE:—If utilised for publication please acknowledge release from the Hon. Minister for Mines.

TABLE VI

TOTAL MINERAL OUTPUT OF WESTERN AUSTRALIA

Recorded mineral production of the State to 31st December, 1974, 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)	,,	95 757 747·11	599 510 940·00
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	,,	4 098·69	1 029 757·06
Bismuth	kg	7 375·28	14 495·67
Building Stone (*g*)—			
Chrysotile-Serpentine	tonne	4·52	106·00
Granite (Facing Stone)	,,	1 058·72	38 904·00
Lepidolite	,,	84·15	713·18
Prase	,,	9·65	275·00
Quartz (Dead White)	,,	1 617·78	33 914·00
Quartz Crystal	,,	1 829·79	24 967·40
Quartz	,,	25 798·40	353 755·31
Quartzite	,,	10 633·40	50 419·00
Sandstone	,,	680·75	4 020·00
Sandstone (Donnybrook)	,,	84·33	3 486·00
Slate	,,	238·77	2 115·00
Spongolite	,,	3 893·99	42 516·00
Tripolite	,,	268·24	264·00
Calcite	,,	5·08	50·00
Chromite	,,	14 650·43	416 593·50
Clays—			
Brick, Pipe and Tile Clays	,,	1 351 039·29	1 866 018·16
Bentonite	,,	13 835·33	99 123·52
Cement Clays	,,	521 946·92	970 742·67
Fireclay	,,	1 581 064·49	1 610 133·09
Fullers Earth	,,	466·77	3 821·00
White Clay—			
Ball Clay	,,	30 713·99	211 446·60
Kaolin	,,	6 511·83	24 739·97
Coal	,,	45 966 414·15	159 701 808·38
Cobalt (Metallic By-Product Nickel Mining)	,,	1 183·93	3 969 383·88
Copper (Metallic By-Product Nickel Mining)	,,	6 122·04	5 437 458·00
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	18 818·68	6 042·00
Emery	tonne	21·49	750·00
Felspar	,,	74 298·56	566 567·04
Fergusonite	,,	·30	782·80
Gadolinite	,,	1·02	224·00
Glass Sand	,,	1 211 312·83	952 799·61
Glauconite	,,	(*h*) 6 570·77	300 769·00
Gold (Mint and Export)	kg	2 153 226·62	1 161 701 447·00
Graphite	tonne	155·66	2 608·40
Gypsum	,,	1 885 058·54	4 593 816·47
Iron Ore—			
Pig Iron Recovered	,,	973 474·60	50 257 747·12
Ore Exported	,,	348 813 675·95	2 272 556 610·82
Pellets Exported	,,	21 352 821·37	204 464 514·33
Locally Used Ore	,,	12 686 604·43	76 878 682·60
For Flux	,,	58 996·10	74 096·00
Jarosite	,,	9·69	75·00
Kyanite	,,	4 283·34	43 562·00
Lead Ores and Concentrates	,,	489 720·00	10 636 394·41
Limestone	,,	10 594 038·00	11 029 616·52
Lithium Ores—			
Petalite	,,	8 041·97	124 123·05
Spodumene	,,	108·29	3 627·20
Magnesite	,,	31 350·76	335 422·86
Manganese—			
Metallurgical Grade	,,	1 915 942·00	41 201 607·08
Battery Grade	,,	2 253·85	90 860·20
Low Grade	,,	5 135·47	81 538·20
Mica	kg	48 936·79	8 386·78

TABLE VI.—Total Mineral Output of Western Australia—*continued*

Mineral		Quantity	Value $A
Mineral Beach Sands—			
Ilmenite Concentrates	tonne	7 034 627·87	74 761 191·20
Monazite Concentrates	,,	29 659·87	3 563 188·71
Rutile	,,	26 653·40	2 787 693·75
Leucoxene	,,	82 637·21	5 648 281·96
Zircon	,,	505 330·35	17 055 685·46
Xenotime	,,	202·30	212 889·87
Crude Concentrates (Mixed)	,,	158·45	1 553·00
Molybdenite	,,	78·74	1 730·00
Nickel Concentrates	,,	1 564 700·73	495 252 073·00
Nickel Ore	,,	348 465·16	17 609 955·62
Ochre—			
Red	,,	12 296·65	246 969·11
Yellow	,,	454·78	5 955·50
Peat	,,	4 051·54	62 633·00
Petroleum (Crude Oil)	bbls.	105 227 862·00	285 269 027·25
(Natural Gas)	$m^3 10^3$	2 343 334·94	13 782 567·37
(Condensate)	bbls.	78 226·54	N.A.
Palladium (By-Product Nickel Mining)	kg	197·07	479 356·00
Platinum (By-Product Nickel Mining)	,,	126·28	443 485·00
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
Ruthenium (By Product Nickel Mining)	kg	5·28	7 300·00
Salt	tonne	14 295 101·18	43 660 106·00
Semi Precious Stones—			
Amethyst	kg	26 737·90	22 784·29
Beryl (coloured)	,,	90·72	100·00
Chalcedony	,,	74 903·59	29 629·70
Chrysoprase	,,	122 202·34	121 142·00
Dravite	,,	8 640·03	15 593·78
Green Beryl	,,	5·00	104·00
Magnesite	,,	5 072·98	2 780·00
Moss Opal	,,	82 941·92	33 120·91
Moss Agate	,,	16 256·75	4 800·00
Opal	,,	4·32	16 994·00
Opaline	,,	11·34	7·50
Opalite	,,	1 020·00	400·00
Prase	,,	3 955·33	729·50
Quartz	,,	33 483·73	13 544·85
Tiger Eye Opal	,,	1 596·64	5 167·67
Topaz (Blue)	,,	3·17	3·50
Tourmaline	,,	1 035·10	2 123·90
Sillimanite	tonne	2·03	26·00
Silver (*c*)	kg	426 835·95	8 826 589·23
Soapstone	tonne	574·48	3 855·70
Talc	,,	321 132·28	(*g*) 4 719 451·65
Tanto/Columbite Ores and Concentrates	,,	2 112·67	5 193 148·41
Tin	,,	32 413·37	30 669 693·76
Tungsten Ore and Concentrates—			
Scheelite	,,	171·87	143 424·24
Wolfram	,,	309·84	125 810·16
Vermiculite	,,	3 253·03	34 380·63
Zinc (Metallic By-Product) (*d*)	,,	2 934·08	(*j*)
Zinc Ore (Fertiliser)	,,	20·32	200·00
Total Value to 31st December, 1974			5 690 063 605·45

(*a*) By-Product from Gold Mining.
(*b*) Part By-Product from Gold Mining.
(*c*) By-Product from Gold, Copper and Lead Mining.
(*d*) By-Product from Lead Mining.
(*e*) Quantity not recorded.
(*f*) Value of mineral or concentrate recovered.
(*g*) Incomplete.
(*h*) Mineral Recovered.
(*i*) Assayed Metallic Content.
(*j*) Value included in Lead Value.
(*k*) Based on the price assessed by the Industries Assistance Commission for Barrow Island crude oil at Kwinana.
(*l*) Nominal well-head value.

Footnote.—Comprehensive mineral production records maintained in the Statistical Branch of the Department of Mines show locality, producers, period, quantity, assayed or metallic content, and value of the various minerals listed above.

TABLE VII

Showing average number of men employed above and below ground in the larger mining companies operating in Western Australia during 1973 and 1974.†

Company	1973			1974		
	Above	Under	Total	Above	Under	Total
Gold*—						
Central Norseman Gold Corporation N.L.	112	85	197	131	87	218
Hill 50 Gold Mine N.L.	52	51	103	40	47	87
Kalgoorlie Lake View Pty. Ltd. (Boulder)	558	387	945	630	386	1 016
Kalgoorlie Lake View Pty. Ltd. (Mt. Charlotte)	16	132	148	14	131	145
North Kalgurli Mines Ltd.	117	98	215	107	28	135
All Other Operators	232	161	393	275	151	426
State Average	1 087	914	2 001	1 197	830	2 027
Alumina (from Bauxite)—						
Alcoa of Australia (W.A.) N.L.	1 798	....	1 798	1 965	....	1 965
Coal—						
Griffin Coal Mining Co. Ltd.	174	....	174	199	....	199
Western Collieries Ltd.	137	308	445	163	323	486
Iron Ore—						
Charcoal Iron & Steel	11	....	11	11	....	11
Dampier Mining Co. Ltd.	459	....	459	465	....	465
Goldsworthy Mining Ltd.	625	....	625	700	....	700
Hamersley Iron Pty. Ltd.	1 549	....	1 549	1 736	....	1 736
Mt. Newman Mining Co. Pty. Ltd.	997	....	997	905	....	905
Western Mining Corporation	72	....	72	41	....	41
Cliffs Western Australian Mining Co. Pty. Ltd.	173	....	173	192	....	192
Mineral Beach Sands—						
Allied Eneabba Pty. Ltd.	....	....	....	11	....	11
‡Cable (1956) Ltd. and Ilmenite Minerals Pty. Ltd.	57	....	57	....	....	....
Cable Sands Pty. Ltd.	....	....	....	78	....	78
Jennings Mining Limited	....	....	....	120	....	120
Western Mineral Sands Pty. Ltd.	44	....	44	45	....	45
Westralian Sands Ltd.	84	....	84	85	....	85
Western Titanium N.L.	152	....	152	211	....	211
Nickel—						
Anaconda Australia Inc.	5	3	8	18	79	97
Great Boulder Gold Mines Limited and North Kalgurli Mines Ltd.	269	110	379	273	119	392
Metals Exploration N.L.	89	125	214	96	127	223
Western Mining Corporation	780	600	1 380	737	641	1 378
Petroleum—Crude Oil—						
West Australian Petroleum Pty. Ltd.	158	....	158	146	....	146
Salt—						
Dampier Salt Limited	114	....	114	120	....	120
Lefroy Salt Co.	16	....	16	17	....	17
Leslie Salt Co.	36	....	36	46	....	46
Texada Mines Pty. Limited	270	....	270	314	....	314
All Other Minerals	279	....	279	258	....	258
State Total—Other than Gold	8 348	1 146	9 494	8 952	1 289	10 241

* 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 Cable Sands Pty. Ltd. in January 1974.

By Authority: WILLIAM C. BROWN, Government Printer