MINES ANNUAL REPORT 1970

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

MINES

1970 ANNUAL REPORT

The Department of Mines Western Australia

REPORT OF THE

DEPARTMENT *of* MINES

WESTERN AUSTRALIA

FOR THE YEAR 1970

By Authority: WILLIAM C. BROWN, Government Printer
1971

90726/7/71

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 1970, *together with the reports from the officers controlling Sub-Departments, and Comparative Tables furnishing statistics relative to the Mining Industry.*

I. R. BERRY,
Under Secretary for Mines.

Perth, 1971.

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Report of the Department of Mines for the Year 1970

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DIVISION I

PART 1—GENERAL REMARKS

The Honourable Minister for Mines:

I have the honour to submit for your information a report on the Mining Industry for the year 1970.

The estimated value of the mineral output of the State (including gold, coal and petroleum) for the year was $579,375,085, an increase of $236,803,286 compared with that for the preceding year and constitutes an all-time record, 69 per cent. higher than the figure set in 1969.

To the end of 1970 the progressive value of the whole mineral production of the State amounted to $2,689,889,916 of which gold accounted for $1,093,086,112 (See Table IV at back).

Minerals other than gold and coal rose in value to $562,478,745 an increase of $242,418,254 above that for 1969 to establish a new all-time record 75 per cent. higher than the 1969 figure. This increase was due mainly to the continued expansion of iron ore, nickel and petroleum production.

The production increases were reflected in royalty revenue which totalled $18,986,472 for the year as against $12,697,914 in 1969 and $8,827,700 in 1968.

IRON ORE

Iron ore production for export and local use continued to grow rapidly, rising from 24,681,710 tons valued at $183,046,603 in 1969 to 42,506,004 tons valued at $328,315,877 in 1970 and easily held its position as the State's leading mineral, a position which gold lost in 1966 after holding it for 75 years.

Five companies are now mining iron ore in this State with Hamersley Iron Pty. Limited being the largest producer and exporting almost 19·4 million tons of Mt. Tom Price iron ore valued at about $152·8 million through Dampier.

Mt. Newman Mining Co. Pty. Limited, the last of the five to commence production, is now second largest producer having shipped almost 11·4 million tons of Mt. Whaleback iron ore valued at about $85·8 million through Port Hedland.

Goldsworthy Mining Limited was third with 6·8 million tons exported from Mt. Goldsworthy deposit and valued at a little under $54 million f.o.b. Port Hedland.

Dampier Mining Co. Ltd. continued production of iron ore from Cockatoo and Koolan Islands and reported just over one million tons of ore exported overseas and valued at $7·2 million and 1·7 million tons valued at $11·9 million shipped to B.H.P. steelworks within Australia. Also, this company reported 1·5 million tons of iron ore from Koolyanobbing (valued at $11·9 million) railed to Kwinana. Of this 527,000 tons were shipped to Eastern States and 235,000 tons exported overseas.

Western Mining Corporation reported production of 590,000 tons from Koolanooka valued at $4,792,000 f.o.b. Geraldton.

PETROLEUM

(Crude Oil)

Sales of oil from Barrow Island during 1970 increased from 13·1 million barrels valued at $48 million in 1969 to 16·6 million barrels valued at $53·7 million and production increased to nearly 46,000 barrels per day.

Offshore drilling activity continued during 1970 but no commercial petroleum was discovered.

(Natural Gas)

During the year it was established that the Dongara/Yardarino/Mondarra/Gingin fields were capable of producing gas at a rate of approximately 80 million cub. ft./day for a period of 15 years and a decision was made to construct and operate a 255 mile natural gas pipeline from Dongara to Pinjarra. The necessary pipeline licence was issued on 2/12/70 to the operators, West Australian Natural Gas Pty. Ltd.

GOLD

The estimated value of gold received at the Perth Branch of the Royal Mint plus that exported in gold-bearing material was $11,069,049 a decrease of $6,638,170 compared with the figure for 1969. This decrease was due mainly to the fall in production and to a significant extent to the lower premiums obtained on the free market.

The quantity of gold advised as being received at the Perth Branch of the Royal Mint (340,029·82 fine ounces) together with that contained in gold-bearing material exported for treatment (1,578·25 fine ounces) totalled 341,608·07 fine ounces which was 123,803·55 fine ounces less than for the previous year. (See Table I (b), Part 2.)

Details of gold production for the year reported directly to the Department as distinct from that received at the Mint are set out in Table I at back. The total tonnage of gold ore treated was 1,740,020 being 266,696 tons less than for 1969.

The famous "Golden Mile" locality of Kalgoorlie-Boulder mining centres in the East Coolgardie Goldfield has to the 31st December, 1970, treated 96·4 million tons of ore for 38 million fine ounces of gold valued at a progressively estimated $622·9 million. These figures represent 58·86 per cent. of the State's reported gold ore tonnage treated and 57·10 per cent. of its gold production.

At the peak of its gold production in 1903 there were 42 companies actively producing on the "Golden Mile". This number has been gradually reduced to only three large companies now operating.

West Australian gold included in sales on overseas premium markets by the Gold Producers' Association Ltd., for the period September 1969, to August 1970, totalled 367,809 fine ounces. The premium received in excess of the Mint value amounted to $393,229, an overall average of 106·911 cents per fine ounce as compared with an average of 564·82 cents per fine ounce for the period July, 1968, to August, 1969.

Subsidy payments by the Commonwealth Government during the year under the Gold-Mining Industry Assistance Act, totalled $3,019,240 an increase of $2,129,532 compared with the previous year. This increase reflects the much lower premiums obtained on the free market during the year. Of the subsidy paid $2,992,034 went to large producers and $27,205 to small producers.

Since the peak post-war production of nearly 900,000 fine ounces in 1957 the annual output of gold has decreased by some 559,000 fine ounces to the present figure of a little over 341,000 fine ounces in 1970.

Subsidy payments by the Commonwealth again have not been sufficient to offset rising costs and, as there appears to be no prospect of a price rise, gold production in W.A. will continue to decline unless there is a substantial increase in the subsidy. Under the Gold-Mining Industry Assistance Act as it now stands payments under the Act will apply to production until 30th June, 1973.

COAL

Coal production from Collie during the year showed an increase of 107,204 tons over that for 1969 and the overall average value per ton rose by 46 cents.

Figures for the last three years were:

	1968	1969	1970
Tons	1,087,379	1,090,530	1,197,734
Total value	$4,816,725	$4,804,089	$5,827,291
Average value per ton	$4.4297	$4.4052	$4.8653
Average Effective Workers	649	628	635
Proportion of Deep Mined Coal	44.35%	43.31%	39.02%

ALUMINA

(from Bauxite)

Alcoa of Australia (W.A.) N.L., (formerly Western Aluminium N.L.) exported from Kwinana almost 950,000 tons of alumina having an estimated value of nearly $60·8 million. The quantity of alumina produced during 1970 showed an increase of some 191,000 tons over that for the previous year.

NICKEL

The total value of nickel in concentrates and nickel briquettes and powder amounted to an estimated $87·4 million, an increase of over $71 million for 1969. The various sources of the nickel ores and concentrates which are at present all handled at some stage by Western Mining Corporation are commented on in detail in the State Mining Engineer's report.

OTHER MINERALS

Other minerals to yield over a million dollars for the year were Salt valued at $6·5 million, Ilmenite—$5,984,389 (down $·8 million on 1969), Manganese—$3,743,921, Copper and Cobalt (by-products of nickel mining) $2 million and $1·2 million respectively, Tin concentrates—$1,606,537, and Pig Iron valued at $3,505,910 was recovered by the Wundowie Charcoal Iron and Steel Industry from Koolyanobbing.

While the gold-mining industry is declining, the intense activity in the search for other minerals coupled with the current development of new iron ore, bauxite and nickel mines—to mention but a few—and the planned expansion of already large producers indicate that the State's mining industry can face the future with assurance of continued growth and prosperity.

PART 2—COMPARATIVE STATISTICS

TABLE 1

SUMMARY

Mineral Production : Quantity, Value, Persons Engaged

	1969	1970	Variation
IRON ORE—			
Reported to Department—			
Tons	24,780,301	42,604,644	+ 17,824,343
Value ($A)	$186,476,065	$331,821,787	+ $145,345,722
Persons Engaged	1,765	2,183	+ 418
PETROLEUM—CRUDE OIL—			
Reported to Department—			
Barrels	13,140,280	16,663,905	+ 3,523,625
†Value ($A)	$48,108,530	$53,710,900	+ $5,602,370
Persons Engaged—			
Effective Workers (excluding absentees)	217	166	— 51
GOLD—			
Reported to Department (Mine Production)—			
Ore Tons	2,006,717	1,740,020	— 266,697
Gold (fine ounces)	439,650	349,999	— 89,651
Average Grade (dwts. per ton)	4·381	4·023	— ·358
Persons Engaged—			
(a) Effective Workers (excluding absentees)	3,235	1,942	— 1,293
(b) Total Pay Roll	3,505	2,157	— 1,348
Mint and Export (Realised Production)—			
Gold (fine ounces)	465,412	341,608	— 123,804
Estimated Value ($A) (including Overseas Gold Sales Premium)	$17,707,219	$11,069,049	— $6,638,170
COAL—			
Reported to Department (Mine Production)—			
Tons	1,090,530	1,197,734	+ 107,204
Value ($A)	$4,804,089	$5,827,291	+ $1,023,202
Persons Engaged—			
Effective Workers (excluding absentees)	628	635	+ 7
OTHER MINERALS—			
Reported to Department—			
Value ($A)	$85,475,896	$176,946,058	+ $91,470,162
Persons Engaged—			
Effective Workers (excluding absentees)	2,653	3,586	+ 933
TOTAL ALL MINERALS—			
Value ($A)	*$342,571,799	*$579,375,085	+ $236,803,286
Persons Engaged—			
Effective Workers	8,498	8,512	+ 14

* All-time record.

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

TABLE 1 *(a)*

Quantity and Value of Minerals, other than Gold and Silver, produced during Years 1969 *and* 1970

Western Australia

Mineral	1969		1970		Increase or Decrease for Year Compared with 1969	
	Quantity	Value	Quantity	Value	Quantity	Value
	Tons	$A	Tons	$A	Tons	$A
Alumina (from Bauxite)	758,964·00	48,571,900	**949,987·00**	**60,799,000**	+ 191,023·00	+ 12,227,100
Asbestos (Chrysotile)	26·80	1,126	....	....	— 26·80	— 1,126
Barytes	1,018·08	15,271	**565·05**	**6,916**	— 453.03	— 8,355
Beryl	....	....	**15·55**	**5,796**	+ 15·55	+ 5,796
			lbs.		lbs.	
Bismuth	....	....	**3,780·00**	**6,867**	+ 3,780·00	+ 6,867
			Tons		Tons	
Building Stone (Quartzite)	1,317·00	6,515	**1,516·00**	**7,240**	+ 199·00	+ 725
(Quartz)	....	....	**4,960·00**	**60,682**	+ 4,960·00	+ 60,682
(Quartz—Dead White)	455·00	11,396	....	....	— 455·00	— 11,396
(Sandstone)	24·00	144	....	....	— 24·00	— 144
(Spongolite)	231·50	3,051	**140·50**	**1,859**	— 91·00	— 1,192
(Tripolite)	4·00	4	....	....	— 4·00	— 4
Clays (Bentonite)	255·00	1,552	**115·50**	**774**	— 139·50	— 778
(Cement Clay)	10,801·69	10,718	**22,413·07**	**47,551**	+ 11,611·38	+ 36,833
(Fireclay)	98,101·00	97,756	**130,810·00**	**120,051**	+ 32,709·00	+ 22,295
(Kaolin)	258·44	1,505	**187·48**	**1,113**	— 70·96	— 392
(White Clay-Ball Clay)	683·00	7,738	**850·00**	**9,631**	+ 167·00	+ 1,893
(Brick, Pipe and Tile Clay)	188,084·00	285,457	**30,558·00**	**50,947**	—157,526·00	— 234,510
Coal	1,090,530·10	4,804,089	**1,197,733·50**	**5,827,291**	+ 107,203·40	+ 1,023,202
Cobalt (Metallic By-Product Nickel Mining)	86·01	127,245	**332·73**	**1,197,680**	+ 246·72	+ 1,070,435
Copper (Metallic By-Product Nickel Mining)	918·61	554,978	**2,095·66**	**2,037,360**	+ 1,177·05	+ 1,482,382
Copper Ore and Concentrates	2,644·27	583,332	**2,978·20**	**662,762**	+ 333·93	+ 79,430
Cupreous Ore and Concentrates	1,128·48	82,464	**603·99**	**126,890**	— 524·49	+ 44,426
Felspar	458·00	6,870	**645·00**	**9,675**	+ 187·00	+ 2,805
Glass Sand	48,932·00	*26,630	**95,569·00**	***34,046**	+ 46,637·00	+ 7,416
Gypsum	64,398·17	138,863	**89,987·11**	**247,915**	+ 25,588·94	+ 109,052
Iron Ore (Pig Iron Recovered)	61,344·00	3,429,462	**61,537·00**	**3,505,910**	+ 193·00	+ 76,448
(Exported)	22,787,496·68	163,254,529	**40,626,314·65**	**308,950,211**	+17,838,817·97	+145,695,682
(Pellets)	1,894,213·95	19,792,074	**1,879,689·81**	**19,365,666**	— 14,524·14	— 426,408
Lead Ores and Concentrates	1,104·38	158,289	**456·59**	**64,779**	— 647·79	— 93,510
Limestone*	1,302,841·29	1,214,415	**1,168,849·67**	**1,246,403**	— 133,991·62	+ 31,988
Lithium Ores (Petalite)	710·00	11,297	**771·00**	**12,259**	+ 61·00	+ 962
Magnesite	....	....	**2,180·00**	**31,600**	+ 2,180·00	+ 31,600
Manganese (Metallurgical Grade)	179,044·77	3,557,921	**202,373·50**	**3,743,921**	+ 23,328·73	+ 186,000
Mineral Beach Sands (Ilmenite)	681,501·96	6,820,288	**550,660·15**	**5,984,389**	—130,841·81	— 835,899
(Monazite)	2,610·30	324,705	**4,693·23**	**621,603**	+ 2,082·93	+ 296,898
(Rutile)	1,643·02	152,325	**2,251·61**	**200,483**	+ 608·59	+ 48,158
(Leucoxene)	6,745·40	298,441	**12,130·30**	**634,171**	+ 5,384·90	+ 335,730
(Zircon)	27,279·13	791,045	**60,956·02**	**1,508,811**	+ 33,678·89	+ 717,766
(Xenotime)	10·00	2,535	**55·00**	**71,922**	+ 45·00	+ 69,387
Nickel Concentrates	67,647·01	16,417,100	**265,439·84**	**85,524,150**	+ 197,792·83	+ 69,107,050
Nickel Ore	....	....	**40,116·05**	**1,892,880**	+ 40,116·05	+ 1,892,880
Ochre (Red)	588·40	11,768	**608·54**	**6,085**	+ 20·14	— 5,683
Peat	1,523·30	12,714	**974·25**	**20,888**	— 549·05	+ 8,174
	Troy ozs.				Troy ozs.	
Palladium (Metallic By-Product Nickel Mining)	320·75	9,656	....	....	— 320·75	— 9,656
			Troy ozs.			
Platinum (Metallic By-Product Nickel Mining)	472·69	36,931	**1,449·18**	**155,454**	+ 976·49	+ 118,523
	bbls		bbls		bbls	
Petroleum—Crude Oil	13,140,280·00	48,108,530	**16,663,905·00**	**53,710,900**	+3,523,625·00	+ 5,602,370
	Tons		Tons		Tons	
Pyrites Ore and Concentrates (For Sulphur)	18,237·54	205,850	**1,398·79**	**15,765**	— 16,838·75	— 190,085
Salt	582,835·00	1,899,087	**1,815,935·62**	**6,476,489**	+1,235,100·62	+ 4,577,402
	lbs.		lbs.		lbs.	
Semi Precious Stones	48,302·00	14,852	**72,269·00**	**45,224**	+ 23,967·00	+ 30,372
	Tons		Tons		Tons	
Talc	33,208·15	708,746	**31,293·93**	**742,257**	— 1,914·22	+ 33,511
Tanto/Columbite Ores and Concentrates	189·92	236,031	**68·58**	**246,510**	— 121·34	+ 10,479
Tin Concentrates	794·46	1,332,013	**759·06**	**1,606,537**	— 35·40	+ 274,524
Vermiculite	....	....	**299·42**	**1,797**	+ 299·42	+ 1,797
Total	....	324,139,208	....	**567,649,110**	....	+243,509,902

TABLE 1 *(b)*

Quantity and Value of Gold and Silver Exported and Minted during Years 1969 *and* 1970

Minerals	1969		1970		Increase or Decrease for Year Compared with 1969	
	Quantity	Value	Quantity	Value	Quantity	Value
	Fine oz.	$A	Fine Oz.	$A	Fine Oz.	$A
Gold (Exported and Minted)....	465,411·62	†17,707,219	**341,608·07**	**11,069,049**	—123,803·55	— 6,638,170
Silver (Exported and Minted)	450,862·08	725,372	**418,769·71**	**656,926**	— 32,092·37	— 68,446
Total	....	18,432,591	....	**11,725,975**	....	— 6,706,616
Grand Total	....	342,571,799	....	**579,375,085**	....	+236,803,286

* Incomplete. † Including Overseas Gold Sales Premium.

TABLE 2
ROYALTIES

Mineral	Royalty Collected 1969	Royalty Collected 1970	Increase or Decrease Compared with 1969
	$	$	$
Alumina	167,913.16	218,722.45	+ 50,809.29
Amethyst	16.71	0.50	— 16.21
Asbestos	4.02	....	— 4.02
Barytes	66.28	31.18	— 35.10
Bentonite	13.65	5.80	— 7.85
Bismuth	....	36.70	+ 36.70
Building Stone	207.43	464.41	+ 256.98
Chalcedony	3.00	....	— 3.00
Chrysoprase	....	185.00	+ 185.00
Clay	5,630.87	7,324.84	+ 1,693·97
Coal	27,544.19	29,267.23	+ 1,723.04
Cobalt	410.86	469.30	+ 58.44
Dravite	52.73	8.42	— 44.31
Felspar	21.35	33.35	+ 12.00
Glass Sand	1,899.40	4,498.20	+ 2,598.80
Gypsum	5,816.70	3,134.48	— 2,682.22
Ilmenite	54,830.60	37,588.49	— 17,242.11
Iron Ore	10,350,101.89	15,901,333.34	+ 5,551,231.45
Leucoxene	578.36	1,000.67	+ 422.31
Limestone	29,087.68	18,677.00	— 10,410.68
Magnesite	1.65	327.00	+ 325.35
Manganese	24,351.18	27,695.93	+ 3,344.75
Monazite	1,559.70	1,094.53	— 465.17
Moss Opal	....	3.46	+ 3.46
Nickel	343,117.28	593,656.22	+ 250,538.94
Ochre	29.42	30.43	+ 1.01
Oil (Crude)	1,657,638.03	2,054,396.99	+ 396,763.96
Palladium	48.36	....	— 48.36
Petalite	47.60	108.50	+ 60.90
Platinum	184.95	298.29	+ 113·34
Prase	3.25	....	— 3.25
Pyrites	1,595.10	735.60	— 859.50
Rutile	156.21	138.25	— 17.96
Salt	16,850.30	76,891.32	+ 60,041.02
Talc	2,888.86	3,948.51	+ 1,059.65
Tanto Columbite	1,875.59	601.16	— 1,274.43
Tin	295.06	132.90	— 162.16
Vermiculite	....	14.97	+ 14.97
Wolfram	12.07	....	— 12.07
Zircon	3,052.65	3,498.79	+ 446.14
Xenotime	12.67	118.06	+ 105.39
	12,697,913.81	18,986,472.27	+6,288,558.46

TABLE 3

Showing for every Goldfield the amount of Gold reported to the Mines Department as required by the Regulations, also the percentage for the several Goldfields of the total reported (and the average value of the yield in pennyweights per ton of ore treated).

Goldfield	Reported Yield 1969	Reported Yield 1970	Percentage for each Goldfield 1969	Percentage for each Goldfield 1970	‡ Average Yield per ton of ore treated 1969*	‡ Average Yield per ton of ore treated 1970*
	Fine Oz.	Fine Oz.	Per cent.	Per cent.	Dwts.	Dwts.
1. Kimberley	....		....	....	....	....
2. West Kimberley	....	....	....	....	....	....
3. Pilbara	858	531	·195	·152	19·343	17·241
4. West Pilbara	37	....	·008	....	....	....
5. Ashburton	....	....	....	....	....	....
6. Gascoyne	1,484	826	·337	·236	34·315	28·844
7. Peak Hill	7	9	·002	·002	....	....
8. East Murchison	114	206	·026	·059	4·587	10·953
9. Murchison	27,039	6,639	6·144	1·895	4·785	4·520
10. Yalgoo	23	....	·005	....	2·331	....
11. Mt. Margaret	1,052	787	·239	·225	33·629	7·282
12. North Coolgardie	463	129	·105	·037	4·587	2·628
13. Broad Arrow	881	381	·201	·109	4·637	9·491
14. North-East Coolgardie	1,400	808	·318	·231	2·064	2·285
15. East Coolgardie	332,329	284,284	75·518	81·133	3·930	3·700
16. Coolgardie	1,428	628	·325	·179	5·103	2·130
17. Yilgarn	1,744	3,004	·396	·857	12·607	9·275
18. Dundas	70,379	50,928	15·993	14·535	8·146	6·768
19. Phillips River†	711	1,119	·162	·319	13·410	5·348
20. South-West Mineral Field	67	19	·015	·005	8·646	10·428
21. State Generally	48	92	·011	·026	....	....
	440,064	350,390	100·000	100·000	4·382	4·023

* Gold at $A31.25 per fine oz. or $A1.5625 per pennyweight.
† Includes By-product of Copper Mining.
‡ Averages exclude alluvial and dollied gold.

TABLE 4

The Output of Gold from the Commonwealth of Australia during 1970

State	Output of Gold	Value*†	Percentage of Total
	Fine oz.	$A	%
Western Australia	341,608	10,675,250	57·37
Northern Territory	122,639	3,832,472	20·60
Queensland	72,666	2,270,812	12·20
Tasmania	39,401	1,231,281	6·62
New South Wales	10,442	326,312	1·75
Victoria	8,145	254,545	1·37
South Australia	525	16,406	·09
Total	595,426	18,607,078	100·00

* $A31.25 per fine ounce.
† Exclusive of Overseas Gold Sales Premium by Gold Producers' Association

TABLE 5

Total Coal output from Collie River Mineral Field, 1969 *and* 1970, *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—	Tons	$A	No.	No.	No.	Tons	Tons	Tons
1969	472,313	2,811,821	93	355	....	....	1,330	1,054
1970	467,298	2,829,376	96	335	....	....	1,391	1,082
Open Cut Mining—								
1969	618,217	1,992,268	....	....	180	3,435	....	....
1970	730,436	2,997,915	....	....	204	3,581	....	....
Totals—								In all Mines
1969	1,090,530	4,804,089	93	355	180	....	....	1,737
1970	1,197,734	5,827,291	96	335	204	....	....	1,836

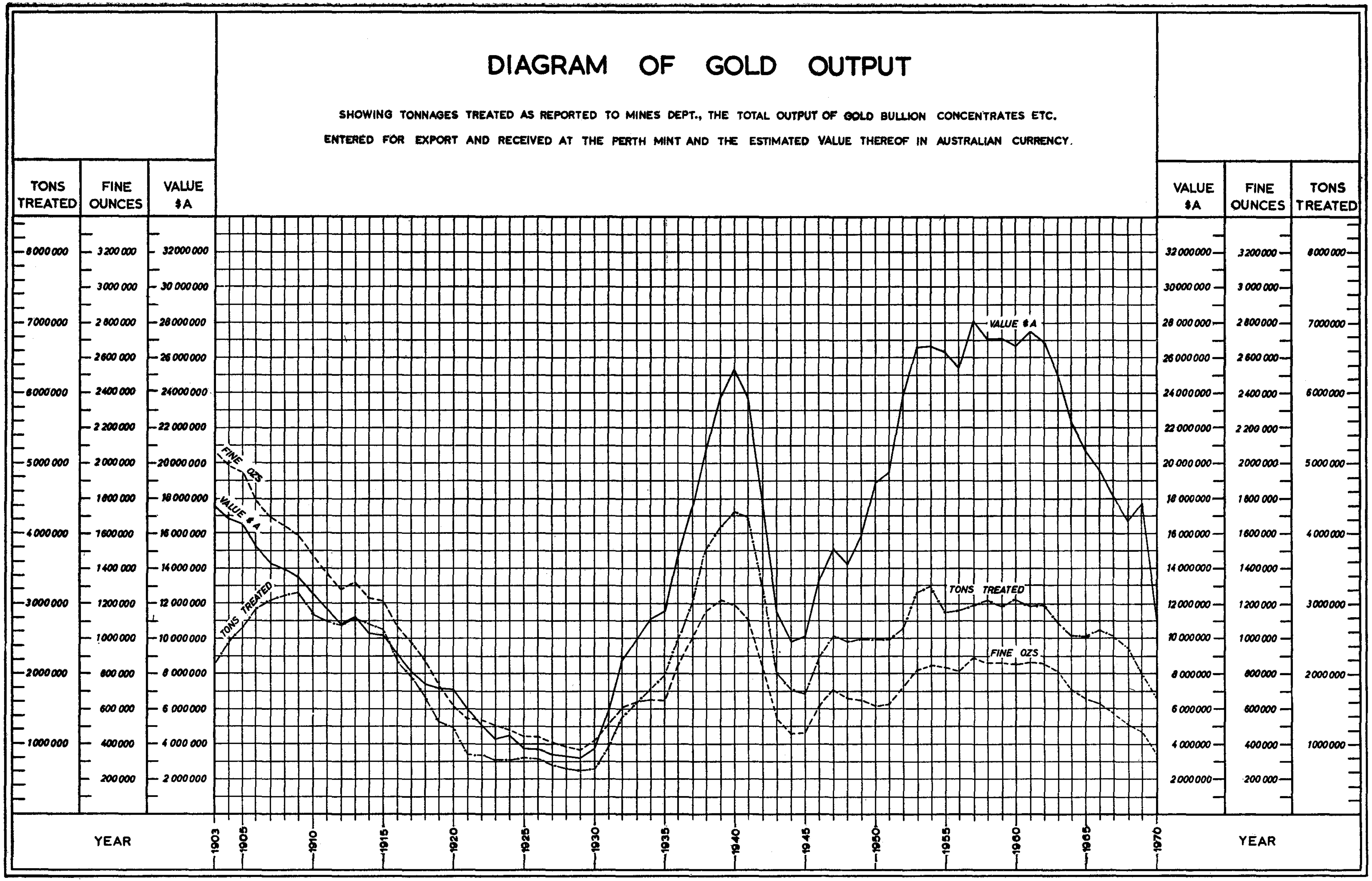
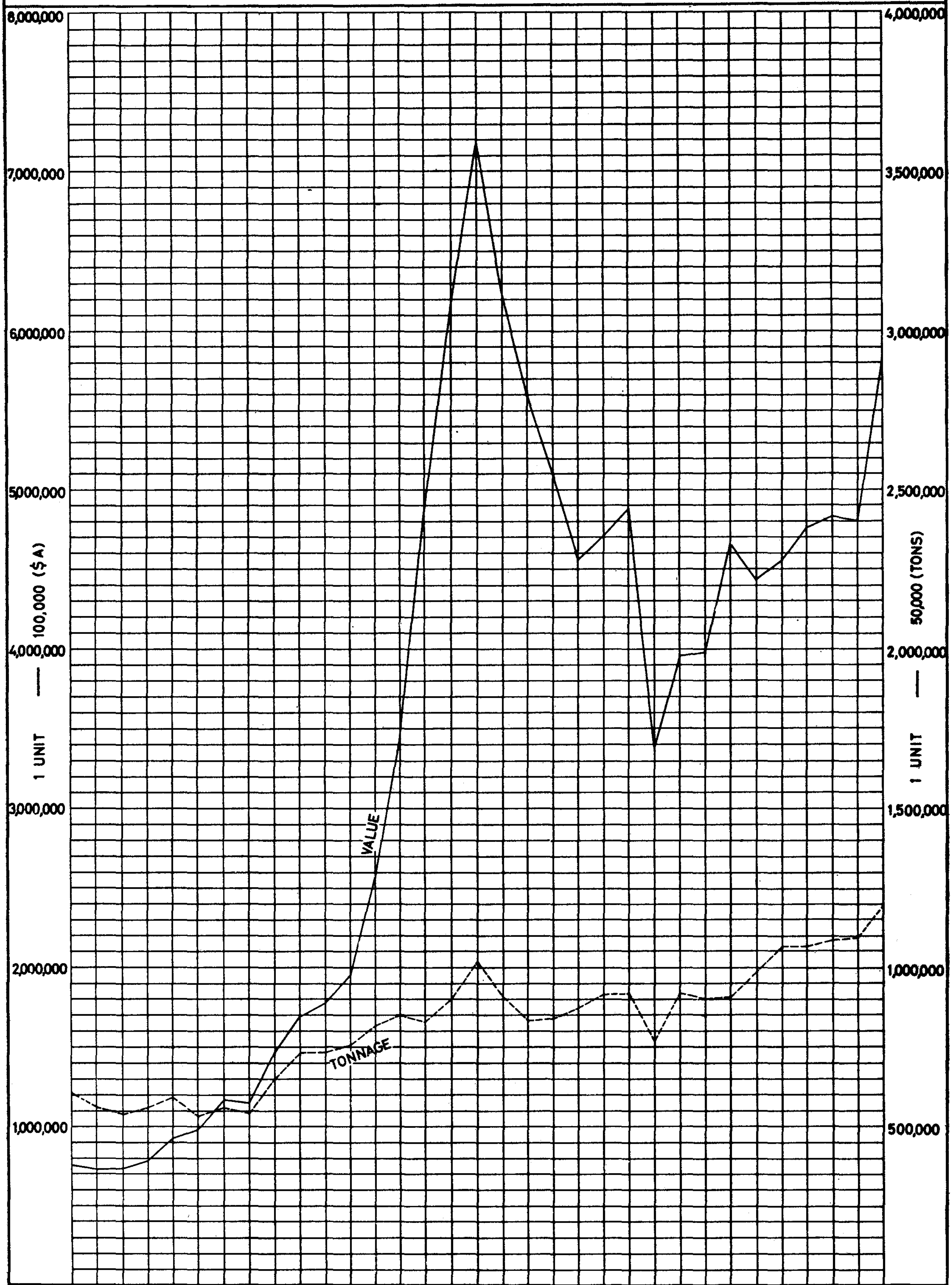


DIAGRAM OF GOLD OUTPUT
SHOWING TONNAGES TREATED AS REPORTED TO MINES DEPT., THE TOTAL OUTPUT OF GOLD BULLION CONCENTRATES ETC. ENTERED FOR EXPORT AND RECEIVED AT THE PERTH MINT AND THE ESTIMATED VALUE THEREOF IN AUSTRALIAN CURRENCY.
TONS TREATED
FINE OUNCES
VALUE $A
YEAR
FINE OZS
VALUE $A
TONS TREATED

GRAPH OF COAL OUTPUT

SHOWING QUANTITIES AND VALUES AS REPORTED TO MINES DEPARTMENT



YEAR	VALUE $A	TONS
1938	750,176	604,793
1939	725,622	557,535
1940	729,000	539,427
1941	778,556	556,574
1942	922,990	581,176
1943	979,442	531,546
1944	1,166,150	558,322
1945	1,145,792	543,363
1946	1,460,208	642,287
1947	1,680,498	730,506
1948	1,760,472	732,938
1949	1,944,490	750,594
1950	2,575,498	814,351
1951	3,433,576	848,475
1952	4,914,592	830,461
1953	6,146,146	886,182
1954	7,177,636	1,018,343
1955	6,264,148	903,792
1956	5,595,012	830,008
1957	5,105,310	838,660
1958	4,560,398	870,882
1959	4,713,064	917,434
1960	4,878,390	922,393
1961	3,260,518	765,740
1962	3,961,556	919,112
1963	3,970,120	902,495
1964	4,678,934	987,420
1965	4,409,972	993,741
1966	4,562,087	1,061,08
1967	4,765,503	1,062,151
1968	4,816,725	1,087,379
1969	4,804,089	1,090,530
1970	5,827,291	1,197,733

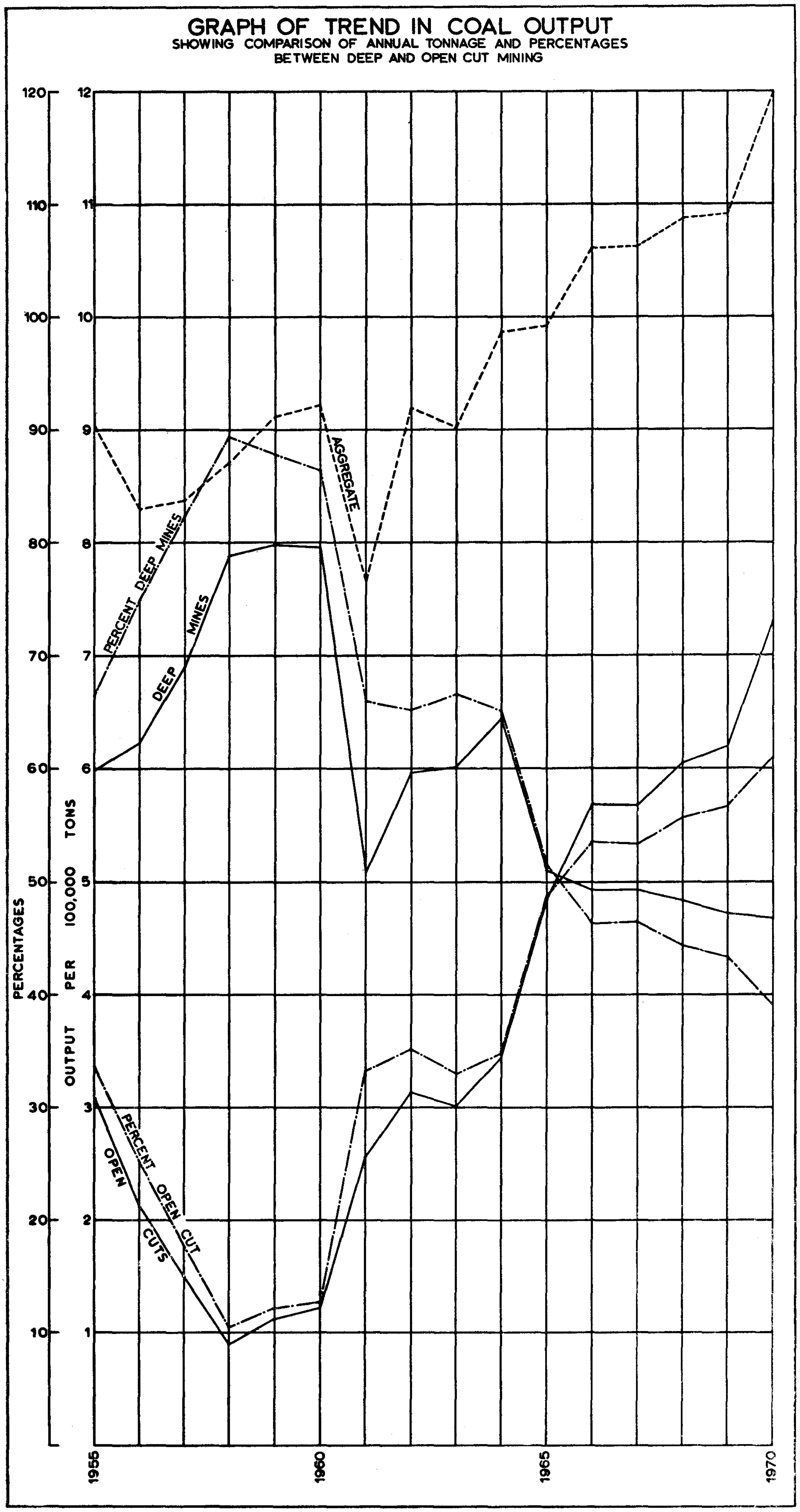

GRAPH OF TREND IN COAL OUTPUT
SHOWING COMPARISON OF ANNUAL TONNAGE AND PERCENTAGES
BETWEEN DEEP AND OPEN CUT MINING
PERCENTAGES
OUTPUT PER 100,000 TONS
120
110
100
90
80
70
60
50
40
30
20
10
12
11
10
9
8
7
6
5
4
3
2
1
AGGREGATE
PERCENT DEEP MINES
DEEP MINES
PERCENT OPEN CUT
OPEN CUTS
1955
1960
1965
1970

TABLE 6

MINING ACT, 1904.

LEASES AND OTHER HOLDINGS UNDER VARIOUS ACTS RELATING TO MINING.

Total Number and Acreage of Mining Tenements applied for during 1970 *and in force as at* 31*st December,* 1970 (*compared with* 1969)

—	Applied for				In Force			
	1969		1970		1969		1970	
	No.	Acres	No.	Acres	No.	Acres	No.	Acres
Gold—								
Gold Mining Leases	385	8,375	**226**	**4,761**	1,184	22,868	**1,375**	**26,308**
Dredging Claims	2	600	**15**	**4,500**	4	927	**5**	**1,182**
Prospecting Areas	308	5,990	**276**	**5,696**	281	6,013	**221**	**4,191**
Temporary Reserves	....	....	....	....	145	48,246	**173**	**49,949**
Totals	695	14,965	**517**	**14,957**	1,614	78,054	**1,774**	**81,630**
Coal—								
Coal Mining Leases	8	2,486	**60**	**19,944**	51	15,645	**52**	**15,016**
Prospecting Areas	6	16,628	**27**	**74,190**	....	....	....	....
Temporary Reserves	2	57,600	....	....	2	4,320	**2**	**4,320**
Totals	16	76,714	**87**	**94,134**	53	19,965	**54**	**19,336**
Other Minerals—								
Mineral Leases	65	15,599	**100**	**25,278**	259	69,057	**299**	**45,933**
Dredging Claims	690	192,851	**712**	**207,903**	468	35,765	**413**	**32,982**
Mineral Claims	20,659	5,837,245	**42,866**	**12,150,760**	5,527	1,376,104	**20,272**	**5,344,357**
Prospecting Areas	159	3,431	**198**	**38,722**	126	2,688	**86**	**2,023**
Temporary Reserves	278	24,439,592	**116**	**6,483,840**	673	58,746,595	**655**	**40,615,982**
Totals	21,851	30,488,718	**43,992**	**18,906,503**	7,104	60,230,209	**21,725**	**46,041,277**
Other Holdings—								
Miner's Homestead Leases	6	1,490	**2**	**302**	340	34,620	**335**	**33,786**
Miscellaneous Leases	2	96	....	....	103	1,652	**102**	**1,660**
Residence Areas	1	2	**1**	**1**	62	61	**62**	**50**
Business Areas	....	....	**2**	**2**	17	17	**26**	**15**
Machinery Areas	2	10	**4**	**16**	26	72	**26**	**78**
Tailings Areas	....	....	**2**	**10**	23	89	**24**	**97**
Garden Areas	4	17	**9**	**43**	71	233	**70**	**243**
Quarrying Areas	11	252	**45**	**1,016**	23	408	**45**	**854**
Water Rights	1	3	**11**	**346**	141	3,241	**141**	**3,210**
Licenses to Treat Tailings	33	....	**79**	....	14	....	**22**	....
Totals	60	1,870	**155**	**1,736**	820	40,393	**852**	**39,993**
Grand Totals	22,622	30,582,267	**44,751**	**19,017,330**	9,540	60,270,602	**24,405**	**46,182,236**

TABLE 6 (a)

SPECIAL ACTS

Leases applied for during 1970 *and in force at* 31*st December,* 1970 (*Compared with* 1969)

Mineral	Applied for				In Force			
	1969		1970		1969		1970	
	No.	Acres	No.	Acres	No.	Acres	No.	Acres
Bauxite	....	....	....	....	7	3,137,280	**7**	**3,137,280**
Iron	....	....	....	....	4	419,106	**4**	**419,106**
Salt	1	541,450	....	....	2	593,430	**2**	**593,430**
Totals	1	541,450	....	....	13	4,149,816	**13**	**4,149,816**

TABLE 6 (b)
PETROLEUM ACTS

Permits, Licenses and Leases applied for during 1970 *and in force as at* 31*st December*, 1970 (*Compared with* 1969)

Holding	Applied for				In Force			
	1969		1970		1969		1970	
	No.	Blocks	No.	Blocks	No.	Blocks	No.	Blocks
Onshore—								
Petroleum Act, 1936—								
Permits to Explore	3	3,543	....	....	21	13,722	....	....
Licences to Prospect	7	50	....	....	7	47	....	....
Totals	10	3,593	....	....	28	13,769	....	....
Petroleum Act, 1967—								
Exploration Permits	22	3,921	**44**	**4,273**	....	....	**40**	**5,840**
Production Licences	....	....	....	....	....	....	....	....
Petroleum Lease (Barrow Island)	....	....	....	....	1	8	**1**	**8**
Totals	22	3,921	**44**	**4,273**	1	8	**41**	**5,848**
Petroleum Pipelines Act, 1969—								
Pipeline Licence	....	....	**1**	**(252.8 miles)**	....	....	**1**	**(252.8 miles)**
Totals	....	....	**1**	**(252.8 miles)**	....	....	**1**	**(252.8 miles)**
Offshore—								
Petroleum (Submerged Lands) Act, 1967:								
Exploration Permits	1	88	....	....	35	11,880	**35**	**11,880**
Production Licences	....	....	....	....	....	....	....	....
Petroleum Lease (Barrow Marine)	....	....	....	....	1	12	**1**	**12**
Totals	1	88	....	....	36	11,892	**36**	**11,892**
Grand Totals	33	7,602	**45**	**4,273**	65	25,669	**78**	**17,740**

(A Block contains approximately 30 sq. miles and the numbers given above include part blocks.)

TABLE 6 (c)
MINING ACT, 1904

Leases in Force at 31*st December*, 1970 *in each Goldfield, Mineral Field or District*

Goldfield, Mineral Field, or District	Gold Mining Leases		Mineral Leases		Miner's Homestead Leases		Miscellaneous Leases	
	No.	Acres	No.	Acres	No.	Acres	No.	Acres
Ashburton	....	....	7	136	....	....	....	....
Black Range	52	1,199	....	....	....	....	....	....
Broad Arrow	30	486	2	562	....	....	1	5
Bulong	6	98	....	....	....	....	1	3
Collie	....	....	....	....	....	....	49	14,491
(Private Property)	....	....	....	....	....	....	2	520
Coolgardie	96	1,775	103	25,742	22	1,858	6	60
Cue	12	264	2	208	4	1,113	....	....
Day Dawn	18	350	6	877	....	....	....	....
Dundas	382	8,439	....	....	19	935	....	....
East Coolgardie	314	5,583	....	....	64	3,298	61	1,144
Gascoyne	2	48	1	8	....	....	....	....
Greenbushes	....	....	63	9,185	11	588	....	....
Kanowna	8	133	....	....	11	682	....	....
Kimberley	1	24	....	....	....	....	....	....
Kununalling	3	59	....	....	2	520	....	....
Kurnalpi	3	72	....	....	....	....	....	....
Lawlers	20	400	....	....	5	1,110	....	....
Marble Bar	74	1,168	2	49	....	....	9	142
Meekatharra	35	559	1	10	11	1,866	....	....
Menzies	21	390	....	....	7	740	1	10
Mount Magnet	77	1,243	4	38	1	10	....	....
Mount Malcolm	49	843	....	....	10	1,288	....	....
Mount Margaret	4	80	....	....	7	58	....	....
Mount Morgans	4	81	1	35	....	....	....	....
Niagara	1	14	....	....	1	20	....	....
Northampton	....	....	9	178	....	....	....	....
(Private Property)	....	....	2	33	....	....	....	....
Nullagine	22	410	....	....	2	22	3	50
Peak Hill	6	144	14	485	6	750	1	1
Phillips River	2	20	12	266	105	14,519	....	....
(Private Property)	....	....	1	291	....	....	....	....
South-West	1	24	4	662	....	....	1	5
(Private Property)	....	....	11	2,524	....	....	....	....
Ularring	12	189	....	....	1	20	....	....
West Kimberley	....	....	23	755	....	....	....	....
West Pilbara	3	57	8	90	2	11	9	188
Wiluna	3	72	11	1,834	17	3,879	....	....
Yalgoo	9	139	2	33	1	10	....	....
Yerilla	18	352	6	1,800	1	10	....	....
Yilgarn	74	1,341	4	132	25	479	10	57
(Private Property)	13	252	....	....	....	....	....	....
Outside Proclaimed	....	....	....	....	....	....	....	....
Totals	1,375	26,308	299	45,933	335	33,786	154	16,676

Gold Mining Leases on Crown Land	1,362	26,056 acres
Gold Mining Leases on Private Property	13	252 ,,
Miner's Homestead Leases on Crown Land	335	33,786 ,,
Mineral Leases on Crown Land	285	43,085 ,,
Mineral Leases on Private Property	14	2,848 ,,
Other Leases on Crown Land	152	16,156 ,,

TABLE 6 (d)

MINING ACT, 1904

Claims and Authorised Holdings in Force at 31st December, 1970 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		Water Rights		Quarrying Areas	
	Number	Acres	Number	Acres	Number	Acres	Number	Acres	Number	Acres	Number	Acres	Number	Acres	Number	Acres	Number	Acres	Number	Acres
Ashburton	15	352	....	....	210	54,058	....	....	....	....	....	....	....	....	....	....	....	....	2	48
Black Range	4	83	....	....	577	173,575	4	4	....	....	....	....	....	....	....	....	....	....	....	....
Broad Arrow	24	410	....	....	596	160,943	1	1	1	1	....	....	....	....	....	....	3	8	....	....
Bulong	7	105	....	....	523	148,226	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Collie	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
(Private Property)	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Coolgardie	35	661	....	....	2,389	657,141	3	3	....	....	1	1	....	....	3	7	5	17	21	472
Cue	26	507	....	....	318	87,402	4	1	....	....	....	....	....	....	....	....	1	3	1	24
Day Dawn	4	80	....	....	43	12,413	....	....	....	....	....	....	....	....	4	20	....	....	....	....
Dundas	4	82	....	....	1,103	301,894	....	....	....	....	....	....	1	5	1	3	2	12	3	60
East Coolgardie	17	235	....	....	652	175,044	33	33	....	....	3	12	12	56	9	42	11	32	4	42
Gascoyne	8	172	2	410	108	21,314	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Greenbushes	....	....	....	....	2	143	1	1	....	....	....	....	....	....	8	34	2	31	....	....
Kanowna	10	176	....	....	679	199,915	....	....	....	....	....	....	....	....	2	7	1	1	....	....
Kimberley	....	....	....	....	1,273	371,017	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Kunanalling	7	156	....	....	428	121,724	....	....	....	....	....	....	....	....	....	....	3	25	....	....
Kurnalpi	5	96	....	....	556	162,012	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Lawlers	1	24	....	....	432	113,504	....	....	....	....	2	6	1	5	....	....	1	1	....	....
Marble Bar	21	480	390	30,740	1,873	465,337	2	2	5	5	7	21	2	10	13	48	41	1,322	11	168
Meekatharra	7	156	....	....	786	223,653	....	....	....	....	....	....	....	....	....	....	1	4	....	....
Menzies	3	54	....	....	700	183,500	....	....	....	....	1	1	....	....	3	9	5	13	....	....
Mount Magnet	17	394	....	....	153	43,591	1	1	....	....	....	....	....	....	8	10	3	6	....	....
Mount Malcolm	....	....	....	....	363	106,184	....	....	....	....	....	....	....	....	8	31	10	165	....	....
Mount Margaret	....	....	....	....	403	119,970	....	....	....	....	....	....	....	....	....	....	3	3	....	....
Mount Morgans	....	....	....	....	429	123,710	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Niagara	....	....	....	....	43	13,393	....	....	....	....	....	....	....	....	....	....	3	6	....	....
Northampton	15	300	....	....	28	3,158	....	....	....	....	....	....	....	....	....	....	....	....	....	....
(Private Property)	....	....	....	....	6	441	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Nullagine	8	168	20	2,634	555	80,130	....	....	....	....	3	7	3	4	3	5	14	58	....	....
Peak Hill	2	16	....	....	227	54,570	....	....	....	....	2	8	1	5	....	....	1	10	....	....
Phillips River	....	....	....	....	107	22,798	....	....	....	....	....	....	....	....	....	....	....	....	....	....
(Private Property)	....	....	....	....	18	4,637	....	....	....	....	....	....	....	....	....	....	....	....	....	....
South West	3	72	....	....	187	21,072	....	....	....	....	....	....	....	....	....	....	....	....	....	....
(Private Property)	4	96	....	....	214	35,028	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Ularring	4	96	....	....	190	55,292	....	....	....	....	1	1	2	4	....	....	6	7	....	....
West Kimberley	....	....	1	300	34	8,804	....	....	....	....	2	10	....	....	....	....	1	12	2	16
West Pilbara	6	144	5	80	577	144,384	4	1	13	6	....	....	....	....	4	19	9	39	1	24
Wiluna	....	....	....	....	1,323	256,928	....	....	....	....	1	1	1	3	...	....	5	1,325	....	....
Yalgoo	9	194	....	....	856	239,703	....	....	6	2	1	5	1	5	....	....	1	10	....	....
Yerilla	6	99	....	....	563	159,196	....	....	....	....	....	....	....	....	....	....	5	12	....	....
Yilgarn	27	495	....	....	569	167,880	9	3	1	1	2	5	....	....	4	8	4	88	....	....
(Private Property)	3	71	....	....	178	50,625	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Outside Proclaimed	5	240	....	....	1	48	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Totals	307	6,214	418	34,164	20,272	5,344,357	62	50	26	15	26	78	24	97	70	243	141	3,210	45	854

TABLE 7

MEN EMPLOYED

Average number of Men reported as engaged in Mining during 1969 and 1970

Goldfield	District	Gold 1969	Gold 1970	Other Minerals 1969	Other Minerals 1970	Total 1969	Total 1970
Kimberley	....	....	....	....	....	....	....
West Kimberley	....	....	....	373	**335**	373	**335**
Pilbara	Marble Bar	36	**2**	561	**510**	597	**512**
	Nullagine	11	**20**	2	**2**	13	**22**
West Pilbara	....	....	....	596	**793**	596	**793**
Ashburton	....	....	....	219	**332**	219	**332**
Gascoyne	....	5	**4**	....	**5**	5	**9**
Peak Hill	....	2	**1**	319	**529**	321	**530**
East Murchison	Lawlers	9	**6**	....	....	9	**6**
	Wiluna	....	**1**	....	....	....	**1**
	Black Range	3	**2**	....	....	3	**2**
Murchison	Cue	7	....	....	....	7	....
	Meekatharra	5	**2**	2	**2**	7	**4**
	Day Dawn	1	....	....	....	1	....
	Mt. Magnet	193	**116**	....	....	193	**116**
Yalgoo	....	5	....	7	**3**	12	**3**
Mt. Margaret	Mt. Morgans	4	....	....	....	4	....
	Mt. Malcolm	18	**3**	....	....	18	**3**
	Mt. Margaret	2	....	....	....	2	....
North Coolgardie	Menzies	44	**2**	....	....	44	**2**
	Ularring	30	**1**	....	....	30	**1**
	Niagara	5	....	....	....	5	....
	Yerilla	10	**2**	....	....	10	**2**
Broad Arrow	....	92	**3**	....	**136**	92	**139**
North-East Coolgardie	Kanowna	23	**3**	....	....	23	**3**
	Kurnalpi	26	**1**	....	....	26	**1**
East Coolgardie	East Coolgardie	2,175	**1,488**	....	....	2,175	**1,488**
	Bulong	16	**2**	....	....	16	**2**
Coolgardie	Coolgardie	96	**4**	818	**1,264**	914	**1,268**
	Kunanalling	22	**3**	2	....	24	**3**
Yilgarn	....	113	**23**	90	**98**	203	**121**
Dundas	....	282	**253**	5	....	287	**253**
Phillips River	....	....	....	124	**122**	124	**122**
South-West Mineral Field	....	....	....	1,426	**1,713**	1,426	**1,713**
Northampton Mineral Field	....	....	....	23	**7**	23	**7**
Greenbushes Mineral Field	....	....	....	68	**80**	68	**80**
Outside Proclaimed Goldfield	....	....	....	....	**4**	....	**4**
Collie Coalfield	....	....	....	628	**635**	628	**635**
Total—All Minerals	....	3,235	**1,942**	5,263	**6,570**	8,498	**8,512**

Minerals Other than Gold—	1969	1970
Alumina (from Bauxite)	906	**1,165**
Barytes	2	**4**
Beryl	....	**2**
Building Stone	10	**12**
Bismuth	....	**1**
Clays	24	**19**
Coal	628	**635**
Copper	124	**122**
Cupreous Ore (Fertiliser)	27	**39**
Felspar	5	**6**
Glass Sand	10	**13**
Gypsum	11	**10**
Iron Ore	1,765	**2,183**
Lead	23	**7**
Limestone	34	**26**
Manganese	26	**22**
Mineral Beach Sands (Ilmenite, etc.)	339	**372**
Nickel	813	**1,381**
Peat	5	**5**
Petroleum—Crude Oil	217	**166**
Semi-precious Stones	5	**8**
Salt	115	**220**
Talc	12	**12**
Tanto Columbite	....	**3**
Tin	162	**137**
Total, Other Minerals	5,263	**6,570**

PART 3—STATE AID TO MINING

(*a*) *State Batteries*

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

From inception to the end of 1970, gold, silver, tin, tungsten, lead, copper and tantalite ores to the value of $40,882,049 have been treated at the State Batteries. Included in the above amount is $16,062,167 gold premium and $173,608 premium paid by sales of gold by the Gold Producers Association Ltd. $38,936,886 came from 3,628,587¼ tons of gold ore, $459,824 from 83,989·40 tons of tin ore, $38,896 from 3,971¾ tons tungsten ore, $1,368,556 from 61,576½ tons lead ore, $11,932 from 220½ tons of copper ore and $61,997 from 1,955½ tons of tantalite ore, and silver valued at $3,958 recovered as a By-Product from the cyaniding of Gold Tailings.

During the year 22,810½ tons of gold ores were crushed for 8,656 oz. bullion, estimated to contain 7,336 oz. fine gold equal to 6 dwts. 10 grs. per ton. The average value of sands after amalgamation was 2 dwts. 3 grs. per ton, making the average head value 8 dwts. 13 grs. per ton. Cyanide plants produced 1,161 oz. fine gold, giving a total estimated production for the year of 8,497 oz. fine gold valued at $274,619.

The working expenditure for the year for all plants was $503,451 and the revenue was $54,385 giving a working loss of $449,066 which does not include depreciation, interest or Superannuation. Since the inception of State Batteries, the Capital expenditure has been $1,858,330 made up of $1,469,820 from General Loan Funds; $303,694 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 $74,546 compared with $83,878 for 1969.

The actual expenditure from inception to the end of 1970 exceeds revenue by $6,549,748.

(*b*) *Prospecting Scheme*

At the end of the year 21 men were in receipt of prospecting assistance as compared with 24 at the end of 1969.

Total expenditure for 1970 was $12,136 and refunds amounted to $1,858.

Assisted prospectors crushed 345 tons of ore during the year for 125 oz. of gold.

Progressive total figures since the inception of the scheme are:

Expenditure $1,015,521.

Refunds $197,545.

Ore Crushed 125,232 tons.

Gold Won 57,776 oz.

The rate of assistance remained at $17·50 per man per week in the more remote localities and $15 per man per week in the less isolated areas.

(*c*) *Geological Survey of Western Australia*

The year 1970 was one of extraordinary activity in mineral exploration and again great demands on the services of the Geological Survey were made in providing regional geology, specialists services and information from the Survey's library and other records.

The scope of the advice and information available from the Branch is well known and its officers provide advice to the mining and allied industries where required, advise on exploration for and development of minerals and water supplies.

PART 4—KALGOORLIE METALLURGICAL LABORATORY

This Laboratory which is administered by the Mines Department is subsidised to some extent by the Commonwealth Scientific and Industrial Research Organisation. Its main function is to assist the mining industry in research, and the nature of its investigations and reports for the year 1970 are summarised in Division V of this report.

PART 5—GOVERNMENT CHEMICAL LABORATORIES

This Branch has wide functions covering both the governmental and private sectors of the community as the names of its six Divisions indicate:

(1) Agriculture Division.

(2) Engineering Chemistry Division.

(3) Foods, Drugs, Toxicology and Industrial Hygiene Division.

(4) Industrial Chemistry Division.

(5) Mineralogy, Mineral Technology and Geo-Chemistry Division.

(6) Water Division.

The widespread nature of the work of the Laboratories with other Government Departments is illustrated by Table I of Division VII of this report.

During the year alterations and additions to the buildings of the Engineering Chemistry Division were completed and progress was made in re-building the former Fuel Technology Division building to accommodate the Water Division.

PART 6—EXPLOSIVES BRANCH

The Explosives Branch continued to carry out its fundamental function of ensuring that the quality of explosives and their transport and storage complied with the State requirements and the registration and licensing required under the Flammable Liquids Regulations.

1970 was the first full year of operations under the Flammable Liquids Regulations and at the 31/12/1970, 3,961 licenses were in operation.

The activities of the Branch are set out in detail in Division VIII of this Report.

PART 7—MINE WORKERS' RELIEF ACT AND MINERS' PHTHISIS ACT

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

A total of 10,659 examinations were made of which 4,281 were made under the Mine Workers' Relief Act and 6,378 under the Mines Regulation Act. Of the latter 5,959 were new applicants and 419 were re-examinees.

Compensation payments under the Miners' Phthisis Act continued to decrease and totalled $9,462 compared with $11,362 for the previous year.

PART 8—SURVEYS AND MAPPING BRANCH

Surveys of mining tenements continued at record high level with a total of 2,343 completed in 1970 at a cost of $292,306 compared with 1,288 at a cost of $97,900 in 1969. It also charted a record number of 28,024 applications for mining tenements compared with 9,835 in 1969.

PART 9—STAFF

The move of the Department to Mineral House in May, 1970, helped to increase the general efficiency by bringing together Branches which had been spread for many years over eight different localities throughout the city.

Members of the staff both in Perth and on the goldfields again met the intense pressures generated by the mining boom, working long hours to cope with the immense volume of work and I am pleased to record my appreciation of the efforts of all concerned.

I have mentioned here only the main items of the Department's activities, and detailed reports of Branches are contained in Division II to IX hereunder.

I. R. BERRY,
Under Secretary for Mines.

Mines Department,
Perth.

DIVISION II

Report of the State Mining Engineer for the Year 1970

Under Secretary for Mines:

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

- Mineral and Metal Production—
  by J. K. N. Lloyd, Assistant State Mining Engineer;
- Mine Inspection and Accident Statistics—
  By J. M. Faichney, Mining Engineer/Acting Senior Inspector of Mines;
- Petroleum Exploration and Production—
  By A. J. Sharp, Petroleum Engineer;
- Coal Mining—
  By R. S. Ferguson—Mining Engineer/Senior Inspector of Mines;
- Drilling Operations—
  By D. A. Macpherson—Drilling Engineer;
- Board of Examiners—
  By W. J. Cahill—Secretary, Board of Examiners.

MINERALS, METALS AND OIL

For the year 1970, the value of mineral and petroleum production increased by 70 per cent. to $579,611,726 as compared with $341,743,043 for the previous year.

The value of iron ore production was $328,315,877 followed by nickel ore and concentrates at $87,417,030, alumina at $60,799,000 and petroleum at $53,710,900.

The value of salt production increased sharply from $1,899,087 to $6,476,489, whereas gold production declined from $16,891,239 to $11,326,577.

The Kwinana nickel refinery was completed and brought into production during the year and construction of the alumina refinery at Pinjarra was commenced. During the year the Kwinana alumina refinery added the fifth and sixth digester units to bring its designed output of alumina to 1¼ million tons per annum.

DRILLING

During the year the Drilling Section was responsible for the drilling of 25,302 feet in 143 bores. Most of the work was by way of exploratory drilling for ground water and was mainly carried out at Port Hedland, Gnangara, Muchea and Gwelup.

Drilling was also carried out to provide additional information on the coal resources of the Collie coal field. This involved 10 bores and a total drill footage of 7,830 feet.

STAFF

Appointments—

P. Swainston. — Mining Engineer — District Inspector of Mines 4-8-70

Resignations—

L. Burrows.	23-1-70
G. Munro.	15-5-70
A. W. Ibbotson.	8-5-70
M. Ryan.	28-8-70

A. Y. WILSON,
State Mining Engineer.

MINERAL AND METAL PRODUCTION

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

Mineral production for the year 1970 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—Development Footages.

Table 3—Principal Gold Producers.

TABLE 1

Mineral and Metal Output

Product	1969 Tons	1969 Value	1970 Tons	1970 Value
		$A		$A
Alumina	758,964·00	48,571,900	949,987·00	60,799,000
Asbestos	26·80	1,126	....	....
Barite	1,018·08	15,271	565·05	6,916
Bentonite	255·00	1,552	115·50	774
Beryl	....	....	15·55	5,797
Bismuth	....	....	1·69	6,867
Building Stone	2,031·50	21,110	6,616·50	69,781
Clays	297,928·13	403,174	184,818·55	229,293
Coal	1,090,530·10	4,804,089	1,197,733.50	5,827,291
Cobalt	86·01	127,245	332·73	1,197,680
Copper—				
Ore and Concentrates	2,644·27	583,332	2,978·20	662,762
Fertilizer Grade	1,128·48	82,464	603·99	126,890
Metal	918·61	554,978	2,095·66	2,037,360
Felspar	458·00	6,870	645·00	9,675
Glass Sand	48,932·00	26,630	95,569·00	34,046
Gold (fine ounces)	440,064·98	16,891,239	350,389·61	11,326,577
Gypsum	64,398·17	138,863	89,987·11	247,915
Ilmenite	681,501·96	6,820,228	550,660·15	5,984,389
Iron Ore	24,681,710·63	183,046,603	42,506,004·46	328,315,877
Iron Ore—Pig Iron	98,590·00	3,429,462	98,640·00	3,505,910
Lead Ore and Concentrates	1,104·38	158,289	456·59	64,779
Leucoxene	6,745·40	298,441	12,130·30	634,171
Limestone	1,302,841·29	1,214,415	1,168,849·67	1,246,403
Lithium Ore—Petalite	710·00	11,296	771·00	12,259
Magnesite	....	....	2,180·00	31,600
Manganese	179,044·77	3,557,921	202,373·50	3,743,921
Monazite	2,610·30	324,705	4,693·23	621,603
Nickel Ore and Concentrates	67,647·01	16,417,100	305,555·89	87,417,030
Ochre	588·40	11,768	608·54	6,085
Palladium (ounces Troy)	320·75	9,656	....	....
Petroleum (barrels)	13,140,280·00	48,108,530	16,663,905·00	53,710,900
Platinum (ounces Troy)	472·69	36,931	1,449·18	155,454
Pyrite	18,237·54	205,850	1,398·79	15,765
Rutile	1,643·02	152,325	2,251·61	200,483
Salt	582,835·00	1,899,087	1,815,935·62	6,476,489
Semi-precious Stones	21·56	14,852	32·26	45,224
Silver (fine ounces)	450,862·08	725,372	418,769·71	656,926
Talc	33,208·15	708,746	31,293·93	742,257
Tantalo-Columbite	72·48	236,031	68·58	246,510
Tin Concentrate	794·46	1,332,012	759·06	1,606,537
Vermiculite	....	....	299·42	1,797
Xenotime	10·00	2,535	55·00	71,922
Zircon	27,279·13	791,045	60,956·02	1,508,811
Totals	....	341,743,043	....	579,611,726

TABLE 2

Development Footages Reported by the Principal Mines

Gold or Mineral Field	Mine	Shaft Sinking	Driving	Cross Cutting	Rising and Winzing	Exploratory Drilling	Total
		feet	feet	feet	feet	feet	feet
Gold—							
Murchison	Hill 50 Gold Mine N.L.	72	2,126	740	528	5,535	9,001
Dundas	Central Norseman Gold Corpn. N.L.	....	275	239	1,400	35,184	37,098
East Coolgardie	Gold Mines of Kalgoorlie (Aust.) Ltd.	....	10,478	....	2,383	7,173	20,034
	Lake View and Star Ltd.	....	3,104	1,335	1,700	7,806	13,945
	North Kalgurli (1912) Ltd.	19	2,379	597	270	6,173	9,438
	Totals in Gold Mines	91	18,362	2,911	6,281	61,871	89,516
Copper— Phillips River	Ravensthorpe Copper Mines N.L.	82	2,737	668	423	....	3,910
Nickel—							
Coolgardie	Western Mining Corpn. Ltd.	71	32,370	....	27,277	253,327	313,045
	Metals Exploration N.L.	64	2,571	117	2,130	1,664	6,546
	International Nickel Aust. Ltd.	347	....	59	39	21,788	22,233
Broad Arrow	Scotia (Great Boulder-North Kalgurli)	185	2,234	698	940	3,187	7,244
North Coolgardie	Carr Boyd Rocks (Great Boulder-North Kalgurli)	404	214	12	167	5,867	6,664
	Totals in Nickel Mines	1,071	37,389	886	30,553	285,833	355,732
	Totals in All Mines	**1,244**	**58,488**	**4,465**	**37,257**	**347,704**	**449,158**

ALUMINA

Alcoa of Australia (W.A.) N.L. (previously Western Aluminium N.L.), railed to the Kwinana Refinery, 3,419,185 tons of bauxite obtained from the No. 2 mining site near Jarrahdale. Alumina sales totalled 949,987 tons having an estimated value of $60,799,000 f.o.b. Kwinana. Alumina from Kwinana is supplied to Alcoa of Australia's aluminium smelter at Point Henry, Geelong, Victoria and is exported to the United States, Japan and other world markets under long term contracts. In Victoria, 1970 was the first full year of operation of the Point Henry smelter at its 90,000 tons capacity level.

Expansion of the Kwinana alumina refinery was completed during the year with the addition of the fifth and sixth digester units which will increase output of alumina to 1¼ million tons per annum.

Construction at the new refinery site at Pinjarra involves two digester units which are scheduled to begin production in 1972. Bauxite will be supplied to the refinery from adjacent deposits in the Darling Range. The ore is to be transported to the refinery by a 36 inch conveyor approximately 20,500 feet long coming down the Darling scarp.

In mined and cleared areas at Jarrahdale, 490 acres have been replanted with tree species of commercial potential including Tallowwood, Sydney blue gum, Tasmanian blue gum, yellow stringy bark, pinus radiata and pinus pinaster.

BARITE

At North Pole in the Pilbara, *Associated Minerals Pty. Ltd.* obtained 520 tons valued at $6,240. *Universal Milling Co. Pty. Ltd.'s* production from Chesterfield was only 45 tons valued at $676 f.o.r. Meekatharra.

BENTONITE

Lake deposits at Marchagee and Woodanilling were the source of the year's production of 115½ tons.

BISMUTH

A total of 3,780 lb. valued at $6,867 were obtained from deposits near Yinnietharra in the Gascoyne Goldfield.

BUILDING STONE

Production from mining tenements granted under the provisions of the Mining Act, was 6,616 tons valued at $69,781. Production included 4,960 tons of quartz from Mukinbudin, 1,516 tons of quartzite from Toodyay and 140 tons of spongolite from Fitzgerald River and Mount Barker.

CLAYS

Reported clay production from the Metropolitan Area, Byford, Clackline, Glen Forrest, Bullsbrook and Goomalling totalled 184,819 tons valued at $229,293.

COAL

The total output from all mines in the Collie Coal field was 1,197,733 tons valued at $5,827,291 at the pit head. During the past ten years the increased demand for Collie coal has enabled the companies to lift annual production 56·4 per cent. over the period. Over the same period the average pit head value has risen 48 cents per ton or 10·9 per cent.

The Muja Open Cut operated by the *Griffin Coal Mining Co. Ltd.* produced 626,191 tons of coal which represented 52·3 per cent. of the total output for the coal field. The average ratio of overburden removed to coal mined was 4·7 to 1. At the end of the year there was approximately 466,000 tons of coal exposed in the open cut.

Western Collieries Ltd. increased output by 108,869 tons to 571,542 tons obtained from the Western No. 2 mine (467,298 tons) and Western No. 5 open cut (104,244 tons). At the open cut the coal was won from the Cardiff and Neath seams.

The report of the Senior Inspector of Coal Mines covers more fully coal mining operations at Collie.

COBALT

Nickel concentrates exported contained 333 tons of cobalt valued at $1,197,680. Most of the cobalt (314 tons) was contained in concentrates exported by *Western Mining Corporation Ltd.* with the remainder coming from the Great Boulder-North Kalgurli mine at Scotia.

COPPER

Ravensthorpe Copper Mines N.L. treated 44,513 tons of ore for a recovery of 2,978 tons of concentrate containing 562 tons of copper, 984 fine ounces of gold and 2,888 fine ounces of silver. Development work completed during the year included 82 feet of shaft sinking, 2,737 feet of driving, 668 feet of crosscutting and 423 feet of winzing and rising. Since the inception of mining operations early in 1957, the company has produced 54,465 tons of concentrate estimated to contain 11,650 tons of copper, 19,000 fine ounces of gold and 66,000 fine ounces of silver valued at $7,900,000 f.o.b. Esperance. Mill feed amounted to 836,318 tons made up of 797,022 tons of ore and 39,296 tons of old dumps and sands averaging 1·4 per cent. copper recovered. It is expected that underground operations will cease on or about the 3rd March, 1971.

Western Mining Corporation Ltd. reported the production of 2,041 tons of metal contained in nickel concentrates from Kambalda. Nickel concentrates, from mining operations by the Great Boulder-North Kalgurli partnership at Scotia, contained 55 tons of copper.

Notable producers of ore for use as a trace element in fertilizers were *Thaduna Copper Mines Co. Pty. Ltd.* with 466 tons of 18·08 per cent. ore valued at $94,247, *K. J. McPherson* at Glen Ellen Pool in the Pilbara with 59 tons of 27·46 per cent. ore valued at $17,116 and *Group Explorations Pty. Ltd.* at Ilgarari in the Peak Hill Goldfield with 22 tons of 27·00 per cent. ore valued at $5,722. Total production from all sources of this type of ore was 604 tons of ore averaging 19·25 per cent. copper.

FELSPAR

Australian Glass Manufacturers Co. reported the production of 645 tons from its quarry at Londonderry in the Coolgardie Goldfield. The company also obtained 771 tons of petalite from the same source.

GLASS SAND

Glass sand production totalled 95,569 tons valued at $34,046 which value does not include the value of a parcel of 5,625 tons exported by *Ready Mix Concrete (W.A.) Pty. Ltd.* Sand deposits worked during the year included Lake Gnangara 17,336 tons, Jandakot 77,225 tons and Yoganup 1,008 tons. Principal producers were *Silicon Quarries Pty. Ltd.* at Jandakot with 71,600 tons and *Australian Glass Manufacturers Co.* at Lake Gnangara with 16,893 tons.

GOLD

The ore treated during the year amounted to 1,740,020 tons as compared with 2,006,716 tons in the previous year. Gold recovered was 350,390 fine ounces as compared with 440,065 fine ounces for 1969. Grade of ore mined was lower, recovery being 4·03 dwts. per ton as against 4·39 dwts. per ton for 1969.

The calculated value of the gold produced was $11,326,577 which included $376,902 distributed by the Gold Producers Association from the sale of 367,809 fine ounces of gold at an average premium of $1·07 per fine ounce. The Mint value of gold throughout the year was $31·25 per fine ounce.

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

TABLE 3

Principal Gold Producers

Mine	1969			1970		
	Tons Treated	Fine Ounces	Dwts. per ton	Tons Treated	Fine Ounces	Dwts. per ton
Gold Mines of Kalgoorlie (Aust.) Ltd.	766,068	135,824	3·55	815,322	130,155	3·19
Lake View & Star Ltd.	492,802	108,741	4·41	418,203	98,031	4·69
North Kalgurli (1912) Ltd.	332,027	62,696	3·78	288,550	53,075	3·68
Central Norseman Gold Corporation N.L.	172,648	70,067	8·12	149,772	50,506	6·74
Hill 50 Gold Mine N.L.	110,753	26,878	4·85	28,703	6,581	4·59
Great Boulder Gold Mines Ltd.	84,140	22,397	5·32	....	....	....
State Batteries	26,307	7,126	5·42	22,811	7,336	6·43
State Batteries Tailings Treatment	....	2,740	....	....	1,161	....
Other Sources	21,971	3,596	3·27	16,659	3,545	4·26
Totals in all Mines	2,006,716	440,065	4·39	1,740,020	350,390	4·03

Gold Mines of Kalgoorlie (Aust.) Ltd. with a production of 815,322 tons of ore for a return of 130,155 fine ounces of gold at an average recovery of 3·19 dwts. per ton was the State's leading producer. Production from the Fimiston leases was 159,463 tons yielding 42,146 ounces and from Mount Charlotte 655,859 tons yielding 88,009 ounces.

Ore reserves at the end of June were reported to be 542,000 tons at 4·8 dwts. for the Fimiston leases and 4,097,000 tons at 3·6 dwts. for Mount Charlotte. Development completed during the year included 10,478 feet of driving and crosscutting, 1,357 feet of winzing and 1,026 feet of rising which work was concentrated on the Perseverance leases and below the 1,000 feet horizon of Mount Charlotte.

In July 555,000 tons of ore were blasted in "B" block crown and rib pillars in the Charlotte mine. The final blast of the series in December involved the breaking of 420,000 tons. Recording of vibrations from blasting indicated that all were below permissible limits. New plant installed at the Oroya treatment plant included a 6 ft. x 8 ft rod mill, together with associated conveyor and pumps.

Lake View and Star Ltd. produced 98,031 fine ounces of gold from the treatment of 418,203 tons of ore at an average recovery of 4·69 dwts per ton. The previous year's production was 108,741 fine ounces from the treatment of 492,802 tons.

Estimated ore reserves as at 30th June were 2,298,100 short tons at 4·69 dwts. per ton.

Underground mining operations were restricted to one shift per day for the full year with hoisting of ore only remaining on two shifts. Rising costs and shortage of mining labour forced the company to limit development work to extensions of payable grade work that could be rapidly mined out.

Exploration in conjunction with Consolidated Gold Fields Australia Ltd. continued throughout the year in the Lake Rebecca, Pinjin, Kurnalpi, Block 59 Hampton Area, Sandstone and Lake Barlee areas.

North Kalgurlie (1912) *Ltd.* treated 288,550 tons of ore for a recovery of 53,075 fine ounces of gold at an average recovery of 3·68 dwts. per ton. During the previous year 62,696 fine ounces were recovered from 332,027 tons.

Ore reserves at June 23rd were calculated at 459,700 tons at 4·57 dwts. per ton. This reserve represents broken ore in stopes and ore that can be mined with a minimum of development work. Development work completed during the year included 19 feet of shaft sinking, 2,379 feet of driving 597 feet of cross cutting, 270 feet of rising and winzing and 6,173 feet of exploratory drilling.

Central Norseman Gold Corporation N.L. treated 149,772 tons for a recovery of 50,506 fine ounces of gold. Gold recovery was at the rate of 6·74 dwts. per ton as compared with the previous year's recovery of 8·12 dwts. per ton when 172·648 tons yielded 70,067 fine ounces.

Development completed during the year included 275 feet of driving, 239 feet of cross cutting, 1,400 feet of rising and 35,184 feet of exploratory drilling. Most of the ore mined came from the Crown ore body on the Phoenix mine between the Nos. 15 and 32 levels. It is expected that mining at the Princess Royal mine will cease in the coming year. The estimated reserves at the end of June were 245,000 tons averaging 8·2 dwts. per ton.

Hill 50 Gold Mine N.L. at Mount Magnet treated 28,703 tons of ore for a return of 6,581 fine ounces of gold, average recovery being 4·59 dwts. per ton.

Work was concentrated on opening up indicated ore reserves below the bottom haulage level at 2,760 feet, main shaft. Stripping of an internal shaft below that level was continued to the 3,010 feet level. The Morning Star shaft was sunk a further 72 feet a plat cut at 909 feet and a loading station constructed at 948 feet. The treatment of ore was suspended during the period 9th June to the 1st September to effect modifications to the plant.

Smaller producers of note were the *Constance Una* at Parkers Range with 1,737 fine ounces from 3,036 tons, *Star of Mangaroon* in the Gascoyne with 826 fine ounces from 616 tons, *Bank of Kalpini* in the Kanowna district with 743 fine ounces from 6,248 tons, *Radio* at Golden Valley in the Yilgarn with 739 fine ounces from 3,103 tons, and the *Daisy* at Mount Monger with 626 fine ounces from 512 tons.

GYPSUM

Plaster and cement manufacturers obtained their supplies of gypsum from Yellowdine, Lake Brown, Lake Cowcowing, Nukarni and Norseman.

Total gypsum production for the year was 89,987 tons valued at $247,915. Included in this output was 20,573 tons obtained in the Shark Bay area and exported by *Garrick Agnew Pty. Ltd.* Reported production of plaster of paris was 29,508 tons.

ILMENITE, LEUCOXENE, MONAZITE, RUTILE, XENOTIME, ZIRCON

Sales of ilmenite totalled 550,660 tons valued at $5,984,389. Minerals associated with ilmenite returned $3,036,990 to the producers.

Western Titanium N.L. at Capel produced 174,486 tons of ilmenite assaying 54·76 per cent. titanium dioxide, 7,704 tons of upgraded ilmenite assaying 89·26 per cent. TiO_2, 1,113 tons of leucoxene, 1,931 tons of monazite, 1,355 tons of rutile, 55 tons of xenotime and 33,464 tons of zircon. Sluicing operations in the area adjacent to the Bunbury-Busselton Highway ceased in mid December and preparations were made to mine a new site east of the railway and south of the dry treatment plant. This new cut will be mined using bulldozers and front end loaders. The sand will be dumped into bins, screened and them pumped to the wet concentrating plant.

Western Mineral Sands Pty. Ltd. at Capel produced 169,400 tons of ilmenite assaying 54 per cent. TiO_2. Residues totalling 46,781 tons were sold to Westralian Sands Ltd. There has been no major alteration to the mining method which continues as a sand excavation operation using front end loaders.

Westralian Sands Ltd. produced 112,964 tons of ilmenite assaying 56·57 per cent. TiO_2, 3,592 tons of leucoxene, 1,736 tons of monazite, 896 tons of rutile and 18,588 tons of zircon. Ore mined by contractors totalled 978,889 tons which came from three benches in the company's open cut at Yoganup. The ore is carted nearly a mile to the wet concentrating plant. From the wet plant the concentrate is carted about 8 miles to the dry separation plant at Capel.

Ilmenite Minerals Pty. Ltd. and Cable (1956) *Ltd.* wholly owned subsidiaries of *Kathleen Investments* (*Aust.*) *Ltd.* produced 86,106 tons of ilmenite assaying 54·33 per cent. TiO_2, 7,425 tons of leucoxene, 1,026 tons of monazite and 8,904 tons of zircon. At Wonnerup 23 acres of ground was mined to an average depth of 13 feet with the 75 ton per hour suction dredge. The 5 to 20 per cent. heavy mineral bearing sand is pumped to a shore based skid mounted wet concentrating plant. At Stratham approximately 8 acres of ground was dredged to an average depth of 40 feet. The ore is concentrated by a 305 ton floating wet plant. The 90 to 98 per cent. heavy mineral concentrate from both mining sites is carted to the dry separation plant at Bunbury.

IRON ORE

Total iron ore production for the year was 42,604,644 tons valued at $331,821,787. This output represents a 72 per cent. increase on the 1969 output of 24,780,301 tons.

Hamersley Iron Pty. Ltd. exported 19,386,182 tons of 64·65 per cent. iron ore and pellets valued at $152,811,211 f.o.b. Dampier. Included in the above total was 1,879,690 tons of pellets valued at $19,365,666.

At Mount Tom Price quarry benches have been established at 45 feet intervals. Blast hole drilling is completed on a 24 feet square pattern for 12¼ inch diameter holes and a 15 feet square pattern for 7½ inch diameter holes. Site mixed Ireco slurry, ammonium nitrate fuel oil explosive and boosters are used at the rate of 0·8 lb. of explosive per ton of ore broken. At Paraburdoo access roads to the top of the 4 East ore body have been completed and a start made on quarry preparation and crushing facilities. A 64 mile standard gauge railway, linking Paraburdoo to Tom Price is under construction.

Port expansion at Dampier includes the construction of a shipping terminal at East Intercourse Island to handle 150,000 ton capacity ore carriers. Dredging of the sea bed at the new deep berth has been completed and dredging of the departure channel has commenced. A causeway linking the island with the mainland has been completed.

The company's work force in the North-West is now 1,884 persons, an increase of 478 on the total employed at the end of the previous year. Nearly half the work force (910) is employed at Tom Price, 779 at Dampier, 104 on Railways and 91 at Paraburdoo.

Mount Newman Mining Co. Pty. Ltd. exported 11,382,975 tons of 62·91 per cent. iron ore which included 479,316 tons shipped to the Eastern States. The total value of the 1970 shipments was $85,857,438 f.o.b. Port Hedland.

The present labour force of 1,518 includes 807 employees at Newman, 547 at Port Hedland and 164 on the 265 mile standard gauge railway between the mine at Mount Whaleback and the shipping terminal.

At Mount Whaleback quarry benches have been established at 50 feet intervals. Broken ore is loaded into 75 and 100 ton capacity WABCO Haulpacs by 10 cubic yard capacity P. & H. electric shovels. An Allis Chalmers primary cone crusher reduces the broken ore from 3 feet to minus 8 inch and then the ore is passed to secondary cones and crushed to minus 4 inch. Tertiary crushing is carried out, at Port Hedland, to give two product sizes, minus 1 inch and minus ¼ inch.

Construction work has started on a duplication of the crushing plant and train loading facilities at the mine. At Nelson Point, Port Hedland an expansion programme has included the deepening of approach channels to 42 feet below port low water mark, enlarging the stock pile area to take over 2 million tons and extending the loading wharf to berth two bulk ore carriers each exceeding 100,000 tons capacity.

Goldsworthy Mining Ltd. reported the sale overseas of 6,817,878 tons of iron ore assaying 63·93 per cent. Fe and valued at $53,979,245 f.o.b. Port Hedland. The work force was increased by 81 to 637 as compared with the previous year. At present 420 persons are employed at Goldsworthy, 141 at Finucane Island and 76 on the railway.

Additional equipment put into service at the quarry site included two 60R Bucyrus Erie drills for drilling 12¼ inch diameter holes, four 10 cubic yard capacity electric shovels and seven 120 ton capacity trucks. Benches at 30 feet intervals are drilled to a 20 or 27 feet square pattern depending on the hole sizes of 9 or 12¼ inch. The loading ratio is about ½ lb. explosive per ton of ore broken.

Dampier Mining Co. Ltd. produced a total of 4,328,993 tons of iron ore averaging 64·13 per cent. Fe and valued at $30,875,829.

Koolan Island ore exported overseas amounted to 1,058,488 tons of 66·45 per cent. Fe ore valued at $7,211,933. Shipments to the Eastern States totalled 1,313,358 tons of 64·50 per cent. Fe ore from Cockatoo Island and 389,931 tons of 67·20 per cent. Fe ore from Koolan. The nominal value of these shipments was $11,927,816. The loading berth at Cockatoo can accommodate 55,000 tons capacity vessels and at Koolan the shipping terminal is being upgraded to take carriers up to 100,000 ton capacity.

Koolyanobbing production was 1,567,216 tons averaging 61·50 per cent. Fe and valued at $11,736,080. Included in the Koolyanobbing production was 527,102 tons shipped to the Eastern States and 235,017 tons exported overseas from Kwinana.

Western Mining Corporation Ltd. mining the Koolanooka Hills deposit exported 589,976 tons of 60·57 per cent. Fe ore valued at $4,792,154 f.o.b. Geraldton. Most of the ore mined during the year came from the 1,065, 1,035 and 1,005 feet benches. Early in the new year a start was made on developing the 975 feet bench which is 55 feet below the plain level in the area.

The Charcoal Iron and Steel Industry at Wundowie obtained 98,640 tons of iron ore from the Koolyanobbing deposits. Limestone feed for the two blast furnaces came from Beaconsfield near Fremantle and timber for charcoal production was obtained from a forest area near the works. Pig iron production was 61,537 tons valued at $3,505,910.

LEAD

Sales of lead concentrate from the Northampton district totalled 457 tons. The concentrate contained 301 tons of lead valued at $64,779 f.o.b. Geraldton. Most of the recorded production was from ore mined in the previous year. *Canadian Southern Cross Mines N.L.* reported the sale of 226 tons of concentrate from its mine at Mary Springs. This mine was kept dewatered. The *North Ellen* was the source of 143 tons of lead concentrate which was won from shallow excavations and the treatment of dump material.

LIMESTONE

Reported production of limestone was 1,168,850 tons valued at $1,246,403. Not all production is reported to this Department. There is a large demand for limestone as a road foundation in and around the Metropolitan Area. Limestone used for building purposes, road construction, agricultural purposes, flux and cement manufacture was quarried at Wanneroo, Mount Many Peaks, South Coogee, Mullaloo, Esperance, Parry Inlet, Jandakot and Fremantle.

LITHIUM ORE

Australian Glass Manufacturers Co. obtained 771 tons of petalite from its felspar quarry at Londonderry in the Coolgardie Goldfield.

MAGNESITE

The only producer *Norseman Gold Mines N.L.* reported the sale of 2,180 tons obtained from a deposit near Ravensthorpe. Reserves are reputed to be at least 5 million tons.

MANGANESE

Exports from Port Hedland totalled 191,283 tons of 48·27 per cent. manganese ore valued at $3,674,659. Horseshoe production exported through Gerladton amounted to 11,090 tons (35%Mn) valued at $69,262.

In the Pilbara the three producers were *Westralian Ores Pty. Ltd.* with 131,095 tons of 46·90 per cent. ore, *Longreach Manganese Pty. Ltd.* with 25,000 tons of 50 per cent. ore and *Dampier Mining Co. Ltd.* with 35,188 tons of 52·13 per cent ore. All of the ore was obtained from open cuts in deposits at Mount Cooke, Mount Sydney and Woodie Woodie.

NICKEL

Western Mining Corporation Ltd. reported the sale of 255,407 tons of 11·44 per cent. nickel concentrate having an estimated value of $82,179,550. Included in this concentrate output was 5,391 tons of the metal produced at the company's refinery at Kwinana. At Kambalda, the company treated 929,726 tons of its own ore to produce 237,224 tons of concentrate. Proved sulphide ore reserves at Kambalda and Saint Ives were reported as 17,169,000 tons averaging 3·4 per cent. nickel.

Development completed during the year included 71 feet of shaft sinking (Durkin service shaft), 32,370 feet of driving and crosscutting, 27,277 feet of winzing and rising and 253,327 feet of exploratory drilling. Development was continued at a high rate to allow for a production of 30,000 tons per annum of contained nickel to be reached and maintained. A new ore shoot (Hunt) was discovered at the south end of the Kambalda dome. Drilling west of the Juan shoot has indicated at least two new ore shoots in the area.

Construction of the Kwinana nickel refinery was completed in May and the first shipment of nickel metal was made to an Australian Company, Commonwealth Steel Ltd., during that month. Initial shipments to overseas customers commenced during June. Other refinery products are ammonium sulphate, copper sulphide and mixed nickel-cobalt sulphide. Production of nickel briquettes and powder reached the design rate of 15,000 tons per annum late in the year. To commemorate the official opening of the refinery on the 15th September, the company has sponsored a Chair of Environmental studies and Conservation at the proposed Murdoch University to be established in 1975.

The *Scotia* operations of the *Great Boulder Gold Mines Ltd.* and *North Kalgurli* (1912) *Ltd.* partnership produced 10,846 tons of 11·43 per cent. nickel concentrate from the treatment of 66,637 tons or ore. A total of 10,032 tons of concentrate valued at $3,344,600 was exported through Esperance. Also contained in the concentrate was 55 tons of copper and 19 tons of cobalt having an estimated value of $134,300. Sulphide mickel ore reserves was estimated to be 1¼ million tons averaging 3·07 per cent. nickel and 0·25 per cent. copper.

Shaft sinking continued to approximately 700 feet and at the 660 feet horizon a cross cut was constructed to the ore body and driving commenced. Three 200 gallon per minute capacity electric pumps were installed underground to cope with increasing water flow. A raise borer capable of boring and reaming to 3 feet was purchased late in the year. New plant installed at the Great Boulder, Fimiston included an ore terminal for the road trains containing a 250 ton bin and Ross feeder, a weigh bridge of 31 tons capacity and 27 new flotation cells.

At Carr Boyd Rocks shaft sinking has reached 404 feet and levels developed at 200 and 350 feet. The 66,000 volt power line to Scotia was extended another 24 miles to the mine where a new headframe has been erected and a 1,000 h.p. winder, ex Edwards shaft, Fimiston, brought into service. Drilling has indicated an ore reserve of 2 million tons of sulphide ore averaging 1·41 per cent. nickel and 0·41 per cent. copper.

Metals Exploration N.L. at Nepean produced 40,116 tons of ore averaging 3·05 per cent. nickel and valued at $1,892,880. This ore was treated at Western Mining's concentrator at Kambalda.

In the Mount Margaret Goldfield, *Poseidon Ltd.* is sinking a winze to 400 feet and has started construction of two declines. It is estimated that production at Windarra will commence in 1972.

International Nickel Aust. Ltd. in partnership with *Broken Hill Pty. Co. Ltd.* completed 347 feet of shaft sinking at Mount Edwards some two miles north of Widgiemooltha. The planned depth of this exploration shaft is 1,250 feet.

Anaconda Australia Inc. has commenced shaft sinking at Redross (about 16 miles south of Widgiemooltha) and at Wannaway some 12 miles north west. Diamond drilling has indicated reserves of 1 million tons averaging 3½ per cent. nickel and 4½ million tons averaging 1·3 per cent. nickel.

OCHRE

Universal Milling Co. Pty. Ltd. obtained 609 tons of red ochre from the Wilgie Mia deposit in the Weld Range.

PETROLEUM

Shipments of Barrow Island crude oil totalled 16,663,905 barrels valued at $53,710,900 at Kwinana. Fifty-four wells were drilled on Barrow Island during the year. In the Dongara gas field 19 wells have been drilled to evaluate the structure. Production from this field should commence late in 1971. The report of the Petroleum Engineer covers more fully the activities of the companies engaged in the search and production of oil and gas.

PLATINUM

Nickel concentrates exported by *Western Mining Corporation Ltd.* contained 1,449 ounces of platinum valued at $155,454.

PYRITE

Gold Mines of Kalgoorlie (Aust.) Ltd. forwarded to works at Fremantle 1,399 tons of auriferous pyritic concentrate containing 631 tons of sulphur valued at $15,765.

SALT

Production reported to the Department of Mines was 1,815,936 tons valued at $6,476,489 f.o.b.

Texada Mines Pty. Ltd. operating at Lake MacLeod about 40 miles north of Carnarvon exported 1,139,433 tons through its port at Cape Cuvier.

From Port Hedland, the *Leslie Salt Co.* exported 553,478 tons and from Esperance *Lefroy Salt Pty. Ltd.* shipped 123,025 tons harvested from Lake Lefroy near Widgiemooltha.

SEMI PRECIOUS STONES

Twenty-five tons of chrysoprase valued at $37,000 was obtained from Wingelina. Other semi precious stones amethyst, moss opal, dravite, and chalcedony valued at $8,224 were won from deposits in the Ashburton, Gascoyne, Broad Arrow and Dundas Goldfields.

SILVER

Silver as a by-product of gold, copper and lead mining amounted to 418,770 fine ounces valued at $656,926.

TALC

Three Springs Talc Pty. Ltd. operating an open cut at Three Springs produced 31,294 tons of talc valued at $742,257. Twelve men are employed at the mine.

TANTALO-COLUMBITE

Sixty-nine tons of concentrate containing 2,246 units of Ta_2O_5 valued at $246,510 were produced during 1970. *Greenbushes Tin N.L.* was the State's leading producer with 35 tons of tantalite concentrate containing 1,771 units of Ta_2O_5 valued at $208,971. Total production from the Greenbushes field amounted to 51 tons of concentrate. Other producing centres were Dalgaranga in the Yalgoo Goldfield and Eleys, Hillside and Wodgina in the Pilbara.

TIN

Production for the year was 759 tons of concentrate containing 521 tons of tin valued at $1,606,537. Output of concentrate from Greenbushes was 402 tons, from the Pilbara 346 tons and from the West Pilbara 11 tons.

Greenbushes Tin N.L. was the State's leading tin producer with 360 tons of concentrate valued at $784,384. Early in the year, the dredge "Jim Crow" which for about two years was used as a stationary plant, returned to dredging on the south western side of the company's area.

Pilbara Tin Pty. Ltd. at Moolyella reported the production of 106 tons of concentrate valued at $244,575 f.o.b. Port Hedland.

Other notable producers were *J. A. Johnston & Sons Pty. Ltd.* at Eleys with 66 tons of concentrate, *M. R. Edwards* at Moolyella with 37 tons and *Vultan Minerals Ltd.* at Greenbushes with 27 tons.

VERMICULITE

Mount Palmer in the Yilgarn was the source of 299 tons of vermiculite obtained by *Mineral By-Products Pty. Ltd.*

MINE INSPECTION—ACCIDENT STATISTICS

J. M. Faichney—Mining Engineer and Acting Senior Inspector of Mines

Fatal and serious mining accidents reported to the Department are presented below and where relevant the corresponding figures for the year 1969 are shown in brackets.

There were 12 (13) fatal and 312 (405) serious accidents. The segregation of accidents in Table "B' continues to illustrate the decline in Gold Mining whilst both Nickel and Iron mining increase. There continues to be much construction work on installation for nickel and iron mining and some accidents involve construction workers engaged in the Mining Industry.

In Gold mines there were 4 (4) fatal and 116 (17 9 serious accidents with an accident rate per 1,000 men of: fatal 1·85 (1·14), serious 53·78 (51.20).

In Iron mines there were 4 (3) fatal and 38 (51) serious accidents with an accident rate per 1,000 men of: fatal 0·80 (0·85), serious 7·62 (14·06).

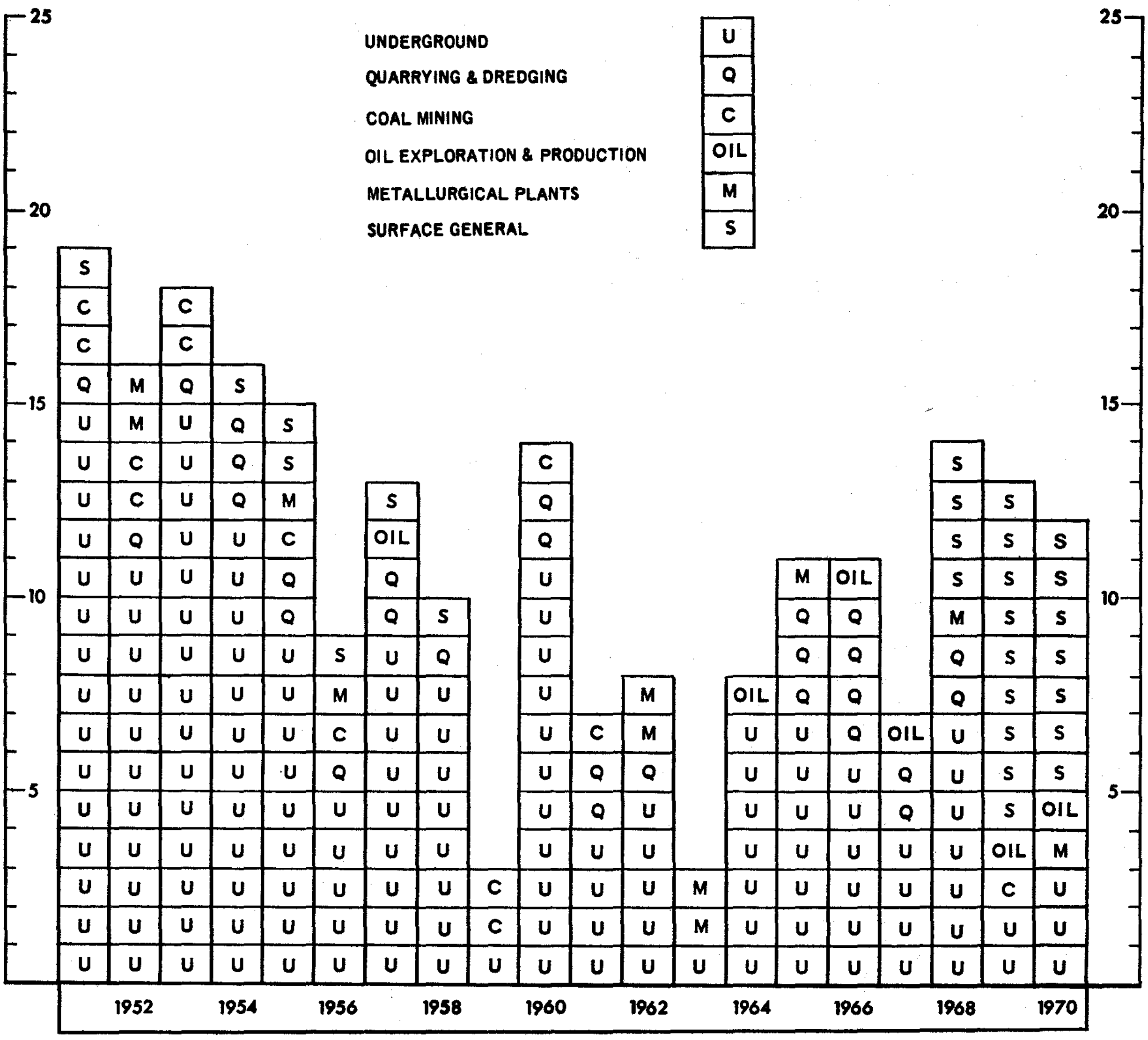
In Nickel mines there were 2 (2) fatal and 58 (44) serious accidents with an accident rate per 1,000 men of: fatal 1·45 (2·46), serious 42·00 (54·12).

There were fatal accidents in Oil 1 (1) and Salt 1 (–) production.

Below is a diagram showing fatal accidents over the past 20 years. These are classified according to the category of mining operation.

A classification of serious accidents showing the nature of injury is given in Table "A".

DIAGRAM OF FATAL ACCIDENTS
SEGREGATED ACCORDING TO CLASS OF MINING



WINDING MACHINERY ACCIDENTS

There were 14 accidents involving winding machinery reported during the year.

There was one derailment in the underlay Regent Shaft of Central Norseman Gold Corporation N.L.

In vertical shafts there were four Cage/Skip Hangups. There was no serious damage to shafts, skips, skip attachments or ropes.

Miscellaneous mishaps. There were three of these but none caused serious damage to the shafts involved.

There were six overwinds in the year. Five of these could be attributed to the inattention of the driver. The sixth occurred when there was a power failure and the loaded skip ran back in the shaft causing the empty skip to enter the sky shaft where the high limit switch failed to operate the emergency braking system. Minor damage only was caused by these overwinds.

In all cases repairs, replacement, modifications, and the cutting and recapping of ropes was carried out to ensure compliance with safety requirements.

FATAL ACCIDENTS.

Hereunder are brief descriptions of fatal accidents occurring during the year.

Name and Occupation	Date	Mine	Details and Remarks
Agoni, Felice (Underground locomotice driver)	25/2/70	Gold Mines of Kalgoorlie (Aust.) Ltd. Mount Charlotte Mine	Agoni was crushed between an underground locomotive and a ventilation door. There were no witnesses but it is possible that he accidentally knocked the control lever into a reverse position whilst still outside the cab. He suffered a fractured skull.
Wotjanowski, Dymtro (Timberman)	2/4/70	Lake View and Star Ltd. Chaffers shaft	He was assisting a machine miner to rill ore into a hole in a shrink stope when ore under his feet dropped causing him to be buried. He died of asphyxia.
Baumgartner, Josef (Plant operator)	16/5/70	Western Mining Corporation Ltd. (Kambalda Nickel Operations)	Death was due to traumatic shock due to amputation of the right arm. The injury was received when his arm became entangled in a conveyor belt tail pulley whilst attempting to remove spillage from under the belt.
Louder, William Raymond (Electrician)	23/5/70	Gold Mines of Kalgoorlie (Aust.) Ltd. Reward Shaft Mount Charlotte Mine	Louder was fatally injured when a transloader he was driving down the incline drive between the No. 8 and 9 levels hit a rock wall and overturned.
O'Connor, Stephen (Braceman)	31/5/70	Western Mining Corporation Ltd. (Kambalda Nickel Operations) Durkin Shaft	Whilst endeavouring to undo a shackle connecting a wire sling to a kibble he slipped backwards and fell down the shaft. He received multiple injuries.
Hinton, Graham George (Driller)	16/6/70	W.A. Petroleum Pty. Ltd. Barrow Island	A steel sinker bar was accidentally pulled into a pulley 100 ft. above the derrick floor. The sinker bar broke and struck the deceased who was standing on the derrick floor. He received fatal head injuries.
Quinlivan, Peter John (Plant Operator)	16/8/70	Western Mining Corporation Ltd. (Kambalda Nickel Operations. Concentrate handling at Esperance)	Death was due to crush injury of neck. There were no eye witnesses to this accident but he was found alongside a conveyor belt, and it is believed that he received his injuries when drawn through a cover over the conveyor.
Floyd, R. E. (Electrical linesman)	7/10/70	Goldsworthy Mining Ltd.	Floyd was electrocuted when he contacted a live 6,000 volt lightning arrestor stud on a power pole at the quarry site. He was ascending the pole to retrieve a sling left on the crown of the pole and apparently was unaware power had been restored.
Noble, T. (Carpenter)	6/11/70	Shark Bay Gypsum Pty. Ltd.....	Noble was electrocuted whilst using a portable electric power saw to cut asbestos sheet for fluming.
Crockett, B. T. (Wheeled scraper driver)	8/11/70	Hamersley Iron Pty. Ltd. Contractor—M.K.M.O.	Engaged on railroad construction. He was thrown out of a wheeled scraper when it ran off a road and a wheel passed over his head.
Pivac, Mirko (Rigger)	11/12/70	Hamersley Iron Pty. Ltd. Contractor — Transfield (W.A.) Pty. Ltd.	Pivac received internal injuries when he fell 52 feet on to a concrete floor whilst on the erection of a structural steel building at Dampier.
Sunjic, Mirko (Builder's labourer)	19/12/70	Hamersley Iron Pty. Ltd. Contractor — Fluor Australia Pty. Ltd.	A sudden " willy willy " caused a brick dividing wall to collapse on men working on powerhouse construction at Paraburdoo. Death was due to multiple skull fractures and fracture of the cervical vertibrae.

TABLE A
Serious Accidents for 1970

Class of Accident	Kimberley	West Kimberley	Pilbara	West Pilbara	Peak Hill	Murchison	North Coolgardie	Broad Arrow	East Coolgardie	Coolgardie	Dundas	Phillips River	Greenbushes	South-West	Collie	Ashburton	Total
Major Injuries—Exclusive of Fatal—																	
Fractures—																	
Head	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Shoulder	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Arm	....	....	1	....	....	....	....	....	1	....	1	....	....	1	....	1	5
Hand	....	....	3	1	....	....	....	....	1	2	....	....	....	3	1	1	12
Spine	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Rib	....	....	....	....	1	....	1	....	....	....	....	....	....	2	2	....	6
Pelvis	1	....	....	....	....	....	....	....	....	1	....	....	....	....	....	....	2
Thigh	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Leg	....	1	1	1	....	....	....	....	1	1	....	....	....	1	....	....	6
Ankle	....	....	....	1	....	....	....	....	1	1	....	1	....	....	....	....	4
Foot	....	....	....	....	....	....	....	....	4	6	....	....	....	2	....	....	12
Amputations—																	
Arm	....	....	....	....	....	....	....	....	....	....	....	....	....	1	....	....	1
Hand	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Finger	1	2	....	....	....	....	....	....	....	2	1	....	....	1	2	....	9
Leg	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Foot	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Toe	....	....	....	1	....	....	....	....	....	....	....	....	....	....	....	....	1
Loss of Eye	....	....	....	....	....	....	....	....	....	1	....	....	....	....	....	....	1
Serious Internal	....	....	....	....	....	....	....	....	3	....	....	....	....	1	....	....	4
Hernia	....	....	....	....	....	....	....	....	....	....	1	....	....	2	....	....	3
Dislocations	....	....	....	2	....	....	....	....	....	2	....	....	....	1	....	....	5
Other Major	....	1	2	1	....	1	....	....	1	1	....	1	....	6	....	....	14
Total Major	2	4	7	7	1	1	1	....	12	17	3	2	....	21	5	2	85
Minor Injuries—																	
Fractures—																	
Finger	....	....	1	....	....	1	....	....	13	4	1	3	1	1	1	1	27
Toe	....	....	....	....	....	....	....	....	1	2	....	....	....	1	....	....	4
Head	....	....	....	....	....	....	....	....	1	....	....	....	....	....	....	....	1
Eyes	....	....	....	1	....	....	....	....	5	....	....	....	....	1	....	....	7
Shoulder	....	....	....	....	....	....	....	....	....	....	....	1	....	1	....	....	2
Arm	....	....	....	....	....	....	....	2	7	1	....	....	....	....	2	1	13
Hand	....	....	1	....	....	....	....	4	15	4	2	2	1	3	....	2	34
Back	1	3	....	....	....	....	....	1	15	8	3	2	....	4	4	2	43
Rib	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Leg	....	....	....	1	....	....	2	2	17	2	....	1	....	6	7	3	41
Foot	1	....	1	2	....	1	....	....	14	1	....	....	....	7	4	1	32
Other Minor	....	....	2	....	1	1	....	2	3	5	....	....	....	3	5	1	23
Total Minor	2	3	5	4	1	3	2	11	91	27	6	9	2	27	23	11	227
Grand Total	4	7	12	11	2	4	3	11	103	44	9	11	2	48	28	13	312

There were no serious accidents reported in the year under review in the following Goldfields :—
Yilgarn, Gascoyne, East Murchison, Mount Margaret, North-East Coolgardie, Yalgoo, Nabberu, Eucla, Warburton, Northampton.

Table 'B' shows the fatal, serious and minor accidents reported and the number of men employed, classified according to the mineral mined.

TABLE B

Accidents Segregated According to Mineral Mined and Processed

Mineral	Men Employed	Accidents		
		Fatal	Serious	Minor
Bauxite (Alumina)	1,165	....	18	38
Coal	635	....	28	194
Copper	161	....	11	38
Gold	2,157	4	116	412
Gypsum	10	....	....	....
Ilmenite etc	372	....	12	71
Iron	4,987	4	38	249
Lead	7	....	....	....
Manganese	22	....	....	....
Nickel	1,381	2	58	300
Oil (Production and Exploration)	680	1	24	58
Salt	220	1	....	....
Tin	137	....	2	26
Other Minerals	203	....	....	....
Rock Quarries	260	....	5	21
Totals	12,397	12	312	1,407

Table 'C' shows the fatal and serious accidents classified according to the accident causes and also shows the different Mining Districts in which the accidents occurred.

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	....	....	....	....	....	....	....	....	....	....	....	4	....	4
West Kimberley	....	....	....	....	....	....	....	....	....	....	....	7	....	7
Pilbara	....	....	....	....	....	....	....	....	....	....	1	12	1	12
West Pilbara	....	....	....	....	....	....	....	....	....	....	3	11	3	11
Ashburton	....	....	....	....	....	....	....	....	....	....	1	13	1	13
Peak Hill	....	....	....	....	....	....	....	....	....	....	....	2	....	2
Gascoyne	....	....	....	....	....	....	....	....	....	....	1	....	1	....
Murchison	....	....	....	....	....	....	....	....	....	2	....	2	....	4
East Murchison....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Yalgoo	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Northampton	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Mount Margaret	....	....	....	....	....	....	....	....	....	....	....	....	....	....
North Coolgardie	....	....	....	....	....	1	....	....	....	....	....	2	....	3
Broad Arrow	....	....	....	1	....	1	....	....	....	5	....	4	....	11
North-East Coolgardie....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
East Coolgardie	....	2	....	10	....	....	....	....	3	68	....	23	3	103
Coolgardie	....	....	....	7	1	4	....	....	....	23	1	10	2	44
Yilgarn	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Dundas	....	....	....	1	....	....	....	....	....	6	1	2	1	9
Phillips River	....	1	....	....	....	....	....	....	....	10	....	....	....	11
Greenbushes	....	....	....	....	....	....	....	....	....	....	....	2	....	2
South West	....	....	....	....	....	....	....	....	....	....	....	48	....	48
Collie	....	....	....	....	....	....	....	....	....	23	....	5	....	28
Nabberu	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Warburton	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Eucla	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Total for 1970	....	3	....	19	1	6	....	....	3	137	8	147	12	312
Total for 1969	....	4	2	16	....	11	....	1	....	193	11	180	13	405

PROSECUTIONS

There were no prosecutions during the year.

SUNDAY LABOUR PERMITS

Twenty-nine (29) permits to employ labour underground in mines on Sunday were issued.

One permit was issued to Gold Mines of Kalgoorlie (Aust.) Ltd. so that three men could complete a survey of rock mechanic stations on the Mount Charlotte mine in order to obtain accurate measurements of ground movement.

The Great Boulder Gold Mines Ltd, were issued with three (3) permits for operations off the Mitchell shaft at the Scotia nickel mine in the Broad Arrow Goldfield. Two of the permits were to ensure safe working conditions in the completion of a rise from the 490 ft. to the 230 ft. levels. The other permit was to remove the penthouse and the cryderman mucker from the shaft. Another application for a permit by this Company was refused as it was not in accord with Section 45 of the Mines Regulation Act.

Twenty-two (22) permits were issued to Western Mining Corporation Ltd. (Kambalda Nickel Operations). Two of these were on the Silver Lake shaft. One was to lower a raise borer to No. 5 level and prepare a concrete base, and the other was to dismantle and hoist the raise borer up the ventilation shaft to the surface. Twenty (20) were on the Durkin shaft and provided for work such as:—

- maintenance of ore pass controls;
- stripping a loading pocket;
- stripping ore passes and replacing grizzly bars;
- installing steel and concrete floor in loading pockets;
- installing chain control at ore pass;
- erect a spillage bin and convert an internal shaft from a hoist and kibble to a winder and cage operation;
- instal a penthouse in the shaft, complete bratticing above the penthouse and instal counterweight stops and door to isolate the sink compartment.

Two (2) permits were issued to Metals Exploration N.L. to:—

- stand protective timber and complete grizzly installation;
- remove ventilation ducting from the manway compartment at the Nepean mine.

One permit was issued to Central Norseman Gold Corporation to complete an ore pass connection to the No. 22 level of the Regent shaft.

AUTHORISED MINE SURVEYORS

Two (2) Certificates for Authorised Mine Surveyors were issued during the year.

CERTIFICATES OF EXEMPTION

(Section 46 of Mines Regulation Act)

None were issued.

PERMITS TO FIRE OUTSIDE PRESCRIBED TIMES

A permit was issued to Gold Mines of Kalgoorlie (Aust.) Ltd. to detonate a long hole blast beneath the Australia East Open Cut at 6.00 a.m. It was sought for this time as a minimum, if any, of mining personnel would be underground in adjacent mines at this early hour.

Anaconda Australia Inc. were granted permission to fire at times other than those prescribed during the sinking of the Redross and Wannaway shafts.

PERMITS TO RISE

Permits for the construction of 32 rises totalling 4,309 feet were issued. Seventeen of the rises were made using the rising gig (or stage) method and 15 with the conventional method. Six of the rises were principally for ventilation purposes and the others for development, prospecting and evaluation.

VENTILATION

The ventilation of mine workings continued to receive constant attention.

Inspections of the underground workings of all metalliferous mines throughout the State were made and dust counts and temperatures recorded. Many primary and secondary airflows were measured and assistance given to operating mining companies to conduct airflow surveys and overcome dust collection problems.

Most crushing and screening installations associated with metalliferous treatment plants, hard rock quarries, the iron ore operations and the dry separation plants in the heavy mineral sands industry were inspected.

The total number of dust samples taken in the year was 1,247. This figure includes both surface and underground. The average count was 284 particles per cubic centimetre. In 1969 the average dust count was 254 p.p.c.c. for a total of 1,073 samples. The higher average dust count is attributed to the greater number of samples and the higher count obtained in surface plant, together with the need for the newer metalliferous mines to stabilise their methods of dust control.

Results of dust counts made during the year are tabulated below, with the corresponding figures for 1969 shown in brackets.

Dust Samples from	Samples Giving Over 1,000 p.p.c.c.	Total Number of Samples	Average Count
Surface Plants	42 (29)	279 (215)	430 (380)
Assay Offices	1 (1)	18 (44)	290 (200)
Stoping	6 (6)	552 (443)	239 (260)
Levels	11 (10)	221 (177)	263 (250)
Development	— (1)	177 (194)	223 (220)
	60 (47)	1,247 (1,073)	284 (254)

Pressurised control rooms are provided for operators in most crushing plants, particularly at iron ore mines and for most of the working shift they are in relatively dust free atmospheres. This also applies to some of the rigs used for drilling large quarry blast holes.

There was no fatal fuming accident in the year, but 10 fuming accidents were reported and investigated.

Constant attention and strict control was maintained on the testing of mine atmosphere wherever diesel engines were in use underground. Regular sampling and analysing of the undiluted exhaust gas from the diesel engines was also undertaken.

Nine new diesel engine equipped units were added to the units in use at the Kambalda Nickel Operations of Western Mining Corporation Ltd. and two units were introduced to the Nepean mine of Metals Exploration N.L. Before permits are issued to allow any units to be put into regular use, the diesel exhaust gases are sampled and analysed.

The number of diesel engine equipped units in use at the end of 1970 were:—

Mount Charlotte mine of Gold Mines of Kalgoorlie (Aust.) Ltd.	10
Kambalda Nickel Operations of Western Mining Corporation Ltd..	21
Nepean mine of Metals Exploration N.L.	2

There were no occurrences of methane gas this year but an odorous gas was encountered when a stripping cut intersected a diamond drill hole in the Durkin Shoot at Kambalda. The quantity was small and analysis showed that the main gas was carbon dioxide.

The testing of toxic fumes and vapours associated with various assay laboratories and reduction plants continued.

A complete programme of urinary sampling of men engaged in gold assay offices where litharge is used was organised and carried out by the Ventilation Branch for the Department of Public Health.

ALUMINIUM THERAPY

Provision for the prophylactic treatment with aluminium powder was available at most gold mines.

GROUND VIBRATIONS

The Spregnether Seismograph was used on eleven separate assignments to determine ground vibration. The work covered vibrations from W.A.G.R. ore carrying trains ; minor blasting on the Mitchell Freeway Project ; large scale underground blasting at the Mount Charlotte mine of Gold Mines of Kalgoorlie (Aust.) Ltd. ; four quarry blasts ; small scale blasting in limestone to excavate a tank site ; and mine pit blasts on an iron ore operation. Most of these assignments were to advise Engineers on safe blasting practice and techniques and to deal with complaints.

GENERAL

The routine inspection of mining operations throughout the State was curtailed by the shortage of experienced Mining Engineers on the staff.

The active co-operation of the four Workmen's Inspectors of Mines was appreciated.

PETROLEUM EXPLORATION & PRODUCTION

A. J. Sharp—Petroleum Engineer

BARROW ISLAND OILFIELD DEVELOPMENT

(Operators—West Australian Petroleum Pty. Ltd.)

Drilling

During the year a total of 54 wells were drilled on Barrow Island. In an attempt to locate additional gas reserves two wells, Y-24 and S-67 were drilled to the Jurassic horizon. In both cases the wells failed to locate commercial quantities of gas.

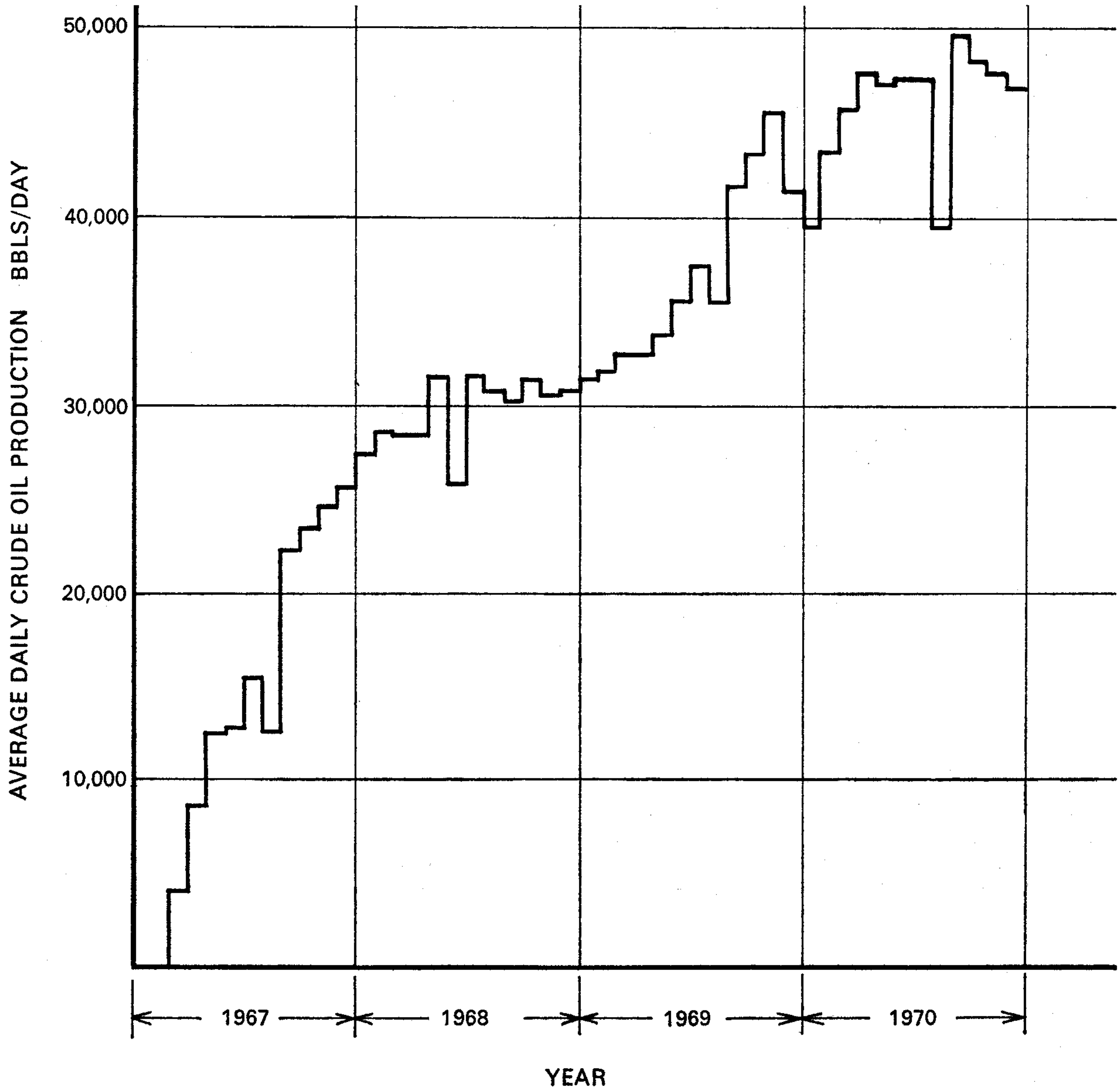
The following table gives a comparison of the number and status of wells as at December, 1969 and at December, 1970.

	No. of Wells, December, 1969	No. of Wells, December, 1970
Producing oil wells	309	329
Part-time producing oil wells	12	2
Non-producing wells	7	9
Water injection wells	107	153
Water source wells	7	9
Other	6	....
Total number of wells	448	502

Production

The average daily production for the year increased from 37,000 bbls/day in 1969 to nearly 46,000 bbls/day in 1970. The Windalia reservoir water injection scheme which commenced in April, 1968 was completed during the year and water is now being injected into the Windalia reservoir at between 110,000 and 120,000 bbls/day. A graph showing the average daily crude oil production rate since the start of production at Barrow Island is shown below.

AVERAGE DAILY CRUDE OIL PRODUCTION RATE OVER EACH MONTH SINCE START OF PRODUCTION



DONGARA/YARDARINO/MONDARRA/GINGIN GASFIELD DEVELOPMENT:

(Operators—West Australian Petroleum Pty. Ltd.)

During the year it was established that the Dongara/Yardarino/Mondarra/Gingin fields are capable of producing gas at a rate of approximately 80 million cub. ft/day for a period of 15 years.

The initial round of drilling was completed in the Dongara gas field in February, 1970, where a total of 19 wells were drilled to evaluate the structure. Preparations are being made in the four fields to develop production facilities ready for the commencement of transmission of gas in late 1971.

LAND EXPLORATION DRILLING

Two exploration wells were drilled during 1970. No commercial petroleum was discovered. Land exploration and appraisal drilling operations carried out in 1970 are summarised in the attached table.

OFFSHORE EXPLORATION DRILLING

Offshore drilling activity showed a slight decrease from 30 rig months in 1969 to 27 rig months in 1970. This was due to the Glomar Tasman being used to drill a well in the Northern Territory adjacent area, after which the drilling vessel went to Singapore for a refit.

No commercial petroleum was discovered during the year. Offshore exploration drilling operations are summarised in the attached table.

DONGARA/PINJARRA NATURAL GAS PIPELINE

(Operators—West Australian Natural Gas Pty. Ltd)

West Australian Natural Gas Pty. Ltd. conducted negotiations with the State Electricity Commission, Alcoa and other potential large scale users for the sale of the Dongara/Yardarino/Mondarra/Gingin gas. These negotiations indicated that a natural gas pipeline from Dongara to Pinjarra would be a viable commercial proposition and on 11th September, 1970 the participants in West Australian Natural Gas Pty. Ltd. applied for a pipeline licence. After agreement had been reached on the sale of gas to the State Electricity Commission, a pipeline licence was issued on 2nd December, 1970 to construct and operate a natural gas pipeline from Dongara to Pinjarra with laterals to Midland Brick, Perth Gas, Swan Cement, Fremantle Gas, S.E.C. Kwinana and Western Aluminium. The main pipeline will be 14 in. in diameter with an initial capacity of 80 million cub. ft/day. Provision is to be made for the installation of compressors at a later date.

LEGISLATION

Regulations under the Petroleum Pipelines Act, 1969 were gazetted on 30th June, 1970. The Regulations set down the standards for the construction and operation of petroleum pipelines.

The Petroleum Pipelines Act was amended to allow the Minister to give consent to the construction and operation of a pipeline over property where an easement has been acquired but the licensee is unable to register the easement due to circumstances beyond his control.

In February, 1970 a Direction pursuant to Section 101 of the Petroleum (Submerged Lands) Act was given to all offshore permittees setting down requirements regarding petroleum exploration operations and operations for the recovery of petroleum.

A. J. SHARP

CHART APPEARS
ON PAGE 34

(3)—90726

OFFSHORE PETROLEUM EXPLORATION DRILLING IN WESTERN AUSTRALIA, 1970

Operator	Contractor	Rig	January	February	March	April	May	June	July	August	September	October	November	December
B.O.C.	Global Marine	Glomar Tasman	Northern Territory Drilling and Refit					Lacepede No. 1 7,500′ Pl. and ab.		Leveque No. 1 2,951′ Pl. & ab.	Enderby No. 1 7,051′ Pl. & ab.	Legendre No. 2 11,871′ Pl. & ab.		
W.A.P.E.T.	Offshore Drilling	Jubilee	Flag No. 1 12,475′ Pl. & ab.	Ripple No. 1 7,476′ Pl. & ab.	Pepper No. 1 9,000′ Pl. & ab.		Trial Rocks No. 1 12,123′ Pl. & ab.			Tow and waiting on weather			Warnbro No. 1 12,009′ Pl. & ab.	
W.A.P.E.T.	Odeco	Ocean Digger											Roe No. 1 7,001′ Pl. & ab.	
A.R.C.O.	Zapata	Navigator						Gull No. 1 11,225′ Pl. & ab.						

LAND PETROLEUM EXPLORATION/APPRAISAL DRILLING IN WESTERN AUSTRALIA, 1970

Operator	Contractor	Rig	January	February	March	April	May	June	July	August	September	October	November	December
W.A.P.E.T.	O.D.E.	Ideco H.40	Dong. No. 18 6,300′ Gas well	Dong. No. 19 7,150′ Oil well										
Lennard	Int. Air Drill	Ideco Rambler							Napier No. 4 3,166′ Pl. and ab.		Napier No. 5 5,437′ Pl. and ab.			

COAL MINING

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

The total output of coal won from the Collie Coalfield during the year amounted to 1,197,733 tons, an increase of 107,203 tons over the previous year's then record output of 1,090,530 tons. This represents an increase of 9.83 per cent on the 1969 output.

The three collieries contributing to the output were Western No. 2 Mine, Muja Open Cut and Western No. 5 Open Cut Mine, which commenced production during the year.

The total value of the coal produced during 1970 was $5,827,291 an increase of $1,023,202 or 21% compared with the 1969 value of $4,804,089.

The open cut component of the total output increased by slightly over four per cent to practically 61 per cent.

Western Collieries Ltd. Western No. 2 Mine

This colliery again increased production against the previous record output and attained an output of 467,298 tons, an increase of 4,625 tons over the 1969 output of 462,673 tons.

Bord and pillar operations within panels continued in widespread areas of the mine, notably in No. 4 West "D" Panel and No. 5 West "A" Panel where first working of the coal was practically completed by the end of the year.

Development in No. 1 West "A" and "B" Panels was affected by "vug" conditions in some areas and soft water bearing floors were a feature of the No. 2 West District Headings.

In the main, the emphasis at the mine was on development drivages in district multiple headings and in rise and, to some extent, dip headings from these to facilitate subsequent development work. These drivages continued in widely separated areas of the mine (the faces of the No. 6 East Headings are, when measured on a direct line, over 2.7 miles from the faces of the No. 1 West Headings).

The No. 5 East District Headings were driven to termination near the fault adjacent to the downthrown abandoned No. 2 "B" East Dip Panel Workings. The lower heading was driven into the fault for a short distance.

The aggregate "make" of water from various parts of the mine is slightly in excess of 3,000,000 gallons per day.

The general ventilation of the mine was good throughout the two separate ventilation circuits.

Western No. 5 Open Cut Mine

This mine commenced production on the 3rd March, 1970 and achieved an output of 104,244 tons of which 90,360 tons was won from the Cardiff Seam, and 13,884 tons was won from the Neath Seam.

Following initial site clearance at the end of 1969 overburden removal to establish the Cardiff Seam excavation in the form of a "box-cut" close to the blind outcrop was continued with mobile scraper units and it was from this excavation that the first coal was produced.

The 13 ft. thick Cardiff Seam was won over the whole of the excavation which is approximately 21 chains in length and an average of 2¾ chains wide.

Excavation of overburden above the Neath Seam commenced at the beginning of July and the first coal was won from the North-end of the area in November at the time when winning of the exposed coal on the Cardiff Seam was nearing completion. By the end of the year, the Neath Seam excavation was about 16½ chains long and varied from 2½ to 4 chains wide with the 8–9 ft. thick seam exposed over approximately half of the area.

The overburden removal was mainly effected by mobile scrapers while the coal was loaded out by Cat. 950 and Cat. 988 Front-end-loaders.

Erection of the new change house was completed except for connection of lavatory facilities to the septic system and this project exemplified high standards of workmanship.

Preparations were in hand for bitumenising the surface of the approximately 4.8 miles long coal haulage road to Muja Generating Station.

Lighting along the high and back walls of the excavations and on the overburden dumps provided satisfactory illumination of the main working areas during the hours of darkness on the afternoon shift.

The Griffin Coal Mining Company, Limited, Muja Open Cut

This colliery was again the largest producer on the field and the output of 626,192 tons exceeded the previous year's output of 618,217 tons an increase of 7,975 tons.

The total quantity of overburden removed to expose coal amounted to 2,934,890 cubic yards or 248,250 cubic yards less than the figure of 3,183,140 cubic yards of overburden removed to expose coal in 1969. The average ratio of overburden removed to coal mined was 4.7 to 1 compared with 5.2 to 1 the previous year. An additional 27,400 cubic yards of overburden was removed for various pit preparation and ancillary purposes.

Overburden removal to expose the Hebe Seam completely over Block No. 2 and over Block No. 3 at the South West Area of the Open Cut was completed down to the top split of the seam. The seam is split into 4 ft., 9 ft. and 18 ft. thicknesses of coal over much of the area, necessitating removal of shale bands interposed between the coal. Another feature of this area is the benched working necessary due to the steep gradient of the seams and strata as they approach blind outcrop.

The 200W Bucyrus Erie Walking Dragline was being utilised on initial stripping along the blind outcrop of the Hebe Seam on Block No. 5 in advance of Block No. 4.

In general, excavation berms and all overburden dumps were stable and safe. Road conditions in the workings and on the surface and lighting in and around the excavations were maintained to high standards.

There was a quantity of approximately 466,000 tons of exposed coal at the Open Cut at the end of the year compared with 415,000 tons at the end of the previous year.

General

The accident record in the industry continued to be good. Of a total of 222 reported accidents, 194 were minor and 28 were classified as serious mainly for statistical purposes where an employee was absent from work for 15 days or more.

Sound or noise levels associated with the use of equipment in the underground and open cut collieries were measured by officers of the Commonwealth Acoustic Laboratories in conjunction with the State Public Health Department and arrangements were being made for hearing tests to be carried out on personnel from the mines.

A drilling programme on the coalfield was undertaken by the Mines Department following recommendations made in the report by New South Wales Mining Engineers.

It is confidently expected that several new markets involving industries which will use Collie Coal will be developed in the near future and that apart from the declining market for locomotive coal there will also be an increased demand by some traditional consumers.

There was a balance in the number of new entrants to the industry and in reductions due to retirements deaths and resignations. The nett effect was that the number of persons employed in the industry at the end of 1970 was 626, the same as at the end of the previous year.

DRILLING OPERATIONS

D. A. MacPherson—Drilling Engineer

During 1970 the Drilling Section was responsible for the drilling of 25,302 feet in 143 bores, the work being done completely by Departmental employees and equipment.

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

Comments on Staff and Plant matters are also given.

RED GUM SPRINGS

This job was done to complete the 1969 investigation into the possibility of obtaining a satisfactory water supply for the Red Gum Springs picnic area in the Stirling Ranges National Park. The work was carried out for and financed by the National Parks Board of Western Australia.

The work entailed screening a previously drilled bore, developing the bore and testing it. The screen was installed using an Auger rig and the development and testing were carried out by use of a small portable air compressor.

A feature of the job was the use of a gravel walled screen necessitated by the extremely small particle size of the unconsolidated water bearing formation. The job was completed and all plant and materials moved out of the area.

MANDURAH

This work was done as part of the State wide ground water investigations conducted by the Geological Survey of Western Australia and was financed by the Department of Mines.

The work involved development by air of two existing water level observation bores, constructed during the 1969 investigation in this area, followed by the taking of water samples.

HARVEY DAM

This job was done to investigate the condition of the internal concrete and the foundations of Harvey Dam. The work was carried out for and financed by the Department of Public Works. The work consisted of vertical and inclined Diamond core drilling in the dam structure and in the underlying strata.

PORT HEDLAND—STAGES 2, 3 & 4

This work was a continuation of the 1969 investigation into the possibility of obtaining water for Port Hedland from groundwater sources additional to those already being utilised. The work was carried out for and financed by the Public Works Department.

Stage 2 consisted of the construction of bores by cable tool method and their completion to observation bore status. Stages 3 and 4 consisted of the construction of bores by cable tool method and their subsequent testing to determine quality and quantity of available water. The bores in all stages were located partly on the basis of seismic survey work carried out in the area by the Geological Survey of Western Australia.

The work was made difficult and expensive because of the absence of access roads in the area, the presence of numerous creek and river channels and the prevalence of bull dust.

The work programme was completed and all plant and material moved out of the area.

GNANGARA SANDBEDS—STAGES 2 & 3

This job was a continuation of the 1969 investigation of Perth's ground water resources conducted on behalf of the Metropolitan Water Supply Sewerage and Drainage Board and financed by that Department.

Stage 2 of this job, which entailed drilling one pumping bore and four observation bores at each of fifteen sites and prolonged testing of the pumping bores, was in progress at the commencement of 1970 and was completed during the year.

Stage 3 of this job consists of the construction of one fully penetrating screened bore and one fully penetrating gravel packed bore at each of two selected sites in the job area and their subsequent testing to provide a basis for selection of the most suitable bore construction method in the area. This stage was in progress at the end of 1970.

Difficulties have been encountered throughout this job due to the very sandy terrain, high ground water levels and unconsolidated sand strata.

GNANGARA

This small job was carried out to permit installation of a pump in an existing bore and to restore the supply from the bore. The job was undertaken for the Metropolitan Water Supply Sewerage and Drainage Board and financed by that Department.

The work involved fishing lumps of wood and concrete from the bore and breaking up a bridge of rubble on the top of the screened section by diamond drilling and subsequent air development to clean the bore and restore the supply.

COLLIE

This job was done to provide additional information on the Coal resources in certain sections of the Collie Coal fields. The work formed part of the State Mineral Resources investigation programme conducted by the Geological Survey of Western Australia and was financed by the Department of Mines.

The work involved drilling a number of bores by Rotary methods with continuous diamond coring being carried out through some sections of each bore hole.

Difficulty was encountered at three sites due to swampy terrain. On one occasion the drilling rig became so badly bogged that it could not be moved by two large bulldozers.

WITTENOOM

This job was part of the Statewide Stratographic investigation programme conducted by the Geological Survey of Western Australia and was financed by the Department of Mines.

The job was located on the Weeli Wolli Formation south of Wittenoom and involved continuous coring of one diamond drilled bore hole at an angle of 60° to horizontal.

PORT HEDLAND

This job was carried out to investigate foundation conditions at Port Hedland Harbour required in preparation of designs for a barge loading facility. The work was carried out on behalf of and financed by the State Shipping Service.

The work involved obtaining samples by thin wall sample tube and carrying out penetration tests in soft strata and diamond core drilling underlying harder strata. Some of the work was carried out with the plant on land and the remainder with the plant mounted on a barge floating in water.

WYNDHAM

This job was done to provide information on the strata underlying Wyndham harbour required for the design of a barge loading facility. The work was carried out on behalf of and financed by the State Shipping Service.

The job involved obtaining strata samples by thin wall sample tube and carrying out penetration tests in the upper soft strata and diamond core drilling in the underlying hard strata. The work was carried out with the plant mounted on a barge floating in water.

Considerable difficulties were experienced in the work due to the large tide range and the strong currents experienced at some sites.

The pre-planned programme for this job was completed prior to the end of 1970 but due to the unsatisfactory nature of the strata at the initial sites, additional work had to be carried out and this was still in progress at the end of 1970.

MUCHEA

This job forms part of the Statewide water investigation programme conducted by the Geological Survey of Western Australia and was financed by the Department of Mines.

The work was a continuation of the 1969 investigation and involves the drilling of one pumping bore and one observation bore at selected bore sites by cable tool methods and testing the pumping bore at each site.

Work was not continuous on this job during 1970 and the job will be continued during 1971.

MIRRABOOKA

This job formed part of an investigation of Perth's ground water resources conducted by the Metropolitan Water Supply, Sewerage and Drainage Board and was financed by that Department. The work entailed drilling one bore by cable tool method and testing the bore to determine water quality and quantity

GWELUP—STAGE 1

This job forms part of an investigation of Perth's ground water resources conducted by the Metropolitan Water Supply, Sewerage and Drainage Board and was financed by that Department.

Stage 1 of this job entails drilling a bore at each of six sites to determine strata and water quality and the subsequent development of these bores to serve as water level observation points.

The job was commenced late in 1970 and five bores (one abandoned) were drilled by Rotary methods.

The work will be continued in 1971.

STAFF

At the beginning of 1970, Mr. L. Honey commenced duty with the Drilling Section as Drilling Supervisor.

At the beginning of 1970, Mr. R. Cleasby commenced duty with the Drilling Section as Assistant Drilling Supervisor.

On 5th January, 1970, Mr. T. Van Beek commenced duty with the Drilling Section as Clerk, Carlisle.

On 16th February, 1970, Mr. C. Davidson commenced duty with the Drilling Section as Assistant Drilling Supervisor.

On 18th May, 1970, Mr. M. Bennett commenced duty with the Drilling Section as Engineer Drilling.

On 17th July, 1970, Mr. T. Van Beek resigned from the Department and in his place on 20th October, 1970, Mr. W. Beardmore commenced duty with the drilling section as Clerk, Carlisle.

PLANT

During 1970 a truck mounted Speedstar 71 rotary/cable tool drilling plant was received and placed in service.

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

The items of major plant listed below were written off during the year because of age and low utilisation rates. The first item was sold by tender during 1970. The second item will be offered for sale by tender during 1971. The items concerned are :—

Ruston Bucyrus 22RW cable tool drilling plant.

Mindrill A2000 Diamond drilling plant.

At the end of 1970, action was in progress for the purchase of the following items of plant :

Heavy duty four wheel drive tractor.

Trailer mounted power swivel unit.

Truck mounted medium capacity Rotary Drilling plant.

At the end of 1970, action was also in progress in conjunction with the Geological Survey of Western Australia for the purchase of a Gamma Ray well logging unit to replace the existing well logging unit used by the Geological Survey. Delivery of the new items is expected during 1971.

TABLE SHOWING WORK CARRIED OUT DURING YEAR ENDED 31/12/70

Place	Purpose	Type of Work	Construction	No. of Bores	Footage
Redgum Springs	Groundwater Investigation/ Production	Bore screening and testing	Dept. of Mines	1	....
Mandurah	Groundwater Investigation....	Air redevelopment and water sampling	Dept. of Mines	2	....
Harvey Dam	Dam Investigation	Diamond drilling	Dept. of Mines	5	233
Port Hedland (Stage 2)	Groundwater Investigation	Cable tool drilling	Dept. of Mines	10	2,114
Port Hedland (Stage 3)	Groundwater Investigation	Cable tool drilling and bore testing	Dept. of Mines	12	1,994
Port Hedland (Stage 4)	Groundwater Investigation	Cable tool drilling and bore testing	Dept. of Mines	7	1,274
Gnangara Sandbeds (Stage 2) (Perth)	Groundwater Investigation/ Production	Rotary drilling and bore testing	Dept. of Mines	66	7,815
Gnangara Sandbeds (Stage 3) (Perth)	Groundwater Investigation/ Production	Cable tool drilling and bore testing	Dept. of Mines	2	324
Gnangara	Restoration supply	Removal of foreign objects....	Dept. of Mines	1	....
Collie	Coal Investigation	Rotary core drilling	Dept. of Mines	10	7,830
Wittenoom	Stratagraphic Investigation....	Diamond drilling	Dept. of Mines	1	893
Port Hedland	Foundation Investigation	Penetration testing and diamond drilling	Dept. of Mines	6	235
Wyndham	Foundation Investigation	Penetration testing and diamond drilling	Dept. of Mines	9	467
Muchea	Groundwater Investigation	Cable tool drilling and bore testing	Dept. of Mines	5	1,361
Mirrabooka (Perth)....	Groundwater Investigation/ Production	Cable tool drilling and bore testing	Dept. of Mines	1	140
Gwelup (Stage 1) (Perth)	Groundwater Investigation	Rotary drilling	Dept. of Mines	5	622
			Totals	143	25,302

BOARD OF EXAMINERS

FOR MINE MANAGERS' AND UNDERGROUND SUPERVISORS' CERTIFICATES

W. J. Cahill—Secretary

Herewith I submit the Annual Report on the Activities of the Board of Examiners for the year 1970.

Mining Law Examinations

An examination in Mining Law for the Mine Manager's Certificate of Competency was held on April 20, 1970.

Details were as follows :—

Entries	18
Admitted	18
Pass	12

The names of the successful candidates were :—

First Class

J. W. Farthing
R. J. Griffin
G. F. Jenkins
R. W. Laakso
N. A. MacArthur
D. D. Mainwaring
M. D. O'Brien
I. Sheppard
T. Tennant
R. M. Hennessy

Second Class

J. A. Kitenbergs
J. Schrott

In view of the events in the Mineral Industry the Board subsequently resolved to hold an additional Examination on November 2, 1970.

Details were as follows :—

Entries	7
Admitted	7
Pass	6

The names of the successful candidates were :—

First Class

P. Swainston
P. R. Hill
P. A. R. Odd
J. Parker
M. Quick
C. J. B. Lewis

Underground Supervisor's Examination

The written examination was held on 1st September, 1970, and applications were received from the following centres :—

Kalgoorlie	31
Mt. Magnet	1
Ravensthorpe	2
	34

The results were as follows :—

Passed	16
Deferred	1
Fail	15
Did not sit	2
	34

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

D. K. Alman—Kalgoorlie
L. Bonandrini—Kalgoorlie
M. W. Cahill—Kalgoorlie
F. R. Jasper—Kalgoorlie
B. F. McGillivray—Kalgoorlie
A. Mathieson—Kalgoorlie
K. J. Piirto—Kalgoorlie
J. N. Pryce—Kalgoorlie
S. J. Shade—Kalgoorlie
M. Sproge—Kalgoorlie
R. A. Strachan—Kalgoorlie
W. Tagliaferri—Kalgoorlie

H. N. Thomas—Kalgoorlie
J. Vanadzins—Kalgoorlie
R. Western—Kalgoorlie
L. G. Woo—Kalgoorlie

Mine Managers' Certificates

The following were successful applicants for the Mine Managers' Certificates :—

First Class	*Second Class*
R. W. Laakso	M. R. Lonsdale
R. M. Hennessy	B. J. McCahon
P. C. Lockyer	J. A. Kitenbergs
I. Macky	
R. A. Tastula	
P. Swainston	

General

Seven meetings were held during the year on March 3, March 23, May 12, July 21, September 24, November 19 and December 14. Of these, those held on March 3, November 19 and December 14 were special meetings and were held in Perth.

At the beginning of the year Dr. A. V. Pegler was appointed as Principal, School of Mines, Kalgoorlie and replaced Mr. J. D. Collister as a member of the Board of Examiners.

During the year the Board of Examiners visited Kalgoorlie and Ravensthorpe to examine candidates orally for the Underground Supervisors' Examination.

DIVISION III

Report of the Superintendent of State Batteries—1970

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, 1970.

Crushing Gold Ores

One 20 head, four 10 head, and eight 5 head mills crushed 22,810½ tons of ore made up of 181 separate parcels, an average of 126.02 tons per parcel. The bullion produced amounted to 8,656 ozs. which is estimated to contain 7,336 ozs. of fine gold equal to 6 dwts. 10 grs. of gold per ton of ore.

The average value of the ore after amalgamation, but before cyanidation, was 2 dwts. 3 grs. Thus the average head value of the ore was 8 dwts. 13 grs. which is 1 dwt. 6 grs. more than the previous year's average.

A total of 1,648½ tons of tantalite ore was also crushed at the plants that crush mainly gold ores. The average cost of crushing the 24,459 tons was $15.34 per ton, compared with 1969 when 26,322¼ tons were crushed at a cost of $12.26 per ton.

Cyaniding

Five plants treated 7,953 tons of tailings from amalgamation for a production of 1,161 fine ozs. of gold. The average content was 3 dwts. 19 grs. before cyanidation, while the residue after treatment averaged 22 grs. The theoretical extraction was, therefore, 76·26% The actual extraction was 77·10%.

The cost of cyaniding was $10·13 per ton, which was more than the previous year, when 19,608 tons were treated at a cost of $6·27 per ton.

Silver recovered by the cyanidation of gold tailings amounted to 130·68 fine ozs. valued at $162·06.

TREATMENT OF ORES OTHER THAN GOLD

Lead Ores

During the year the Northampton State Battery crushed 3,744¾ tons of lead ore with an estimated average content of 7·70% lead. There were 18 separate parcels, giving an average of 208·04 tons of ore per parcel.

A total of 260·75 tons of concentrates was produced. The concentrates averaged 57·97% lead giving an estimated content of 151·156 tons of lead in concentrates.

Three thousand four hundred and eighty-four tons of tailings were discarded. These had an average content of 3·94% lead, giving a total of 137·31 tons of lead discarded in tailings.

The recovery of lead in the concentrates was 52·40% of the lead in the ore delivered to the Plant.

The cost of operating the Northampton State Battery, including administration, was $44,512·23, being $11·89 per ton of ore crushed. Revenue received was $7,547·00 being $2·02 per ton. The corresponding figures for 1969 when 7,203 tons of ore were crushed, were operating cost $58,005·64 being $8.05 per ton, and revenue $14,433·00 being $2·00 per ton.

Most of the lead ore crushed was from old dumps or from surface deposits. This ore was low grade and contained large amounts of oxidized minerals, causing the low recovery and low grade concentrates.

Tin ore

No tin ore was crushed for the year but the Marble Bar magnetic separator plant treated 60·65 tons of low grade alluvial concentrates for a recovery of 109,595 lb. of high grade tin concentrates valued at $102,458.

Tantalite-Columbite Ores

The Boogardie State Battery crushed 1,547½ tons of tantalite ore from which 9,018 lbs. of concentrates valued at $28,935 were recovered.

The Marble Bar State Battery crushed 101 tons of tantalite ore. This was crushed for sampling purposes only, no attempt being made to recover any concentrates.

Six hundred and seventy-two lbs. of tantalite concentrates, valued at $1,150 were recovered from the tin concentrates treated at the Marble Bar magnetic separator plant.

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

	1970 $	Grand Total $
Par Production—		
Crushing	62,326	18,209,678
Cyanidation	9,861	4,491,433
Gold Premium—		
Crushing	166,936	12,578,507
Cyanidation	26,412	3,483,660
Open Market Premium—		
Crushing	7,843	130,425
Cyanidation	1,241	43,183
Total Gold Production	$274,619	$38,936,886

OTHER ORES REALISED

	1970	Grand Total
	$	$
Silver	162	3,958
Tin—		
Ores and Concentrates	102,458	458,680
Residues	....	1,144
Tungsten Concentrates....	....	38,896
Agricultural Copper Ore	....	11,932
Lead Concentrates	36,994	1,368,556
Tantalite-Columbite Concentrates	30,085	61,997
Total Other Ores	$169,699	$1,945,163
Grand Total	$444,318	$40,882,049

FINANCIAL

	Tons	Expenditure	Receipts	Loss
		$	$	$
Crushing (Gold Mills)	24,459	375,431	26,477	348,954
Magnetic Separator Plant (Marble Bar)	60·65	2,930	2,006	924
Crushing Lead Mill (Northampton)	3,744·75	44,512	7,547	36,965
Cyaniding	7,953	80,578	18,355	62,223
	....	$503,451	$54,385	$449,066

The loss of $449,066 is an increase of $40,811 on the previous year. It does not include depreciation and interest on capital.

Capital expenditure of $29,284·59 from Consolidated Revenue Fund and $5,255·99 from General Loan Fund was incurred as follows:—

		$
Boogardie	House for Battery Manager	1,700.00
Leonora	Installation of Jaw Crusher, Conveyor and Bins	201.96
	Erection of Cyanide Plant	19,096.81
Marble Bar	Changeover to A.C. Power	1,171.55
Marvel Loch	Changeover to A.C. Power and installation of Jaw Crusher, Conveyor and Bins	4,959.55
Meekatharra	Changeover to A.C. Power	843.29
Truck	Toyota 30 cwt.	2,357.00
Truck	Bedford 5 ton	4,210.42
		$34,540.58

Cartage Subsidies

	Tons	Cost
Ore carted to State Plants	12,450½	$22,815

Comparative Figures for the last three years are :

Year	State Plants				Private Plants		
	Tons Crushed	Tons Subsidised	% Subsidised	Cost	Tons Subsidised	Cost	Total Cost
				$			$
1968....	25,210¼	9,918¾	39·34	12,225	Nil	Nil	12,225
1969....	33,568¾	14,912¼	44·42	20,629	Nil	Nil	20,629
1970....	28,264½	12,450½	44·05	22,815	Nil	Nil	22,815

Administrative

Expenditure amounted to $74,546·15 equivalent to $2·30 per ton of ore crushed and cyanided, compared with an expenditure of $83,878·59, $1·58 per ton, for 1969.

	1969	1970
Salaries	53,095.43	46,193.40
Pay Roll Tax	8,497.65	8,543.97
Workers' Compensation	14,667.31	12,371.70
Travelling and Inspection	3,901.10	4,092.63
Sundries	3,716.91	3,344.45
	$83,878.40	$74,546.15

Staff

Engineer, W. Bracegirdle, retired during the year, Senior Draughtsman, G. Rasmussen, took over the Engineer's duties and P. Flematti was promoted to Mechanical Supervisor.

General

The gold ore crushed was 3,500 tons less than in 1969. This reduced tonnage, together with increases in costs, caused a considerable increase in the cost per ton crushed.

As anticipated, a very low amount of tailings were cyanided, caused by the low quantity purchased, and the low accumulation of untreated tailings where there are workable leaching plants.

With the present lack of interest in gold production, the crushing rate of gold ore is not likely to increase. The recent increase in wages and salaries will cause a continued rise in costs.

The Northampton leach plant operated mainly on low grade ore from dumps or near the surface. The biggest producer in the area, the Mary Springs Mine, did not operate during the year.

Concentrating tables were installed at the Boogardie State Battery, to treat tantalite ore from Dalgaranga, about 50 miles west of Mt. Magnet. Early crushings were most encouraging, giving good recoveries of high grade tantalite concentrates. With continued production the ore grade dropped and unless the grade can be raised, ore production is likely to cease in early 1971.

The Marble Bar magnetic plant operated most efficiently, producing high grade tin concentrates and some marketable tantalite concentrates. There was an increase of low grade tin concentrates treated, from 43·5 tons in 1969 to 60·65 tons in 1971.

K. M. PATERSON,
Superintendent State Batteries.

Schedule No. 1

NUMBER OF PARCELS TREATED, TONS CRUSHED, GOLD YIELD BY AMALGAMATION AND HEAD VALUE FOR THE YEAR ENDED 31st DECEMBER, 1970

Number of Parcels Treated	Battery	Tons Crushed	Yield by Amalgamation				Amalgamation Tailings Content		Contents of Ore-Fine Gold			
			Bullion		Fine Gold				Total		Per Ton	
			Ozs.	Dwts.	Ozs.	Dwts.	Ozs.	Dwts.	Ozs.	Dwts.	Dwts.	Grs.
3	Boogardie	89·00	2	17	2	8	....	11	2	19	....	16
37	Coolgardie	3,966·75	963	0	816	3	260	18	1,076	21	5	10
43	Kalgoorlie....	10,083·75	2,796	2	2,369	14	539	15	2,909	9	5	18
9	Lake Darlot	478·00	114	0	96	12	22	5	118	17	4	23
12	Leonora	1,354·00	1,049	9	889	8	319	18	1,209	6	17	21
8	Marble Bar	616·00	412	17	349	18	315	14	665	12	21	15
22	Marvel Loch	3,382·50	2,292	19	1,943	6	574	9	2,517	15	14	21
6	Meekatharra	604·25	82	16	70	4	106	22	177	6	5	21
3	Menzies	368·00	22	4	18	16	15	14	34	10	1	21
15	Norseman	92·00	197	18	167	14	15	17	183	11	39	22
14	Ora Banda	861·25	431	14	365	17	171	12	537	9	12	12
3	Sandstone	135·00	113	5	96	0	41	10	137	10	20	9
6	Yarri	780·00	177	6	150	5	40	0	190	5	4	21
181		22,810·50	8,656	7	7,336	5	2,425	5	9,761	10	8	13

Average Tons per Parcel 126.02
Average Yield by Amalgamation per ton (Fine Gold) .... **6 dwts. 10 grs.**
Average Value of Tailings per ton (Fine Gold) .... **2 dwt. 3 grs.**

Schedule No. 2

DETAILS OF EXTRACTION TAILINGS TREATMENT 1970

Battery	Tons Treated	Head Value			Tail Value			Calculated Recovery		Actual Recovery	
		Per Ton		Total content	Per Ton		Total content				
		Dwts.	Grs.	Ozs.	Dwts.	Grs.	Ozs.	Ozs.	%	Ozs.	%
Kalgoorlie....	3,000	3	01	456·55	0	18	112·10	344·45	75·44	343·27	75·19
Leonora	78	9	00	35·10	4	08	16·85	18·25	51·99	17·47	49·77
Marble Bar	670	8	11	283·90	2	02	69·90	214·00	75·38	218·45	75·18
Marvel Loch	3,247	3	08	545·75	0	18	119·40	426·35	78·12	440·66	80·74
Norseman	958	3	20	184·25	0	20	39·20	145·05	78·72	145·91	79·19
	7,953	3	19	1,505·55	0	22	357·45	1,148·10	76·26	1,160·76	77·10

Schedule No. 3

DIRECT PURCHASE OF TAILINGS FOR THE YEAR ENDED 31st DECEMBER, 1970

Battery	Tons of Tailings Purchased	Initial Payment to $28 per Fine oz.
		$
Coolgardie	87·50	219.31
Kalgoorlie	675·50	2,270.16
Leonora	516·00	2,417.29
Marble Bar	625·25	5,157.67
Marvel Loch	1,876·75	3,352.79
Meekatharra	622·50	783.66
Norseman	49·50	16.22
Ora Banda	85·50	882.83
Sandstone	126·00	380.94
	4,664·50	15,480.87

Schedule No. 4

STATEMENT OF RECEIPTS AND EXPENDITURE FOR THE YEAR ENDED 31st DECEMBER, 1970

Milling

Battery	Tons Crushed	Management and Supervision	Wages	Stores	Total Working Expenditure	Cost per Ton	Repairs and Renewals	Sundries	Gross Expenditure	Cost per Ton	Receipts	Receipts per Ton	Profit	Loss
		$	$	$	$	$	$	$	$	$	$	$	$	$
Boogardie	1,636·50	9,343.84	8,606.54	2,526.55	20,476.93	12.51	8,052.96	6,878.92	35,408.81	21.56	3,185.35	1.95	....	32,223.46
Coolgardie	3,966·75	5,909.74	13,011.78	6,099.06	25,020.58	6.31	7,784.72	9,340.81	42,146.11	10.62	3,476.92	.88	....	38,669.19
Cue	....	....	....	400.94	400.94	....	329.45	1,064.08	1,794.47	....	917.71	....	....	876.76
Kalgoorlie	10,083·75	14,784.67	35,154.23	14,360.31	64,299.21	6.38	12,724.05	26,516.75	103,540.01	10.27	8,785.88	.87	....	94,754.13
Lake Darlot....	478·00	3,531.46	1,815.99	749.89	6,097.34	12.76	744.01	1,852.50	8,693.85	18.19	444.55	.93	....	8,249.30
Laverton	....	....	312.00	....	312.00	....	....	94.84	406.84	....	332.28	....	....	74.56
Leonora	1,354·00	8,205.73	9,022.20	3,367.28	20,595.21	15.21	4,903.97	6,833.45	32,332.63	23.88	1,444.20	1·07	....	30,888.43
Marble Bar	717·00	9,169.36	5,754.29	3,040.45	17,964.10	25.05	5,446.30	2,774.07	26,184.47	36.57	1,354.62	1.89	....	24,829.85
Marvel Loch	3,382·50	5,401.61	17,834.99	4,052.79	27,289.39	8.07	4,944.77	6,813.23	39,047.39	11.54	3,543.84	1.05	....	35,503.55
Meekatharra....	604·25	5,236.28	8,556.24	2,616.58	16,409.10	27.16	5,134.71	2,490.41	24,034.22	39.77	643.43	1.06	....	23,390.79
Menzies	368·00	4,754.78	2,738.17	1,362.80	8,855.75	24.06	3,386.95	2,465.19	14,707.89	39.92	326.55	.89	....	14,381.34
Norseman	92·00	2,712.95	1,154.53	1,091.24	4,958.72	53.90	1,729.52	1,126.76	7,815.00	84.95	170.44	1.85	....	7,644.56
Nullagine	....	164.09	1,365.09	186.58	1,715.76	....	1,822.81	329.46	3,868.03	....	....	....	....	3,868.03
Ora Banda	861·25	5,425.44	3,643.92	2,102.32	11,171.68	12.97	2,499.01	3,546.35	17,217.04	19.91	863.61	1.00	....	16,353.43
Paynes Find....	....	....	298.62	49.60	348.22	....	100.50	32.15	480.87	....	....	....	....	480.87
Peak Hill	....	....	386.80	....	386.80	....	....	....	386.80	....	....	....	....	386.80
Sandstone	135·00	1,395.20	1,783.13	258.34	3,436.67	25.46	1,398.67	1,317.60	6,152.94	45.58	141.75	1.05	....	6,011.19
Yarri	780·00	....	6,953.50	1,112.50	8,066.00	10.34	1,080.08	1,825.34	10,971.42	14.07	793.50	1.01	....	10,177.92
Head Office	....	....	....	....	....	....	....	....	....	....	52.43	....	52.43	....
Sub-Total	24,459·00	76,035.15	118,392.02	43,377.23	237,804.40	9.72	62,082.48	75,301.91	375,188.79	15.34	26,477.06	1.08	52.43	348,764.16
Marble Bar (Magnetic Plant)	60·65	....	2,262.29	242.00	2,504.29	41.29	78.48	589.58	3,172.35	52.30	2,006.00	33.08	....	1,166.35
Northampton (Lead)	3,744.75	10,617.63	9,922.80	4,713.21	25,253.64	6.74	9,276.85	9,981.74	44,512.23	11.89	7,547.09	2.02	....	36,965.14
Total	28,264·40	86,652.78	130,577.11	48,332.44	265,562.33	9.40	71,437.81	85,873.23	422,873.37	14.96	36,030.15	1.27	52.43	386,895.65

OPERATING LOSS $386,848.22

Schedule No. 5

STATEMENT OF RECEIPTS AND EXPENDITURE FOR THE YEAR ENDED 31st DECEMBER, 1970

Cyaniding

Battery	Tons Treated	Management and Supervision	Wages	Stores	Total Working Expenditure	Cost per Ton	Repairs and Renewals	Sundries	Gross Expenditure	Cost per Ton	Receipts	Receipts per Ton	Profit	Loss
		$	$	$	$	$	$	$	$	$	$	$	$	$
Coolgardie	....	3,535.02	3,597.39	119.17	7,251.58	....	569.75	1,131.69	8,953.02	....	....	....	....	8,953.02
Kalgoorlie	3,000·00	3,132.70	12,027.70	4,882.44	20,042.84	6.68	465.56	11,779.35	32,287.75	10.76	7,590.63	2.53	....	24,697.12
Lake Darlot	....	....	....	....	....	....	....	227.48	227.48	....	....	....	....	227.48
Leonora	78·00	651.36	2,507.80	84.21	3,243.37	41.58	52.80	1,358.77	4,654.94	59.68	385.56	4.94	....	4,269.38
Marble Bar	670·00	190.16	2,130.14	670.56	2,990.86	4.46	....	2,247.92	5,238.78	7.82	2,248.78	3.36	....	2,990.00
Marvel Loch	3,247·00	....	12,229.88	1,991.27	14,221.15	4.38	628.69	5,845.00	20,694.84	6.37	9,963.00	3.07	....	10,731.84
Norseman	958·00	2,712.95	1,471.88	1,435.96	5,620.79	5.87	323.86	2,575.78	8,520.43	8.89	2,486.52	2.59	....	6,033.91
Total	7,953·00	10,222.19	33,964.79	9,183.61	53,370.59	6.71	2,040.66	25,165.99	80,577.24	10.13	22,674.49	2.85	....	57,902.75
							Interest Paid to Treasury	....	....		4,320.00			4,320.00
									80,577.24		18,354.49			62,222.75
												Operating Loss	....	62,222.75

STATE BATTERIES

TRADING AND PROFIT LOSS ACCOUNT FOR THE YEAR ENDED 31st DECEMBER, 1970

1969		1970	
$	Trading Costs—	$	$
237,219	Wages	261,417	
75,776	Stores	57,516	
74,502	Repairs, Renewals and Battery Spares	73,479	
122,105	General Expenses and Administration	115,359	
509,602			507,771
	Earnings—		
101,347	Milling and Cyaniding Charges		58,705
408,255	Operating Loss for the Year		449,066
	Other Charges—		
61,585	Interest on Capital	61,822	
27,557	Depreciation	30,524	
10,431	Superannuation—Employers Share	13,768	
99,573			106,114
507,828	Total Loss for the Year		555,180

BALANCE SHEET AS AT 31st DECEMBER, 1970

31st December, 1969	Funds Employed	31st December, 1970	
$	Capital—	$	$
1,464,564	Provided from General Loan Fund	1,469,820	
274,409	Provided from Consolidated Revenue Fund	303,694	
1,738,973			1,773,514
	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—		
2,451,570	Interest on Capital		2,513,392
	Other Funds—		
6,099,979	Provided from Consolidated Revenue Fund (Excess of payment over collections)		6,549,748
10,375,338			10,921,470
	Deduct—		
	Profit and Loss :		
9,539,756	Loss at Commencement of Year	10,047,584	
507,828	Loss for Year	555,180	
10,047,584	Total Loss from Inception		10,602,764
327,754			318,706

Employment of Funds

1969		1970	
	Fixed Assets—		
1,727,790	Plant, Buildings and Equipment	1,762,331	
1,480,874	Less Depreciation	1,511,398	
246,916			250,933
	Current Assets—		
19,036	Debtors	19,923	
80,484	Stores	82,315	
12,241	Battery Spares	13,784	
	Purchase of Tailings :		
29,441	Treasury Trust Account	25,565	
68,295	Tailings not treated	72,120	
12,883	Estimated Gold Premium	11,008	
222,380			224,715
469,296	Total Assets		475,648
	Deduct—		
	Current Liabilities :		
15,256	Creditors	18,813	
111,667	Liability to Treasurer (Superannuation—Employers Share)	125,436	
	Purchase of Tailings :		
1,736	Creditors	1,685	
12,883	Estimated Premium Due	11,008	
141,542			156,942
327,754			318,706

DIVISION IV

Annual Report of the Geological Survey Branch of the Mines Department for the Year 1970

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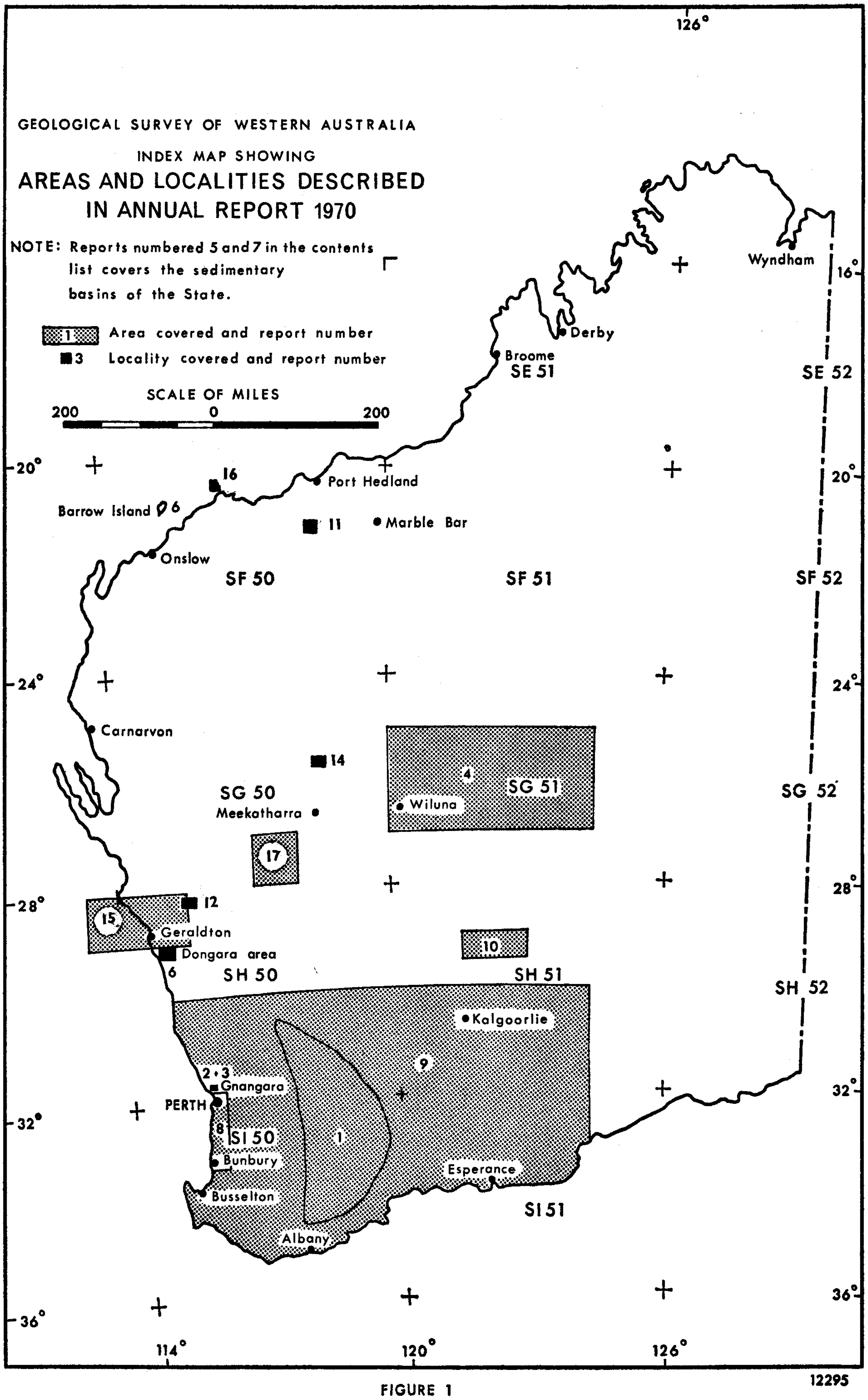

FIGURE 1

(4)—90726

DIVISION IV

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Annual Report of the Geological Survey Branch of the Mines Department for the Year 1970

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The Under Secretary for Mines

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

INTRODUCTION

The mineral exploration boom continued throughout 1970, with new companies continually joining in the search for new mineral deposits.

There was renewed activity in the search for, or rather the proving of, iron ore deposits, particularly in the Hamersley Range iron province. Detailed drilling programmes were commenced and in some cases are still continuing on such deposits as Rhodes Ridge, Koodaiderie, McCamey's Monster, Marillana and Mount Gibson. Further mines are expected to be developed on some of these deposits.

Bauxite attracted considerable attention, and Western Aluminium (Alcoa) commenced the establishement of an additional alumina plant at Pinjarra, its plant at Kwinana having reached its maximum production size of 1·2 million tons of alumina per year. The Amax alumina project in the Kimberley is in its final planning stage before the commencement of construction. Alwest, in conjunction with Broken Hill Proprietary, and Hanwright, in conjunction with Pacminex, are carrying out feasibility studies for the establishment of alumina plants near Bunbury and to the north of Perth respectively. A number of other companies are searching for suitable deposits.

The mining of nickel ore continued at Kambalda, Scotia and Nepean. Development work in preparation for mining is being done at Mount Windarra (Poseidon), Carr Boyd, Spargoville (Selection Trust), Widgiemooltha (3 miles northwest, Inco and B.H.P.), Redross and Wannaway (Anaconda and C.R.A.). Nickel mineralisation warranting further investigation has been reported from many localities; in particular, Mount Clifford, Siberia, Pyke Hill, Mount Monger, Trough Wells and Mount Keith.

Those engaged in oil exploration had another disappointing year. Most of the exploration was concentrated off-shore with no significant results. Plans were announced for the development and piping of gas from Dongara to Perth. There should be more search on-shore again under the new Act and with ground becoming available.

The exploration boom is attracting attention to minerals other than those mentioned above. There has been a revival of interest in mineral sands and many new companies have become involved. Most were investigating the possibility of locating and operating large lower grade deposits. This has resulted in the location of some additional high and low-grade deposits. The investigations have been carried beyond the Bunbury-Busselton area around the coastal areas. A promising deposit containing rutile has been found near Eneabba. One company, Norseman Titanium, has announced its intention of establishing a new plant and mine near Capel, while several other companies are carrying out detailed feasibility studies.

Exploration has been directed towards the discovery of many other minerals, in particular copper, silver-lead-zinc, uranium, diamonds, platinum and coal.

Three lectures followed by field excursions were arranged during 1970. The first was on the Geraldton 1 : 250,000 sheet, which involves both Precambrian and Phanerozoic geology and attracted about 90 persons. The second was on the Norseman 1 : 250,000 sheet, which attracted about 100, and the third was a repeat of the Kurnalpi 1 : 250,000 which attracted about 120. The attendances again illustrated that there is a keen demand for the results of geological mapping before publication. It is hoped to arrange further lectures during 1971.

ACCOMMODATION

The move to Mineral House from the seven substandard buildings previously occupied took place in May, 1970. The staff and laboratories are now housed in first class accommodation which is appreciated by all concerned.

The new library lay-out is proving to be of great value to the public, who can now pursue their literature searches in comfort. The small geological museum is also attracting considerable interest.

Further additions to our core stores are being proposed for the next financial year. This is required to cope with the material being lodged with the Survey and collected during the current exploration boom.

STAFF

The Branch suffered severe setbacks this year due to the resignations of senior staff as well as junior staff, the majority of whom resigned to accept more lucrative positions in private enterprise. Many of the senior officers leaving had contributed greatly to the development of the Survey, in particular Messrs. L. E. de la Hunty, J. Sofoulis and R. R. Connolly, all of whom had over 20 years' service. Also Drs. P. E. Playford and R. C. Horwitz, both of whom were in charge of Divisions, had, by their own ability and example, made a major contribution to the geology of this State and to the development of the Survey.

During the year the number of professional vacancies rose to 19. However by the end of the year it appeared as if most of the positions will be filled during 1971. Nearly all new staff are being recruited from overseas, in particular the United Kingdom, and so will lack local experience.

There were also many changes in the clerical and general staff. It is also difficult to recruit suitable staff in these fields.

The establishment of the Branch at the end of 1970 was 51 professional, 7 clerical and 16 general officers.

PROFESSIONAL

Appointments

Name	Position	Effective Date
Thom, R., B.Sc. (Hons.)	Geologist, Level 1	5/1/70
Thom, J., B.Sc. (Hons.)	Geologist, Level 1 (Temp.)	19/1/70
Clure, V., B.Sc. (Hons.)	Geologist, Level 1 (Temp.)	29/6/70
Carter, J., B.Sc. (Hons.)	Geologist, Level 3	7/9/70
Marcos, G., B.Sc.	Geologist, Level 1 (Temp.)	7/10/70
Toledo, M., B.Sc. (Hons.)	Geologist, Level 1	19/10/70
Barnes, R., B.Sc. (Hons.)	Geologist, Level 1	23/11/70

Resignations

Ryan McMahon, M.	Geologist, Level 1	27/1/70
Boyer, D. D.	Geologist, Level 1	2/4/70
Playford, P. E.	Supervising Geologist, Level 5	10/4/70
Horwitz, R. C.	Supervising Geologist, Level 5	10/4/70
Barnett, J. G.	Geologist, Level 1	10/4/70
Newton-Smith, J.	Geologist, Level 1	22/5/70
Whincup, P.	Geologist, Level 2	22/5/70
Connolly, R. R.	Geologist, Level 2	29/5/70
de la Hunty, L. E.	Supervising Geologist, Level 5	4/6/70
Sofoulis, J.	Senior Geologist, Level 3	4/6/70
Williams, X. K.	Geochemist, Level 3	22/6/70
Brown, W.	Geologist, Level 1	10/7/70
Doepel, J. J. G.	Geologist, Level 1	18/9/70
Pippet, A. H.	Production Geologist, Level 4	30/10/70

Promotions

Sanders, C. C.	Geologist, Level 2	19/12/69
Bestow, T. T.	Supervising Geologist, Level 5	14/1/70
Gordon, F. R.	Supervising Geologist, Level 5	14/1/70
Low, G. H.	Senior Geologist, Level 3	18/3/70
Blockley, J. G.	Senior Geologist, Level 3	1/7/70
Daniels, J. L.	Supervising Geologist, Level 5	15/7/70
Williams, I. R.	Senior Geologist, Level 3	12/8/70
Muhling, P. C.	Geologist, Level 2	16/10/70
Baxter, J. L.	Geologist, Level 2	20/11/70

CLERICAL AND GENERAL

Appointments

Watt, J.	Geophysical Assistant	3/4/70
D'Silva, A.	Clerk (Temp.)	15/6/70
Jeffrey, S.	Geological Assistant	29/6/70

Transfers In

Dunham, J.	Typist	2/2/70
Williams, G.	Laboratory Assistant	15/6/70
Allison, L.	Library Assistant	15/7/70
Hewitt, P.	Clerk	10/8/70
Bradshaw, B.	Clerk	7/12/70

Resignations

Birch, S.	Typist	30/1/70
Schellpeper, S. H. W.	Geophysical Assistant	5/2/70
Squires, G.	Laboratory Assistant	6/3/70
Leeder, K. A.	Geological Assistant	13/3/70
Bruce, R.	Library Assistant	22/5/70
Mitchell, P.	Clerk (Temp.)	29/5/70
Smith, P.	Clerk	20/8/70
Gayski, A.	Laboratory Assistant	18/9/70
Jeffrey, S.	Geological Assistant	16/10/70
Allison, L.	Library Assistant	31/12/70

Transfers Out

Dunham, J.	Typist	3/11/70
Jennings, D.	Clerk	10/12/70

OPERATIONS

HYDROLOGY AND ENGINEERING GEOLOGY DIVISION

E. P. O'Driscoll (Chief Hydrogeologist), F. R. Gordon, T. T. Bestow (Supervising Geologists), K. Berliat (Senior Geologist), A. D. Allen, C. C. Sanders, B. R. Paterson, W. A. Davidson, J. A. Bunting, G. W. A. Marcos, R. Barnes and A. S. Harley.

Hydrology

The Government-assisted scheme of exploratory drilling for water in the drought-affected areas was completed in July. Some further drought relief work has been carried out in the last 3 months of the year in the Fitzgerald and Chillinup areas, where a limited programme of drilling has resulted in the discovery of new sources of supply on public reserves.

Drilling for the Metropolitan Water Board has continued in the Gnangara area, where another 68 boreholes have been sunk for pump testing or observation. A large programme of test pumping has been carried out in order to determine bore yields and aquifer characteristics.

An investigation into the groundwater potential of the De Grey-Shaw-Strelley river system has continued with a view to establishing additional water sources for the expanding needs of Port Hedland. Further refraction seismic and also resistivity surveys have been carried out on new section lines. An additional 30 boreholes have been drilled, about half of which have been test pumped. The large volume of data is in process of evaluation.

Although there has been no deep exploratory drilling in the Perth Basin this year, the collection of hydrographic data pertaining to the Pinjarra area has continued and this will be of considerable value in the later assessment of the infiltration conditions in this part of the Basin.

Water level recorders are being installed on strategically sited observation boreholes in all areas subject to long term investigation. The network of stations will provide valuable data for the assessment of water resources. The first water balance study based on such data was completed during the year.

Modifications to the Department's formation testing equipment have greatly improved its reliability in use which, together with the application of more sophisticated means of interpretation, has facilitated the derivation of more hydrologic data from tests. Four completely successful formation tests were run during the year on bores drilled for the Public Works Department. One of these was later developed for production and the results substantially confirmed predictions made by formation tests.

During the winter break in the drought assistance programme, it was possible to complete 21 boresite inspections for private landholders which, owing to staff shortages, had been outstanding since before the inception of drought relief in 1969. However, as the shortage of staff has continued, it has not proved possible to re-institute the inspection service.

Engineering Geology

The most important work of the year was the compilation of a Bulletin which is nearing completion, on the Meckering Earthquake. The earthquake was a remarkable scientific event but probaby the most significant aspect was the information it provided on earthquake mechanism and hazards in the State.

The stripping of the foundation area of the South Dandalup dam site enabled a study to be made of the relationship of the upper parts of the granite weathering profile to the bed rock types as shown in drilling.

Dam sites in the Upper Helena Valley and in the Darkin Valley were mapped as part of the feasibility study for the augmentation of the Goldfields Water Supply. Detailed studies at the Upper Helena site included the location and logging of six diamond drill holes and the logging of a centre line trench and numerous test pits in the foundation area and in proposed borrow locations.

Geological assistance was given to the consultant geologist, Mr. Peter Burgess, at the Ord River Main Dam. The successful completion of the foundation excavation of the dam and emplacement of the lower part of the dam and core, marks the virtual completion of a project with which the Geological Survey has been involved for over 10 years.

SEDIMENTARY (OIL) DIVISION

R. N. Cope, G. H. Low (Senior Geologists) and D. C. Lowry.

Details of exploration and production activities of companies were collated and appraised. Studies of the economic potential of Barrow Island oilfield and the Dongara gasfield were up-dated.

The surface mapping of the Perth Basin is being compiled and the assembly of the sub-surface information has commenced.

The manuscripts for a bulletin on the " Geology of the Western Australian part of the Eucla Basin " and the Phanerozoic stratigraphy for the " Geology of Western Australia " were completed and edited ready for publication.

A deep drilling programme for coal was carried out on the Collie Mineral Field where two areas were investigated as recommended in a report by Messrs. Menzies and Hanrahan. Reports on the projects are being prepared.

A reconnaissance was made of the Officer Basin in preparation for a regional survey commencing in 1971. This will be a joint project with the Commonwealth Bureau of Mineral Resources.

REGIONAL GEOLOGY DIVISION

J. L. Daniels (Supervising Geologist), I. R. Williams (Senior Geologist), P. C. Muhling, C. F. Gower and R. Thom.

Eastern Goldfields area

Geological mapping was completed on the Edjudina 1 : 250,000 Sheet area and compilation is in progress.

Compilation and drawing is continuing with the following 1 : 250,000 Sheet areas : Norseman, Zanthus, Balladonia, Malcolm, Esperance, Mondrain Island and Cape Arid.

Murchison area

Regional mapping of Yalgoo and the compilation of Murgoo sheet is continuing.

Blackstone-Warburton Area

A Bulletin on the geology of the Blackstone-Warburton area has been compiled and is being prepared for printing. The drawing of the Scott 1 : 250,000 sheet was finalised.

General

Compilation of a new State Geological Map is almost complete.

Some officers within the section have contributed several chapters to the Survey's Bulletin on the Geology of Western Australia.

In collaboration with the Engineering Geology section a study has been made of the drainage patterns of much of the western part of the State. This forms part of a larger study by the Engineering Geology section on the Meckering Earthquake.

The progress of geological mapping at 1 : 250,000 scale at the end of 1970 is shown in Figure 2.

MINERAL RESOURCES DIVISION

J. G. Blockley, J. D. Carter (Senior Geologists) and J. L. Baxter.

The study of the tin deposits throughout the State was continued. All field inspections and studies have been completed and the results are now being compiled ready for publication.

The suspected carbonatite occurrences near Mount Fraser were mapped in detail and a geochemical survey carried out. The results have been compiled.

A senior geologist (J. Carter) commenced the study, assessment and filing of geological information supplied to the Department with respect to exploration results on mining tenements.

The known reserves of ilmenite in the State were assessed by examining all deposits, which had been tested in the southwest area and scrutinising each company's estimates.

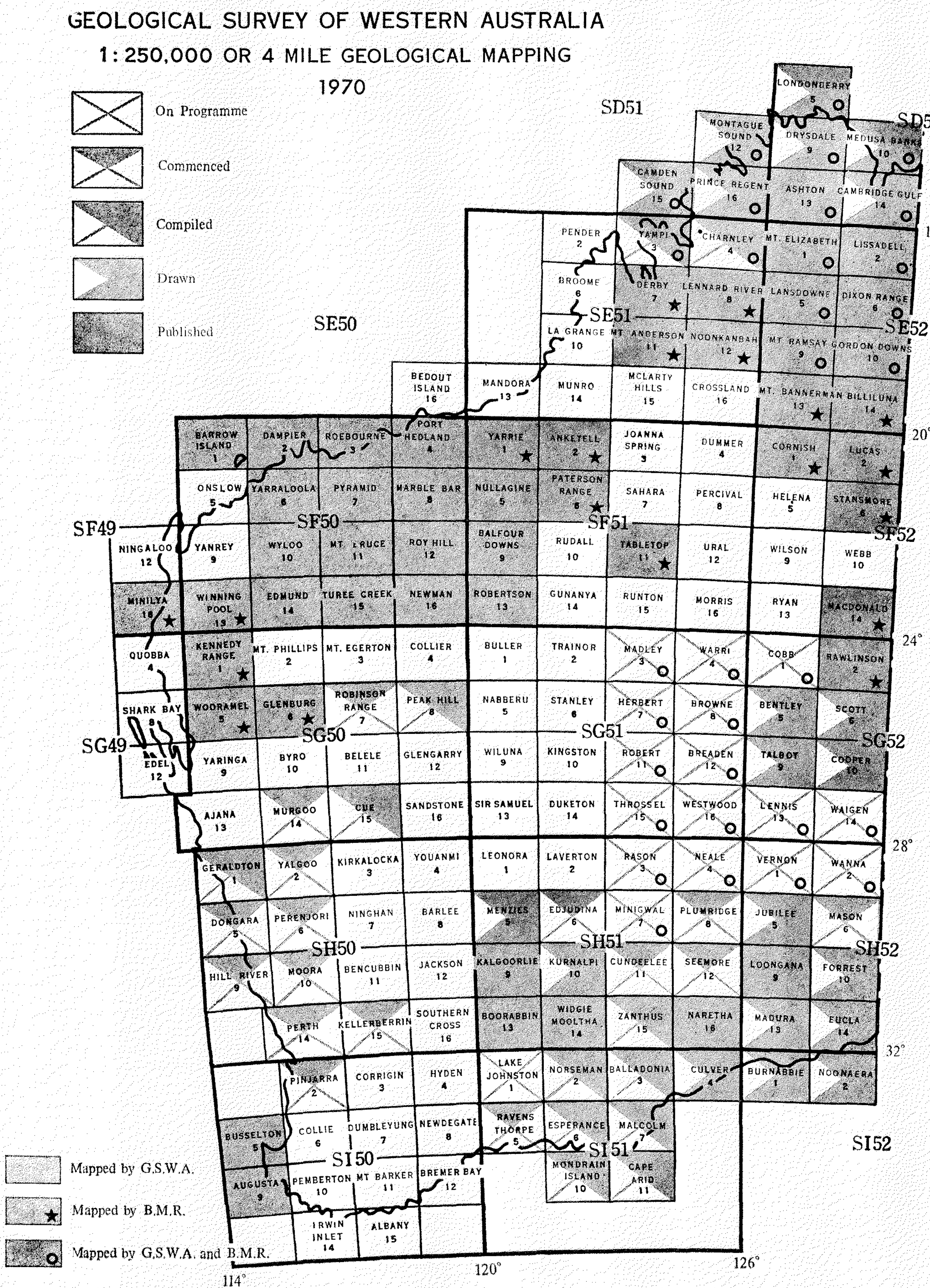
COMMON SERVICES DIVISION

Petrology—(J. D. Lewis and R. Peers)

During 1970 the Petrology Section provided services to all Divisions of the Geological Survey. Twenty-four written reports were made and petrological advice given to many geologists by personal discussion. Some identifications were made and advice given to the general public on specimens submitted.

Despite the disruption caused by moving to new accommodation, a record number of nearly 1,500 thin sections was prepared by the laboratory staff.

As there were no new regional mapping projects started this year no visits were made to field parties. Mr. Lewis spent 5 weeks during April and May investigating intrusive carbonate rocks near Meekatharra in conjunction with the geochemical investigations. In September Miss Peers made an extensive collecting trip in the Geraldton area in order to provide petrological data for the Northampton Block.


GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
1: 250,000 OR 4 MILE GEOLOGICAL MAPPING
1970
On Programme
Commenced
Compiled
Drawn
Published
Mapped by G.S.W.A.
Mapped by B.M.R.
Mapped by G.S.W.A. and B.M.R.
SD51
SD52
SE50
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SF49
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16°
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28°
32°
114°
120°
126°
LONDONDERRY 5
MONTAGUE SOUND 12
DRYSDALE 9
MEDUSA BANKS 10
CAMDEN SOUND 15
PRINCE REGENT 16
ASHTON 13
CAMBRIDGE GULF 14
PENDER 2
YAMPI 3
CHARNLEY 4
MT. ELIZABETH 1
LISSADELL 2
BROOME 6
DERBY 7
LENNARD RIVER 8
LANSDOWNE 5
DIXON RANGE 6
LA GRANGE 10
MT. ANDERSON 11
NOONKANBAH 12
MT. RAMSAY 9
GORDON DOWNS 10
BEDOUT ISLAND 16
MANDORA 13
MUNRO 14
MCLARTY HILLS 15
CROSSLAND 16
MT. BANNERMAN 13
BILLILUNA 14
BARROW ISLAND 1
DAMPIER 2
ROEBOURNE 3
PORT HEDLAND 4
YARRIE 1
ANKETELL 2
JOANNA SPRING 3
DUMMER 4
CORNISH 1
LUCAS 2
ONSLOW 5
YARRALOOLA 6
PYRAMID 7
MARBLE BAR 8
NULLAGINE 5
PATERSON RANGE 6
SAHARA 7
PERCIVAL 8
HELENA 5
STANSMORE 6
NINGALOO 12
YANREY 9
WYLOO 10
MT. BRUCE 11
ROY HILL 12
BALFOUR DOWNS 9
RUDALL 10
TABLETOP 11
URAL 12
WILSON 9
WEBB 10
MINILYA 16
WINNING POOL 13
EDMUND 14
TUREE CREEK 15
NEWMAN 16
ROBERTSON 13
GUNANYA 14
RUNTON 15
MORRIS 16
RYAN 13
MACDONALD 14
QUOBBA 4
KENNEDY RANGE 1
MT. PHILLIPS 2
MT. EGERTON 3
COLLIER 4
BULLER 1
TRAINOR 2
MADLEY 3
WARRI 4
COBB 1
RAWLINSON 2
SHARK BAY 8
WOORAMEL 5
GLENBURG 6
ROBINSON RANGE 7
PEAK HILL 8
NABBERU 5
STANLEY 6
HERBERT 7
BROWNE 8
BENTLEY 5
SCOTT 6
EDEL 12
YARINGA 9
BYRO 10
BELELE 11
GLENGARRY 12
WILUNA 9
KINGSTON 10
ROBERT 11
BREADEN 12
TALBOT 9
COOPER 10
AJANA 13
MURGOO 14
CUE 15
SANDSTONE 16
SIR SAMUEL 13
DUKETON 14
THROSSEL 15
WESTWOOD 16
LENNIS 13
WAIGEN 14
GERALDTON 1
YALGOO 2
KIRKALOCKA 3
YOUANMI 4
LEONORA 1
LAVERTON 2
RASON 3
NEALE 4
VERNON 1
WANNA 2
DONGARA 5
PERENJORI 6
NINGHAN 7
BARLEE 8
MENZIES 5
EDJUDINA 6
MINIGWAL 7
PLUMRIDGE 8
JUBILEE 5
MASON 6
HILL RIVER 9
MOORA 10
BENCUBBIN 11
JACKSON 12
KALGOORLIE 9
KURNALPI 10
CUNDEELEE 11
SEEMORE 12
LOONGANA 9
FORREST 10
PERTH 14
KELLERBERRIN 15
SOUTHERN CROSS 16
BOORABBIN 13
WIDGIE MOOLTHA 14
ZANTHUS 15
NARETHA 16
MADURA 13
EUCLA 14
PINJARRA 2
CORRIGIN 3
HYDEN 4
LAKE JOHNSTON 1
NORSEMAN 2
BALLADONIA 3
CULVER 4
BURNABBIE 1
NOONAERA 2
BUSSELTON 5
COLLIE 6
DUMBLEYUNG 7
NEWDEGATE 8
RAVENSTHORPE 5
ESPERANCE 6
MALCOLM 7
AUGUSTA 9
PEMBERTON 10
MT BARKER 11
BREMER BAY 12
MONDRAIN ISLAND 10
CAPE ARID 11
IRWIN INLET 14
ALBANY 15

Fig. 2.

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The liaison with the Physics Department of the Western Australian Institute of Technology on geochronology continued and further reports on the results appear in this Annual Report.

As in previous years, chemical and mineralogical work carried out at the Government Chemical Laboratories has materially assisted many of the projects.

Palaeontology—(B. S. Ingram and J. Backhouse)

Much of the year has been devoted to routine palynological examination of bore samples for the Hydrology Division. This can be seen in the summary below of the 39 file reports prepared during 1970 (note : palynology and micropalaeontology sometimes attempted on the same samples).

Division requesting report	Field of Palaeontology		
	Macropalaeontology	Micropalaeontology	Palynology
Hydrology/Engineering	....	4	31
Sedimentary/Oil	....	....	1
Regional/Mineral Res.	1	....	1
Outside organisations	....	1	5

Both the palynological and the foraminiferal projects on the Ginginup corehole material are continuing, as is the benthonic foraminiferal study of the Plantagenet Group near Esperance. Some time has been spent assisting in arranging palaeontological displays for the Museum.

Mr. Backhouse was seconded to the Sedimentary Division for several months to assist in the supervision of the drilling in the Collie Basin.

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

There was a marked decrease in well-logging activities during 1970 as indicated by comparison with the 1969 statistics (in parenthesis). Forty-one (107) logging operations were carried out on 38 (103) individual bores to give a total of 31,760 (67,150) of footage recorded. Point resistivity and gamma-ray logs, run in a series of exploratory coal bores in the Collie Basin, materially assisted the project by providing accurate seam thicknesses in intervals of poor core recovery and by inter-bore correlations.

Normal laboratory services were maintained and 470 field determinations of water salinity made.

Geophysical surveys for underground water in the Pilbara, using seismic refraction and resistivity techniques, occupied 19 weeks' field work. The Port Hedland township supply project was continued and a locality near Roebourne was investigated. In all 40·4 line miles (68·3 km) of refraction shooting and 29 line miles (49 km) of resistivity profiling were completed and these results are being processed.

An experimental survey was made in the Pilbara to evaluate the efficacy of the gravity method to define high-grade hematite bodies beneath a cover of lower grade material. Whilst interesting anomalies were obtained, the low density contrast between the hematite and overlying goethitic canga and the ambiguities inherent in gravity interpretations coupled with severe terrain effects precluded reliable delineation of the ore bodies.

Geochemistry—(vacant).

A detailed geochemical survey using the mobile field laboratory was made on the Mount Fraser area, Peak Hill Goldfield where carbonatites were thought to occur.

A paper was prepared on the use of selenium as an indicator for mineralisation.

Since the resignation of Miss Williams no geochemical surveys have been attempted.

Technical Information—(J. Thom, V. Clure, M. Toledo and S. M. Fawcett).

This section has been called on in recent years to carry a heavy burden of work answering inquiries and providing advice arising from the mineral exploration boom. In order to cope with such activity quickly and efficiently, a great depth of local geological knowledge is required which can be only acquired by long experience in the section. Staff resignations, in particular that of Mr. R. R. Connolly, have left the section with no experienced officers. It will take some time before new staff can give a similar quick service again.

The section, in particular the library, has greatly improved facilities and conditions as a result of the move to Mineral House.

The library continues to be used extensively, especially by consultants and company geologists for reference. Loans to staff numbered 2,614 and to others 626 during 1970.

Requisitions raised on Surveys and Mapping Branch for drafting services and photography totalled 696. A larger portion of the copying of out-of-print publications is directed to other services.

Twenty-two records and one Information Pamphlet were prepared and issued during the year. Considerable time was spent in the preparation of manuscripts and proof-reading, as can be gauged from the Publications and Records listed later.

The new Geological Museum was established in Mineral House. While all showcase displays were ready for the official opening of the building, the displays in the drawers are still being developed.

ACTIVITIES OF THE COMMONWEALTH BUREAU OF MINERAL RESOURCES

The geological and geophysical projects carried out by the Bureau of Mineral Resources included the following :—

1. Compilation of 1 : 250,000 geological sheets and bulletins on the Kimberley Division as a joint project with the Survey.
2. Continuation of the conodonts in the Bugle Gap area of the Canning Basin in conjunction with the Survey's studies.
3. Aeromagnetic and radiometric survey of Wiluna, Glengarry and Kingston 1 : 250,000 sheets at 1-mile spacings.
4. Continuation of the helicopter gravity survey of the State.
5. Preliminary survey for the proposed geological mapping of the Officer Basin in conjunction with this Survey.

PROGRAMME FOR 1971

HYDROLOGY AND ENGINEERING DIVISION

A. *Hydrology*

1. Continuation of the hydrological survey of the Perth Basin including deep drilling.
2. Hydrogeological investigations and/or exploratory drilling for groundwater in the following areas :—
   (a) Lake Gnangara extending to Yanchep-Pinjar area.

(b) Wiluna district—further drilling and pump testing.

(c) Pilbara area—further investigations on the de Grey river system and Harding River.

(d) Gascoyne—further drilling and assessment.

(e) Agaton area—additional bores with test pumping.

(f) Bunbury area—deep drilling.

(g) Town water supplies for following centres: Capel, Carnamah, Coolup, Leeman, Still Bay, Green Head, Esperance, Albany, Wedge Island, Cervantes and Ledge Point.

3. Hydrogeological Investigation for Metropolitan Water Board:—

   (a) Gnangara—development and test pumping.

   (b) Gwelup—logging and supervision of shallow and deep drilling.

   (c) Balcatta—logging of deep bores.

   (d) Commencement of a major regional study of Metropolitan area.

4. Kimberley—hydrological assistance to pastoralists.

   (a) Bore site selection as required.

   (b) Completion of compilation of hydrogeological mapping in conjunction with the Bureau of Mineral Resources.

5. Continuation of bore census work in selected areas.

6. Miscellaneous investigations as requested by Government departments and public.

B. *Engineering Geology*

1. South Dandalup Dam Site—progressive mapping of abutments, floor and trenches as required.

2. North Dandalup Dam Site—further mapping.

3. Harris River Dam Site—reconnaissance mapping and probable drilling.

4. Geological mapping of railway cuttings on standard gauge Perth-Northam.

5. Other investigations as requested by Government departments if staff is available.

SEDIMENTARY (OIL) DIVISION

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

2. Evaluate oil and gas discoveries and assess the resources of the State.

3. Completion of 1 : 250,000 geological map sheets of the Perth Basin.

4. Continuation of the subsurface study of the Perth Basin and the preparation of the Bulletin.

5. Commencement of the field work on the Officer Basin study in conjunction with the Bureau of Mineral Resources.

6. Completion of reports on drilling for coal on the Collie Mineral Field.

REGIONAL GEOLOGY DIVISION

1. Compilation of new State Geological map 1 : 2,500,000.

2. Compilation of the Edjudina and Murgoo 1 : 250,000 maps.

3. Commencement of field mapping of the Lake Johnston and Ravensthorpe 1 : 250,000 sheets.

4. Commencement of a re-assessment of the regional geology of the Eastern Goldfields (Menzies-Edjudina sheets to south coast).

MINERAL RESOURCES DIVISION

1. Continuation of the mineral survey of the Yalgoo and Murchison Goldfields.

2. Completion of a mineral resources bulletin on the tin deposits of Western Australia.

3. Continuation of a survey of the mineral sands resources of the State.

4. Miscellaneous investigations as required and dependent on the availability of staff.

PUBLICATIONS AND RECORDS

Issued during 1970

Annual Report 1969.

Publications catalogue 1970.

Bulletin 119: The iron formations of the Precambrian Hamersley Group, Western Australia with special reference to associated crocidolite.

Geological map of Ashton 1 : 250,000 sheet (SD/52–13 International Grid) with explanatory notes.

Geological map of Kalgoorlie 1 : 250,000 sheet (SH/51–9 International Grid) with explanatory notes.

Geological map of Loongana 1 : 250,000 sheet (SH/52–9 International Grid) with explanatory notes.

Geological map of Mount Elizabeth 1 : 250,000 sheet (SE/52–1 International Grid) with explanatory notes.

Geological map of Naretha 1 : 250,000 sheet (SH/51–16 International Grid) with explanatory notes.

Geological map of Wyloo 1 : 250,000 sheet (SF/50–10 International Grid) with explanatory notes.

In press

Bulletin 121—Devonian corals from the Canning Basin, Western Australia.

Bulletin 122—The geology of the Western Australian part of the Eucla Basin.

Geological maps 1 : 50,000, Perth Metropolitan area (4 sheets).

Geological map of Bentley 1 : 250,000 sheet (SG/52–5 International Grid) with explanatory notes.

Geological map of Cooper 1 : 250,000 sheet (SG/52–10 International Grid) with explanatory notes.

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

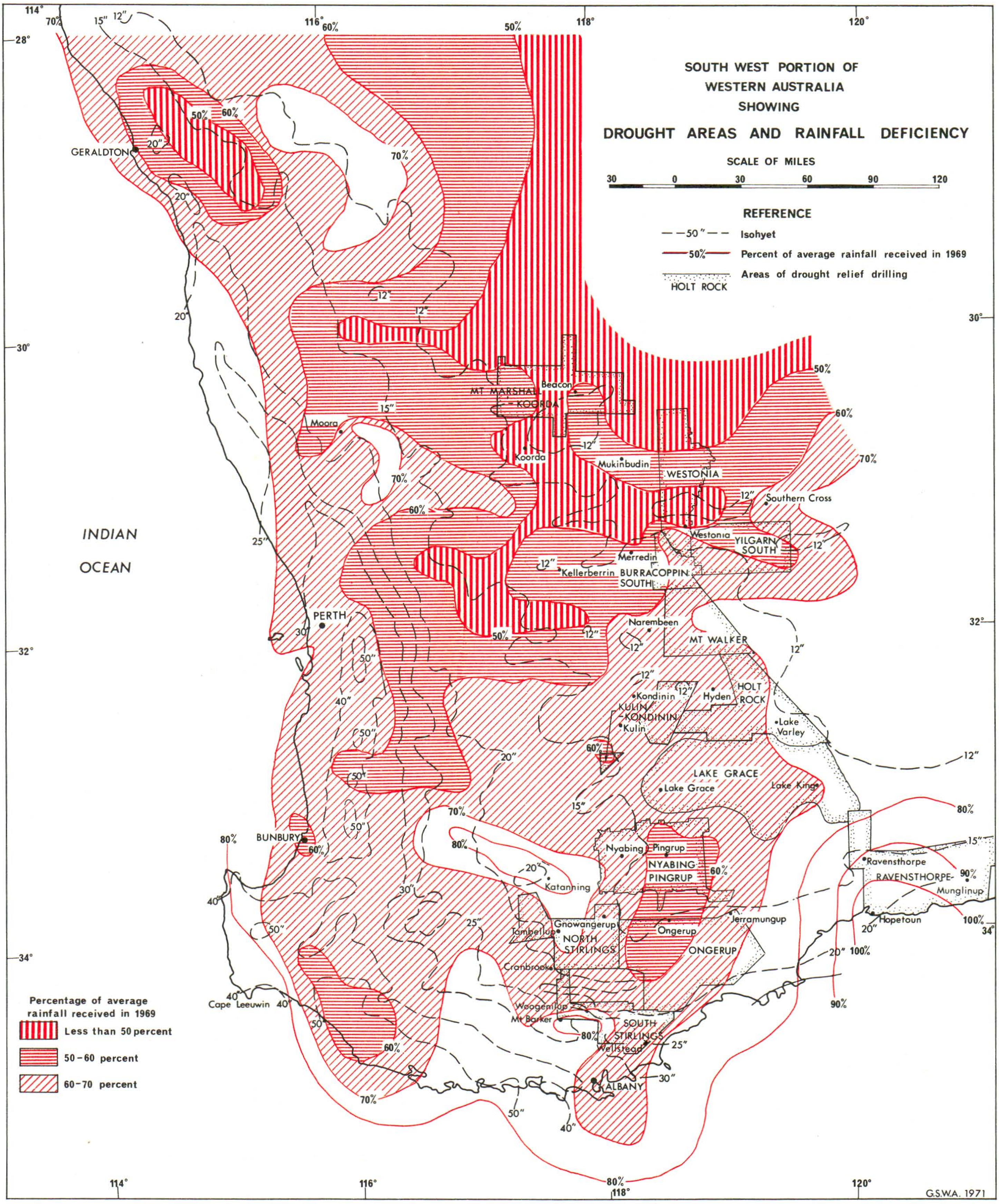
Geological map of Eucla/Noonaera 1 : 250,000 sheet (SH/52–14 International Grid) with explanatory notes.

Geological map of Madura/Burnabbie 1 : 250,000 sheet (SH/52–13 International Grid) with explanatory notes.

Geological map of Scott 1 : 250,000 sheet (SG/52–6 International Grid) with explanatory notes.

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

PLATE 1



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In preparation

Bulletin 123—Geology of the Blackstone Area, Western Australia.

Bulletin The Meckering Earthquake.

Mineral Resources Bulletin 9—Lead, zinc and silver deposits of Western Australia.

Geological maps 1 : 250,000 with explanatory notes, the field work having been completed: Peak Hill, Edjudina, Esperance, Murgoo.

Geological map 1 : 2,500,000 Western Australia.

Special publication, The Geology of Western Australia.

Records produced

1970/1 Explanatory notes on the Kurnalpi 1 : 250,000 geological sheet, by I. Williams.

1920/2 The geology and geochemistry of a cupriferous area at Yalgoo Goldfield, W.A., by J. Sofoulis and X. Williams.

1970/3 Explanatory notes on the Menzies 1 : 250,000 geological sheet, by M. Kriewaldt.

1970/4 Geochemical prospecting for copper, lead and zinc on the Northampton Mineral Field, by X. Williams.

1970/5 Explanatory notes on the Geraldton 1 : 250,000 geological sheet, by R. Horwitz, P. Playford, J. Baxter and R. Peers.

1970/6 Iron deposits of the Robinson Ranges, Peak Hill Goldfields W.A., by J. Sofoulis (restricted).

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1970/8 Geochemical survey of the Mount Frazer area, W.A., by X. Williams.

1970/9 Explanatory notes on the Norseman 1 : 250,000 geological sheet, by J. Doepel.

1970/10 Explanatory notes on the Zanthus 1 : 250,000 geological sheet, by J. Doepel and D. Lowry.

1970/11 Explanatory notes on the Balladonia 1 : 250,000 geological sheet, by J. Doepel and D. Lowry.

1970/12 Explanatory notes on the Malcolm 1 : 250,000 geological sheet, by J. Doepel.

1970/13 Selenium as a guide to mineral exploration, by X. Williams.

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1970/20 The ilmenite resources between Waroona and Augusta, W.A. 1970, by J. Baxter (confidential).

1970/21 The water balance in the North Gnangara area, by T. Bestow

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1st February, 1971.

J. H. LORD,
Director.

FINAL REPORT ON THE UNDERGROUND WATER INVESTIGATION FOR DROUGHT RELIEF 1969/70 IN WESTERN AUSTRALIA

by J. H. Lord

INTRODUCTION

The 1969 drought and the arrangements made by the Western Australian Government to assist in the search for underground water in the areas affected were outlined in the 1969 Annual Report of this Survey (Lord, 1970). The described methods of search were continued into 1970 until the end of the drought.

The serious drought situation was fortunately changed suddenly in February, 1970, when an unusual tropical cyclone, code-named "Glenis", traversed the eastern portion of the wheat belt. This brought drought-breaking rains, which filled many dams and relieved the water shortage in most of the drought areas, except the far southern areas. The emergency measures reduced quickly as areas were completed, until only two groups were operating, one in the far south and one in the Mount Marshall-Koorda Area. The last group completed its drilling programme in July, 1970.

INSPECTIONS

The procedure previously adopted was continued. Seven districts had been completed or were in progress at the end of 1969. As additional staff became available new areas for the scheme were selected by the Farm Water Supply Advisory Committee (F.W.S.A.C.). In all, inspections followed by drilling were carried out in 13 areas as shown on Plate 1.

After the cyclone, water supplies were adequate in most areas, except the far south in the Stirling and Ravensthorpe areas, where new areas were nominated by the F.W.S.A.C. and commitments in previously selected areas were met.

During the drought relief work a total of 575 private properties and 253 Government reserves were inspected, and drilling was recommended on 521 and 162 respectively (see Table 1). It should be remembered that the inspecting geologists were instructed to recommend drilling even if there was only a remote chance of locating water.

DRILLING

The drilling was continued along the lines described in the 1969 report. The Mayhew 1000 drills proved to be the faster and more adaptable for this type of work and are recommended for any such work in the future.

During the programme 220,781 feet (67,294m) of drilling was carried out. In addition, 1,663 feet (506·9m) were drilled in the Tunney area after a group of local property owners had employed a consulting geologist to make an inspection and choose sites on the properties concerned.

The cost of this drilling averaged about $1·14 per foot. When the cost of inspections and supervision of drilling by geologists and field assistants was included the final cost was slightly below $1·50 per foot of drilling.

There has been criticism of the drilling methods used, but nobody has been able to suggest an alternative procedure which would have allowed so much drilling to be done in such a short period of time at a comparably low cost.

Of the holes which were considered successful in the sense that they were classed as "Wet-suitable supply" (10 per cent), a few have proved not to be so, either due to insufficient supply or higher salinity. The emergency methods used are the reason for this. It should be remembered that no one has tested the holes classified "Wet-insufficient supply" (13·5 per cent) or "Wet-saline supply" (17 per cent) and it could be that a similar small number of these holes might have been success holes if more time and money had been expended on their development. Any property owner with a hole

TABLE 1. RESUMÉ OF INSPECTIONS AND RESULTS—DROUGHT RELIEF PROJECT, 1969–1970

Areas	Mount Marshall-Koorda	Westonia	South Yilgarn	South Burra-coppin	Mount Walker	Kulin-Kondinin	Holt Rock	Lake Grace	North Stirling	South Stirling	Nyabing-Pingrup	Ongerup	Ravens-thorpe	Total
Inspections—														
Private Property	31	24	15	21	32	33	49	52	26	43	83	121	45	575
Government Reserves	2	7	....	1	2	14	53	79	4	9	75	5	2	253
Total	33	31	15	22	34	47	102	131	30	52	158	126	47	828
Drilling Recommended—														
Private Property	24	22	15	21	25	31	49	43	24	39	77	111	40	521
Government Reserves	1	6	....	1	2	7	37	40	4	8	49	5	2	162
Total	25	28	15	22	27	38	86	83	28	47	126	116	42	683
Drilled Successfully—														
Private Property	9	9	1	6	8	6	28	6	14	24	7	35	21	174
Government Reserves	....	2	....	1	1	2	12	4	2	5	8	1	1	39
Total	9	11	1	7	9	8	40	10	16	29	15	36	22	213
Drilled Unsuccessfully—														
Private Property	15	13	14	15	17	25	21	37	10	15	70	76	19	347
Government Reserves	1	4	....	....	1	5	25	36	2	3	41	4	1	123
Total	16	17	14	15	18	30	46	73	12	18	111	80	20	470

TABLE 2. RESUMÉ OF DRILLING RESULTS—DROUGHT RELIEF PROJECT, 1969–1970

Areas	Mount Marshall-Koorda	Westonia	South Yilgarn	South Burra-coppin	Mount Walker	Kulin-Kondinin	Holt Rock	Lake Grace	North Stirling	South Stirling	Nyabing-Pingrup	Ongerup	Ravens-thorpe	Total	Per cent.
No. of Holes Drilled—															
Dry	90	159	74	105	85	120	105	173	20	34	251	160	30	1,406	53·3
Wet—Insufficient Supply	41	76	23	32	15	14	24	11	9	28	25	38	20	356	13·5
Wet—Saline Supply	5	22	3	9	14	14	34	31	21	35	109	134	18	449	17·0
Wet—Suitable Supply	10	22	1	12	12	10	43	11	16	31	30	43	22	263	10·0
Abandoned	20	4	5	17	19	4	1	20	2	10	26	32	5	165	6·2
Total	166	283	106	175	145	162	207	246	68	138	441	407	95	2,639	....
Footage Drilled—															Ave. Depth
Dry	8,710	8,144	7,021	9,114	8,137	9,013	6,664	14,233	1,519	2,486	16,477	12,673	1,879	106,070	75·4
Wet—Insufficient Supply	4,751	5,528	2,671	3,231	1,411	1,963	2,448	1,550	873	3,232	1,722	4,187	2,177	35,744	100·4
Wet—Saline Supply	330	1,900	290	1,067	1,243	1,804	3,220	2,585	1,647	2,431	7,899	12,579	1,179	38,174	85·0
Wet—Suitable Supply	868	1,816	30	1,069	1,184	1,343	4,427	1,306	1,239	3,843	2,660	5,020	1,925	26,730	101·6
Abandoned	1,240	165	356	1,961	2,421	310	168	1,660	107	963	1,715	2,813	184	14,063	85·2
Total	15,899	17,553	10,368	16,442	14,396	14,433	16,927	21,334	5,385	12,955	30,473	37,272	7,344	220,781	83·7
Water Located—															
Suitable supplies in thousands of gallons/day	23·6	77·5	1·2	19·7	20·0	83·8	207·6	25·6	144·3	234·7	63·2	202·0	81·7	1,285·0	....

which was "wet" but in which the supply was not up to 1,000 gallons (4,500 litres) per hour or the salinity was only just in excess of the maximum may find that a close investigation is warranted.

The logs of all holes drilled have been filed and incorporated in the hydrological records of the Geological Survey.

RESULTS

When considering the results of this operation it must be remembered and emphasised that many of the areas inspected and drilled were considered geologically unfavourable for underground water.

Despite this, one in ten of the holes drilled was classified as successful under the conditions of the project, namely 1,000 gallons (4,500 litres) or more per day with a salinity of less than 11,000 ppm (see Table 2). This success ratio varied greatly with the areas, the poorest being the South Yilgarn with one success every 106 holes with the best being the North Stirling area, with one success in 4·2. The Holt Rock area had a success ratio of one in five which was surprisingly good, and shows that in future more reliance should be placed on underground water supplies in this district.

When the drilling results are considered in terms of private properties drilled they show that water was found on one in every three of the properties recommended for drilling and one in 4·1 of the Government reserves.

The quantity of water found was usually in the range 1,000 gallons (4,550 litres) to 5,000 gallons (22,700 litres) per day. In the Holt Rock area larger supplies were located, with one bore producing 17,000 gallons (77,300 litres) per day. To the south, in the Stirling area, the Plantagenet rocks produced better supplies, with several bores yielding over 20,000 gallons (100,000 litres) and one bore 43,000 gallons (195,500 litres) per day.

The 263 successful bores located during the whole operation were tested to produce a total of 1,285,000 gallons (5,387,000 litres) per day, or an average of 4,800 gallons (21,800 litres) per day in each bore.

During the drought period the Government carted over 16 million gallons (73 million litres) of water to central tanks and dams at the cost of almost one cent per gallon. To this should be added the cost of the farmer carting the water up to 20 miles (32·2 km) to his farm.

So provided it is developed and used, the water is worth at least $12,000 per day. This would save the Government about one million dollars during a three-month drought if water had to be carted instead.

CONCLUSIONS

While the methods used may be criticised they proved successful under the emergency circumstances. The results more than justified the expense incurred when considered in the long term.

The programme has clarified the underground water potential in many difficult areas and the results, which are incorporated in the records of the Geological Survey, will be of great assistance in the future.

In some areas, such as Holt Rock, North and South Stirling, and Ongerup, property owners should be encouraged to investigate their properties for stock supplies of underground water. The methods used for drought relief are recommended for such testing.

In other areas, such as South Yilgarn, South Burracoppin, Mount Walker, and Lake Grace, the search for underground water by individual farmers cannot be recommended as the chances of success are very remote.

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THE WATER BALANCE IN THE NORTH GNANGARA AREA

by T. T. Bestow

ABSTRACT

The seasonal groundwater level fluctuations which have been recorded in the North Gnangara area over the period 1967 to 1970, together with the aquifer characteristics derived from pump tests, have been used to derive a simple water balance. In the absence of any surface run-off it is estimated that only 7·3 per cent of the mean annual rainfall contributes to groundwater discharge and the remainder is lost by evaporation or is transpired by vegetation.

INTRODUCTION

Since 1964 an intensive hydrogeological investigation has been in progress in the general area east and southeast of Lake Gnangara, some 12 miles (19 km) north of Perth. A programme of controlled test pumping on 13 sites has recently been completed (Bestow, 1970) which, together with some earlier results (Morgan, 1964; Sanders, 1965) now gives an adequate picture of the general hydrogeology.

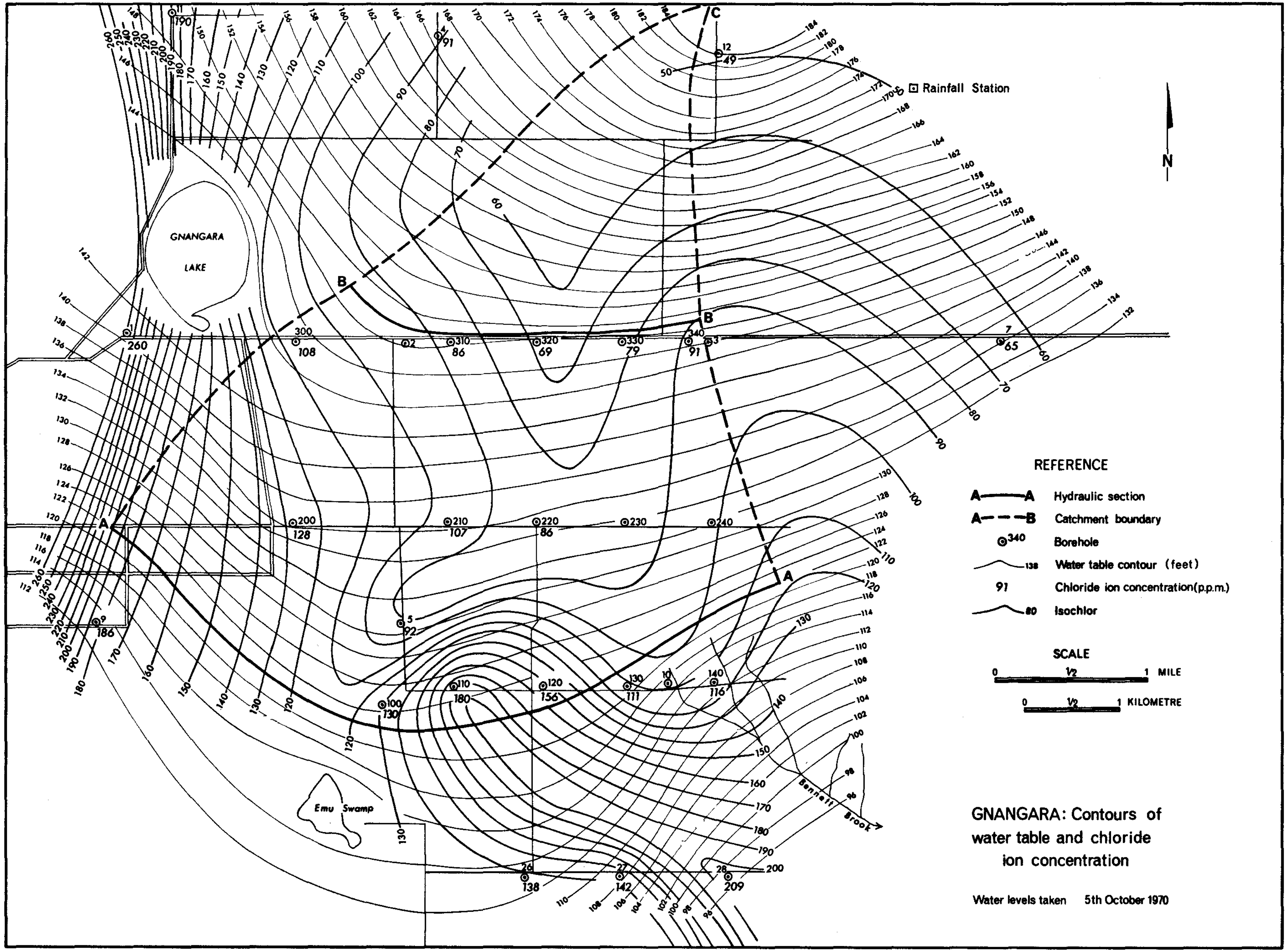
The Metropolitan Water Board propose to abstract groundwater from the "North Gnangara" area (Plate 2) for public supply. There is consequently a need to assess the current water balance before there is any disturbance by pumping.

RAINFALL

The area has a mediterranean type of climate, with a rainfall almost entirely confined to the winter months. This is evident from Plate 3, which is based on a station just north of the area under discussion. In 1967–1970, 88 to 94 per cent of the total annual rainfall occurred in the 7 months April to October and 70 to 85 per cent in the 5 months May to September. The mean annual rainfall for these 4 years is 31·40 inches (79·76 cm) which includes the drought year of 1969, when the total rainfall was only 19·08 inches (48·46 cm).

GROUNDWATER MOVEMENT

The form of the water table on the 5th October, 1970, is shown on Plate 2. From a maximum elevation of 184 feet (56·1 m) at bore 12, the water table declines towards the south and southwest. These are also the general directions of groundwater move-



GNANGARA: Contours of water table and chloride ion concentration

PLATE 2

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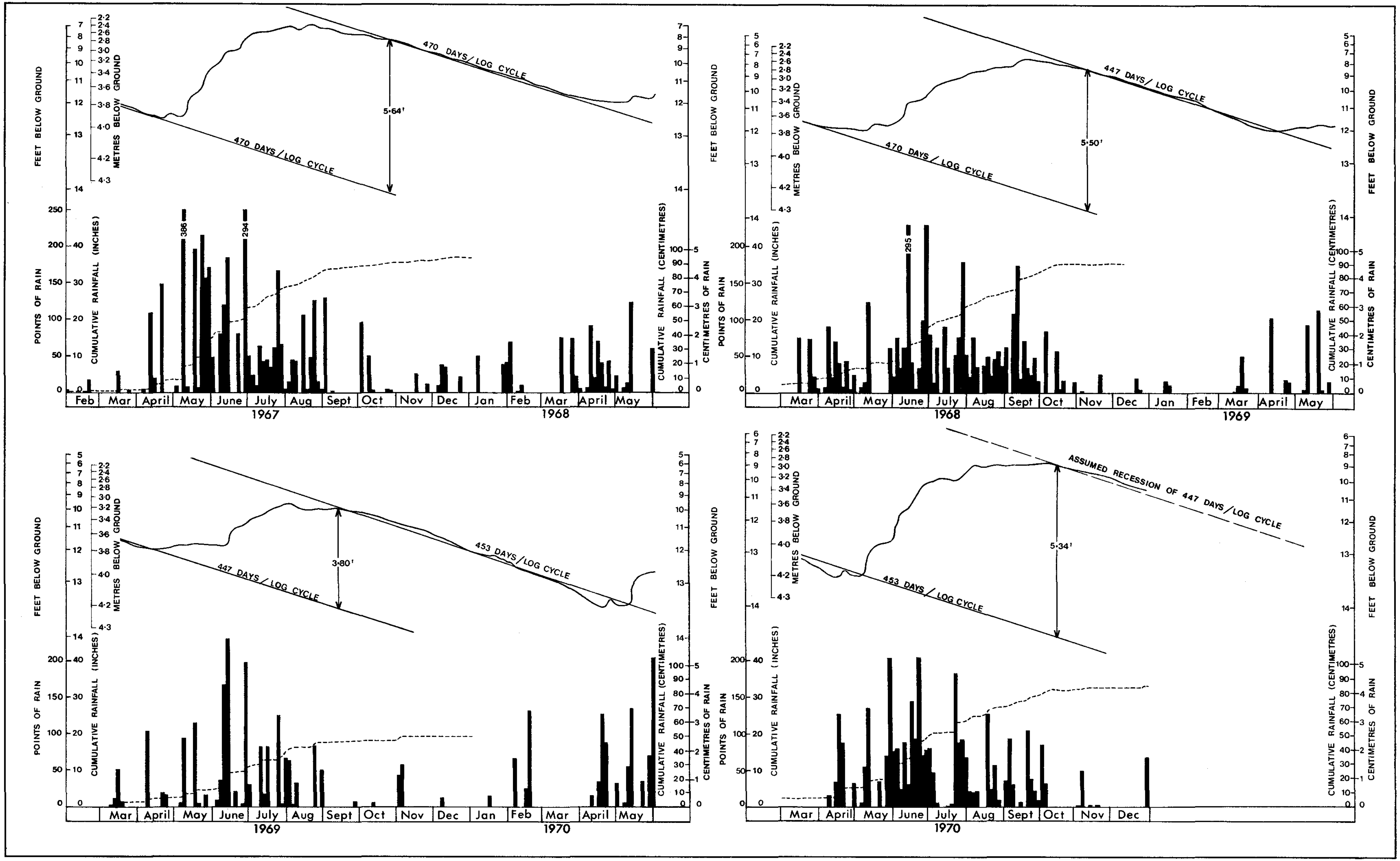


PLATE 3

GNANGARA NO 5 BOREHOLE: HYDROGRAPHS FOR 1967 – 1970 AND RAINFALL HYPSOGRAMS

12266

ment. The hydraulic gradient varies appreciably from place to place with a range of between 6 and 20 feet ($1 \cdot 1$ to $3 \cdot 8 \times 10^{-3}$ to one) per mile. It is particularly steep in the vicinity of the three surface discharges for groundwater: Lake Gnangara (evaporation), Emu Swamp (evaporation) and Bennett Brook (springs). Apart from the last, there is no surface runoff in the drilled area. The water table is generally not more than 16 feet (4·8 m) below the surface within the North Gnangara area, and the average depth during the early winter is about 6 feet (1·8 m).

SEASONAL FLUCTUATIONS IN WATER LEVEL

The water table changes in elevation in response to rainfall, but data are lacking on differences of magnitude over the area of study. However, in the absence of any marked areal variations in rainfall, the amount of any rise that occurs will probably be the same throughout the area, and any associated increase in the regional hydraulic gradients will be slight. On a regional scale, seasonal changes of gradient are of the order of 3 feet (1 m) over 12 miles (19 km) or say 0·25 feet ($4 \cdot 7 \times 10^{-5}$ to one) per mile over a whole year. As the range of gradients has been established as 6 to 20 feet ($1 \cdot 1 \times 10^{-3}$ to $3 \cdot 8 \times 10^{-3}$ to one) per mile, seasonal changes are about 4 per cent. However, more marked seasonal changes of gradient are probable near the three surface outlets. The springs feeding Bennett Brook show increased discharges as the water table gradient steepens during winter rainfall.

Water levels in bore No. 5 from February, 1967, have been plotted (Plate 3), which indicates that the water table levels lie in the range 11·9 to 13·5 feet (3·63 to 4·12 m) below the surface, between mid-April and mid-May. The maximum elevations, which occur between August and September, lie in the range 6·9 to 9·6 feet (2·10 to 2·93 m) below the ground. Shortly after reaching a maximum the hydrograph tends to follow a straight line recession until next seasonal rise takes place.

SALINITY PATTERN

The water samples collected during pump testing had a range of total dissolved solids of 220 to 520 ppm, between one-half and two-thirds being sodium chloride. This is a low salinity and a sensitive guide to movement, and the extent to which the concentration of dissolved salt increases is apparent from the contours of equal chloride concentration (Plate 2).

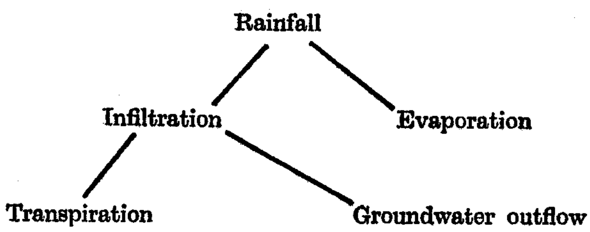
The chlorinity is least at bore 320, increasing towards the west, south and east. However, "troughs" of low chlorinity extend towards the three surface water outlets already referred to, corresponding to relatively high rates of groundwater movement in their directions. Conversely, relatively high chlorinities occur at bore 110 and west of Lake Gnangara.

THE WATER BALANCE MODEL

In the virtual absence of surface runoff, the hydrologic regime can be illustrated by a diagram, necessarily somewhat idealised because some components cannot be separated without more data.

Annual rainfall is divisible into two components, one which adds water to underground storage and another which does not. The latter includes direct evaporation, soil wetting and plant transpiration losses.

The infiltration of groundwater component is also divisible into a relatively small movement out of the area and a large transpiration loss.



Rainfall therefore contributes to four components, a composite and a simple component that may be directly derived from available data, and the remaining two by difference.

WATER BALANCE AT GNANGARA

The area analysed is between the 122 and 149–foot (37·2 and 45·4 m) water table contours (Sections A–A and B–B) bounded laterally by the curved lines A–B. This has a surface extent of 8·55 square miles (2,214 ha). Although a small part of the North Gnangara area near sites 130 and 140 is thus excluded, this is more than compensated for by the addition of an area west of site 200.

A further catchment area C–B–B of 2·71 square miles (702 ha), is also considered in the calculation.

Rainfall

Annual rainfall from 1967 to 1970 is in Table 1, together with the calculated input to the area A–B–B–A in millions of gallons. In the drought year 1969 this amounted to 2,420 million gallons ($11 \cdot 00 \times 10^6$ m^3), but the mean for the four years analysed is 3,980 million gallons ($18 \cdot 09 \times 10^6$ m^2).

TABLE 1. ANNUAL WATER BALANCE

Year	Water Level in No. 5 Bore (feet below surface)		Total Annual Rainfall (1)		Infiltration (2)			Evaporation (3)			Transpiration (5)			Groundwater Outflow (4)	
	Maximum	Minimum	Inches	Million galls.	Inches	Million galls.	% of (1)	Inches	Million galls.	% of (1)	Inches	Million galls.	% of (1)	Million galls.	% of (1)
1967	6·9	12·5	37·15	4,710	20·30	2,575	54·6	16·85	2,125	45·4	18·14	2,302	48·8	273	5·8
1968	7·5	11·9	35·57	4,510	19·80	2,512	55·6	15·77	1,998	44·4	17·65	2,239	49·6	273	6·0
1969	9·6	12·0	19·15	2,430	13·68	1,735	71·4	5·47	695	28·6	11·52	1,462	60·2	273	11·2
1970	8·7	13·5	33·75	4,280	19·22	2,438	56·9	14·53	1,842	43·1	17·07	2,165	50·5	273	6·4
Mean	....	....	31·40	3,980	....	....	59·6	....	....	40·4	....	....	52·3	273	7·3

(1 inch = 2·54 cm ; 1 foot = 0·305 m ; 1 million gallons = 4,546 m^3)

Total Infiltration

Most of the rain falls during a fairly short period of time and the water table responds sharply. Rorabaugh (1960) has shown that following such recharge the water levels fall exponentially with time after a period of stabilisation.

Although affected by summer rainfall, the groundwater hydrographs for Gnangara No. 5 bore do follow a fairly straight line recession at the rate of 10 feet change of level in 437 to 470 days (1 m in 143 to 154 days). Each period of rainfall imposes further recharge on an existing curve of recession, the volume of such infiltration being calculable from the curve displacement, if the specific yield of the re-saturated aquifer is known.

So far no pump test at Gnangara has continued long enough to cause complete gravity drainage, and hence the ultimate specific yield has not been determined. However there is little doubt that in an essentially unconfined aquifer, a relatively large figure is probable, and is here assumed to be 0·3.

As each water level recession is exponential, the amount of the displacement between the two exponential lines is time dependent. This displacement is larger if measured in the middle of the period of recharge than at the end. The actual elevations and the times of occurrence of the maximum and minimum water levels depend on the rainfall distribution, and should not be used to assess total infiltration. However, the water table response will be substantially complete after 95 per cent of the rain has fallen; and appropriate time to measure the water table rise caused by infiltration. For 1967 (Plate 2) this rise is taken to be 5·64 feet (1·72 m) near the end of October. By chance the difference between the measured minimum and maximum water levels is 5·6 feet (1·71 m) (Table 1), and for this recharge period the infiltration is taken to be $5 \cdot 64 \times 12 \times 0 \cdot 3$ or 20·3 inches (51·6 cm). The infiltration for the succeeding 3 years has been similarly derived. However the displacement between the recession curves before and after recharge is larger than the difference between the minimum and maximum water levels by up to 58 per cent (for 1969) for the reason mentioned.

During the recharge period, water levels follow successive small recession curves after each rainfall, and also some evapo-transpiration will be occurring. It is not possible to take full account of these influences, so that the derived figure of infiltration must be regarded as that part of the total infiltration remaining after that period.

As determined, the infiltration accounts for between 54·6 and 71·4 per cent of the annual rainfall and is greatest when the water table is low.

Evaporation

This is taken as the difference between total annual rainfall and the infiltration figure just described. It necessarily includes water taken up by wetting the soil profile or used directly by plants both during and partly subsequent to the recharge period.

For natural water level fluctuations evaporation is greatest when the water table is at its shallowest, and lies in the range 28·6 to 45·4 per cent of the total annual rainfall.

Groundwater Outflow

This may be defined as the contribution to groundwater discharge made by rainfall on the area, and is the difference between the total groundwater outflow and groundwater inflow from outside the area.

Two methods may be used to estimate the groundwater outflow: one is by the application of groundwater hydraulics to flow through aquifer sections and the other is by estimating this from the degree to which cyclic salt becomes concentrated during subsurface water movement.

(a) *Hydraulic Method.* The inflow may be derived by the application to section B–B of d'Arcy's law, which states that the quantity of water passing is proportional to the permeability, hydraulic gradient, and cross sectional area.

The mean of the transmissivities derived from the pump tests on bores 300, 310, 320, 330 and 340 is 20,400 gpd/ft (304 m^3/day/m) and the mean hydraulic gradient is 12·6 feet per mile ($2 \cdot 39 \times 10^{-3}$ to one) (measured at six equally spaced points). The section is 2·375 miles (3·821 km) long. Hence

$$Q = 20{,}400 \times \frac{12 \cdot 6}{5{,}280} \times 2 \cdot 375 \times 5{,}280$$
$$= 610{,}500 \text{ gallons } (2{,}776 \text{ m}^3) \text{ per day.}$$

Similarly the total groundwater discharge may be calculated. The mean of the transmissivities obtained at sites 100, 110, 120, 130, 140 and 200 is 14,100 gpd/ft (210 m^3/day/m) and the mean gradient 15·7 feet per mile ($2 \cdot 97 \times 10^{-3}$ to one).

Thus as the section A–A is 5·0 miles (8·02 km) long the discharge

$$Q = 14{,}100 \times \frac{15 \cdot 7}{5{,}280} \times 5 \cdot 0 \times 5{,}280$$
$$= 1{,}107{,}000 \text{ gallons } (5{,}032 \text{ m}^3) \text{ per day.}$$

The net groundwater discharge due to rainfall within the area under study is 1,107,000 minus 610,500 or 496,500 gallons (2,257 m^3) per day.

(b) *Chlorinity method.* The aquifer has been continually leached during Quaternary time, and it is virtually certain that all the original salt has been removed, the only source of salt now present in groundwater being from rainfall. Teakle (1937) determined the mean salt (NaCl) content of the rainfall at the Perth Observatory (5½ miles (8.4 km) east of the shoreline) as being 27.2 ppm by titration. The chloride ion concentration is thus

$$\frac{27.2 \times 35.5}{58.5} = 16.5 \text{ ppm.}$$

All this salt is retained within the soil, aquifer material, and groundwater. Through evaporation and transpiration losses, the salt becomes progressively concentrated during groundwater movement. The mean chlorinity of the groundwater passing through the section A–A is 141 ppm, hence it may be inferred that the rainwater falling on the catchment has become concentrated in the ratio 16.5 : 141, so that only the fraction $\frac{16.5}{141}$ of the total annual rainfall remains as groundwater discharge from that catchment.

The area of the catchment commanded by section A–A is 8.55 + 2.71 or 11.26 square miles (2,916 ha), hence if the mean annual rainfall is 31.40 inches (79.76 cm) the mean daily discharge is:

$$\frac{11.26 \times 31.40 \times 14.8346 \times 10^6}{365} \times \frac{16.5}{141} = 1.681 \text{ million}$$

gallons (7,642 m^3).

However, it is necessary to deduct the groundwater inflow through the section B–B, in order to determine what proportion of the total groundwater discharge originates solely within the defined area A–B–B–A.

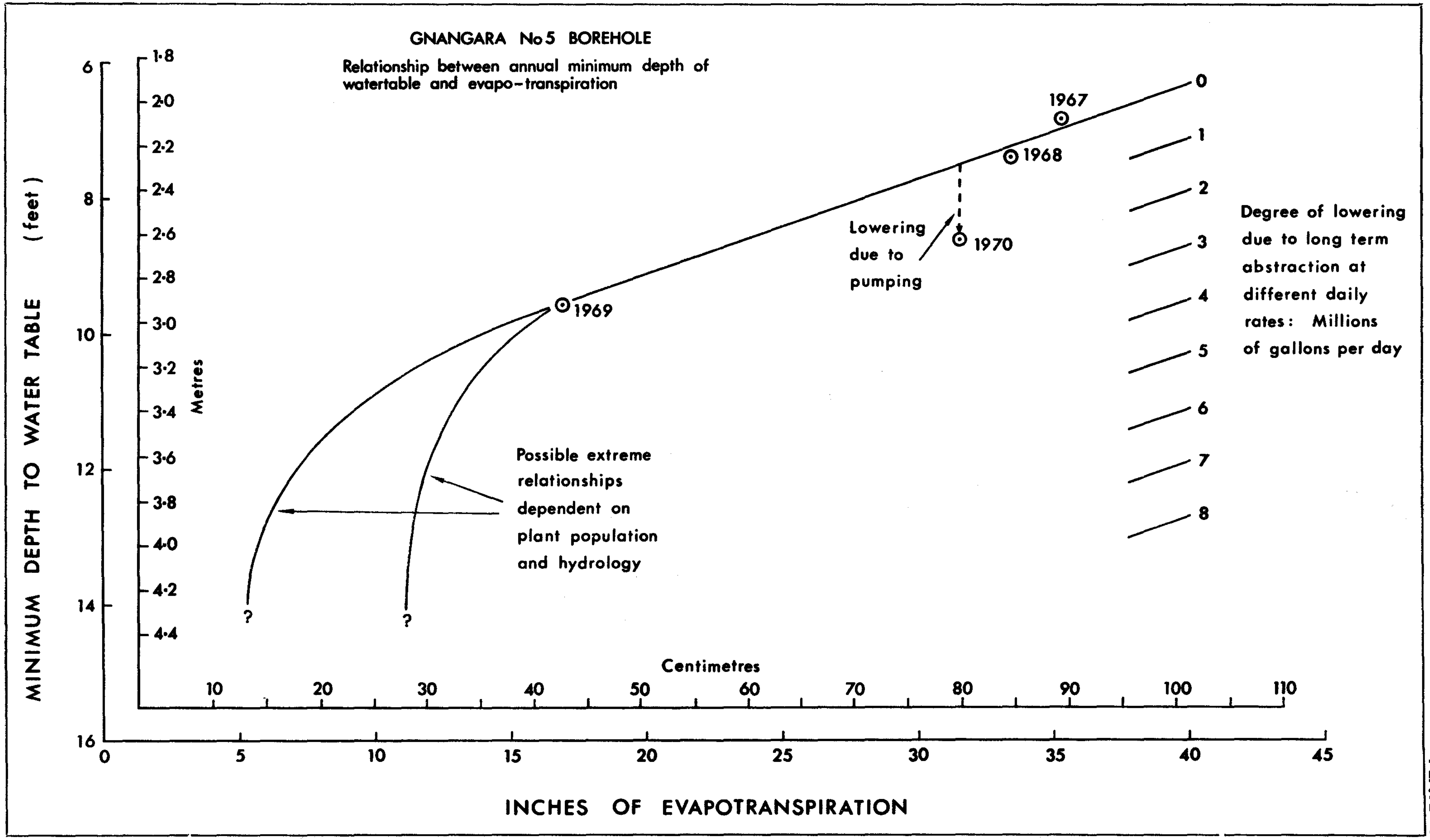


PLATE 4

12263

The mean chlorinity in this section is 84 ppm and as the catchment area is 2.71 square miles (702 ha), the daily inflow is:

$$\frac{2.71 \times 31.40 \times 14.8346 \times 10^6}{365} \times \frac{16.5}{84} \text{ or } 679{,}000 \text{ gallons } (3{,}087 \text{ m}^3) \text{ per day.}$$

The net groundwater discharge by this method is 1,681,000 minus 679,000 or 1,002,000 gallons (4,555 m^3) per day.

The mean of the discharges determined by the two methods is 749,000 gallons (3,405 m^3) per day or 273 million gallons (1.24×10^6 m^3) per year. As the hydraulic gradients are unlikely to vary appreciably with time under normal conditions, this discharge is not expected to vary greatly from year to year and it is suggested that 4 per cent (see p. 15) is the maximum regional order of variation from the mean. However for the present purposes the discharge is assumed to be constant and the mean annual rainfall contribution is 7.3 per cent.

Transpiration

After deducting the groundwater discharge, the rest of the total infiltration is lost by transpiration, abstraction by pumping, and by downward seepage to deep aquifers.

Pumping would appear, from the hydrographs to be increasing with time. In March to May 1970 the water level has clearly been lowered below the recession line. This is probably more than a local pumping effect near the observation bore, as the peak water level in 1970 falls below the predicted level (Plate 4).

The amount of downward seepage to deep aquifers is unknown, but should be determined by pump tests. There is nevertheless little doubt that a large proportion of water is lost by transpiration.

The transpiration loss is greatest when the water table is highest (18.14 inches at a peak water level of 6.9 feet below ground as compared with 11.52 inches when the peak level is 9.6 feet below ground).

CONCLUSIONS

1. Approximately 93 per cent of the mean annual rainfall of about 31.40 inches (79.76 cm) is currently being lost by evaporation and transpiration and only 7 per cent contributes to groundwater discharge.

2. When the water table is low, water losses by evaporation and transpiration are less than when water levels are high. It is anticipated that pumping will reduce such losses by lowering water levels.

3. Under relatively undisturbed conditions, evaporation and transpiration are increasing the concentration of dissolved salts as much as 12 times, and could similarly concentrate chemical and other non-volatile contaminants entering the aquifer.

4. Over a long period of abstraction, the resultant reduction in the evapo-transpiration loss would improve water quality with time as the proportion of "old" groundwater in storage is reduced.

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THE AQUIFER CHARACTERISTICS AND YIELD OF THE GNANGARA SAND BEDS 1970 PUMP TEST SERIES

by T. T. Bestow

ABSTRACT

Drawdown data derived from test pumping on 13 sites located in the North Gnangara area have been analysed by distance-drawdown methods to derive aquifer characteristics for the Quaternary sand aquifers. The analyses show these to have transmissivities in the range of approximately 6,200 to 36,500 gallons per day per foot (92·5 to 544 m^3/day/m) with a mean of 16,000 gpd/ft (239 m^3/day/m). However the aquifer storage coefficients at all sites have been shown to be dependent on the pumping time. This is due to delayed gravity drainage and it is anticipated that much longer periods of pumping would be required to determine the ultimate values than were available in the test series. The maximum values reached in 48 hours were found to be in the range 0·01 to 0·16.

INTRODUCTION

In the first half of 1970, 13 out of a total of 15 pumping boreholes, in a production field of about 7½ square miles (194 ha) had been test pumped. One was tested for a period of 3 days and the remainder for 2 days. Pumping rates were in the range 5,400 to 25,000 gph (589 to 3,434 m^3/day) with a mean of 12,800 gph (1,397 m^3/day).

The apparently low storage coefficient arrived at by computer-oriented analysis of aquifer characteristics based on leaky-artesian curve-matching techniques, gave cause for concern. A low coefficient would of course indicate that the quantity of water in storage could be less than that needed to sustain long term production, and that large long-term drawdowns would be inevitable.

The current study has therefore been directed to the following objectives:

1. To determine the general hydraulic conditions.
2. To assess the aquifer characteristics.

GEOLOGY

The Gnangara sand beds, which are of Quaternary age, consist of medium to fine-grained, poorly sorted sands with a variable clay content. Within the area of the current tests these sands reach a thickness of up to 170 feet (51·8 m). Locally, clay predominates to form more or less impermeable bands which may persist over appreciable areas. A sandy limestone occurs over parts of the area, particularly near the base of the sequence and immediately above the greensands and silts of the underlying Upper Cretaceous formations. The latter provides a slightly undulating floor which also marks the unconformity below the Quaternary.

HYDROLOGY

Groundwater occurs under essentially unconfined conditions within the sand beds, but may locally be subject to some degree of confinement below clay lenses. The water table is at a depth of between 3 and 15 feet (1 to 5 m) below the natural surface. Recharge takes place directly by infiltration from rainfall and there is also underflow from the north and northwest. The hydraulic gradient is about 13 feet ($2 \cdot 46 \times 10^{-3}$ to one) per mile (Plate 2 of Bestow, 1971). Groundwater discharge takes place by underflow to the southeast and southwest, by spring discharge in the vicinity of bore 140, and also by evaporation from swampy ground and by transpiration from plants. There may also be a downward movement of groundwater into the underlying Upper Cretaceous beds.

TEST CONDITIONS

At each test pumping site observation boreholes were laid out on two lines, approximately at right angles north-south and east-west with the pumping bore at the intersection. Observation bores were generally placed at 50 and 150 feet (15·2 and 45·7 m) on one line and at 75 and 225 feet (22·9 and 68·6 m) from the pumping bore on the other. These bores had 3-inch (7·6 cm) diameter PVC casing inserted, with slots at depths which corresponded with those in which a screen was installed in the pumping borehole. An additional observation borehole was sited approximately 100 feet (30·5 m) from the pumping bore, with casing slots over nearly the full thickness of the aquifer. The screen of the pumping bore was installed in the coarsest sand, the aperture size being determined as a result of sieve analyses of samples recovered from the test interval. A 60 per cent pass figure was taken as being the appropriate aperture size. Bore development was conducted by surging and air lifting.

METHODS OF ANALYSIS

The analyses and interpretation of pump test data must necessarily be based on certain assumptions having regard to the hydraulic conditions. However, natural conditions frequently diverge from the ideal and it is necessary to accept approximations in order to derive meaningful information, however approximate this may be.

Under conditions in which a borehole is pumped at a constant rate, and yet the resultant changes in hydraulic head in the surrounding aquifer have not reached equilibrium, it is theoretically possible by the Theis formula to relate the drawdown or lowering of head, which occurs at a particular distance from a pumping bore, to the aquifer characteristics. This is strictly applicable only if the following conditions pertain:

1. The water-bearing formation is isotropic or has uniform hydraulic properties in both horizontal and vertical directions.
2. The formation has a uniform thickness and is of infinite areal extent.
3. No addition or depletion of the volume of groundwater is made except by pumping.
4. The pumped well penetrates the full thickness of the aquifer.
5. The water removed from storage in the formation is discharged instantaneously as the head is reduced.

Although the Gnangara sand beds are of fairly uniform thickness through the area influenced by a lowering of the hydraulic head during the course of a particular pump test, the formation itself is far from uniform. Both vertical and horizontal variations in permeability undoubtedly occur within the area of influence of a pumping bore.

Although recharge may have occurred in the course of some tests as a result of rainfall, this is likely to have been slight. In no case did the pumping well fully penetrate the aquifer and in consequence the flow lines of water entering the pumping bore from the formation were convergent.

The modified Theis formula states that

$$s = \frac{114 \cdot 6\, Q \quad W(u)}{T}$$

Where s is the drawdown in feet at any point in the vicinity of a constantly discharging borehole, Q is the rate of discharge in gallons per minute.

T = transmissivity in gallons per day per foot.

W(u) is the well function of u.

The Theis formula also states that

$$u = \frac{1 \cdot 56\, r^2 S}{Tt}$$

Where r is the distance in feet from the centre of the pumping bore to the point of drawdown measurement.

S = coefficient of storage.

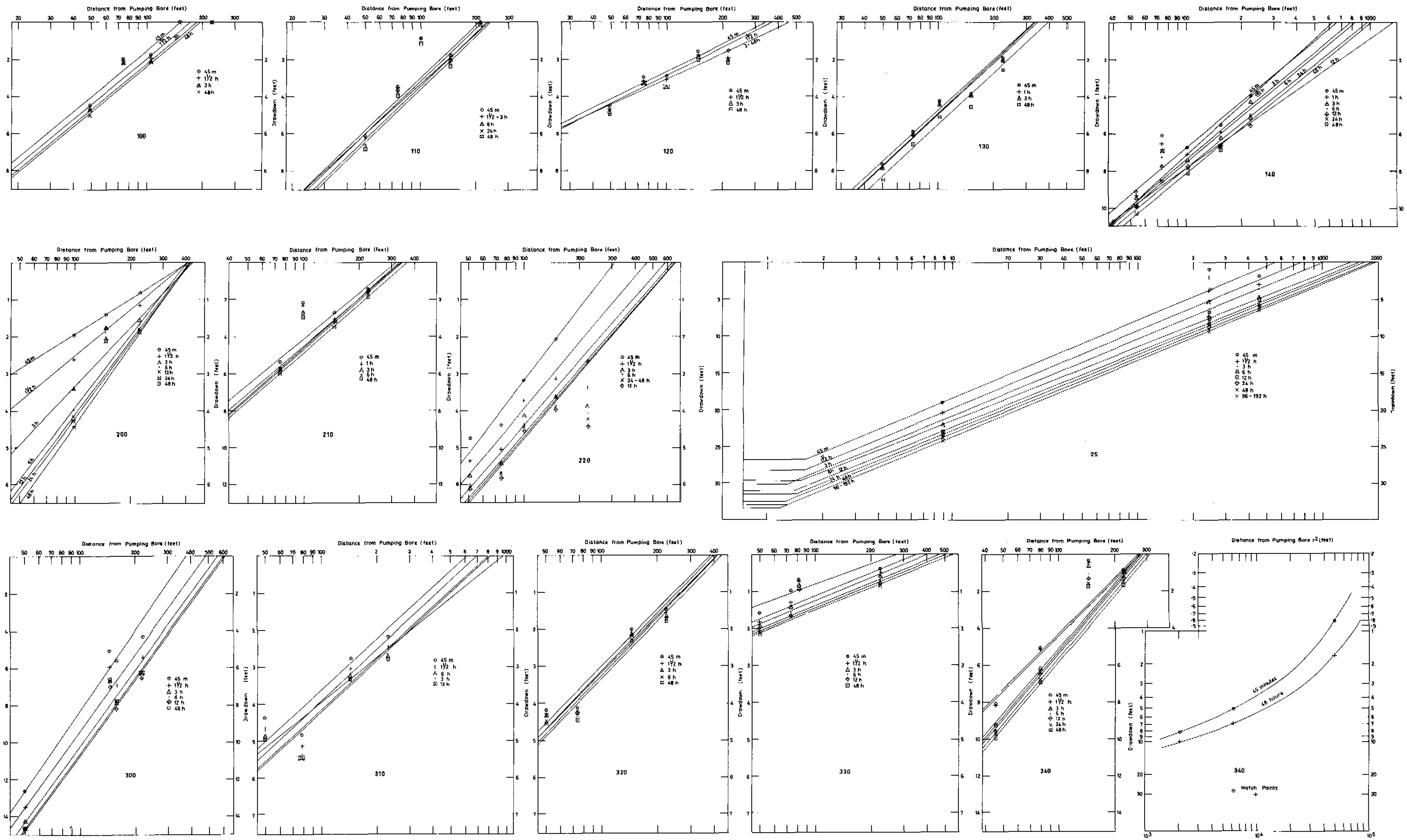
t = time since pumping started in days.

The parameters T and S may be derived by the well known method of matching a curve of log drawdown (for each observation bore) against log time on an appropriate scale with a master curve of W(u) versus u. Figures for u, W(u), S and t may be derived from a match point and applied to the above formula. However such simple matches are not possible with the data from Gnangara owing to divergence from the type curve. This divergence could be interpreted as a boundary condition consequent upon either recharge at a distance or leakage under confined conditions. Matches are in most cases obtainable with the curves of Hantush and Jacob (1955) which take account of downward leakage through a confining bed under essentially leaky artesian conditions. Pertinent figures for T may be derived by this method but it is questionable whether the vertical permeability or coefficient of storage (S) are valid owing to the difficulty of defining a confining bed and the fact that S is apparently not constant. It can be shown by other methods to vary with time.

One of the assumptions listed above in the derivation of the Theis formula is that the water removed from storage is discharged instantaneously with the decline in head. However, some unconfined aquifers drain relatively slowly within the cone of depression so that complete gravity drainage can take many days depending on the nature of the formation.

The problem of drainage or delayed yield has been analysed by Boulton (1954) who took account of differences of vertical and horizontal permeability. The analysis of pump test data by this method follows similar graphic techniques to Theis in that log plots of s against log time must be matched with type curves on an appropriate scale. However an unambiguous match can only be obtained by the continuance of pump tests for sufficiently long periods of time. In the case of the tests on the Gnangara sand beds this would be dependent on the vertical permeability and is estimated to be between 4 and 110 days. As only short term tests were carried out this method may not be applied.

Lohman (1970) has suggested in unpublished work that in an ideal test situation the coefficient of storage, S, should be calculated on intervals of say 2 days during a long period test and a graph prepared of S against t. This would show that S would approach a maximum value with time and that S and T should be determined for that time.



DISTANCE - DRAWDOWN PLOTS FOR GNANGARA BOREHOLES

This period of time would be a constant for all observation wells, hence S and T could be calculated from an equation in which only s and r are variables. In the case of relatively thin unconfined aquifers Jacob's correction to the observed drawdown s and derived value of S should be applied in straight line solutions of the non-steady state flow equation derived by Cooper and Jacob (1946) and also Jacob (1950). Although this method has serious shortcomings in this context, it has been adapted for the derivation of the Gnangara sand bed aquifer characteristics as it is convenient and probably makes best use of the data provided by short term pump tests when S is not constant.

DERIVATION OF AQUIFER CHARACTERISTICS FROM DISTANCE DRAWDOWN

GENERAL APPLICATION

Cooper and Jacob showed that for small values of u, (i.e. $\frac{1 \cdot 56\ r^2\ s}{Tt}$ is less than $\cdot 01$, the minor terms in the infinite series relating W(u) to u could be neglected so that

$$T = \frac{528\ Q}{\triangle\ s}$$

Where Q is discharge in gallons per minute and $\triangle$ s is the slope of the distance-drawdown graph (i.e.) change of drawdown in feet over a log cycle plot of distance).

and $$S = \frac{0 \cdot 36\ Tt}{r_0^2}$$

Where r_0 is the distance at which the projected distance-drawdown line meets the zero drawdown axis (s = o).

However other authorities state that results are acceptable up to values of u of 0·05 (Johnson, 1966).

As the conditions for the Gnangara pump tests generally exceed the limit for u of 0·01 and indeed exceed 0·05 in many instances, it is necessary to be clear as to the effects exercised by the variables contained in this parameter.

$$U = \frac{1 \cdot 56\ r\ \ S}{Tt}$$

As S appears in the numerator it is obvious that other things being equal, u is larger for unconfined aquifers than it is for confined ones. When the method is applied to unconfined conditions t must be much larger than when testing under confined conditions. As r also appears in the numerator and is squared the use of drawdown measurements in distant bores required that t must be large to compensate. As T appears as a denominator, large values of transmissivity favour the use of the method, whereas small values necessitate larger values of t.

GNANGARA SAND BEDS

The water level measurements for all boreholes subjected to test pumping at t = 45m, 1½h, 3h, 6h, 12h, 24h and 48 hours have been corrected in accordance with Jacob on the presumption that the Gnangara sand beds are underlain by essentially impermeable material.

$$s^1 = s - \frac{s^2}{2b}$$

Where s^1 is corrected drawdown, s is measured drawdown and b is saturated aquifer thickness.

These corrected data have been used to prepare distance-drawdown graphs for each of the sites tested (Plate 5). So far as is practicable, separate lines have been drawn for each of the times listed above. The straight line plots have been drawn through the mean of the drawdown points where these do not actually fall on a straight line. The data provided by boreholes that are not responding to pressure changes have been ignored. In consequence of this, the plots relating to only three sites actually use the data from all five observation boreholes and six plots use the data from only three observation bores.

In most instances the distance-drawdown plots are nearly parallel, which gives consistent values of transmissivity. However at Site 200 marked changes in the slope of the distance-drawdown plots with time probably reflect variations in the pumping rate (Plate 5).

Values of T and S have been calculated from the Cooper and Jacob formulae for each of the times listed, between 45 minutes and 48 hours, and are shown in Table 1.

TABLE 1. AQUIFER CHARACTERISTICS DERIVED FROM DISTANCE/DRAWDOWN

Gnangara Borehole No.	Pumping Rate (gph)	Aquifer Thickness b(feet)	Time		Radius of Depletion Cone r_0 feet	Slope of d.d Plot s	Transmissivity T gallons/day/ft	Storage Coefficient	
			Hours	Days				Derived S	Corrected S^1
100	6,000	135	¾	·03125	154	8·3	6,450	·003	·003
			1½	·06250	171	8·3	6,350	·005	·005
			3	·125	184	8·3	6,350	·008	·007
			6	·25	190	8·2	6,400	·16	·015
			12	·5	190	8·1	6,500	·032	·029
			24	1	195	8·1	6,500	·065	·060
			48	2	195	8·1	6,500	·120	·110
						Mean	6,420		
						Estimated....	6,400		
110	15,300	140	¾	·03125	210	9·5	14,200	·0036	·0033
			1½	·06250	220	9·5	14,200	·0066	·0062
			3	·125	220	9·5	14,200	·0130	·0120
			6	·25	230	9·1	14,800	·0250	·0230
			12	·5	230	9·6	14,100	·0480	·0430
			24	1	230	9·6	14,100	·0970	·0890
			48	2	240	9·6	14,100	·1800	·1600
						Mean	14,240		
						Calculated....	12,000		
120	7,000	127	¾	·03125	340	5·0	12,300	·001	·001
			1½	·06250	366	5·0	12,300	·002	·002
			3	·125	460	4·6	13,400	·003	·003
			6	·25	460	4·6	13,400	·006	·006
			12	·5	460	4·6	13,400	·012	·011
			24	1	460	4·6	13,400	·023	·022
			48	2	460	4·6	13,400	·046	·043
						Mean	13,080		
						Rounded	13,000		

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TABLE 1: AQUIFER CHARACTERISTICS DERIVED FROM DISTANCE/DRAWDOWN—*continued*

Gnangara Borehole No.	Pumping Rate (gph)	Aquifer Thickness b(feet)	Time		Radius of Depletion Cone r_e feet	Slope of d.d Plot s	Transmissivity T gallons/day/ft	Storage Coefficient	
			Hours	Days				Derived S	Corrected Si
130	20,000	129	¾	·03125	330	9·1	19,300	·002	·002
			1½	·06250	330	9·4	18,700	·004	·004
			3	·125	345	9·3	18,900	·007	·006
			6	·25	355	9·3	18,900	·013	·012
			12	·5	370	9·3	18,900	·025	·022
			24	1	380	9·3	18,900	·047	·042
			48	2	390	9·3	18,900	·089	·080
						Mean	18,900		
						Estimated....	18,700		
140	14,000	124	¾	·03125	660	8·3	14,900	·0004	·0004
			1½	·06250	620	9·0	13,700	·0008	·0007
			3	·125	780	8·3	14,900	·0009	·0008
			6	·25	830	8·3	14,900	·0019	·0017
			12	·5	1,300	7·0	17,600	·0019	·0017
			24	1	960	8·0	15,400	·006	·0054
			48	2	1,000	8·1	15,200	·011	·0099
						Mean	15,200		
						Estimated....	15,000		
200	11,900	157	¾	·03125	410	3·25	32,400	·002	·002
			1½	·06250	410	4·20	25,000	·003	·003
			3	·125	440	5·25	19,800	·005	·005
			6	·25	405	6·50	16,100	·009	·008
			12	·5	420	6·60	15,900	·016	·015
			24	1	420	6·70	15,700	·032	·030
			48	2	420	7·10	14,800	·060	·056
						Mean	20,000		
210	6,500	159	¾	·03175	320	8·35	6,850	·0008	·0007
			1½	·06250	330	8·60	6,650	·0014	·0013
			3	·125	330	8·90	6,400	·0026	·0024
			6	·25	340	8·80	6,500	·0051	·0047
			12	·5	350	8·75	6,500	·0095	·0081
			24	1	360	8·70	6,550	·0180	·0170
			48	2	370	8·70	6,550	·0340	·0310
						Mean	6,570		
						Estimated....	6,200		
220	10,000	144	¾	·03125	310	6·45	13,600	·0016	·0015
			1½	·06250	460	5·90	14,900	·0016	·0015
			3	·125	580	5·75	15,300	·0020	·0018
			6	·25	630	5·75	15,300	·0035	·0033
			12	·5	660	5·80	15,200	·0063	·0059
			24	1	650	5·75	15,300	·0130	·0120
			48	2	650	5·75	15,300	·0260	·0240
						Mean	15,000		
						Estimated....	15,000		
300	25,000	161	¾	·03125	370	14·30	15,400	·0013	·0011
			1½	·06250	480	13·80	16,000	·0015	·0013
			3	·125	560	13·60	16,200	·0023	·0020
			6	·25	590	13·50	16,300	·0042	·0037
			12	·5	610	13·45	16,300	·0078	·0068
			24	1	610	13·45	16,300	·0156	·0140
			48	2	610	13·45	16,300	·0312	·0250
						Mean	16,100		
						Estimated...	16,100		
320	7,000	164	¾	·03125	390	5·25	11,700	·0009	·0008
			1½	·06250	400	5·20	11,800	·0017	·0016
			3	·125	420	5·15	11,900	·0030	·0029
			6	·25	410	5·30	11,600	·0062	·0059
			12	·5	430	5·25	11,700	·0110	·0100
			24	1	440	5·20	11,800	·0290	·0210
			48	2	450	5·20	11,800	·0440	·0420
						Mean	11,800		
						Estimated....	11,500		
330	5,400	112	¾	·03125	265	1·80	26,200	·0042	·0041
			1½	·06250	340	2·10	26,700	·0044	·0043
			3	·125	400	2·05	23,600	·0065	·0064
			6	·250	640	2·10	22,700	·0097	·0095
			12	·5	500	2·05	23,200	·0170	·0170
			24	1	520	2·00	23,800	·0320	·0310
			48	2	550	2·00	23,800	·0570	·0560
						Mean	23,700		
						Estimated....	23,500		
340	20,800	155	¾	·03125	275	9·95	18,400	·0027	·0025
			1½	·06250	280	10·05	17,400	·0050	·0045
			3	·125	275	11·70	15,700	·0074	·0066
			6	·25	280	11·70	15,700	·0180	·0160
			12	·5	290	11·70	15,700	·0340	·0300
			24	1	300	11·75	15,600	·0620	·0550
			48	2	310	11·80	15,500	·1100	·0980
						Mean	16,300		
						Calculated from Theis curve (at t = 48h)	13,200	·173	·154
25	12,120	126	¾	·03125	540	10·7	10,000	·0004	·0004
			1½	·06250	760	10·5	10,200	·0004	·0004
			3	·125	1,000	10·4	10,300	·0005	·0004
			6	·25	1,400	10·0	10,600	·0005	·0004
			12	·5	1,560	10·2	10,500	·0008	·0007
			24	1	1,700	10·2	10,500	·0014	·0012
			48	2	1,800	10·3	10,400	·0024	·0021
			96	4	1,900	10·4	10,300	·0043	·0037
			192	8	1,900	10·4	10,300	·0086	·0075
						Mean	10,300		

1 gph = 0·1091 m^3/day; 1 ft = 0·3048 m; 1 gallon per day per foot = 0·01491 m^3/day/m.

Fairly typical conditions are displayed at Site No. 140 where bore 140F was pumped at 14,000 gallons per hour (152 m^3/day) and the rate of drawdown increase per log cycle of distance is 8·3 feet (2·53 m) (from Plate 5) at 45 minutes.

Then

$$T = \frac{528 \times Q}{\Delta s} = \frac{528 \times 14{,}000}{8 \cdot 3 \times 60}$$

= 14,900 gallons per day per foot (222 m^3/day/m)

The distance-drawdown line intercepts the zero drawdown axis at 660 feet and as

$$S = \frac{0 \cdot 36\ T\ t}{r_0^2} = \frac{0 \cdot 36 \times 14{,}900 \times 0 \cdot 03125}{660^2} = 0 \cdot 0004$$

As the aquifer tested is relatively thin, it is necessary to apply a correction to this value of storage coefficient so that $S' = \frac{(b - s')}{b} S$

where s' is the drawdown at the geometric mean distance.

In this instance

$$S' = \frac{(124 - 11 \cdot 5)}{124} 0 \cdot 0004$$

= 0·0004 (to the nearest whole figure)

For this value of S and at r = 226 feet (68·9 m)

$$u = \frac{1 \cdot 56\ r^2\ S}{Tt} = \frac{1 \cdot 56 \times 226^2 \times \cdot 0004}{14{,}900 \times \cdot 03125} = 0 \cdot 068$$

This is in excess of the ideal limit of 0·01 and also the desirable limit of 0·05 (at the outermost observation borehole).

However a check drawdown calculation at r = 226 feet (68·9 m) may be made by applying the Theis equation to using the parameters derived from the distance-drawdown calculation.

$$s = \frac{114 \cdot 6\ Q\ W(u)}{T}$$ so that for

$$u = 0 \cdot 068$$

$$W(u) = 2 \cdot 178$$ and

$$s = \frac{114 \cdot 6 \times 14{,}000 \times 2 \cdot 178}{14{,}900 \times 60}$$

= 3·91 feet (1·189 m)

This corresponds closely with the corrected measured drawdown of 3·89 (1·186 m) and as the value of u decreases for observations nearer the pumping borehole it follows that the values of S and T derived for this period of pumping are substantially correct.

Values of S and T may be similarly calculated for Site No. 140 from the distance-drawdown data for the pumping periods 1½ to 48 hours. At 48 hours

$$T = \frac{528 \times 14{,}000}{60 \times 8 \cdot 1}$$

= 15,200 gallons per day per foot (227 m^3/day/m) and

$$S = \frac{0 \cdot 36 \times 15{,}200 \times 2}{1{,}000^2} = 0 \cdot 011$$

$$S' = \frac{(124 - 12 \cdot 1) \times 0 \cdot 11}{124} = 0 \cdot 0099$$

The results of calculations (Table 1) for the intermediate pumping times show that the derived values of T remain within comparatively narrow limits. However the values of S almost double with each doubling of the pumping time (t). This relationship is plotted graphically in Plate 6.

The value of u increases with each increase in S and decreases with every increase in t. Nevertheless as S is not directly proportional to t, u tends to decrease with increasing pumping time.

In the case of No. 140 site at t = 2 days and r = 226

$$u = \frac{1 \cdot 56 \times (226)^2 \times 0 \cdot 009}{15{,}200 \times 2} = 0 \cdot 026$$

This value involves a negligible error in the calculation of S and T.

EFFECTS OF HIGH VALUES OF THE PARAMETER u

When a distance-drawdown analysis is made of other pump tests the value of u is generally greater than 0·068 and reaches a maximum at Site 340 when relatively high values of S have been derived. Here u = 0·88 at 45 minutes and 0·246 at 2 days. It is therefore pertinent to compare the straight line solutions with the matching curve technique in order to assess the magnitude of the error involved in the method adopted.

At this site, observation bores B (at r = 78·75 feet (24·00 m)), C (at r = 223·5 feet (68·12 m)) and D (at r = 45·5 feet (13·87 m)) responded to pumping from bore F; and a log-log plot of draw-down (s) against r^2 matches the Theis curve at each of the two sets of three points (for t = 45 minutes and 48 hours) (Plate 5).

The match point for t = 45 minutes corresponds to

$$W(u) = 10$$

$$\frac{1}{u} = 10$$

r^2 = 6,200 feet (18·90 m)

s = 28 feet (8·53 m)

and as Q = 20,800 gph (2,269 m^3/day)

$$T = \frac{114 \cdot 6\ Q\ W(u)}{s} = \frac{114 \cdot 6 \times 20{,}800 \times 10}{60 \times 28}$$

= 14,200 gpd/ft (212 m^3/day/m)

and

$$S = \frac{T\ t\ u}{1 \cdot 56 \times r^2} = \frac{14{,}200 \times 0 \cdot 03125 \times 0 \cdot 1}{1 \cdot 56 \times 6{,}200} = 0 \cdot 0044$$

then applying Jacobs correction

$$S_1 = \frac{(155 - 13 \cdot 6)}{(\ 155\ )} \cdot 0044 = 0 \cdot 0040$$

The match point for 48 hours corresponds to

$$W(u) = 10$$

$$\frac{1}{u} = 10$$

r^2 = 9,800 feet (2,990 m)

s = 30 feet (9·1 m)

Q = 20,800 gph (2,269 m^3/day)

so that

$$T = \frac{114 \cdot 6 \times 20{,}800 \times 10}{60 \times 30}$$

= 13,200 gpd/ft (197 m^3/day/m)

and

$$S = \frac{13{,}200 \times 20\cdot1}{1\cdot56 \times 9{,}800}$$
$$= 0\cdot173$$
$$S' = \frac{(155 \times 16\cdot8)}{155} 0\cdot173$$
$$= 0\cdot154$$

The errors involved in the straight line solution which have been adopted for this bore (and hence probably the maximum errors for the test series) can be summarised:

t	u	Storage Coefficient			Transmissivity (gallons/day/ft.)		
		st. line solution	matching curve	error	st. line solution	matching curve	error
45m	0·88	0·0025	0·0040	—35%	18,400	14,200	+30%
48h	0·246	0·0980	0·1540	—36%	15,500	13,200	+17%

1 gallon/day/ft = 0·01491 m^3/day/m.

Even an error of 36 per cent is probably less than the range of permeabilities and storage coefficients which exist at each site and is within the range of observational errors possible in the pump tests. The straight line distance-drawdown method of analysis therefore provides a reasonable order of recovery to meet the objectives of the study.

AQUIFER CHARACTERISTICS

Transmissivity

As will be seen from Table 1, the transmissivities derived by the distance-drawdown method for each site generally fall within a narrow range for the period of time over which the analyses have been applied, i.e. 45 minutes to 48 hours. The range of transmissivities derived from the tests on Sites 220, 300 and 340 is appreciable and is thought to be due to variations in the pumping rate in the first 1½ hours. The much more extreme range of transmissivities derived for Site 200 is thought to be due to an increasing pump rate during the test. In consequence of this no great reliance can be placed on the mean transmissivity figure of 20,000 gpd/ft (298 m^3/day/m) calculated for this site. It is more probably nearer 14,000 gpd/ft (209 m^3/day/m).

The estimated transmissivities for each of the test sites show a range from 6,200 (92·5) for Site 210 to 36,500 (544) for Site 310 with a mean for all sites of 16,000 gpd/ft (239 m^3/day/m). As the mean saturated thickness is 147 feet (44·8 m) this represents a mean permeability of 109 gpd/ft^2 (5·32 m^3/day/m^2). This is a value typical of a fine sand (Hurr, 1966); however the range of values indicates a typical grading from very fine sand to medium sand.

Storage coefficient

The distance-drawdown analyses clearly demonstrate the time dependence of the value of S derived by the method (Plate 6). In about half of the tests the cone of depression reached near-equilibrium after 6 hours and the remainder in 12–24 hours. The test on Site 200 was exceptional in that equilibrium was apparently not reached until after 48 hours of pumping. This characteristic clearly shows that, subsequent to equilibrium, the pumping rate was largely sustained by gravity drainage within the cone of depression. All tests demonstrate a roughly constant relationship between S and t after equilibrium, so that for every doubling of the pumping time the derived value of S is increased by 80 to 100 per cent. In no case has the pumping continued sufficiently long for gravity drainage to reach completion within the cone of depression, so that even after 48 or 72 hours of pumping the storage coefficient was continuing to rise. During the period subjected to analysis (45 minutes to 48 hours), the values of S increased to between 16 and 52 times the initial value; and the final 48 hour values (corrected for "thin" aquifer conditions but *not* for u), reached between 0·0099 and 0·16. A few of the real values could be up to 40 per cent higher after correction for high values of u.

It is nevertheless clear that the ultimate (long term) value of S would be very much higher than any of those derived from the current series of tests. The nearly straight line relationship between S and t exhibited by the log-log plots on Plate 6 indicates that in order to reach an S value of 0·3 the tests would need to have been prolonged to minimum periods of between 3·8 and 110 days. As these periods of time are approached it is probable that the relationship between S and t will cease to be linear and become asymptotic to S, in which case very much longer periods of pumping could be needed.

The ultimate value of S could be greater than 0·3 but cannot be assessed until after an appropriately long period of pumping. There is no method of analysis available which will provide an accurate figure for S without long period pump tests.

COMPARISON OF RESULTS WITH THE PUMP TEST ON GNANGARA No. 25

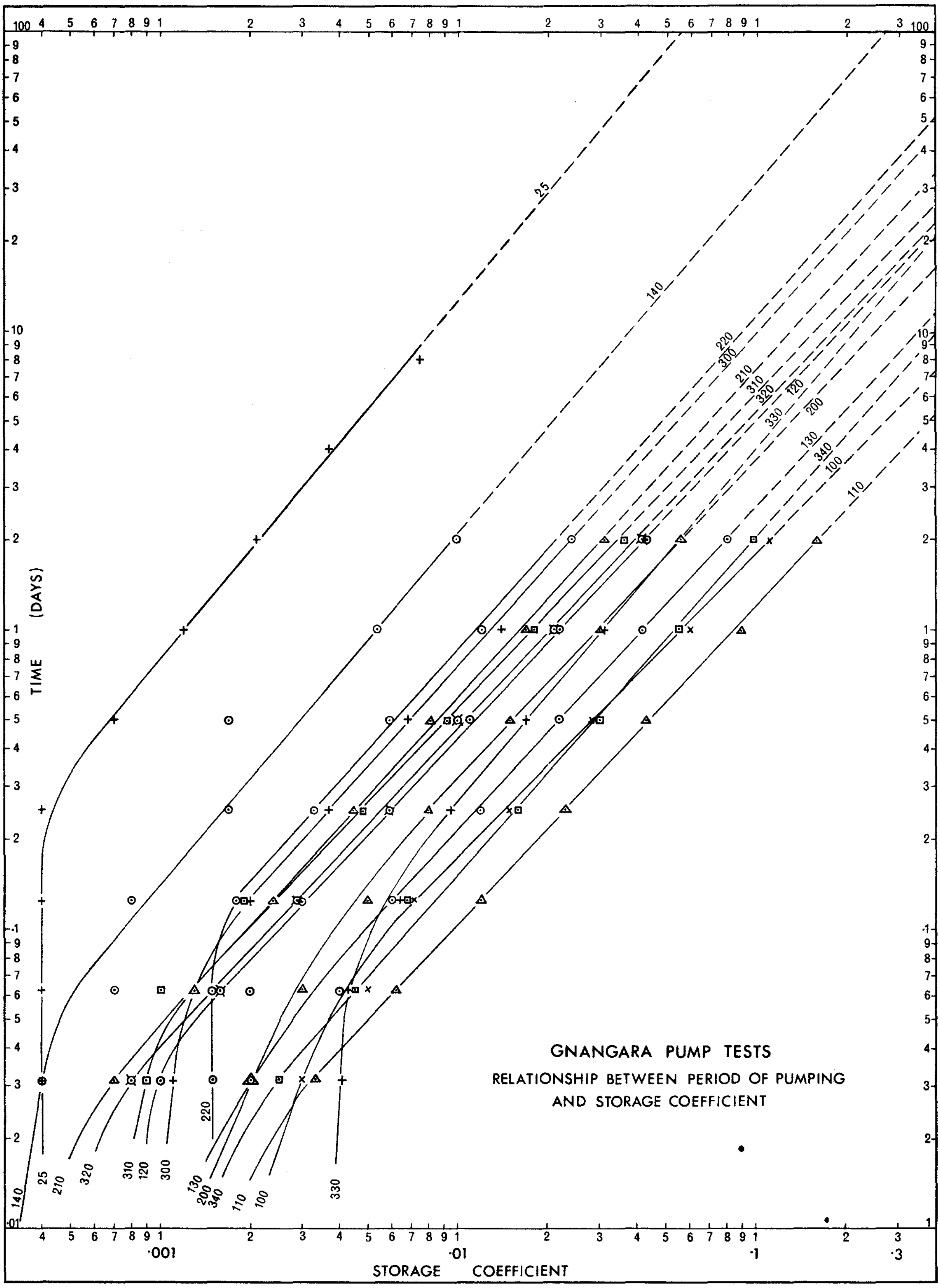
A 12-day pump test was carried out during the latter half of 1966 on borehole No. 25E in South Gnangara. The rate of pumping was 205 gallons per minute, and water levels were observed in bores spaced, 9, 244, 245 and 457·9 feet (2·7, 74·4, 74·7, 139·6 m) from the pumping bore. A Theis drawdown analysis (by J. R. Passmore) derived the following aquifer characteristics:

		T		S
		gpd/ft	m^3/day/m	
Bore 25A	(r = 457·9′)	9,200	137	0·000157
		10,250	153	
Bore 25B	(r = 244′)	43,800	596	0·004840
Bore 25C	(r = 9′)	11,800	176	0·000094
	Mean	13,700	200	0·0017

The same distance-drawdown analysis as that applied to the recent pump tests has now been applied to the No. 25E test. The data are plotted on Plate 5 for the following times: 45 m, 1½ h, 3 h, 6 h, 12 h, 24 h, 48 h, 96 h, and 192 hours (corrected figures). The values of T and S have been derived by the application of the Jacob-Cooper distance-drawdown formulae and are listed in Table 1.

The calculated values of u for the most distant borehole exceed 0·05 for times shorter than 3 hours, but are less for all times and observation bore distances thereafter. The method is therefore fully applicable for the greater part of the test. The distance-drawdown plots indicate that equilibrium was not reached until relatively late in the test (after 24 hours pumping) by which time the cone of depression had extended to 1,700 feet (518 m), a distance in excess of any of the more recent tests.

The transmissivities derived by the method lie in the range 10,000 to 10,600 gpd/ft (149 to 158m^3/day/m) with a mean of 10,300 gpd/ft (154 m^3/day/m) which is close to the values obtained from two out of three observation bores using the Theis matching curve method. This value of transmissivity comes in the lower half of the range exhibited by the current series of tests.


GNANGARA PUMP TESTS
RELATIONSHIP BETWEEN PERIOD OF PUMPING AND STORAGE COEFFICIENT
TIME (DAYS)
STORAGE COEFFICIENT
·001
·01
·1
·3
25
140
220
300
210
310
320
120
330
200
130
340
100
110

12265

However, the values of storage coefficient rise in the course of the test from 0·0004 to 0·0075 (at 192 hours), but exhibit a rate of increase with time similar to the current tests. It is nevertheless clear that it took longer for gravity drainage to commence at No. 25 Site than at any of the present sites, and also it would take substantially longer for this to reach a maximum value.

The storage coefficient/time graph (Plate 6) indicates that a minimum pumping period of 720 days would be required to reach a storage coefficient of 0·3.

SUMMARY AND CONCLUSIONS

1. The aquifer transmissivities lie in the range 6,200 to 36,500 gallons per day per foot (92·5 to 544 m^3/day/m) with a mean of 16,000 gpd/ft (230 m^3/day/m), which for an average aquifer thickness of 147 feet (44·8 m) represents a permeability of 109 gpd/ft (5·32 m^3/day/m^2). This value corresponds to a "fine sand" grading.

2. Under abstraction conditions the Gnangara sand bed aquifer appears to pass through three hydraulic stages: a comparatively rapid initial development of the cone of depletion which, in the present pumping field takes up to 3 hours, a period of near-equilibrium during which the water pumped is largely obtained by relatively slow gravity drainage, and a final phase in which the cone of depression continues to expand in response to further dewatering. The current tests were confined to the first two stages.

3. During the first stage of testing, the storage coefficients derived by distance-drawdown analysis were in the relatively low range of 0·0004 to 0·004. However, in the course of the second stage of testing, the storage coefficients rose to a value at 48 hours of 14–52 times the initial value, reaching maxima of at least 0·01 to 0·16. Owing to the method of derivation these values are very approximate and real values may be as much as 40 per cent. higher.

4. It is evident that had the pump tests continued for much longer periods, aquifer drainage would have continued and larger storage coefficients would have been derived. By extrapolation, it is estimated that the minimum pumping time required to achieve aquifer drainage, to a storage coefficient of 0·3, would be between 3·8 and 110 days. However, the behaviour of the system under conditions approaching complete gravity drainage is not known, and very much longer periods might be required.

5. A comparison of the results from the current series of tests with those of Gnangara No. 25 Site, suggests that essentially similar hydraulic conditions exist in the southern part of the Gnangara area. It is nevertheless true that No. 25E bore would require a much longer period of pumping for gravity drainage to approach completion (at least 720 days at S = 0·3).

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HYDROGEOLOGICAL RECONNAISSANCE OF PARTS OF NABBERU AND EAST MURCHISON MINING AREAS 1970

by C. C. Sanders and A. S. Harley

ABSTRACT

A survey was made to locate possible shallow aquifers in the Nabberu Mining District, north and east of Wiluna.

The most promising formations yielding large supplies of generally good quality groundwater are alluvial and calcrete valley fills. Other rock types give small supplies of variable quality water.

Several areas are suggested for further hydrological study.

INTRODUCTION

During 1970, the groundwater resources of part of the Nabberu and East Murchison mining areas were investigated. The survey extended over six 1 : 250,000 Geological Sheets, of which Nabberu and Stanley were intensively traversed for existing bores and wells. Some minor traverses, mainly in areas of known watering points, were made on Herbert and Robert Sheets at the western margin of the Officer Basin, and some hydrologic information from Wiluna and Kingston was updated (Sanders, 1969).

Groundwater is mainly in valley-fill alluvial and colluvial deposits, although some is obtained from fractured sandstones, shales and dolomites, and weathered greenstones.

The water resources near Wiluna have been documented by others, principally Ellis (1953), Chapman

(1962), and Mabbutt and others (1963), who recognised the aquifer potential of calcrete and alluvial valley fills. At Wiluna, during the peak of gold mining operations, the consumption of potable or slightly brackish groundwater from 34 shallow calcrete wells was up to 1,000,000 gallons ($4 \cdot 5 \times 10^6$ l) per day. Elsewhere in the East Murchison extensive calcrete and alluvial deposits are known to yield large supplies of good quality groundwater (Sanders, 1969).

The present aim was to assess the hydrological potential north and east of Wiluna, in anticipation of water requirements for expanding mining activities.

Plate 7 shows drainage trends, catchment areas, and bore and well salinities; Plate 8 the interpretive solid geology.

REGIONAL GEOLOGY

There is little documented geological information on the area and Plate 8 has been compiled from photo-interpretation, augmented by field observations.

The region falls within the Salinaland and Sandland physiographic divisions of Jutson (1950), characterised by internal drainage terminating in salt lakes. The western four sheets form part of the Precambrian Plateau, with the Archaean Yilgarn block unconformably overlain to the north by Proterozoic sediments. Eastwards, undifferentiated Permian and Mesozoic rocks in the Officer Basin overlie the Precambrian basement and possibly rocks of Lower Palaeozoic age. Capping much of the area is Tertiary and Quaternary alluvial and colluvial material.

ARCHAEAN

The greater portion of the Archaean basement is a series of granites intruding older metasedimentary and metavolcanic rocks. The metasediments are water-laid acid tuff, sandstone, banded chert and banded iron formation, and minor black shale and greywacke. These are interbedded with metavolcanics, which range from acid to basic in composition, and are intruded by sills and minor acid to ultrabasic dykes.

The rocks have a characteristic vertical dip with a northwesterly to northerly strike. The Archaean rocks are deeply weathered, the degree depending on both the chemical and textural composition, and mode of formation.

PROTEROZOIC

These rocks are mainly of sedimentary origin, comprising interbedded quartzite, shale and dolomite, with minor banded iron formation, greywacke, conglomerate and limestone. Some of the carbonate rocks have algal structures and oolitic bands. Some acid volcanics have been reported (Horwitz and Daniels, 1967, p. 51). Lithologically the rocks are comparable with the lower division of the Middle Proterozoic Bangemall Group (Daniels, 1966).

Generally the beds have a shallow dip to the northeast, complicated by at least two fold periods, a primary northwesterly axial direction with a superimposed northeasterly one.

Fine to medium-grained dolerites intrude several areas; two sulphide-rich granophyric intrusions on the southwestern side of the Parker Range dolerite on the Stanley Sheet being probably differentiates unrelated to the exposed dolerite.

LOWER PALAEOZOIC

There is a single outcrop of basalt in the northeastern corner of the Robert Sheet, which is thought to be Ordovician (Lowry, 1970).

UNDIFFERENTIATED PERMIAN AND MESOZOIC

These rocks crop out as mesa and butte features overlying Precambrian and Lower Palaeozoic on the eastern part of the area.

Along the western edge of the zone the outcrops are deeply weathered, partly ferruginised shales, with occasional erratics mainly of granite and quartzite and localised layers of siltstone and sandstone. The beds are probably Permian glacial deposits.

Farther east on Herbert and Robert Sheets, are outcrops of tillite with some erratics, shale, siltstone and sandstone (Lowry, 1970). Only the Permian tillite, and some fossiliferous siltstone beds assigned to the Cretaceous, can be dated.

TERTIARY-QUATERNARY

Sandplain, lake deposits, and desert eolian sands make up more than 50 per cent of the land surface, with alluvial/colluvial and calcrete valley fills occupying about another 5 per cent.

The oldest rocks are on remnants of the ancient plateau preserved mainly north of the Lake Nabberu-Lake Carnegie drainage system. Ferruginous laterite and siliceous duricrust cap most of the surface remnants. After lateritisation during a period of high rainfall, an intensely arid climate produced accumulations of thick eolian sands on the older surface.

The resultant sand plains form a distinctive geomorphological unit between the high bedrock outcrops and the regional drainage lines.

Rock units of the older plateau have extensive marginal colluvium often cemented to form very resistant talus.

Near drainage lines the colluvium becomes finer grained and merges with fluviatile material transported by infrequent floods, the sediments ranging from fine silt and clay to coarse conglomerate. The fluctuating intensities of rainfall and runoff have caused sharp vertical depositional changes in the rock type and therefore the permeability.

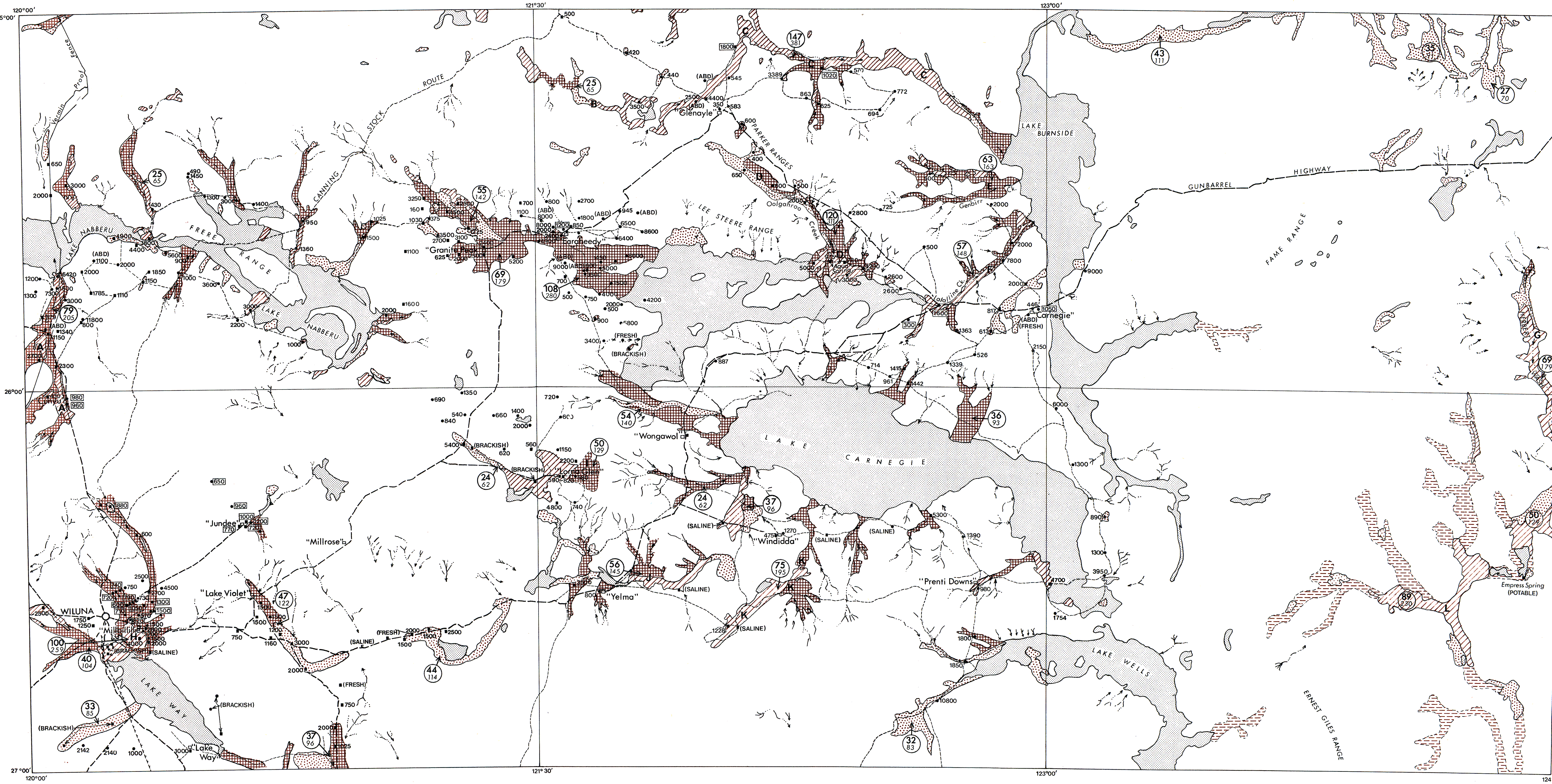
The main drainage valleys and most fossil drainage channels have rubbly calcrete overlying fluviatile material, the calcrete in some areas reaching 30 feet (9 m) in thickness and forming the most promising aquifers. Wide calcrete valley tracts often continue for many miles, the most extensive being on Glenayle Station in the northern part of the Stanley Sheet. Patchy calcrete occurs as dissected remnants of what were probably much larger deposits around the salt lakes.

The lower valley tracts and lake basins have fine-textured saline alluvium interbedded with lime, gypsum and salt. Mabbutt and others (1963) report that the amount of fill in some lake basins may exceed 150 feet (46 m) as in Lake Way, south of Wiluna.

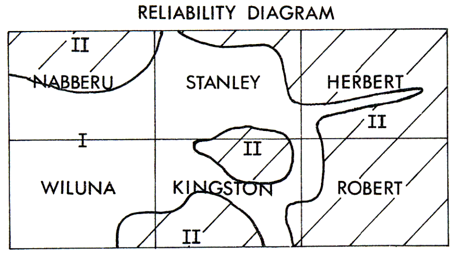
ORIGIN OF CALCRETE

Calcrete deposits are common on the Proterozoic rocks of Nabberu and Stanley Sheets, decreasing towards the south and east. Sanders (1969) points out that calcretes in the East Murchison are similarly common in the north, but south of Wiluna become restricted to the main fossil drainages and relict patches bordering the larger salt lakes. The patchy distribution and confinement to drainage lines indicate a genetic and depositional control different from that of the kankar deposits of the Eastern Goldfields, which are the result of soil-forming processes akin to the caliches of Texas and New Mexico.

Calcrete, a calcium and minor magnesium carbonate, probably formed as a primary chemical precipitate from solution in ground and surface waters. Soufoulis (1963) suggested that calcretes



RELIABILITY DIAGRAM



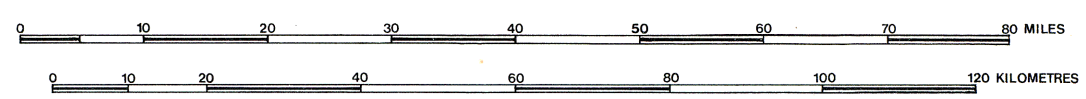
I. Compiled from mapping, hydrological census and reconnaissance traverses.

II. Compiled from photo-geological interpretation and few reconnaissance traverses.

INDEX TO ADJOINING SHEETS

COLLIER	BULLER	TRAINOR	MADLEY	WARRI
PEAK HILL	NABBERU	STANLEY	HERBERT	BROWNE
GLENGARRY	WILUNA	KINGSTON	ROBERT	YOWALGA
SANDSTONE	SIR SAMUEL	DUKETON	THROSSELL	WESTWOOD

SCALE 1:1,000,000



GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

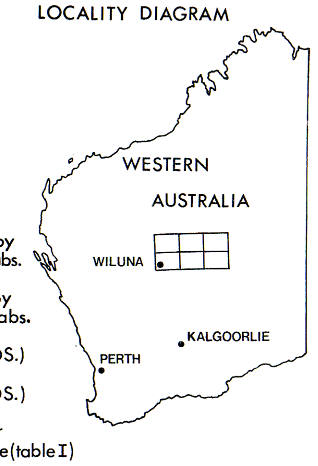
ALLUVIAL AND CALCRETED DRAINAGES
EAST MURCHISON AND MT. MARGARET GOLDFIELDS
NABBERU MINING DISTRICT

To accompany report by C.C.Sanders and A.S.Harley. 1970

REFERENCE

- Alluvium
- Probable Alluvium
- Interpreted Desert Drainage Lines
- Massive Calcrete
- Minor and patchy calcrete with alluvium
- Lacustrine deposits (mainly saline)
- 56/145 Areal extent of calcrete and alluvium catchment in square miles (square kilometres) over 25 square miles (65 square kilometres)
- "Jundee" Homestead
- Major road
- Minor road
- Drainage trend
- O Town
- 740 Well, salinity (ppm. T.D.S.) by conductivity. Govt. Chem. Labs.
- 230 Bore, salinity (ppm T.D.S.) by conductivity. Govt. Chem. Labs.
- 1740 Well, field salinity (ppm. T.D.S.)
- 1390 Bore, field salinity (ppm. T.D.S.)
- E Major catchment area. For potential recharge estimate (table I)

LOCALITY DIAGRAM



were deposited from 'ponded' sections of the drainage after cessation of a past period of high rainfall. However he does not indicate whether this is an annual and cyclic event over a long period, or just long term continued chemical precipitation from supersaturated surface waters. The present authors consider that ponding can explain large areas of calcrete, but that slow replacement by lime of fluviatile silts and gravels was and is aiding in the formation of calcrete. The silica is probably reconstituted as chert. In the Wiluna area localised calcrete within extensive alluvial sediments suggests this latter process.

A major problem is the source and quantity of lime required for the development of extensive calcrete deposits. It has been suggested that the high carbonate concentration resulted from slow water movement over calcium-rich basic and ultrabasic igneous rocks, but most calcrete deposits are in areas away from the Archaean greenstone belts, mainly centred in Proterozoic sediments. It is therefore likely that the dolomites and limestones of the Proterozoic province are also major contributors of lime for calcretes, especially in the area surveyed where few basic rocks are found.

HYDROLOGY

Prior to field inspection, all main drainages and calcrete areas were identified on air-photographs. Nearby bores and wells were sampled, an almost complete census of watering points being made on the northern and eastern sheets.

Groundwater is very common, but is shallowest and freshest in alluvial deposits and the fine gravel and calcrete of the valley fills. These are more extensive on the Stanley Sheet than on Nabberu, Kingston, and Wiluna. Fluviatile deposits are uncommon in the desert basin of Herbert and Robert Sheets, but calcrete occurs as patchy and massive deposits in some depressions, being often obscured by dune sands, but easily identifiable on air-photographs, which also show broad drainage patterns trending toward the calcrete. The drainage lines are difficult to discern on the ground because of movable dunes, the drainages probably becoming active only during rare flash floods. Unfortunately there is no groundwater information available from this area.

Groundwater is at present used for pastoral purposes, domestic and stock requirements being very small compared with potential reserves. The reported yields from bores and wells are not considered reliable, as supplies are usually governed by equipment used, and yields reflect demand rather than potential.

The water table generally is between 10 feet (3 m) and 50 feet (15 m) below natural surface, although it may be as deep as 120 feet (36 m) in zones of fractured or weathered Archaean or Proterozoic rocks. In alluvial and calcrete areas the water table has uniformly low hydraulic gradients and is at shallow depth.

Replenishment occurs entirely from rainfall and mainly during major storms. In the Wiluna-Carnegie area, recharge rates have been calculated by Chapman (1962) for catchments at Lorna Glen Station on Kingston Sheet, and at Wiluna; and also by Sanders for Wiluna, assuming that average groundwater flow equals the long term average recharge. At Lorna Glen, Chapman calculated recharge at 1·3 per cent of the mean annual rainfall on the 50 square miles (129 sq km) of immediate alluvial and calcrete catchment area, while at Wiluna a figure of 3·3 per cent was computed for 100 square miles (259 sq km) of catchment. From the results of recent pumping tests on new bores in fluviatile sediments at Wiluna, Sanders considers between 2·8 per cent and 3·2 per cent of the mean annual rainfall infiltrates to the water table in the 100 square miles (259 sq. km) of alluvium and calcrete catchment. As the catchments at Lorna Glen and Wiluna are similar to others in the region it is reasonable to apply a recharge coefficient of 3 per cent of mean annual rainfall to most trunk valley sediments. On this basis, potential recharge to an aquifer can be estimated. For example, for the calcrete and alluvial aquifer north and east of Glenayle Station homestead, Stanley Sheet (Plate 7, catchment C) with an extent of about 147 square miles (381 sq km) and an assumed average yearly rainfall of 8 inches (20·3 cm), the estimated potential recharge is 1,880 acre feet (2·32 x 10^6 cu m) per year.

Similar calculations have been made for other drainage systems, (Plate 7), (Table 1).

TABLE 1. OCCURRENCE, SALINITY, CATCHMENT AREA, POTENTIAL RECHARGE AND YIELD FOR SELECTED ALLUVIAL AND CALCRETED AQUIFERS

1:250,000 Sheet	Station or Locality	Catchment (Plates 7 and 8)	Water Quality ppm TDS	Immediate catchment area, square miles (Plate 8) °	Potential annual recharge, acre feet (assumed mean annual rainfall 8 in., 20·3 cm)‖	Maximum reported yields in gallons per day (gpd)
Nabberu	Cunyu	A	430–6,420	79·0	1,010	1 well, 20,000 gpd*
Stanley	Glenayle .... Glenayle	B C	3,500 .... 545–4,400	22·8 147·0	292 1,880	
	Wongawol	D	400–5,000	120·4	1,540	1 well, 35,000 gpd* 1 well, 20,000 gpd* 5 wells, 12,000 gpd*
	Wongawol .... Carnegie	E F	500–? 1,360–7,800	62·7 57·0	800 730	1 well, 8,000 gpd* {1 well, 16,000 gpd* {2 wells, 12,000 gpd*
Herbert	'Herbert Wash'	G	....	69·0	880	
Wiluna	Wiluna	H	600–4,000	100·0	1,350†	2 bores, 408,000 gpd
Kingston	Lorna Glen	I	600–2,300	50·0‡	350‡	1 well, 280,000–480,000 gpd
	Windidda .... Windidda	J K	.... 1,228–?	55·9 74·6	720 950	 1 well, 9,000 gpd*
Robert	Robert Desert Basin	L	....	89·3	1,140	

* Indicates pump capacity rather than potential yield of well or bore.
† Computed from pumping tests (Sanders).
‡ Computed from pumping tests, and surface mapping, T. Chapman (1962).
1,350 acre feet per annum is equivalent to a daily extraction of about 1,000,000 gallons.
° Immediate catchment area includes alluvium and calcrete as shown in Plates 7 and 8.
‖ Potential recharge calculated on basis of 8 in. annual rainfall over the region and 3 per cent infiltration to water table.
1 square mile = 2·589998 square kilometres; 1 acre foot = 1,233·489 cubic metres; 1 imperial gallon = 4·545961 litres.

Because arid zone drainages are essentially influent, groundwater extraction should not exceed recharge and annual recharge estimates give some idea of possible aquifer yields.

Permian and Mesozoic. Where seen outcropping in the desert areas of Herbert and Robert Sheets, these sediments were generally too fine grained and well indurated to be useful aquifers.

Table 2 gives standard chemical analyses of some bore and well waters.

TABLE 2. STANDARD CHEMICAL ANALYSES OF WATER FROM SOME WELLS AND BORES

Analyses	Cunyu Homestead No. 1 Bore	Glenayle Well	Glenayle Sandy Well	Wongawol Niminga Bore	Wongawol Learys Bore	Carnegie Homestead Bore	Wiluna Town Well 112	Millbillillie Top Kukububba Well	Lorna Glen East Mill Well
Catchment	A	C	C	F	....	....	H	H	I
pH	8·0	8·0	8·1	7·7	8·0	7·9	8·1	7·3	7·7
Total Dissolved Solids, ppm—									
by evaporation	910	1,820	970	1,570	300	1,050	800	2,320	600
by conductivity	980	1,810	1,020	1,600	310	1,060	740	1,880	560
NaCl	445	862	438	806	91	422	239	565	216
Total hardness	364	644	401	631	75	326	380	1,340	260
Total alkalinity	153	281	217	188	95	215	176	233	160
Ca	60	106	75	126	18	63	78	333	66
Mg	52	92	52	77	7	41	45	124	23
Na	148	342	150	260	69	224	106	173	82
K	30	47	28	26	9	20	9	15	16
Fe	<0·05	<0·05	<0·05	<0·05	<0·05	<0·05	<0·1	<0·05	<0·1
HCO_3	186	342	265	229	116	262	214	284	195
CO_3	....	....	....	....	....	....	....	....	....
Cl	270	523	266	459	55	256	145	343	131
SO_4	104	297	96	242	24	187	166	936	38
NO_3	102	147	89	126	47	85	85	57	91
SiO_2	71	76	93	80	34	47	80	45	76
B	0·6	0·8	0·4	0·6	0·5	0·9	....	0·8	....
F	0·8	1·5	1·1	1·2	0·7	1·0	....	1·0	....

Areas worthy of further investigation are:

NABBERU 1 : 250,000 *SHEET*

At *Cunyu Station* 40 miles (64 km) north of Wiluna, potable water is obtained from alluvium and calcrete. One bore for domestic purposes has been tested at 20,000 gallons per day (0·09 x 10^6 l) but no other adequate pump-tests have been made.

The drainage system (A) near Cunyu Homestead trends north into Lake Nabberu, has a catchment area of 79 square miles (205 sq km) and an estimated recharge of 1,010 acre feet (1·25 x 10^6 cu m) per annum. Brookfield *in* Mabbutt and others (1963) considered the catchment area to be 240 square miles (622 sq km) from air-photograph interpretation of the drainage divide; and by applying a recharge coefficient of 1 per cent of the mean annual rainfall for 'depositional land surfaces' and 5 per cent for 'erosional land surfaces', estimated the annual recharge at 4,500 acre feet (5·55 x 10^6 cu m).

The present survey suggests that this latter figure is probably too large.

STANLEY 1 : 250,000 *SHEET*

1. *Glenayle Station* near the northwest corner of Stanley Sheet is at the junction of two fossil calcrete drainage systems (catchments B and C, Plate 7).

There are few bore and well data, especially for catchment B with only one well. Groundwater is used mainly for stock, and wells are developed only to a depth where sufficient supply is obtainable for immediate needs. Well and bore logs are unrecorded and the true depth of calcrete or alluvium is unknown. No adequate pump testing has been done.

For catchment B the groundwater salinity is 3,500 ppm TDS in the existing well, and the estimated annual potential recharge is 292 acre feet (0·36 x 10^6 cu m).

Catchment C is very extensive, having an immediate catchment area of 147 square miles (381 sq km) and an estimated recharge of 1,880 acre feet (2·32 x 10^6 cu m) per year. This figure may be conservative. Proven groundwater salinity ranges from 545 to 4,400 ppm TDS.

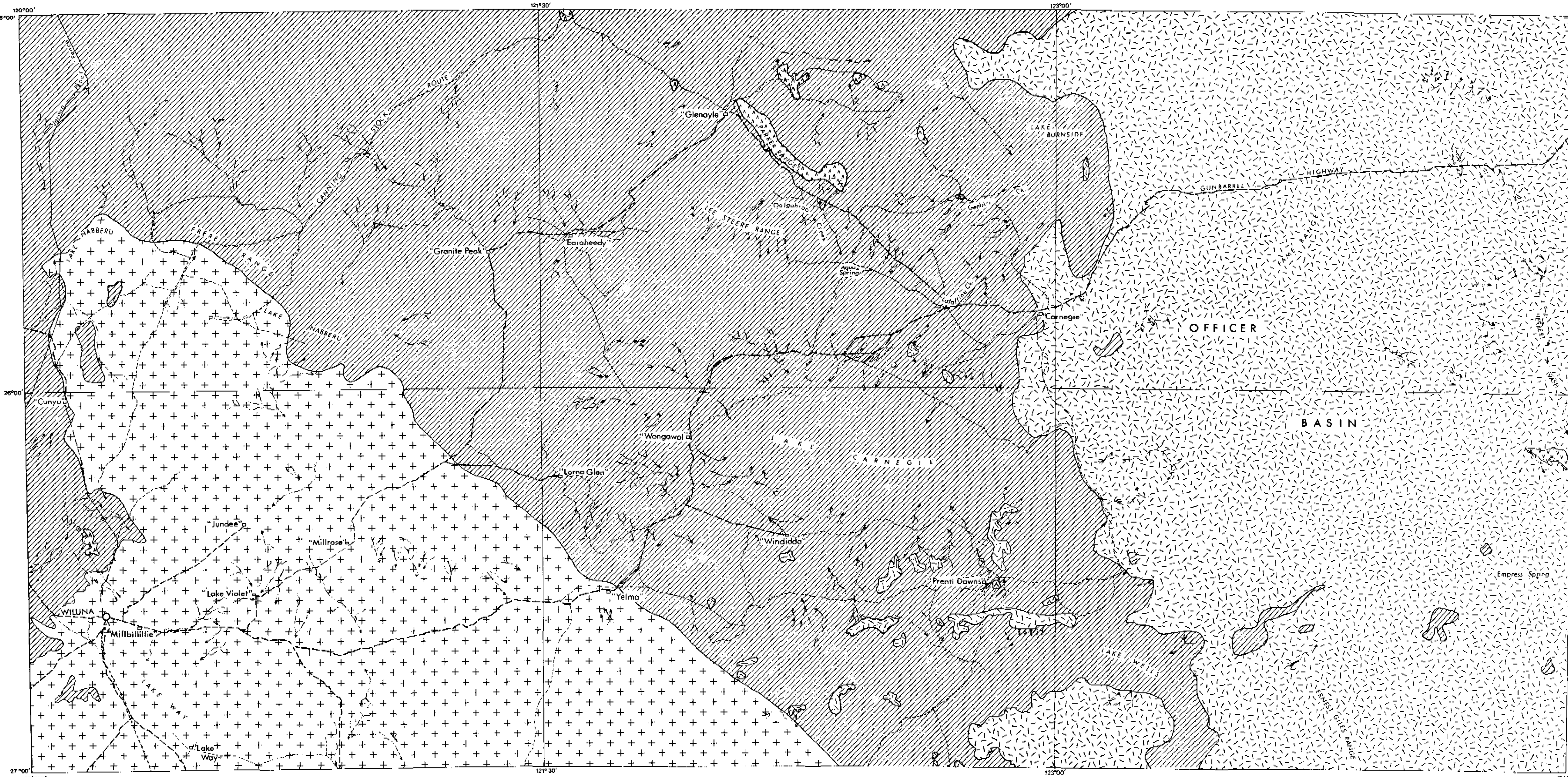
2. *Wongawol Station* occupies much of the central Stanley Sheet.

There is a narrow alluvial and patchy calcrete drainage on the southern side of the Parker Ranges, (catchment D) trending southeast along Oolgahroo Creek and finally broadening out into an area of massive calcrete centred about Aqua Spring. Groundwater salinities range from 400 to 5,000 ppm TDS, one well having been tested at 35,000 gallons (0·16 x 10^6 l) per day and five other wells at 12,000 gallons (0·05 x 10^6 l) per day. The total depth of calcrete is not known. The catchment area is about 120 square miles (311 sq km) and estimated recharge is 1,540 acre feet (1·90 x 10^6 cu m) per year.

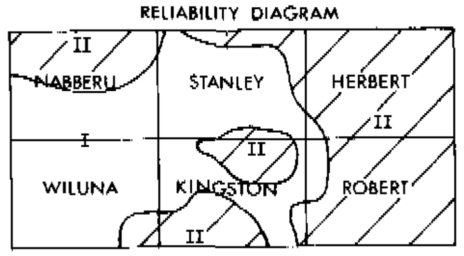
Two catchments trending east and north-east into Lake Burnside occur on the eastern part of *Wongawol Station* and on *Carnegie Station:*

(i) *Catchment E* is mainly alluvial along tributaries to Genbirr Creek. Potential is considered poor, as the catchment area is about 63 square miles (163 sq km) with a recharge potential of 800 acre feet (0·99 x 10^6 cu m) per annum in poorly permeable formations.

(ii) *Catchment F* along Lalalline Creek comprises areas of massive calcrete and alluvium containing groundwater of 1,360 to 7,800 ppm TDS salinity. One well has been tested at 16,000 gpd (0·07 x 10^6 l) and another two at 12,000 gpd (0·05 x 10^6 l). Although the catchment area, 57 square miles (148 sq km) is smaller than 'E', groundwater extraction would probably be easier because of the high calcrete permeability. Estimated recharge is 730 acre feet (0·90 x 10^6 cu m) per year.



RELIABILITY DIAGRAM



I. Compiled from mapping, hydrological census and reconnaissance traverses.

II. Compiled from photo-geological interpretation and few reconnaissance traverses.

INDEX TO ADJOINING SHEETS

COLLIER	BULLER	TRAINOR	MADLEY	WARRI
PEAK HILL	NABBERU	STANLEY	HERBERT	BROWNE
GLENGARRY	WILUNA	KINGSTON	ROBERT	YOWALGA
SANDSTONE	SIR SAMUEL	DUKETON	THROSSELL	WESTWOOD

SCALE 1:1,000,000

0 10 20 30 40 50 60 70 80 MILES

0 10 20 40 60 80 100 120 KILOMETRES

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

PRE-CAINOZOIC SOLID GEOLOGY

EAST MURCHISON AND MT. MARGARET GOLDFIELDS

NABBERU MINING DISTRICT

To accompany report by C.C.Sanders and A.S.Harley. 1970

REFERENCE

Undifferentiated Permian and Mesozoic

Ordovician

Dolerite intrusion

Proterozoic

Archaean

"Jundee" Homestead

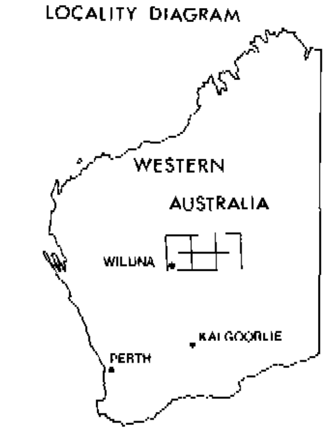
Major road

Minor road

Drainage trend

Town

LOCALITY DIAGRAM



12268

HERBERT 1 : 250,000 *SHEET*

The *Herbert Wash* (G) near the eastern boundary is a broad expanse of massive calcrete. The area is at least 69 square miles (179 sq km) with a conservative recharge potential of 800 acre feet ($0\cdot99 \times 10^6$ cu m) per annum. The Wash is a centre of internal drainage and has a large potential for development, except for its inaccessibility. The groundwater quality is unknown.

WILUNA 1 : 250,000 *SHEET*

This sheet was previously reported by Sanders (1969). However, recent work on the East Wiluna aquifer (H) indicates a safe annual extraction of 1,350 acre feet ($1\cdot67 \times 10^6$ cu m) of groundwater containing less than 2,500 ppm total salts. Yields as high as 408,000 gpd ($1\cdot85 \times 10^6$ l) can be expected from bores.

KINGSTON 1 : 250,000 *SHEET*

1. Chapman (1962) calculated that 350 acre feet ($0\cdot45 \times 10^6$ cu m) of irrigation water per year was available from an area near *Lorna Glen Station*. The catchment area is about 50 square miles (129 sq km) and yields of between 280,000 ($1\cdot27 \times 10^6$ l) and 480,000 gpd ($2\cdot18 \times 10^6$ l) can be expected.

2. On *Windidda Station* two main calcrete and alluvial catchments (J and K) drain north and east into Lake Carnegie. Groundwater information is scant, and reliable groundwater data are available from only one well. Estimated annual recharge for catchment J is 720 acre feet ($0\cdot89 \times 10^6$ cu m) and for catchment K 950 acre feet ($1\cdot17 \times 10^6$ cu m).

ROBERT 1 : 250,000 *SHEET*

No adequate hydrological information is available from the broad desert basin area, although extensive calcrete is apparent on air-photographs. Catchment L has an area of 89 square miles (230 sq km) of calcrete, with a possible yearly recharge of 1,140 acre feet ($1\cdot40 \times 10^6$ cu m).

Empress Spring near catchment L was reported by David Carnegie in 1896 as being in limestone with potable water at a depth of about 50 feet (15 m).

CONCLUSIONS AND RECOMMENDATIONS

Alluvium and calcrete are mainly untested but seem the most promising aquifers in the region.

Further hydrological studies could be made, including drilling, in a number of areas mainly on Nabberu and Stanley Sheets. Broad drainages in the vicinity of Glenayle and Carnegie Stations on Stanley Sheet, and Cunyu Station north of Wiluna, have most potential for groundwater development.

Some broad calcrete areas in the Officer Basin could store large volumes of good quality water. As yet this area is inaccessible.

The Permian and Mesozoic sediments appear to have little potential as good aquifers.

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PETROLEUM EXPLORATION IN WESTERN AUSTRALIA IN 1970

by R. N. Cope

INTRODUCTION

Exploration drilling took place predominantly on the continental shelf of Western Australia during 1970, thus continuing the trend begun in 1968–69. No discoveries of petroleum were made although an 800 bbls (127 m³) day flow of oil was encountered in the gas appraisal well Dongara No. 19 (see p.32). In September 1970 the Dongara Gas-field was declared to be commercial. The only encouragement encountered was hydrocarbon indications in Flag No. 1, Ripple Shoals No. 1 and Pepper No. 1 (see below).

The amount of exploratory drilling again decreased in 1970 as compared with the previous year, as shown below:—

	1969	1970
New field wildcat wells	14	10
Extension test wells	3	0
Stratigraphic test wells	4	1
Total footage	149,521	103,917
(metres)	(45,572)	(31,672)

One of the wells completed in 1970, Flag No. 1, had already reached 10,871 feet (3,313 m) in 1969, and four new field wildcat wells were still drilling at the end of 1970.

Other exploration activity in 1970 remained at a similar level to that of 1969, as illustrated below:—

Type of Survey		1969 Party months	1970 Party months
Land seismic	....	20·05	39·1
Marine seismic	....	12·13	8·6
Aeromagnetic	....	10,675 line miles	0
Gravity	....	0	2·0
Geological	....	6·25	9·8

OIL TENEMENTS

The conversion of tenements held under the Petroleum Act (1936) to conform with the Petroleum Act (1967) has proceeded smoothly and at the end of 1970 the only remaining tenements held under the 1936 Act are Petroleum Leases 1H and 2H relating to oil production at Barrow Island (Plate 9).

As part of the process of transfer of titles, certain onshore areas were relinquished by the holders in the Perth, Carnarvon and Canning Basins. On 11th September, 1970 these areas, together with certain fringe basinal areas not so far released, totalling about 41,000 square miles (106,190 km^2), about 85,000 square miles (220,150 km^2) of the Officer Basin and some 19,000 square miles (49,210 km^2) of the offshore Eucla Basin, were gazetted as available for application under Section 30 of the Petroleum Act, 1967, and Section 20 of the Petroleum (Submerged Lands) Act, 1967 (see Plate 9). The total acreage available for bidding was divided into 30 areas onshore (up to 200 5-minute blocks) and 2 offshore (up to 400 5-minute blocks). For the 18 Officer Basin areas, the closing date set was 1st February, 1971 and for the remaining onshore and the offshore areas, the date was 16th November, 1970. Applications for the latter areas were under consideration at the end of the year.

An important stipulation, additional to those of the Petroleum Acts, attached to the release of the above areas for petroleum prospecting, is that during the first 2-year period the successful applicant will be unable to transfer or dispose of the Exploration Permit and will be held responsible for ensuring that the work commitments of any farm-out agreement which may be entered into are carried out.

PETROLEUM TENEMENTS UNDER THE PETROLEUM (SUBMERGED LANDS) ACT 1967

Exploration Permits

Number	No. of graticular sections	Expiry date of current term	Registered holder or applicant
WA-1-P	364	14/11/74	Woodside (Lakes Entrance) Oil Co. N.L., Shell Development (Australia) Pty. Ltd., B.O.C. of Australia Ltd.
WA-2-P	381	14/11/74	West Australian Petroleum Pty. Ltd.
WA-7-P	135	10/7/75	,, ,, ,, ,,
WA-8-P	18	17/6/75	Coastal Petroleum N.L.
WA-9-P	56	17/6/75	,, ,, ,,
WA-10-P	36	15/6/75	,, ,, ,,
WA-12-P	5	11/9/75	Associated Australian Oilfields N.L.
WA-13-P	387	29/8/74	West Australian Petroleum Pty. Ltd.
WA-14-P	396	29/8/74	,, ,, ,, ,,
WA-15-P	352	20/3/75	Australian Aquitaine Petroleum Pty., Arco Ltd.
WA-16-P	354	16/4/75	,, ,, ,, ,,
WA-17-P	378	22/4/75	,, ,, ,, ,,
WA-18-P	322	16/4/75	,, ,, ,, ,,
WA-19-P	142	20/3/75	Alliance Oil Development Australia N.L.
WA-20-P	34	10/10/74	West Australian Petroleum Pty. Ltd.
WA-21-P	241	14/11/74	,, ,, ,, ,,
WA-22-P	81	3/10/74	,, ,, ,, ,,
WA-23-P	398	3/10/74	,, ,, ,, ,,
WA-24-P	208	17/10/74	,, ,, ,, ,,
WA-25-P	256	16/10/74	,, ,, ,, ,,
WA-26-P	400	22/12/74	Canadian Superior Oil (Aust.) Pty. Ltd., Australian Superior Oil Co. Ltd., Philips Australian Oil Co., Sunray Australian Oil Co. Inc.
WA-27-P	294	18/5/75	,, ,, ,, ,,
WA-28-P	375	24/3/75	Woodside (Lakes Entrance) Oil Co. N.L., Shell Development (Australia) Pty. Ltd., B.O.C. of Australia Ltd.
WA-29-P	400	18/5/75	,, ,, ,, ,,
WA-30-P	400	2/7/75	,, ,, ,, ,,
WA-31-P	400	18/5/75	,, ,, ,, ,,
WA-32-P	395	2/7/75	,, ,, ,, ,,
WA-33-P	389	18/5/75	,, ,, ,, ,,
WA-34-P	397	2/7/75	,, ,, ,, ,,
WA-35-P	400	2/7/75	,, ,, ,, ,,
WA-36-P	57	18/5/75	,, ,, ,, ,,
WA-37-P	118	2/6/75	,, ,, ,, ,,
WA-39-P	104	12/3/75	BP Petroleum Development Australia Pty. Ltd., Abrolhos Oil N.L.
WA-40-P	102	12/3/75	,, ,, ,, ,,
WA-41-P	33	15/6/75	Coastal Petroleum N.L.
EP 3	200	27/8/75	West Australian Petroleum Pty. Ltd.
EP 5	132	26/7/75	,, ,, ,, ,,
EP 6	199	27/8/75	,, ,, ,, ,,
EP 7	200	27/8/75	,, ,, ,, ,,
EP 8*	200		,, ,, ,, ,,
EP 9	200	27/8/75	,, ,, ,, ,,
EP 12	182	3/9/75	,, ,, ,, ,,
EP 13	200	27/8/75	,, ,, ,, ,,
EP 14	200	27/8/75	,, ,, ,, ,,
EP 15	200	27/8/75	,, ,, ,, ,,
EP 16	200	27/8/75	,, ,, ,, ,,
EP 17	200	27/8/75	,, ,, ,, ,,
EP 18	200	27/8/75	,, ,, ,, ,,
EP 19	200	27/8/75	,, ,, ,, ,,
EP 20*	200	....	Australian Aquitaine Petroleum Pty. Ltd.
EP 21	90	26/7/75	West Australian Petroleum Pty. Ltd.
EP 23	172	6/8/75	,, ,, ,, ,,
EP 24	172	6/8/75	,, ,, ,, ,,
EP 25	96	6/8/75	,, ,, ,, ,,
EP 26	1	27/8/75	BP Petroleum Development, Abrolhos Oil N.L.
EP 27	2	19/8/75	,, ,, ,, ,,
EP 28	4	19/8/75	,, ,, ,, ,,
EP 29	7	19/8/75	,, ,, ,, ,,
EP 31	200	6/10/75	Beach-General Exploration Pty. Ltd., and Australian Aquitaine Petroleum Pty. Ltd.
EP 32*	200	....	,, ,, ,, ,,
EP 33*	200	....	,, ,, ,, ,,
EP 34*	1	....	Woodside (Lakes Entrance) Oil Co. N.L., Shell Development (Australia) Pty. Ltd., B.O.C. of Australia Ltd.
EP 35*	1	....	,, ,, ,, ,,
EP 36*	1	....	,, ,, ,, ,,
EP 37	149	22/9/75	West Australian Petroleum Pty. Ltd.
EP 38	130	22/9/75	,, ,, ,, ,,
EP 39	160	22/9/75	,, ,, ,, ,,
EP 40*	81	....	,, ,, ,, ,,
EP 41*	188	....	,, ,, ,, ,,
EP 42	200	1/9/75	,, ,, ,, ,,
EP 43	163	1/9/75	,, ,, ,, ,,
EP 44	113	1/9/75	,, ,, ,, ,,
EP 45	197	19/11/75	,, ,, ,, ,,
EP 46	199	1/9/75	,, ,, ,, ,,
EP 47	199	19/11/75	,, ,, ,, ,,
EP 48	199	19/11/75	,, ,, ,, ,,
EP 50	110	1/9/75	,, ,, ,, ,,
EP 51	57	8/9/75	Lennard Oil Pty. Ltd.
EP 52	34	8/9/75	,, ,, ,,
EP 53	49	15/9/75	West Australian Petroleum Pty. Ltd.
EP 54	123	22/9/75	Alliance Oil Development Aust. N.L.
EP 55	178	22/9/75	West Australian Petroleum Pty. Ltd.

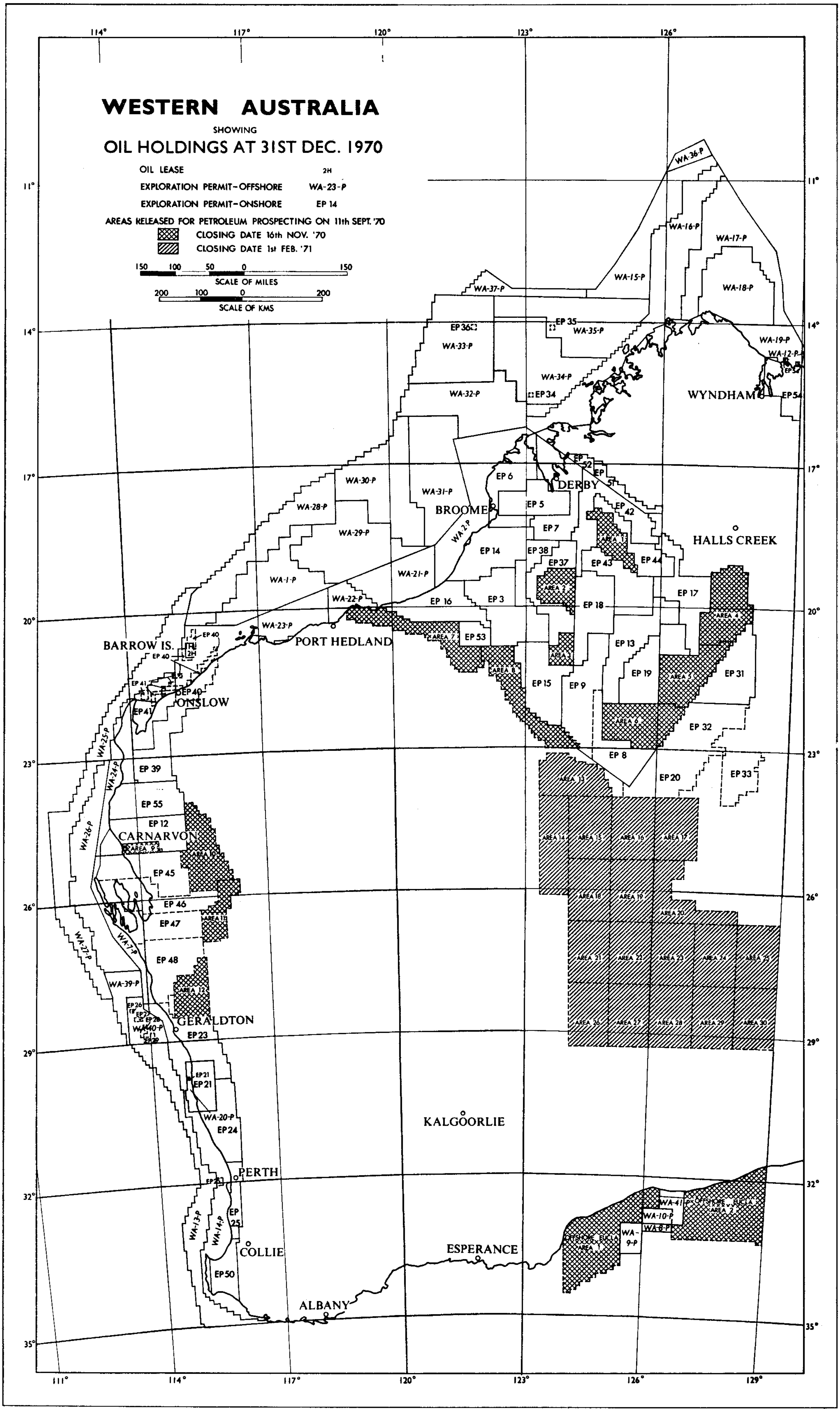
PETROLEUM LEASES

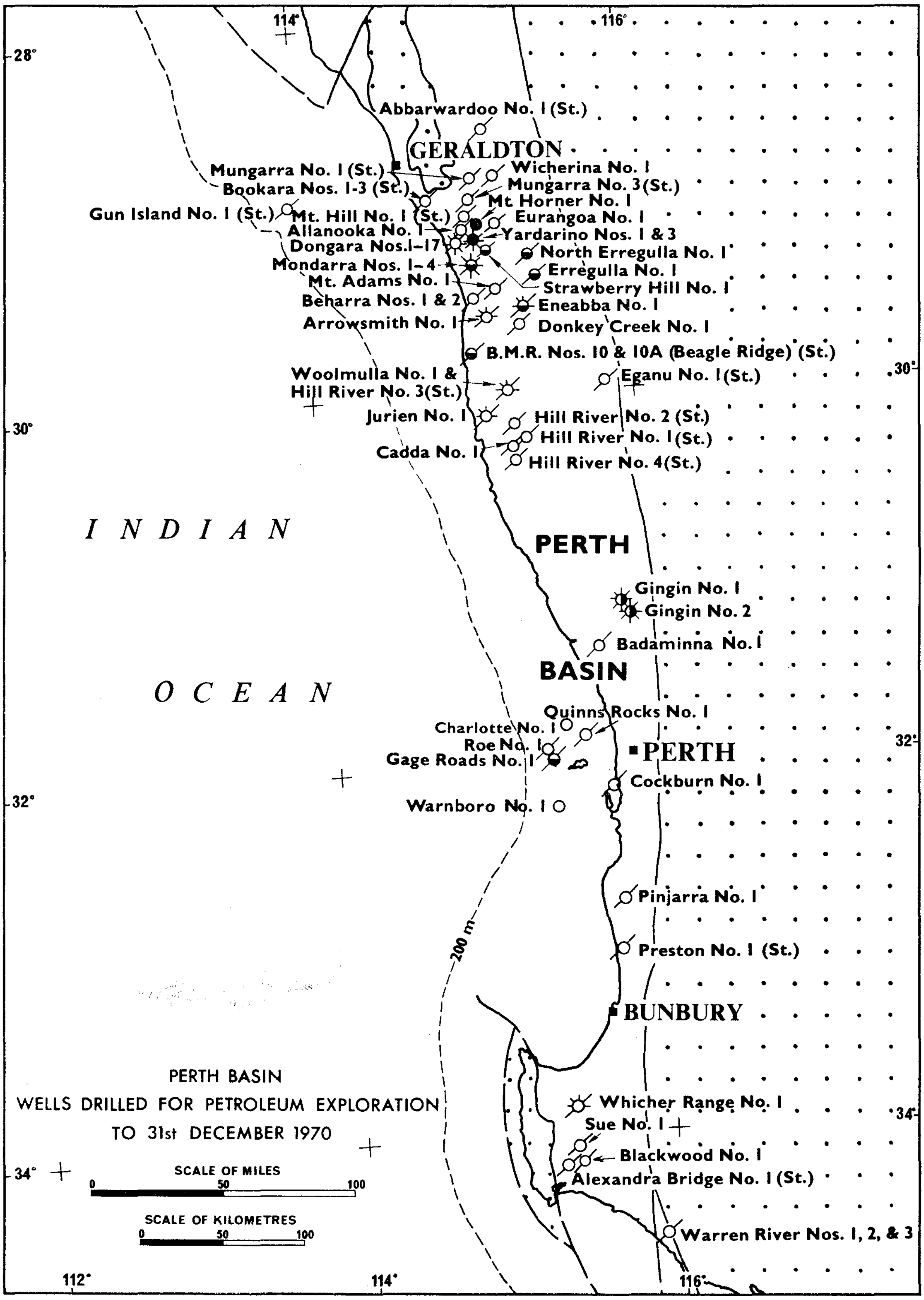
Number	Area (square miles)	Expiry date of current term	Holders
1H	100	2/2/88	West Australian Petroleum Pty. Ltd.
2H	100	2/2/88	,, ,, ,, ,, ...

* These tenements had been applied for but had not been approved by 31st December, 1970.

DRILLING

The positions of wells drilled for petroleum exploration in Western Australia to the end of 1970 are shown in Plates 10 to 12. The general data relating to each well are given in Table 1.


WESTERN AUSTRALIA
SHOWING
OIL HOLDINGS AT 31ST DEC. 1970
OIL LEASE 2H
EXPLORATION PERMIT-OFFSHORE WA-23-P
EXPLORATION PERMIT-ONSHORE EP 14
AREAS RELEASED FOR PETROLEUM PROSPECTING ON 11th SEPT. '70
CLOSING DATE 16th NOV. '70
CLOSING DATE 1st FEB. '71
SCALE OF MILES
SCALE OF KMS
BARROW IS.
ONSLOW
PORT HEDLAND
BROOME
DERBY
HALLS CREEK
WYNDHAM
CARNARVON
GERALDTON
PERTH
COLLIE
ALBANY
ESPERANCE
KALGOORLIE



PERTH BASIN
WELLS DRILLED FOR PETROLEUM EXPLORATION
TO 31st DECEMBER 1970

12270

WELLS DRILLED FOR PETROLEUM EXPLORATION IN WESTERN AUSTRALIA DURING 1970

Basin	Well	* = Subsidised	Concession	Operating Company	Type	Position: Latitude South (° ′ ″)	Position: Longitude East (° ′ ″)	Elevation and water depth: G.L.	Elevation and water depth: D.F. K.B.	Elevation and water depth: W.D.	Dates: Commenced	Dates: Reached T.D.	Dates: Completed	Total depth or (depth reached) in feet B.D.F.	Bottomed in	Status
Perth	Charlotte No. 1	*	WA-14-P	Wapet	NFW	31 48 36	115 26 56	....	99	—132	19/12/70	....	....	5,153	....	Drilling
	Roe No. 1	*	WA-13-P	Wapet	NFW	31 56 28	115 19 07	....	100	—345	23/11/70	13/12/70	18/12/70	7,001	U. Jurassic	P & a
	Warnboro No. 1	*	WA-14-P	Wapet	NFW	32 14 20	115 20 45	....	79	—156	26/11/70	....	....	11,859	....	Drilling
Carnarvon	Flag No. 1	....	WA-23-P	Wapet	NFW	20 27 55	115 38 44	....	+76	—44	2/9/69	13/1/70	3/2/70	12,475	U. Jurassic	P & a
	Pepper No. 1	....	WA-23-P	Wapet	NFW	21 03 29	115 18 05	....	+90	—25	13/3/70	3/5/70	8/5/70	9,000	U. Jurassic	P & a
	Ripple Shoals No. 1	....	WA-23-P	Wapet	NFW	21 07 10	115 24 07	....	+79	—26	6/2/70	4/2/70	9/3/70	7,476	U. Jurassic	P & a
	Tryal Rocks No. 1	....	WA-25-P	Wapet	NFW	20 24 42	115 09 08	....	+93	—152	17/5/70	16/8/60	24/8/70	12,123	U. Jurassic	P & a
	Enderby No. 1	*	WA-1-P	B.O.C.	NFW	20 09 25	116 24 24	....	+30	—177	13/9/70	10/10/70	14/10/70	7,051	? Triassic	P & a
	Legendre No. 2	*	WA-1-P	B.O.C.	NFW	19 37 27	116 46 49	....	+30	—190	16/10/70	16/12/70	23/12/70	11,871	? L. Jurassic	P & a
Canning	Napier No. 4	*	EP 52	Lennard	STR	16 55 00	124 05 35	....	300	....	15/7/70	18/8/70	22/8/70	3,166	Precambrian	P & a
	Napier No. 5	*	EP 52	Lennard	NFW	17 06 30	124 28 06	232	243	....	8/9/70	19/10/70	27/10/70	5,437	Precambrian	P & a
	Lacepede No. 1A	*	WA-31-P	B.O.C.	NFW	17 05 18	121 26 42	....	30	—191	21/6/70	16/8/70	20/8/70	7,500	? Permian	P & a
Browse	Lynher No. 1	*	WA-32-P	B.O.C.	NFW	15 56 24	121 04 59	....	30	—181	25/12/70	....	....	960	....	Drilling
	Leveque No. 1	*	WA-32-P	B.O.C.	NFW	15 45 12	122 00 18	....	+30	—254	22/8/70	1/9/70	6/9/70	2,951	Precambrian	P & a
Bonaparte Gulf	Gull No. 1	....	WA-17-P	Arco	NFW	11 56 29	127 54 37	....	39	—441	5/6/70	....	....	10,765	....	Drilling

P & a = plugged and abandoned.

The general results of the drilling are discussed for each basin in turn below.

PERTH BASIN

The small but promising flow of oil encountered in the Lower Cretaceous in Gage Roads No. 1 early in 1969, was followed up by the commencement of an offshore drilling programme in the Cretaceous embayment extending across the continental shelf near Perth in November, 1970. Roe No. 1 was drilled 3½ miles (5·6 km) west-northwest of Gage Roads No. 1 and near the Cretaceous crest of the same structure, but reached a total depth of 7,001 feet (2,134 m) in the Upper Jurassic, without encountering hydrocarbons. This well was drilled by the "Ocean Digger" semi-submersible rig which then proceeded to spud in Charlotte No. 1, some 23 miles (37 km) northwest of Fremantle. Meanwhile the "Jubilee" jack-up rig was drilling Warnboro No. 1 some 27 miles (43 km) southwest of Fremantle. At the end of the year Warnboro No. 1 had reached 11,859 feet (3,615 m) and Charlotte No. 1, 5,153 feet (1,571 m), both without encountering any indications of hydrocarbons.

The only onshore drilling in the Perth Basin during 1970 was the appraisal drilling of Dongara No. 18 and No. 19 (see p. 32).

CARNARVON BASIN

As shown in Table 1, both B.O.C. and Wapet continued with drilling programmes to evaluate their offshore permits in the northern Carnarvon Basin. B.O.C's Enderby No. 1 bottomed in a trachyte flow, probably of Triassic age, at 7,051 feet (2,149 m) without hydrocarbon indications. Their Legendre No. 2, only 5 miles (8 km) northeast of Legendre No. 1 (which produced a flow of 1,014 bbls (161 m^3) /day oil from the Lower Cretaceous), was likewise dry.

Continuing their evaluation of WA–23–P Wapet drilled Flag No. 1, Ripple Shoals No. 1 and Pepper No. 1. Flag No. 1 produced a very small flow of gas and oil (1·1 Mcf (31,149 m^3) /day at 750 psi (53 kg/cm^2) and ½ pint (0·3 l) of oil of 48° API, on a ¼ inch (0·64 cm) choke) from the Lower Cretaceous Muderong Shale. Ripple Shoals encountered a very minor hydrocarbon show in the Neocomian Birdrong Sandstone, while Pepper No. 1 found weak oil and gas shows in the top of the Barrow Group, of lowermost Cretaceous age.

In WA–25–P, however, Wapet's Tryal Rocks No. 1 was completely dry.

CANNING BASIN

Two wells were drilled onshore, one stratigraphic test Napier No. 4 and one wildcat Napier No. 5 both in Lennard's EP 52. Both of these wells penetrated the Upper Palaeozoic sequence known at the surface on the Lennard Shelf, but they failed to locate hydrocarbons.

On the continental shelf, B.O.C. drilled Lacepede No. 1 A in WA–31–P and in the offshore extension of the Fitzroy Trough. This well reached the Permian without encountering any hydrocarbon shows.

BROWSE BASIN

Leveque No. 1, the first well in this basin was terminated at 2,951 feet (899 m) after entering Precambrian basement. It is situated on the shallow Leveque Platform which lies along the southern margin of the basin. Lynher No. 1, 65 miles (105 km) to the west-southwest was drilling ahead at 960 feet (293 m) at year's end.

BONAPARTE GULF BASIN

Arco's Gull No. 1 in WA–17–P encountered a rather monotonous sequence of Mesozoic clastic sediments, but no hydrocarbons. At the end of the year the well was progressing rather slowly owing to increasing lithification, having reached 10,765 feet (3,281 m).

GEOPHYSICAL OPERATIONS

SEISMIC

During 1970, seimic surveys were conducted in the Perth, Carnarvon, Canning, Browse, Bonaparte Gulf and Eucla Basins, Details are as follows.

Basin	Permit No.	Company	Seismic Party Months
Perth	EP 21	Wapet	0·07 land
„	EP 23	„	1·82 „
„	EP 24	„	2·26 „
„	EP 25	„	1·71 „
„	WA-13-P	„	0·43 marine
„	WA–14–P	„	0·27 „
„	WA–20–P	„	0·01 „
„	WA–39–P	BP Dev. Aust. Pty. Ltd.	0·25 „
„	WA–40–P	„ „ „	0·50 „
Carnarvon	EP 41	Wapet	0·04 „
„	WA–1–P	B.O.C. of Aust. Ltd.	1·31 „
„	WA–7–P	Wapet	0·04 „
„	WA–23–P	„	0·03 „
„	WA–24–P	„	0·04 „
„	WA–25–P	„	0·21 „
„	WA–26–P	Can. Sup. Oil Aust. Pty. Ltd.	0·03 „
„	WA–27–P	„ „ „ „	0·07 „
Canning	EP 3	Wapet	2·72 land
„	EP 5	„	1·87 „
„	EP 6	„	1·03 „
„	EP 7	„	0·07 marine
„	EP 7	„	0·76 land
„	EP 8	„	1·24 „
„	EP 9	„	0·46 „
„	EP 13	„	1·78 „
„	EP 14	„	1·80 „
„	EP 15	„	1·40 „
„	EP 16	„	2·10 „
„	EP 17	„	1·93 „
„	EP 18	„	0·38 „
„	EP 19	„	2·20 „
„	EP 31	Aust. Aquitaine Pet. Pty. Ltd.	2·50 „
„	EP 42	Wapet	3·83 „
„	EP 43	„	1·10 „
„	EP 44	„	0·97 „
„	EP 51	Lennard Oil N. L.	0·50 „
„	EP 52	„ „	1·50 „
„	EP 53	Wapet	0·18 „
„	WA–2–P	„	0·63 marine
„	WA–21–P	„	0·18 „
„	WA–22–P	„	0·02 „
„	WA–28–P	B.O.C. of Aust. Ltd.	0·60 „
„	WA–29–P	„ „	0·53 „
„	WA–30–P	„ „	0·17 „
„	WA–31–P	„ „	0·25 „
„	WA–32–P	„ „	0·70 „
Browse	WA–33–P	„ „	0·32 „
„	WA–35–P	„ „	0·48 „
Bonaparte	EP 54	Alliance Oil Dev. N. L.	3·00 land
„	WA–15–P	Arco Ltd.	0·26 marine
„	WA–16–P	„	0·25 „
„	WA–17–P	„	0·22 „
„	WA–18–P	„	0·12 „
„	WA–36–P	„	0·01 „
„	WA–36–P	B.O.C. of Aust. Ltd.	0·12 „
Eucla	WA–8–P	Coastal Pet. N. L.	0·10 marine
„	WA–9–P	„ „	0·13 „
„	WA–10–P	„ „	0·10 „
„	WA–41–P	„ „	0·10 „

Total Party Months : Land 39·11
Marine 8·59

GRAVITY

Gravimetric surveying was undertaken in the Perth and Carnarvon Basins as follows:

Basin	Permit No.	Company	Party Months
Perth	WA-13-P	Wapet	1·00
Carnarvon	EP 45	„	0·27
„	EP 46	„	0·20
„	EP 47	„	0·33
„	EP 48	„	0·20

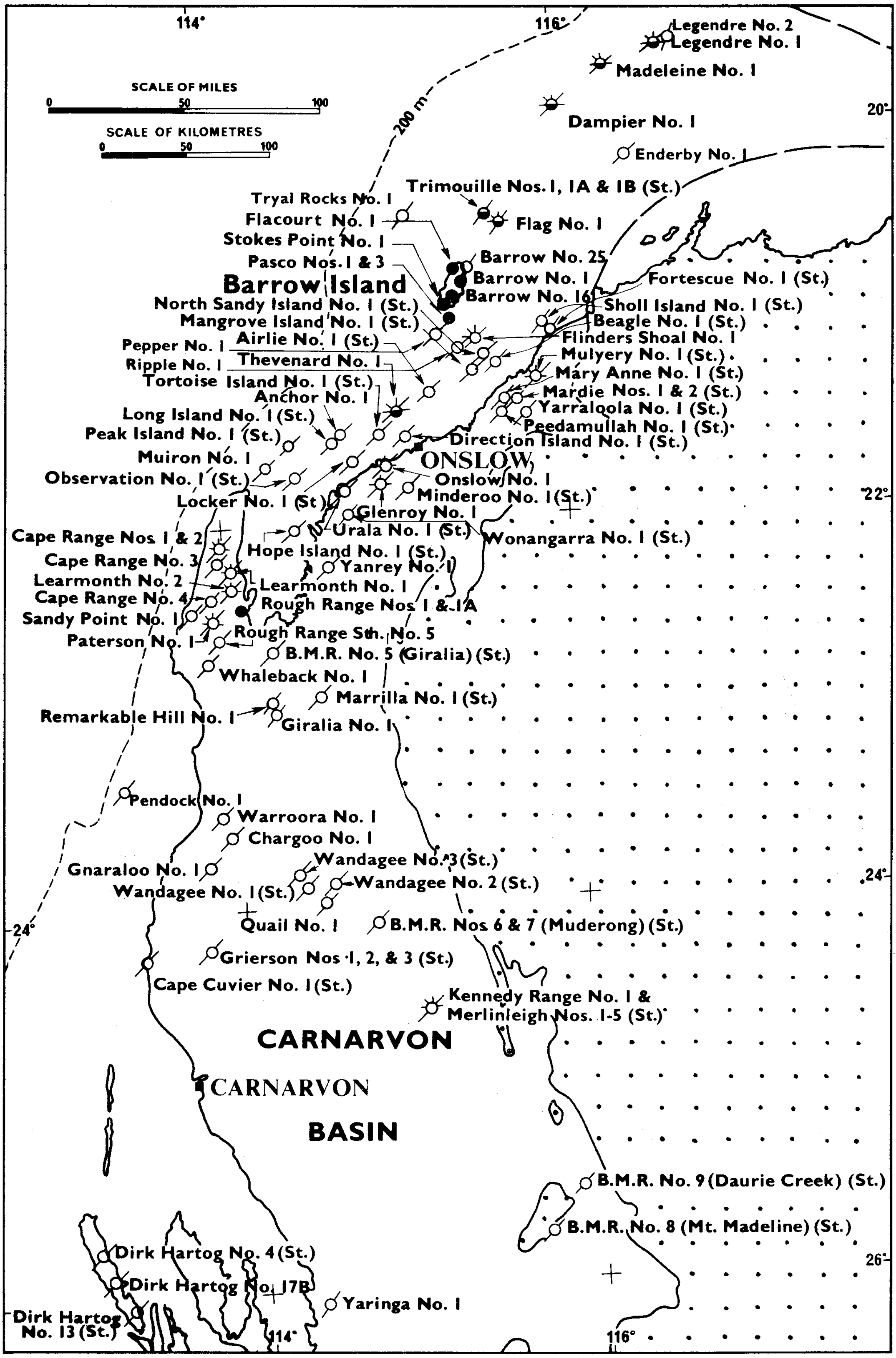
Total Party Months : 2·00

GEOLOGICAL OPERATIONS

Field geological investigations were carried out by oil exploration companies in the Canning Basin only. The breakdown is as follows:

Basin	Permit	Company	Geological (Geologist months)
Canning	EP 17	Wapet	2·00
„	EP 31	Aust. Aquitaine Pet. Pty. Ltd.	2·00
„	EP 42	Wapet	3·83
„	EP 51	Aust. Aquitaine Pet. Pty. Ltd.	1·00
„	EP 52	Lennard Oil N. L.	1·00

Total : 9·83 geologist months



CARNARVON BASIN : WELLS DRILLED FOR PETROLEUM EXPLORATION TO 31st DECEMBER 1970

12271

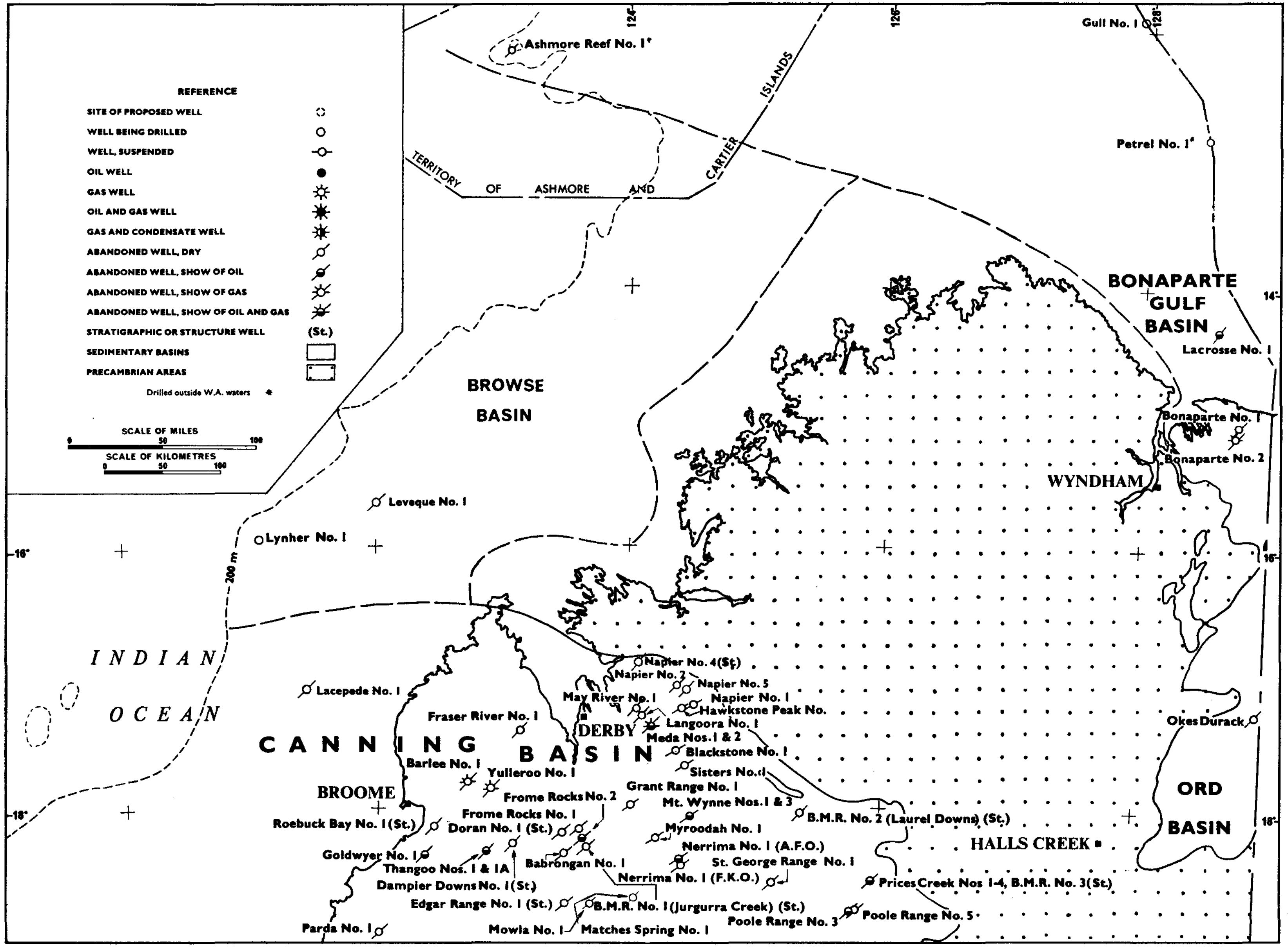
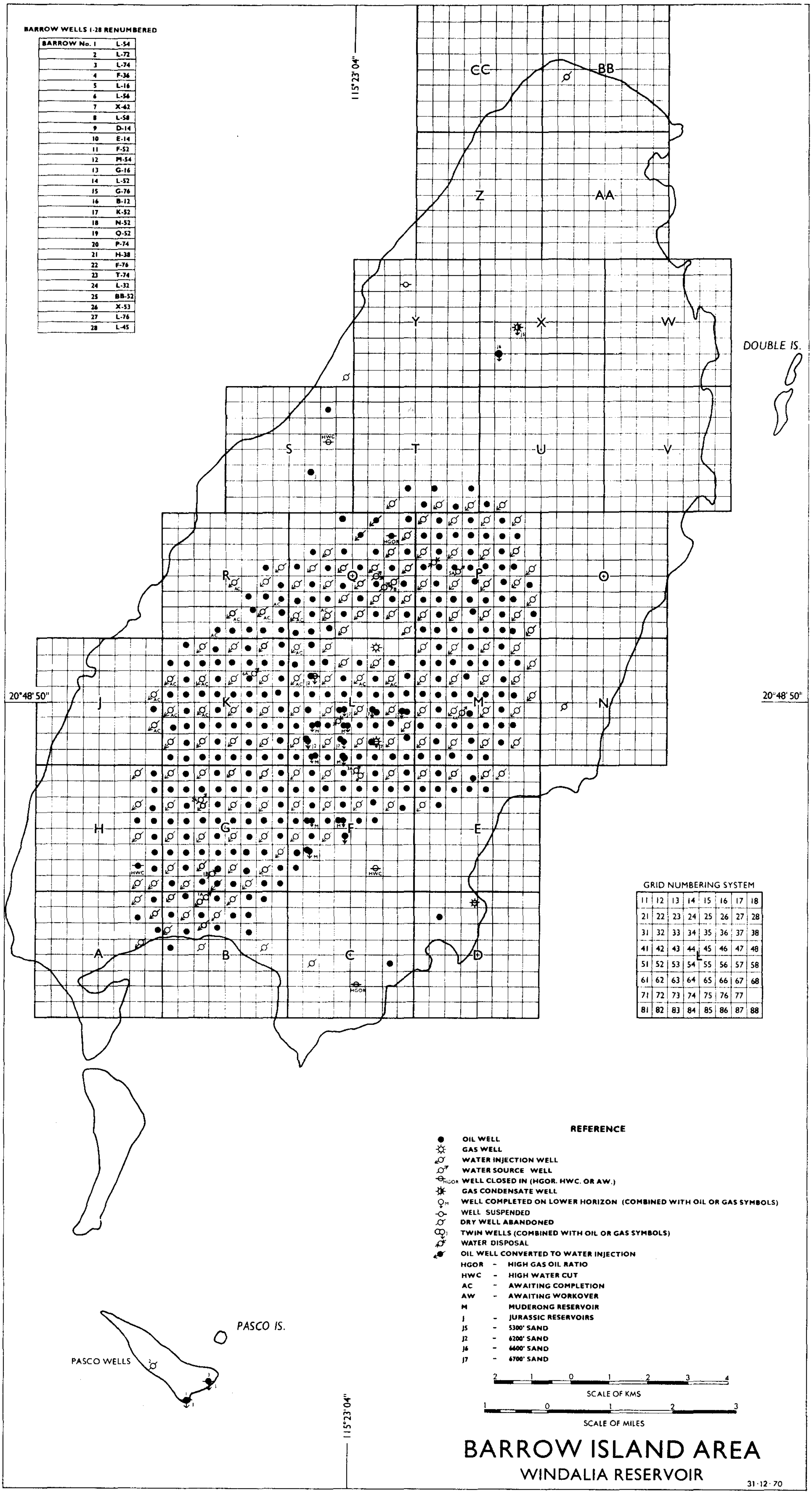
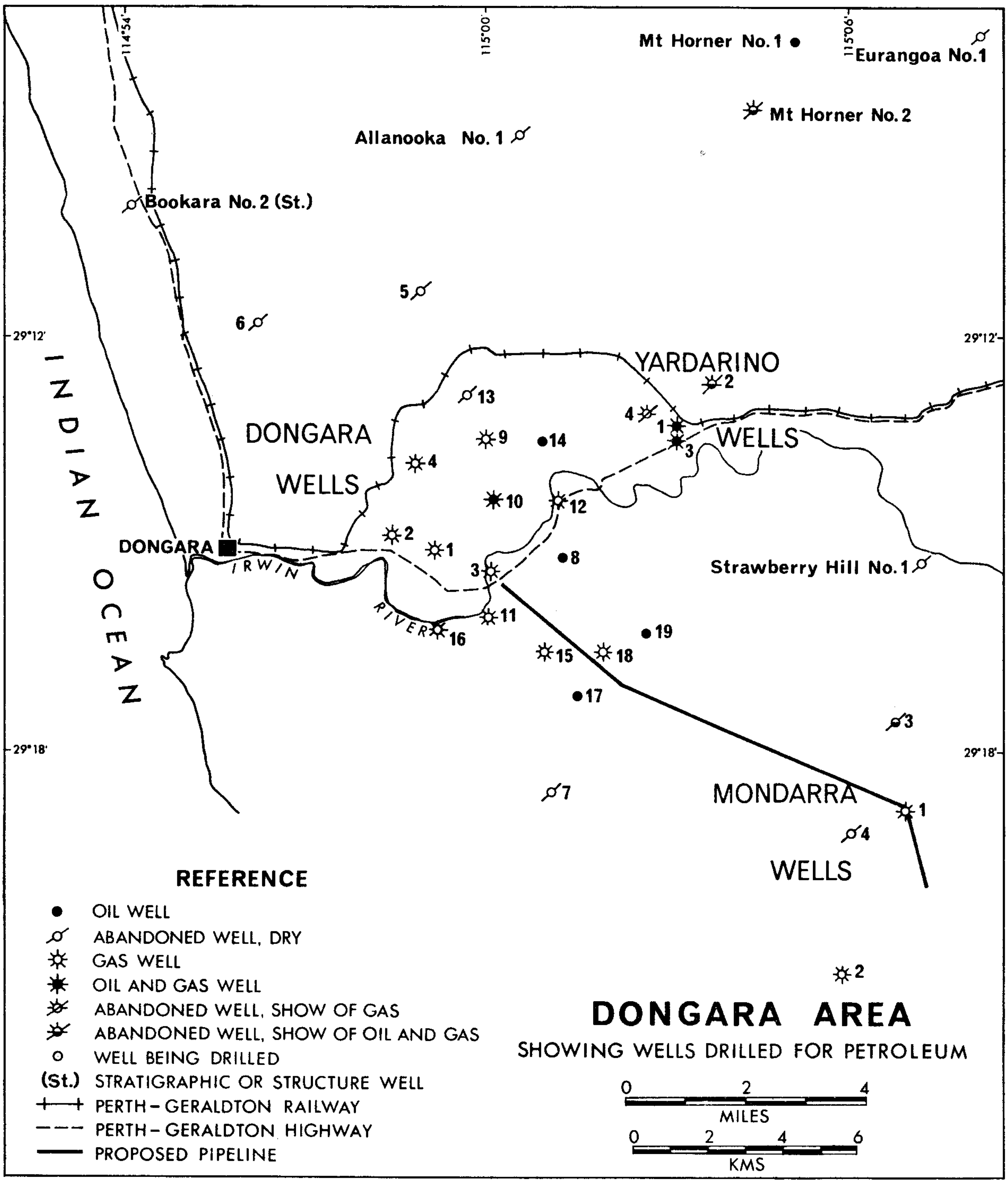


PLATE 12

NORTHERN CANNING, BROWSE AND SOUTHERN BONAPARTE GULF BASINS; WELLS DRILLED FOR PETROLEUM TO 31st DEC 1970. 12272


BARROW WELLS 1-28 RENUMBERED
BARROW No. 1 L-54
2 L-72
3 L-74
4 F-36
5 L-16
6 L-56
7 X-42
8 L-58
9 D-14
10 E-14
11 F-52
12 M-54
13 G-16
14 L-52
15 G-76
16 B-12
17 K-52
18 N-52
19 O-52
20 P-74
21 H-38
22 F-76
23 T-74
24 L-32
25 BB-52
26 X-53
27 L-76
28 L-45
115°23'04"
20°48'50"
20°48'50"
DOUBLE IS.
PASCO IS.
PASCO WELLS
GRID NUMBERING SYSTEM
11 12 13 14 15 16 17 18
21 22 23 24 25 26 27 28
31 32 33 34 35 36 37 38
41 42 43 44 45 46 47 48
51 52 53 54 55 56 57 58
61 62 63 64 65 66 67 68
71 72 73 74 75 76 77
81 82 83 84 85 86 87 88
REFERENCE
OIL WELL
GAS WELL
WATER INJECTION WELL
WATER SOURCE WELL
WELL CLOSED IN (HGOR. HWC. OR AW.)
GAS CONDENSATE WELL
WELL COMPLETED ON LOWER HORIZON (COMBINED WITH OIL OR GAS SYMBOLS)
WELL SUSPENDED
DRY WELL ABANDONED
TWIN WELLS (COMBINED WITH OIL OR GAS SYMBOLS)
WATER DISPOSAL
OIL WELL CONVERTED TO WATER INJECTION
HGOR - HIGH GAS OIL RATIO
HWC - HIGH WATER CUT
AC - AWAITING COMPLETION
AW - AWAITING WORKOVER
M MUDERONG RESERVOIR
J - JURASSIC RESERVOIRS
J5 - 5300' SAND
J2 - 6200' SAND
J6 - 6600' SAND
J7 - 6700' SAND
SCALE OF KMS
SCALE OF MILES
BARROW ISLAND AREA
WINDALIA RESERVOIR
31·12·70



DONGARA AREA
SHOWING WELLS DRILLED FOR PETROLEUM

12274

PETROLEUM DEVELOPMENT AND PRODUCTION IN WESTERN AUSTRALIA IN 1970

by R. N. Cope

BARROW ISLAND (Wapet)

The initial phase of development of the Barrow Island Field ended in July, 1970, with the drilling in this year of 13 Windalia producing wells, 29 Windalia water injection wells and 2 water supply wells.

The positions of all wells drilled on the field to the end of 1970 are shown on Plate 13. The total footage of development drilling on Barrow Island during the year amounted to 120,461 feet (36,717 m), a decrease of 313,144 feet (95,446 m) on the 1969 figure.

Oil production rose from an average of 41,319 barrels (6,569 m^3) per day in December, 1969 to 46,940 barrels (7,463 m^3) per day in December, 1970, giving an increase for the year of 3,295,606 barrels (523,968 m^3). Provision for this increase was made by the installation of a fifth 200,000 barrel (31,798 m^3) storage tank, giving a total storage capacity on the island of 1,000,000 barrels (158,990 m^3).

The increase in production was achieved by drilling 13 additional Windalia producers, by extending gas lift to another 18 Windalia wells and by putting a further 47 Windalia wells on pump. The water flood scheme also contributed by maintaining formation pressure; the maximum field injection rate of about 115,000 BWPD (18,284 m^3WPD) has now been reached.

Artificial lifting capacity has been further increased at an average rate of 14 wells per month. Two 1,000 hp (1,014 PS) compressors are now in operation in order to utilise low pressure Windalia gas for the gas lift system.

It is estimated that production for 1971 from Barrow Island will be in the order of 18·5 million barrels ($2 \cdot 94 \times 10^6$ m^3) of oil and 9 billion cubic feet ($2 \cdot 5 \times 10^8$ m^3) of gas.

Reserves of the Barrow Field are said by Wapet to be 200 million barrels (32×10^6 m^3) of recoverable oil producible by primary and secondary methods.

Details of well status by reservoirs, production figures and wells drilled during the year on Barrow Island, are tabulated below:

TABLE 1. BARROW ISLAND OIL AND GAS PRODUCTION, 1970

Reservoir	Production for year 1970			Cumulative production		
	Oil (bbls)	Water (bbls)	Gas (mcf)	Oil (bbls)	Water (bbls)	Gas (mcf)
Windalia	16,166,734	1,510,348	11,292,677	44,259,599	2,237,930	31,107,674
Muderong	284,952	34,566	215,912	451,683	77,495	372,671
Jurassic 5,500 ft	12,377	49,369	344,334	12,673	49,376	354,316
Jurassic 6,200 ft	24,941	41,275	1,293,421	45,184	64,390	1,764,171
Jurassic 6,600 ft	24,278	82,140	84,114	181,823	201,993	529,428
Jurassic 6,700 ft	179,887	63,121	605,859	839,722	158,639	2,146,312
Total field	16,693,169	1,780,819	13,836,317	45,790,684	2,789,823	36,274,572

Water injected: 30,524,981 bbls. Cumulative water injected: 55,721,397 bbls. N.B.: 1 bbl = 0·15899 m^3 1 cu. ft = 0·028317 m^3

TABLE 2. BARROW ISLAND WELL STATUS BY RESERVOIRS AT 31st DECEMBER, 1970

Reservoir	Flowing	Pumping	Gas lift	Non-producing	Water injection wells	Injection source wells	Total
Windalia	63	96	158	6	153	9	485
Muderong	4	....	4	....	....	....	8
Jurassic 5,500′	1	....	....	....	....	....	1
Jurassic 6,200′	1	....	....	1	....	....	2
Jurassic 6,600′	1	....	....	....	....	....	1
Jurassic 6,700′	2	....	1	2	....	....	5
Total	72	96	163	9	153	9	502

Grand total: 502 wells.

TABLE 3. BARROW ISLAND OIL AND GAS DISPOSAL 1970

	Oil (bbls)	Gas (mcf)
Total production	16,693,169	13,836,317
Field fuel	1,236	405,719
Gas flared	....	13,431,318
Oil shipments	16,674,890	....
Percentage of field utilisation....	0·0074	2·9
Percentage of gas flared	....	97·1
Royalty received	$2,090,883·37	....

N.B.: 1 bbl = 0·15899 m^3
1 cu ft = 0·028317 m^3.

TABLE 4. WELLS DRILLED ON BARROW ISLAND 1/1/70 TO 31/12/70

Well	Elevation: Rotary Table (feet)	Elevation: First Flange (feet)	Total Depth (feet)	Com-menced	Com-pleted	Original Status*
C 57	63	52	3,615	5/2/70	9/2/70	P
D 11	N.A.	N.A.	2,799	23/6/70	28/6/70	P
E 15	110	99	2,552	12/1/70	16/1/70	WI
J 58	137	126	2,535	10/2/70	13/2/70	P
K 33	174	164	2,531	4/1/70	7/1/70	WI
K 73	165	155	2,654	7/1/70	11/1/70	P
L 24	207	197	2,490	16/1/70	19/1/70	WI
L 26	208	197	2,521	19/1/70	22/1/70	WI
L 27	181	171	2,464	26/1/70	29/1/70	P
L 62	183	172	2,377	22/1/70	25/1/70	P
L 82	149	139	2,306	29/1/70	4/2/70	P
P 11	192	182	2,553	21/4/70	23/4/70	WI
P 12	175	165	2,553	7/4/70	10/4/70	P
P 13	184	173	2,545	23/4/70	26/4/70	WI
P 22	184	173	2,553	4/4/70	7/4/70	P
P 24	174	164	2,556	31/3/70	3/4/70	P
Q 28	199	188	2,557	27/2/70	1/3/70	WI
Q 33	136	125	2,467	11/6/70	14/6/70	WI
Q 37	183	173	2,530	14/6/70	16/6/70	WI
Q 42	180	169	2,559	8/6/70	10/6/70	WI
Q 44	149	138	2,493	2/6/70	5/6/70	WI
Q 46	208	197	2,480	5/6/70	7/6/70	WI
Q 46/56	234	223	4,118	16/2/70	27/2/70	WSW7A
Q 48	207	197	2,553	2/3/70	5/3/70	WI
Q 51	140	130	2,522	22/3/70	26/3/70	WI
Q 53	172	162	2,552	17/3/70	22/3/70	WI
Q 55	168	158	2,522	29/5/70	2/6/70	WI
Q 56/57	212	202	4,060	21/7/70	31/7/70	WSW7B
Q 57	218	208	2,587	15/5/70	17/5/70	WI
Q 64	210	199	2,553	14/3/70	17/3/70	WI
Q 65	208	197	2,553	11/4/70	14/4/70	P
Q 66	211	200	2,527	10/5/70	14/5/70	WI
Q 67	195	184	2,493	17/4/70	20/4/70	P
Q 68	174	163	2,497	5/3/70	7/3/70	WI
Q 75	193	183	2,522	25/5/70	29/5/70	WI
Q 77	170	160	2,480	22/5/70	25/5/70	WI
Q 84	161	150	2,460	10/3/70	14/3/70	WI
Q 88	214	203	2,494	8/3/70	10/3/70	WI
R 48	131	120	2,526	17/6/70	20/6/70	WI
R 57	102	92	2,526	22/3/70	26/3/70	WI
S 67 J	127	115	7,601	26/6/70	15/7/70	P
T 83	189	178	2,551	30/4/70	4/5/70	WI
T 86	154	143	2,552	18/5/70	22/5/70	WI
T 88	145	134	2,522	26/4/70	29/4/70	WI
Y 24 J	134	122	7,523	19/5/70	18/6/70	S

Datum adopted for Barrow Island wells is 18·4 feet above mean sea level or 23·44 feet above Indian Spring low water mark.
* P = Windalia Producer.
WI = Windalia water injection well.
W8W = Water source well.
S = Suspended.
Total development drilling during 1970 on Barrow Island was 127,984 feet.
N.B.: 1 foot = 0·3048 m.

DONGARA FIELD

The development drilling programme that was started in 1969 was finished in February 1970 with the drilling of an additional two wells (Table 5, Plate 14).

TABLE 5. DONGARA DEVELOPMENT WELLS

Well Number	18	19
Latitude S	29° 16′ 29″	29° 16′ 14″
Longitude E	115° 01′ 54″	115° 02′ 36″
Elevation G.L.	327′	360′
Elevation R.T.	343′	378′
Date spudded	9/1/70	7/2/70
Date completed	26/1/70	28/2/70
Total depth	6,300′	7,150′
Formation bottomed in	Irwin River Coal Meas.	Holmwood Shale
Perforated interval	5,710–5,740′	5,838–5,858′
Producing Formation	Basal Triassic Sand	Basal Triassic Sand
Product	Gas	Oil
Production rate	10 MMCFD	800 BPD
Choke size	½ inch	¼ inch

N.B.: 1 foot = 0·3048 m; 1 inch = 2·54 cm.
1 cubic foot = 0·0283 m^3.
1 bbl = 0·159 m^3.

In December 1970 contracts were let for the construction of a 255-mile (410 km) long, 14-inch (36 cm) diameter gas pipeline between Dongara and Pinjarra via Kwinana. Wapet have announced that a through-put of 70 to 80 million cubic feet (20 to 23 x 10^5 m^3) per day would be maintained over a period of 15 years. This would be achieved presumably by drawing on the reserves of the otherwise uncommercial fields of Yardarino, Mondarra and Gingin. Owing to declining production from Dongara, filling the pipeline after 15 years would depend on further gas discoveries. The gas reserves of the Dongara Field alone are said to be in the order of 500 Bcf (14 x 10^9 m^3). Initially in 1972 the principal consumers will be the Alcoa alumina refinery at Pinjarra (60 per cent) and the State Electricity Corporation (20 per cent).

THE PHANEROZOIC STRATIGRAPHY OF WESTERN AUSTRALIA: A CORRELATION CHART IN TWO PARTS

by P. E. Playford and R. N. Cope

INTRODUCTION

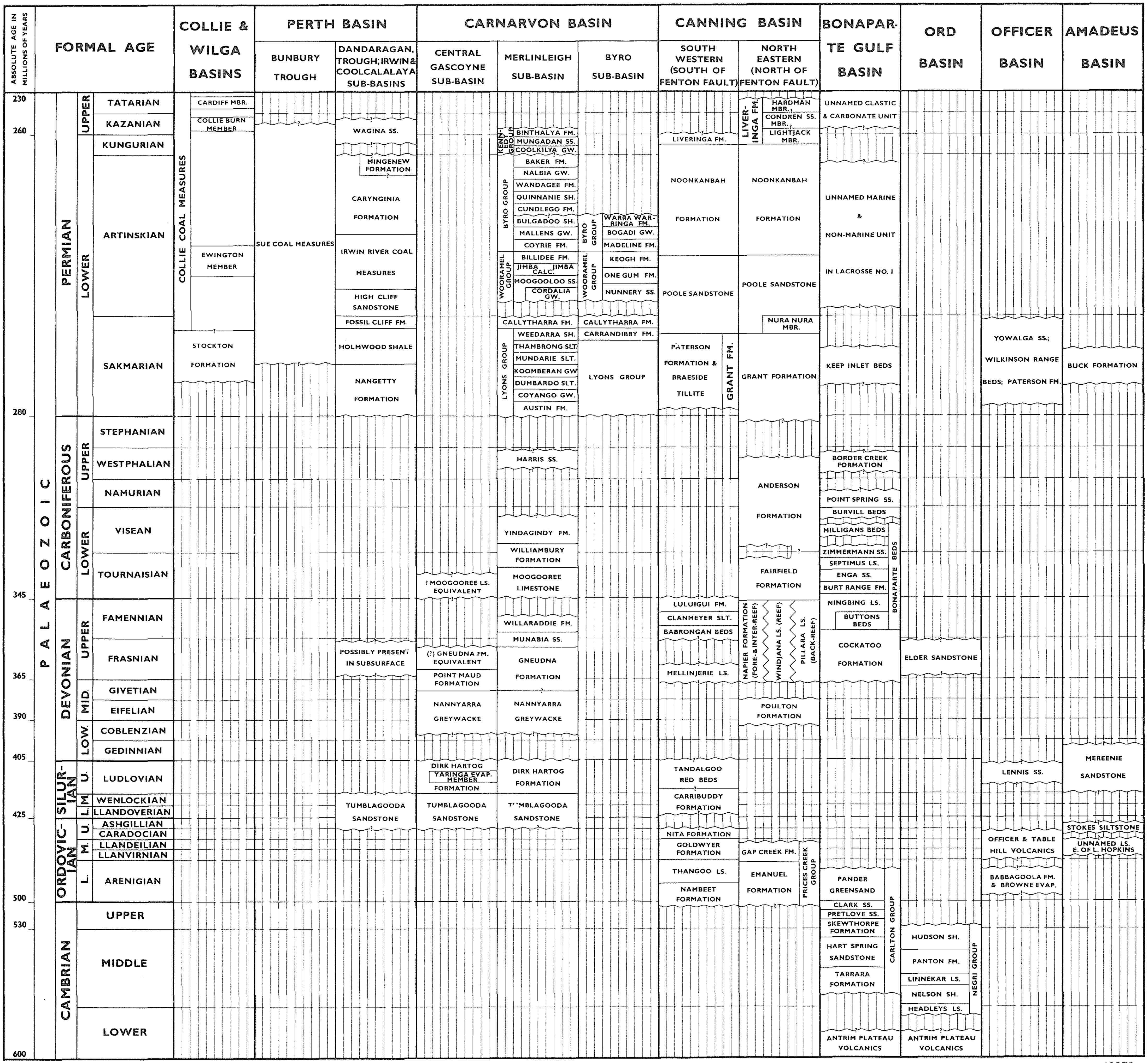
The object of the accompanying correlation charts is to present the rock and time-stratigraphy of all the Phanerozoic sedimentary basins of the State in a form which is both comprehensive and readily usable. Separate charts have been used for the Palaeozoic and post-Palaeozoic, firstly to give the clearest possible presentation in a limited space, and secondly to vary the coverage of the sub-basinal columns in a way best suited to the basin stratigraphy. These correlation charts are published here in order to make them available for general use as soon as possible: the charts will also appear in a different form in a volume on the "Geology of Western Australia" currently being prepared for publication.

TIME–STRATIGRAPHY

The vertical time scale is only approximately proportional to absolute age, owing to the uneven distribution of rock-units to be illustrated. Formal time units are taken down to stage level, except in the cases of the Cambrian, Tertiary and Quaternary Periods, where stages have been omitted for reasons of space and of difficulty of correlation. However, where stage names are used the correlation with time-rock units defined outside Australia is usually only approximate. A few exceptions occur, such as the Bajocian of the northern Perth basin.

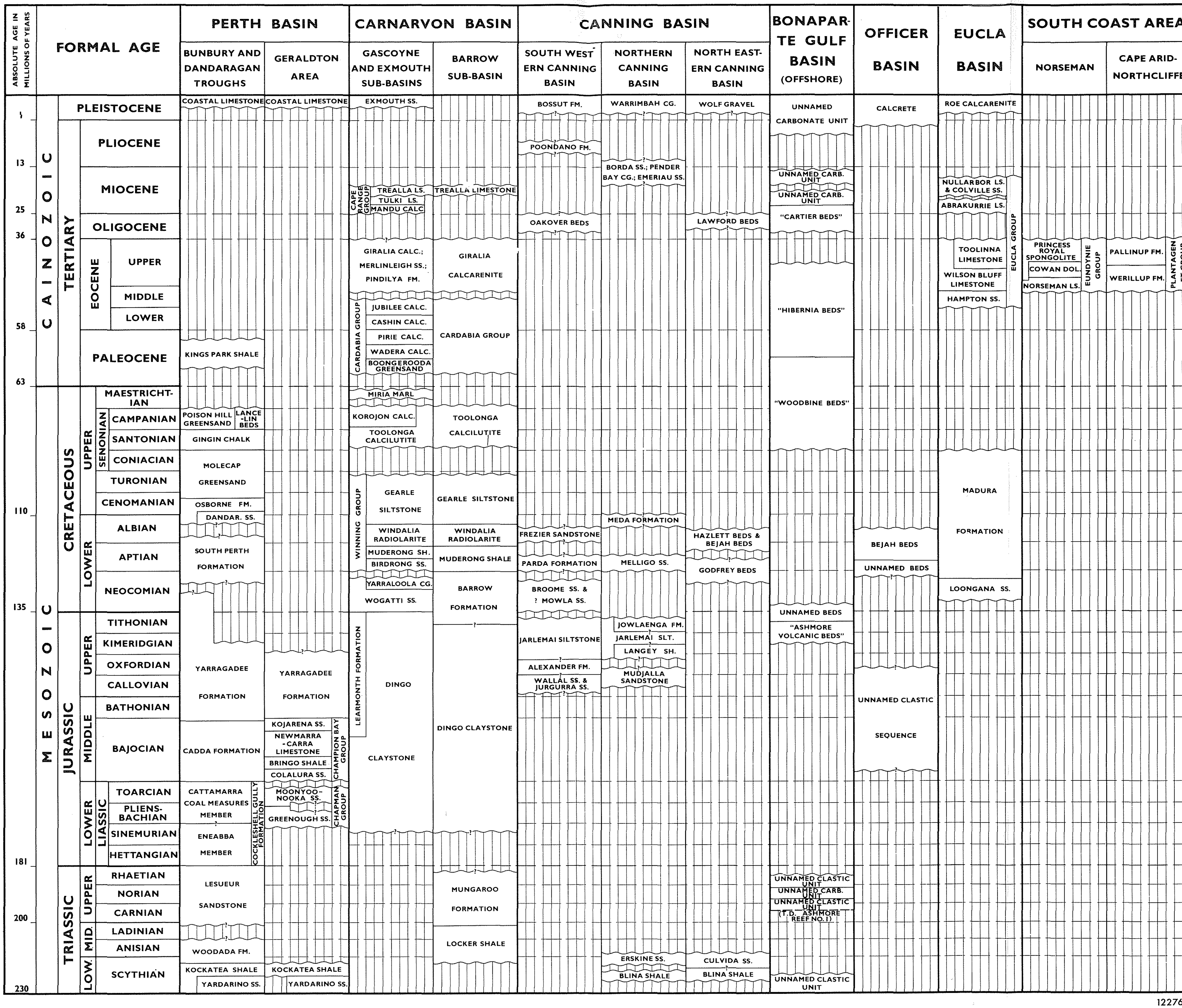
ROCK-STRATIGRAPHY

Descriptions of most of the rock units figured are available in McWhae and others, 1958, and all will be described in the forthcoming "Geology of Western Australia" already referred to. A number of rock units will be described there for the first time, and those figured on the correlation chart are listed by basins as follows:—Perth Basin: Sue Coal Measures, Yardarino Sandstone, Eneabba Member, Cattamarra Coal Measures Member; Carnarvon Basin: Barrow Formation; Canning Basin: Poulton Formation, Babrongan Beds; Officer Basin: Babbagoola Formation, Browne Formation, Officer Volcanics, Lennis Sand-

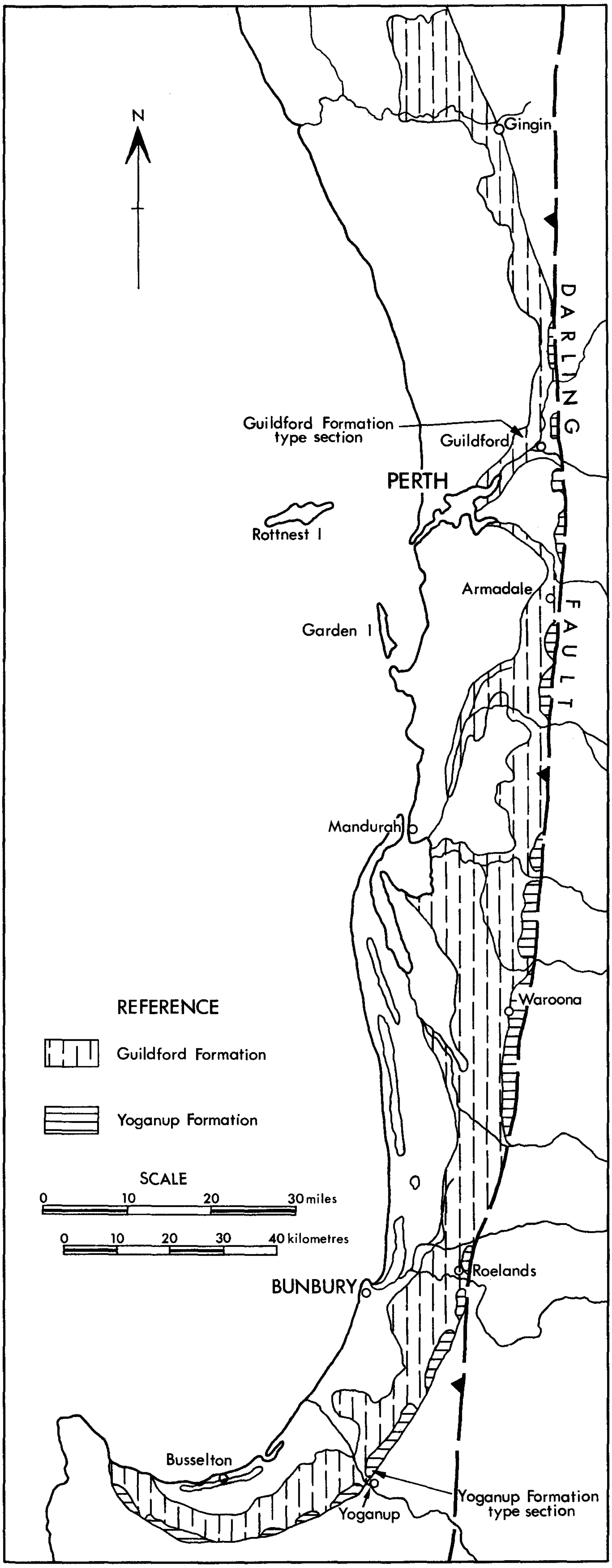


12275

PHANEROZOIC STRATIGRAPHY OF WESTERN AUSTRALIA, CORRELATION CHART.
PART I CAMBRIAN TO PERMIAN



PHANEROZOIC STRATIGRAPHY OF WESTERN AUSTRALIA, CORRELATION CHART.
PART II TRIASSIC TO CAINOZOIC



DISTRIBUTION OF GUILDFORD AND YOGANUP FORMATIONS IN THE PERTH BASIN

12277

stone. In the Bonaparte Gulf Basin certain rock-unit names have been introduced informally for distinctive intervals of the oil exlporation well Ashmore Reef No. 1 (Craig, 1969). Insufficient data are available regarding the lateral distribution and variation of these potential formations, and informal status is therefore conferred by the use of inverted commas. They are "Ashmore Volcanic Beds", "Woodbine Beds", "Hibernia Beds" and "Cartier Beds".

ADDITIONAL COPIES

Additional copies of these correlation charts may be purchased from the Geological Survey of Western Australia, 5th Floor, Mineral House, 66 Adelaide Terrace, Perth.

REFERENCES

Craig, R. W., 1969, Geology *in* Ashmore Reef No. 1 well completion report: Burmah Oil Co. Australia Petroleum Search Subsidy Act report (unpublished).

McWhae, J. R. H., Playford, P. E., Lindner, A. W., Glenister, B. F., and Balme, B. E., 1958, The stratigraphy of Western Australia: Geol. Soc. Australia Jour., v.4, pt.2

DEFINITION OF TWO QUATERNARY FORMATIONS IN THE PERTH BASIN

by G. H. Low

INTRODUCTION

The purpose of this paper is to define and amend two formations which are to appear on maps published by the Geological Survey. The Yoganup Formation is defined for the first time. The Guildford Formation is an amendment of Guildford Clays. Plate 17 shows the distribution of these two formations.

GUILDFORD FORMATION

The Guildford Formation consists of sands and clays, chiefly of alluvial origin, but it also includes minor marine and estuarine lenses. It underlies the coastal plain between the Coastal Limestone and the piedmont zone at the foot of the Darling Scarp. Exposures of the unit in the Swan River valley from Upper Swan (31° 46′ 30″ S, 116° 01′ 10″ E) downstream to Guildford, together with strata at shallow depths in water bores in the area, were originally called the "Guildford Clays" by Aurousseau and Budge (1921). The sequence was renamed the Guildford Formation in an unpublished thesis by Baker (1954), who pointed out that sand sometimes replaces clay as the dominant lithology. The beds intersected in the West Guildford artesian bore (31° 54′ 30″ S, 115° 57′ 20″ E) down to a depth of 108 feet 3 inches (32·99 m) are proposed here as the type section. The driller recorded the following sequence in the upper part of the bore, from the surface.

Feet	Inches		Feet	Inches	
0	0	—	25	6	Clay, brown
25	6	—	27	0	Sand, brown, coarse
27	0	—	72	0	Clay, brown and blue, interbedded
72	0	—	100	0	Sandstone
100	0	—	108	3	Boulders

(Note 1 foot = 30·48 cm).

The Guildford Formation is best exposed along the valleys of the Swan, Helena, Serpentine and Murray Rivers and is known from numerous water bores over the same area. McArthur and Bettenay (1960) referred to the upper surface of the formation as the Pinjarra Plain and distinguished a sequence of depositional systems for several of the major rivers, mainly on the basis of soils. The formation consists of interbedded lenticular sand and clay, calcareous in places, with occasional thin lenses of basal conglomerate. A thin band of marine shells (including *Anadara* and *Dosinia*) at about 15 feet above present day mean sea level was reported by Fairbridge (1953) from clay pits at Caversham, near Guildford, and at Folly Flats, 30 miles (48·2 km) to the south.

The formation progressively interfingers to the west with shallow neritic to littoral sediments, probably representing the basal part of the Coastal Limestone. It is about 100 feet (30·4 m) thick and ranges from 70 feet (21·3 m) below sea level to 50 feet (15·2 m) above. It unconformably overlies the Paleocene Kings Park Shale or the Cenomanian to Albian Osborne Formation in the metropolitan area east of Perth and is extensively covered by the Pleistocene Bassendean Sand. The formation unconformably overlies Lower Cretaceous South Perth Formation in the Pinjarra area.

The exact age of the Guildford Formation is not known, but it is believed to belong to the Pleistocene, possibly middle to late Pleistocene.

YOGANUP FORMATION

The Yoganup Formation represents a shore line deposit that includes a basal beach conglomerate and a foredune. Any carbonate originally present has been leached out and the unit is variably lateritised. In some places it carries economic concentrations of heavy minerals, principally ilmenite and zircon.

The deposits form a land surface which McArthur and Bettenay (1960) mapped as the "Ridge Hill Shelf", and Welch (1964) described the deposits under the heading "Lower Escarpment Shoreline". Lowry (1965) mapped them as the "Ridge Hill dune system", and Ward (1967) referred to them as the "Yoganup Shoreline Series".

The formation occurs in a narrow strip up to 1 mile (1·6 km) wide. It is best represented around the foot of the Whicher Scarp southwest from the vicinity of Burekup, but remnants occur north along the Darling Scarp for 120 miles (193·1 km) to the vicinity of Upper Swan. The unit unconformably overlies Lower Cretaceous South Perth Formation or Lower Jurassic Cockleshell Gully Formation and at its eastern boundary abuts against scarps formed along the South Perth Formation or

Precambrian rocks. It is disconformably overlain in places by up to 40 feet (12·1 m) of Pleistocene-Recent alluvium in the form of outwash fans.

The formation is named after the Yoganup Railway Siding and the proposed type section is in Westralian Sands Ltd.'s open cut near Yoganup (33° 38′ 50″ S, 115° 36′ 10″ E). At this locality a thin basal conglomerate with rounded quartz and quartzite clasts is overlain by clayey sand containing two parallel ilmenite-rich bands which are each up to 15 feet (4·5 m) thick (Morgan, 1964). This is overlain by a lenticular bed of grey clay, followed by a yellow sand probably representing a foredune or beach ridge. The section is about 30 feet (9·1 m) thick.

The grey clay unit has not been recognised north of Roelands where the formation abuts against Precambrian rocks. The sand grains in the formation are typically medium to coarse grained, rounded and moderately well sorted.

The base of the formation ranges in elevation from about 120 to 150 feet (36·5 to 45·7 m) above sea level and dips away from the scarps at angles of up to 10 degrees.

No fossils are known from the Yoganup Formation, but because of its stratigraphic position, degree of alteration and dissection and its elevation above sea level, it is believed to be Pleistocene, possibly Middle Pleistocene, in age.

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A GEOLOGICAL INTERPRETATION OF THE BUREAU OF MINERAL RESOURCES GRAVITY MAP OF THE SOUTHWESTERN PART OF WESTERN AUSTRALIA

by J. L. Daniels

ABSTRACT

The Bureau of Mineral Resources (B.M.R.) reconnaissance gravity map of south-west Australia can be subdivided into five main areas. Each of these has its own distinctive gravity pattern.

Some of the gravity features within these zones have been interpreted. Among these, and crossing the Archaean of the Yilgarn Block, are two east-northeast-trending lineaments, which are parallel to an important suite of dykes and thought to represent lines of transcurrent faulting.

Also in the Archaean are several gravity high spots which in some cases correspond to areas in which acid volcanic material is present. It is sugested that these gravity high spots correspond to centres of acid volcanicity, possibly associated with cauldron subsidence.

Between the Archaean of the Yilgarn Block and the Proterozoic of the Albany-Fraser Province, is a wide zone in which elements of the gravity pattern of both regions are present.

INTRODUCTION

In 1969 the Bureau of Mineral Resources undertook a helicopter gravity survey of the southwest of Western Australia. The results were published as a contoured map (1969).

This brief report is an attempt, by a geologist, to subdivide the region and present tentative explanations of some of the features and trends shown on the B.M.R. gravity map.

REGIONAL SUBDIVISION

The map may be subdivided into eight main areas, each of which has a fairly distinctive gravity pattern. The areas are shown in Plate 18, and the general characteristics of each are listed below:

1A. This is a narrow northwest-trending zone with a generally low gravity relief and a regional slope to the northeast.

1B. This broad area has a northwest trend, is of generally low gravity values and is crossed by several widely spaced and poorly defined northwest-trending high and low axes. There are two major breaks, trending east-northeast, in the continuity of the high and low axes, and the centre of the area contains several spot gravity highs.

1C. This zone, in the central north sector of the map area, consists of closely spaced high and low gravity axes with a general northwesterly trend. In several places spot gravity highs occur.

2. Zone 2 is a triangular area forming a large part of the southwest corner of the State. It exhibits high gravity values marginal to the Darling Fault with a gradual diminution to the northeast. Some well-defined northwest-trending high and low axes are present in the southwest and these interrupt the major northerly-trending gravity high ridge which runs parallel to the western margin of the zone. A few vague northeast-trending axes can be seen crossing the zone. Its main gravity characteristics were first described by Everingham (1965).

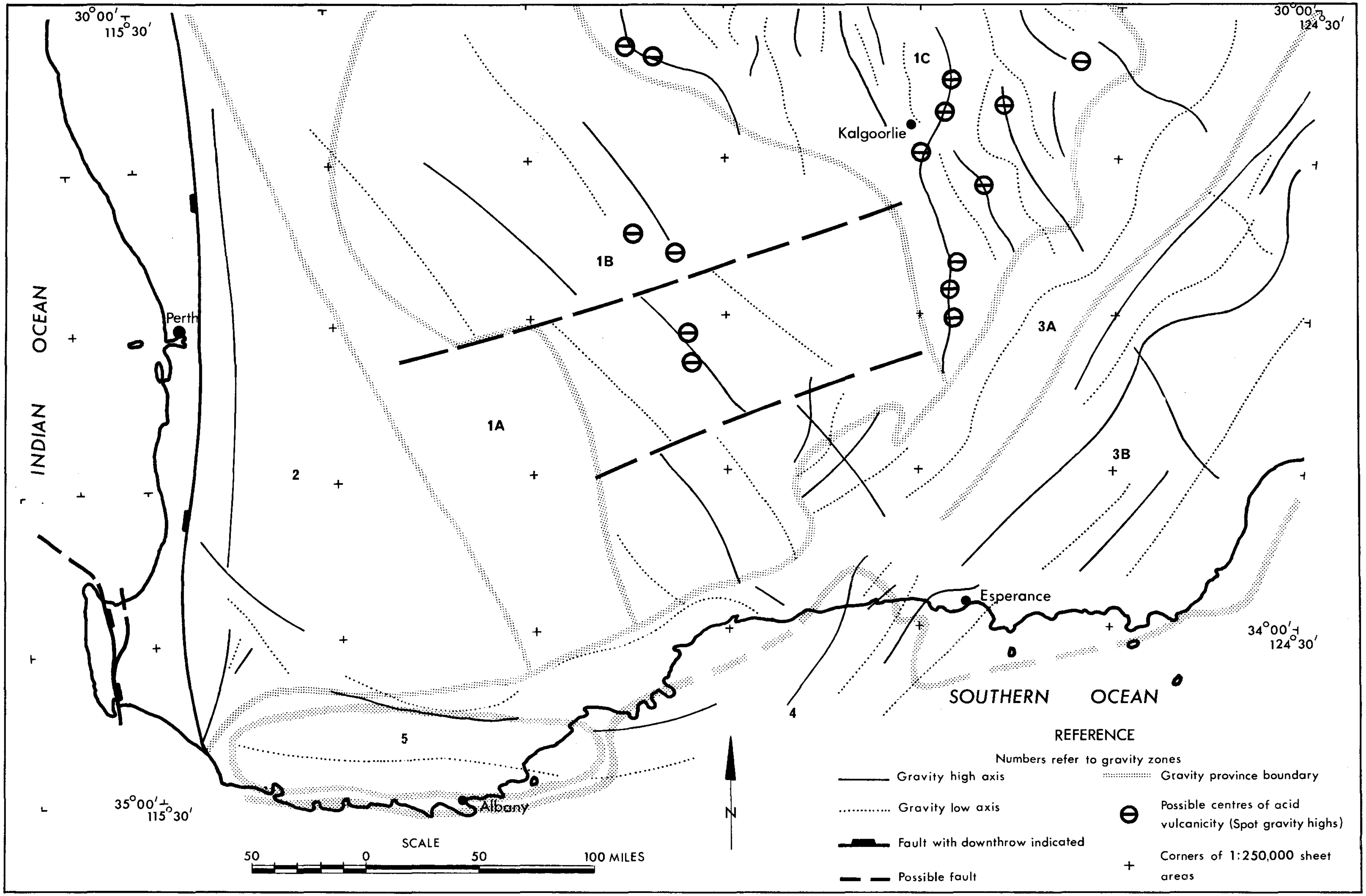

PLATE 18

TECTONIC DOMAINS DEDUCED FROM THE BMR GRAVITY MAP OF SOUTHWESTERN AUSTRALIA

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3. Zones 3A and 3B together form an arc on the south and southeast sides of the above described zones. High and low axes are fairly closely spaced and although somewhat sinuous have a northeasterly trend in the east, becoming more easterly in the southwest. The zone abruptly truncates many of the features of Zones 1 and 2.

The westerly extension of this zone's northerly margin may be drawn in several ways. That shown on Plate 18 excludes the southwest portion of Zone 2 with closely spaced high and low axes. This portion may be related to Zone 3B. However the overall gravity high of the area relates it more to Zone 2. A possible geological explanation is given below.

4. Zone 4 is not well defined, but flanks the southern side of Zone 3B, which it apparently truncates, and would appear to be a zone of moderately high gravity, though the data is meagre.

5. Zone 5 is an oval gravity-low area with an easterly trending long axis. It is developed in Zone 3B in the southwest corner of the State, near Albany.

Some of the main geological inferences derived from this areal subdivision are noted below, and a summary of the known or suggested natures of the boundaries between the areas is given in Table 1.

DISLOCATIONS WITH ZONE 1B

The northwest trend of the gravity highs and lows of this zone is broken in two places in such a way as to suggest the presence, in those places, of major, parallel, crustal fractures. The displacement of the axes suggests that the movement on these fractures is, at least in part, lateral.

Matching of the individual high and low axes across these breaks is open to question, but a minimum lateral displacement of 20 miles (32·1 km) is indicated.

A simple overlay of the map (Plate 18) on the Western Australia geological map (1966 edition) shows that the trend displayed by the suggested dislocations is also that of the so-called east-west dykes.

No lateral movement approaching 20 miles (32·1 km) is known along any of these dykes and hence it is suggested that the main movement along these lines took place before the emplacement of the dykes.

GRAVITY HIGH SPOTS IN THE ARCHAEAN

Several gravity high spots are located in the Archaean of Zones 1B and 1C. They are well developed in the Widgiemooltha (Sofoulis, 1966) and Kurnalpi Sheet (Williams, 1970) areas and correspond with local developments of acid volcanic rocks. The same applies to the gravity high in the northern part of the Jackson Sheet area. The surface geology related to the gravity highs in the Southern Cross and Hyden Sheet areas is not known.

The geological interpretation of this association of low density rocks on the surface with gravity high spots is conjectural. It necessitates the incorporation, in the explanation, of the presence of higher density rocks at depth.

An excellent example of a similar gravity high, on an extensive gravity ridge, in association with acid volcanics is seen in the northeast corner of the Talbot Sheet area in the Warburton Range region. In this example the acid volcanics are confined to a cauldron subsidence area (Daniels, 1969), while the gravity high is thought to be caused by underlying gabbroic rocks, only small amounts of which are exposed at the surface (Daniels, in prep.).

With this example in mind it is suggested that the gravity high spots in the Archaean (Plate 18) are the sites of acid vents and probably also are cauldron subsidence areas. They are worthy of investigation for mineralisation.

ARCHAEAN-PROTEROZOIC CONTACT

The most noticeable feature of the gravity interpretation is the truncation of the structures in the Yilgarn by those developed in the south and southeast. The former reflect the broad regional gravity characteristics of the Archaean while the latter are related to the igneous and metamorphic rocks of the Albany-Fraser Province—a Proterozoic mobile belt. The gravity features associated with this belt presumably developed at the time of formation of the belt and are important in understanding the development of the Proterozoic in Western Australia.

The contact between the two is gradational and there exists between them a wide zone, especially evident in the east and the extreme southwest. This zone shows features of the gravity patterns of both the Archaean and the mobile belt.

The mixed pattern in this contact zone is interpreted to mean that the influence of the mobile belt extends for a considerable distance into the Archaean of the Yilgarn Block.

DISTRIBUTION OF MIDDLE PROTEROZOIC SEDIMENTARY ROCKS

Several elongate outcrops of Proterozoic sedimentary rocks are present within the Albany-Fraser Province (Mount Ragged and Mount Baring), on or near its margin (Stirling Range and Barren Range) or in the mixed zone between the Archaean and the Proterozoic (Woodline Beds). In each case the elongation of the outcrops is parallel to the dominant trend in the gravity pattern. This suggests that the deposits accumulated in long narrow troughs whose development, and perhaps also their preservation, was controlled by movements in narrow zones associated with the later development of the mobile belt.

COLLIE AND WILGA BASINS

The elongation of the Collie and Wilga Basins is parallel to the northwest regional gravity trend in that region. This is the dominant trend in part of a larger area, referred to above, and whose gravity pattern is interpreted as an overlap of the Archaean and Proterozoic patterns. The development of the Collie and Wilga Basins probably took place along lines of weakness related to the mobile belt which forms the Albany-Fraser Province.

ZONE 4

This zone appears to truncate part of Zone 3. It is likely to be an integral part of the Albany-Fraser Province, but because of the possible truncation it may be related to a younger belt of metamorphism and igneous activity of which only the northern margin is present in Western Australia.

ZONE 5

There is little doubt that the large gravity low forming Zone 5 is caused by the Albany Granite.

TABLE 1. KNOWN OR SUGGESTED NATURE OF BOUNDARIES BETWEEN UNITS

Contact of Zones	Known or interpreted nature of geological boundaries
1A–2	" Meckering line ". Zone of seismicity probably representing crustal fracture (Everingham, 1965)
1A–1B	Unknown
1B–1C	Unknown
Western side of 2	Darling Fault
2–3	Possibly metamorphic
3–1A, 1B, 1C	Possibly metamorphic
3A–3B	Fault or major shear (Wilson, 1958)
3–4	Possibly intrusive
3–5	Intrusive

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PORPHYRITIC DOLERITES OF THE EDJUDINA SHEET AREA

by C. F. Gower

ABSTRACT

Porphyritic dolerites with plagioclase phenocrysts up to 5 cm long are described from the Edjudina 1 : 250,000 sheet area. The phenocrysts occur in zones, usually in the upper part of the dolerite, and there is a gradation from non-porphyritic to extremely porphyritic dolerite expressed by an upward increase in the size and abundance of phenocrysts. Feldspar buoyancy is suggested as partly explaining the distribution of the phenocrysts.

INTRODUCTION

During regional mapping of the northern half of the Edjudina 1 : 250,000 Sheet area many occurrences of porphyritic dolerite were recorded. The phenocrysts in the dolerites are plagioclase feldspar and, due to their large size and great abundance, give the rock an extremely distinctive appearance. The phenocrysts are in zones which show little change laterally, but considerable vertical variation.

FIELD OCCURRENCE

Although only porphyritic dolerites occurring within the Ejudina sheet area are considered here they are not unique to this region and have been recorded from other parts of the Eastern Goldfields. For example, by Jutson (1914) from Ora Banda, by I. R. Williams (pers. comm.) from northwest of Bulong, and in the Norseman area by Halberg (1970). Various names have been applied to the rock-type and have been discussed by D. A. C. Williams (1967). The names include gabbro porphyrite, diabase porphyrite, porphyritic andesite, porphyritic microgabbro in addition to the term porphyritic dolerite which is used here. "Cat Rock" is the local name for these dolerites, originally applied by the goldminers because of its spotted appearance.

The best development of porphyritic dolerite on the Edjudina sheet area is between Pyke Hill and Eucalyptus, and there are also minor occurrences in the vicinity of Mount Percy, Yerilla, Kookynie and Glenorn (Plate 19).

The porphyritic dolerites trend parallel to the strike of the country rock and in general appear to be concordant and intrusive, though it is possible that some of the finer grained varieties may be extrusive. Fine-grained porphyritic basic rocks, almost certainly lavas, are also present and may be related genetically to the dolerites. The decision whether the porphyritic dolerite is intrusive or not must often be made on grain size and other textural grounds, since poor outcrop obscures diagnostic criteria, including detailed field relationships. The thickness of the porphyritic dolerites ranges from less than 10 feet (3 m) to over 400 feet (122 m), though the larger thicknesses are generally the result of multiple intrusion. Where outcrop is good, the porphyritic dolerites can be traced laterally over distances of up to 10,000 feet (3,000 m).

Homogeneous non-porphritic dolerites and gabbros, some of which are layered, are frequently associated with the porphyritic dolerites. These both intrude the porphyritic dolerites and are intruded by them. It is obvious that the igneous history is complex and that the porphyritic dolerite intrusive events are inseparable from those involving the non-porphyritic dolerites and gabbros. The country rock is almost always basalt, often containing intercalated sediments which, in places, have been used as avenues along which the dolerites and gabbros have intruded.

FELDSPAR PHENOCRYSTS

The plagioclase phenocrysts are white or creamy, subhedral to euhedral and may be up to 5 cm long. Often they weather out as small bosses on the surface of the rock, but the reverse may also be true, giving the rock a pitted appearance. They have been extensively saussuritized, and it is impossible to determine the original composition of the phenocrysts. Comparison, if valid, with similar but less altered rocks from other parts of the Eastern Goldfields indicates that the phenocrysts were probably in the andesine-labradorite range. They are often zoned, and inclusions are common.

The phenocrysts show considerable distributional variation within the dolerites. In some parts of an intrusion they may be completely absent but at other parts of that same body they can be so numerous that the groundmass is relegated to interstitial status. Where they are absent there is sometimes evidence of mineral layering and small-scale differentiation.

One feature noted was a change from non-porphyritic dolerite to extremely porphyritic dolerite, expressed by a gradual increase in the size and abundance of feldspar phenocrysts accompanied by an increase in groundmass grain size. The feldspars are rarely more than 0·5 cm when they first appear, but within a distance of about 10 feet (3 m) they may be as large as 5 cm. Often where the phenocrysts are very numerous they cluster to form glomerocrysts up to 10 cm in diameter. It seems that the change from non-porphyritic to porphyritic dolerite takes place in an upward sense with most of the phenocrysts collected at or near the top of the dolerite. However it was not possible to prove that this is always the case. No evidence of a gradation in a downward sense was observed, but bands of phenocrysts near the (interpreted) base of some of the intrusives were seen. Exposure is not good enough to decide whether or not these bands represent

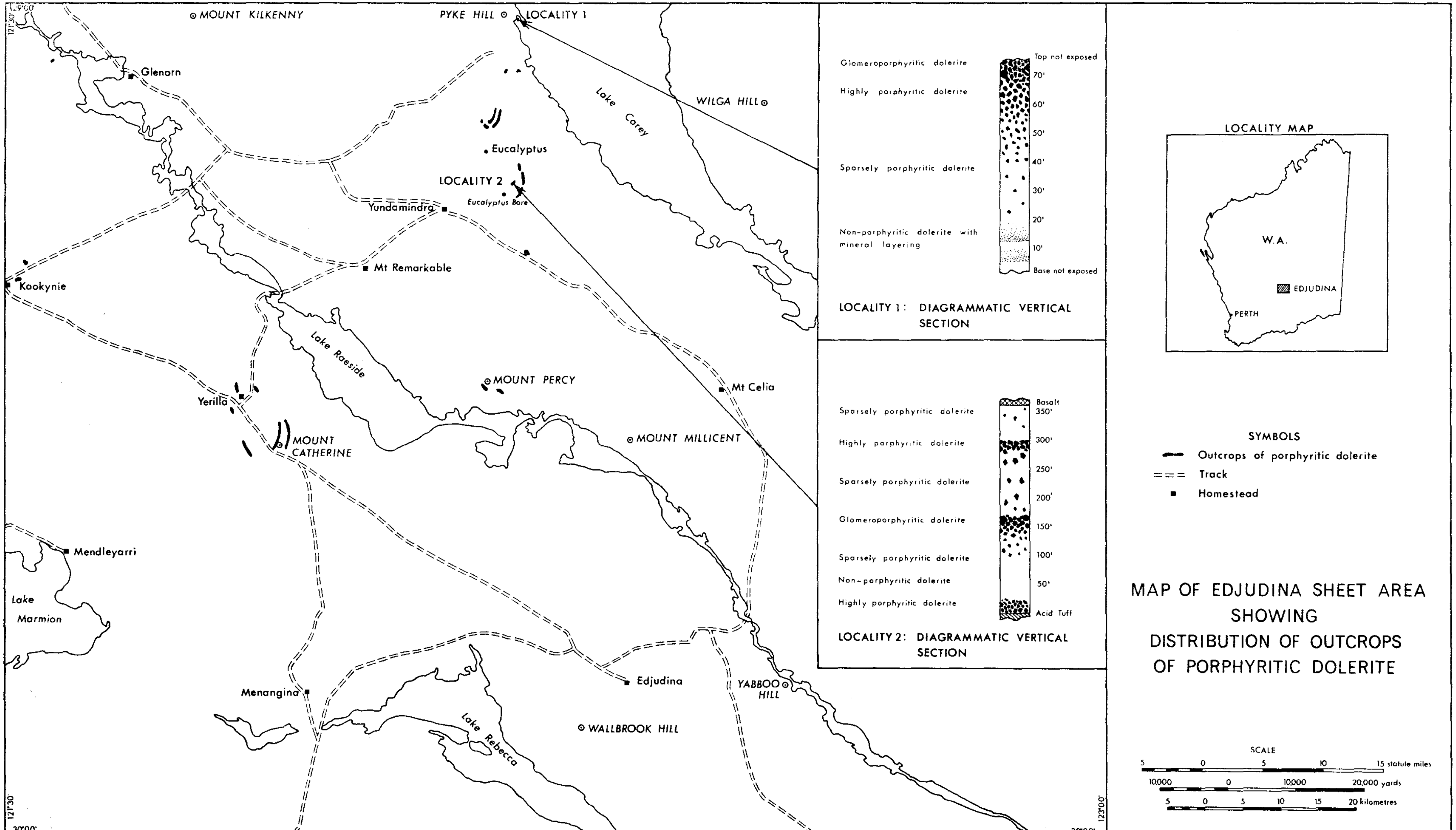

PLATE 19

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separate intrusions. The base of some of the intrusions is difficult to ascertain. Differentiated gabbros and dolerites near the porphyritic intrusives sometimes indicated facing; pillow lavas and graded bedding in intercalated sediments also occasionally proved useful.

DESCRIPTION OF SELECTED SECTIONS

Locality 1

This is a small island about 7,000 feet (2,100 m) east-southeast of Pyke Hill, located near the edge of Lake Carey (see Plate 19). The island is elongate north-south, parallel to the strike, and is roughly 500 feet (150 m) long and 150 feet (45 m) wide. The rocks dip eastwards at about 80°. A suite of specimens was collected across the width of the island at the southern end where exposure is good. On the west side of the island is a medium to coarse-grained basic rock composed originally of plagioclase and pyroxene with minor quartz and accessory opaque minerals. The plagioclase has been saussuritized and the pyroxenes largely uralitized. The grain size ranges up to about 0·5 cm. The texture is variable with good mineral layering and some small-scale differentiation developed, indicating that the succession is east-facing. A few feet farther east the rock shows an increase in feldspar content in the groundmass and also has a few plagioclase phenocrysts. These are generally euhedral and less than 1 cm long. Continuing east the rock shows an increase in the number and size of phenocrysts, though there is little change in the groundmass. Near the top the phenocrysts are very large (4 cm) and the matrix subordinate. At the top, on the eastern side of the outcrop, the rock is glomeroporphyritic with feldspar in clusters which have diameters up to 10 cm. The groundmass is now coarse grained (0·6 cm.) and confined to interstices between the phenocrysts. Neither the top nor the base of the body is exposed and although it is often the case that the margins of exposure also represent the boundaries of geological units there is no evidence that this is so here, thus how representative the exposed section is of the whole body cannot be ascertained.

Locality 2

This is a roughly circular outcrop located about 8,000 feet (2,400 m) northeast of Eucalyptus Bore (see Plate 19). It is made up of a varied sequence of both porphyritic and non-porphyritic basalts, dolerite and gabbro with thin acid bands and a thin ultramafic. The strike of the rocks is east-northeast; they dip very steeply south-southeast and are in places vertical. Much of the northern half of the outcrop consists of a thick south-facing differentiated gabbro. South of this is a variable gabbro which is succeeded by two thin acid bands, probably tuffaceous in origin, separated by a thin ultramafic. Porphyritic dolerite is present south of the thin acid bands and makes up most of the southern half of the outcrop. The dolerite is porphyritic at its base in contact with the acid layer, with phenocrysts ranging up to 2 cm long set in a medium to coarse-grained groundmass. There is a rather abrupt change to medium-grained dolerite (non-porphyritic) southwards though no obvious break in continuity could be seen. The medium-grained dolerite grades into porphyritic dolerite in which the phenocrysts are up to 3 cm long, set in a coarse-grained groundmass. The change from non-porphyritic to porphyritic dolerite takes place over a distance of about 3 feet (91 cm) and is expressed by an increase in the quantity of phenocrysts without any marked change in their size. South of this is a broad band of porphyritic dolerite containing large euhedral, but sparsely scattered, phenocrysts and this is followed by a narrow zone, about 2 feet (61 cm) wide, of extremely porphyritic dolerite. The rock-type at the south side of the outcrop is porphyritic basalt. The total thickness of the section is 1,300 feet (400 m) of which porphyritic dolerite comprises 400 feet (122 m).

DISCUSSION

The most important features of the dolerites to be discussed are: (i) lateral uniformity, (ii) vertical variation, (iii) a gradation from non-porphyritic to porphyritic dolerite, (iv) the confinement of phenocrysts into zones within the dolerites, and (v) the accumulation of phenocrysts in quantities far in excess of that to be expected during normal intrusion and crystallisation.

The obvious mechanism is gravitational separation with the phenocrysts migrating into zones. The gradation from non-porphyritic to porphyritic dolerite can be explained as due to migration incomplete at the time of crystallisation. That there is a change from non-porphyritic to porphyritic dolerite in an upward sense and that the phenocrysts are most common in the upper levels suggests that the feldspars were rising. This concept is not new and has been appealed to by Grout (1928), von Eckermann (1938), Morse (1968) with supporting laboratory evidence by Tilley and others (1965). Grout also points out that the large phenocrysts would tend to rise more quickly than the small ones of the same density. This explains the gradation in size in the transition zone.

Buoyancy does not explain all the features observed. It does not explain why phenocrysts sometimes occur near the base of a dolerite, or why there is sometimes a non-porphyritic section near the top. Some of these anomalous features may be explained as the result of multiple injection and the boundaries to individual intrusions have not been recognised either because they are not developed or because they are obscured by poor outcrop.

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GEOLOGY AND MINERAL RESOURCES OF THE WODGINA DISTRICT

by J. G. Blockley

ABSTRACT

The Wodgina district, located about 80 miles (129 km) south of Port Hedland in the Pilbara Goldfield, includes a typical Archaean "greenstone" belt preserved in a synclinal keel in granitic rocks. The "greenstones" comprise metamorphosed basalt, tuff, ferruginous chert, clastic sediments, felsite and untramafic rock. These rocks were intruded by an older gneissic granite and a younger porphyritic granite. Pegmatite veins, generated from the porphyritic granite, have been past sources of tin, tantalum and beryllium minerals. They also contain significant, but so far un-mined deposits of lithium. A small amount of copper ore was produced from mineralised shears and from a disseminated deposit near a felsite sill. The district has untested deposits of iron ore, and layered ultramafic rocks of the type elsewhere associated with nickel mineralisation.

INTRODUCTION

Since tin was discovered at Wodgina in about 1902, the Wodgina district has been an important source of pegmatite minerals, yielding cassiterite, tantalo-columbite and beryl as well as a little copper. It also has significant deposits of lithium minerals, some iron ore and potential for nickel.

Although there have been many published descriptions of the economically and scientifically interesting pegmatites, there is no geological map of the whole field showing the locations of the various deposits or mining centres. This, together with the lack of lease surveys, has resulted in several of the centres being either not marked, or placed incorrectly, on plans.

The present report is an attempt to correct this gap in the records by presenting a 1 : 100,000 scale geological map of the district, showing as many of the mines as could be located, together with a brief description of its geology and mineral resources (Plate 20). This mapping was done in 1969 during a survey of the tin deposits of the Pilbara Goldfield.

LOCATION, ACCESS AND FACILITIES

The Wodgina district, as the term is commonly used, includes the mining centres of Wodgina, Stannum, Mill's Find, Numbana and Mount Francisco. It covers a tract of country extending from lat. 21° 20′ S, long. 118° 40′ E to Lat. 21° 28′ S, long. 118° 33′ E, and includes two prominent ranges of 'greenstone' hills which rise to heights of about 600 feet (180 m) above the surrounding granitic plains. The area forms part of the Marble Bar 1 : 250,000 Sheet area (Noldart and Wyatt, 1962).

Wodgina, the main centre in the district, is 75 miles (121 km), by graded road, south of Port Hedland. The other centres in the district are connected to Wodgina by tracks. The greater part of the district is in the Yandeyarra Aboriginal Reserve, and non-aborigines require a permit from the Department of Native Affairs for entry.

When mapped by the writer in 1969, the only mining activity in the district was a little prospecting. During past mining operations, water was obtained from wells sunk close to the workings or treatment plants. Supplies were always considered inadequate, and any future operators will probably have to seek water in the alluvium and jointed granite along the Turner River.

PREVIOUS WORK

The first, and most complete account of the geology of the Wodgina district is that by Maitland (1906). His report includes geological maps of the Wodgina and Stannum centres and descriptions of the mines working at that time. Montgomery (1907), Woodward (1910), Blatchford (1913), and Cleland (1913) all described tin and tantalite deposits in the district. Finucane and Telford; (1939), Miles, and others (1945), and Ellis (1950) gave accounts of the tantalite workings in the district; the first of these also included a geological map of the Wodgina centre. Simpson (1912, 1919, 1928) recorded the occurrence of uranium and thorium minerals in the pegmatites, and the compilation of the State's mineral occurrences by the same author (Simpson, 1948, 1951, 1952) summarised information on the tin, tantalum, lithium and beryllium deposits of the district. Low (1963) published some details of a copper deposit at Mount Francisco.

GENERAL GEOLOGY

The rock assemblage of the Wodgina and Mount Francisco ranges is typical of an Archaean 'greenstone belt', and includes metamorphosed basalt ferruginous chert, clastic metasedimentary rocks, and acid and ultramafic intrusives. These rocks are preserved as roof pendants along a synclinal keel in a large area of granitic rocks, consisting of an older gneissic granite and younger porphyritic granite. Near its contact with the metamorphic rocks, the porphyritic granite grades into a marginal phase which is even-grained or pegmatitic in texture. Prominent pegmatite veins, in most places closely associated with the marginal granite, cut the metamorphic rocks and were the source of the tin, tantalite and beryl mined from the district.

The main structural feature in the Wodgina district is a syncline trending north-northeast which passes through the middle of the Wodgina range and extends with interruptions by granite intrusion to Mount Francisco. Upon this syncline are superimposed many complex drag folds, particularly in the chert bands, and northwesterly-trending cross folds. The interpretation of the overall structure is further complicated by the lenticular shape of many of the rock units, and by a number of cross faults. A major north-northeasterly fault can be traced, by means of quartz reefs and its displacement of rock units, from south of Mount Francisco to the central part of the Wodgina range. Farther north, its course is marked by topographic lineaments such as straight creek beds, but displacement and quartz filling are no longer seen.

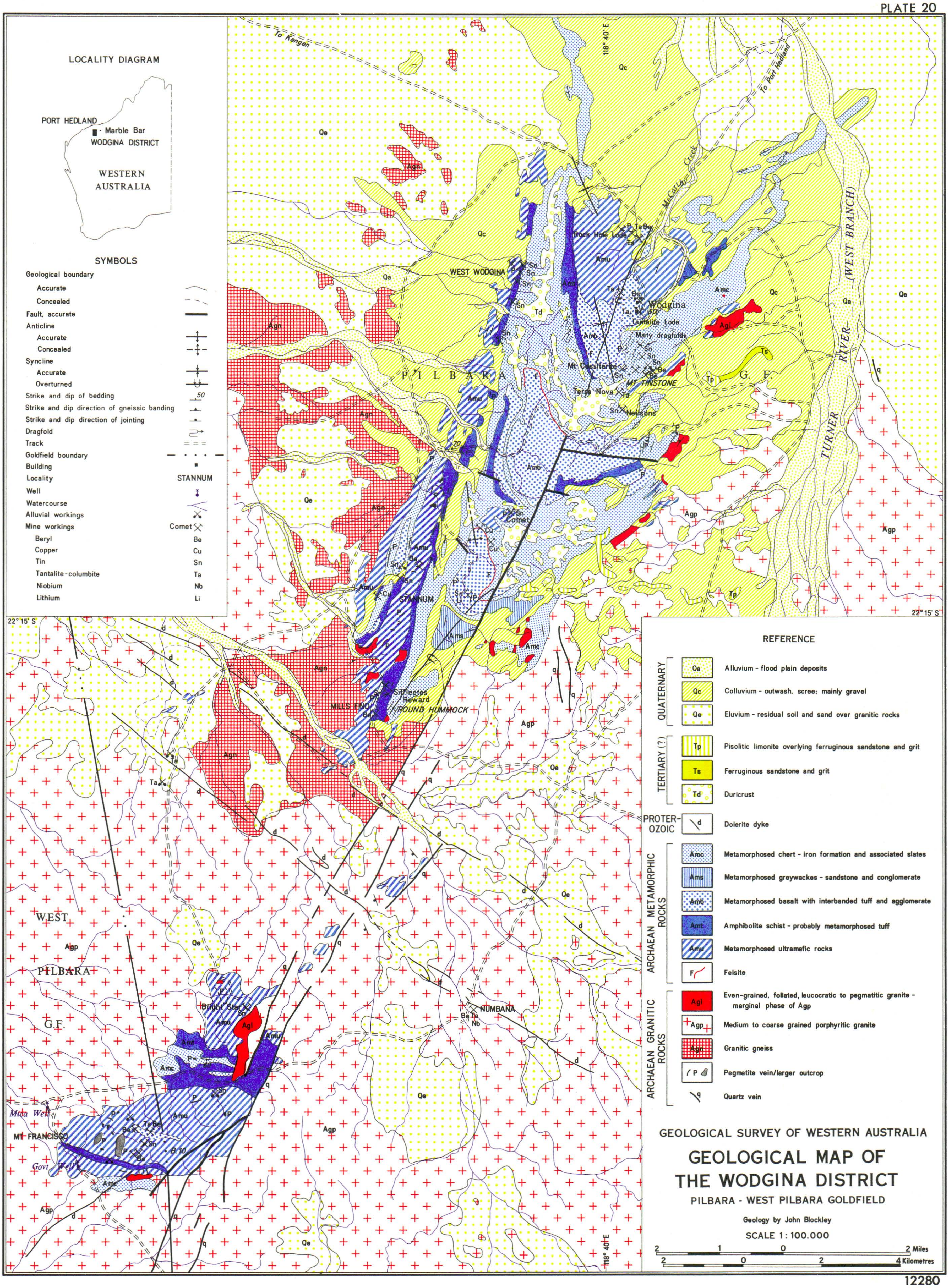
The disposition of the thicker basalts and clastic sedimentary rocks along the axis of the syncline suggests that the present structure follows a former depositional trough (perhaps controlled by the major fault) in which the lavas and sediments accumulated.

Younger rock units in the district are duricrust, pisolite and ferruginous sandstone of probable Tertiary age, and recent residual soil, outwash and alluvium.

ARCHAEAN METAMORPHIC ROCKS

The following brief descriptions of the metamorphic rocks are based on field observations and the examinations of a few thin sections.

PLATE 20



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Ferruginous chert

Recrystallised ferruginous chert, with interbedded slate and rare iron formation is the most abundant of the metamorphic rocks. It forms the higher ridges in the district and its outcrop has controlled the topography, which reflects the geological structure. In thin section, it consists of finely crystalline quartz, grunerite and iron oxides with accessory apatite. In some exposures, the chert grades upwards into a cream coloured rock composed of fine-grained quartz and zoisite, but in general, attempts to subdivide the ferruginous chert stratigraphically were unsuccessful.

Metabasalt

Metabasalt is well exposed at Wodgina, Stannum and in a broad valley north of the Comet mine. The unit as mapped also includes some metamorphosed tuff, agglomerate and dolerite. Although these basic rocks are now recrystallised to quartz-epidote-plagioclase amphibolites, primary structures such as amygdales, pillows and agglomeratic bands are well preserved, and attest to their volcanic origin. All of the metabasalt units are lenticular, and are thickest in the keel of the main syncline.

Amphibole schist

The most poorly exposed of the metamorphic rocks is the amphibole schist. It is commonly, though not always, found associated with the metabasalt, and in places, grades laterally into this rock. The schist is made up of well foliated actinolitic amphibole, plagioclase and quartz. No direct evidence of the original identity of this rock was seen, but its basic composition and close association with the metabasalt suggests that it is a metamorphosed basic tuff.

Ultramafic rock

Ultramafic rock is well exposed in the hills north of the Wodgina centre, along the west side of the Wodgina range, and at Mount Francisco. It also forms a number of small remnants in the granite, particularly between Round Hummock and Mount Francisco. In most outcrops, this rock is conformable with the other metamorphics, but in some places, transgression and rafting were noted, and a few cross-cutting dykes were also seen.

Ultramafic rock is particularly well exposed in the Wodgina district, forming ridges 200 to 300 feet high (60 to 90 m), with very little soil cover. Many exposures have a coarse layering, clear on air-photographs, but less so on the ground. This layering is parallel to the attidude of the surrounding metamorphic rocks, and is folded. It seems to be primary, and not due to metamorphism.

In the area north of the mines at Wodgina, the ultramafic rock shows not only the coarse layering, but also a fine banding, of the order of one or two centimetres thickness. In this area, many outcrops of the rock have a spotted texture due to clots of more iron-rich material about one centimetre in diameter. The origin of these structures is not known at present, but their close analogy with features described from the Tumbiana Pisolite (Trendall, 1965) and elsewhere, suggests that in this locality the ultramafic rock may be tuffaceous.

The ultramafic rock consists of fine-grained tremolite, chlorite, talc and magnetite. In some specimens, the outlines of primary olivine grains can be discerned, but in all thin sections examined, the original rock-forming minerals were completely recrystallised.

Metasediments

Metamorphosed clastic sedimentary rocks crop out on the eastern side of the Wodgina range, near the Stannum centre. The most conspicuous rock type amongst these is a deformed conglomerate with pebbles of chert and quartz stretched out at right angles to the fold axes, parallel to the "a" lineation direction. Other rock types present are chlorite and biotite schist (with pebble bands) and quartzite.

Felsite

Lenticular sills of felsite are exposed at Stannum, in the valley north of the Comet mine, and near Wodgina. The rock is very fine grained, with local spheroidal textures, is cream to white, and is cleaved. The sills were intruded close to, or along the contact of chert and metabasalt or amphibole schist. In most places they are conformable, though a discordant contact was noted near the Stannum tin mine.

The felsite consists of small phenocrysts of altered plagioclase and irregular patches of amphibole and chlorite set in a fine-grained matrix of granulated quartz and feldspar. Fresh microcline is developed in pressure shadows alongside the phenocrysts.

GRANITIC ROCKS

Gneissic granite

Gneissic granite, composed of quartz, microcline, plagioclase, green biotite (partly replaced by chlorite) and actinolite, crops out on the western and southern sides of the Wodgina range, and underlies much of the sand-plain between Wodgina and the Yule River. It ranges from well banded gneiss to foliated granite. Remnants of greenstone, aligned parallel to the foliation, are common. In many places the gneiss contains concordant bands of porphyritic granite with phenocrysts set parallel to the gneissic trend, and is cut by dykes of massive, even-grained granite. Concordant pegmatites are common in the more gneissic parts.

Porphyritic granite

The porphyritic granite intrudes the gneissic granite, with much interfingering at the contact. It occupies most of the southern part of the Wodgina district, and extends considerably beyond it (Blockley, 1970). Although aligned phenocrysts and broad compositional banding were noted in a few places, the rock is generally massive, forming tors and rounded domes in contrast to the more subdued outcrops of the gneiss. It is made up of phenocrysts of microcline set in a matrix of quartz, oligoclase, microcline and brown or green biotite.

The marginal phase of the porphyritic granite varies from even, medium-grained granite to pegmatite. It contains muscovite rather than biotite, and in some outcrops carries pink spessartite garnet. In many places it is foliated parallel to the attitude of the adjacent metamorphic rocks. Its composition is generally more acid than the porphyritic granite, but varies considerably due to assimilation of the intruded metamorphic rocks.

Pegmatites

The rare-metal pegmatites form clearly intrusive veins within the metamorphic rocks, or rarely, as at Numbana, in the granite. Most veins have a north-northeasterly strike, parallel to that of the host rocks, but many dip only gently, and cut the bedding direction of their host rocks. The greater number of pegmatites have irregular shapes and were probably intruded into tension gashes. However, some, like the Tantalite lode at Wodgina, follow well-defined faults.

The pegmatites consist mainly of inter-grown quartz and albite, but lenses or veins of blue quartz, pure albite, or quartz-albite-muscovite are common. Microcline, green muscovite, blue-green tourmaline, lepidolite and spessartine are other common constituents of the pegmatites. Some pegmatite veins have a more or less zonal arrangement of the mineral assemblages, but in others this is not so. Simple pegmatites also occur, and consist usually of either quartz-albite or blue quartz. Some of the tin-bearing pegmatites at Wodgina have a late-stage phase of blue tourmaline and muscovite, which may occur along the edge of the veins, or as detached veins on parallel shears. Wall-rock alteration about pegmatites cutting basic and ultramafic rocks has produced a selvage of biotite.

MINERAL DEPOSITS

Tin deposits

About 470 tons (478 tonnes) of tin concentrate were mined from the Wodgina district. It was won from pegmatites, and from eluvium in small gullies in their immediate vicinity. Because of the wide scattering of the tin-bearing pegmatites, and the unfavourable topography, no concentrations of alluvial cassiterite suitable for large-scale placer mining were formed.

The Mount Cassiterite tin mine at Wodgina had the largest production in the district. The cassiterite was won from a pegmatite lode striking about 080°, dipping southerly, worked in patches from three adits over a total length of 450 feet (135 m) to a depth of 250 feet (75 m) below its highest point. The width of the lode ranged from 12 inches (30 cm) to 14 feet (4·3 m), and averaged 5 feet (1·5 m) on the No. 3 level. Cassiterite occurred in the pegmatite, in marginal veins of blue tourmaline, and in the biotite selvage to the main vein. Pieces of up to 80 pounds (35 kgm) in weight were recorded. The ore milled averaged about 3 pounds of tin concentrate to the ton (1·4 kgm per tonne).

Smaller tin mines were located on a number of pegmatites cropping out on the ridge east of the Mount Casserite mine, and all the gullies in that area were hand-worked for alluvial tinstone.

At West Wodgina, Stannum, Mill's Find and Mount Francisco, cassiterite was mined from quartz-albite pegmatites in which it is found in small, but very rich patches. In many of these veins, the tinstone is associated with lepidolite. One pegmatite worked at West Wodgina yielded 9 hundred-weights of tin concentrate from 20 tons (460 kgm from 20·3 tonnes) of ore. Three samples of the faces worked at the Bright Star mine at Mount Francisco assayed 1·71, 0·47 and 0·77 per cent tin respectively, and a sample from the dump at Mill's Find assayed 0·50 per cent tin.

Tantalum deposits

The production of tantalite and tantalo-columbite from the Wodgina district is recorded as 178 tons (181 tonnes), of which 110 tons (112 tonnes) came from the Tantalite lode on M.C. 107 at Wodgina. The main tantalum mineral produced was mangano-tantalite, but mangano-columbite, tanteuxenite and microlite have also been recorded.

The Tantalite lode is a pegmatite vein striking north, dipping 40° east, and extending for about 2,200 feet (670 m) along strike. It has a true width of from 10 to 30 feet (3·0 to 9·1 m). It consists of a granitic textured core, with marginal and cross-cutting veins of almost pure albite. The tantalite is invariably found in the albite-rich parts. Mining was restricted to depths of 30 feet (9·1 m) or less. The ore treated on the lease averaged about 3 pounds of concentrate to the ton (1·4 kgm per tonne), but this included some eluvial ground and only the richer parts of the lode.

At Wodgina, tantalite was also mined from pegmatite veins north west of the main lode, and from the Terra Nova mine south of Mount Tinstone.

Tantalite and tantalo-columbite has also been mined from near Stannum, Mount Francisco and Numbana. Most of the production was from eluvium, though some may have been won by knapping and hand-cleaning the better grade pegmatite lodes.

Beryllium

Beryl was first identified at Wodgina by E. S. Simpson in 1927, and first mined in 1943, since when 1,177 tons (1,198 tonnes) containing about 136 tons (138 tonnes) of BeO have been produced. Much of the beryl is of the variety rosterite, having a high content of caesium. The ore is white or grey, lacks distinctive cleavage and crystal form and is readily mistaken for quartz.

The greatest production of beryl came from the north end of the Tantalite lode at Wodgina where it occurred in bunches and masses associated with albite. One mass was reported to have been 38 feet (11·6 m) long, 24 feet (7·3 m) high and 18 feet (5·5 m) wide, lying more or less horizontally. Beryl was also mined from two pegmatites on the east side of the range below Mount Tinstone, and from near M.C. 310, northwesterly from the Tantalite lode.

At Mount Francisco several benches and open cuts have been put in on gently dipping pegmatites cropping out in an area northwest of the trigonometrical station B10. Beryl and tantalite were seen in the workings, and it is assumed that these mines produced most of the beryl recorded from the Mount Francisco centre, although descriptions of the positions of the unsurveyed tenements listed in Table 3 place some of them at other locations.

Beryl was also mined from a quartz-cored pegmatite at Numbana where is it associated with columbite and books of muscovite.

Lithium

Lithium minerals such as lepidolite, spodumene and lithiophyllite occur in many of the pegmatites in the Wodgina district, although as yet no production has been recorded.

Lepidolite is known from the main Tantalite lode, from the Tinstone lease, and from a vein about 1 mile (1·6 km) north of Wodgina along the Port Hedland Road. It is present in the tin pegmatites at West Wodgina, Stannum, and the Eve Eva mine at Mount Francisco. A chip sample of the pegmatite at Stannum assayed 1·62 per cent Li_2O.

Lithiophyllite occurs in the Tantalite and the Rock Hole lodes at Wodgina, and in the Mount Francisco centre. Samples have assayed from 4·5 to 7·9 per cent Li_2O. Spodumene is known from the Mount Cassiterite and Stannum tin mines.

Copper

About 8 tons (8·1 tonnes) of copper ore were mined from Stannum and Mount Francisco. The latter deposit was not located, but Low (1963) considers it to have been in a quartz vein in granite.

At Stannum, disseminated malachite was worked in two places, on, or immediately below a felsite sill. Although low in grade, the "stratiform" disposition of the lode should be an encouragement to further prospecting. About 1½ miles (2·4 km) west of Stannum, a copper bearing shear in amphibolite schist has been recently opened up. The lode is about 150 feet (45 m) long, up to 6 feet (1·8 m) wide and contains malachite and chalcanthite.

Iron ore

The pisolite and canga deposits, although not sampled, are probably of comparable grade to similar material in the Hamersley Range area. The largest pisolite mesa is estimated to contain about 1 million tons (1,000,000 tonnes) of limonite. Total resources of the area would be in the order of 5 to 10 million tons (5 to 10 million tonnes) of pisolite and canga.

Other minerals

Simpson (1928) records 74 minerals from the Wodgina district, including such potentially economic minerals as bismuth, gold, molybdenite, galena, chalcocite, sphalerite and mineralogical curiosities such as the radioactive minerals thorogummite, pilbarite, hydrothorite, maitlandite and nicolayite.

The large area of ultramafic rocks gives the district potential for the discovery of nickel and associated metals.

TABLE 1. TIN PRODUCTION FROM THE WODGINA DISTRICT

Centre	Tenement No.	Name of Lease or Operator	Period	Concentrate Produced: Lode Tons	Concentrate Produced: Stream Tons	Concentrate Produced: Total Tons	Concentrate Produced: Metal Content Tons	Value $ Aust.	Remarks
Wodgina....	MC 84	Mount Cassiterite	1904–08	133·52	13·85	147·37	N.A.	28,368.00	Part same ground
	ML 84, 93, 148	Mount Cassiterite Leases....	1908–18	195·50	1·60	197·10	N.A.	33,826.00	
	ML 93	Mount Cassiterite North	1906–07	9·67		9·67	N.A.	1,942.00	
	ML 89	Tinstone	1906–09	14.70		14·70	N.A.	2,780.00	Part same ground
	ML 255	Mount Tinstone	1913–14	2·45		2·45	N.A.	560.00	
	MC 109	McLeod, D. W.			3·94	3·94	2·12	5,757.13	
	ML 86, 87, 95	H.M.—Anchorite Leases	1917		5·00	5·00	N.A.	1,000.00	Part same ground
	ML 195	Cassiterite No. 1	1912	0·35		0·35	N.A.	98·00	
	ML 85	Commonwealth	1906	2·95		2·95	N.A.	696.00	
	ML 88	Chamberlain	1906	0·35		0·35	N.A.	120.00	
	Sundry Claims		1903–51	5·78	50·94	56·72	N.A.	11,633.84	
West Wodgina	ML 203	Wodgina Queen	1912–13	1·60		1·60	N.A.	380.00	
	ML 213	Referenda	1912	1·05		1·05	N.A.	294.00	
	DC 732	McLeod, D. W.	1968		3·93	3·93	2·42	5,955.31	
Stannum	ML 77	Stannum	1902–06		6·10	6·10	N.A.	922.00	Same ground
	ML 198	Stannum	1912	0·90		0·90	N.A.	252.00	
	ML 192	Comet	1912	0·30		0·30	N.A.	72.00	
Mills Find	ML 178	Siffleete's Reward	1910–13	3·50		3·50	N.A.	712.00	
	Sundry Claims		1906		0·85	0·85	N.A.	138.00	
Mount Francisco	MC 390	McPherson, N. E. and Fetwadjieffa	1957		0·13	0·13	N.A.	144.80	
	MC 910	Crow, Yegarla	1967			5·67	3·03	7,874.00	Mainly stream tin
	DC 15 WP	McLeod, D. W.	1967			1·54	0·97	2,654.13	
	PAs. 312, 313 WP	Nomads Pty. Ltd.....	1965			2·48	1·73	6,004.50	
	PA 2751	McLeod, D. W.	1965			0·25	0·18	604.80	
	Crown Land	Sundry Persons	1963–64			1·57	0·83	1,828.20	
						470·47			

TABLE 2. TANTALO-COLUMBITE PRODUCTION FROM THE WODGINA DISTRICT

Group	Tenement No.	Name of Lease or Operator	Period	Tantalite: Tons	Tantalite: Ta_2O_5 Units	Tantalite: Value $ Aust.	Tantalite/Columbite (Mixed Oxides): Tons	Tantalite/Columbite (Mixed Oxides): Ta NbO_5 Units	Tantalite/Columbite (Mixed Oxides): Value $ Aust.	Tantalo-columbite Total: Tons	Tantalo-columbite Total: Value $ Aust.	Remarks
Wodgina	MLs 86, 87, 95	HM & Anchorite	1905–29	104·49	N.A.	38,822.00				104·49	38,822.00	Part same ground
	ML 293	May Be	1925	2·00	N.A.	480.00				2·00	480.00	
	MC 107, etc.	Northwest Tantalum NL	1956	·60	30·15	2,550.50				·60	2,550.50	
	MC 107, 355	L. J. Wilson	1957–67	3·18	191·98	20,777.82				3·18	20,777.82	
	ML 89	Tinstone	1934	·50	N.A.	260.00				·50	260.00	
	ML 352	Terra Nova	1932	·45	N.A.	282.00				·45	282.00	
	PA 2438	J. H. Walkerden	1955				·15	10·53	796.00	·15	795.30	
Stannum	PC 732	D. W. McLeod....	1968	2·79	86·62	15,098.61				2·79	15,098.61	
Mills Find(?)....	PAs 2454, 2456, 2458	McPherson & Party	1956				0·37	23·57	1,862.00	·37	1,862.00	
Mount Francisco	MC 350	J. Ball	1956	·04	·84	53.40				·04	53.40	
	MC 390	McPherson & Fetwadjieffa	1957				·05	3·12	18.05	·05	18.05	
Numbana	PA 2413	L. C. Stein & Party	1953				1·26	95·98	7,161.30	1·26	7,161.30	
	MCs 294,306	Rare Metals Ltd.	1954				1·70	128·22	10,840.00	1·70	5,420.00	
	MCs 373, 378 379, 380	and Graydon & Party	1956				·56	35·93	2,836.00	·56	2,836.00	
Miscellaneous Tenements	MC 340	Sherlock & Parker	1956	·07	1·44	93.80				·07	93.80	10 miles SE Mt. Francisco
	DC 126, 127	Northern Minerals	1956				3·01	187·76	14,060.00	3·01	14,060.00	Pastoral Ck 8 miles E Wodgina
	MC 364, 365 MC 260	Syndicate Blanithensca	1955				2·18	132·71	9,174.00	2·18	9,175.30	14 miles SE Mt. Francisco
Crown Land & Sundry Person			1905–64	54·77	N.A.	23,693.08				54·77	23,693.08	
										178·17		

TABLE 3. BERYL PRODUCTION FROM THE WODGINA DISTRICT

Mining Centre	Tenement No.	Operator	Period	Production			Remarks
				Beryl Tons	BeO Units	Value $ Aust.	
Wodgina	MC 107 etc.	Tantalite Ltd. (Defence Project 83)	1943–52	754·26	8,607·68	51,496.00	Same ground
	MC 107	L. J. Wilson	1958	0·91	7·36	227.40	
	MCs 305, 314, 355	Northwest Tantalum Ltd.	1955	0·64	7·41	209.00	
	PA 2438	J. Walkerden & Party	1954–55	4·15	45·27	1,367.20	Near MC 310
	PA 2575	M. Seigne	1957–59	4·08	46·61	1,451.20	¾ mile S ML 88
	PA 2096	A. E. Rogers	1944	3·32	43·79	256.60	
	PA 2104	G. Lamont	1944	46·68	563·66	3,569.80	Location unknown
	PA 2116	G. Hooley	1944	4·29	56·59	331.70	
	PA 2337	J. Gilbert	1950	0·99	12·61	185.70	
Stannum	MC 352	W. Marshall	1956	4·27	48·28	1,361.50	
Mount Francisco	MC 365	Hooley, Rogers & Radley	1947–48	27·54	347·80	2,511.22	
	MC 350	J. A. Johnston	1954–56	46·69	545·70	15,855.70	
	MC 512	W. Hall	1959	13·90	156·89	5,059.80	
	PA 2411	Thompson, Coffin & Ball	1953	10·36	118·70	3,338.70	
	PA 2534	F. O'Donnell	1956–57	2·71	32·24	995.90	Partly same ground
	PA 2559	R. H. Otway	1957–58	8·83	105·35	3,255.40	
	MC 234	R. H. Otway	1951–53	6·71	81·17	2,276.12	
	MC 286	W. Coffin	1953–54	18·22	194·82	5,844.60	
	MC 614 (PA 2591)	D. J. Butterfield	1959–62	9·62	109·41	3,368.40	
	MC 311	A. Hall	1954	2·09	25·48	718.40	
	MC 393 (PA 2467)	W. Ball	1955	2·16	26·00	733.30	
	PA 2442	C. Newlands	1955	0·57	6·92	195.00	
	ML 370	J. M. Henderson	1958–62	30·56	353·70	11,179.20	
Numbana	PA 2413 (MC 306)	Stein & McAlpine	1952	2·91	36·72	1,035.60	
	MC 294, 306	A. E. Hall & F. D. Pinchin	1953–54	4·78	55·11	1,560.90	
Miscellaneous	MCs 340, 343	Sherlock & Parker	1954–62	19·53	236·81	7,032.40	15 miles SSE Wodgina
	PA 2410	Bell Bros. & D. C. Watkins	1953	·75	9·66	277.80	19 miles N Wodgina
Wodgina-Mount Francisco area	Crown land	Sundry Persons	1945–61	146·23	1,701·36	39,979.34	
				1,177·75	13,583·10		

TABLE 4. COPPER PRODUCTION FROM THE WODGINA DISTRICT

Centre	Tenement No.	Operator	Period	Production		Value $
				Tons ore	Units Cu	
Mount Francisco	P.A. 2529	P. Coffin	1957	4·17	17·67	16.40
Stannum	P.A. 2687		1963	3·65	22·81	47.90

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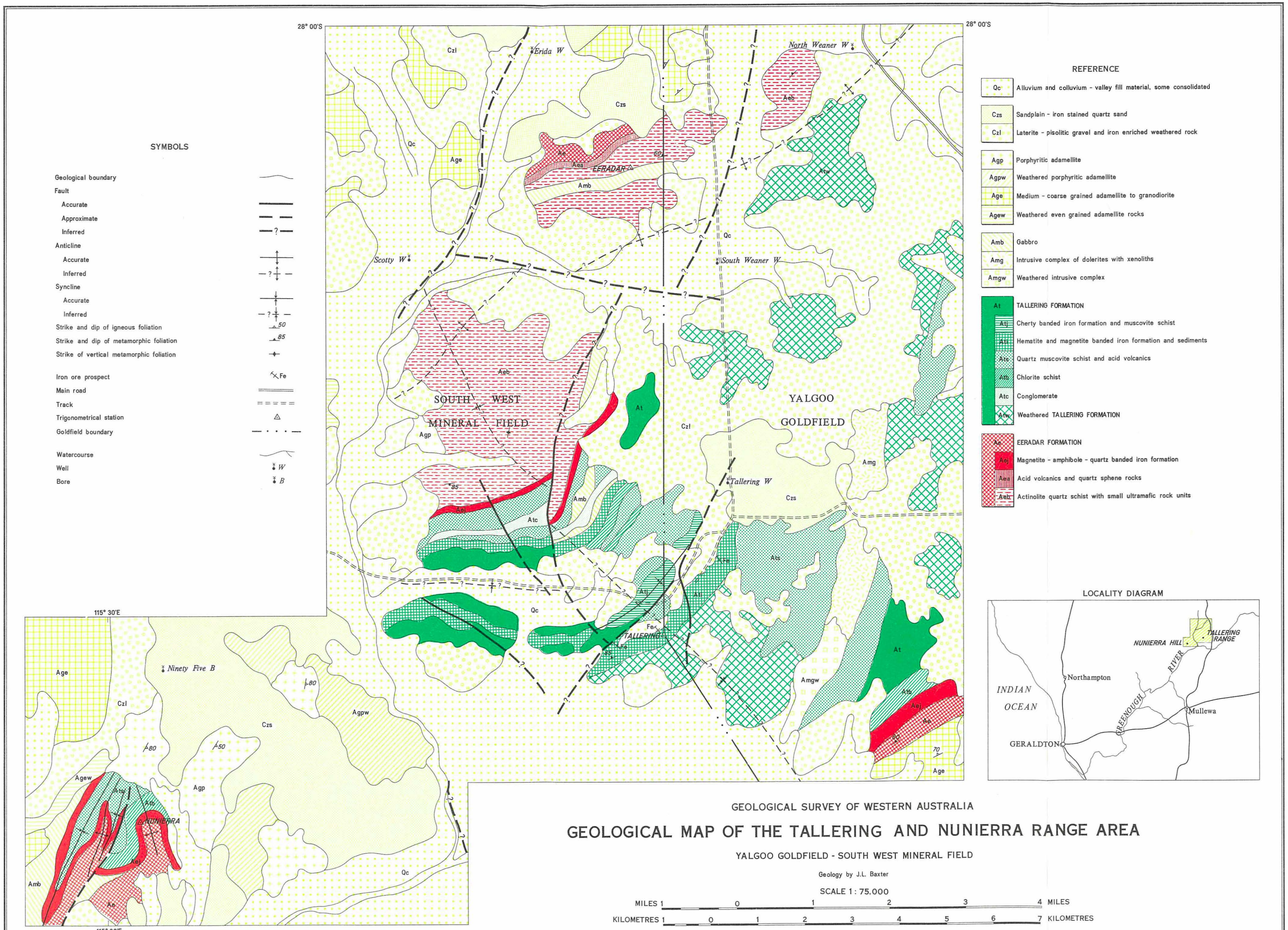


GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

GEOLOGICAL MAP OF THE TALLERING AND NUNIERRA RANGE AREA

YALGOO GOLDFIELD - SOUTH WEST MINERAL FIELD

Geology by J.L. Baxter

SCALE 1 : 75,000

MILES 1 0 1 2 3 4 MILES

KILOMETRES 1 0 1 2 3 4 5 6 7 KILOMETRES

THE ARCHAEAN STRATIGRAPHY OF THE TALLERING RANGE AND NUNIERRA HILL AREA

by J. L. Baxter

ABSTRACT

In the Tallering Range and Nunierra Hill area a folded and faulted succession of Archaean sediments is divided into two formations, the Eerada Formation and the overlying Tallering Formation. The succession is intruded by adamellite, granodiorite and gabbro. Lithologic, chemical and palaeogeographic evidence suggests that the succession was deposited in a basin sinking more rapidly to the south. Banded iron formation occurs in both formations, and is of different types, each type being related to its associated sedimentation.

INTRODUCTION

The Tallering Range area is 30 miles north of Mullewa and is reached from the Mullewa-Gascoyne Junction road. The ranges contain banded iron formation in which there are lenticular deposits of hematite.

The area was mapped by the writer during 1969 as part of the Yalgoo 1 : 250,000 sheet mapping programme.

HISTORICAL

H. Y. L. Brown (1871) first noted the occurrence of the hematite deposits, when he carried out the reconnaissance of the area with a view to locating gold-bearing rocks. Maitland (1924) collected specimens from the banded iron formation and the hematite deposits and briefly described the geology. Johnson (1950) carried out a reconnaissance of the area during mapping of the Murchison region. Connolly (1960) described drilling carried out by the State Government to assess the potential of the hematite deposits. In 1961 Western Mining Corporation took up a Temporary Reserve for iron over Tallering Range and began detailed exploration of the deposits.

GENERAL GEOLOGY

The Archaean stratigraphic succession has been subdivided into two formations, the Tallering Formation and the Eerada Formation. These formations have been intruded by gabbro and adamellites. The Archaean rocks are overlain by Cainozoic superficial deposits. (Plate 21).

STRATIGRAPHY

EERADA FORMATION

The Eerada Formation has a thickness of approximately 2,000 feet (600 m) where exposed in the area, but the base of the formation is not seen. It consists essentially of fine-grained quartz-actinolite rocks which also contain varying amounts of feldspar, sphene, tourmaline, epidote and sericite. There is a thin banded iron formation unit at the top of the formation. The type area is 3 miles south of Eerada trigonometrical station, after which the formation is named. Three rock types have been separately mapped within the formation: banded iron formation, acid volcanic rocks, and actinolite-quartz schist.

Banded iron formation is developed in lenses at the top of the formation. It consists of bands of quartz and amphibole with discontinuous bands of hematite and magnetite. It occurs with actinolite-quartz-feldspar rock similar to that described below from the lower part of the formation.

Acid volcanic rocks with quartz-sphene rocks and quartz-muscovite schists are developed throughout the formation, usually in thin bands. In the Eerada area there is sufficient thickness for separate mapping in the central part of the formation.

The actinolite-quartz schist consists of fine-grained actinolite and quartz with varying amounts of chlorite, epidote, sericite, tourmaline, sphene, feldspar and minor apatite. Four analyses of this rock appear in Table 1. This rock type is best developed in the lower part of the formation, in which there is a cyclicity, with the cycles varying from 10 feet (3 m) to 50 feet (16 m) in thickness. Each cycle is marked by a decrease in the amount of actinolite from bottom to top.

TABLE 1. CHEMICAL ANALYSES FROM EERADA FORMATION

Locality 4 miles (6·4 km) bearing 335° from Tallering Trignometrical Station

Sample		24274	24275	24276	24277
SiO_2		58·32	56·29	50·12	56·74
Al_2O_3		15·83	15·25	16·84	14·37
Fe_2O_3		0·87	0·07	0·57	1·83
FeO		5·60	5·67	7·63	6·23
MgO		5·91	8·26	11·16	7·43
CaO		7·86	6·97	8·50	7·48
Na_2O		3·17	1·93	0·65	2·51
K_2O		0·23	0·96	0·51	0·32
H_2O^+		1·09	2·77	2·30	1·57
H_2O^-		0·09	0·15	0·09	0·05
CO_2		0·01	0·10	0·04	0·01
TiO_2		0·62	0·48	0·41	0·59
P_2O_5		0·16	0·12	0·10	0·12
MnO		0·13	0·13	0·15	0·13
Total		99·89	99·15	99·07	99·38
C.I.P.W. Norm	q	11·90	10·94	3·94	11·99
	c	0·00	0·00	0·09	0·00
	Or	1·35	5·67	3·01	1·89
	Ab	26·82	16·32	5·49	21·23
	An	28·28	30·11	41·26	27·00
	Di	7·81	2·46	....	7·49
	(Wo	4·00	1·27	....	3·86
	En	2·38	0·80	....	2·42
	Fs)	1·42	0·38	....	1·20
	Ay	19·69	29·18	40·93	24·06
	(En	12·33	19·76	27·79	16·07
	Fs)	7·36	9·41	13·14	7·99
	Mt	1·26	0·10	0·82	2·65
	Il	1·17	0·91	0·77	1·12
	Ap	0·37	0·28	0·23	0·28
	Cc	0·02	0·22	0·09	0·02

Analyst R. S. Y. Pepper.

TALLERING FORMATION

The Tallering Formation is approximately 5,000 feet (1,500 m) thick, but lithological units within it vary in thickness over the area. It consists essentially of fine-grained quartz-muscovite schist with minor quartzite, conglomerate and banded iron formation. The type area is Tallering Range. The subdivision of the formation is shown in Table 2.

TABLE 2. TALLERING FORMATION SUBDIVISION

Rock Types	Lithological Map Unit	Description
Quartz-muscovite schist		iron-stained sericite-quartz schist
Cherty banded iron formation	Atj	irregularly banded cherty magnetite iron formation
Quartzite		fine-grained quartzite with minor sericite
Quartz-muscovite schist	Ats	predominantly quartz and muscovite with chlorite and feldspar in some bands—there is minor chlorite
Chlorite schist	Atb	Chlorite-feldspar-quartz rock
Hematite banded iron formation		fine-grained hematite-quartz banded iron formation with regular banding and lenses of hematite
Acid volcanics		fine-grained quartz-chlorite rocks with phenocrysts of feldspar
Conglomerate	Ati	conglomerate of fine-grained quartzite pebbles in a sandy matrix
Magnetite banded iron formation		fine-medium-grained magnetite-quartz banded iron formation with accessory amphibole and local concentrations of pyrite
Quartzite		fine-grained quartzite with minor sericite
Quartz-muscovite schist	Ats	predominantly quartz and muscovite with chlorite and feldspar in some bands—the unit has numerous quartz veins through it from which traces of gold have been found
Conglomerate	Atc	pebble to cobble size conglomerate with sandy matrix, clasts fine-grained quartzite and granitoid rocks
Chlorite schist	Atb	pale green slightly pleochroic chlorite, feldspar and quartz rock with minor actinolite

INTRUSIVE ROCKS

INTRUSIVE COMPLEX OF DOLERITES

Intruding the Tallering Formation there is a complex of dolerites with numerous basic and sedimentary xenoliths. This has been mapped as one unit as the outcrops are small and the rocks mixed.

GABBRO

Medium-grained gabbros intrude the succession. These are mainly conformable, although they show disconformable relationships due to thickening. They appear to be simple intrusions.

MEDIUM TO COARSE-GRAINED ADAMELLITE TO GRANODIORITE

Medium to coarse, even-grained adamellitic to granodioritic rocks are exposed on the northwest and southeast of the layered succession. The rocks appear to be related to the syncline, as there is a foliation in the adamellite concordant with that of the adjacent sedimentary succession.

PORPHYRITIC ADAMELLITE

A porphyritic adamellite has intruded the entire succession. The bodies of adamellite are elongated parallel to a major direction of faulting in the area. There was stress along this direction while this rock was emplaced, as there is shear and flow directional evidence of the stress in the intrusion.

DEPOSITIONAL ENVIRONMENT

The following features of the rocks are significant for environmental interpretation:—

1. Boulders in Tallering Formation conglomerate on the north limb of the syncline have diameters of up to 15 inches (38 cm), whereas those on the south limb have a maximum diameter of about 8 inches (20 cm), and there is thinning of the conglomerate bands to the south.

2. The thicknesses of the quartz-muscovite schist units of the Tallering Formation increase to the south.

3. The grain size of all sediments decreases to the south.

4. The banded iron formation exposed on the north limb of the syncline contains lenses of quartzite, and is coarser grained than that on the south limb, and there is better development of the hematite and magnetite bands on the south limb.

From these features it is suggested that there was land to the northwest at the time of deposition of the Tallering Formation and that the basin of deposition was subsiding to the south.

STRUCTURE

The observed geological structure of the area is consistent with a compressional force applied to the layered succession from a direction of 150 degrees. This is reflected by faults parallel to the directions of maximum shear and folds at right angles to the direction of force. Cross-folding, probably related to the intrusion of the porphyritic adamellite has taken place about an axis trending 130 degrees. This intrusion appears to have distorted the axes of pre-existing folds and the direction of faults along its margins suggesting that the intrusion was from the southwest (Plate 22).

FOLDING

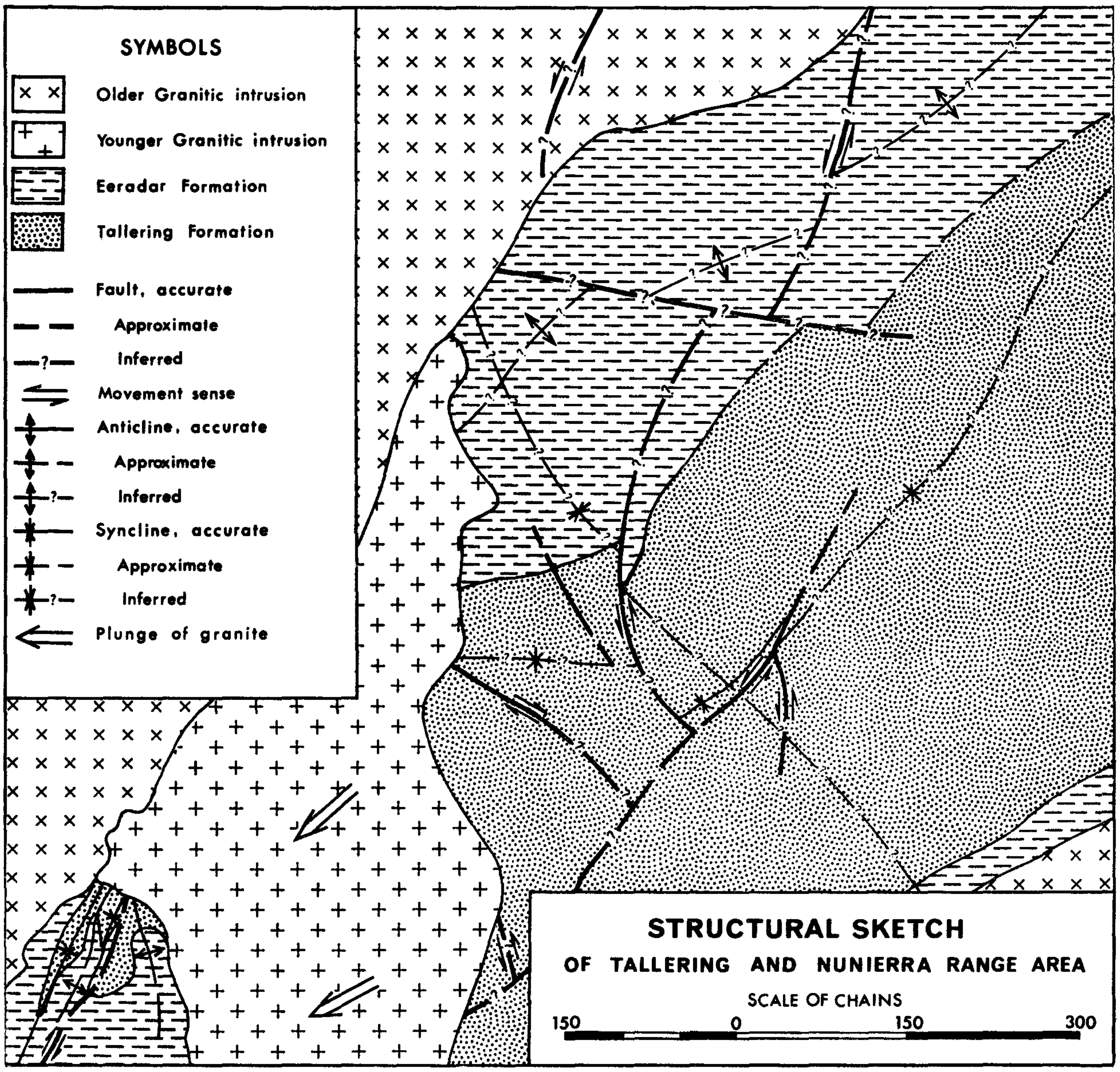
The main northeast-plunging syncline is a similar fold (Hills, 1963) which has been slightly distorted by the thickening of the Tallering Formation to the south.

The warp produced by the younger granitic intrusion may be a parallel fold (Hills, 1963) for, although at Tallering Range there is a pronounced plunge down the axis of this fold, 3 miles north of Tallering Range there is little evidence of its presence.

The faulting appears to be in part strike-slip and in part, hinge faulting. This is inferred from the different displacement of individual beds within the succession. Most faults are arcuate. The inferred faults have been interpreted from lineaments on air-photographs and differences in strikes of rocks on either side of the faults. The major north-south fault along the eastern edge of the younger intrusion predates the intrusion, and has probably controlled its shape.

GEOLOGICAL HISTORY

A suggested interpretation of the geological evidence in this area is given below. Interpretation is uncertain, as there are two environments present and the relationship of these to the overall development of the Yilgarn Block is not known.


SYMBOLS
Older Granitic intrusion
Younger Granitic intrusion
Eeradar Formation
Tallering Formation
Fault, accurate
Approximate
Inferred
Movement sense
Anticline, accurate
Approximate
Inferred
Syncline, accurate
Approximate
Inferred
Plunge of granite
STRUCTURAL SKETCH
OF TALLERING AND NUNIERRA RANGE AREA
SCALE OF CHAINS
150
0
150
300

12282

Stage 1

The first event recorded in the area is the deposition of a possible dolomitic mud which was presumably laid down in deep water, the clays being contributed from a land mass of low relief. Intermittent acid volcanicity on the land contributed to the deposition of the acid volcanic rocks exposed in the north of the map area. This period closed with the formation of thin lenses of what is now a banded amphibole-quartz rock within the otherwise argillaceous succession. This banded rock has concentrations of magnetite and hematite in it and is interpreted as a type of banded iron formation, presumably laid down during a period of quiescence which may have been caused by the isolation of the basin from the source of argillaceous material.

Stage 2

Following the period of quiescence, a short period of basic volcanicity deposited the rocks on the south side of the syncline in the Tallering Formation. This was accompanied by a steepening of the depositional slope with a concomitent increase in the rate of deposition, with fine-grained sandstone and intermittent conglomerate being laid down. The source of this material appears to have been northwest of the basin. Three major banded iron formation horizons were formed in the Tallering Formation, presumably during a period in which there was little contribution of terrigenous material to the depository.

Banded iron formation associated with quartzite, conglomerate and acid volcanics (probably tuffaceous) was deposited between two fine-grained sandstone units, and represents a change in the normal conditions of deposition. This may have been effected by fluctuations in the rate of subsidence.

Stage 3

During Stage 2 the basin must have been sinking steadily to the southeast as there is a marked increase in the development of the sandstone in this area. It is suggested that at this stage the compressive stress developed along a northwest-southeast line and folding of the basin began. At this stage the intrusion of the older even-grained granodiorite also began to affect the area, and may have been the cause of the stress that formed the syncline and subsequent faulting.

Stage 4

In the closing stages of folding there was a series of gabbros intruded into the succession.

Stage 5

The final episode recorded in the Archaean in the area was the intrusion of the porphyritic adamellite which appears to have been controlled in direction by a major north-south fault. The adamellite disturbed the adjacent country rocks, rotating them toward the north along both margins.

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"SPINIFEX TEXTURE" IN A SLAG, AS EVIDENCE FOR ITS ORIGIN IN ROCKS

by J. D. Lewis

ABSTRACT

Textures found in an iron/silicate slag bear a remarkable resemblance to "spinifex texture" as found in the Archaean mafic and ultramafic rocks of Western Australia, and provide evidence on the origin of the texture. Fayalite in the slag has crystallized as complex dendritic crystals or, more commonly, as thin plates elongated along the a and c axes. The arrangement of the olivine plates gives rise to a variety of textures which are described and compared with the natural texture. By analogy with the slag textures it is shown that spinifex texture is an original igneous texture formed by rapid chilling of the magma. Preservation of the delicate structure indicates a lack of convection currents and mechanical disturbance during crystallization, and recent work on ceramics suggests that crystallization may have been from an initially formed glass. Spinifex texture can be found in both intrusive and extrusive bodies and cannot, by itself, be used as a criterion for determining the mode of emplacement.

INTRODUCTION

The term "spinifex texture" is in common use in Western Australia to describe a distinctive assemblage of minerals in which tremolite, chlorite or serpentine form long bladed crystals or aggregates set in a granular matrix of chlorite or tremolite, or both. The rocks in which this texture is commonly present are the altered ultramafic rocks of the Archaean greenstone belts which are often colloquially named "spinifex rock".

The name "spinifex" is derived from spinifex grass (*Triodia* sp.), common in the arid areas of Australia; the long dry blades grow in clumps up to several feet high and the matted older growth bears a marked resemblance to the patterns found on rock surfaces. The term was first used by miners in the Eastern Goldfields of Western Australia (Blockley, 1956) but since the recent interest in ultramafic rocks in the search for nickel the name has become widely used among geologists.

Interpretation of the origin of spinifex texture has varied from primary igneous to metamorphic, depending on the significance attached to small amounts of remnant olivine or pyroxene. An igneous origin for spinifex texture presumes that olivine has been replaced without destroying the original texture, whereas the metamorphic interpretation relies on the replacement of olivine or pyroxene along particular zones leaving lath-like remnants of the original mineral. The most commonly accepted view is that spinifex texture is formed in rapidly cooled zones of the ultramafic magma, and represents a primary igneous texture. The origin of spinifex texture assumes importance when the mode of emplacement of the ultramafic bodies and their possible association with sulphide ore deposits is considered.

The purposes of this paper are to describe in detail the variety of textures found in a slag, and to compare them with the textures found in nature, in the belief that this, along with other work on glass and ceramics, will give clues as to the origin of spinifex texture.

THE EULAMINNA COPPER MINE

The slag samples examined were collected at the old Eulaminna Copper mine in the Mount Margaret Goldfield, 27 miles (43·5 km) east of Leonora. The mine was active between 1899 and 1908, producing a total of about 4,200 long tons of copper. Mainly ores from the oxidised zones were smelted but some sulphides were also treated. The sulphide ores were roasted in a reverberatory furnace to produce a copper matte and an iron silicate slag. From the old workings it appears that the slag was then transferred to large crucibles, transported a short distance, and then poured out on the ground. The temperature of the slag at this point is problematic but the temperature at the discharge of the furnace would have been about 1,100°C so that solidification and crystallization probably took place at about 800°–1,000°C. At the time of pouring the slag was sufficiently liquid to spread out in a thin film so that cooling would be very rapid.

Two specimens of the slag have been studied in detail, one is in the form of a very thin "flow" about 2–3 cm thick and the second from a "flow" at least 15 cm thick. The slag consists of olivine and glass, the olivine being a pale yellow, slightly pleochroic fayalite, and the glass, of unknown composition, is dark brown and highly charged with iron oxides. Spinifex texture is present throughout the thickness of each of the thin flows but is developed only marginally in the thick flow, the central part being made up of larger discrete skeletal olivine crystals.

SPINIFEX TEXTURES IN THE SLAG

Crystals grown in the slag take several forms. Most commonly, fayalite crystallised in thin plates showing approximately equal development along the a and c axes and negligible development along the b axis. More rarely growth took place preferentially along the c axis, resulting in acicular crystals. The crystal plates are either fans or in random orientation. Alternatively crystal growth was dendritic, the original plate giving rise to second and third order growths in optical continuity. In all cases growth was skeletal, but for the dendritic forms, where cooling had been sufficiently slow, there has been later growth along the b axis, with consolidation of the crystal.

The textures found in the slag will be described under two headings, those formed by the arrangement of single olivine plates and those formed by the dendritic growth of a single olivine crystal. The textures seen in thin section, however, depend not only on the mutual arrangement of the olivine plates but also on the direction in which the rock is sectioned, and similar patterns may arise from both dendritic growth and the arrangement of single plates.

Single crystal plate textures

The most typical of spinifex textures both in the natural rock and the slag is that the olivine plates are arranged like the pages of a book and radiate from a point. In thin section this produces a fan which usually extends through an angle of only 10°–15°. The plates have a length/breadth ratio of up to 150 : 1 and are skeletal crystals usually showing a line of glass inclusions along the centre. Although crystal growth has proceeded from a single nucleus the plates are not in strict optical continuity and the formation of branches, or dendritic growth, is not pronounced. Several types of fan are shown in Figure 3. In type a (lettered types in the succeeding text refer to the lettered sketches of Figure 3) the thin olivine plates of uniform thickness radiate from a point so that progressively more glass is found in the fan, but in type b further plates have been added so that the fan has grown to keep the proportion of glass roughly constant throughout. The third type of fan is of wedge shaped olivine plates and is found in the thicker flows where cooling has been slower. The terminations of the crystal plates are rarely seen, except in type c, but where noted they are usually pyramidal.

Random sectioning of a fan of olivine plates produces a variety of patterns including fans which do not proceed back to a point of origin and, if the section is parallel to the 001 plane, a lamellar pattern which can also be found in sections of dendritic crystals.

The fans of olivine plates invariably have their point of origin within the glassy margin of the flow of slag which means that although the a and

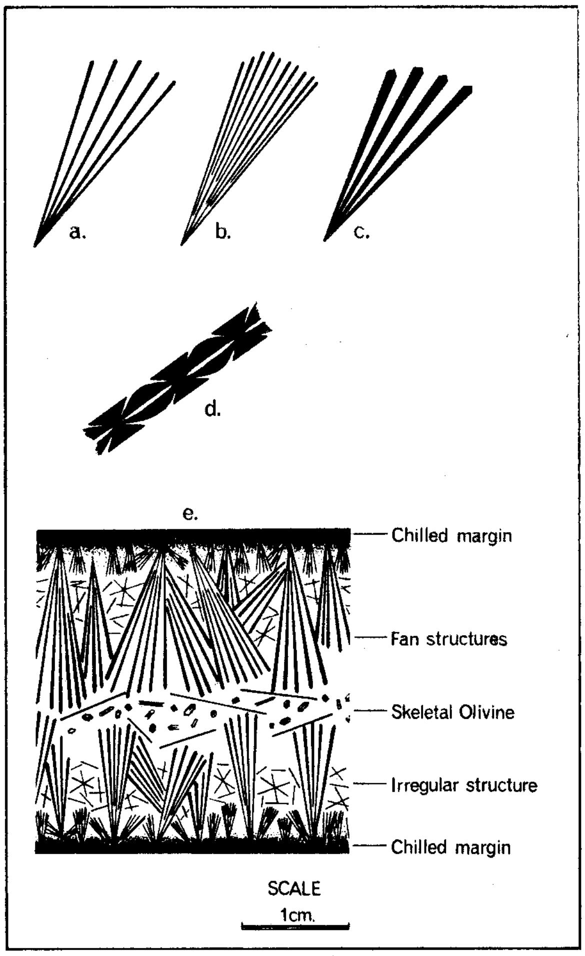


FIG. 3 a,b,c: Typical fan structures found in the slag. d: skeletal structure of olivine plates within a fan. e: zonation of structures within a 'flow' of iron/silicate slag.

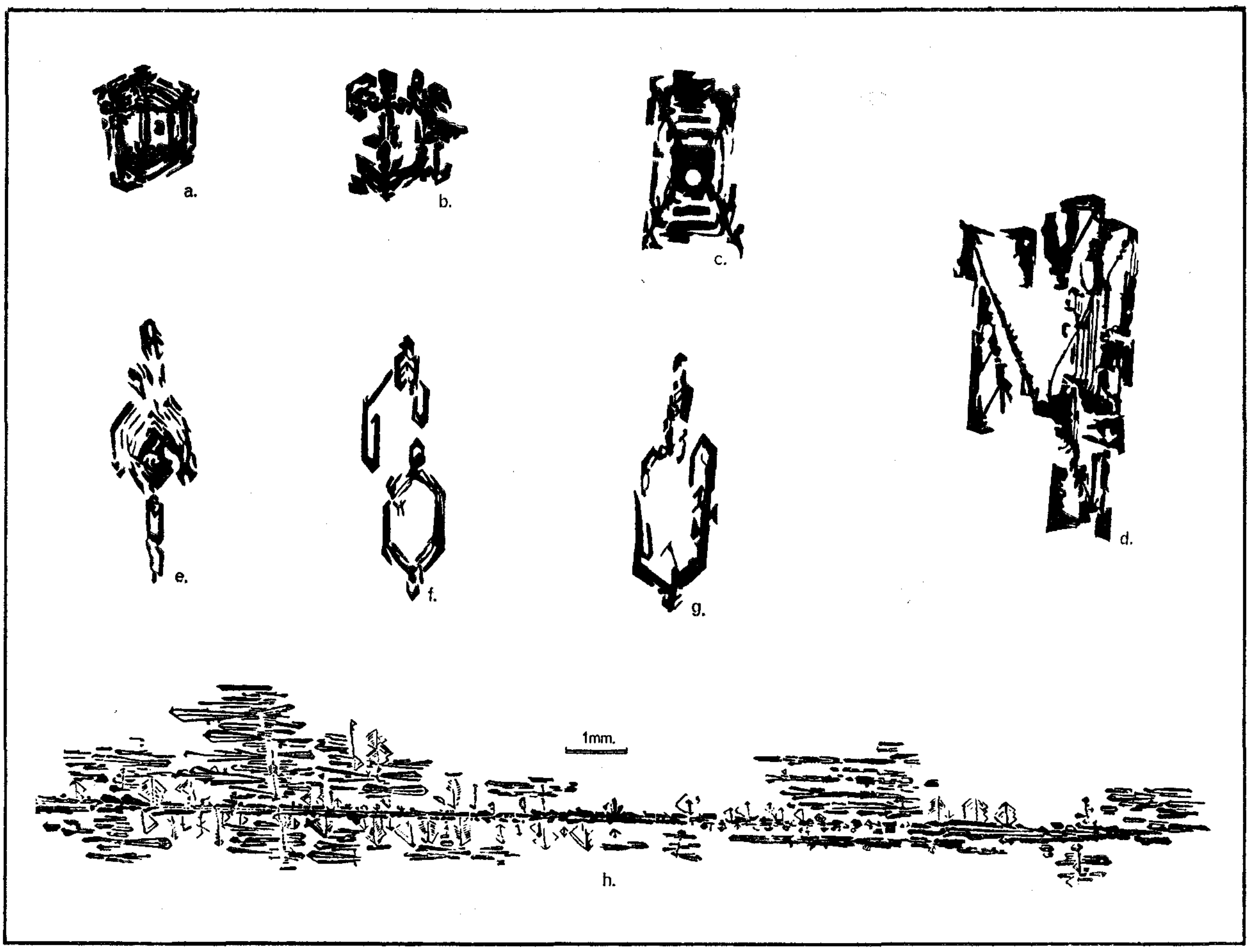


FIG. 4
a–d Skeletal fayalite in iron/silicate slag (x20).
e–g Skeletal olivine from an ultramafic body $2\frac{1}{2}$ miles (4 km) north of Eucalyptus, Mount Margaret Gold Field (x20).
h Part of a single dendritic fayalite crystal from the slag (All drawn from photographs).

b axes of fans may be in random orientiation the c axes are parallel to within 10°–15°. If several such fans are sectioned perpendicular to their c axes the result is a pattern with an apparent three dimensional effect in which the individual lamellae appear to step down towards a central depression. This is illustrated in Plate 23b, the overall effect being similar to a hopper crystal of halite.

Fan textures and their derivatives are developed in the marginal zones of the slag, but the thin plates of olivine nearer the centre of the flow are often in random orientation, giving a distinct but irregular pattern. This irregular texture may not, however, be completely random, as it contains stellate groupings where two or three plates intersect at a point. This arrangement does not appear to be fortuitous, as two of the plates appear to have a constant angle of about 50° between them, the third plate being placed in the obtuse angle. The relationship may be due to twinning.

Textures due to dendritic growth

Dendritic crystals in the slags are developed on a coarser scale than the single crystal plates described above and are associated only with the thicker "flows" which presumably cooled more slowly. Fan textures are less prominent, confined to marginal zones and are of type c with wedge-shaped skeletal crystals. The complexity of individual crystals is shown by Figure 4b where small scale secondary growths have produced major third order growths parallel to the original crystal. As with the previously described types the basic unit is a crystal plate developed along the a and c axes. Second order growths, parallel to the 001 plane are developed on a very fine scale at intervals along the original growth, and these give rise to further third order skeletal growths which are also plate like and parallel to the original crystal. The result, when fully developed, is a texture which is macroscopically similar to the fan textures already described, but with the fans replaced by bunches of parallel plates of olivine in strict optical continuity with each other.

On a finer scale there are also many instances where a herringbone texture has developed as part of the dendritic growth. In Figure 4h these are seen at intervals along the main crystal plate and are caused by the development of the dome faces of the olivine rather than the pinacoid faces that give the predominant texture. The mode of formation of herringbone textures is best seen on the larger skeletal crystals (Fig. 4d). In the 001 plane skeletal growth is initially concentrated along the direction of the prism faces giving a cruciform shape to the crystal, but when growth in this direction ceases the pinacoid faces develop. Growth takes place from several points along the arms of the original cross and leads to a herringbone texture. This style of growth takes place in all planes so that the final crystal appears to be successive shells of olivine separated by glass.

ZONATION OF TEXTURES WITHIN THE SLAG

In the "flows" of slag greater than 10 cm thick, where cooling has been slower, spinifex texture has developed only in a narrow marginal zone, but in the thin "flows" the texture is developed throughout. Most of the textural varieties described can be found within a single flow with a distinct zoning as shown diagrammatically in Figure 3e. The most typical arrangement is that both top and bottom margins are black glass from which has arisen a narrow zone of very fine fan texture of type b. The fans are perpendicular to the cooling surfaces and have their point of origin within the glassy margin. This zone is succeeded by a narrow zone of irregular and stellate groupings. Centrally there is a wide zone of fan structure of type a, the fans having their point of origin within the outer zones and growing inward towards the centre. The fans developing from the upper surface are usually better developed than those from the lower so that the zones are slightly asymmetric. In particular flows, perhaps depending on the thickness and rate of cooling the central part is often crowded with skeletal olivine crystals that show equal development along all axes.

COMPARISON WITH NATURAL OCCURRENCES

The study of naturally occurring spinifex texture is complicated by the fact that most specimens have been completely pseudomorphed by tremolite, chlorite or serpentine. Additional difficulties arise from the fact that natural magmas have a more complex composition than the slags and therefore there has been multiphase skeletal and dendritic growth. Nevertheless a broad correlation is easily demonstrated between the natural and artificial textures. Plates 23 and 24 show examples of various textures found in natural rocks, slag and a remelted basalt, while Figure 4 illustrates the shapes of skeletal olivine found in slag and an ultramafic body at Yundamindra, north of Kalgoorlie.

The ultramafic body at Mount Hogan, northeast of Kambalda had an original mineralogy consisting of large plates of olivine with smaller interstitial plates of clinopyroxene and dendritic growths of chromite. In the present rock the olivine has been replaced by serpentine and the pyroxene by tremolite. The hopper texture developed by the main fans of olivine plates (Plate 24a) compares well with similar textures in the slag (Plate 23b) while on a smaller scale there is a marked resemblance between the natural texture of the ultramafic rock and the textures developed in a melted and chilled basalt (Plate 24b and 23d). The pyroxene of the Mount Hogan mass often shows well developed fans and irregular textures, similar to that in a high magnesian basalt from the Seabrook Hills, about 20 miles east of Mount Hogan (Plate 24), and these can be compared with the irregular textures developed in an ultramafic body at Yundamindra, southeast of Leonora, and textures in the slag (Plate 24c and 23a).

Dendritic growth of olivine in the natural rocks has not been observed except for a few poorly developed examples in the Yundamindra mass but dendritic growth of chromite is illustrated from Mount Hogan (Plate 24b) and dendritic magnetite is prominent in the remelted basalt (Plate 23d).

A further point of comparison between the natural and artificial spinifex textures is the mode of growth of the olivine plates. In most examples of natural spinifex texture the process of replacement of the original mineral by serpentine or tremolite has destroyed the delicate internal structure and resulted in a pseudomorph in which the structure reflects that of the new mineral. In the specimen of ultramafic rock from Yundamindra, however, instead of a felted mass of tremolite blades the original olivine has been replaced by small flakes of tremolite which outline the original structure of the olivine. A close examination of Plate 24c shows that each individual olivine plate is a complex skeletal growth which contains numerous small inclusions of glass arranged either as a central core or as a diagonal pattern depending on how exactly the crystal plate was sectioned. Although not easily seen on the photograph (Plate 24c) many of the olivine plates within the Yundamindra mass show the same pattern and indicate that their mode of growth was similar to that in the slag.

The scale of development of spinifex texture is usually much greater in the natural rock than in the slag. Specimens of ultramafic rock showing plates of olivine up to 30 cm long by 15 cm across are not uncommon whereas in a flow of slag greater than about 5 cm thick the olivine plates cease to grow and are replaced by equidimensional skeletal olivine crystals. Despite this difference in scale, however, the textures produced are broadly similar.

DISCUSSION

Dendritic and skeletal growth of crystals is common in metals and forms an important topic of study for metallurgists. Theories of the formation of such crystals are many and have been reviewed by Buckley (1951) and Saratovkin (1959). Geologically the problem has received little attention since the work of Fouque and Michel-Levy in the nineteenth century which has been reviewed more recently by Drever and Johnston (1957). Spinifex texture in Archaean ultramafic rocks from Canada has been reported and discussed by Naldrett and Mason (1968) and Naldrett and Gasparini (in press) and an allied texture, harrisitic texture, described by Brown (1957) and Wadsworth (1961) from the tertiary volcanic rocks of Rhum, Scotland. Recently work on the production of opal glass and ceramics has led to renewed interest in nucleation and crystal growth in glassy media (Rodgers, 1970) which has a direct bearing on geological phenomena.

The causes of dendritic and skeletal growth are not fully understood but some substances, for example metals in the early stages of crystallization, seem to favour the dendritic habit while others will only adopt this habit if impurities are present. Other factors which favour dendritic growth are rapid cooling and the lack of mechanical stirring or convection currents, both of which would tend to equalise concentration and lead to the uniform development of the crystals (Buckley, 1951, p. 486). Saratovkin (1959, p. 47) sums up the growth of dendritic and skeletal crystals thus: "The forms occur in rapid growth when the space around the crystals contain foreign particles not removed by convection or diffusion".

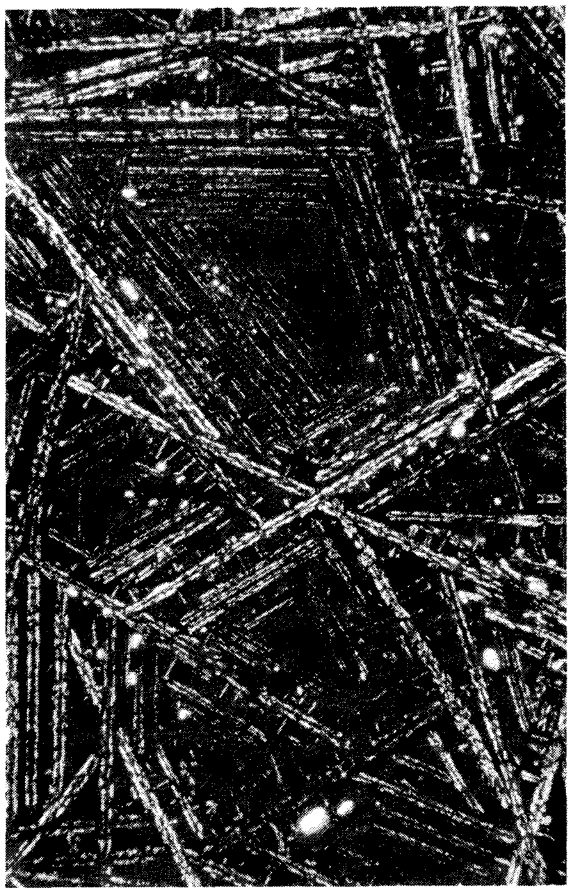
In the slags described above, the thinness of the individual flow led to rapid cooling and the lack of convection currents. The preservation of delicate fans of olivine plates perpendicular to the cooling surface suggests that by the time crystallization

PLATE 23 (opposite)

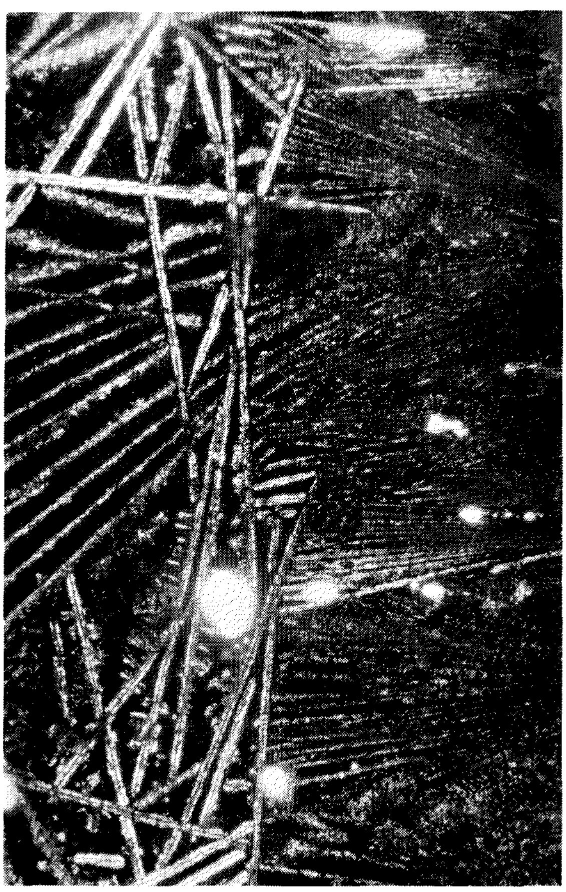
Photographs micro of slag and remelted basalt

A 15133. Nearly complete section through a thin "flow" of slag showing well developed fan texture developed from upper margin and poorly developed fan and irregular texture at lower margin(PPLx5).
B 15133A. Section of fan structures at right angles to the plane of A showing hopper texture. Note the skeletal structure of individual crystal plates (PPL x 30).
C 15133B. Detail of margins of slag "flow" showing two generations of fan structures (PPL x 30).
D Section of remelted and chilled olivine tholeiite basalt from Carnarvon Ranges, S. Queensland. Plates of olivine outline a spinifex texture along with dendritic magnetite and feathery masses of feldspar (PPL x 75) (Photo : D. R. Hudson C.S.I.R.O.).

A



B



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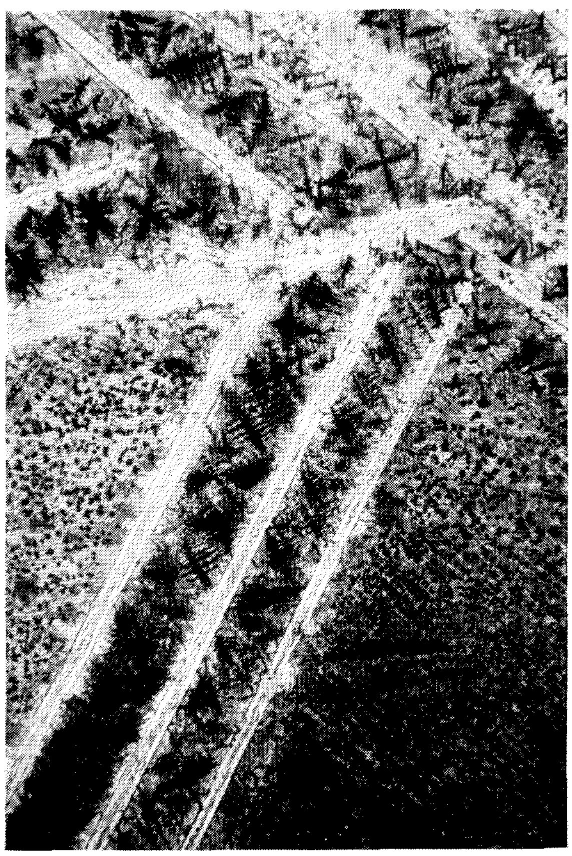

D

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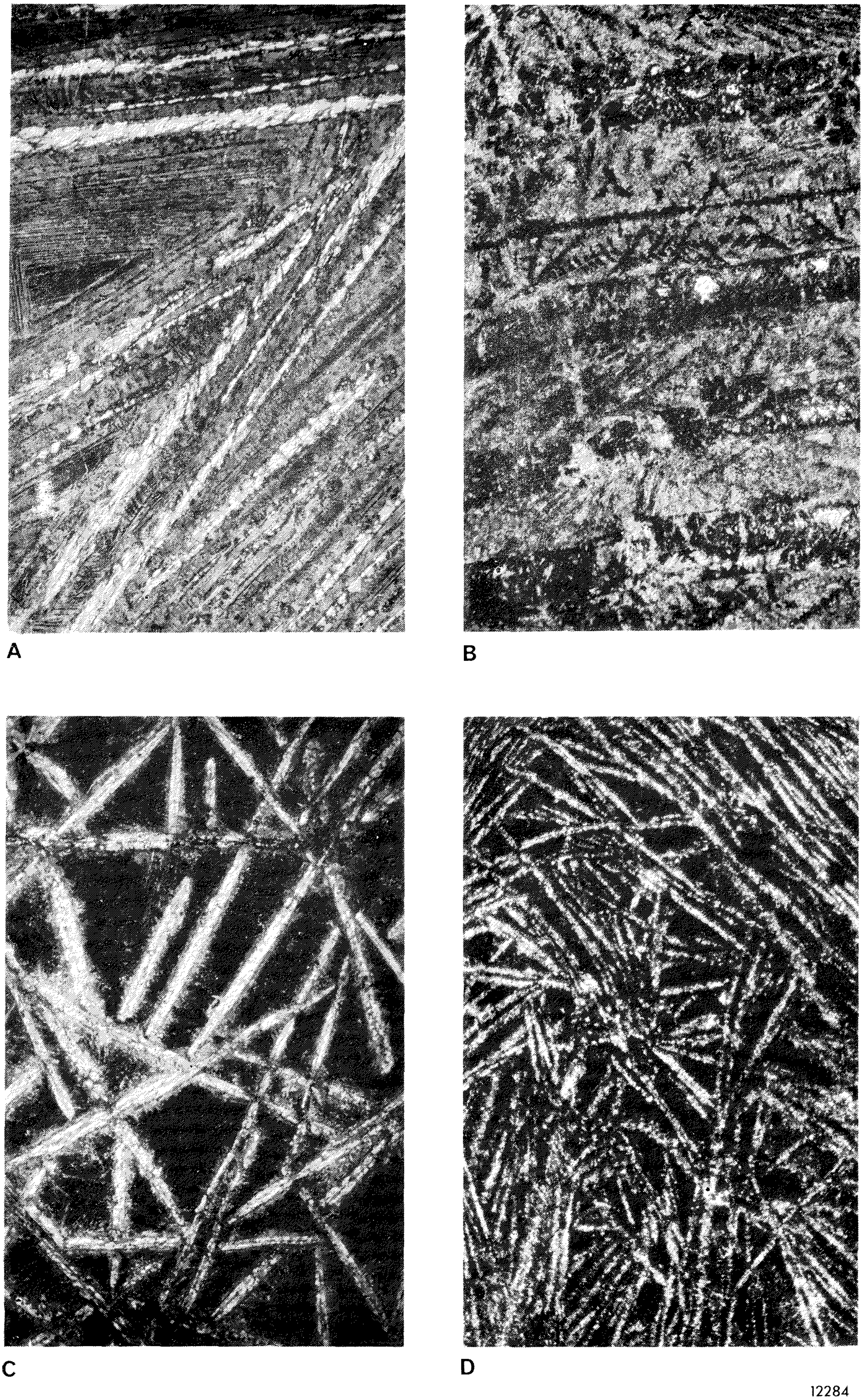

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subject to mechanical disturbance. While the ultramafic bodies in which natural spinifex textures are found are not thin bodies, the presence of the texture would suggest that convection currents and mechanstarted the slag had ceased to flow and thus was not ical disturbance were not present in those parts of the mass where the texture is found. Whether the spinifex texture developed directly from the crystallization of the molten material or represents the products of devitrification of an initially formed glass it is not now possible to determine. Drever and Johnston (1957, p. 310) use the fact that skeletal olivines were found mainly at or near the chilled margin of the rocks that they studied to suggest that their formation depended in part on undercooling and increased viscosity and quote their own and other experiments to show that typical skeletal olivine can be generated by annealing an artificially melted basalt. Plate 23d shows an example of the shapes taken by olivine and magnetite in a basalt which has been melted and chilled.

The work of Rodgers (1970) on crystal growth in glasses provides further evidence for the origin of spinifex texture. In his experiments small quantities of ferric and chromium oxide were added to a glass and specimens heated to allow nucleation and crystallization (devitrification) to take place. A glass of composition CaO 26 per cent, MgO 6 per cent, Al_2O_3 15 per cent, SiO_2 53 per cent with $0 \cdot 6$ per cent added Cr_2O_3 was found to devitrify in two stages, first the dendritic crystallization of diopside followed by the crystallization of feathery masses of anorthite between the diopside crystals. This appears to be analogous to the presence of large plates of olivine with smaller interstitial growths of clinopyroxene and chromite found in the less siliceous ultramafic rocks of the Eastern Goldfields. Nucleation in the glasses studied by Rodgers took place both at the surface and internally, the early formed diopside growing from nuclei within the glass while the later formed anorthite grew from surface nuclei (Rodgers, 1970, fig. 5). In the slags studied the reverse applies, initial nucleation being from the cooling surface with internal nucleation following. The source of nuclei for the olivine in natural spinifex texture cannot be determined but clinopyroxene appears to have nucleated on the surface of the existing olivine plates while chromite grew on independent internal nuclei.

Although the textures in the slag and glasses were undoubtedly formed during rapid cooling a related dendritic growth of olivine is found in the layered ultrabasic rocks of Rhum (Brown, 1956; Wadsworth, 1961), where parallel growths of olivine plates sometimes exceed 1 foot (30 cm) in length. The olivines grow upward from the preceding layer of cumulate material and are believed to be formed during periods of non-deposition of plagioclase (Brown, 1956, p. 18). Alternatively, the same result would follow if the rate of crystallization of olivine increased for any reason. But whatever may be the cause of this type of olivine growth, the rocks are relatively deep seated and cooled slowly.

Spinifex texture, as developed in the Archaean ultramafic rocks of Western Australia and Canada (Naldrett and Mason, 1968; Naldrett and Gasparini, in press) appears to have more affinity with the quickly cooled iron-silicate slag described in this article and the devitrified glasses described by Rodgers than with harrisitic structure developed in the ultrabasic rocks of Rhum, but the conditions required for its formation in nature remain obscure. The texture is probably due to the quenching of the magma and its sudden supersaturation, the cause of the rapid cooling being the particular environment into which the body is emplaced. Naldrett and Mason report the texture from intrusive bodies but Naldrett and Gasparini suggest that its presence may indicate an extrusive ultramafic lava. From the natural and artificial examples cited in this article it is evident that spinifex texture could form in both intrusive and extrusive rocks, so that the present state of our knowledge is perhaps best summed up by Drever and Johnston (1957, p. 310) who write that: "The only hypothesis that can be established which is consistent with all the evidence is that the growth of olivine is rapid, that the morphology of individual crystals is extremely sensitive to, and dependent on, the physical and chemical environment of their point of growth and that olivine of almost any shape or size can crystallise from a magma"!

PLATE 24 (opposite)

Photographs micro of natural spinifex textures

A Ultramafic intrusive body, Mount Hogan, E. Coolgardie Gold Field. Plates of olivine, now pseudomorphed by serpentine, outline a characteristic hopper texture. Interstitial material is tremolite after clinopyroxene, and chromite (PPL x 5).

B Detail of Mount Hogan Ultramafic body. Between the large plates of olivine are smaller pyroxene plates and dendritic chromite grains (PPL x 15).

C 26792. Irregular spinifex texture in a small ultramafic body 8 miles south-east of Yundamindra Homestead, Mount Margaret Gold Field. Note that the skeletal nature of the original olivine plates is still preserved (cf. Plate 23B) (PPL x 15).

D High magnesian basalt, Mount Seabrook, E. Cologardie Gold Field. Spinifex texture outlined by tremolite pseudomorphs after clinopyroxene (PPL x 15).

ACKNOWLEDGEMENTS

The author would like to acknowledge the help given by Mr. D. A. C. Williams of the University of Western Australia in lending thin sections of ultramafic rocks from Mount Hogan and Mount Seabrook, and by Dr. D. R. Hudson of C.S.I.R.O. for the photograph of a chilled basalt melt.

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THE GEOLOGY OF SOME CARBONATE INTRUSIONS IN THE MOUNT FRASER AREA, PEAK HILL GOLDFIELD, WESTERN AUSTRALIA

by J. D. Lewis

ABSTRACT

Six small carbonate-rich intrusive bodies in the Mount Fraser area contain a variety of agglomerates, carbonated shales and intrusions of quartz-pyrite rock and carbonated quartz dolerite. In each body the emplacement of small plugs of quartz-pyrite rock or quartz dolerite has been followed by the formation by fluidisation of vent agglomerates, consisting of fragments of locally available sedimentary and igneous rock with a matrix of ankerite. One body consists largely of carbonated and remobilised sediments.

The absence of fenitization and alkali-rich igneous rocks indicates that these bodies are not carbonatites, while the presence of chloritoid demands a low-temperature origin. The origin of the carbonate is unknown but is possibly related to a greenstone belt in the underlying Archaean Shield. Except for No. 5, all the bodies are emplaced in the axial zone of the Mount Fraser Anticline and although they bear certain resemblances to both volcanic vents and diapiric intrusions their mode of emplacement is best described as pseudo-volcanic.

INTRODUCTION

Five small carbonate-rich intrusive masses were discovered by Dr. W. N. MacLeod during the regional mapping of the eastern part of the Robinson Range 1 : 250,000 sheet. In a preliminary report (MacLeod, 1970) these were distinguished from the carbonated basic and ultrabasic rocks found elsewhere in the Archaean Shield of Western Australia, and were thought to be carbonatites. Due to the possible economic importance of carbonatites, and the distinct lack of such bodies in Australia, a programme of detailed mapping and geochemical sampling was undertaken during 5 weeks in April and May 1970. Only the geological investigations will be reported in this article, the geochemistry being the subject of a separate report (Lewis and Williams, 1971).

REGIONAL GEOLOGY

The Mount Fraser area lies at the northern edge of the Archaean Yilgarn Block (Plate 25). To the south of the Murchison River, granites, gneisses and greenstones of the Shield are exposed, but to the north the rocks are principally the strongly folded Robinson Range Beds, which consist of shales, siltstones and banded iron formation with minor greywackes (MacLeod, 1969). The age of the sedimentary series is probably Archaean but may possibly be Lower Proterozoic and equivalent to the Mount Bruce Supergroup found in the south of the Pilbara. MacLeod (1969, p. 6) bases their assignment to the Archaean on their similarity to other Archaean clastic sequences and the presence of gold mineralization. Metamorphism of the sediments is slight, the finer grained shales now having a slaty cleavage parallel to the bedding.

The general structural trend of the Robinson Range Beds is west-southwest to east-northeast but this trend is disturbed by several cross folds trending north-northeast to south-southwest. In the vicinity of the carbonate intrusions there is a north-plunging asymmetric anticline, complementary to the Mount Fraser Syncline (Sofoulis, 1970), both being outlined by the superior resistance of banded iron formation beds. The anticline trends north-northeast and the western limb through Mount Padbury dips at 45°–70° westward; the eastern limb through Mount Fraser either dips vertically or is slightly overturned to the east.

Later geological history is now represented only by the products of erosion and lateritisation. Fossil drainage channels have formed the repository for manganese deposits which more recent erosion has left as mesaform remnants and spur cappings at 50–100 feet (17–33 m) above the present valley floor (de la Hunty, 1963).

THE CARBONATE INTRUSIONS

Five of the carbonate intrusions to be described lie in a straight line along the axial zone of the Mount Fraser Anticline, the sixth being about 2 miles (3·2 km) to the east and emplaced in the vertical eastern limb of the fold. Throughout the axial zone of the anticline there are small intrusions of quartz-pyrite rock of a similar type to that associated with the carbonate rock, but these were not mapped in detail and will not be described. Except No. 4, all the intrusions are of a similar size and measure no more than 1,000 feet (305 m) across; individual units within each complex are small, and in the northernmost complex agglomerate bands only a few feet wide by a few yards long can be distinguished. The true size of No. 4 is difficult to gauge, as its eastern margin is covered by alluvium and rock scree; its length is about 1 mile (1·6 km) and it might well extend beneath the thick alluvial cover to include No. 6 on the other side of the valley.

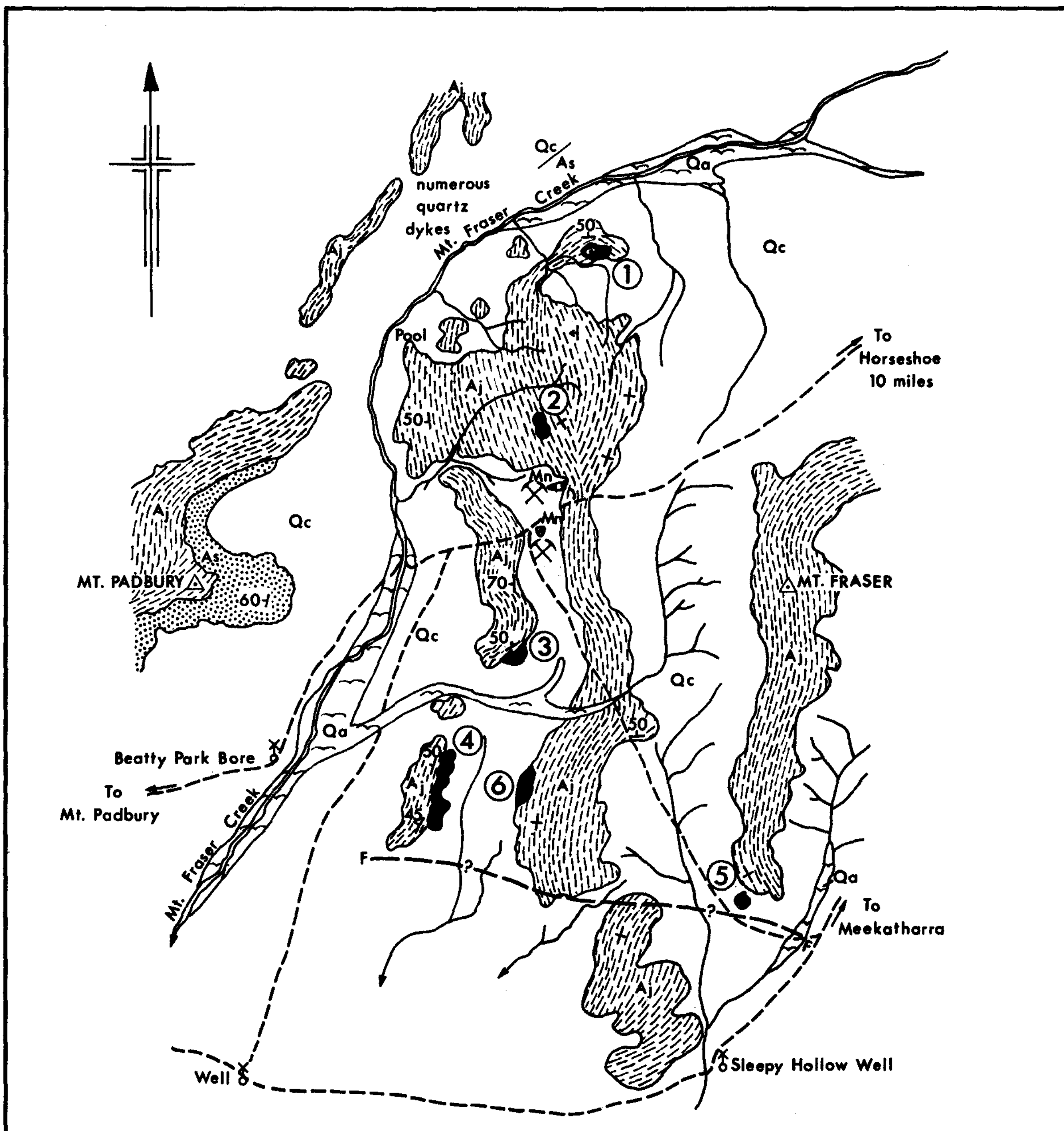
The carbonate bodies are intruded into Robinson Range Beds which, in the central zone of the Mount Fraser Anticline, are predominantly shales and siltstones, with only minor banded iron formation and greywackes. The easternmost body, No. 5, is intruded into a more iron rich part of the sequence.

The nature of the carbonate rocks has led, in most cases, to very deep weathering with the result that their preservation appears to depend on the surrounding country rocks. All the intrusions are exposed on hillsides, where they are easily seen due to the contrast between the light-coloured quartz-pyrite scree and the rust-red shale scree.

For convenience the numbering system of MacLeod (1970) has been retained, and the intrusions will be described in detail from north to south.

No. 1 (Plate 26)

This is the northernmost intrusive body that contains carbonate rocks and the best exposed. The intrusion occupies the crest and southern half of an isolated hill which rises about 150 feet (50 m) above the level of the plain and measures about 1,500 feet (455 m) from east to west by about 600 feet (182 m) north to south. The northern slopes of the hill are formed of shales, siltstones, greywackes and banded iron formation that dip steeply northward. Contact relationships between the carbonate and country rock cannot be seen in detail but appear to be sharp and complex as tongues of carbonate agglomerate intrude the shales. To the south of the hill the limits of the carbonate cannot be established because of scree cover.

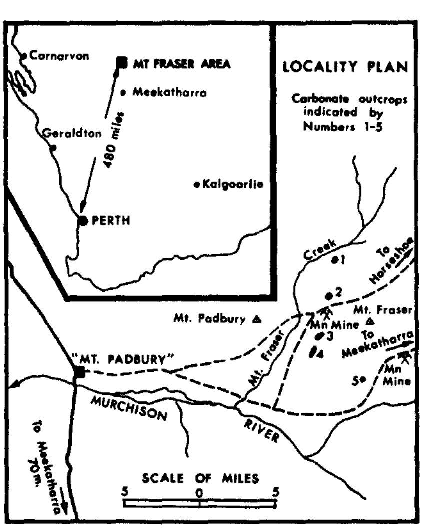


REFERENCE

- Qa — River alluvium
- Qc — Colluvium. Rock scree and soil cover
- Aj — Banded iron formation and shale
- As — Sandstone, siltstone
- Carbonate and associated intrusive rocks
- Manganese deposit

SYMBOLS

- Vertical strike and dip of bedding
- Strike and dip of bedding
- 50 Strike and dip of bedding, measured
- F —?— Fault, inferred



GEOLOGICAL SKETCH MAP OF THE
MOUNT FRASER AREA

SCALE

2 0 2 4 miles

2 0 2 4 6 kms

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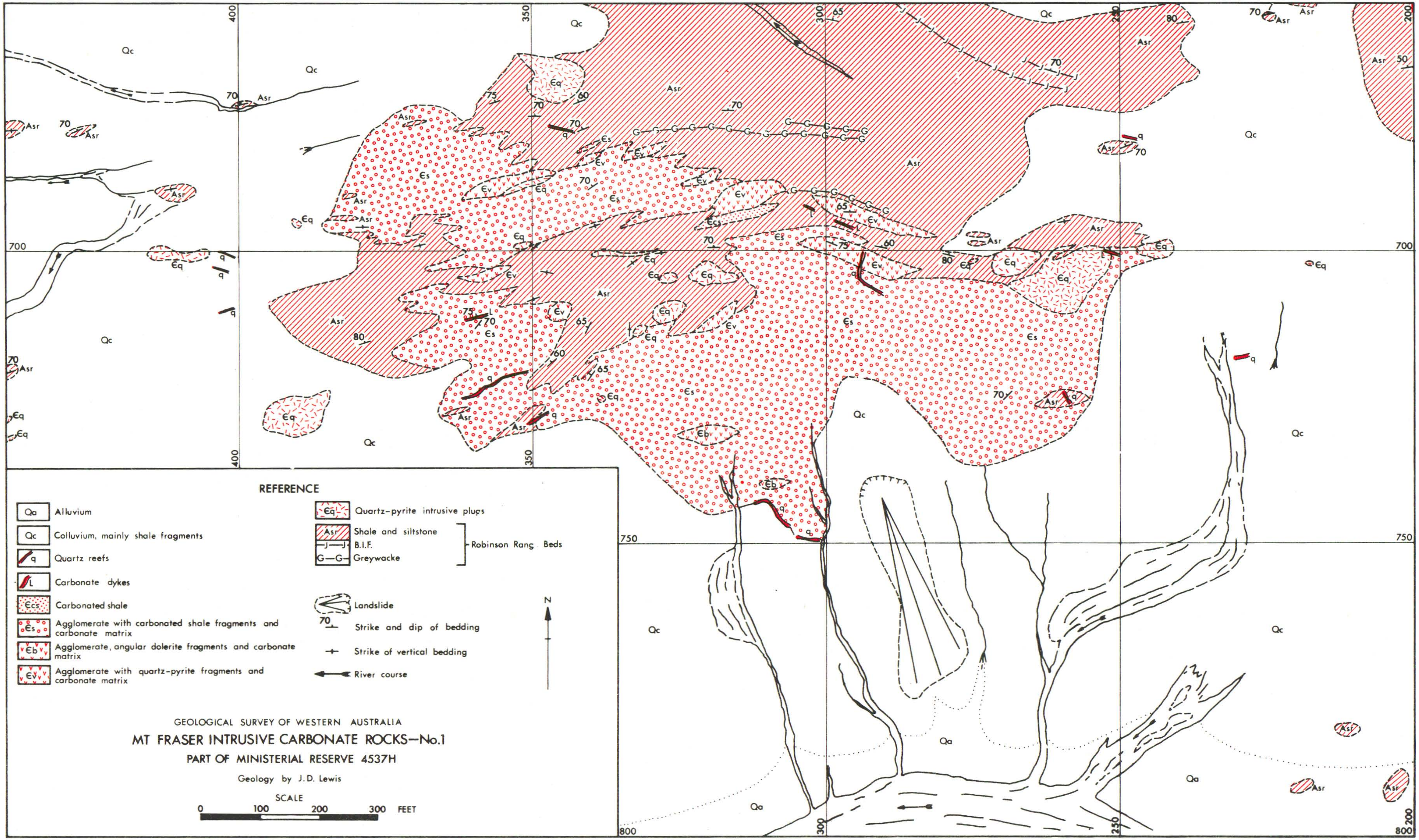
PLATE 26



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The principal components of the mass are several small intrusions of quartz-pyrite rock and innumerable lenses of carbonate-rich agglomerate. Minor components include small dykes of almost pure carbonate and viens of white milky quartz carrying a little specular hematite. Quartz-pyrite rock appears to be the earliest intrusion, individual bodies ranging from about 200 feet (60 m) across to small plugs and dyke-like bodies only a few feet across. Most are oval and elongated east-west, parallel to the main axis of the complex. The quartz-pyrite rock is well jointed, fine grained and pale grey when fresh, it weathers to a pale brown colour. Flow banding, when present, is nearly vertical, parallel to the margin of the intrusion and is often outlined by trains of small pyrite cubes. Marginally the rock is often brecciated by the later emplacement of the carbonate agglomerates. This is well displayed on the small plug at 327710, where the quartz-pyrite intrusion contains dark veins of limonitised pyrite, small flakes of green biotite, and ankerite. The intrusive nature of the quartz-pyrite rock is demonstrated by the occurrence at 340670 where the shales surrounding a small mass of quartz-pyrite rock have been disrupted.

The bulk of the complex is made up of agglomerates consisting of fragments of country rock and quartz-pyrite rock in a carbonate matrix. Three distinctive types of agglomerate can be mapped. The commonest type contains small fragments of shale up to 1 inch (2·5 cm) across set in a sparse carbonate matrix; the shale fragments are themselves highly carbonated and the whole weathers to a characteristic grey-green rubble. Less commonly the agglomerate contains fragments of quartz-pyrite rock which may form up to half the agglomerate. This type of agglomerate is usually adjacent to quartz-pyrite intrusions and its distribution probably depends on the local availability of such fragments. Near the southern margin of the body there are several agglomerate lenses that contain angular fragments of an altered igneous rock, and probably represent the last phase of agglomerate formation.

The last phase of carbonate intrusion was the emplacement of several small dykes of almost pure carbonate. The best example, consisting mainly of ankerite with a little quartz and muscovite, occurs near the summit of the hill at 295695, it is about 2 feet (61 cm) thick and exposed over a length of about 100 feet (30 m). Smaller examples are found in several other localities. Irregular sheets and veins of white milky quartz up to 2 feet (61 cm) thick and sometimes carrying a little specular hematite make up the final phase of activity within the complex.

The quartz-pyrite rock agglomerate is sufficiently distinctive in the field to allow the general structure of the body to be determined. The agglomerate occurs in lenticular masses with the fragments in a planar alignment parallel to the margin and usually near vertical. The lenses are dyke like and range up to a length of about 200 feet (60 m) with a width of up to 20 feet (6 m); throughout the body the lenses have a roughly east-west trend. In the main mass of agglomerate the rock type is more uniform but small included lenses of shale and subtle differences within the agglomerate indicate that the mass was emplaced in the form of closely spaced lenses which have coalesced. Again the lenses are dyke like and trend roughly east-west so that the overall structure of the mass is that of a group of closely spaced lenticular bodies that have coalesced. Some of the shale remnants caught between the agglomerate lenses are quite large, and MacLeod (1970, p. 28) mentions one that is about 300 feet (90 m) square. Detailed mapping shows that this block is not entirely surrounded by agglomerate so that with the general structure of the body there is no basis for postulating a ring dyke of agglomerate.

The fragments contained in the agglomerates are of rocks of local origin, either shale or quartz-pyrite rock. This combined with the distribution of the agglomerate with quartz-pyrite fragments suggests that the agglomerates have not been transported for large distances.

No. 2 (Plate 27)

The two small hills which make up this body are a little to the north of the Mount Fraser manganese mine. The northerly hill rises sharply about 150 feet (15 m) above the plain, while the southerly hill is much lower and rounded. The whole body occupies an area of only 900 feet (250 m) by 400 feet (120 m).

The northern outcrop consists of a roughly circular plug of quartz-pyrite rock carrying varying amounts of small cubes of pyrites up to 5 mm across, it is intruded into vertical or steeply dipping shales and includes a lens of shale within it.

The southern hill consists of two carbonated igneous intrusions and a small quartz-pyrite intrusion with a mass of carbonated and brecciated shale between them. The largest intrusion has a roughly triangular shape and a sharp margin against the carbonated shale, it is a fine-grained pale grey rock carrying small rhombs of carbonate. The eastern third of this hill is composed of a fine-grained altered igneous rock which contains much carbonate. Lenses of carbonated shale within the mass, and its indented contact with the country rock, give the impression that this intrusion was formed by the coalescing of several north-south trending lenticular bodies. Two small intrusions of quartz-pyrite rock are also present in the southern part of the complex, and adjacent to one is a small area of carbonate agglomerate containing fragments of both shale and quartz-pyrite rock.

The bulk of the rock exposed between the intrusive masses is a strongly carbonated shale. The rock appears to be a highly weathered shale but closer inspection reveals many small rhombs of carbonate and the development of green chromian muscovite. The extent of the carbonated shales cannot be determined, as much of the surrounding area is scree covered.

Narrow dykes of quartz-pyrite rock occur in the surrounding area; all trend north-south and appear to be connected with the activity of this centre.

No. 3 (Plate 27)

Centre 3 lies about a mile (1·6 km) south of the Mount Fraser manganese mine and half a mile (0·8 km) west of the main north-south track. A prominent ridge formed by two quartz-pyrite intrusions stands out on the flank of a hill of shale and banded iron formation while the carbonate rocks lie poorly exposed in the dip between the intrusions and the main hillside or slightly better exposed as a separate body a little to the northwest of the quartz-pyrite rock.

The body is intruded into steeply dipping shales, siltstones and banded iron formation. Both carbonate and quartz-pyrite rock are concordant with the bedding of the host rock but in a few places the actual margin can be seen and their intrusive nature demonstrated.

The main intrusions of quartz-pyrite rock form a prominent ridge about 80 feet (24 m) high on the south side of the body. At its western end the rock is strongly banded, the banding being outlined by pyrite cubes and the weathering out of ankerite. At this point the intrusive relationship of the quartz-

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pyrite rock to the enclosing shales can be seen. The margin of the quartz-pyrite rock dips northward at 45°, which is the dip of the banding within the mass, and the enclosing shales have been slightly carbonated and hornfelsed.

Apart from the intrusions of quartz-pyrite the main rock type is a uniform, fairly fine-grained and highly carbonated agglomerate. The agglomerate is deeply weathered, and much of the outcrop is covered by a grey-green rubble. Originally the fragments within the agglomerate were shale but carbonation and weathering have destroyed all but the megascopic structure. Small outcrops of carbonate agglomerate are present to the north of the quartz-pyrite intrusions, but the main mass is to the north-west. Numerous lenses of shale occur within the agglomerate, and to the west of the complex several small lenses of agglomerate have been mapped within the shale.

Other rock types within the complex are several fairly thick sheets of milky quartz and two narrow dykelets of pure calcite at 480660. A single basalt dyke intruded into the shales near the western margin of the body probably predates the carbonate.

Because of the deep weathering and uniform rock types the detailed structure of this body cannot be determined, but the presence of lenses of shale within the agglomerate suggest that the agglomerate was intruded as lenses similar to those in complex No. 1. The northeastern margin of the body is, however, quite well exposed and can be accurately followed over the spur of the hill. Where best exposed the margin of the agglomerate dips steeply westward at 70° and intrudes shales with a similar dip. A 20-foot (6 m) wide marginal zone surrounding the agglomerate is less resistant to weathering than either the shale or the agglomerate so that the margin of the carbonate body stands out against this narrow aureole of slightly altered shale. The uniform nature of this contact suggests that if lenticular intrusions were involved in the formation of this body they were rather larger than those in complex No. 1.

No. 4 (Plate 28)

This body is probably the largest in the district but is also the poorest exposed. The western margin, protected by the more resistant shales and banded iron formations, is well exposed at several points over a distance of nearly a mile (1·6 km) but a few hundred feet downslope, scree cover becomes complete. The exposed mass is, then, a narrow band of disconnected outcrops scattered along a hillside. From the detailed mapping the suggestion of MacLeod (1970, p. 28) that this complex might extend across the valley floor and even include complex No. 6 as part of its eastern margin, cannot, because of the cover of scree and alluvium, be proved.

The western margin of the body is marked by several small intrusions of altered igneous rock which carries plentiful cubes of pyrite. The largest intrusion is only about 300 feet (90 m) long and all form prominent crags. The altered igneous rock is fine grained and pale grey when fresh but it is usually highly veined by carbonate minerals and some exposures show small iron-stained rhomboidal pits due to the weathering out of ankerite. Large pyrite cubes up to 2·5 cm across are especially prominent in a white quartz vein which invades the rock at 190740. The intrusion at the southern end of the complex is different from all other exposures in containing large pyritohedra rather than cubes of pyrite.

Most of the carbonate rock is very poorly exposed and consists of patches of grey-green calcareous rubble from which little indication of rock type or structure can be deduced. At the southern end of the body, however, are some relatively good exposures which indicate that most of the carbonate rock observed elsewhere probably consists of an agglomerate of altered and carbonated shale fragments set in a carbonate matrix. Outcrops in the vicinity of 180420 show good examples of intrusive agglomerates and structures similar to those of a small volcanic neck. The carbonate rocks of this area consist principally of a fine-grained and highly weathered agglomerate, but intruded into this are lenses of much coarser and less weathered agglomerate in which the shale fragments are more angular, and commonly make up the major portion of the rock. These lenses are arranged in an arcuate fashion around a plug of altered igneous rock and dip steeply towards it. This is the only structure in the whole region that shows a concentric structure. Within the igneous intrusion there are also several lenticular brecciated zones from a few inches to a few feet wide where carbonate-rich fluids have invaded the rock. Angular fragments of acid igneous rock make up the bulk of these zones, carbonate forming only a minor matrix.

Throughout the length of the contact between the carbonate body and the enclosing shales and banded iron formation there appears to be little or no contact metamorphism but at 190510 the shales have been converted to a talc-carbonate schist. In parts the rock appears to be almost pure talc but usually it is a talc-rich shale with rhombs of carbonate. This small area of talcose rock grades into normal shale, and appears to be the product of localised metasomatism.

No. 6 (Plate 29)

MacLeod (1970, p. 28) reported an area of talc-carbonate rock on the eastern side of the valley containing No. 4 and suggested that these might have been derived from an ultrabasic body. The rocks in question crop out on a low spur, and mapping shows that they grade eastward into normal shale and banded iron formation. Westward from this spur there are several small outcrops of highly carbonated igneous rock, and it is probable that the altered shales are part of a marginal zone of a carbonate body that is largely hidden by scree. The talcose rocks are quite variable, and generally grade from almost completely altered rocks in the west to only slightly altered shales in the eastern part of the area. The altered igneous rocks present are strongly veined with carbonate, and many outcrops are agglomeratic, with carbonate minerals making up over half the rock.

The total area covered by this body is at least 2,000 feet by 1,000 feet (600 m and 300 m) but most of this area is covered by scree and alluvium, so that nothing can be determined of the structure of the mass.

No. 5 (Plate 30)

The small plug of quartz-pyrite rock at the northern end of this body rises a hundred feet or so above the level of the gravel plain and stands out strikingly against the hillside of banded iron formation and shale. The associated carbonate rocks form a low rounded hill about 600 feet (180 m) in diameter to the south of the quartz-pyrite plug.

This body is in several ways somewhat different from others in the area, the most obvious being that it is intruded into the steeply dipping eastern limb of the Mount Fraser Anticline, rather than the axial zone. The rock types present are also slightly different, in that the plug of quartz-pyrite rock and dykes of similar rock carry abundant chloritoid

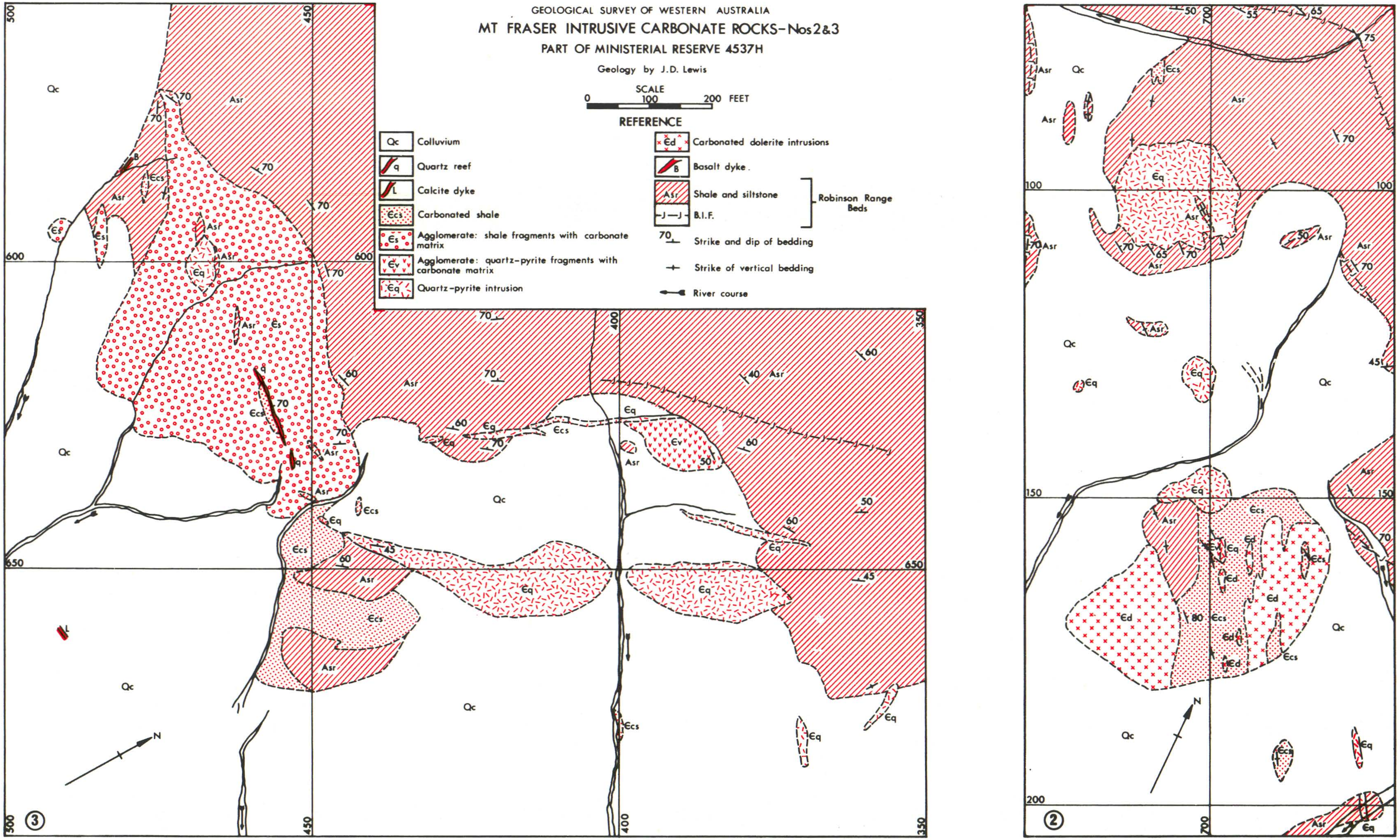

PLATE 27

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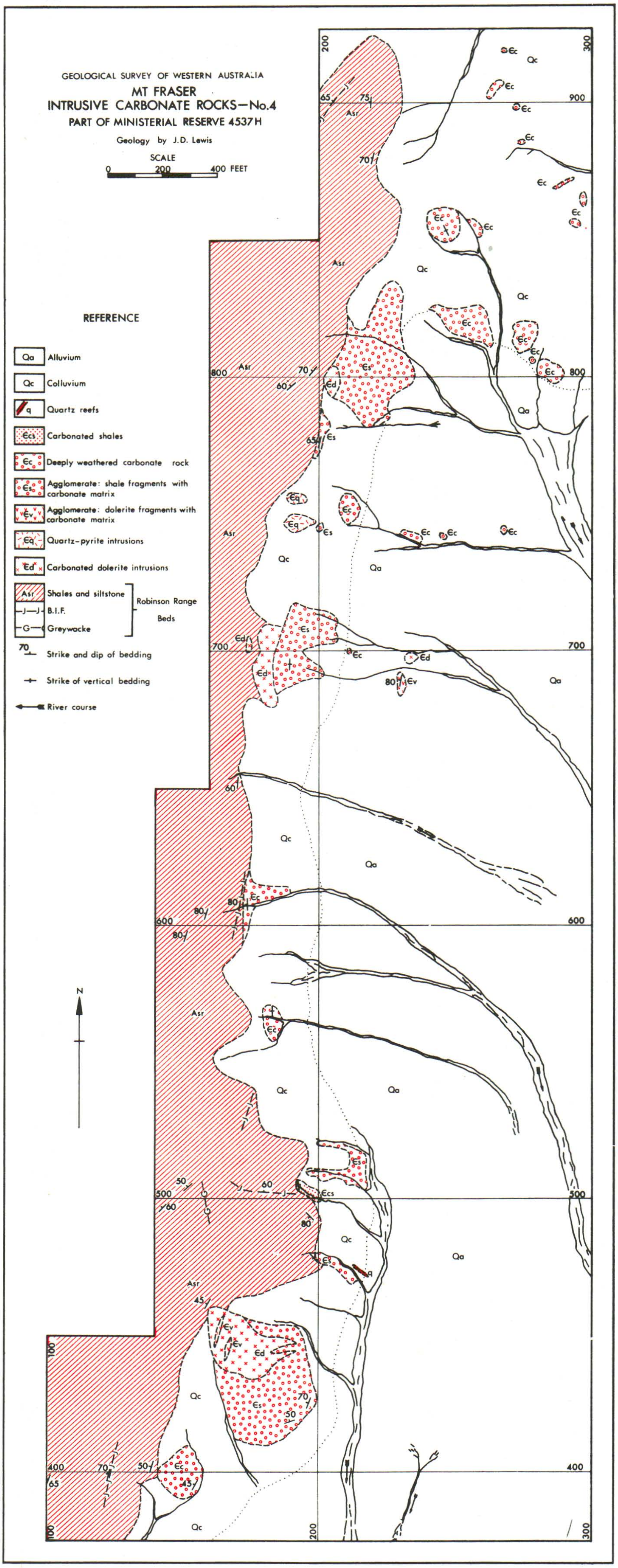
PLATE 28



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and the carbonate rocks have the overall appearance of a highly folded sedimentary sequence. Carbonate-rich agglomerates are present but only in small amounts. Exposure over much of the complex is very good but nowhere are the margins of the body visible, the carbonate being surrounded by a scree of shale fragments and hematite blocks from the surrounding hills. Secondary carbonate deposits, or kankar, also obscure some areas.

The quartz-pyrite plug at the northern end of the body is approximately circular and about 150 feet (46 m) in diameter. The margins of the plug are obscured by scree, but vertical flow banding within the mass indicates an intrusive body. The fresh rock is fine grained and pale grey with a few small cubes of pyrite and a little green chromian muscovite and chloritoid visible. Parts of the mass have been extensively veined by carbonate material with the development of rhombs of ankerite, and in others masses of pale green chromian muscovite have been developed. Dykes of similar material occur within the main carbonate mass, and to the east of the main plug there are three small dykes which once carried cubes of pyrite up to 1 cm across, now completely altered by secondary silicification.

Within the carbonate mass there are a few small areas of carbonate-rich agglomerate carrying angular quartz-pyrite rock set in a matrix of ankeritic carbonate. The remainder of the mass appears to have been a sedimentary sequence that has been highly folded and carbonated. In many areas what at first appear to be quartz-rich fragments in an agglomerate are in fact previously continuous bands of quartzite that have been extended to give lenticular boudins. The whole rock appears to be a thinly laminated series of quartz-rich and carbonate-rich bands. Almost everywhere the laminations are vertical and if followed along strike several folds can be easily traced. In the nose of certain folds, as at 300560 there is an accumulation of quartz-chloritoid rock and at 300580, where the folds have broken, a dyke-like intrusion of the same rock type. The laminations are only coincidentally parallel to the margins of the intrusion and at the eastern margin strike perpendicularly to it.

Field evidence suggests that this body consists largely of a remobilised mass of finely laminated sediments. The original sediments could have been alternating bands of sandstone and shales but of a type not seen at the surface elsewhere in the district.

Other localities

Throughout the axial zone of the Mount Fraser Anticline there are numerous small intrusions of quartz-pyrite rock easily distinguished from other quartz intrusions by the presence of pyrite. None of these intrusions is associated with any carbonate rock, but some show alteration of adjacent shales similar to parts of No. 6.

PETROGRAPHY

Although each of the carbonate bodies is slightly different they are composed of few rock types, so that it is convenient to describe them as a single petrographic province. The rock types commonly met with are quartz-pyrite intrusions and highly carbonated igneous intrusions, agglomerates, carbonated and altered shales, and small dykes and veinlets of almost pure carbonate.

Quartz-pyrite intrusions

In hand specimen this rock is usually pale grey and fine grained, and carried numerous cubes of pyrite. In thin section a fine-grained equigranular mosaic of quartz is seen to comprise 90 per cent or more of the rock, the remainder being small cubes of pyrite and a little chromian muscovite or biotite. Some specimens contain a small amount of carbonate, usually a clear dolomite or ankerite. The pyrite has altered to limonitic material. The carbonate is a secondary mineral introduced during the emplacement of the agglomerates. In several slides, notably 15124 and 15057 which are from brecciated portions of quartz-pyrite intrusions, the ankerite is present in veins in the rock.

Rocks of this type occur in bodies No. 1, 2, and 3, but only one small area has been found in No. 4. A somewhat different rock type is present in No. 5, where in addition to quartz and pyrite there is abundant chlorite and chloritoid, a little chromian muscovite and many small grains of rutile. The intrusive mass to the north of No. 5, dykes within the complex and quartz-rich lenses at the nose of folds all contain chloritoid with the characteristic "bow-tie" structure. The bulk of the rock is a fine-grained mosaic of quartz but often small flakes of muscovite have developed along the margins of the grains. Chromian muscovite is especially prominent in a specimen taken from a pod within the main outcrop (15044). A pale green chlorite with anomalous Berlin blue interference colours forms a significant proportion of many slides and this is usually associated with many small prisms of rutile.

Carbonated igneous intrusions

These rocks are present in bodies No. 2, 4, and 6, and in hand specimen appear to be highly altered dolerite with cubes of pyrite. Unlike the quartz-pyrite rock most specimens have been strongly carbonated and now contain 40 per cent or more of ankerite, often as discrete rhombs. Carbonation and recrystallization of the original minerals makes identification of the original igneous rock type almost impossible.

In thin section the rock contains about 50 per cent of ankerite which has usually exsolved hydrated iron oxides. Albite (An_{3-10}) is the next commonest mineral, and in several specimens forms medium-grained laths which give the rock the appearance of an altered dolerite (e.g. 15087, 15090). This texture is possibly an original texture, and every variation can be found, as the rock has been recrystallized, to the feathery intergrowths of quartz and untwinned plagioclase present in 15077 and 15078. Specimen 15090 shows good examples of interstitial micropegmatite, and many specimens contain small grains of rutile, which, in 15081 and 15132, are arranged as rods which appear to be relict textures after ilmenite. The only mafic minerals present are a little brown or green biotite and chlorite which gives an anomalous brown interference colour.

Ankerite, pyrite and chromian muscovite, present to a greater or lesser degree in all specimens, appear to have been introduced into the original rock after its emplacement. In most specimens the minerals are distributed throughout the rock, but in some they form discrete veins. Specimen 15078 from No. 4 contains a vein of coarsely crystalline ankerite, albite and chlorite, and in specimen 15098 both ankerite and pyrite are confined to veins.

The igneous intrusives have been extensively altered since their emplacement but sufficient remnant textures remain to suggest that they were originally doleritic in character. Carbonate metasomatism and extensive recrystallization have produced the variety now found. There has also been the introduction of soda, silica, sulphur and chromium. Specimen 15098 from No. 2 has been so silicified that it appears as a quartz-pyrite rock with lenses of albite having a doleritic texture, while in specimen

15128 from No. 6 the rock is now about 60 per cent ankerite with large masses of chromian muscovite and even a little tourmaline.

Agglomerates

The agglomerates are usually so highly weathered that thin sections are of little use. Megascopic features have often been preserved and in the field several types can be distinguished. In thin section however, it is seen that many of the fragments, especially of the shales, have been so highly altered and carbonated that it is difficult to distinguish fragment from matrix.

With the exception of the northernmost body, No. 1, the agglomerates contain only fragments of locally available rock, either sedimentary or igneous. Agglomerates with shale fragments are the commonest but the shale has been so altered that it is almost unrecognisable and now consists usually of a fine-grained assemblage of quartz, sericite, chlorite and ankerite. Fragments of quartz-pyrite rock often occur in agglomerates near intrusions of the rock, and have usually been little altered except for the growth of rhombs of ankerite. In No. 4 fragments of carbonated igneous rock are common but often, due to the carbonation of the original rock, the fragments appear to grade into the matrix. Even in specimen 15132, from a small breccia vein in an igneous mass at the southern end of No. 4, matrix is indistinguishable from fragments, although in hand specimen angular fragments are easily outlined. Only in specimen 15058 can carbonated igneous rock fragments, of a type not known elsewhere in the complex, be easily distinguished from a matrix of pure ankerite and later quartz veins.

The matrix of the agglomerate probably consists of comminuted rock fragments as well as the introduced carbonate. Many small grains of quartz and chlorite lie within the matrix, probably derived from the breakup of the smaller fragments. In specimen 15058 where the fragments have been little affected by carbonation the matrix is of pure ankerite. Specimen 15123 from complex 3 contains abundant large flakes of biotite, probably derived from an igneous rock not found exposed.

Carbonated shales

Several of the complexes contain outcrops of rock which appear to be highly altered shales. These vary from the complete conversion of the shale to a pure talc-carbonate rock at 190510 in No. 4 to exposures in No. 2 which retain all the characteristics of shale but contain porphyroblasts of ankerite. In addition nearly the whole of No. 5 appears to be a finely laminated sedimentary sequence that has been carbonated.

The carbonated shales of No. 6 (spec. 15125) now consist of a fine-grained aggregate of talc containing many flakes of brown biotite and clots of chlorite. Carbonate minerals originally present have been pseudomorphed by chalcedony with their original rhombic outline preserved by limonite. Similar shales from No. 1 (spec. 15068, 69) have been converted almost entirely to ankerite, only their megascopic features indicating their origin. From No. 2, specimen 15089 is an altered siltstone which has been recrystallized to a fine-grained aggregate of quartz feldspar and sericite and in which discrete porphyroblasts of ankerite have grown. The carbonation in this specimen was probably accompanied by shearing as the porphyroblasts show an augen structure.

No. 5 consists entirely of a carbonated sedimentary sequence. The quartz-rich bands have the same mineralogy as the quartz-pyrite intrusion at the north end of the complex and consist of a fine-grained quartz mosaic with much chlorite and some chloritoid and small rutile grains. Shale-rich bands have been altered to a fine-grained chlorite-quartz rock which carries a high proportion of ankerite in the form of veins and discrete rhombs. Carbonate veining of at least two generations can be seen. In specimen 15050 the host rock is now a fine-grained chlorite-quartz aggregate, and there are many parallel veins of iron-stained ankerite traversing the rock. This pattern has been disrupted by the emplacement of a fine network of veins of clear carbonate which has fragmented the earlier carbonate veining.

Carbonate-rich dykes and veins

Small veins of pure carbonate are present in many of the intrusive bodies, but two examples are noteworthy. In No. 1 there are several well-defined dykes of a fine-grained rock consisting of ankerite with a little interstitial quartz and muscovite. The texture of the ankerite is equigranular but the muscovite sometimes outlines flow banding.

About 500 feet (150 m) to the southwest of No. 3 two veins of almost optical quality calcite were located. The veins contain a little quartz and chlorite as secondary veinlets but otherwise consist of large crystals of calcite up to an inch (2·5 cm) across. The relationship of these veins to the main carbonate complex is unknown.

ORIGIN OF CARBONATE

In recent years much work has been done in efforts to establish definite criteria for the differentiation of carbonate minerals derived metasomatically and magmatically. The geological characteristics of carbonatites have been listed by Verwoerd (1967) and Pecora (1956). Gold (1963) provides a comparison of the trace element content of magmatic and sedimentary carbonates. Geologically, carbonatites belong to alkaline petrographic provinces, and the usual associated igneous rocks are silica-deficient and include nepheline syenites, ijolites and more basic rocks. In addition most carbonatites are surrounded by an aureole of alkali metasomatism (fenitization) and contain a distinctive suite of accessory minerals including apatite, magnetite, soda-rich amphiboles and pyroxenes, and often radioactive and rare-earth minerals such as pyrochlore.

The Mount Fraser carbonate rocks conform to none of the above criteria. The associated intrusives are quartz-pyrite rock and a possible quartz dolerite, alteration of the surrounding rocks is limited to the introduction of carbonate and the conversion of the shales to talc-rich rock, and no trace of apatite or alkali-rich minerals have been found. On the contrary the general lack of alteration of the country rock and the abundance of such low-temperature minerals as chlorite, muscovite and chloritoid suggest that no elevated temperature was reached during the emplacement of the Mount Fraser carbonate bodies. Siliceous rocks are sometimes found associated with carbonatites as at Songwe Scarp (Brown, 1964) where a siliceous intrusive breccia has been emplaced after the carbonatite and where late-stage quartz veining is also common. The Songwe Scarp carbonatite is also similar to the Mount Fraser intrusions in being predominantly ankeritic, containing pyrite rather than magnetite and lacking many of the alkali minerals usually associated with carbonatites. The presence of a wide zone of feldspathised schists, the radioactivity of certain sections of the intrusions and the con-

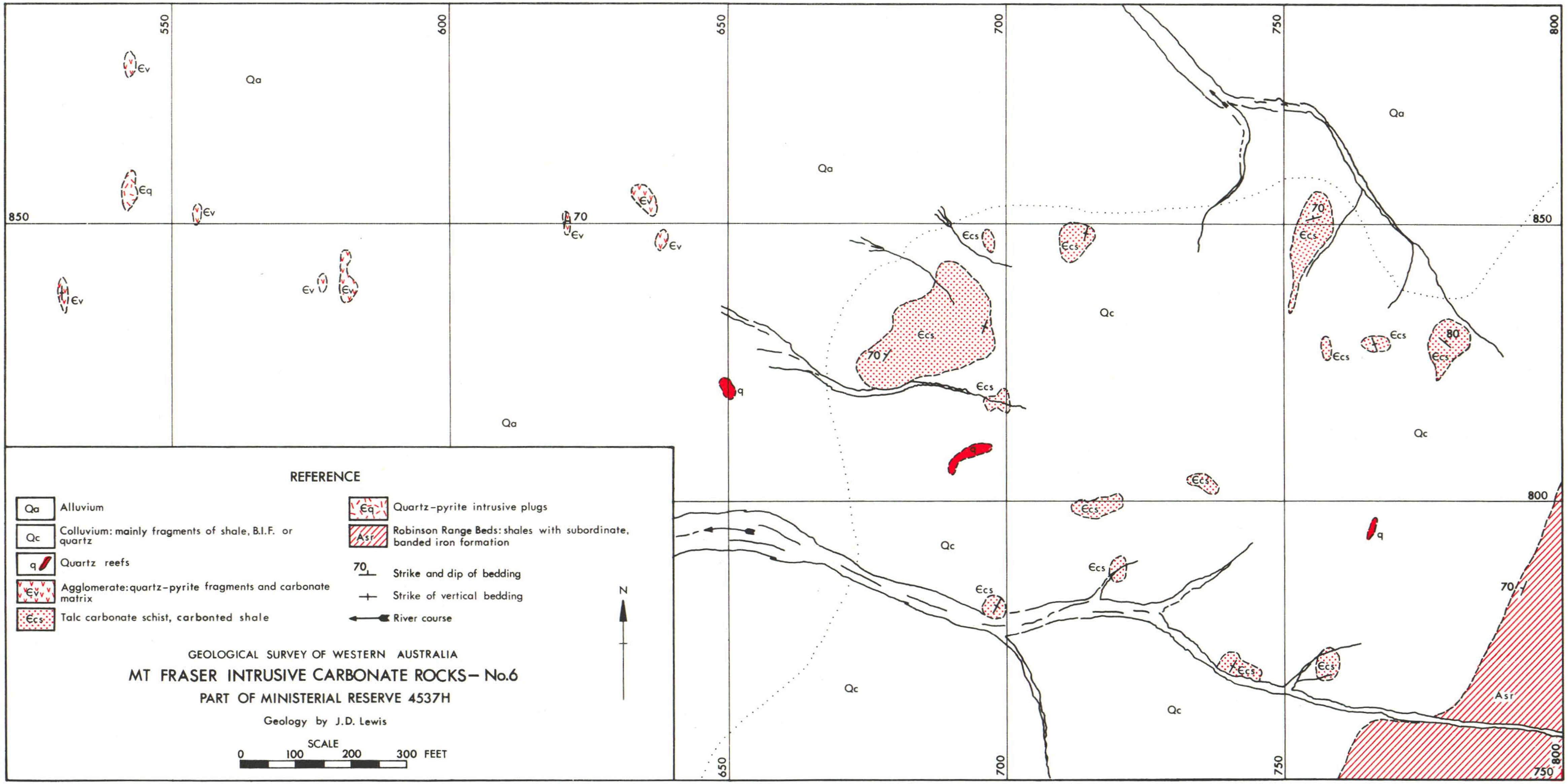

PLATE 29

12289

PLATE 30

REFERENCE

Qc	Colluvium: fragments of shale, B.I.F. and hematite.
Qk	Kankar overlying remobilised sediments.
Ac	Remobilised and carbonated sediments, showing trend lines of bedding. Thinly laminated quartzite and shale.
70	Strike and dip of bedding
+	Strike of vertical bedding
Єq	Quartz-pyrite-chloritoid intrusive plug.
Єqc	Carbonated quartz-pyrite rock.
Єqs	Silicified quartz-pyrite rock.
Єq /	Dykes and pods of quartz-pyrite-chloritoid rock.
◄	River course

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

MT FRASER

INTRUSIVE CARBONATE ROCKS—No.5

PART OF MINISTERIAL RESERVE 4537H

Geology by J.D. Lewis

SCALE

0 100 200 FEET

12290

centration of characteristic trace elements, however, all point to a carbonatitic origin for the Songwe Scarp intrusion while the lack of such features in the Mount Fraser rocks indicates otherwise.

The geochemistry of the Mount Fraser carbonates is dealt with in a separate report (Lewis and Williams, 1971), where it is shown that trace elements do not indicate a magmatic origin for the carbonate minerals.

The alternative to a magmatic origin for the carbonate is a metasomatic origin in which the carbonate is derived from some pre-existing sedimentary sequence, remobilised and emplaced into its present position. The difficulty of this explanation is to find a suitable source rock from which to remobilise the carbonate materials. The only description of the local stratigraphy is by MacLeod (1969) for the neighbouring Peak Hill area and nowhere are carbonates mentioned in a thick sequence of shales, sandstones, greywackes and banded iron formation. Low temperature emplacement of the carbonate is, however, required by the presence in No. 5 of chloritoid, which is usually a low-grade regional metamorphic mineral, but has also been found in association with hydrothermal quartz-carbonate veins (Milne, 1949) and with hydrothermal quartz vesin (Heitannen, 1951; Michot, 1954). Similarly rutile, the high-temperature polymorph of TiO_2, found in several of the carbonated dolerites and throughout the rocks of No. 5, is also associated with chloritoid (Heitannen, 1951; Michot, 1954; Simpson, 1931). Although MacLeod (1970) wished to distinguish the Mount Fraser carbonate bodies from the carbonated basic and ultramafic rocks of the Eastern Goldfields they do in fact have certain mineralogical resemblances to the rocks described by Simpson (1931) from Lake View near Kalgoorlie. In the Kalgoorlie region the carbonate metasomatism appears to be unrelated to the presence of ultramafic rock, and is clearly later than the serpentinization of these masses (Williams, in press). There appears to be a connection between carbonation and the presence of sedimentary and acid volcanic rocks but the source of the CO_2 remains unknown. It is possible that the carbonate found in the Mount Fraser area is related to a greenstone belt in the Archaean shield which underlies the area at no great depth.

Ultramafic rocks cannot be ruled out as a source of the carbonate, however, as lime metasomatism is often associated with the serpentinization of diopsidic pyroxene and the formation of rodingite dykes, as at Eulaminna in the Mount Margaret Goldfield (Miles, 1950). The carbonate rocks of the Mount Fraser area have been enriched in both Ni and Cr compared with both sedimentary limestones and carbonatites (Lewis and Williams, 1971) so that a connection between the carbonates and an unexposed ultramafic body cannot be entirely discounted. A magnetometer traverse over several of the complexes, however, does not suggest the presence of an ultramafic mass at shallow depth (Lewis and Williams, 1971).

One last possibility is that the carbonate is derived from dispersed carbonate from within the Robinson Range Beds. Although MacLeod (1969) found no carbonate horizons within the sedimentary sequence it is possible that dolomite is present as a dispersed phase throughout the sequence and has been concentrated in the core of the Mount Fraser Anticline by tectonic forces. No carbonates were found in the few thin sections of sedimentary rocks studied, but the Mount Bruce Supergroup in the Pilbara, to which the Robinson Range Beds are possibly related, does contain dolomites and dolomitic shales (Daniels, 1966). Such an origin would explain the carbonate minerals but would not account for the high nickel and chromium values found.

MODE OF EMPLACEMENT

The alignment of five of the six carbonate intrusions along the axis of the Mount Fraser Anticline points to some form of tectonic control over the emplacement of the complexes. The relationship of the folding in the Robinson Range Beds to basement structures in the area is not known, but the emplacement of a line of dolerite and quartz-pyrite intrusions which originated from the basement along the axis of an anticline in the overlying sediments seems unlikely to be fortuitous. Although the origin of the carbonate material is not known, its rise to its present position appears to be controlled, and may have been initiated by the rise of the dolerite magma. In each complex the earliest rock type has been either a plug of dolerite or quartz-pyrite rock.

The carbonate material probably rose in the form of a tenuous aqueous fluid, rich in carbonates, which was able to insinuate itself into the sedimentary shales and siltstones to give the carbonated shales of No. 2 which contain porphyroblasts of ankerite. Further reaction of the carbonate fluids with the silica of the shales has produced the talc-chlorite-carbonate rocks of No. 6. In addition the carbonate-rich fluids were able to metasomatise the dolerite and to a lesser extent the quartz-pyrite rock to produce the complex assemblage of minerals now found.

The gradual conversion of shales ultimately to talc-rich rocks was only able to operate while the pressure remained high and CO_2 remained in solution. The release of pressure, probably occasioned by fracturing of the overlying rock allowed the rapid release of CO_2 and the formation of the agglomerates found in all the complexes. Only in No. 4 does one of the intrusive bodies appear to have been the direct cause of pressure release. At the southern end of the complex, agglomerate is arranged in an arcuate fashion around a dolerite plug which itself contains brecciated zones. In the best exposed body, No. 1, pressure release appears to have been governed by weaknesses along the bedding planes of the shale, so that the agglomerate forms lenses parallel to the bedding. Formation of agglomerate in No. 1 extended over a considerable period of time as evidenced by the detailed structure of the agglomerate mass. Small lenses of shale remain, apparently undisturbed, within the agglomerate and show that the agglomerate consists of many small lenses that have coalesced. Each lens represents a separate vent with only one or two active at any given time. The fact that agglomerates containing fragments of quartz-pyrite rock are only found close to intrusions of that rock also shows that the activity was not explosive but rather a steady release of gas at high pressure. This lack of transport of the fragments indicates that each vent formed a small fluidised bed, a process now recognised to be important in the emplacement of fragmental volcanic rocks (Reynolds, 1954).

No. 5 has been emplaced by a different mechanism from the other bodies as throughout most of its area little or no trace can be found of the shales and banded iron formation which must have been present. The rocks now found appear to be a thinly laminated quartzite/shale assemblage in which the shale members have been highly carbonated. It is probable that this took place at depth and that the whole mass was then intruded in the solid state into its present position with the carbonate minerals acting as a lubricant. The formation of vents and their associated agglomerates are only a minor feature of this complex.

DISCUSSION

The Mount Fraser carbonate intrusions do not apparently correspond exactly with any described category of intrusion. The bodies contain elements similar to volcanic phenomena but also contain other features which suggest a relatively low temperature origin for the carbonate rocks. Again, the fact that the carbonate probably originated locally and that No. 5 is formed of a sedimentary sequence remobilised and emplaced in the solid, indicates an affinity with diapiric structures. Most diapiric structures involve evaporite beds, usually gypsum or halite, which under particular conditions of overburden have been remobilised and intruded into the overlying sedimentary sequence. Such salt dome structures may be initiated in several ways but usually there is no association with any igneous intrusion. In Western Australia diapirs are known from the Woolnough and Madley Hills area of the Gibson Desert (Wilson, 1967). In the Madley Hills, six small diapirs have been found along the crest of an anticline. The diapirs are considerably larger than the Mount Fraser intrusions, measuring up to 2 miles across and consist of a central core of brecciated blocks of Upper Proterozoic dolomite with a matrix of gypsum that intrudes the Permian and Jurassic sediments. In the Mount Fraser area the agglomerate is formed of locally available material and there has been little transport of material from lower strata except in No. 5.

In South Australia many diapiric structures have been recognised in the Flinders Ranges. Coats (1964) has shown that the Blinman Dome consists largely of brecciated carbonaceous and argillaceous members of the underlying Willouran Series that have been remobilised and intruded into the overlying Sturtian rocks. The diapirs are located in the cores of anticlines and are thought to have been initiated by tectonic forces. Although evaporites do not form a great part of the Willouran sequence casts of halite cubes are common in rocks of the Blinman Dome (Webb, 1961) and the presence of evaporites no doubt assisted the intrusion of the diapir. Dolerite plugs are common in the Blinman Dome but Coats (1964 p. 18) has shown that these post-date the formation of the diapir. By contrast the igneous intrusions associated with the Mount Fraser carbonates pre-date the formation of the agglomerate and appear to have initiated the rise of carbonate-rich fluids into the sedimentary strata.

Diapirs characteristically show deformation of the enclosing sediments. In both the Western Australian and South Australian examples cited the rim rocks have been upturned and in parts overturned. In the Mount Fraser complexes, however, the enclosing sediments appear to be almost undisturbed to within a few feet of the carbonate agglomerate. In No. 1 many small shale lenses within the agglomerate appear to be undisturbed, showing that the mass could not have been intruded in the solid. No. 5 however, probably was intruded as a solid mass, but the enclosing sediments are everywhere hidden under scree, so that no marginal effects can be seen.

Individual carbonate complexes in the Mount Fraser area have the characteristics of both diapiric and volcanic origin, yet they do not fit easily into either category. In summary it appears that, in response to deep seated structures, a series of quartz-dolerite and quartz-pyrite plugs were intruded into the core of the Mount Fraser Anticline and that these rocks on their passage upward collected and concentrated pre-existing carbonate-rich fluids. On nearing the surface these fluids were able to break through the sedimentary cover so releasing the gases which broke up the country rock to form the agglomerates now seen. The carbonate-rich fluids were also able to metasomatise the dolerite and the enclosing sediments.

The mode of origin and emplacement is perhaps best termed "pseudo-volcanic".

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THE PROTEROZOIC OF THE GERALDTON-NORTHAMPTON AREA

by R. Peers

ABSTRACT

The Proterozoic of the Geraldton 1 : 250,000 sheet area is confined to the southern half of the Northampton Block, and may be divided into three broad units: granulite, granite and migmatite. The granulites were formed by regional metamorphism to granulite facies of a pile of geosynclinal sediments, mainly greywackes but with some intruded gabbro sills. A later porphyritic granite was intruded into the granulites and a zone of migmatite developed along the contact. This migmatite is a product of granite intrusion and not anatexis of a pre-existing rock *in situ*. A garnet and cordierite-bearing border facies to the granite is the result of direct contamination by the invaded granulite. A narrow border of cordierite-bearing granulites adjacent to the migmatite and granite may be a reflection of original sediment composition, or a variation of metamorphic grade, but in view of its close association with the intruded granite is most likely to be the result of local metasomatic activity.

INTRODUCTION

The Proterozoic of the Geraldton-Houtman Abrolhos 1 : 250,000 sheet area (SH/50–1 and part of SH/49–4) occupies about one third of the mainland area and is confined to the southern half of the structural unit known as the Northampton Block (see Plate 31).

The Northampton Block may be divided into three broad units (Horwitz, in prep.), the granulite, the granite, and the migmatite. The granulites are of sedimentary origin with intruded gabbros and were metamorphosed to granulite facies grade by regional metamorphism. During the Middle Proterozoic they were intruded by granite with the production of migmatite along the granite-granulite contact in addition to contact effects within both the granite and the granulite.

The purpose of this investigation was to describ- the petrographic variations within the three Proteroe zoic units and to examine their mutual relationships. Accordingly, 128 specimens were collected from the area during a 6-day field excursion made by the author in August, 1970, and these form the basis of this report. Dr. R. C. Horwitz mapped the Proterozoic of the Geraldton-Houtman Abrolhos 1:250,000 Sheet area in 1968 and 1969. The geological sketch map which accompanies this report is a simplified version of the map subsequently prepared (Horwitz, in prep.).

PREVIOUS WORK

The earliest geological descriptions of the Geraldton area were by A. C. Gregory (1849), J. W. Gregory (1849), F. von Sommer (1849), and F. T. Gregory (1861), (Horwitz, in press). In 1903 A. G. Maitland carried out a systematic mapping project of the Northampton Mineral Field. He recognised various rock types among the "crystalline rocks" of the Northampton Block, including granites, garnetiferous gneisses, mica schists, quartz schist and pegmatite, noting that "it has been found quite impossible to draw any line separating these rocks . . . " (Maitland, 1903, p. 9). In a more recent publication Prider (1958) gave an account of the garnet granulites of the Galena area, which although outside the northern boundary of the sheet area is still within the Northampton Block. Finally, in 1962, Jones and Noldart published a description of the regional geology of the Northampton Mineral Field covering the four 1 inch to 1 mile (1 : 63,360) Military Edition sheets of Ajana, Hutt, Northampton and Nanson.

PETROGRAPHY OF THE GRANULITE

The granulite unit (Pm) is composed largely of garnet granulites, which represent metasediments of an original greywacke composition. About half of the specimens examined from this unit are cordierite-bearing and with one or two exceptions were collected from the eastern margin of the granulite unit, adjacent to the migmatite and granite. The granulites outside the eastern margin of the granulite unit are in general free from cordierite.

GARNET GRANULITES

The garnet granulites have a gneissic banding which is mainly a reflection of grain size variation but is in part due to a variation in the concentration of biotite and garnet. Small-scale pegmatitic layers and schlieren are common and emphasize the banding.

In hand specimen these granulites are well banded with a saccharoidal fabric. They are studded with red garnets which usually reflect the grain size of the layer in which they occur and which weather to an orange colour.

The main rock-forming minerals in order of abundance are quartz, microcline, plagioclase, garnet and biotite. Accessory minerals include zircon, apatite, pyrite, graphite, and an opaque mineral altering to sphene and leucoxene. Sometimes the texture is equigranular, but more commonly a weak foliation is indicated in the general elongation of quartz and feldspar grains and in the preferred orientation of the biotite flakes.

Quartz is abundant, forming anhedral grains with lines of two-phase inclusions and distinct strain extinction. Microcline is the predominant feldspar and occurs as anhedral grains which are fresh and well twinned. All of the microcline is microperthitic with included spindles and blebs of plagioclase. Plagioclase typically forms anhedral grains which are not well twinned and are usually sericitized. When sufficiently unaltered to be identified, the plagioclase was measured as a sodic andesine. Ragged fragments of microcline are included in a coarse antiperthite texture, and where microcline and plagioclase grains are adjacent, myrmekite is typically developed. These granulites are rich in garnet, which occurs as subhedral and anhedral grains of variable size and which is unaltered except for the development of minor muscovite along fracture planes. Most of the garnets poikiloblastically include rounded grains of quartz which in some instances are so abundant as to reduce the garnet to a skeletal grain. Biotite forms elongate flakes which parallel (and help define) the foliation. They are strongly pleochroic with X = pale yellow, Y = orange, and Z = dark reddish-brown, and include small zircon grains which are often surrounded by distinct pleochroic haloes. Accessory minerals include well rounded (relict sedimentary) zircons, rare apatite, minor fresh pyrite, graphite, and a black opaque mineral (ilmenite?) altering to leucoxene and sphene

CORDIERITE-BEARING GARNET GRANULITES

The cordierite-bearing granulites are typically coarser grained than the garnet granulites but are not as well banded although they have a distinct foliation. They do include schlieren of pegmatitic material but not in distinct bands. In general the cordierite-bearing granulites are greasy in appearance and lack the saccharoidal fabric typical of granulites. In those specimens which include abundant sillimanite it is visible in the hand specimen as bundles of white needles and rods.

Mineralogically the main distinction of the specimens in this group is that they include cordierite, although sillimanite is commonly, and spinel rarely associated.

The main rock-forming minerals are microcline, plagioclase, quartz, cordierite, garnet and biotite. Other minerals include sillimanite, spinel, pyrite, leucoxenized opaque grains and graphite.

Microcline is the predominant feldspar and occurs as fresh, anhedral grains which are well twinned and have a well developed microperthitic texture. Rounded grains of quartz are commonly included, and where plagioclase is adjacent there is commonly a development of myrmekite. Plagioclase occurs in varying amounts but is alway subordinate to the microcline. In some specimens it is present only within a narrow band of myrmekite fringing microcline grains. More generally plagioclase forms anhedral grains of mildly sericitized sodic andesine. Quartz occurs as anhedral grains with lines of two-phase inclusions and marked strain extinction.

Cordierite in these granulites is distinguished by its fresh appearance. It occurs as anhedral grains which show well developed lamellar and sector twinning and is only marginally altered to pale yellow pinite. Some of the commonly included zircons are rimmed by pleochroic haloes. The two cordierite-bearing granulites collected from the western side of the granulite unit include only a trace of cordierite, most of which is pseudomorphed by pinite.

Garnet is ubiquitous within the granulites, but concentration varies from band to band. The grains are fresh, euhedral and subhedral, and are colourless in thin section. Most of the garnets poikiloblastically include quartz grains. Biotite is abundant as elongate flakes arranged parallel to the foliation. It is strongly pleochroic with X = pale yellow, Y = orange, and Z = dark reddish-brown, and includes zircon grains rimmed by pleochroic haloes. Sillimanite occurs in all specimens of cordierite-bearing granulite examined but is well developed only in a few specimens. Without exception these are granulites adjacent to a granulite-granite contact. Where poorly developed, sillimanite occurs as bundles of very fine needles, but where well developed it forms euhedral rods arranged in bundles parallel to the foliation. In one specimen the sillimanite developed as a rim about spinel grains which are enclosed within large grains of cordierite. Spinel was noted in only four of the specimens examined and is always closely associated with sillimanite. It varies in colour from olive green to emerald green and is probably hercynite. Accessory minerals include graphite, well rounded (relict detrital) zircons, minor pyrite and black opaque grains (ilmenite?) altering to leucoxene and sphene.

PEGMATITE BANDS IN GRANULITE

A few of the pegmatite bands within the granulite were sampled. They are composed mainly of perthitic microcline with subordinate sericitized plagioclase, quartz and a trace of muscovite, Some of the pegmatites include large red garnets.

QUARTZITE BANDS IN GRANULITE

To the north of the sheet near Rocky Hill there are some feldspathic quartzites which are considered to be metasediments of a more siliceous nature than the granulites within which they are intercalated. They crop out as fine-grained, light-coloured, saccharoidal rocks, spotted white where the feldspar has been kaolinized.

The predominant mineral is quartz which forms large anhedral grains with sutured boundaries. They are crammed with two-phase inclusions and fine needles of sagenite. Microcline forms anhedral grains and is thoroughly kaolinized. The only other minerals are well rounded detrital zircons and minor muscovite.

BASIC GRANULITES

Small gabbroic sills were intruded into the upper part of the sedimentary sequence which now forms the granulite unit, and are now represented by basic granulites. The intrusion near Nabawa has an observed intrusive discordant contact (Horwitz, in press). The following is a description of a pyroxene granulite collected from that intrusion.

The megascopic appearance is of a medium-grained, greasy, brown rock in which feldspar, pyroxene and biotite are readily recognisable.

The principal minerals are plagioclase, orthopyroxene, clinopyroxene, biotite and amphibole. Plagioclase (An_{65}) forms clear, unaltered, anhedral grains which are well twinned on albite, Carlsbad and pericline laws, and enclose rare grains of quartz and calcite. Orthopyroxene (hypersthene?) forms roughly lath-shaped grains up to 3 mm long which are colourless, non-pleochroic, and show incipient alteration to red biotite. Clinopyroxene occurs in less abundance than the orthopyroxene, forming smaller, anhedral, colourless grains. Biotite forms flakes up to 2·5 mm in diameter but also occurs as an alteration product. It is strongly pleochroic with X = pale yellow, Y = orange, and Z = reddish-brown and includes rare zircons surrounded by pleochroic haloes. Ragged blades of amphibole, associated with the pyroxenes, are weakly coloured but distinctly pleochroic with X = very pale yellow, Y = Z = pale yellow.

Other minerals present include a few large, clear, grains of quartz, minor muscovite, euhedral apatite crystals, opaque grains and rutile. The opaque grains are fresh pyrite, and magnetite (?) altering to hematite. Rutile forms anhedral, golden-brown rod-shaped crystals. The texture is granoblastic.

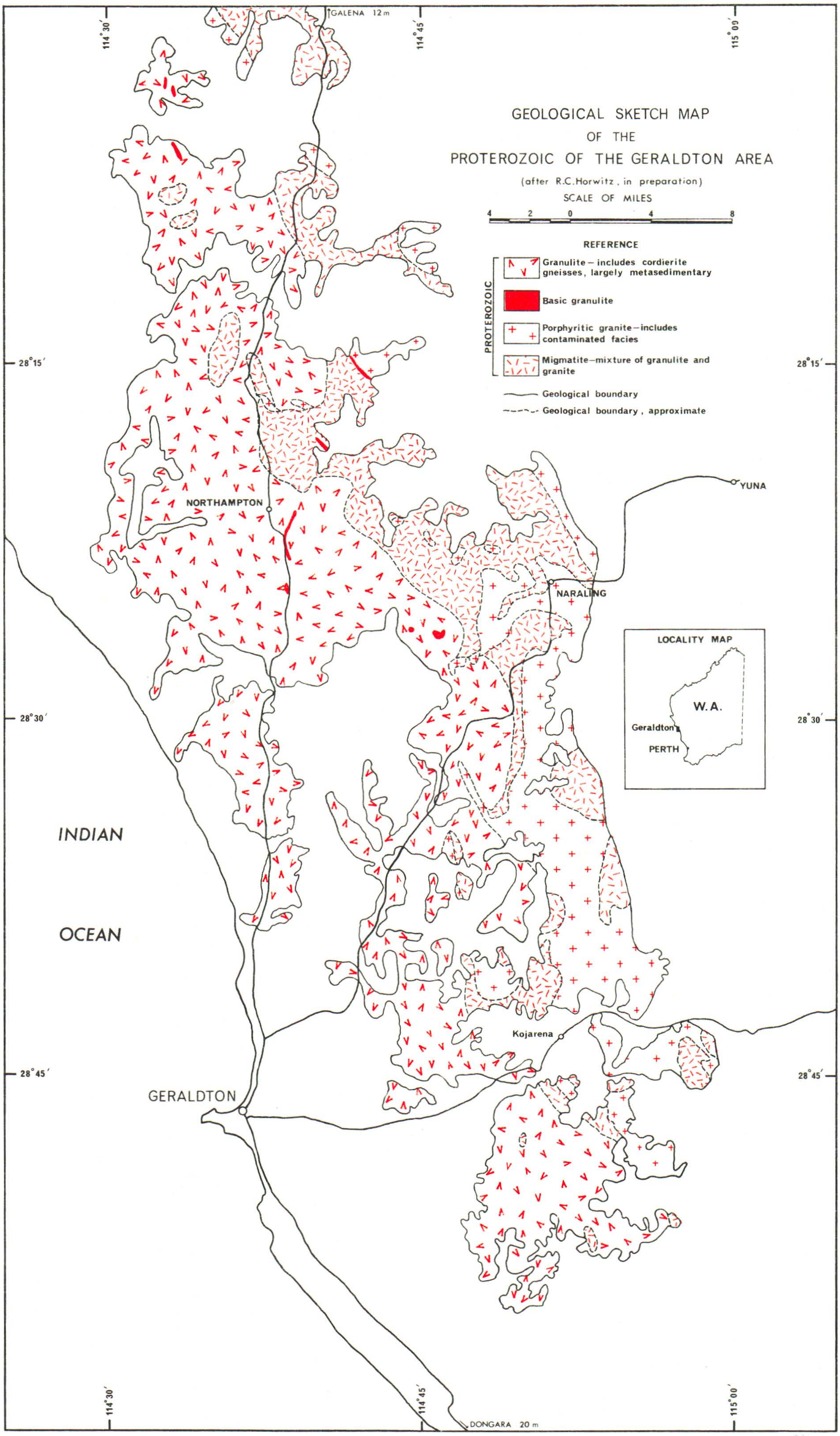
PETROGRAPHY OF THE GRANITE

The granite unit (Pg) is composed of a porphyritic granite and a border facies granite which is contaminated and is characterised by the development of garnet and/or cordierite.

PORPHYRITIC GRANITE

The uncontaminated granite is medium to coarse grained with a well developed foliation due to the alignment of tabulate, pink microcline phenocrysts. This foliation is most striking in outcrop but is less apparent in hand specimen.

The microcline phenocrysts are of variable grain size dependent upon the general grain size of the matrix, but they can be as large as 2 cm x 3 cm x 0·5 cm. They are well twinned on both albite and pericline laws giving the typical "cross-hatched" appearance of microcline, but commonly exhibit simple Carlsbad twinning as well. The margins of the phenocrysts are not sharply delineated and are sometimes rimmed by an irregular zone of myrmekite. The phenocrysts are perthitic but may also


GEOLOGICAL SKETCH MAP
OF THE
PROTEROZOIC OF THE GERALDTON AREA
(after R.C.Horwitz, in preparation)
SCALE OF MILES
4 2 0 4 8
REFERENCE
PROTEROZOIC
Granulite – includes cordierite gneisses, largely metasedimentary
Basic granulite
Porphyritic granite – includes contaminated facies
Migmatite – mixture of granulite and granite
Geological boundary
Geological boundary, approximate
LOCALITY MAP
W.A.
Geraldton
PERTH
GALENA 12 m
DONGARA 20 m
114°30′
114°45′
115°00′
28°15′
28°30′
28°45′
YUNA
NORTHAMPTON
NARALING
Kojarena
GERALDTON
INDIAN
OCEAN

include anhedral grains of quartz, plagioclase and biotite. Alteration is minimal and restricted to minor kaolinization.

In the matrix the main components are quartz, microcline, plagioclase and biotite, with minor muscovite and accessory minerals. Quartz forms anhedral grains which have in some instances recrystallized to a mosaic. Two-phase inclusions are abundant and most grains have strain extinction. The microcline of the matrix is similar to the phenocryst microcline, but lacks the Carlsbad twinning. Plagioclase (oligoclase), the subordinate feldspar, occurs as anhedral grains which are poorly twinned and lightly sericitized. Commonly large grains of microcline are included in a crude antiperthite structure. The biotite of the granite is pleochroic, usually with X = pale yellow, Y = orange, and Z = reddish-brown but rarely the biotite is more green than brown. It forms flakes which include zircon grains rimmed by pleochroic haloes, and is rarely altered to chlorite. A trace of muscovite was noted. Accessory minerals include an opaque black mineral (ilmenite?) which is sometimes altered to leucoxene, and sphene, zircon, and apatite.

Texturally the granites are porphyritic with a medium-grained matrix. In some instances there is a very fine-grained, granulated area between the large grains of quartz and feldspar, which may be due to minor local shearing.

One specimen of pegmatite was collected from the granite. It is composed of pink microcline with some quartz, and a fine-grained, intergranular mosaic of quartz, microcline and plagioclase.

CONTAMINATED GRANITES

The contaminated granites do not belong to a clearly delineated zone but appear to represent a marginal facies of the porphyritic granite. Compositionally the contaminated granites fall into two broad categories; those containing garnets and those containing cordierite (which with only one exception also include garnet).

Typically the garnet granites are medium-grained, porphyritic granites which include euhedral and subhedral garnets and are rich in biotite. Both the abundance of garnet and the grain size of the garnet vary. According to Horwitz (in press), the garnets in the contact granites are much larger than the granulite garnets. In one specimen of contaminated granite, garnets with a diameter of 1·5 cm were measured. Apart from the presence of garnet, these granites are indistinguishable from the porphyritic granites.

The cordierite-bearing granites are fine to medium-grained and are only rarely porphyritic. In most respects they are similar to the garnet-bearing granites particularly when only minor cordierite is present. The proportion of cordierite in these rocks is extremely variable. Where it has occurred in small amounts it is pseudomorphed by pinite, but where it forms a major component of the rock, alteration is not so extensive. Sillimanite is an ubiquitous accessory mineral associated with cordierite and biotite, and varies in abundance roughly in accord with the cordierite. It is typically altered to sericite, but is more resistant to alteration than the co-existing cordierite. Several specimens include grains of green spinel (hercynite?).

Three specimens of granophyre were collected from the marginal facies of the granite and are considered to be closely related to it. They are composed of finely intergrown quartz, kaolinized microcline and plagioclase, with minor pinitized cordierite, muscovite and green biotite. The occurrence of numerous small grains of green spinel and some sillimanite is characteristic of these rocks. Accessory minerals include leucoxenized opaque grains, and zircons.

PETROGRAPHY OF THE MIGMATITE

Included under this heading are the true migmatite and the marginal granite with rafted granulite. The migmatite is a mixture of the older granulite to the west of the Northampton Block (the paleosome metamorphic phase) and the younger intrusive porphyritic granite to the east of the Northampton Block (the neosome igneous phase). The contaminated border facies zone of the granite has already been described. However, I have chosen to describe the granite in which granulite blocks are rafted together with the migmatite to overcome the problem of distinguishing between the two. The contacts between the various facies of the Proterozoic units and indeed between the units themselves are gradational and highly subjective.

An additional problem when describing the migmatite is that the two phases, igneous and metamorphic, are not always easily distinguished. However an attempt has been made from the combined evidence of field observations and hand specimen appearance to separate this suite of specimens into those of granitic and those of granulitic origin. A possible mineralogical distinction is to be found in the composition of the plagioclase. When it could be identified (and this was not very often, because of extensive alteration) the plagioclase was always more sodic in the granite than in the granulite.

GRANULITE FROM MIGMATITE

In hand specimen the granulites occurring within the migmatite are indistinguishable from the granulites of the unit Pm.

The main minerals are quartz, microcline, garnet, biotite and plagioclase. Four of the 25 specimens examined include cordierite which is commonly associated with sillimanite and spinel.

Quartz is the most common mineral in these rocks. It forms anhedral grains with sutured grain boundaries and distinct strain extinction, and includes numerous two-phase inclusions and relict detrital zircons. Where the granulite has suffered minor local shearing the quartz forms a lens-shaped mosaic aligned parallel to the foliation.

Microcline microperthite is the predominant feldspar, forming anhedral, well twinned grains separated from adjacent plagioclase grains by a band of myrmekite. Alteration is limited to minor kaolinization and sericitization. Garnet is ubiquitous within the granulite but varies both in abundance and grain size. It forms anhedral and subhedral crystals which typically enclose round quartz grains in a poikiloblastic texture. Sheared garnets are lens shaped with biotite "pressure-tails". Biotite is generally abundant as flakes which are pleochroic with X = pale yellow, Y = orange, and Z = dark reddish-brown. Distinct pleochroic haloes surround included zircons. In the sheared granulites biotite emphasizes the foliation. It is rarely altered, and then to pale green chlorite. Plagioclase is invariably subordinate to microcline. It forms anhedral grains which are not always well twinned and are commonly sericitized and kaolinized. Where it could be identified it is a sodic andesine. Sometimes coarse grains of microcline are included in an antiperthitic texture. The granulites which are rich in cordierite have only a small amount of plagioclase.

Cordierite constitutes between 10 per cent and 20 per cent of the rock by volume in the cordierite bearing granulites. It is well twinned and forms anhedral and subhedral grains which are commonly altered to pinite along the margins. In one of the specimens pinite has pseudomorphed the cordierite completely. Sillimanite is commonly associated with the cordierite in needles and rods, and sometimes rims a green spinel (hercynite?).

Accessory minerals include graphite, zircons, apatite, and an opaque mineral (ilmenite?) altering to leucoxene and sphene.

GRANITE FROM MIGMATITE

In hand specimen the granite from the migmatite is similar to the granite from the unit Pg except that about half of the suite is non-porphyritic.

The predominant minerals are microcline, quartz, plagioclase and biotite. Minerals which are not always present include garnet, cordierite, sillimanite, spinel, chlorite and muscovite. Accessory minerals include zircons, apatite, epidote and an opaque mineral.

In the porphyritic granites the phenocrysts are composed of well twinned, fresh microcline often showing simple Carlsbad twinning. The microcline is microperthitic and includes round grains of quartz. Where the granite has been sheared the phenocrysts are disrupted and often marginally recrystallized. Myrmekite is common along grain boundaries.

In both the porphyritic and non-porphyritic granites microcline is the predominant feldspar. It is usually less altered than the co-existing plagioclase and forms well twinned, microperthitic, anhedral grains. Quartz forms anhedral grains which have distinct strain extinction and include numerous two-phase inclusions, zircons and very fine, acicular rutile(?). Quartz also occurs within myrmekite and poikilitically included within cordierite. Plagioclase is the subordinate feldspar and was identified (where this was possible) as oligioclase. Usually it is well twinned but sericitization commonly obliterates the twinning. Inclusions of microcline form a coarse antiperthitic texture. Biotite is the characterising mafic mineral in these granites and is usually abundant. It forms flakes, parallel to the foliation in the sheared specimens, and is pleochroic with X = pale yellow, Y = orange, and Z = dark reddish-brown. Included zircons have distinct pleochroic haloes. Some of the biotites is altering to chlorite.

With the exception of only one specimen, all of the granites include garnet which forms anhedral and subhedral grains of varying sizes. In the cordierite-bearing granites the garnet is sieved by quartz and commonly includes spinel and sillimanite. Alteration is limited to a minor development of biotite, chlorite and muscovite along fracture planes. In the sheared granites the garnet is pulled out into a granular lens.

Cordierite occurs in 6 of the 21 specimens in this suite, and in some it is a major component. It forms anhedral and euhedral grains which are fresh except for marginal pinitization. When it occurs in very small amounts it is pseudomorphed by pinite. The fresh cordierite is well twinned but a slight yellowing of the grains due to incipient pinitization provides the clue as to its identity. Rarely, included zircons are surrounded by pleochroic haloes.

Sillimanite typically occurs in association with cordierite. Minor sillimanite was noted in the sheared granites, but in the cordierite-bearing granites it occurs as well developed rods. Some of the sillimanite is intergrown with quartz, and some rims spinel. Well crystallised olive-green spinel (hercynite?) was noted in two of the cordierite-bearing granites. Accessory minerals include zircons, rare apatite and epidote, and an opaque mineral (ilmenite?) altering to leucoxene and sphene. A fresh, black opaque mineral (magnetite?) is associated with spinel.

The six cordierite-bearing granites included under "migmatite" occur with recognisable granulite so that they are not ordinary border-facies granite. These samples were collected from localities mapped as granite and I suggest that they represent granite with rafted granulite.

ASSORTED ROCKS FROM MIGMATITE

Quartzite

The quartzite specimens represent fragments of metamorphosed siliceous bands within the granulite which were caught up by the intruding granite to form migmatite.

They are composed in the main of irregular grains of quartz with sutured boundaries and distinct strain extinction. Sometimes the grain margins are recrystallized to a fine-grained mosaic. The quartz is typically crammed with two-phase inclusions, sagenite needles and rounded zircon grains. In one specimen the relict grain boundaries of well rounded, detrital quartz grains are preserved. Minerals occurring in minor quantities include red biotite with zircons rimmed by pleochroic haloes, kaolinized microcline and sericitized plagioclase. One specimen includes a trace of garnet and opaque grains replaced by sphene.

Pegmatite

Three specimens of pegmatite were collected from the migmatite unit. They are composed of large grains of pink microcline, quartz, and slightly sericitized plagioclase. One of the samples also includes large red garnets with ragged flakes of graphite, and an opaque mineral replaced by sphene. The presence of graphite indicates that this specimen was derived from the granulite unit.

Basic granulites

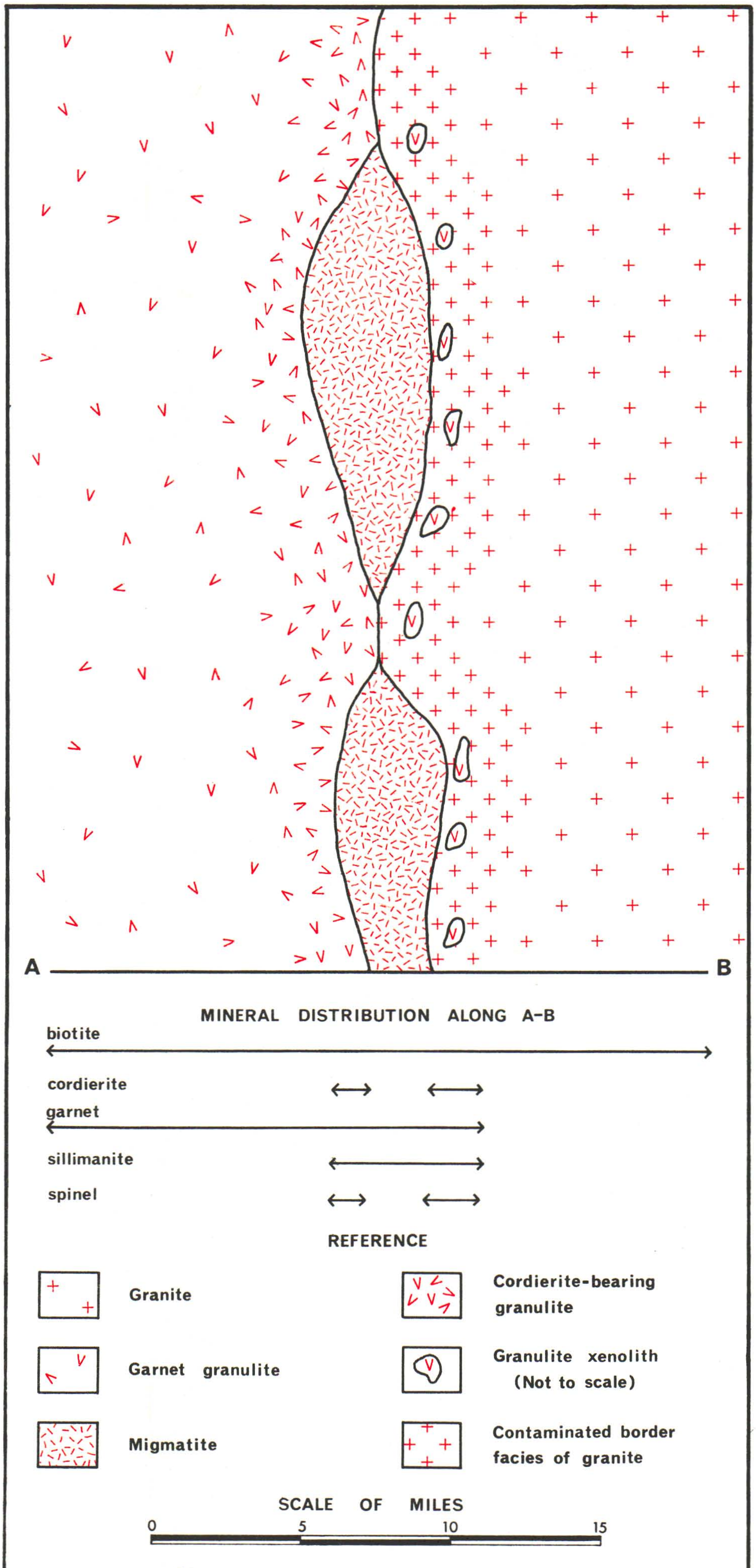
The two specimens included under this heading are both too rich in quartz to be metamorphosed gabbros and so must be interpreted as metamorphosed sediments which have been caught up in the migmatite.

The main minerals are plagioclase, clinopyroxene and quartz. Plagioclase forms well twinned, fresh, equant grains of labradorite. Quartz includes two-phase inclusions and has strain extinction. The clinopyroxene is colourless and is altering to tremolite. One specimen includes a trace of biotite and graphite(?). The other includes minor garnet, sphene and zircon and has secondary calcite developed along fractures.

DISCUSSION

Under this heading it is proposed to attempt an an explanation of the compositional variations within the three units described above, and to consider these variations as evidence for their genetic interrelationships (see Figure 5).

The granulites are the oldest rocks of the Northampton Block. They represent a pile of geosynclinal sediments of essentially greywacke conposition with intercalated siliceous bands (now quartzites), and intruded gabbroic sills (now basic granulites) which have suffered regional metamorphism to granulite facies grade. As suggested by Prider (1958) for the granulites of the Galena area, the graphite content of the granulites is a reflection of the slightly carbonaceous nature of the original sediments. The sedimentary origin of the granulites is indicated by their highly aluminous nature and the presence of layers of graphite, and relict detrital zircon grains. This is in agreement with the findings



SIMPLIFIED DIAGRAMMATIC PLAN OF THE ROCK RELATIONSHIPS IN THE PROTEROZOIC OF THE GERALDTON SHEET AREA

12299

Fig. 5

of Prider (1958), Wilson (1959) and Jones and Noldart (1962) for granulites from various parts of the Northampton Block.

The occurrence of cordierite-bearing granulites may be explained in several ways. As Mehnert (1968, p. 336) states, "the difficulty of a polygenetic interpretation of the same rock arises with many Mg-Fe-Al-rich metamorphites". These cordierite-rich rocks may represent metamorphosed sediments of the same chemical composition (probably pelitic sediments). In this case they are a response to a slightly lower grade of regional metamorphism than that which produced the garnet granulites. Alternatively they may be a product of some later metamorphic effect as an overprint on the granulite facies regional metamorphism.

Wilson (1959) considers there to be much evidence that the granulites of the Northampton Block have suffered more than one metamorphism. The co-existence of pyrope-almandine and cordierite in the granulites of greywacke composition, and the coexistence of the garnet-cordierite granulites with the hypersthene-augite-plagioclase granulites of gabbroic composition are regarded by him as evidence that the latest metamorphism was mainly thermal.

The general persistence of the cordierite-bearing granulites within a narrow band adjacent to the granite and migmatite suggests (perhaps circumstantially) a genetic relationship between the intrusion of the granite and the occurrence of cordierite. Detailed chemical data from the granulites would clarify this point but without it no definite conclusion can be drawn. However a likely possibility is that the granite was responsible at the time of intrusion for local magnesium metasomatism within the adjacent granulites. It is known that the granite was intruded as a sheet (Horwitz, in press) so the two anomalous specimens of cordierite-bearing granulite collected from localities away from the eastern margin may be related to small granite apophyses.

Layers of pegmatite and acid schlieren throughout the granulite unit are for the most part the result of local metasomatic activity, the bands having been "sweated" out of the country rock rather than intruded by an unrelated magmatic phase.

The porphyritic granite was intruded as a sheet into the granulites, with the development of a band of migmatite along the contact, and a narrow contaminated marginal facies within the granite itself. This contaminated zone is characterised by xenoliths of granulite rafted within the granite, and also by the occurrence of garnet and cordierite. With the possible exception of some granite pegmatites, cordierite is not a normal product of magmatic crystallization (Deer, Howie and Zussman, 1962, Vol. 1). Recorded accounts of cordierite-bearing igneous rocks, including granites, have without exception ascribed the cordierite to contamination by country rock such as argillaceous sediments, cordierite-bearing schists and gneisses which have enriched the magma in aluminium. The presence of garnet within the granite border facies also suggests that contamination by the intruded granulite has taken place. The production of garnets by contamination of the granite was first suggested by Horwitz (in prep.).

From both field and petrographic evidence the migmatite is a mechanical mixture of the granulite and the invading granite. In this case there is no question of the migmatite being of metasomatic origin. The absence of cordierite from the migmatite (as opposed to the granite contaminated by granulite xenoliths which were described with the migmatites) may be explained by the fact that this was an environment of tremendous stress, and therefore not conducive to cordierite formation, (Harker, 1950). The ubiquitous occurrence of almandine garnet is consistent with the migmatite being an area of high pressure.

CONCLUSIONS

The conclusions are best stated as a suggested genesis of the Northampton Block.

1. Geosynclinal sediments (carbonaceous greywackes, shales and intercalated siliceous sediments) were deposited and intruded by gabbroic sills.

2. Regional metamorphism (of which there was probably more than one episode) at granulite facies grade converted the sedimentary pile into garnet granulites with some quartzites and basic granulites. Metamorphic differentiation gave rise to pegmatite and aplite layers.

3. The granulites were intruded by granite. Formation of the granitic magma may have been concomitant with the latest regional metamorphism of the granulites, but the granite itself was not responsible for the metamorphism of the granulites. Migmatites were formed along the contact as the granite was intruded. Possible magnesium metasomatism of the marginal granulite by the granite resulted in the development of the cordierite-bearing granulites. Granulite contamination (especially the addition of aluminium) gave rise to the garnet and cordierite-bearing marginal facies of the granite.

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THE AGE OF THE GIDLEY GRANOPHYRE

by J. R. De Laeter* and A. F. Trendall

ABSTRACT

The Gidley Granophyre, which has been informally called the Dampier granophyre, is an intrusion of granophyre and associated gabbro along the basal unconformity of the Precambrian Fortescue Group. The main outcrop is in the Dampier Archipelago and adjacent mainland, between about 20° 30–45′ S and 116° 30–45′ E, with an area of about 52,000 km². Fourteen analysed samples yielded two Rb-Sr isochrons. The best interpretation of the younger isochron is argued to be 2,196± 26 m.y. The older age, of 2,612 ± 56 m.y., is thought to be unrealistic. The Gidley Granophyre is probably coeval and cogenetic with likely Fortescue Group lavas in the Yarraloola area, with a previously reported age of 2,190 ± 100 m.y., and is probably related to the Cooya Pooya Dolerite.

INTRODUCTION

This paper reports further results from a cooperative geochronological programme, initiated in 1968, between the Western Australian Institute of Technology and the Geological Survey of Western Australia (De Laeter and Trendall, 1970). The work reported is on a granophyre body intruded along the unconformity between the Archaean rocks of the Pilbara Block and the overlying rocks of the Fortescue Group, in the North West Division of the State.

ACKNOWLEDGEMENTS

Mr. W. W. Thomas and Mr. I. D. Abercrombie of the Department of Physics, Western Australian Institute of Technology, were responsible for the X-ray fluorescence analyses and the chemical work respectively.

REGIONAL GEOLOGICAL AND GEOCHRONOLOGICAL SETTING

The Pilbara Block (Plate 32) is an area of Archaean granitic metasedimentary and metavolcanic rocks, between approximate latitudes 20° and 22° S and longitudes 116° and 121° E. It has a total extent of about 20,000 square miles (52,000 km²), and its geological structure is typical of that of many Archaean shield areas, with metasedimentary and metavolcanic rocks forming steep, sinuous, synclinal "greenstone belts" separating broad domes of gneiss and granite.

To the north, the Pilbara Block is bounded by either the Indian Ocean or Phanerozoic rocks of the Canning Basin, but on its southern and eastern margins its limits are defined by the major regional unconformity at the base of the overlying Fortescue Group. This sequence, consisting mainly of basic lavas and associated pyroclastic rocks, is the lowermost of three groups which together constitute the Mount Bruce Supergroup. The Hamersley Group, which succeeds the Fortescue Group, is characterised by abundant and extensive iron formations, while the uppermost Wyloo Group contains mainly clastic sedimentary rocks, with locally important dolomite and basalt.

Although all three groups are locally folded, and the Wyloo Group is metamorphosed in the southernmost part of its outcrop, the Fortescue Group dips only gently away from the Pilbara Block at the unconformity, and is not metamorphosed in its vicinity. The resultant supposition that this unconformity represents a substantial interval of time is confirmed by the available geochronological data, which have been summarised by Compston and Arriens (1968, p. 566–7). Twelve granites from the Pilbara Block have yielded a Rb-Sr isochron of 3,050 ± 180 m.y., with acid lavas from one of the greenstone belts also between these limits. Separate minerals from a pegmatite had previously given ages of about 2,900 m.y., also by the Rb-Sr method, while De Laeter and Trendall (1970) reported an isochron age of 2,880 ± 55 m.y. for a late (post-folding) intrusive porphyry.

The age of the Fortescue Group is not well established. Compston and Arriens (1968) report 2,190 ± 100 m.y. for interbedded acid igneous rocks. These may be either lavas or sills, and, if the latter, this age is only a minimum one. However, ages of 2,000 ± 100 m.y. for the undoubtedly extrusive Woongarra Volcanics of the overlying Hamersley Group, and of 2,020 ± 165 m.y. for acid igneous rocks interstratified with the Wyloo Group, which is itself intruded by granite about 1,700 m.y. old, indicate the general credibility of 2,190 m.y. as a possible age of extrusion if the Fortescue Group rocks are lavas. Compston and Arriens (1968) conclude that the best age estimate for the lowermost Fortescue Group rocks is between 2,250 and 2,200 m.y., although the data for this estimate remain unpublished. Thus the unconformity below the Fortescue Group may represent a time gap of about 600 m.y.

THE GIDLEY GRANOPHYRE

Definition

Although it was mapped in 1962, as described below, the Gidley Granophyre was not formally named, and has been referred to as "granophyre in the Dampier Archipelago" (Kriewaldt, 1964) or informally as "Dampier granophyre" (Trendall, 1963). The following details are therefore set out for the purpose of formal definition in accordance with the requirements of the Australian Code of Stratigraphic Nomenclature (Geological Society of Australia, 1964). The name Gidley Granophyre is proposed for a stratiform intrusion of granophyre and associated quartz gabbro along the basal unconformity of the Fortescue Group over Archaean rocks of the Pilbara Block, in the Dampier Archipelago and adjacent mainland part of northwestern Western Australia. Gidley Island is an island of the archipelago (Plate 33). No type section is specified, since much of the outcrop, as represented by Kriewaldt (1964) and more generally in Plate 33 of the present paper, between the limits 20° 24′ and 20° 44′ S and 116° 26′ and 116° 53′ E, has good exposure. In its thickest part the sheet probably reaches a thickness of about 10,000 feet (3,000 m). The Gidley Granophyre is Precambrian, its exact age being the main topic of this present paper.

Outcrop, form and field relationships

The outcrop of the Gidley Granophyre falls entirely within the Dampier and Barrow Island 1 : 250,000 sheet, which was mapped in 1962 by four Geological Survey geologists (Kriewaldt, 1964). The appropriate part of this map is here reproduced, with slight modifications, as Plate 33.

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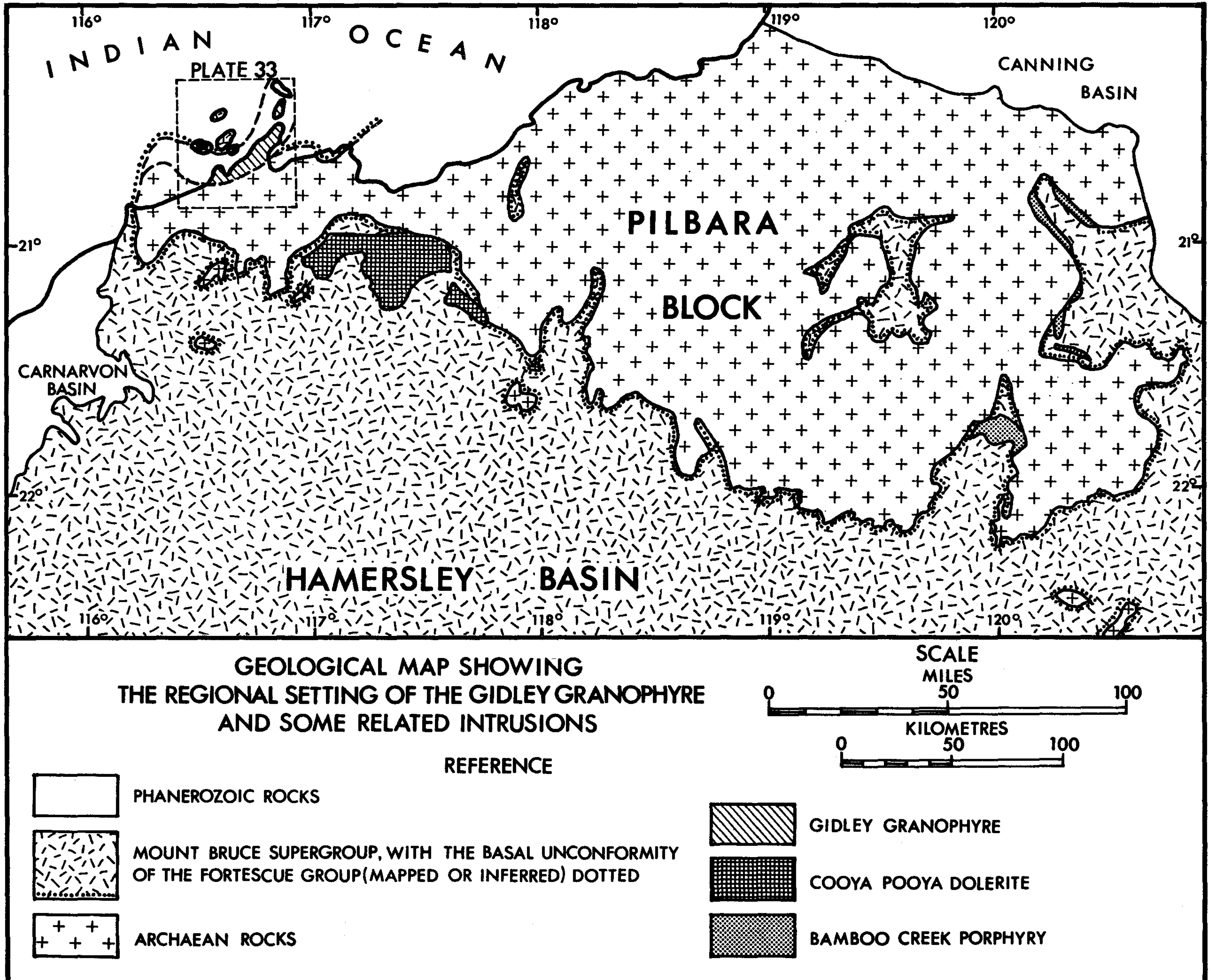
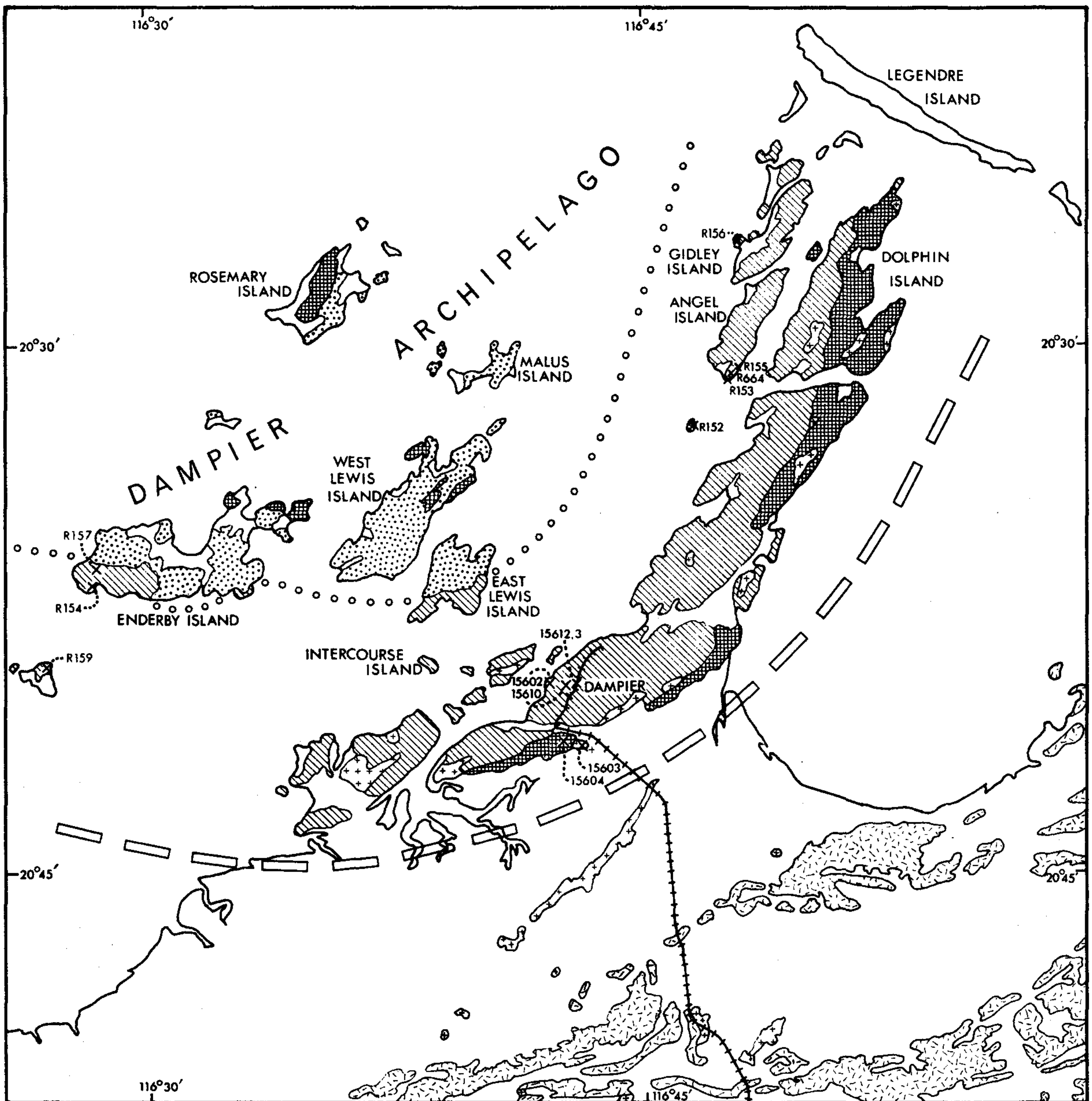


GEOLOGICAL MAP SHOWING THE REGIONAL SETTING OF THE GIDLEY GRANOPHYRE AND SOME RELATED INTRUSIONS



GEOLOGICAL MAP OF THE DAMPIER ARCHIPELAGO
(after Kriewaldt 1964)

SCALE
MILES
0 5 10
KILOMETRES
0 5 10

REFERENCE

- TERTIARY AND PLEISTOCENE COVER
- FORTESCUE GROUP – BASIC AND INTERMEDIATE LAVAS WITH SOME SEDIMENTARY ROCKS
- MIXED METASEDIMENTARY AND METAVOLCANIC ROCKS OF ARCHAEAN AGE
- ARCHAEAN GRANITIC ROCKS
- POST-ARCHAEAN INTRUSIVE GRANOPHYRE
- POST-ARCHAEAN INTRUSIVE GABBRO AND DOLERITE

(Last two: ALL PART OF THE GIDLEY GRANOPHYRE EXCEPT POSSIBLY SOME DOLERITE SILLS WITHIN THE FORTESCUE GROUP)

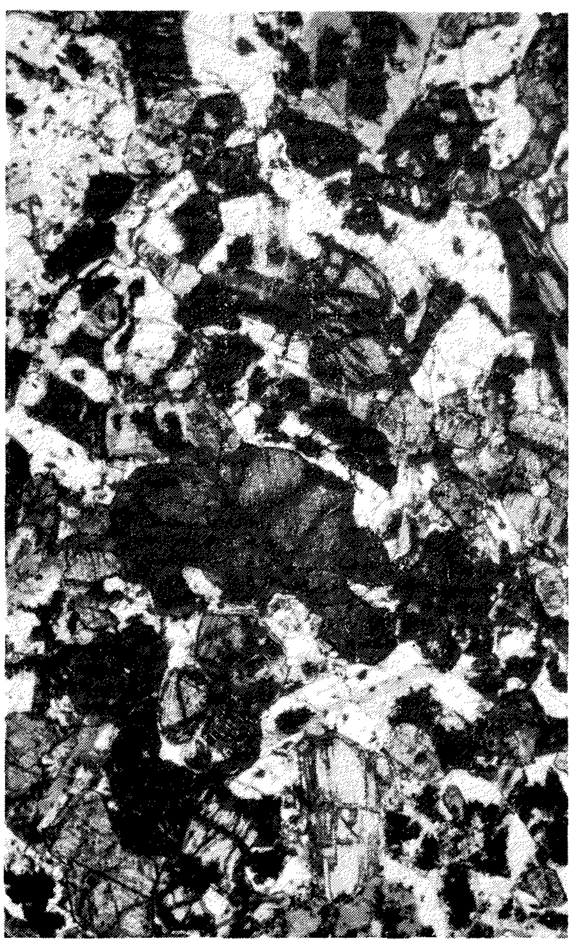
STANDARD GAUGE RAILWAY (DAMPIER TO TOM PRICE)

ASSUMED APPROXIMATE MARGINS OF THE GIDLEY GRANOPHYRE
- UPPER
- LOWER

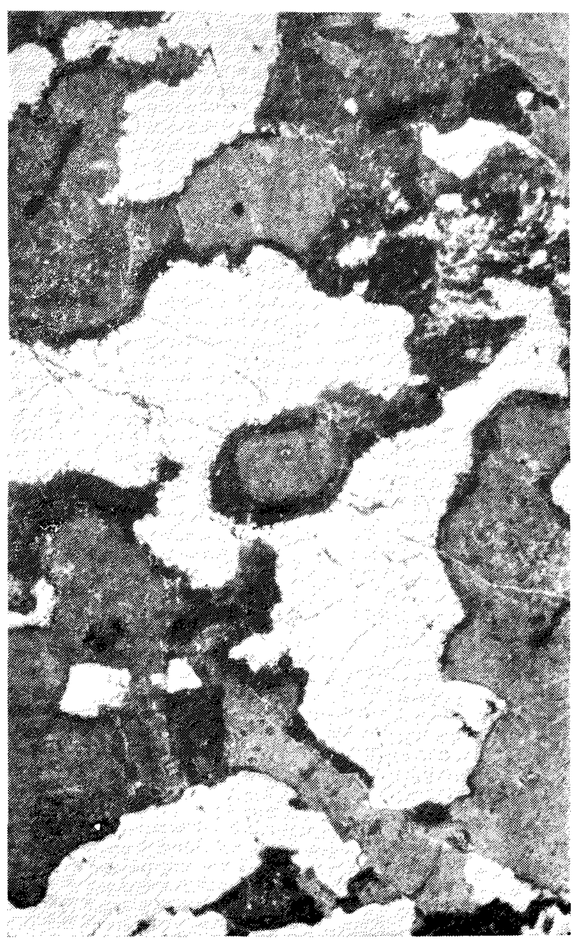
12293

A 1MM

B 1MM



C 2MM



D 2MM

Kriewaldt (1964, p. 9) summarised the field relationships of the granophyre as follows. It "is intruded at the unconformity between Archaean granitic rocks and overlying gently dipping basaltic lavas of the Proterozoic. At the top of the granophyre, metasomatised by it, are small lenses of altered arkose, basal to the lava. The marginal granophyre is light coloured. Small dykes, apparently offshoots of the granophyre, intrude the overlying basalt on Enderby Island". The relationship between the granophyre and the gabbros and dolerites of the same general area is not clear, and Kriewaldt (1964) regards some of the basic rocks as "possibly contemporaneous with the granophyres, others with the younger dolerite dykes" which cut the granophyre. These dykes are omitted from Plate 33; on the published 1 : 250,000 map they appear as two intersecting sets, with bearings of about 045° and 160°, which cut all the Precambrian rock units.

Structural information is also omitted from Plate 33. Northerly and northwesterly dips recorded from Enderby, West Lewis, Malus and East Lewis Islands lie mainly between 5° and 10°, and although the base of the granophyre is not exposed it may be assumed that it forms an open syncline with a gentle northerly plunge, as suggested by the possible lines of top and base marked on the map. In this interpretation the extensive belt of gabbro extending southward from the eastern part of Dolphin Island appears as a basal part of the intrusion.

Petrography

In hand specimen the granophyre is normally a massive, homogeneous, dark green, dark blue, purple or black rock, sometimes with a false impression of coarse granularity imparted by a patchy mottling of two contrasted colours. One local variant has red and green mottling with an apparent "grain size" of about 3 mm, to give a general purple colour.

This two-fold division corresponds to one which is normally discernible in thin section (Plate 34 A) whether or not it is macroscopically visible. In the red and green mottled rocks the green material consists mainly of an irregular intergrowth of quartz and alkali feldspar. The texture of the intergrowth is complex. It consists partly of irregular patches, about 0·1–0·2 mm across, of barely resolvable micropegmatitic intergrowth in which the individual quartz and feldspar bodies are 5–20 μ across, and partly of alternating strips of these two minerals about 10 μ wide and as long as 2 mm. The longer of such quartz strips consist of several optically distinct sections, and are interpreted as paramorphs after tridymite (Ray, 1947; Wager and others, 1953). The red material consists also of a close intergrowth of quartz and alkali feldspar, but here subhedral to euhedral feldspars, often with a tendency to skeletal growth and about 0·1–0·2 mm across, lie in an even quartz mosaic of average grain diameter about 0·5 mm. The feldspar is cloudy with dusty (possibly hematite) inclusions which are absent along the clear cleavage lines, which are thus rendered conspicuous. These two types of material are irregularly and closely intergrown, with vaguely defined intergradational margins; there is, however, a preference of that first described to have convex margins against the second, so that the latter appears interstitial to the former. This impression is heightened in some rocks by a spherulitic tendency in the first. The exact nature of the alkali feldspar involved in both types of intergrowth remains uncertain. Trendall (1963) gave reasons for regarding some as high albite, but subsequent total rock analyses suggest that such is potassic, and the vague and irregular extinction often present seems indicative that unmixing may have led to a fine-scale association of sodic and potassic feldspar.

Although the textural details of the quartz-feldspar intergrowth in these rocks vary from sample to sample, there is no indication from the material studied of any divisibility into distinctly definable textural types. One such textural detail is the occasional presence, in the cores of spherulites, of subhedral low albites up to 0·5 mm across. Other minerals present in subordinate amounts in the granophyre include small rounded opaque grains, and irregular patches of epidote, sphene and chlorite. These sometimes form aggregates, rectangular in section, suggesting derivation from an original ferromagnesian mineral. Chlorite, in some of the granophyres, also fills abundant intersecting cracks.

The gabbro sample analysed (15604) comes from the basal part of the intrusion (Plate 33) and is illustrated in Plate 34 B. Groups of subhedral, somewhat altered, clinopyroxenes up to 5 mm across, lie in a matrix consisting mainly of an aggregate of subhedral laths of andesine-labradorite generally about 1 mm long. Some orthopyroxene is also present. The cores of the plagioclase laths often have dense saussurite, and they are marginally zoned to albite. The interstices between the plagioclase laths are occupied variously by pyroxene, quartz or, most commonly, a micrographic intergrowth of quartz and albite. Irregular areas of chlorite are probably derived from the alteration of pyroxene, and a few scattered flakes of red-brown biotite are also present.

Other gabbros within the Gidley Granophyre, as defined in this paper, are more classically gabbroic in thin-section appearance. An example from Dolphin Island, shown in Plate 34 C, is noritic, with an approximately equigranular mosaic of hypersthene, augite and labradorite. Some petrographic resemblance to 15603 is, however, provided by a few interstitial pockets of quartz or of micrographic albite/quartz intergrowth.

A rock closely associated with the granophyre, and whose petrography is conveniently described here, is 15603. This rock was collected as a granite just below the gabbro (Plate 33; Plate 34 D), and was analysed in this study. It consists of a coarse (2–5 mm) anhedral mosaic with three components: clear quartz, plagioclase and potassic feldspar. The plagioclase is probably albite, and occurs in single equant grains so crowded with small sericite flakes as to make its exact determination impossible. The potassic feldspar forms smaller grains and has characteristics closely similar to the alkali feldspar of the granophyre. It is crowded with dark dusty inclusions, whose absence conspicuously defines the cleavage, and has a patchy, complex extinction. This feldspar also occurs as rims, about 0·1 mm thick, separating most contacts between quartz and plagioclase. The rock has evidently been markedly altered by the overlying intrusion.

PLATE 34 (opposite)

A R152, typical thin section appearance of the Gidley Granophyre (PPL). An area of coarser micropegmatitic intergrowth runs downwards and to the right from the centre of the photograph. The remainder of the photograph is occupied by irregular and finer grained quartz-feldspar intergrowth. A quartz paramorph after a tridymite plate appears to the upper left.

B 15605, a gabbro from about 2 miles (3.2 km) south of Dampier (crossed nicols). A twinned orthopyroxene lies at the top of the photograph. To the left of it, and also extending downwards from its lower end towards the left lower corner, are fine-grained areas of micropegmatitic intergrowth. There is white quartz along the lower edge. The dark area on the right is saussurite, white, less altered plagioclase appears to the upper left.

C R665, gabbro from Angel Island (oblique nicols). This noritic rock contains only scattered patches of micropegmatite; none are visible here.

D 15603, an altered granite (PBL). The clear quartz is cracked and rimmed by dark alkali feldspar separating it from pale grey albite. The darker grey feldspar to the lower left is entirely alkali feldspar, as is the patchy material to the upper right.

MATERIAL USED

The work reported here took place in two stages. In the first stage all samples of granophyre and associated rocks collected in 1962 during 1 : 250,000 scale mapping were assembled. Obviously weathered samples were discarded, and preliminary XRF determinations of Rb and Sr were carried out on the remainder. On the basis of these results the samples with highest and lowest Rb/Sr, and four distributed between, were analysed isotopically, in the hope that a single isochron of high quality would appear. This hope was disappointed, both initially and after analysis of two additional samples.

In the second stage, 13 further samples were collected from the vicinity of the town of Dampier, by Mr. J. G. Blockley, and were similarly dealt with. The resultant total of 14 analyses appeared to give a pattern capable of rational interpretation, presented farther below. In our judgement, a more positive result is unlikely without the addition of more extensive work than could be justified at present.

Of the 14 samples finally analysed 12 are granophyres (all numbers preceded by R, and 15602, 15610, 15612 and 15613), one a gabbro (15604) and one a contact altered granitic rock (15603). The petrography of these has already been described, and their locations appear on Plate 33.

EXPERIMENTAL PROCEDURE

Sample preparation

About 100g of each sample were reduced to —100 mesh using a jaw crusher and a Kurt Resch hammer mill. After splitting, about 10g were further ground for about 15 minutes in a Kurt Resch automatic mortar grinder.

Chemistry

An accurately weighed sample of each rock selected for analysis was placed in a teflon dish. For a 0·5g sample approximately 10 mls of 48 per cent HF and 1·5 mls of 70 per cent $HClO_4$ were required for the dissolution, the mixture finally being taken to dryness on a hotplate. The residue was then dissolved in 30 mls of 2·5N HCl and the solution taken to dryness. Approximately 10 mls of 2·5N HCl were then added and the solution transferred to a quartz ion exchange column containing 20g of wet Dowex 50W-X8, 200–400 mesh cation exchange resin. Strontium was eluted using 2·5N HCl, the cut being taken between 40 mls and 50 mls. The eluted sample was taken to dryness, redissolved in a minimum of 2·5N HCl, and placed on a micro column containing 1g of cation resin. The strontium was then eluted as before and the eluant taken to dryness ready for mass spectrometric analysis.

Mass spectrometry

Isotopic analyses were carried out on a 12-inch radius, 90° magnetic sector, solid source mass spectrometer. The source and collector slits were set to 0·004 in. and 0·020 in. respectively to provide a resolution of approximately 400. The sample was mounted as the chloride on the side filament of a conventional triple filament surface ionization source. Rhenium filaments, which were outgassed prior to use, were employed throughout. No evidence of rubidium or strontium contamination from the filaments or ion source could be detected. New filament buttons were used for each sample and the source was cleaned between successive analyses.

The usual operating currents for strontium, loaded as the chloride, are 4·0 amps for the centre ionising filament, and approximately 1·0 amps for the side filaments. For rubidium chloride, slightly lower currents were used. For a strontium analysis the filament currents were initially adjusted to a value where strontium emission was minimal. These conditions were retained for about 1 hour to enable the alkali beam, which was invariably present, to be reduced to a level where it no longer had a serious suppressing effect on the production of strontium ions. After the rubidium beam was reduced to a negligible size, the side filament temperature was gradually increased until an Sr^{88} ion beam of the order of 10^{-12} amps was obtained. For a r μg sample this beam could be maintained over several hours of operation without a marked decrease in intensity.

An electron multiplier with a gain of about 10^4 was used as the ion detector. The resulting signals were amplified in a vibrating reed electrometer with a 10° 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 calibrated for scale factors, linearity and speed of response.

The isotopic peaks were scanned from the lowest mass to the highest mass and then back again, this operation constituting one sweep. Ten sweeps usually comprised a mass spectrometer "run". The sweep speed was adjusted so that at least 5 counts of 1 second each were recorded across the top of each peak, whilst a minimum of time was spent on the baseline between the peaks. The computer was programmed to select a number representative of the height of each peak immediately after sweeping through the peak. This information was then stored in memory until the mass spectrometer run was finished, after which a complete statistical analysis of the isotopic ratios was carried out. The final results could thus be presented at a teletype, situated in the mass spectrometer laboratory, within a minute of the end of run.

Sr isotope ratios were also measured for unspiked Sr extractions. The mass range 84 to 88 was scanned on a sensitive scale during the analysis in order to detect the presence of any Rb at mass 85. The isobaric contribution of Rb^{87} to the Sr^{87} ion beam was always less than 0·01 per cent.

Replicate analyses of M.I.T. standard strontium carbonate were made over a period of time to give a mean value of Sr^{88}/Sr^{86} of 8·2850 rather than 8·3752 as determined by other authors (Faure and Hurley, 1963). The difference is largely due to the influence of electron multiplier-induced mass discrimination. After correcting the measured Sr^{88}/Sr^{86} ratio to 8·3752, the actual value found for the M.I.T. standard Sr^{87}/Sr^{86} ratio was 0·70. The Sr^{87}/Sr^{86} ratios contained in Table 1 have likewise been normalised to Sr^{88}/Sr^{86} equal to 8·3752.

X-ray Fluorescence

This technique 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 for the Rb-Sr analyses. Finely ground samples (–200 mesh) were pressed with a boric acid backing and were then in a form suitable for X-ray fluorescence analysis.

Rubidium was read at a 2 θ position of 26·56° and strontium at a 2 θ position of 25·09°. Before selecting the background positions, consideration was given to possible interference effects, and the profile of the background in the vicinity of the RbKa and SrKa peaks was carefully observed. The most satisfactory background positions for this spectrometer were found to be at 2 θ positions of 27·06° and 25·81° for rubidium and 25·59° and 24·59° for strontium.

A preset count of 2 x 10^5 was used for each position and a dead-time correction was then made. Each sample was measured a number of times depending on the concentrations of rubidium and strontium in the particular sample.

A conversion factor from intensity to weight ratios was determined by analysing a number of standard rocks, with a wide range in Rb-Sr ratio, in which the concentration of rubidium and strontium was accurately known.

The values of the concentration of rubidium and strontium in the standard rocks were determined by isotope dilution as discussed by De Laeter and Abercrombie (1970), and these values have been used in determining the calibration curve for X-ray fluorescence.

This calibration curve allowed for matrix effects and the variable fluorescent response between rubidium and strontium. Machine drift during an analysis was obviated by analysing a reference sample between each run. In addition an appropriate standard rock was analysed with each suite of samples.

Isotope dilution

The Rb/Sr ratios of three of the samples listed in Table 1 were also determined by isotope dilution. This enables a minor adjustment to the X-ray fluorescence values to be made, if necessary, for differences in matrix between the standard rocks and the samples representing the Gidley Granophyre. However the results were identical within experimental error and thus no adjustment was made.

Weighed quantities of Rb^{87} and Sr^{84} spikes were added to the rock samples prior to dissolution. Each sample was dissolved as discussed above in a HF-$HClO_4$ mixture, and the rubidium and strontium separated by cation exchange chemistry. Blank determinations showed that the Rb and Sr contamination introduced by the chemical processing was less than 10^{-8}g and 10^{-7}g respectively. Full details of the isotope dilution technique used in this laboratory are given by De Laeter and Abercrombie (1970).

RESULTS

The measured Rb/Sr and Sr^{87}/Sr^{86} ratios, as well as the Rb^{87}/Sr^{86} ratios calculated from these, are given at the 95 per cent confidence level, in Table 1, for each of the 14 samples analysed. Ages which may be computed from selected groups of these samples are discussed in the following section. All computations employ the method of Williamson (1968), which minimises the weighted sum of squared residuals. All age calculations are based on a Rb^{87} decay constant of 1·39 x 10^{-11} year^{-1}. The errors associated with the age and initial Sr^{87}/Sr^{86} ratio (R_i) are calculated from the standard deviation of the slope and intercept respectively.

TABLE 1. ANALYTICAL DATA FOR SAMPLES OF THE GIDLEY GRANOPHYRE

Sample	Rb/Sr	Rb^{87}/Sr^{86}	Sr^{87}/Sr^{86}
R 152	5·67	17·30 ± 0·24	1·2760 ± 0·0023
R 153	2·77	8·25 ± 0·08	1·0275 ± 0·0020
R 154	3·24	9·64 ± 0·10	1·0226 ± 0·0007
R 155	2·12	6·27 ± 0·06	0·9615 ± 0·0025
R 156	2·57	7·64 ± 0·09	1·0100 ± 0·0023
R 157	1·47	4·32 ± 0·04	0·8848 ± 0·0006
R 159	5·49	16·66 ± 0·22	1·2295 ± 0·0010
R 664	0·17	0·49 ± 0·006	0·7171 ± 0·0005
15602	5·328 (5·237)*	15·97 ± 0·32	1·1878 ± 0·0025
15603	1·011	2·95 ± 0·06	0·8053 ± 0·0010
15604	0·322 (0·320)	0·93 ± 0·018	0·7391 ± 0·0009
15610	2·984 (2·969)	8·83 ± 0·18	0·9867 ± 0·0018
15612	4·773	14·36 ± 0·28	1·1360 ± 0·0024
15613	2·024	5·96 ± 0·12	0·9078 ± 0·0012

* Values in parenthesis were determined by isotope dilution; all others in this column by X-ray fluorescence.

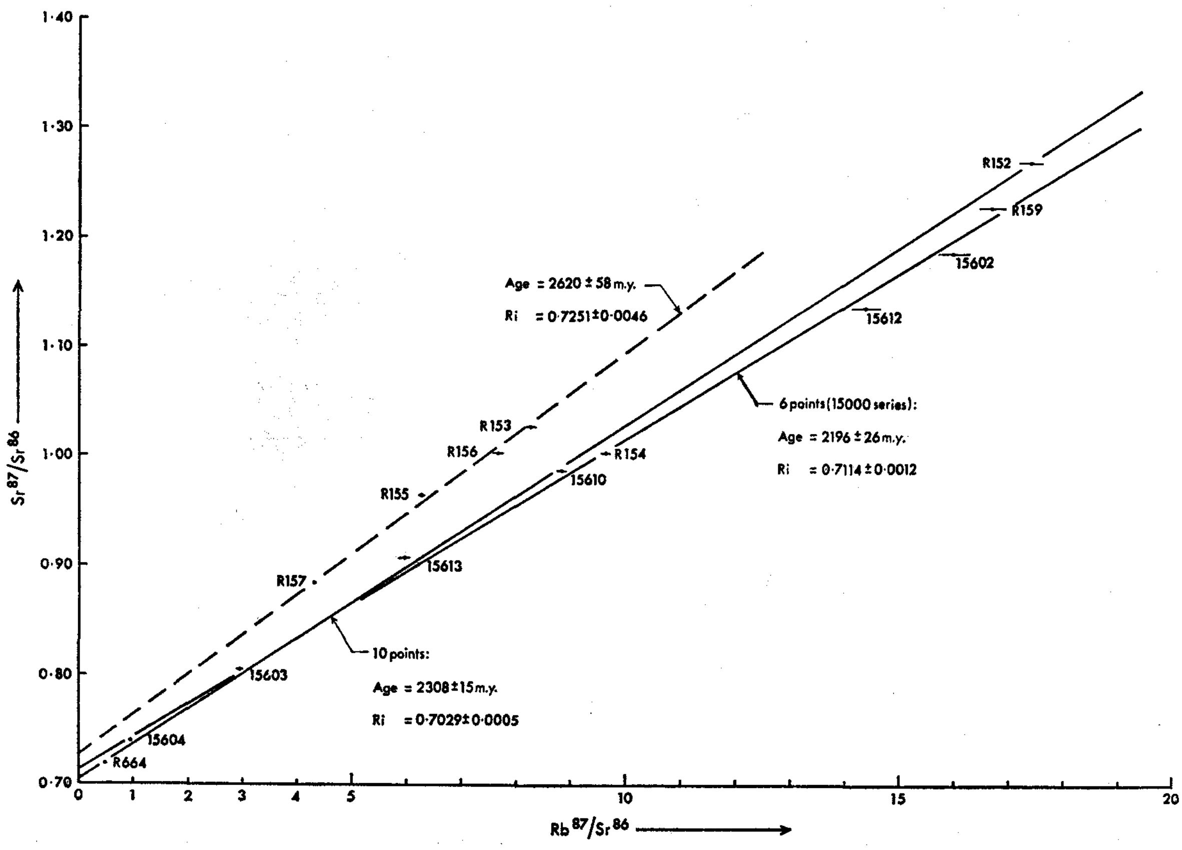


Fig. 6 Isochron plot of the 14 analysed samples. See text for discussion 12300

DISCUSSION

The data of Table 1 are plotted in Figure 6. Inspection indicates an apparent distribution along two possible isochrons, an older one defined by R153, R155, R156, and R157, and a younger one defined by the remaining rocks. The validity and significance of each can be discussed separately.

There are 10 points on the possible younger isochron, and a computation of these gives an age of 2,307 ± 15 m.y., with an R_i of 0·7032± 0·0005. This isochron appears on Figure 6. However, 7 of the 10 defining points depart from it by greater than experimental error, and it is likely both that "geological effects" control the positions of at least some of these rocks, which require explanation, and also that the computed age may be a spurious one.

Subsequent discussion of this rather poor isochron is conveniently carried out in three stages, represented by the following three questions:

1. What are the upper and lower age limits which could be defined by selective exclusion of points, and are there rational grounds for such selection?

2. What apparent limits to the age are set by data already available, combined where necessary with geological interpretation?

3. Is there a hypothesis which inter-relates more geological and geochronological data, both new and previously reported more satisfactorily than any other?

An isochron defined by six of the samples from the immediate vicinity of Dampier (2,196 ± 26 m.y. with R^i 0·7114 ± 0·0012) is also shown on Figure 6. It is clear, without computation, that extreme limits of approximately 2,150 and 2,350 m.y. may be obtainable by exclusion of chosen points. There are, however, no clear grounds for any exclusion. Only 15603 and 15604 are petrographically distinct types, and their exclusion would probably not improve the statistical reliability of any resultant isochron obtained from the remaining rocks, all of which are petrographically uniform granophyre. Possible exclusions on other grounds than petrographic dissimilarity are discussed farther below.

We may now consider the second of the enumerated questions. Although the intrusive status of granophyre has been questioned (Holmes, 1960) there seems little doubt, from Kriewaldt's (1964) descriptions, that the Gidley Granophyre originated by the injection of magma, whatever the origin of this. To be consistent with available data the granophyre must therefore be younger than the lowermost part of the Fortescue Group.

Exactly how much younger it might be is speculative, on two counts. Firstly, the thickness of Fortescue Group cover at the time of intrusion is not known. Kriewaldt (1964, p. 8) gives the thickness of this group in the Dampier Archipelago as 4,000 feet (1,200 m), increasing to 7,000 feet (2,100 m) at Cape Preston, where the Fortescue Group crosses the mainland coast about 40 miles (64 km) to the west. Granophyric textures are assumed to relate to the fairly rapid cooling of the magma, and high-level intrusion is therefore a preferred hypothesis, but there is little published information on which to set a depth limit; Davies (1959, p. 212) has estimated a roof thickness of 1,700–2,000 feet (510–610 m) for a thinner granophyre sill in Wales, 1,600–2,000 feet (480–610 m) thick.

Secondly, even if the depth of intrusion were known, the time interval represented by, say, 2,000 feet (610 m) of Fortescue Group lava is also unknown. Trendall and Blockley (1970, p. 298) have suggested, with several qualifications, possible limits of 2,000 and 6,000 years per foot for the subsidence rate of the Hamersley Basin, in which the Fortescue Group accumulated. If the general order of these speculative estimates is correct then 10 m.y. may have been more than adequate for the extrusion of a sufficient thickness of Fortescue Group lavas to provide cover for the intrusion of the Gidley Granophyre.

On the other hand, the lowermost few thousand feet of the Fortescue Group *may* have taken several hundreds of millions of years to accumulate, and the lowest feasible limit of basal Fortescue Group age is an age younger than the latest igneous event in the Pilbara Block, by the time necessary for erosion to set the scene for Fortescue Group deposition. This period can only be guessed at, but in round terms, 80 m.y. after the age of the Copper Hills Porphyry would give a maximum possible age of 2,800 m.y.

There is, however, an available argument which makes the age of the Fortescue Group irrelevant. The material for Compston and Arriens' (1968) age of 2,190 ± 100 m.y. for acid igneous rocks of the group came from the Nallanaring Volcanic Member of the Jeerinah Formation in the Yarraloola 1 : 250,000 sheet area (Williams, 1968: approximate locality 20° 30′ S, 116° 15′ E), and lie the same order of thickness above the base of the group as is likely to have covered the Gidley Granophyre at the time of intrusion. Whatever estimate for rate of Fortescue Group accumulation is used in the one case must clearly also be used in the other, so that from existing data 2,190 ± 100 becomes a likely older limit for the Gidley Granophyre regardless of the basal age of the Fortescue Group. On the other hand there is no useful younger age limit for the granophyre from existing data, since the transecting basic dykes have not been dated.

Thus, in this discussion so far, we have for the Gidley Granophyre a youngest possible isochron limit of about 2,150 m.y. by irrational discarding of inconvenient points, and an argued older limit of 2,190 ± 100 from existing data. It remains to consider the third question, and to propose a hypothesis which is both geologically and isotopically plausible, and which takes into account the widest possible range of information.

For the genesis of the Gidley Granophyre two extreme hypotheses are available: either it is a differentiate from basic magma during this period, or it results from the regeneration of older crustal material. In the first case a simple isochron with a low R_i would be expected, and in the latter, assuming that "regeneration" produced isotopic uniformity, a simple isochron with a high R_i. These two isochrons are represented diagrammatically by A and D in Figure 7.

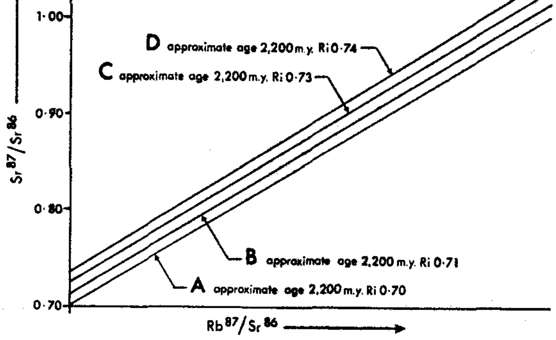


Fig. 7 Diagram illustrating arguments put forward in the discussion

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Since the results are more complex it may be examined whether the complexity is explicable in terms of a combination of the two extremes. Suppose the Gidley Granophyre to have been generated primarily by direct differentiation of mantle-derived material, and secondarily by concurrent digestion of older crust; and suppose that the proportion of digested material in the magma varied slightly in different parts. Such a situation would result in the potential local existence now of a family of parallel isochrons intermediate between A and D of Figure 7, of which two, B and C, are there represented. In such a situation, a very large number of Gidley Granophyre samples would be expected to define a broad "isochronal zone", having A and D as limits.

But suppose now that the *minimum* contamination with older crust is in fact close to B, and take into account the fact that the granophyre appears largely to have digested the underlying *granitic* rocks. In this situation, the more digested material in the magma, the higher the total Rb/Sr ratio may be expected to become, so that, with random sampling, while isochron B may appear in practice, only the upper (right-hand) parts of the higher parallel isochrons (C and D) may appear. In this situation the "real" isochron, B, may become steepened by the inadmissible inclusion of points from higher isochrons, with complementary depression of the ordinate intercept, or R_i.

We suggest that such may be the origin of the difference between the two plotted isochrons of Figure 6, and that the data of that Figure may incorporate a real isochron represented by the six points provided by the samples close to Dampier. It can now be examined whether any other geochronological or geological evidence supports this. Taking the latter first there are indications that at least some differentiation has taken place: there exists a basal gabbro layer whose petrographic affinity with the granophyre argues against its separate intrusion in that position as a later (or earlier) unrelated body. The ratio of granophyre to gabbro (possibly about 3 : 1), and the comparatively clear dichotomy between these two components of the intrusion, do indicate, however, that differentiation could not have occurred entirely in place.

A possible solution to this point may lie in the Cooya Pooya Dolerite, whose position is shown in Plate 32. Both this dolerite and the Gidley Granophyre may be the remaining north and south parts of a major intrusion in the crest of the gentle anticlinal arch whose axis follows the east-west trend of the Archaean outcrop now lying between. This extensive, mainly basic sheet was intruded at or close above the basal Fortescue Group unconformity in the Yarraloola and Pyramid 1 : 250,000 sheet areas (Williams, 1968; Kriewaldt and Ryan, 1967).

Until further data become available we therefore suggest that:

1. The age of 2,196 ± 26 m.y. derived from the six samples close to Dampier is probably the most acceptable present estimate for the age of the Gidley Granophyre.

2. The acceptance of this figure involves a preferred hypothesis that the granophyre originated by the differentiation of acid magma from mantle material at about this time, and that variable digestion of older granitic crust took place at some stage before emplacement.

3. Emplacement may have taken place in more than one stage, with continuing differentiation.

4. The Gidley Granophyre is probably both coeval and cogenetic with the stratiform acid rock within the Fortescue Group from which Compston and Arriens' (1968) age of 2,190 ± 100 m.y. was derived.

We have no ready explanation for the older (2,612 ± 56 m.y.) isochron of Figure 6. The four defining rocks (R153, R155, 6, 7) are not locally grouped, but are petrographically similar, and the isochron cannot be invalidated on petrographic grounds. A common feature of all four samples of possible significance, is that they lie near the top of the intrusion. At present, we prefer to regard these samples as a group properly belonging to 2,196 m.y. isochrons of even higher R_i than D of Figure 7, which accidentally define a meaningless age; the problem requires further work for its final elucidation.

Further work on both the Cooya Pooya Dolerite and Gidley Granophyre would be useful to consolidate and extend the results here reported. It could advantageously include analyses of the Bamboo Creek Porphyry, which was intruded at the same stratigraphic position at the other extremity of the main northern unconformity of the Fortescue Group; it is shown on Plate 32.

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AGES OF GRANITIC ROCKS IN THE POONA-DALGARANGA AREA OF THE YILGARN BLOCK, WESTERN AUSTRALIA[1]

by P. C. Muhling[2] and J. R. de Laeter[3]

ABSTRACT

The ages of granitic rocks in the area bounded by longitude 117° and 118° E and latitude 27° and 28° S have been determined using the total -rock Rb-Sr method. Ages indicated are 2,590 ± 23 m.y. for a large granitic complex about 72 miles long and 36 miles wide, in the Poona-Dalgaranga area, and 2,605 ± 51 m.y. for several disconnected granitic masses on the eastern edge of the complex. The granites of this area have about the same age and initial Sr^{87}/Sr^{86} ratio as those of the Kalgoorlie area.

INTRODUCTION

This is the second report resulting from a programme of Rb-Sr isotope geochronology on the Precambrian of Western Australia which was initiated in 1968 jointly by the Western Australian Institute of Technology and the Geological Survey of Western Australia (de Laeter and Trendall, 1970).

ACKNOWLEDGEMENTS

Mr. W. W. Thomas and Mr. I. D. Abercrombie, of the Western Australian Institute of Technology, were responsible for the X-ray fluorescence analyses and the chemical work respectively. The Director of the Geological Survey of Western Australia gave permission to publish this work.

GEOLOGY

Regional environment

The Yilgarn Block (Prider, 1965; Daniels and Horwitz, 1969) has a roughly rectangular shape with irregular northern and eastern boundaries and is the largest area of Archaean rocks in Australia. It is located between latitudes 25° to 34° S and between longitudes 117° to 125° E. The west side of the Block is faulted against the Phanerozoic sediments of the Perth and Carnarvon Basins and is bounded on the northwest side by the Gascoyne Mobile Belt (Daniels and Horwitz, 1969) and on the southern and southeastern sides by the Albany-Fraser Province (Daniels and Horwitz, 1969). The northern and northeastern edges are bounded by unconformities with younger Precambrian sediments of the Bangemall Basin (Daniels and Horwitz, 1969) and with Phanerozoic sediments of the Officer Basin.

The Yilgarn Block comprises elongate remnants of folded, metamorphosed volcanic and sedimentary rocks embayed and distorted by intrusive granitic rocks. Most of these areas of metamorphic rocks trend northwesterly, although some in the northwest corner of the Yilgarn Block trend north-east.

The granitic rocks include gneissose and migmatitic types, broadly conformable with the structures of the metamorphic rocks, and discordant types with primary flow structures or massive texture.

Cue Granites

A feature of the northwest corner of the Yilgarn Block is a batholith of granitic rocks, first described by Johnson (1950). Recent mapping (Muhling, 1969; Baxter, in prep.) has enabled sub-division of much of this batholith. The Poona-Dalgaranga area (Figure 8) is part of the western half of the Cue 1 : 250,000 sheet area (SG/50-15) and is enclosed between latitudes 27° 00′ to 28° 00′ S and longitudes 117° 00′ to 117° 45′ E. It includes the eastern part of the batholith defined by Johnson.

The area consists of disconnected areas of rocks metamorphosed to the greenshist facies, folded about axes trending between north and east-northeast and concordantly intruded by intensely foliated granodiorites and adamellites, which in turn have been intruded discordantly by later adamellites and granites.

For the purposes of the age determinations, the granitic rocks were divided simply into "inner granites" (i.e. border facies and internal facies, groups 1 and 2) and "outer granites" (group 3).

Previous age estimates

The only age determinations available for this part of the Archaean of the Yilgarn Block are reported by Compston and Arriens (1968). They indicate ages of 2,615 ± 40 m.y. for granite and 2,920 ± 220 m.y. for the granitic gneiss which it intrudes in the Koolanooka Hills; these are about 100 miles southwest from the Poona-Dalgaranga area. Although no ages had been determined for granitic rocks in the Cue Sheet area, it was thought that possibly the younger granites could have been about the same age as the granite at Koolanooka Hills.

MATERIAL USED

Sampling

The Cue 1 : 250,000 sheet was the only area in the Murchison Goldfield mapped by the Geological Survey in the current mapping programme, by the end of 1968. The radiometric age project was to determine separately the ages of the different textural units of the granitic rocks and thus derive both the ages of the rocks and some clue to the source of magma.

Weathering poses sampling problems in the area and among the granitic rocks few specimens could be collected fresh enough for age determination. Sixteen samples were submitted to check their chemical suitability and to provide a guide for further sampling. Ten samples were selected finally and their locations are shown in Figure 8.

Petrography

All the rocks contain quartz, plagioclase (ranging in composition from albite to andesine) and microcline (often perthitic). The mafic mineral is biotite. Textures range from porphyritic to medium grained with one rock being fine grained. The texture of the even-grained varieties, or in the groundmass of the porphyritic rocks, is allotriomorphic granular.

The "outer granites" (group 3) consist of four granodiorites and one trondhjemite. They have a distinct foliation shown by aligned flakes of biotite and c-axes of quartz and feldspar grains. Evidence of strain indicated by bent and fractured twin planes is present in some grains. Accessory minerals are present in greater quantities than in the "inner" granitic rocks, though the constituent minerals are about the same for both groups (magnetite, apatite, zircon, sphene, allanite and epidote).

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[1] This paper was presented at the Geological Society of Australia Symposium on the Archaean Rocks, held in Perth in May 1970, and is therefore also published in an abridged form in Special Publication No. 3 of the Society.

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[3] Physics Department, Western Australian Institute of Technology.

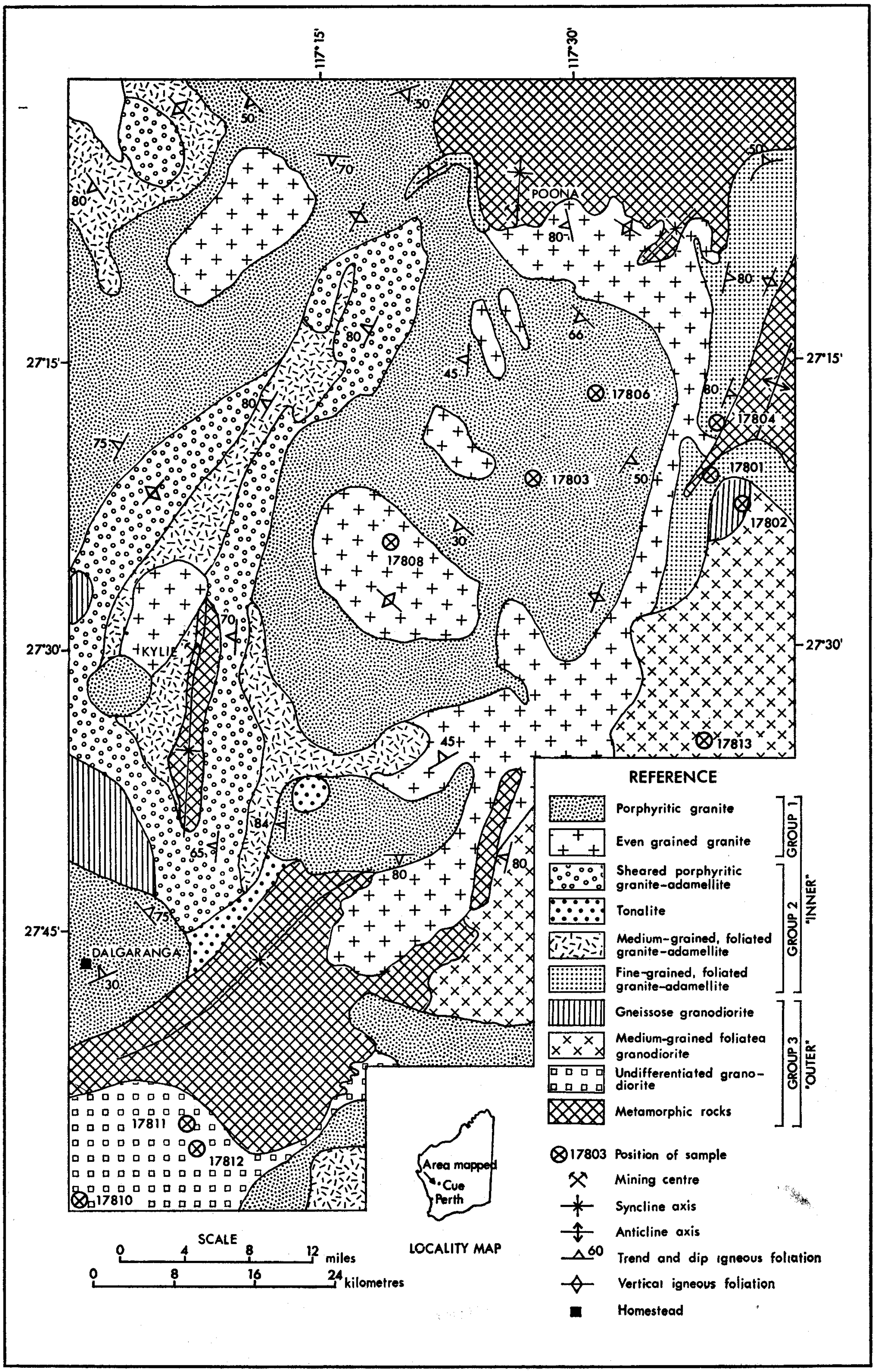

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Fig. 8 Geological map of the Poona-Dalgaranga area

The "inner" granitic rocks (from the internal and border facies rocks) are granites or adamellites in which foliation is poor or absent and much of the biotite is altered to chlorite. Microcline has tended to include or replace earlier minerals, rather than lie interstitial to them, as in the first group. The porphyritic granite of specimen 17803 is unusually rich in potassium feldspar compared with the other granites.

A summary of the petrographic characteristics of these rocks is set out in Table 1 and the modes are shown in Table 2.

TABLE 1. SUMMARY OF CHARACTERISTICS OF TYPES OF GRANITIC ROCKS ON THE CUE 1 : 250,000 SHEET AREA

Groups and Subdivisions			Summary of Characteristics
"INNER"	INTERNAL FACIES OR GROUP 1	Porphyritic granite	Pale pink, medium to coarse-grained granite with phenocrysts ½ to 5 inches long. A platy flow foliation parallels contacts with other rocks. Intrusive into medium-grained granite
		Medium-grained granite	Some porphyritic margins, gradational to even-grained granite. Platy foliation of schlieren, feldspar crystals or biotite crystals. Other parts of granite massive. Intrusive into all border facies rocks
	BORDER FACIES OR GROUP 2	Sheared, porphyritic granite-adamellite	Square or rectangular feldspar phenocrysts (some distorted) set in an intensely foliated groundmass (with quartz lenticles). Intrusive into medium-grained, foliated granite-adamellite
		Medium-grained foliated granite-adamellite	Light grey to white, some parts with streaks of biotite. A distinct foliation of quartz and feldspar grains
		Foliated, micro-granite-adamellite	Contact is conformable with country rock. Locally intrusive into country rock. Most of this rock is foliated, but some is massive
		Contaminated granitic rocks	(a) Grey tonalite; xenoliths of quartz; feldspar and biotite (b) Lenses and flakes of biotite with microline phenocrysts in a pale pink, medium-grained groundmass
"OUTER"	GROUP 3	Medium-grained, foliated granodiorite	A mixture of medium-grained and coarse-grained, foliated rocks with sheared porphyritic granodiorite. A distinct foliation of quartz, feldspar and biotite. Very few pegmatites
		Gneissose granodiorite	A mixture of fine-grained, foliated and medium-grained foliated granodiorites. Banded textures with bands of biotite and pegmatites cut by foliation

TABLE 2. MODES OF SAMPLES (VOLUME BY PER CENT)

Classification : OUTER (Group 3)

Sample No.	17802	17810	17811	17812	17813
Quartz	35	26	18	41	17
Plagioclase	51	56	66	40	66
K-Feldspar	3	13	7	11	6
Biotite	11	5	9	8	9
Magnetite	x	x	x	x	2
Apatite	x		x	x	x
Zircon	x	x	x	x	x
Sphene					x
Allanite		x	x		x
Epidote			x		

Classification : INNER (Groups 1 and 2)

Sample No.	17801	17804	17806	17808	17803 (a)	17803 (b)
Quartz	28	27	26	30	15	25
Plagioclase	39	27	19	21	18	5
K-Feldspar	30	32	52	45	57	60
Biotite	3	14	2	4	10	10
Magnetite	x	x	1	x	x	x
Apatite	x	x	x	x		
Zircon	x		x	x		
Sphene						x
Allanite				x		
Epidote	x			x	x	x

NOTE : 17803 (a) is a fine-grained granite
17803 (b) is a porphyritic granite from the same specimen
x Mineral present

RESULTS

The experimental procedures used were essentially the same as those described by de Laeter and Trendall (1971).

The measured Rb-Sr and Sr^{87}/Sr^{86} ratios, as well as the Rb^{87}/Sr^{86} ratio calculated from them are given in Table 3 for the Cue "inner" and "outer" granitic rocks. Errors in both groups are at the 95 per cent confidence level.

TABLE 3. ANALYTICAL DATA FOR THE CUE SHEET GRANITIC ROCKS

CUE "INNER" GRANITIC ROCKS

Sample No.	Rb-Sr	Rb^{87}/Sr^{86}	Sr^{87}/Sr^{86}
17801 B	0·223 ± 0·003	0·645 ± 0·006	0·7258 ± 0·0009
17801 A	0·965 ± 0·008	2·81 ± 0·03	0·8070 ± 0·0014
17808	1·672 ± 0·017	4·91 ± 0·05	0·8890 ± 0·0025
17804	2·665 ± 0·020	7·91 ± 0·08	0·9938 ± 0·0028
17806 A	4·76 ± 0·05	14·43 ± 0·15	1·2206 ± 0·0028
17803 A	3·29 ± 0·03	9·76 ± 0·10	0·9832 ± 0·0020
17803 B	4·69 ± 0·05	14·12 ± 0·14	1·1438 ± 0·0014
Composite	3·99	11·94	1·0635

Age 2,590 ± 23 m.y. Initial Sr^{87}/Sr^{86} = 0·7028 ± 0·0010

CUE "OUTER" GRANITIC ROCKS

Sample No.	Rb-Sr	Rb^{87}/Sr^{86}	Sr^{87}/Sr^{86}
17813	0·0735 ± 0·001	0·212 ± 0·002	0·7108 ± 0·0008
17811	0·279 ± 0·003	0·808 ± 0·008	0·7356 ± 0·0020
17810	0·330 ± 0·003	0·956 ± 0·010	0·7368 ± 0·0025
17802	0·583 ± 0·006	1·69 ± 0·02	0·7630 ± 0·0023
17812	0·931 ± 0·009	2·71 ± 0·03	0·8035 ± 0·0014

Age 2,605 ± 51 m.y. Initial Sr^{87}/Sr^{86} = 0·7031 ± 0·0009

The isochrons for each group (Figure 9) were derived by the method of Williamson (1968), which minimises the weighted sum of the squared residuals. Age calculations are based on an Rb^{87} decay constant of $1{\cdot}39 \times 10^{-11}$ $year^{-1}$. The errors associated with the age and initial Sr^{87}/Sr^{86} ratio are calculated from the standard deviation of the slope and intercept respectively.

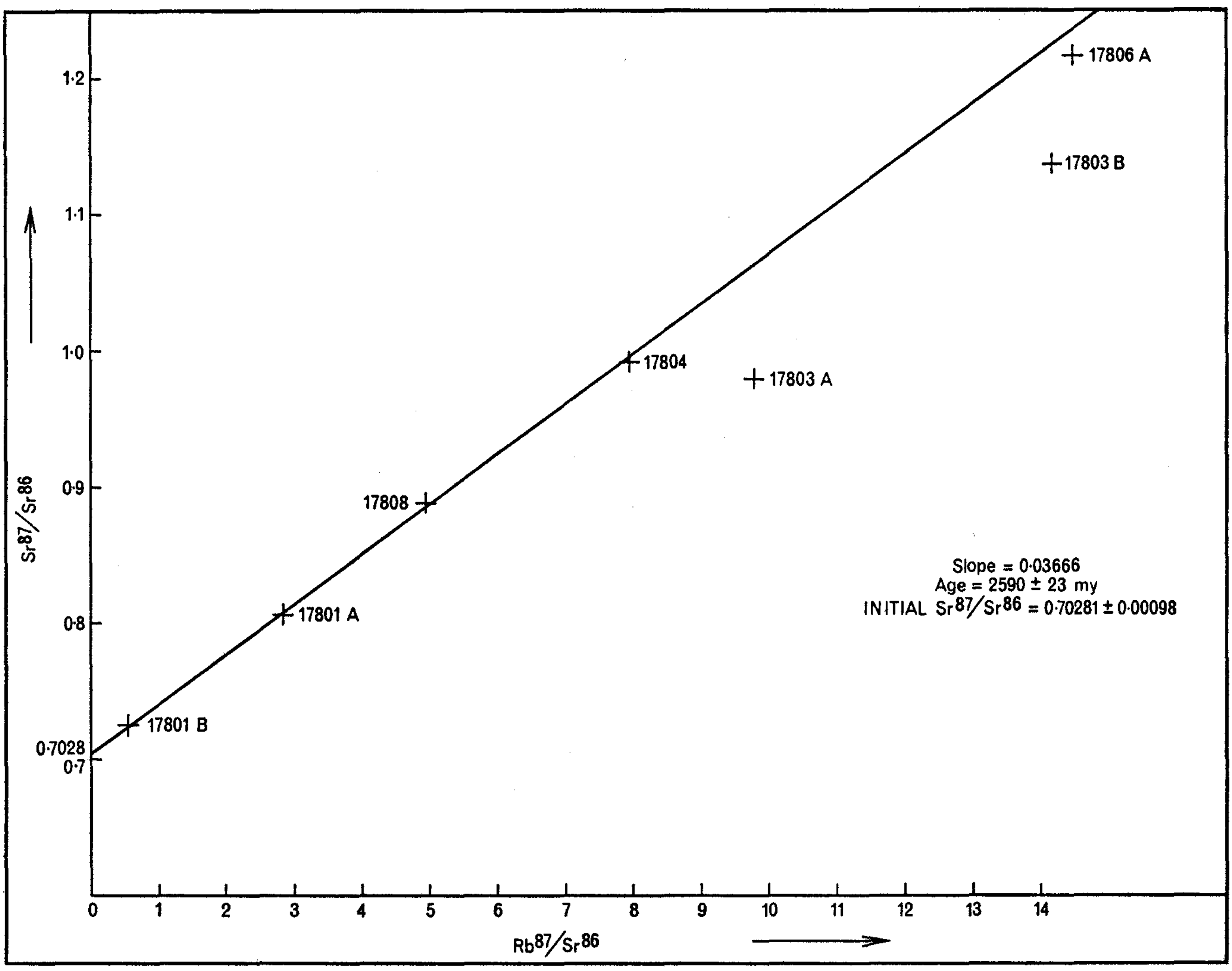
The age for the Cue "inner" granites is 2,590 ± 23 m.y. with an initial Sr^{87}/Sr^{86} ratio of 0·7028 ± 0·0010. The points representing samples 17803A and B do not lie on the isochron. Mapping has suggested these granites to be the same age as the surrounding rocks and therefore a leakage of Sr^{87} or a late addition of Rb may be responsible for this result.

The Cue "outer" granites have an age of 2,605 ± 51 m.y. with an initial Sr^{87}/Sr^{86} ratio of 0·7031 ± 0·0009. The combined age of the Cue "inner" and "outer" granitic rocks was computed to be 2,590 ± 20 m.y. with an initial Sr^{87}/Sr^{86} ratio of 0·7031 ± 0·0006.

DISCUSSION

The division of the Cue Sheet granitic rocks into "inner" and "outer" groups appears to reflect a general difference in Rb-Sr ratios, with the "inner" group having higher ratios than the "outer". No consistent relationship is evident between the present Sr^{87}/Sr^{86} ratios and the composition of the rocks within each group. Both groups include a wide range in texture and composition (granite-granodiorite), yet with the exception of 17803 the analyses of the members of each group plot on or near their respective isochrons.

The outer granites, which appear from mapping to be older than the inner group of granites, also have a slightly older indicated age. However, because of the errors associated with the methods used, both groups are essentially coeval on the isotopic evidence.



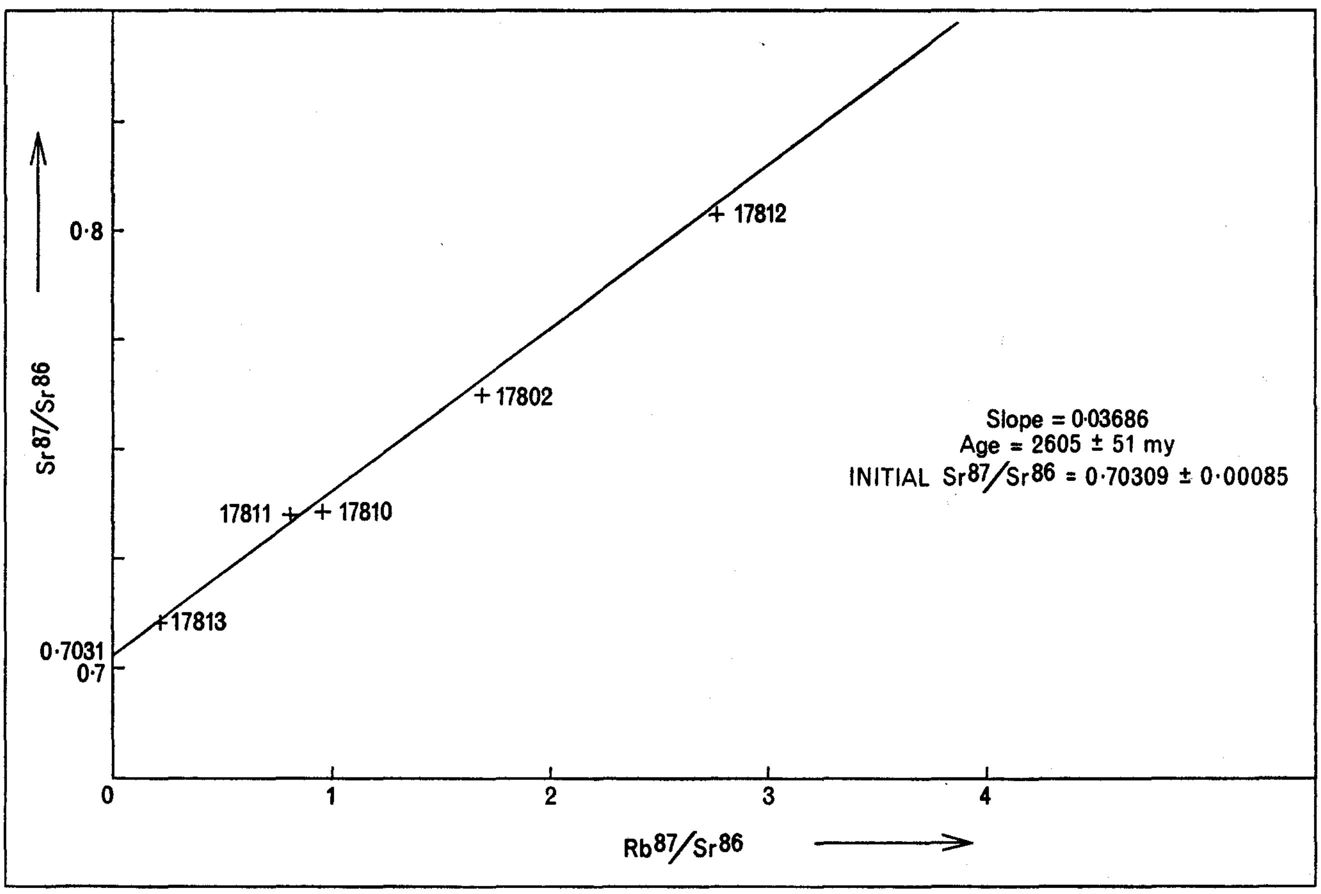


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Fig. 9 Isochron plots for the data of Table 3. The top diagram is for the Cue "inner" granitic rocks; the bottom diagram for the "outer" granitic rocks.

Compston and Arriens (1968) distinguish two main episodes of granite emplacement for Western Australia: "3,050 m.y. to 2,900 m.y. and from 2,750 m.y. to 2,600 m.y.; the time range of the younger is definitely real. Isolated granitic rocks were emplaced a little later than 2,600 m.y. or have been updated slightly by later metamorphism". The Cue Sheet granitic rocks appear to belong to this younger period of granite emplacement in the Archaean of Western Australia.

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APPENDIX 1
PETROGRAPHY OF SAMPLES

GROUP 3—THE "OUTER" GRANITIC ROCKS

17802:

This specimen is from an area of gneissic textured rocks. It is a medium-grained granodiorite with a distinct foliation of biotite grains. The texture is allotriomorphic granular. Plagioclase has little twinning though a few grains have albite and Carlsbad twins. Most grains are mildly zoned and the average composition is oligoclase (An_{24}). The average grain diameter is 1·37 mm. Microcline has poor twinning and a few grains have myrmekite borders against plagioclase. About half of the biotite has been altered to chlorite. Irregular grains of quartz are interstitial to all other minerals and some grains have a shadowy extinction.

17810:

It is one of the third group (Table 1): a medium-grained granodiorite with an allotriomorphic granular texture. A foliation is defined by biotite grains. Fine-grained aggregates of quartz, microcline and plagioclase (with myrmekite) are interstitial to, or enclosed by, medium-grained crystals of the same minerals. Plagioclase (oligoclase An_{25}) is anhedral and in two sizes: 1·8 x 1·0 mm to 3·0 x 2·5 mm and 0·2 x 0·2 mm. It is fresh, has curved albite twinning and a zoned extinction. Anhedral perthitic microcline crystals are bounded by aggregates of fine-grained plagioclase and myrmekite. Long, sinuous aggregates of quartz (with uniform optical orientation) fill interstices and are approximately parallel to the trend of biotite flakes.

17811:

Specimen 17811 is a porphyritic granodiorite with a foliation shown by biotite grains (not all aligned). Phenocrysts of both microcline and plagioclase range up to 5·2 x 7·7 mm. The groundmass grains vary from an average grain diameter of 0·4 mm to 0·9 mm and are of two elements: patches of medium-grained quartz and plagioclase as well as fine-grained interstitial patches of myrmekite and untwinned plagioclase. Myrmekite is confined to the areas of fine-grained crystals. The plagioclase is zoned but most seems to be oligoclase (An_{15}). Perthitic microcline occurs mainly as very poorly twinned anhedral phenocrysts. Signs of stress are: slip along biotite cleavage planes, extinction shadows in quartz, curved twin planes in plagioclase, and trains of fine-grained crystals around plagioclase phenocrysts. There are more accessory minerals than in 17801, 17802 or 17810.

17812:

This is a porphyritic granodiorite. A foliation is shown by quartz and biotite. Grains range in size from 4·2 x 2·6 mm (phenocrysts) to 0·1 x 0·1 mm (groundmass). This rock has been sheared more than any other described here. Anhedral phenocrysts of poorly twinned microcline and oligoclase (An_{18}), with lenticular aggregates of quartz grains are set in a groundmass of microcline, oligoclase and quartz with trains of biotite crystals. The aggregates of quartz are elongated parallel to the foliation, range from 0·9 x 0·4 mm to 0·4 x 0·2 mm, and show a moderately undulose extinction.

17813:

This was collected from an area of medium-grained, foliated granodiorite, east of Mount Charles. The texture is allotriomorphic granular with a foliation of aligned quartz, feldspar and biotite. Anhedral, oval plagioclase grains (oligoclase An_{21}), rounded microcline crystals and aggregates of quartz are separated from each other by short trains of fine-grained quartz, feldspar and myrmekite. Most grains have few inclusions. Oligoclase grains range in size from 3·0 x 2·5 mm to 0·3 x 0·3 mm, have a mildly zoned extinction and poor twinning. Microcline crystals have a zoned extinction and poorly developed twinning which is seen only on crystal edges. Lenticular aggregates of quartz whose individual grains have rounded edges are oriented parallel to the foliation.

GROUPS 1 AND 2—THE "INNER" GRANITIC ROCKS

17801:

This is a porphyritic adamellite from a narrow migmatite zone on the east side of the metamorphic rocks at Big Bell. A foliation visible in both hand specimen and thin section is formed by aligned biotite, plagioclase crystals and lines of quartz grains with shadowy extinction. Anhedral phenocrysts of plagioclase (ranging from 4·9 x 2·6 mm to 1·9 x 1·9 mm) are set in an allotriomorphic granular groundmass of plagioclase, microcline-perthite, quartz and biotite. The phenocrysts are equidimensional and are not aligned parallel to the foliation in the groundmass. The plagioclase is oligoclase (An_{14}), zoned to rims of albite (An_6), where next to microcline perthite; it has albite twinning and has been replaced in patches by microcline. The twin planes of some grains are curved. Perthitic microcline occurs as phenocrysts, but mainly in the groundmass. Cross-hatched twinning is well developed. Quartz forms lines of anhedral grains (4 mm in diameter) or occurs as single elongate grains up to 1·9 mm long. Biotite is interstitial to all other minerals and some is altered to chlorite.

17803:

This specimen was taken from a contact between a porphyritic granite rock, rich in biotite, and a fine-grained granite.

(a) *Fine-grained granite:* The texture is allotriomorphic granular. Anhedral well twinned fresh grains of albite (An_3) have an average size 0·9 x 0·6 mm. Some twin planes are bent or displaced along shears. Anhedral microcline grains (with very few albite inclusions) are fresh and poorly twinned. Their size varies from 0·6 x 0·4 mm to 1·4 x 0·8 mm. Quartz occurs as irregular grains up to 1·4 mm long, with ragged edges. Biotite has formed lines and clusters of crystals.

(b) *Porphyritic granite:* Closely packed phenocrysts of microcline are separated from each other by quartz, biotite, plagioclase and large irregularly shaped areas of quartz up to 11·2 mm long. The groundmass grains vary from 0·4 x 0·4 mm to less than 0·05 x 0·05 mm. Anhedral microcline grains range from 5·6 x 2·8 mm (phenocrysts) down to 0·8 x 0·4 mm. Anhedral grains of accessory plagioclase (andesine An_{33}) show fractured twin planes. A foliation is present, marked by lines of biotite crystals parallel to the contact with the fine-grained granite.

17804:

This specimen is a well foliated, porphyritic adamellite from a lens enclosed in the fine-grained, foliated granite. Square and rectangular phenocrysts of microcline, with short tails and stringers up to 11·0 mm long of optically continuous quartz are set in a groundmass of quartz, plagioclase, microcline and biotite. The plagioclase crystals are anhedral, about half the grains are twinned and some twin planes are bent. Some grains, where next to microcline, are zoned from a core of oligoclase (An_{14}) to a rim of albite (An_5). The microcline is a string and replacement type perthite with phenocrysts up to 11·2 x 5·6 mm with irregular edges, or as groundmass crystals (0·4 x 0·4 mm). It is well twinned in the quadrille pattern. The long stringers of quartz show little undulose extinction, and parallel the foliation together with biotite and some of the microcline-perthite phenocrysts. The biotite is interstitial to all other minerals. The texture shows evidence of stress but little granulation.

17806:

This porphyritic granite was collected from near the Wolfram prospect at Callie Soak. Anhedral phenocrysts of perthitic microcline and oligoclase (An_{28}) are set in a groundmass of both of the feldspars, biotite and quartz. The microcline-perthite ranges from 3·5 x 3·0 mm to 0·4 x 0·3 mm and has good cross-hatched twinning. The largest grains of oligoclase are 1·9 x 1·5 mm but most are 0·6 mm in diameter, have poor albite twinning and have been partially replaced by microcline parallel to 010. Most crystals show reverse zoning to rims of andesine (An_{33}). Quartz forms large irregular blobs filling areas between feldspar crystals.

17808:

It is a medium-grained granite. The texture is allotriomorphic granular, with a poorly developed foliation shown by alignment of biotite flakes. Anhedral grains of oligoclase are zoned to rims of albite, where against microcline, and these rims are wider than those seen in other specimens. The grain size ranges up to 5·4 x 2·7 mm though the average size is 2·0 x 2·0 mm and there is a little faint albite twinning. Perthitic microcline (with bands and stringers of plagioclase) ranges in size from 7·4 x 3·0 mm to 0·6 x 0·6 mm. Quartz grains have a very irregular shape and undulose extinction.

INDEX

DIVISION V

Kalgoorlie Metallurgical Laboratory, Annual Report — 1970

The Under Secretary for Mines :

I submit for the information of the Honourable Minister for Mines my report on the activities of the Kalgoorlie Metallurgical Laboratory for the year 1970.

INTRODUCTION

One hundred and forty-one certificates of testing or analysis were issued during the year.

No C.S.I.R.O. reports were issued during the year as companies seeking research work on current diamond drill cores did not want the locality nor the results made public and confidential certificates were issued to these companies.

During the year laboratory fees were increased and the companies and prospectors concerned did not object to these more realistic charges.

NOTE

Our capacity to carry out research work and assays over the past two years has been limited due to staff reductions. The recent appointment of two laboratory assistants is already freeing the metallurgists (3) from routine work.

A brief description of the research work in the company certificates are included in the report.

G. MUSKETT,
Acting Officer in Charge.

Certificate Number	Owner	State	Ore Type	Type of Investigation	Number of Metallurgical Tests	Number of Assays	
						Gold	Others
4087	Metals Exploration N.L.	W.A.	Nickel	Nickel Solubility	17	....	17
4089	Metals Exploration N.L.	W.A.	Nickel	Magnetic and Solubility	5	....	13
4107	Metals Exploration N.L.	W.A.	Nickel	Flotation Tests	44	....	180
4121	Anaconda Aust. Inc.	W.A.	Nickel	Flotation Tests	12	....	50
4126	Metals Exploration N.L.	W.A.	Nickel	Flotation Tests	17	....	90
4127	Vickers Hadwa Pty. Ltd.	W.A.	Iron	Heavy Media Tests	8	....	86
4151	Gold Mines of Kalg. (Aust.) Ltd.	W.A.	Gold	Gravity Separation	5	....	....
4152	Metals Exploration N.L.	W.A.	Nickel	Flotation Tests	21	....	159
4159	W.A. Gold Development	W.A.	Gold	Amalgamation Tests	2	4	....
4182	Thaduna Copper Mines Pty. Ltd.	W.A.	Copper	Flotation Tests	7	....	31
4185	Metals Exploration N.L.	W.A.	Nickel	Solubility Tests	17	....	17
4186	Metals Exploration N.L.	W.A.	Nickel	Flotation Tests	8	....	32
4187	Metals Exploration N.L.	W.A.	Nickel	Infrasizing Analysis	6	....	42
4191	Metals Exploration N.L.	W.A.	Nickel	Flotation Tests	5	....	22
4195	Metals Exploration N.L.	W.A.	Nickel	Flotation Tests	10	....	50
4201	Metals Exploration N.L.	W.A.	Nickel	Flotation Tests	8	....	44
4203	Metals Exploration N.L.	W.A.	Nickel	Flotation Tests	17	....	85
4210	Metals Exploration N.L.	W.A.	Nickel	Solubility Tests	2	....	8

DIVISION VI

•

Report of the Superintendent Surveys and Mapping for the Year 1970

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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, 1970.

The occupancy of Mineral House in the early part of the year, did much to increase the effectiveness of the work force, although the Branch is spread over five floors of the new building.

This year saw another record, for the number of mining applications lodged with the Department, but despite increased output, further staff resignations caused the Branch to fall further behind.

The Public Plan section of the Branch, which provides the mapping requirements of the Mining Registrars' offices, was the subject of investigation by management consultants, resulting in recomendations for more staff and equipment.

Some time was spent, by myself and my assistant, Mr. Hocking, in the preparation and presentation of evidence to the Mining Act Inquiry Committee, in evaluation of some of the submissions as they affected surveying and mapping, for the Department.

Owing to the great increase of applications for mining tenements in some of the out-stations, it was found necessary to deploy draftsmen to the district offices at Marble Bar, Leonora, Meekatharra, Mt. Magnet and Southern Cross, to assist the Mining Registrars in the introduction of new plans into their areas.

The year was another record for surveys performed, the expenditure for the year reaching an all time record of $292,306.

A total of 15,486 hours of overtime was worked by the staff, in endeavour to cope with the continued upsurge in mining activity throughout the State.

As anticipated there were quite a number of resignations during the year, unfortunately from the ranks of the experienced cartographers as follows :

Cartographic draftsmen	9
Drafting Assistants (male & female)	8
General Division	4
Clerical Division	1

The strength of the Branch at the end of 1970 was, 28 professionals, 34 general, 10 clerical and 18 cadet cartographers, making a total of 90 officers.

There were 50 Licensed Surveyors, duly authorised to perform cadastral surveys for this Department, registered as at 31st December, 1970.

Itemised reports of the activities of the various sections of the Branch are appended hereto.

A. A. HALL,
Superintendent.

SURVEYS AND MAPPING BRANCH ANNUAL REPORT, 1970

Survey and Petroleum—Geodetic Sections

Survey of mining leases, claims and other tenements were carried out during the year by Licensed Surveyors under contract to the Department, Survey work done is summarised by the following tables.

STATISTICAL SUMMARY OF SURVEYS

Table A

Number of Surveyors	37 parties
Number of Tenements surveyed....	2,343*
Number of Field Books lodged	299
Total Boundary Line run	304,887 chains
Total traverse or connection line run	12,576 chains
Total acreage delineated by survey	622,018 acres
Total mileage travelled	26,110 miles
Total value of survey work (actual survey accounts)	$292,306.09
Number of Diagrams drawn	1,830
Number of OPs drawn	1
Number of Surveys examined	1,346

* Includes 26 compiled from original surveys.

Table B

Surveyor	Field books	Surveys	Acres	Value $
Jamieson, J. A.	40	262	64,236	37,171.13
Rodda, F. R.	27	270	74,523	33,271.45
Hille, P. J.	25	229	63,843	29,263.96
Privett, L. G.	21	111	33,377	23,323.88
Byrne, M. J.	24	163	39,161	21,284.23
McKimmie, M. J.	18	162	44,846	20,385.00
Croghan, K. J.	16	170	46,142	20,110.03
Fisher, M. M.	14	144	37,726	18,573.93
Wilson, D. F.	11	114	28,958	13,413.50
Thompson, A. G.	10	91	51,756	11,153.38
Weber, J. F.	11	63	15,564	9,245.19
Gordan, I. M.	14	78	23,181	7,890.48
Cox, D. J.	8	83	21,099	7,682.79
Neale, P.	6	45	7,910	5,973.75
Benetti, R. J.	5	46	12,199	5,477.86
Sparks, I. R.	5	37	10,336	5,348.74
Lenz, W. (including Milne, M.)	6	57	10,811	5,086.04
Meleng, P.	3	32	8,900	3,747.56
Blackadder, P. R.	3	30	6,316	2,804.15
Burkett, L. J.	13	29	....	1,997.50
Johnstone, D. R.	2	14	3,348	1,669.98
Martyr, W. B.	1	10	2,229	1,664.62
Piper, K. H.	3	15	5,308	1,517.19
Callaghan, G. C.	1	8	1,393	1,346.24
Zadnik, J. P.	1	8	1,206	802.85
Pascott, G.	2	4	872	653.57
Kelly, I. E.	3	19	5,631	*501.24
Brittain, W. G.	1	2	536	485.84
Brook, E.	4	20	605	460.01
Roughan, G. E.	1	1	....	*
Totals	299	2,317	622,018	292,306.09

* Exclusive of certain direct costs to the applicants under special arrangement.

These figures indicate a very substantial increase in output which is due to the adoption of improved systems, occupation of the new premises together with a greater dedication by the staff undoubtedly engendered by the example of the Section Leaders.

However, in spite of these record figures, it is apparent that even with this output the number of diagrams drawn and examined have not reached the number surveyed and lodged and therefore a further amount has been added to the backlog which existed at this time last year.

SURVEY EXAMINATION

Survey examination has proceeded at an increased rate in spite of the close attention demanded from the staff in the supervision for the large volume of "special" requests for survey required by Wardens and the public in general.

GEODETIC

This year saw the introduction of the facilities of the Automatic Data Processing Centre to our work. A programme for the computation of survey traverse adjustment to co-ordinates on the Australian Map Grid was adopted and libraried and some trials in staff familiarisation in the preparation of the original survey data have been carried out. Tests so far indicate the great potential of this field and a large volume of processed co-ordinates has so far resulted. This has indicated the need for new thinking in our plan plotting methods and facilities and the feasibility of over-laying our existing standard plans has been investigated and tested. At the moment it seems that where the original sheets have been accurately plotted and sufficient control exists, an overlay is possible. In other cases errors in the original sheets have been revealed, sufficient to warrant re-plotting. The necessary calculations have been carried out by officers of the Survey Sections working overtime and the plotting done by officers in the Petroleum-Geodetic Section.

During the year 34 new standard plans with the Australian Map Grid were drawn and 12 existing plans converted with an A.M.G. overlay.

The upgrading of our standard plans is a matter of some urgency, particularly as new mapping becomes available and with the need to integrate our surveys onto the National Datum.

It is hoped that this work can be further extended next year.

PETROLEUM

All maps both "onshore" and "offshore" have been maintained and tenements and dealings under the Petroleum Acts dealt with as required.

MAPPING SECTION

The Mapping Section handles two areas of work, that of the Geological Survey Branch and that covering the rest of the Department's requirements.

GEOLOGICAL MAPPING

1 : 50,000 *Maps*

Four sheets covering the geology of the Metropolitan area were sent for printing during the year.

1 : 250,000 *Maps*

The main programme of mapping continued and the following sheets were completed and sent for printing :

Madura-Burnabbie	Scott
Cooper	Bentley
Talbot	Eucla-Noonaera

Other sheets to be completed were Kurnalpi, Jubilee and Forrest.

Cue was the only new sheet commenced but work proceeded on :

Menzies	Balladonia
Peak Hill	Zanthus

State Map

Fair drawing was commenced and scribing of boundaries completed and some colour masks prepared.

Bulletins

Bulletin 119 covering Iron Formations in the Precambrian Area of the Hamersley was printed.

Bulletin 121, covering the Blackstone Range area was completed with the exception of 3 colour plates.

Bulletin 122, covering the Eucla Basin area was completed and sent to the Government Printer.

Drawings for 3 other bulletins were commenced, that of Bulletin 125 for the Meckering Area, Mineral Resources Bulletin No. 9 covering Lead deposits of W.A., and the Geology of W.A., to be published with the new State Map.

Technical Plans

During the year 254 miscellaneous plans and diagrams were drawn for G.S.W.A. 134 plans were mounted, 11,500 paper prints were made and 1,545 items requiring photography or process work were prepared.

STANDARD MAPPING

State Map—1 : 2,500,000

The Gazetteer for the State Map published in 1969 was completed and published and has proved to be a best seller. The map was reprinted twice during the year and the Gazetteer once.

A new "Mineral Occurrence" map was also prepared to be printed over the new base map.

1 : 50,000 *Public Plans*

A heavy demand for 1 : 50,000 maps by Mining Registrars, the Public and for our own plan system saw over 350 new plans produced at this scale. Each plan produced requires an original, a working transparency, kept up to date for taking prints and two public plans mounted and coloured, one for the Mining Registrar and one for the Head Office.

The 1 : 50,000 plans produced covered either part or the whole of the following 1 : 250,000 sheet areas :

Peak Hill	Rason
Wiluna	Ninghan
Glengarry	Barlee
Belele	Edjudina
Cue	Jackson
Sandstone	Kalgoorlie
Sir Samuel	Kurnalpi
Duketon	Cundeelee
Throssell	Southern Cross
Yalgoo	Boorabbin
Kirkalocka	Widgiemooltha
Youanmi	Zanthus
Leonora	Hyden
Laverton	Lake Johnston

Plans in the Pilbara area were commenced or revised covering the following 1 : 250,000 sheets :

Yarraloola	Roy Hill
Roebourne	Mt. Bruce
Pyramid	Wyloo
Marble Bar	Yanrey
Nullagine	Edmund
Balfour Downs	

Because of the heavy rate of lodging of Mineral Claims and the situation regarding plans, it was found necessary to send Draftsmen out to the Mining Registrars to help with the changing over of plans and the introduction of new ones and to also help with the plotting of Mineral Claims.

This proved to be very successful in helping both our own work and the Mining Registrar.

Photography and Plan Printing

The move to Mineral House enabled new equipment to be installed and a wider range of work to be done. Although 2 months were lost while the camera was being installed, 5,552 items of photographic and general process work were done including developing and printing of 35 mm film, preparation of projection slides, printing out of micro film cards, colour photography of maps and printing out in colour at 40 in. x 30 in. size.

In the plan printing area, 47,817 prints were prepared, 3,933 plans were photo-copied and 3,621 plans were mounted. The increase in production of 1 : 50,000 plans meant an increase in mountings required for public plans for Head Office and the Mining Registrars.

PUBLIC PLAN SECTION

During the year a total of 31,398 applications were received in the section.

These comprised :

MCs	30,389
PAs	240
GMLs	194
Dredging Claims	327
Mineral Leases	86
Quarrying Areas	30
C.M.L., M.H.L., L.T.T., T.L., G.A., B.A., S.W.R., M.Y.L.S.	132

A total of 28,024 applications have been charted comprising a carry-over of 11,724 from 1969 and 16,300 of the above. There is a backlog of 14,089 applications to be charted.

About 300 Temporary Reserve renewals have been processed with an emphasis on more precise definition of boundaries.

Seven hundred and eighty-nine searches of the Land Titles Office were carried out. Provision for two officers to work full time on this work has been made to clear the backlog of some 5,000 searches.

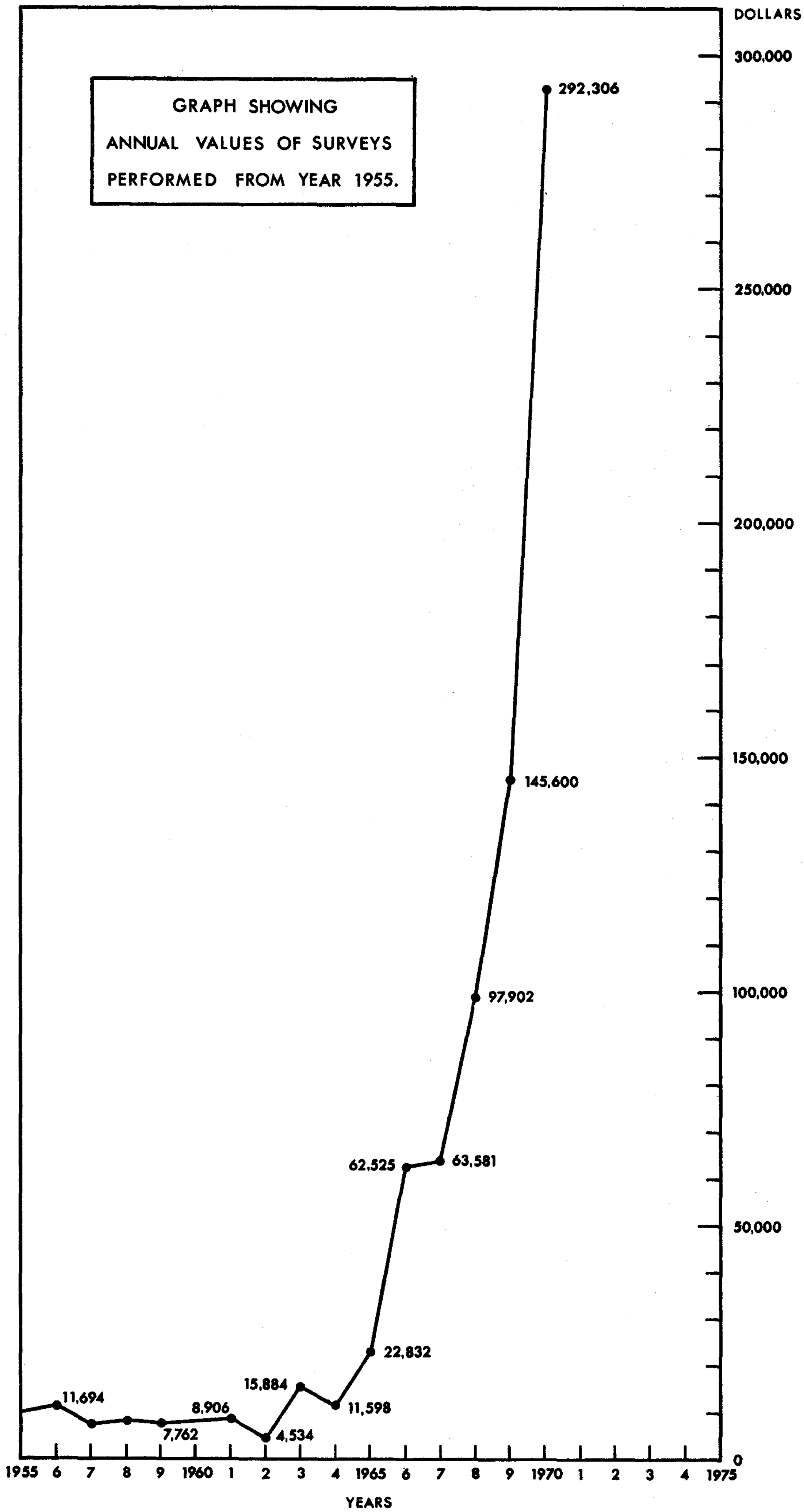
Head Office Plan Sales totalled $11,109·97 made up as follows :—

	$
Dyelines—12,762 at $0·50 each	6,381·00
Dyelines (coloured)—36 at $2·50 each	90·00
Petroleum Map—310 at $1·50 each	465·00
Mining Registrar Map—59 at $ various	14·20
Gas Pipeline Survey Map—6 at $0·30 each	1·60
Survey Diagrams (mounted)—25 at $2·80 each	70·00
Photocopies—7,275 at $0·10 each	727·50
Temporary Reserve—various	82·37
Descriptions	
Transparencies—various	1,689·10
State Map—1,112 at $1·00 each	1,112·00
Mineral Occurrence Map—47 at $1·00 each	47·00
Gazetteer—645 at $0·50 each	322·50
Iron List—55 at $1·50 each	82·50
Nickel List—25 at $1·00 each	25·00

The section has been supplied promptly with large scale plans of areas of intense interest which has made possible the numbers of applications plotted.

It has not been possible to maintain the State Temporary Reserve index map. It is intended that future Temporary Reserve index maps will be on copies of the 1/1,000,000 series maps with a half tone background of the Public Plan index.

Losses of experienced staff, as with all other areas, has caused concern.



GRAPH SHOWING
ANNUAL VALUES OF SURVEYS
PERFORMED FROM YEAR 1955.
DOLLARS
300,000
250,000
200,000
150,000
100,000
50,000
0
292,306
145,600
97,902
62,525
63,581
22,832
15,884
11,694
8,906
7,762
4,534
11,598
1955 6 7 8 9 1960 1 2 3 4 1965 6 7 8 9 1970 1 2 3 4 1975
YEARS

DIVISION VII

CONTENTS

DIVISION VII

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Government Chemical Laboratories Annual Report—1970

•

Under Secretary for Mines:

I have the honour to present to the Honourable Minister for Mines a summarised Annual Report on the operations of the Government Chemical Laboratories for the year ended 31st December, 1970.

Administration

At 31st December, 1970 the Laboratories consisted of 6 Divisions, a Library and a central office, all under the control of the Director (Government Mineralogist, Analyst and Chemist) as follows:—

- Director—L. W. Samuel, B.Sc., Ph.D., M.A.I.A.S., M.R.S.H., M.Inst.F., F.R.A.C.I., F.R.I.C.
- Deputy Director—R. C. Gorman, B.Sc., M.A.I.A.S., A.R.A.C.I.
- Agriculture Division—H. C. Hughes, B.Sc., A.R.A.C.I., Chief of Division.
- Engineering Chemistry Division—Vacant.
- 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.
- Mineral, Mineral Technology and Geo-Chemistry 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. E. Maughan, B.A.
- Office—D. E. Henderson, Senior Clerk.

The close association of these Laboratories with other Government Departments and kindred associations was maintained during 1970 and various members of the staff are members of the following Committees.

- Commonwealth Scientific and Industrial Research Organisation, State Committee.
- Fluoridation of Public Water Supplies Advisory Committee.
- Food and Drugs Advisory Committee.
- Laboratory Safety Committee.
- National Association of Testing Authorities State 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.
- Swan River Conservation Board.
- Veterinary Medicines Advisory Committee.
- Water Purity Advisory Committee.

In addition the Director was a member of Committees dealing with the disposal of the effluent from the Laporte Titanium works and the location of a nickel smelter and the Deputy Director was a member of the Committee considering an Act to replace the Feeding Stuffs Act and the Veterinary Medicines Act, and a member of the Western Australian Institute of Technology Advisory Committee on Applied Chemistry.

Most of these Committees are very active and meet regularly and occupy considerable time of the officers concerned, not only for meetings, but also for inspections, preparation of information and analyses of samples.

The Pesticides Registration Committee dealt with 170 applications for registration of new pesticide formulations. The total number of applications considered by this Committee to 31st December, 1970 is 2,444. A matter of great concern to this Committee is the poisonous nature of many of the newer pesticides, especially as many of them can be absorbed through the skin. The Committee has maintained its past policy of on occasions refusing registration of a pesticide as being too hazardous to health; placing an upper limit on the concentration of the active ingredient in the formulation to be distributed; or has restricted distribution to commercial pest exterminators. For the Swan River Conservation Board we analysed 148 samples of river water and 13 samples of effluents. The Veterinary Medicines Advisory Committee dealt with 981 applications, being 771 renewals, 89 new registrations, 47 changes of formula or claim, 29 deferred, 42 not required to be registered and 3 rejected.

Staff

At 31st December, 1970 the establishment of the Laboratories was 120 being—

Professional	68
General	37
Clerical	9
Wages	6

1970 again proved a difficult year for staff, although not as difficult as 1968 and 1969; not as pre-1968 the difficulty of obtaining sufficient suitable staff, but in the number of changes of staff during the year. Staff changes, staff "turnover", in 1970 was less than in 1968 and 1969 but still much is excess of pre-1968. Apart from the time involved in such changes, they are unsettling and interrupt the free flow of work. Reduced output

(9)—90726

occurs also from the need to train new staff, even at the level of typists because of the not-usual nature of our language and reports. A major adverse effect of this staff turnover is that we are understaffed for so long because of the length of time required to obtain new staff.

Unfortunately it has not yet been possible to finalise the appointment of the Chief of the Engineering Chemistry Division in succession to Dr. Uusna.

Considering the problems and difficulties of the year the result of our operations must be regarded as highly satisfactory, especially as we did manage to pick up a little of the backlog of work. Samples on hand at the end of the year were 2,908 compared with 3,015 at the beginning of the year.

Library

Additions to the library in 1970 totalled 3,308 items. This total included 524 monographs, 2,207 periodicals (separate issues), 577 reports (separate issues). During the year 27 new periodical titles were added to the library, 7 were discontinued, making a total of 262 periodicals now being received.

Loans to outside borrowers were 298. We requested 534 items from other libraries.

Items catalogued and indexed were 4,335.

General

The number of registrations for 1970 was 5,223, an increase of some 10 per cent on the 4,732 for 1969 and the number of samples received increased slightly, from 20,110 in 1969 to 20,666 in 1970. It must be regarded as fortunate that there was no greater increase in our work load since we could cope with it reasonably well despite our difficulties. The number of samples on hand at the end of the year was 2,908 compared with 3,015 at the beginning of the year.

The widespread nature of our work with other Government Departments, indicating the influence which these Laboratories exert on Government expenditure is shown in Table 1. This Table lists the Government Departments as shown in the Public Service List 1970 and shows with which of these our separate Divisions have undertaken work. This is exclusive of work with State Government Instrumentalities such as the Main Roads Department and semi-Government Institutions.

Table 1 shows not only that we were of assistance to 17 of the 29 Government Departments but also the advantage of one centralised organisation for chemistry—an organisation containing the very wide specialized knowledge required for today's problems. Each of a number of Government Departments required work done in a number of Divisions, indeed for only 6 of the 17 Departments was the special knowledge, ability and experience of only one Division sufficient. At the other end of the scale three of the Departments required the services of 5 of our Divisions to cope with their problems.

Table 1

Department	Division						Total
	Agriculture	Engineering Chemistry	Food and Drug	Industrial Chemistry	Mineral	Water	
Agriculture	1	....	1	....	1	1	1
Audit	....	....	....	....	....	....	....
Chief Secretarys	....	....	....	....	....	1	1
Child Welfare	....	....	....	....	....	....	....
Crown Law	....	....	....	....	....	....	....
Education	....	....	....	....	....	....	....
Electoral	....	....	....	....	....	....	....
Fisheries and Fauna	....	....	....	....	....	1	1
Forests	....	....	....	1	....	....	1
Industrial Development	....	1	....	1	1	....	1
Labour	....	....	1	....	....	....	1
Lands and Surveys	....	....	....	....	....	1	1
Local Government	....	....	....	....	....	....	....
Medical	....	....	1	....	....	1	1
Mental Health Services	....	....	1	....	....	....	1
Metropolitan Water Supply, Sewerage & Drainage Board	....	....	1	1	1	1	1
Mines	....	1	1	1	1	1	1
Native Welfare	....	....	....	....	1	1	1
Police	1	....	1	1	1	....	1
Premiers	....	....	....	....	....	....	....
Public Health	1	1	1	1	....	1	1
Public Service Board	....	....	....	....	....	....	....
Public Works	1	....	1	1	1	1	1
State Government Insurance Office	....	....	....	....	....	....	....
State Housing Commission	....	....	....	....	....	1	1
State Taxation	....	....	....	....	....	....	....
Town Planning	....	....	....	....	....	....	....
Treasury	....	....	1	1	....	1	1
Workers Compensation Board	....	....	....	....	....	....	....
TOTAL 29	4	3	10	8	7	12	17

Publications

During the year under review one Report of investigations was published.

Equipment

Major items of equipment purchased during the year included two further atomic absorption spectrophotometers, two further gas chromotographs and a Siemens X-ray fluorescence spectrometry unit.

Buildings

The alterations and additions to the buildings of our Engineering Chemistry Division were completed during the year.

Progress was made in re-building the former Fuel Technology Division building to accommodate the Water Division but unfortunately this is still not yet finished.

The source of the samples received and their allocation to the various divisions are shown in Table 2. In a number of cases sample(s) were allocated to more than one Division because for the full elucidation of the problem it was necessary to call on the ability and experience of different specialists. Such samples are not usually registered twice but do show in the totals of samples received by the Divisions so the total in Table 2 is greater than the total of samples quoted earlier in this report. This co-operation between and mutual assistance of Divisions helps to foster the policy that we are one Government Chemical Laboratories not 6 separate Divisions. Discussion and interchange of ideas between Divisions is encouraged since the problems received by one Division may be helped by, indeed may rely on, the specialist in another Division.

Table 2

SOURCE AND ALLOCATION OF SAMPLES RECEIVED DURING 1970

Source	Division						Total
	Agriculture	Engineering Chemistry	Food and Drug	Industrial Chemistry	Mineralogy	Water	
State—							
Agriculture Department	7,238	38	495	1	3	18	7,793
Education Department	....	....	....	1	....	....	1
Fisheries Department	....	....	24	....	....	23	47
Forests Department	....	....	....	4	....	....	4
Hospitals	....	....	68	....	....	....	68
Industrial Development Department	....	1	....	10	2	....	13
Labour Department	....	....	115	....	....	....	115
Lands & Surveys Department	....	....	....	....	....	1	1
Main Roads Department	....	....	....	3	40	4	47
Medical Department	....	....	2	....	2	9	13
Mental Health Services	....	....	1	....	....	....	1
Metropolitan Water Board	....	....	11	....	4	2,049	2,064
Milk Board	....	....	144	....	....	....	144
Mines Department	16	60	174	3	1,004	439	1,696
National Parks Board	....	....	....	....	....	9	9
Native Welfare Department	....	....	....	....	14	14	28
Police Department	2	....	2,056	....	34	....	2,092
Prisons Department	....	....	....	....	....	3	3
Public Health Department	59	4	535	1	374	54	1,027
Public Works Department	9	....	98	29	15	1926	2,077
State Housing Commission	....	....	....	....	....	7	7
State Shipping Service	....	....	....	....	1	....	1
Swan River Conservation Board	....	....	169	....	....	1	170
Treasury	....	....	105	1	....	1	107
University of Western Australia	....	....	....	....	2	....	2
Western Australian Government Railways	....	....	3	....	....	....	3
Commonwealth—							
Air Department	....	....	....	....	2	4	6
Army Department	....	....	....	....	....	3	3
Health Department	....	....	2	....	....	....	2
Navy Department	....	....	7	....	1	....	8
Repatriation Department	....	....	5	....	....	....	5
Shipping and Transport Department	....	....	....	....	....	1	1
Works Department	....	....	....	....	16	....	16
Public—							
Free	....	....	....	1	42	1	44
Pay	114	61	544	181	1,532	712	3,144
TOTAL	7,438	164	4,558	235	3,088	5,279	20,762

As a result of publicity for the treatment of cancer patients with an aqueous extract of the native shrub Scaevola spinescens these Laboratories continued the field collection of the shrub and the preparation and supply of the extract. When we previously did this, 1957-59, supply was through the Public Health Department but now we are supplying direct, having first obtained the written concurrence and approval of the patient's medical adviser.

The number of registrations and of samples does give some measure of our activities but does not completely describe 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 and so on.

Fees were charged for work undertaken for some State Government Departments, Government Instrumentalities, Commonwealth Government Departments, Hospitals, Milk Board, private firms and the general public, but the greater part of our work is done without charge for other State Government Departments.

The summarised reports of the individual Divisions which follow show the very wide range of subjects dealt with by these Laboratories. Comparing 1970 with 1969 there were some marked alterations in the numbers of various types of samples received. These were:—

	1969	1970
Marked decrease		
Gold ores	292	125
Pasture	1,367	689
Soils	2,277	1,485
Vines	946	359
Marked increase		
Animal specimens	322	1,222
Apple leaves	402	573
Bauxite	n.s.r.	115
Barley	n.s.r.	203
Horse "doping"	nil	168
Fertilisers	139	502
Fish	16	137
Nickel ores	185	426
Peat	n.s.r.	159

n.s.r.—not sufficient for separate recording.

These changes show some interesting variations in emphasis among our numerous clients.

The Department of Agriculture has reversed its change from considering the individual plant components of a pasture to the pasture as a whole; has shown a decrease in activity in soils and vines; an increased attention to animal tissue analysis, to apples, barley and fertilisers.

There has been a decreased interest in gold, but an increased interest in bauxite and nickel and in peat for montan wax.

L. W. SAMUEL,
Director.

AGRICULTURE DIVISION

In spite of the continued need to share the facilities of the Division with the staff of the Water Division, 1970 was a productive year aided by comparatively few staff changes. The output of samples at 8,221 was well in excess of our receivals at 7,438 with the result that the work in hand at the beginning of 1971 was back to the level of 1965. Should the work received in 1971 continue at the stable level of the last two years this should enable us to devote more time to investigation of analytical problems and new methods which will be required because of the new products towards which agriculture in Western Australia is turning.

Table 3 shows the source and nature of samples received in 1970.

Staff

Mr. G. Williams was promoted to Chemist and Research Officer Grade 2 and Mr. I. Wilson joined the chemical staff. The staff handling sample receival and preparation was reorganised by the transfer of Messrs. Bateman and Hill to duties within the laboratory and the appointments of Messrs. Ferguson and Warren in their stead early in the year. Miss D. Knott also took up a position as technician which became available on the resignation of Mr. George.

Table 3

AGRICULTURE DIVISION

	Agriculture Department	Other Government Departments	Public Health Department	Public Pay	Total
Animal—					
Animal tissue	316	....	....	....	316
Blood	46	....	....	....	46
Bone	30	....	....	....	30
Faeces	24	....	....	....	24
Kidney	103	....	....	....	103
Liver	151	....	....	....	151
Meat—lamb	545	....	....	....	545
Urine	6	....	....	1	7
Cereal—					
Barley grain	203	....	....	....	203
Other	31	....	....	1	32
Wheat grain	70	....	....	3	73
Fertiliser—					
Fertiliser Act	143	....	....	....	143
Other	333	15	....	11	359
Horticulture—					
Apple—					
Fruit	85	....	....	....	85
Leaves	573	....	....	....	573
Peel	17	....	....	....	17
Shoots	100	....	....	....	100
Roots	100	....	....	....	100
Tree stumps	50	....	....	....	50
Grape vines	356	....	3	....	359
Other	93	....	1	1	95
Peanuts	72	....	....	....	72
Miscellaneous—					
Bricks	....	....	31	....	31
Other	21	11	18	20	70
Pasture and Fodder—					
Clover	893	....	....	....	893
Feeding Stuffs Act	55	....	....	....	55
Grass	58	....	....	6	64
Hay	12	....	1	7	20
Legumes	64	....	....	....	64
Other	15	12	....	19	46
Pasture	688	....	....	1	689
Stock foods	524	....	....	14	538
Soil—					
Soil	1,461	2	5	17	1,485
TOTAL	7,238	40	59	101	7,438

Instrumentation

The growing requirement for the determination of individual amino-acids for nutritional and plant breeding studies led us to investigate gas-liquid chromatographic techniques for their determination. The investigation proved highly successful and very gratifying since the long established method for their determination required an instrument of double the cost to give comparable capacity and one lacking the flexibility and versatility of the gas chromatograph.

Professional

Report of Investigation "The Determination of Some Nitrogen Fractions in Plants and Soils" by Mr. A. Rowley was published and the results of one of the trials to which these methods have been applied appeared as a joint paper by M. G. Mason and A. M. Rowley.

"The Fate of Anhydrous Ammonia and Urea Applied to a Wheat Crop on a Loamy Sand in the Wheat Belt of Western Australia", Australian Journal of Experimental Agriculture and Animal Husbandry; Volume 9, December 1969.

A paper "Grape Vine Leaf Nutrient Survey" jointly authored by our Mr. J. Jago and Mr. L. Jones of the Department of Agriculture was presented at the Australian Plant Nutrition Conference in Mt. Gambier, South Australia. Mr. Hughes attended this conference and continued on the Committee of the Western Australian Branch of the Royal Australian Chemical Institute. Mr. Jago returned to the Western Australian branch committee of the Australian Society of Soil Science taking office as Vice President.

Soils

1. Nitrogen.

(a) An experiment first started in 1969 but aborted by the drought of that year was continued at Merredin to examine the effects of various cultivation practices. From the day of cultivation early in May through to mid September plots were sampled at weekly intervals or according to rainfall. During the first six weeks the mineralisation as measured by soil nitrate levels was more rapid in the plots which had been scarified and harrowed to a fine tilth than in plots treated only with weedicide. However two inches of rain fell at the end of this time and leaching was much greater under cultivation with the result that nitrate was less in the cultivated plots from that time on.

(b) The effects of one year's pasture on virgin soils at Esperance and Newdegate were tested for soils under pasture obtained from a range of seeding rates for the clovers Daliak, Seaton Park, Yarloop and Bacchus Marsh at Esperance and Geraldton, Daliak, Rose and Beenong at Newdegate.

At Esperance, independent of variety, a seeding rate of 7 lb per acre improved soil nitrogen from an initial 0.025 per cent. to 0.030 but no further significant increase was obtained up to 63 lb per acre, and a massive 189 lb per acre only improved with the first 3 cultivars to 0.033 per cent. and the Bacchus Marsh plot to 0.036 per cent.

The Newdegate story was quite different in that no consistent improvement was shown at any of the lower rates and even the 189 lb per acre only served to increase soil nitrogen from 0.032 per cent. to 0.036.

2. Rotations.

Further samples from a long term clover wheat rotation experiment started at Wongan Hills in 1956, showed means for organic carbon content as follows:

History (years) Clover	Wheat	Organic carbon per cent
2	4	0·55
3	3	0·59
5	1	0·67
6	....	0·75

The water stable aggregates from four of the older plots and the unstable material were separately analysed for carbohydrates, free iron and aluminium oxides and organic carbon. Two plots A and B had a history of fallow, 2 years wheat, 5 years sub-clover, two others C and D were respectively C fallow, 2 years wheat, 3 years sub-clover, 2 years wheat and D fallow, 2 years wheat, 2 years sub-clover and 3 years wheat. The analytical results are shown in Table 4.

TABLE 4

Plot	Per cent of soil	Free Ferric oxide, Fe_2O_3	Free Aluminium oxide, Al_2O_3	Organic Carbon C	Carbohydrate (as glucose)
	per cent	per cent	per cent	per cent	mg/100g
A Stable	40·3	0·76	0·080	0·85	169
Unstable	59·7	0·68	0·071	0·45	72
B Stable	40·2	0·83	0·085	0·66	134
Unstable	59·8	0·72	0·071	0·43	68
C Stable	11·1	0·60	0·071	0·57	126
Unstable	88·9	0·66	0·071	0·29	63
D Stable	10·5	0·76	0·085	0·63	132
Unstable	89·5	0·79	0·094	0·33	54

Both organic carbon and carbohydrate are of the order of twice as concentrated in the stable material as in the unstable. In the soils with a long pasture phase and high aggregate content there is some apparent very slight increase in both free iron and aluminium oxides in the aggregates but this has not survived two croppings. There are also higher contents of both carbohydrate and carbon in the soils with better aggregation, but perhaps the best indicator of poor aggregation is the low organic carbon content of the unstable material.

(b) Similar experiments laid down in 1966 and 1967 at Merredin, Newdegate and Chapman Research Stations designed to represent more districts of the agricultural area and to correspond with changing farm practice, provided many other samples on which organic carbon, nitrogen, phosphorus and sulphur were determined as well as the exchangeable cations.

(c) At high rates of nitrogen, two of four plots receiving sulphate of ammonia and subject to continuous cropping at Wongan Hills, Avondale and Merredin (two soil types) had for several years given significantly lower yields of wheat. The difference between the soils was found on analysis to be primarily one of cation exchange capacity. The more deteriorated sites at Wongan Hills and Merredin had capacities of only 3 and 4 milliequivalents per 100 g. In each instance at the end of eight years cropping the pH had fallen to between 4 and 5 from an initial 6 and the exchangeable bases to about 1.5 meq/100 g, the loss being primarily of calcium. The better soils at Avondale and one at Merredin had C.E.C.'s of approximately 7 and 18 meq/100 g and while cropping had lowered pH of the former to 5.5 and the bases to less than 4 meq/100 g with the highest ammonium sulphate usage, the effects on the heavier Merredin soil were still not measureable within the natural variation of the site and samples.

Miscellaneous

(a) An experiment had been intended to simulate the effects of sheet erosion by sweeping the ground surface so as to remove soil in layers of mean depth of 0.5 mm. The layers removed were submitted to mechanical analysis and tested for cations, organic matter, total nitrogen and hydrochloric acid soluble phosphorus and potassium.

The results would have been as meaningful if, following the removal of surface debris, 2 mm intervals were taken corresponding to the definition of soil. Results presented in this manner are given in Table 5.

Table 5

Effect of simulated Sheet Erosion.

Layer, mm	0–2	2–4	4–6	6–8	8–9
pH	6.6	6.7	6.7	6.6	6.6
			per cent dry basis		
Coarse organic matter	8.3	3.9	5.3	4.2	2.5
			less than 2 mm		
Mechanical Analysis—					
Coarse sand	59.6	58.9	69.5	67.8	70.3
Fine sand	19.3	22.2	15.7	19.9	22.2
Silt + Clay	8.5	8.0	5.6	4.7	2.5
Loss on ignition	12.6	10.9	9.2	7.6	5.0
HCl soluble—					
Phosphorus, P	0.051	0.043	0.042	0.036	0.031
Potassium, K	0.046	0.038	0.041	0.034	0.033
Nitrogen, N	0.36	0.28	0.29	0.22	0.19
			milliequivalents per 100 g		
Exchangeable Cations—					
Calcium, Ca	10.0	8.7	7.9	6.8	5.7
Magnesium, Mg	2.1	1.8	1.6	1.3	1.0
Potassium, K	0.5	0.5	0.5	0.4	0.4
Sodium, Na	0.15	0.15	0.15	0.1	0.1

It was perhaps surprising to find the increase of coarse sand and decrease of silt and clay with depth but, together with the higher organic content which was to be expected in the uppermost layer of soil, this emphasised the relative nutritional value of the surface soil and the losses which could be sustained by flash flooding.

(b) Soils from the Kimberley Research Station having different cultivation and irrigation histories had been sampled to 5 ft. 6 in. depth. These were tested for sodium chloride content and exchangeable sodium percentage (E.S.P.). E.S.P. figures in a new rice bay showed steady rises from 1-2 at the surface to 24 at the greatest depth, (mean for six samples) closely in accord with similar samples of virgin soil.

Samples of surface soil to 2 inches were not different from virgin samples where there was a history of continuous cropping with cotton or sorghum-cotton rotations but old rice bays had higher E.S.P.'s and the opposite effect was found for old sugar cane areas where the E.S.P. was less than one.

(c) Many other soils from all corners of the State were analysed for different properties for the following reasons:—

(i) To establish chemical data for soils at Kalumburu and La Grange Missions to aid in the establishment of vegetable gardens.

(ii) To establish total and extractable copper levels prior to setting up a residual copper experiment at Newdegate.

(iii) To see the effects of grazing rate on various clover cultivars on the organic carbon and nitrogen content of soils for a subsequent wheat crop.

(iv) To advise farmers on soil salinity and acidity.

(v) To advise the Public Health Department on the suitability of soils for septic tank systems in new housing areas and townsites.

Fertilisers

1. Fertilisers Act.

(a) One hundred and forty-three samples were submitted for testing for comparison with registered analyses. Reports were issued for 165 such samples including 29 carried forward from 1969 and more than doubling reports issued in that year.

There was a considerable improvement in standards achieved in that a total of 56 individual deficiencies were found in 32 of the samples. A high proportion of the deficiencies was found in the more complex mixtures of the type sold in small packages rather than those fertilisers used in extensive agriculture. There were only 15 samples of this type but 8 of them were deficient accounting for 20 deficiencies.

There was a great improvement in 1970 in the superphosphates with added molybdenum. Thirty-one samples of these were submitted and only two were deficient. The improvement was attributable to changes in both the amount and method of adding the molybdenum which were introduced following consultation at the works between officers of the Laboratories and the manufacturers.

The deficient samples came from a stockpile made before the changes.

(b) In addition to the above there were 5 referee samples to confirm analyses and 33 samples of superphosphate trace element mixtures taken prior to the acceptance of registrations for the year to ensure that required standards were being achieved.

2. Of particular interest because the problem of rubbish disposal is a growing one in Perth as elsewhere, were two samples of compost from the

Table 6

	Grade A	Grade B
	as received	
pH	8·1	8·6
	per cent	
Moisture	40·9	52·2
Ash	27·1	18·2
Acid insoluble ash	17·9	12·0
Aluminium, Al	0·85	0·56
Nitrogen, N	1·12	1·07
Phosphorus, P	0·31	0·21
Potassium, K	0·21	0·18
Zinc, Zn	0·11	0·074
	parts per million	
Boron, B	68	32
Chromium, Cr	110	66
Copper, Cu	360	190
Lead, Pb	560	290
Manganese, Mn	460	300
Nickel, Ni	38	23

Auckland City Plant at Mt. Wellington, New Zealand. This plant is a mechanised one in which plastics, glass and metals are screened out and other organic material fermented for 5 days before maturing in windrows over some months. The material is then dried and broken up for sale.

With composts from municipal waste as with sewage sludge consideration has to be given to elements potentially toxic to plants as well as to the nutrients. Although friable the samples were still very moist as shown in Table 6. This water holding capacity is a virtue in conditioning sandy soils. The grading refers to the screen size of the bulk material, 0.5 in. for A and 1 in. for B.

3. In order either to confirm or refute suspicions that fertilisers used in experimental work with pastures and cereals may have contained sufficient trace elements to distort results, twenty-eight fertilisers from various sites and sources were tested.

Pastures, Fodders and Stock Foods

1. Feeding Stuffs Act.

It is anticipated that a new Act will be presented for Parliamentary approval during 1971, as the result of recommendations from a committee of Government and industry representatives.

Fifty-five samples were received for checking for compliance with the Act. Including 26 carried forward from 1969 receivals 68 samples were reported on. It was found that of these 52 through either deficiencies or excesses failed to comply with the registered analyses supplied.

2. Clovers and other leguminous pastures.

(a) On a grazing trial at North Bannister large differences, up to 10 kg, had been said to have been recorded for body weight of sheep grazing different clover cultivars. Samples of these taken in June and again in August did not reveal the marked differences in protein and fibre compositions which might have accounted for the differences. Further samples of these same clovers were then analysed for ten other nutrient and minor elements without throwing further light on the problem.

(b) Much work continued with endeavours to provide sufficient cobalt for stock by applying cobalt salts or oxides as a top dressing.

(i) A time of top dressing trial on a mungite loam was sampled in June, August, October and December and the pasture divided into its components.

The clover component showed that for both control (nil) and each rate of top dressing with cobalt sulphate from 0.5 to 2.0 oz per acre applied either in February or April, there was a seasonal fluctuation in cobalt levels. These increased in June and August cuts, fell off in October and increased again in December. A June application of fertiliser apparently delayed the uptake until after August and prevented the falling off in October.

The phalaris component showed uptake of cobalt from the April application at 1 or 2 oz per acre for the June and August cuts, and as with the clover, June application delayed the uptake of cobalt. There was little benefit from any treatment to cobalt levels in the annual grasses apart from the 2 oz per acre applied April or June and that showed only in the December cut.

(ii) An experiment at Harvey checked on sources of cobalt and their residual value on a sandy soil where clover from control plots contained 0.02 to 0.03 parts per million of cobalt on a dry basis.

Cobalt oxide whether graded coarse, medium or fine by particle size could raise the level only to about 0.06 parts per million of dry matter at which it is not adequate for stock. On the other hand cobalt sulphate, the more usual and more expensive source for top-dressing, raised the levels to 0.14 parts per million dry basis at which it is above deficiency levels.

(iii) A number of trials of different cultivars of clover showed that they did have different capacities for taking up cobalt, but it was also shown that where these might be marginal for ruminants cobalt sprays could be used to maintain levels.

(c) Copper continues to be of interest with more emphasis on providing adequate levels for stock in order to cut down on top dressing wherever this is possible.

(i) 60 clover pastures from a trial at Newdegate Research Station were analysed for copper content. Copper in the control (nil treatment) samples ranged from 3.6 to 5.5 parts per million dry basis; all rates of applied copper from 2.5 to 10 lb per acre were sufficient to raise the copper levels to better than 6 parts per million dry basis, adequate for grazing stock.

(ii) A copper source trial at Harvey similar to the cobalt trial above tested the residual value of copper fertilisers applied in the previous year. Four sources of copper were used, copper sulphate, copper ore, copper oxides and cemented copper at rates equivalent to 0.25, 0.5, 1, 2 and 4 lb per acre of copper. Up to 1 lb per acre none of the sources was effective. At 2 lb per acre both copper sulphate and cemented copper continued to give levels of copper sufficient for stock, and all sources were satisfactory at the highest rate. Overall the oxide was the poorest source of copper for the clover.

(iii) Four hundred and forty-six samples of Woogenellup clover from a residual trial at North Bannister were analysed for copper and molybdenum. These were on an ironstone gravelly soil. Cuts were taken each month from July to November and the leaf and petiole material analysed separately, September samples for iron, manganese and zinc in addition.

Copper levels in the petiole were about half to two thirds of the levels found in the leaf material at each stage of the growing season for all levels of applied copper.

In the September samples, iron and manganese concentrations in the petiole were about one quarter to one third of those in the leaf and zinc about two thirds.

From the results of these and previous years results of this and like trials it has been concluded that the leaf is to be the standard sample and 4 to 5 parts per million in the dry matter is the critical level for stock.

(d) From a preliminary study of the effects of gypsum treatment on pasture and sheep at Woogenellup in the high rainfall Albany district samples were taken through the spring of 1969, the summer of 1970 and into May and June 1970. There has been no apparent difference in the spring growth and analyses showed fluctuations in total and sulphate sulphur and nitrogen with the season but no difference between treated and untreated pastures. However examination of the wool from the grazing sheep has shown a difference in quality, the gypsum areas giving better crimp and finer wool.

This experiment has proven the basis for a more elaborate study, one in which the composition of the amino-acids in the pastures will be examined as a possible contribution to different nutrient status not apparent on a crude protein basis.

Miscellaneous Feeding Stuffs

(a) High figures of 1.9 and 5.0 parts per million of molybdenum were found in kikuyu and mixed grasses from a coastal property near Albany where severe scouring and deaths had occurred among calves.

(b) Samples of Mitchell grass taken at intervals throughout the growing season at Camballin, late February to the beginning of April in this particular season, were analysed for protein. The young plants contained 17 per cent protein in the dry matter and had fallen to 10 per cent after three weeks, at which it remained. Mitchell grass is not always such a good protein source, only half this concentration being on record for samples from other northern areas.

(c) Rape is one of the more promising likely crops providing alternatives to wheat in Western Australia. The seed is extracted to obtain an oil and the extracted seed meal can be a valuable stock food. However it contains a toxic principle which must be destroyed in processing. To aid a local firm producing this material we analysed their product for thiocyanate content which proved satisfactory.

(d) Samples from other private sources included pelleted feeds to check on composition and correct mixing, many samples of hay, poultry feeds believed to be affecting egg production and the identification of molasses from molasses with added urea from drums which had lost their labels.

Cereal

1. Wheat.

Work continued with determining the fate of nitrogen from compound fertilisers, urea and ammonium nitrate. Tops, grain and straw from plants at various stages of growth throughout the year were tested for total nitrogen and several of the forms in which it is present in the plants. Protein nitrogen in the grain reflected increased nitrogen fertilisation, from about 1.7 per cent on a dry basis with super-phosphate only, up to 2.0 per cent independent of the type of nitrogen fertiliser. Total nitrogen also increased and approximately three quarters of the increase was present as the protein.

Other samples involved the assessment of the needs for molybdenum in the Lake Grace area by means of grain molybdenum levels, determining copper in grain available at germination, and testing wheat surplus to quota for use as pig feed.

2. Barley.

One hundred and ninety-two samples of barley grain were analysed for crude fibre. These were of the three varieties Beecher, Bussell and Dampier and had been grown with and without nitrogen fertiliser at research stations from Geraldton to Esperance to provide information for an overseas feed quality evaluation. The results indicated that Beecher (a six row barley) in general had a higher crude fibre content, average 6.3 per cent, than the two row barleys, each averaging 4.9 per cent.

3. Oats.

Separated plant parts from Chapman Research Station, where crops in the nearby district had been seriously affected by rust and consequently were not to be harvested, were tested to assess the feed quality of the standing crop. Potentially it could be used for the topping off of lambs in particular.

Results are shown in Table 7.

Table 7

Plant Part	Grain per cent dry basis	Glumes per cent dry basis	Raches per cent dry basis	Leaf per cent dry basis	Stem per cent dry basis
Ash	3.65	9.35	6.00	9.35	4.25
Crude Protein (N x 6.25)	7.35	8.62	6.92	6.12	2.71
Acid detergent fibre	17.9	27.5	36.9	32.7	47.2
Lignin	1.4	2.7	4.4	3.6	6.8

Horticulture

1. Apples.

(a) The association of bitter pit and superficial scald of Granny Smiths with low calcium levels in foliage and fruit has resulted in a number of experiments aimed at raising calcium levels. Apples from storage supported this association when it was found that 30 sound fruit analysed individually averaged 40 parts per million of calcium in the range 29-57 parts per million, and 20 pitted fruits averaged 27 parts per million calcium in the range 19 to 33, warranting further investigation in the 1970-71 season.

Various rootstocks are being studied to see whether any has an advantage in this respect, a number of spraying and fertilising and cultivation trials are under way, and not only the foliar levels but, following the above, individual fruit concentrations of calcium will be followed. In connection with these experiments we analysed peel from Granny Smith apples taken from seedlings which had shown high calcium and low potassium from foliar analyses, suggestive of low bitter pit incidence, but wherein there was a high level of bitter pit. For these samples the pitting did not correlate well with calcium levels; although the peels with the lower levels of calcium were included among the affected fruit, higher levels were also represented. However samples were representative of all fruit in a batch and individual whole fruit may have told a more conclusive story.

(b) Granny Smith apples from 15 growers throughout the South West had been ranked according to their skin colour from pale to deep green at the early stage of maturity. Nutrient determinations showed that with increased depth of colour there was an increase (although possibly not significant) in the content of each of the elements magnesium, nitrogen, phosphorus, potassium, copper and manganese.

Fruit was picked a month later by which time the normal paling of the skin with ripening had occurred at different rates in different areas and the order of skin colour had changed somewhat. However, the colour range again related to nutrient content, both to the content at the time of picking and to the content one month earlier. The most consistent trend was that the palest fruit were from trees giving low nitrogen content.

Deep green is the required colour for marketing of Granny Smiths—fruit which has yellowed not being as acceptable.

(c) New and mature shoots, large and small roots, leaves and stumps of a group of young apple trees were all analysed for nitrogen, phosphorus and potassium to find the distribution of nutrients resulting from using various amounts of ammonium nitrate and/or super-phosphate either as a top-dressing, mixed with the soil or placed below the tree at planting.

The leaves proved the best material for diagnostic purposes in terms of nutrient content and variation with tree vigour apart from convenience. None of the other materials showed promise as an alternative except the fine roots where the effects on concentration by treatments were proportionally greater but against this is the difficulty of obtaining samples particularly in an uncontaminated state.

2. Citrus.

Except for samples from experiments at the Gascoyne Research Station in the problem area of Carnarvon the few citrus leaf samples were for diagnostic purposes. This reflects the now well established standards for nutrient levels in citrus leaves.

The Carnarvon samples were from a range of orange, mandarin and grapefruit grafted onto various rootstocks, and some of them sprayed with trace element mixtures. Spraying was found to have had most marked and consistent effect in raising the molybdenum level. Of probably more significance were the boron figures; boron known to be high in the irrigation waters, was present in excess amounts in eight of the twenty samples and high in each of the others.

3. Grapes.

(a) The Swan Valley survey of nutrient levels in grape vine leaf blades and petioles continued in a season which was not affected by a prolonged heatwave. Results were the subject of a joint paper by Mr. L. Jones of the Department of Agriculture and Mr. J. Jago, Assistant Chief of this Division, delivered to the Australian Plant Nutrition Conference at Mt. Gambier, South Australia in September 1970.

Results obtained from the fertiliser trial currant vines in the first survey (sampled November and December 1968, January 1969) are summarised from the paper as follows:—

(a) Ammonium sulphate increased the nitrogen content in the leaf petioles in December sampling.

(b) Ammonium sulphate increased the manganese in blade and petiole in the three samplings.

(c) Potassium chloride increased the potassium content in blade and petiole in the three samplings.

(d) Super-phosphate increased the phosphorus content particularly for early sampling.

(e) Leaf petioles were more sensitive than blades in responding to fertiliser applications and for more significant figures for sodium and chloride.

(f) Up to one ton of superphosphate, one ton of ammonium sulphate and half a ton of potassium chloride did not appear to affect the leaf content of calcium, sodium, chloride, sulphur, copper, iron and zinc.

Within the trial an area of vines known to have light clay at two feet had visibly deteriorated in recent years. This area was subject to severe leaf scorch by the heatwave at the end of January.

There was a significant inverse correlation between sodium and chloride contents and yield and pruning weights, and a direct relationship with the severity of the leaf scorch for these vines. The tentative critical level for leaf blade sodium was 0.11 per cent, for petiole 0.45 per cent and for leaf blade chloride 0.55 per cent.

Because of the lack of evidence of either deficiency or toxicity with respect to most nutrients it is difficult to draw up local critical standards but these may be obtained by results from the extension of the survey over more of the commercial vineyards.

(b) A comparison of blades and petioles from vines producing grapes of good keeping quality and others from vines giving poor keeping grapes showed that the better quality was given by vines having more of all but one of the nutrients tested and also sodium and chloride. The exception was potassium in which the vines giving the poorer product were comparatively rich.

Animal Nutrition

As shown in Table 3 there was a considerable growth of the numbers of animal tissues received in 1970, apart from the 545 samples of lamb carcass meat. It was pleasing to be able to complete these with more despatch than in the previous year since a high proportion of them were for diagnostic purposes and a prompt result permits more rapid remedial measures.

1. As in more recent years cobalt and selenium analyses continued to dominate.

(a) Experimental work included a two year experiment at Manjimup in which selenium is being administered to sheep either by feeding in licks or by top-dressing pastures. Samples from this not only included the usual tissues, kidney and liver, but also muscle and wool. Pastures were also sampled at 3 month intervals.

(b) Other samples resulted from the feeding of rats in experimental diets, a study of the effects of cobalt on selenium toxicity.

2. Work with other elements included.

(a) The blood and liver of calves from a residual copper trial at Bramley and blood, liver and kidney of lambs from a similar trial at North Bannister provided 195 samples for copper on all and the haematocrit on the blood.

(b) The calcium-phosphorus ratio was determined on the bones of birds from flocks showing osteodystrophy and on chicks fed diets including rock phosphate. The high fluoride content of rock phosphate produced levels in the chick bone up to 4,000 parts per million, a complicating factor in trying to interpret results of effects of calcium and phosphorus.

(c) The calcium-phosphorus ratio was also looked at for other stock, including sheep with bowed legs and cattle from Pinjarra which had splayed feet and general illthrift. At the same time the relative density of the bone and its ash content were determined.

Sheep grazing on apparently healthy pasture on deep sands at Pinjar were failing to gain weight. Tissue and urine from these were analysed for trace elements and fluorine and the bones tested for density, calcium-phosphorus ratio and ash, fluoride and manganese to see whether a mineral deficiency would account for the malnutrition.

(d) An attempt to correlate blood and tissue levels of selenium and establish normal values for manganese gave a mean value of 8.4 with a range of 6.5 to 11.1 parts per million dry basis from 40 samples.

3. An experiment at the Pig Research Station at Medina produced samples of the feeds being offered to the animals, the residues uneaten, the faeces and the urine for the determination of the feeding value and the calorific value (by the Engineering Chemistry Division) in order to permit assessment of the actual consumption by the pigs and the efficiency of their metabolising of the consumed feed.

Similar tests were carried out on the faeces of sheep involved in a drought feeding demonstration at Newdegate.

4. Samples (545) taken from lamb carcasses were analysed for their fat, protein and moisture contents. These were to determine the influence of the time of lambing and breed of sire on the proportions of these constituents and hence on carcass quality.

General

1. Air Pollution.

Because of the presence of sulphur and fluoride in particular in their raw materials and heating or acid treatments as part of their processing, the effluent gases from brickworks and superphosphate factories can carry sufficient sulphur oxides and fluorine compounds to affect plants growing nearby.

Sulphur is a natural and required component of all plant material and changes brought about by industrial air pollution can also be disguised by the use of fungicides containing sulphur in a number of forms. The plant also tends to protect itself by shedding leaves which have received large doses of any toxic material so that sampling to determine pollution by sulphur dioxide is far from clear cut.

However plants from areas remote from industry in Western Australia usually contain of the order of only 5 to 10 parts per million of fluoride in their dry matter. The level of content which can definitely be said to produce adverse symptoms in plant tissue is not clearly fixed and as with all elements whether nutrient or toxic the sensitivity of different plants will vary. The effect of one toxicant is also likely to vary with the presence or absence of another. But with fluoride which is not readily taken up from the soil and which is not used as a pesticide on plants and which tends to build up in plants without causing very rapid defoliation, plant foliage samples tend to show fairly clear patterns of concentration related to the source of the effluent gases and the prevailing winds.

Leaves of affected and unaffected species of native and exotic trees, shrubs, flowers and vines were analysed for inorganic sulphur, fluoride and chloride content, the latter because high salt content of ground or irrigation water could cause chlorotic and necrotic symptoms masking the effects of fluoride and sulphur dioxide. The leaves were from plants in proximity to industries at Bunbury, Esperance, Kwinana and Midland, and levels were obtained to assist officers of the Department of Agriculture and the Clean Air Council in diagnosis of unhealthy plants.

To assist with determining the sources and amounts of fluorine emission samples of clays used in brick and pipe manufacture and fired and unfired bricks were analysed for this element as was fuel oil which proved a very minor source. Local clays and unfired bricks ranged from 130 to 670 parts per million dry basis, of which only 10 to 80 parts per million remained in the brick after firing.

2. Ninety-seven samples of blood were analysed for alcohol by the Kozelka and Hine method as a check on other methods of determination.

3. Spectographic work was very little. Attempts to determine platinum and palladium in silver prills obtained by fire assay of ores were unsuccessful since the method was not sensitive at levels which would be economical to mine.

The one biopsy sample was of tissue next to a screw which had corroded when used in prosthetic surgery.

ENGINEERING CHEMISTRY DIVISION

General

A total of 124 samples was registered to the Division during the year—a number well in excess of that for previous years. This increase was almost entirely due to the reorganisation which included fuel technology in this Division and the consequential large number of registrations of samples of coal, char and associated materials lodged for calorific value and other analytical determinations.

As in previous years the main effort was directed towards a few projects, each of which required extensive investigational work. The demand from industrial and mining companies and from individual sponsors for this investigational work continued at such a level that there was only limited opportunity for work on projects of the Division's own innovation.

Staff

New appointments to the staff for the year were Messrs. A. Bright (Chemist and Research Officer, Grade 3), D. Hide and G. Stone (Laboratory Technicians) and T. Horsten (Laboratory Assistant). However the professional ranks were again depleted when Mr. R. V. Field (Chemist and Research Officer, Grade 2) resigned at the end of the year.

Mr. L. Brennan presented his paper entitled "Energy Resources and Requirements in Western Australia" to the Institute of Fuel Conference on the assessment of Fuel and Energy Resources and Requirements, in Brisbane in November, and visited Eastern State Research Establishments en route. Mr. P. Rolfe spent 3 days visiting C.S.I.R.O. and University centres during a holiday visit to Melbourne in December. Messrs. B. Goodheart and R. Field attended a three day residential symposium on Applied Thermodynamics in November and O. Graieg attended a series of lectures on Industrial Safety in August.

Mr. L. Brennan continued as a member of the Scientific Advisory Committee appointed under the Clean Air Act and Mr. B. Goodheart was appointed the non voting W.A. State representative on the Board of Directors of the Australian Coal Industry Research Laboratories Ltd.

Buildings and Equipment

Resiting of the boundary fence to encompass an area previously let out under lease was effected during the year. A total area of almost two acres is now available to house the activities of the Division.

Upgrading of the Annexe Test Laboratory was completed during the year and a complete maintenance service, including a full paint of the pilot plant, test laboratory and office block added considerably to the efficiency of use of these areas.

Items of equipment procured included a laboratory sized Van Gelder Jaw Crusher for sample preparation.

Project Investigations

As described above, outside sponsored projects received the main priorities, but some further work was done on long standing Divisional projects on ilmenite upgrading and calcination of lime sands.

The development of a process for producing upgraded ilmenite or "sub-rutile" from W.A. ilmenitic sands has been well to the forefront of the Division's efforts for several years. During 1970, some specialised aspects of the upgrading process were examined by the Division in addition to other test work on this theme that was requested by two sponsor companies.

With the continuing increase in the demand for lime, the challenge of utilising W.A. coastal calcareous dune sands for this purpose is still very real, and a series of trials was carried out in the Raining Bed reactor to evaluate its applicability to calcination of these sands.

Upgrading of Ilmenite

Some 700,000 tons of ilmenite concentrates were produced in W.A. in 1970 and the major portion of this was exported from the State—mainly to pigment manufacturers who employ the traditional sulphuric acid production route. In recent years an alternate process based on chlorination, which uses rutile as the raw material, has gained ground, since in certain situations, it has advantages over the sulphate route—particularly with regard to effluent disposal. The demands of the chloride route pigment producers are threatening to outstrip the production capacity of available sources of rutile and the development of a commercial process capable of upgrading ilmenite to a synthetic or sub-rutile is being viewed with increasing importance.

A process devised in this Division some years ago, that led to a successful patent application, has remained in the forefront of interest. Following the successful proving of the process on a semi-commercial scale—15,000 tons per annum of upgraded ilmenite or sub-rutile—a local Company has firm plans to erect a plant capable of producing 100,000 tons per annum of upgraded ilmenite of TiO_2 grade approaching that of rutile.

Naturally occurring rutile is normally around 96 per cent in TiO_2 grade, whereas the product from this Division's reduction—aeration upgrading process is usually of the order of 90-92 per cent titanium, expressed as TiO_2. Thus there is an incentive to lift the TiO_2 grade of the product by removing minor gangue constituents, and some further investigational work was undertaken by the Division on this theme during the year.

Previous studies had shown that the residual iron (approximately 4 per cent) and manganese (approximately 2 per cent) contents of sub-rutile are chemically bound within the mineral lattice and are not easily removed by standard leaching techniques. Aiming to improve the dissolution of these materials, two process modifications were investigated in bench scale trials. The target in the first case was to produce dislocated zones and other lattice imperfections within the vicinity of non-stoichiometric transition metal sulphide zones, formed by "sulphur doping" of ilmenite during metallisation at controlled temperatures. Such crystal imperfections were expected to give rise to enhanced dissolution of mineral constituents, including iron and manganese.

The second refinement was to employ a sulphurous acid wash of the sub-rutile product from the metallisation-aeration process. The aim was to leach residual manganese and iron oxides and sulphides from the mineral lattice, into a reactive "chemical sink" containing complex oxy-sulphur anions present at low pH. Because the acid washing steps could be designed to utilise sulphur dioxide bearing gases produced during the kiln metallising process, it would result in a measure of air pollution control over the overall production of sub-rutile.

In general, the tests showed that by using direct sulphur (or pyrites) treatment during the reduction step and then a sulphurous acid wash, the manganese content of the final product was about 85 per cent lower than that of the sub-rutile produced via the straight forward reduction-aeration process, and the iron content was about 50 per cent lower.

These results suggested that the sulphur content of Collie coal and char used during the metallising stage must exert an influence on the eventual removal of iron and manganese during the leaching process.

One of the areas of difficulty in the upgrading process has been to obtain a sharp separation of fine upgraded ilmenite particles from the iron oxide slurry at the completion of the aeration stage, and some investigational work was done on this topic. Variables such as settling time, mixture pH and influence of additives (for example dispersants) were studied by a standard test method, supported by microelectrophoretic experiments. The pH was found to have a marked effect and separation was enhanced at pH's close to 8.0.

Calcination of Lime Sands

Previous Divisional investigations had shown that a relatively simple electrostatic separation technique could be used to remove the silica from the calcareous dune sands which occur abundantly along the South West and West Coasts of the State. Likely methods of calcining the concentrated carbonate sands had also been examined and pilot plant studies made using an entrainment type roaster and a raining bed reactor. The background to the selection and testing of the raining bed system was outlined in the 1967-69 Annual Reports and one further set of trials, employing several reactor modifications was carried out in 1970.

The trials were aimed to establish the relationship between the measured degree of calcination and the following factors:—

(a) The amount of heat available in the furnace and preheating sections.

(b) The temperature gradient in the furnace.

(c) The residence time of the falling particles.

(d) The flow characteristics of the falling particles.

(e) The degree of recarbonation occurring in the cooling section.

Added insulation applied around the areas of the combustion chamber and calcination zone minimised radiant heat losses but resulted in only a minor increase in degree of calcination—raising the previous figure of 35 per cent to 40 per cent.

A second pair of burners was installed in the combustion chamber—18 inches below and at right angles to the original pair. This resulted in a longer calcination zone and allowed a longer residence time at temperatures above decomposition level. This modification raised the average degree of calcination to 55 per cent and emphasised the importance of residence time and thermal gradient.

A downdraught technique was tried as a means of influencing the particles to fall in a "curtain-like flow." This was responsible for raising the degree of calcination to the order of 65 per cent.

Measuring the concentration of carbon dioxide and other gases a various points along the cooling section revealed that little recarbonation was occurring in this zone.

Recycling partly calcined material through the reactor a second time, upgraded 55 per cent material to a product that was 85 per cent. calcined, and reinforced the contention that residence time in the calcination zone was a most important variable.

This set of trials proved that it would be difficult to obtain highly calcined products in the pilot raining bed reactor without further design modifications. The first essential was to provide for an extended calcination zone with an accompanying increase in residence time and the need to retain a curtain-like flow of particles falling through the reactor.

These further modifications would provide data for a more accurate assessment of the economic efficiency of the raining bed system as applied to lime sands calcination, and provide a more definite indication of the influence of the "scale-forming" characteristics of the product, which had been found to be a severe handicap to the other calcination techniques previously investigated.

Coal Analysis

Implementing the recommendation of a Report on the future development of the Collie coalfield, compiled in 1969 by two senior Eastern States Coal Mining Officials, the Geological Survey carried out a scout drilling programme in certain areas during 1970.

The drilling was in the areas of the Ewington horizon (No. 2 Ewington seam) and the Collieburn horizon (Griffin, Phoenix, Wyvern and No. 1 Seams). In all 51 core samples were received and analysed for proximate analysis (moisture, ash, volatiles and fixed carbon), calorific value and sulphur content. More detailed analyses, including ultimate and ash analyses, reactivity and ash fusion determinations, etc., will be carried out during 1971 on selectively bulked samples from the drilling programme.

Sponsored Investigations

1. Upgrading of ilmenite.—An investigation on this topic, first requested by a Mining Company during 1968, commenced with a series of comprehensive bench scale tests. This was followed by pilot plant trials using the rotary kiln in 1969, and the investigation was continued in 1970. Three detailed progress reports have been furnished to date on this investigation and the Stage IV studies, which are directed at specific aspects of the upgrading process, were under way by the end of the year.

Another ilmenite producing Company requested detailed analyses of certain raw and intermediate materials from the upgrading process, and then later in the year, the same sponsor commissioned an investigation directed at the upgraded product. This work was in progress at the end of the year.

A bench scale investigation of the applicability of the principle of an alternative upgrading process to W.A. ilmenites, which commenced in 1969, was completed during 1970 and the results reported to the Sponsor Company.

2. Salt Processing.—The Department of Industrial Development requested this investigation which was aimed at extending the marketable product range of a local salt supplier. A treatment circuit was devised to produce a form of salt well within the required specification. The report included recommendations of equipment suitable for full scale commercial manufacture and was accompanied by a bulk sample of product suitable for market evaluation purposes.

3. Testing of iron oxide pellets.—Indurated iron oxide pellets, previously prepared from a sample of ore submitted by a Sponsor, were subjected to tests for reducibility and compression strength. This necessitated apparatus construction so that the tests could be in complete accord with standard procedures.

4. Beneficiation of tin-tantalite ore.—An investigation into possible methods of upgrading a bulk quantity of mixed ore defined a suitable technique for separating the constituents into concentrates of marketable grade, and the products were passed to the Sponsor.

5. Pelletising of iron ores.—At the request of a major chemical Company, a project aimed at establishing the influence of certain additives on an iron ore pelletising process was commenced towards the end of the year. The investigation will be based on the production of pellets of acceptable grade in a reproducible pelletising system and the subsequent evaluation and comparison of the products.

6. Miscellaneous.—Other work undertaken for various Sponsors during the year ranged from a determination of basic fundamentals associated with the spontaneous combustion of Collie coal to the crushing of a batch of blast furnace slag for a potential user of that material and micron sizing of dust samples for the Public Health Department.

Consultative Service

During the year advice was given and discussion held on numerous aspects of the Division's projects and areas of activity. Examples of these topics were the evaluation of improved methods for separating the lead content from the casing material of industrial storage batteries, the utilisation of Collie coal—particularly for char and bricoke manufacture, the extraction of vanadium from titaniferous magnetites, the beneficiation of scheelite and other tungsten ores and techniques for smelting and processing nickel ores. Possible methods of solving a South-West coast effluent problem are currently being reviewed by the Government and a general order of magnitude costing was compiled for one method of treatment and another possibility examined in broad detail.

Included among the overseas and interstate visitors to the Division during the year were:—

- Dr. D. Koch—Assistant Chief, C.S.I.R.O. Division of Mineral Chemistry, Melbourne.
- Dr. K. Cannon—Humphreys-Glasgow Ltd., Sydney.
- Mr. H. Mino—Managing Director, Kokan Mining Co., Japan.
- Dr. R. W. Pickering—Director of Research, Electrolytic Zinc Corp., Risdon, Tasmania.
- Mr. A. Hams,—Director, Australian Coal Industrial Reasearch Laboratories, Sydney.
- Mr. B. Judd—Department Scientific and Industrial Research, Wellington, New Zealand.
- Mr. A. W. Fletcher—Chief, Extraction Metallurgy Division, Warren Spring Research Laboratories, England.
- Mr. O. Konishi—Technical Assistant to President, Mitsubishi Chemical Industries Ltd., Japan.
- Dr. P. W. Bakarian—Managing Consultant, Florida, U.S.A.
- Mr. D. Skiles—Union Carbide, Mining and Metals Division Colorado, U.S.A.

FOODS, DRUGS, TOXICOLOGY AND INDUSTRIAL HYGIENE DIVISION.

Following the pattern of recent years the work of this Division in 1970 dealt with samples submitted chiefly by the Departments of Agriculture, Police and Public Health, but as shown in Table 9 lesser numbers were received from various Government Departments and other bodies.

Four thousand five hundred and fifty-eight samples were received during the year, being an increase of 9.4 per cent on the number received in 1969, and 28.5 per cent on those received in 1968.

A broad outline of the variation in numbers during the period 1966-1970 is indicated in Table 8 (selected samples groups):—

Table 8

CLASS	1966	1967	1968	1969	1970
Foods—					
Total	1,084	796	454	480	623
Milks	865	699	367	302	378
Exhibits—Alcohol	484	573	647	1,071	1,037
Human toxicology	718	1,116	814	954	1,074
Industrial hygiene	183	297	288	303	430
Miscellaneous	1,163	1,260	853	873	823
Specimens from patients	147	208	158	196	193
Pesticides	132	145	152	89	129
Pollution—					
Swan River Surveys	110	145	157	126	161
Bunbury Surveys	48	48	48	48	48
Trade Wastes	21	12	23	72	62
Total samples received	4,000	4,485	3,547	4,165	4,558

Table 9 shows the source and condensed description of samples received during 1970.

Table 9

FOODS, DRUGS, TOXICOLOGY AND INDUSTRIAL HYGIENE DIVISION.

	Agriculture Department	Fisheries & Fauna Department	Government Tender Board	Hospitals	Labour Department	Metropolitan Water Board	Milk Board of W.A.	Mines Department	Other Departments: State	Other Departments: Commonwealth	Pay Public	Police Department	Public Health Department	Public Works Department	Swan River Conservation Board	Western Australian Trotting Association	TOTAL
Foods—																	
Apples	17	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	17
Cream	11	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	11
Fish	....	2	....	....	....	....	....	....	....	....	....	....	135	....	....	....	137
Milk	157	....	....	....	....	....	144	....	....	....	1	....	76	....	....	....	378
Vegetables	....	....	....	....	....	....	....	....	....	....	1	....	10	....	....	....	11
Various	1	....	....	....	2	....	....	10	....	....	2	....	52	....	....	....	67
Industrial Hygiene—																	
Air	....	....	....	....	....	....	....	24	....	....	....	....	11	8	....	....	43
Dust	....	....	....	....	13	....	....	....	....	....	....	....	....	....	....	....	13
Gases	....	....	....	....	....	....	....	24	....	....	....	....	....	....	....	....	24
Gas detector tubes	....	....	....	....	....	....	....	76	....	....	....	....	....	....	....	....	76
Urine	....	....	....	....	98	....	....	....	3	....	111	....	9	....	....	....	221
Various	....	....	....	....	1	....	....	....	....	3	6	....	43	....	....	....	53
Miscellaneous—																	
Baits	1	....	....	....	....	....	....	....	....	....	1	19	....	....	....	....	21
Criminal	....	....	....	....	....	....	....	9	....	....	....	68	....	....	....	....	77
Detergents	....	....	105	....	....	....	....	....	2	....	....	....	....	1	....	....	108
Drugs	....	....	....	2	....	....	....	....	1	....	....	55	2	....	....	5	65
Grass	30	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	30
Horse doping	....	....	....	....	....	....	....	7	....	....	....	....	....	....	....	161	168
Pesticides	107	....	....	....	....	....	....	....	....	....	5	....	2	30	....	....	144
Poultry feed	21	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	21
Soil	28	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	28
Various	57	2	....	5	1	....	....	22	1	....	9	3	34	7	....	1	142
Water	1	8	....	....	....	....	....	2	....	....	3	....	1	1	....	....	16
Pollution—																	
Effluent	....	....	....	....	....	....	....	....	1	....	27	....	26	....	8	....	62
Maritime	....	....	....	....	....	....	....	....	....	....	....	11	....	....	....	....	11
Surveys—																	
Bunbury	....	....	....	....	....	....	....	....	....	....	....	....	....	48	....	....	48
Swan River	....	....	....	....	....	....	....	....	....	....	....	....	....	....	161	....	161
Various	....	....	....	....	....	11	....	....	....	....	....	....	3	3	....	....	17
Toxicology—																	
Animal	64	12	....	....	....	....	....	....	....	....	....	6	2	....	....	....	84
Human—																	
Toxicology	....	....	....	4	....	....	....	....	....	....	....	1,052	18	....	....	....	1,074
Sobriety	....	....	....	....	....	....	....	....	....	....	197	401	....	....	....	....	598
Traffic deaths	....	....	....	....	....	....	....	....	....	....	....	439	....	....	....	....	439
Specimens from patients	....	....	....	57	....	....	....	....	....	11	12	2	111	....	....	....	193
TOTAL	495	24	105	68	115	11	144	174	8	14	375	2,056	535	98	169	167	4,558

Foods

Six hundred and twenty-three samples of food were received for examination; 144 of these were samples of cows milk submitted by the Milk Board of Western Australia for checking against the chemical standards for quality prescribed by the Milk Act Regulations. 4.9 per cent of these samples contained less than the legal minimum of milk fat (3.2 per cent), and 70 per cent contained less than the legal minimum of solids not fat (8.5 per cent), while 50 per cent of the samples also failed to comply with the legal standard for freezing-point of milk (0.540 degree Centigrade below zero). The proportion of samples which failed to comply with the standard for fat is much the same as in 1969, but shows an increase in respect of solids not fat and freezing point figures (70 and 50 per cent respectively failing to comply as compared with 62 and 35 per cent in 1969).

In presenting these figures it is emphasised that these analyses apply to Inspectors' samples for which there was *prima facie* evidence of non-compliance with legal standards.

The distribution of analytical figures is shown in the following tables:

Milk Fat

Per cent in sample	Per cent of total samples
Less than 3·00	1·4
3·00—3·19	3·5
3·20—3.49	16·0
3·50—3·74	17·3
3·75—4·00	19·4
More than 4·00	42·4
	100·0

Milk Solids not Fat

Per cent in sample	Per cent of total samples
Less than 8·00	2·8
8·00—8·24	19·4
8·25—8·49	47·9
8·50—8·74	25·7
8·75—9·00	4·2
	100·0

Freezing Point

Degrees C below zero	Per cent of total samples
Less than 0·510	1·4
0·510—0·519	0·7
0·520—0·529	7·7
0·530—0·539	40·2
0·540—0·550	45·8
More than 0·550	4·2
	100·0

Sixty-one samples of bottled milk from metropolitan and country treatment plants were analysed regularly for residues of organo-chlorine insecticides. Although minute traces of dieldrin, D.D.T., etc., were detected in nearly all samples, in only two was the concentration of any one insecticide greater than 0.005 part per million. In one sample the insecticide was D.D.T.; in the other the alpha isomer of B.H.C. was detected.

In a survey of milk from dairy herds conducted by the Department of Agriculture, 133 samples were analysed for organo-chlorine insecticides. Samples for the survey were selected from properties devoted solely to dairy products (control group), and from others where the use of pesticides was expected to be greater on account of the production of potatoes and/or other vegetables on the same property.

The average concentration of insecticides in milk from the control group was found to be much lower than in milk from the other group, in which there were 9 samples where the concentration of D.D.T. and metabolites exceeded 0.005 part per million, and 5 samples where the concentration of dieldrin exceeded this figure.

Eleven samples of cream were analysed for organo-chlorine insecticides; four showed levels of D.D.T. and metabolites exceeding 0.005 part per million, calculated on a whole-milk basis.

Six imported cheeses and two local products were analysed for the Public Health Department to determine levels of organo-chlorine insecticides. Levels were significantly higher in the imported products particularly in respect of D.D.T. and its metabolites.

A variety of other foods were also examined for pesticides either to determine residue levels as a matter of information, or to investigate suspected contamination. These included eggs, egg pulp, calf and sheep liver, sheep kidney, oats, beans, cabbage, carrots, marrow, potatoes, spinach, tomatoes, and canned milks, both powdered and liquid.

Work was continued by the Horticulture Division of the Department of Agriculture on the control of "scald" in apples held in cold storage, and 15 samples of apples treated experimentally with diphenylamine, and 2 samples treated with ethoxyquin, were analysed to determine the concentration of each chemical on the skin of the treated fruit.

One hundred and thirty-five samples of fish and fish products were examined for the Public Health Department. Thirty-two varied products were analysed primarily to determine the nature of the colouring present; 13 contained artificial colouring matter while a number of others appeared to have been coloured with carotene type materials obviously not of natural occurrence in the fish.

Ninety-seven samples were examined in connection with investigations into possible "deterioration." These included 68 samples of smoked fish, chiefly smoked cod, 13 of scallops, 8 of mussels in a "pickling" liquid, and 8 miscellaneous samples. Six samples of canned tuna were analysed for mercury at the end of the year, and a sample of kippers contained crystals of struvite, often mistaken for "glass beads".

A very considerable amount of work was carried out in an investigation of ten commercial fruit juices to ascertain the various parameters which might be used as an index of natural juice content, while a number of non-excisable beverages were analysed for alcohol in a check of a recommended method for determining alcohol in concentrations below two degrees of proof spirit.

Miscellaneous foods examined during the year included aerated waters which had developed an unusual flavour, and identification of foreign matter in samples of flour, sugar, breakfast food and canned strawberries.

Human Toxicology

Exhibits were received from 505 cases of sudden death which were the subject of police investigation. Two hundred and forty-seven cases were as a result of traffic accidents, while 188 cases, comprising 955 exhibits were submitted for examination for poisons or other physiologically active drugs.

Table 10

Poison or Drug	No. of Cases
Carbon monoxide	27
Pentobarbitone	24
Amylobarbitone	12
Phenobarbitone	10
Quinalbarbitone	7
Carbromal	6
Bromvaletone	4
Thioridazine	3
Amitriptyline	2
Desipramine	2
Doloxene	2
Imipramine	2
Librium	2
Methanol	2
*Various (one of each)	17
Negative	90

* Barbiturate (unidentified), butobarbitone, chlorpromazine, chlorpropamide, ethopropazine, fenthion, methaqualone, orphenadrine, parathion, petrol, protriptyline, salicylic acid (from aspirin), sodium carbonate (from decomposed cyanide), strychnine, theophylline (from choledyl), yohimbine.

In 90 cases no poison or drug was detected, but in 98 cases a poisonous substance or a drug was identified as a result of examination. In several cases the concentration of the drug made its toxicological significance uncertain.

Details are listed in Table 10.

In 62 of the 160 cases where a sample of blood was available, alcohol was found to be present. The distribution of the blood-alcohol figures is shown in Table 11.

Table 11

Alcohol, per cent	No. of cases
Negative	98
Less than 0·080	24
0·080—0·149	13
0·150—0·300	22
More than 0·300	3

Blood Alcohol (Traffic Deaths)

Four hundred and thirty-nine samples of blood and/or urine were received in connection with investigations into 247 fatal traffic accidents. Two hundred and fifty-five of these were "post mortem" blood samples which were analysed for alcohol content as a routine procedure.

The distribution of the analytical blood-alcohol figures for the various categories of persons involved in these accidents is shown in Table 12.

Table 12
Traffic Accident Deaths

Alcohol per cent	Drivers	Passengers	Pedestrians
	Number involved		
Negative	55	39	29
0·050 and less	7	8	2
0·051—0·079	8	11	....
0·080—0·149	19	10	3
0·150—0·200	21	5	3
0·201—0·250	14	4	6
0·251—0·300	5	....	6
More than 0·300	3	3	5
	132	69	54

Table 12 shows that 32.5 per cent of fatally injured drivers had a blood-alcohol figure of, or exceeding, 0.150 per cent, while the corresponding figure for passengers and pedestrians was 17.5 per cent. and 37 per cent respectively.

If the "upper limit" were 0.08 per cent, then Table 12 shows that 47 per cent of drivers had a blood-alcohol figure of, or exceeding, this limit.

In presenting these figures it is emphasised that they apply only to the 255 blood samples received for analysis; it is understood that the actual number of "traffic deaths" in Western Australia during 1970 totalled 362.

Blood Alcohol (Traffic Act)

Five hundred and ninety-eight samples of blood were received from the Police and Local Authorities in connection with—

(a) charges of driving while under the influence of alcohol;

(b) other provisions of the Traffic Act.

Samples included under (a) were taken from persons who on being charged with this offence, had exercised the right provided by the Traffic Act to have a blood sample taken by a doctor and submitted for chemical analysis.

Samples included under (b) were taken from persons involved in a traffic accident which resulted in personal injury or damage to property, and of whom it was suspected that alcohol may have been a factor contributing to the accident. In some cases where samples were taken "breath analysis" equipment was not readily available, or could not be used; in others the sample was requested by the subject exercising his rights following a "preliminary test" or a breath analysis (Section 32B(4) and (5) of the Traffic Act.)

Under Section 32AA(1) 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. Under Section 32C(4), 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 vehicle . . ."

The results of analyses of samples taken under the provisions of the Traffic Act are set out in Table 13, the figure being the alcohol content of the blood at the time of the accident or alleged offence, calculated as prescribed by the Blood Sampling and Analysis Regulations, 1966.

Table 13

Alcohol, per cent	No. of cases
0·050 and less	22
0·051—0·079	20
0·080—0·099	17
0·100—0·149	91
0·150—0·200	168
0·201—0·250	146
0·251—0·300	103
More than 0·300	31
	598

In accordance with established practice, each analysis was repeated independently by another chemist, making a total of 1196 analyses in connection with this work.

Table 13 shows that 448 persons, or 75 per cent of the total had a blood-alcohol figure of, or exceeding, 0.150 per cent; 539 persons, or 90 per cent of the total, had a blood-alcohol figure of, or exceeding 0.100 per cent; and 556 persons, or 93 per cent of the total, had a blood-alcohol figure of, or exceeding, 0.080 per cent.

Specimens from patients

One hundred and ninety-three samples were received under this classification, comprising principally samples of urine, blood serum and blood plasma, with smaller numbers of whole blood, gastric washouts, hair, nails, etc. These were analysed in connection with the medical examination of patients for clinical purposes as distinct from industrial hygiene and toxicology. The different types of analyses performed under this classification are detailed in Table 14.

Table 14

Analysis	Number
Lithium	103
Lead	28
Arsenic	19
Dieldrin	10
Drugs (general)	7
Amphetamines	7
Alcohol	6
Copper	6
Thallium	6
Fluorine	5
Mercury	4
Antimony	2
*Various (one of each)	9

*Barbiturates, disipal, fibres (identification) indomethacin, imipramine, methanol, organochlorine insecticides, strychnine, warfarin.

Animal Toxicology

Forty exhibits were received from 20 animal post mortem examinations. Twelve cases were negative, while strychnine was detected in 3 cases, arsenic in 2, lead in 2, and dieldrin in one.

From twenty-one suspected poison baits submitted for examination, strychnine was detected in three, the remainder were negative.

Industrial Hygiene

Four hundred and thirty samples were examined during the year in connection with industrial hygiene investigations, and represents a marked increase in numbers compared with those of recent years.

Two hundred and fourteen of these were specimens of urine from workers engaged in occupations where an actual or potential lead hazard was suspected. Analysis for lead was carried out to assist clinical diagnosis or to provide a "screening" to exclude the possibility of undue exposure.

Of these specimens, 155, or 73 per cent, contained not more than 0.08 part per million (milligram per litre) of lead (as Pb), 23 per cent contained 0.09-0.15 part per million, 2 per cent contained 0.16-0.20 part per million, and 2 per cent contained more than 0.20 part per million.

Other specimens of urine and/or blood were examined for arsenic, mercury, cyanide and organochlorine insecticides in connection with possible exposure of workers to hazardous conditions.

Inspections were made of working conditions in various factories, and samples of air or dust were analysed for—

(1) lead in a plastics factory where lead stearate powder was used;

(2) T.D.I. in a plant where foam plastic was being made;

(3) ethylene dibromide levels in and around a fumigation chamber during normal operations after fumigation of fruit;

(4) toluene levels during various operations in the manufacture of footwear;

(5) sodium fluoroacetate levels during the different operations involved in the manufacture and packaging of poisoned oats.

Eleven inspections were carried out to check working conditions during the unloading of cargo from ships' holds.

These were required as a result of leakage or spillage from containers of various chemicals such as cyanides, methyl bromide, naphthalene and T.D.I. "On the spot" assessments were made of the potential hazard in each case, and advice given as required on ventilation and other measures necessary for safe working conditions.

Forty-eight samples comprising exhaust gases and mine airs were received in connection with the use of diesel equipment underground in coal mines. These were analysed variously for carbon monoxide, carbon dioxide and oxides of nitrogen, while 76 gas detector tubes were examined to compare readings, in the Laboratory, with "on the spot" assessments made by mine officers at the time of taking the air samples.

Pollution

Swan River.—One hundred and forty-eight samples of water were collected and analysed during the year in connection with the regular quarterly surveys of the Swan River, while 13 additional samples were examined to investigate specific instances of suspected pollution.

Leschenault Inlet, Bunbury.—Examinations for the Public Works Department were continued with the regular summer and winter surveys of water in Leschenault Inlet at Bunbury, and 48 samples of water were collected and analysed in the surveys of January and July, 1970.

Maritime.—Eleven samples of suspected oil were received during 1970. These were fluids alleged to have been discharged from ships into waters under the jurisdiction of the Fremantle Port Authority, and were submitted for examination in order to establish that they were in fact oil or similar substance.

Miscellaneous

Pesticides—One hundred and thirty-six samples classified as pesticides were received for examination during the year. The numbers and types of these samples are listed in Table 15.

Table 15

Type of Pesticide	No. of Samples
Aldrin (concentrate)	13
Aldrin (diluted emulsion)	18
Chlordane (technical)	1
Dieldrin (concentrate)	12
Dieldrin (solid)	6
Dipping fluid	5
Endrin (concentrate)	1
Lead arsenate	2
Maldison (bait)	11
Maldison (concentrate)	4
P.C.P.A.	21
Sheep Dip powders	2
Weedicide concentrates—	
2,4-D amine	8
2,4-D ester	17
2,4,5-T ester	7
Various	4

Samples of aldrin concentrate and aldrin emulsion were examined for the Architectural Division, Public Works Department as a check on quality of materials being used with "white ant" preventive treatments as applied to building projects.

Samples of technical dieldrin and of dieldrin concentrates were analysed for the Biological Services Division of the Department of Agriculture, weedicide concentrates were analysed as a measure of quality control for the Weed Control Branch, and similar checks were carried out on samples of maldison concentrate and baits used in programmes of fruit fly control.

Twenty-one samples of P.C.P.A. and four samples of soil were analysed for the Plant Research Division of the Department of Agriculture in connection with suspected contamination with synthetic weedicide, while 18 samples of soil were examined for diuron and 6 for dicamba to investigate the possible causes of poor plant growth.

Criminal—Fifty-five miscellaneous exhibits were examined for the Police Department in connection with investigations by the Criminal Investigation Branch, Drug Squad. Of thirty drugs identified, one third were amphetamines, while there was a marked decrease in the number of cases where cannabis was detected.

Other exhibits examined in connection with criminal enquiries included:—

Suspected flammable liquids and various charred remnants of materials submitted in attempts to establish the cause of a number of fires and damage to property.

Identification of paints and home-made explosives also in connection with malicious damage to property.

Varied articles of clothing and welding equipment thought to be associated with a "breaking and entering" offence.

Foodstuffs suspected of containing poisons or other injurious substances.

Fragments of glass, paint chips, and a number of articles of clothing in connection with motor vehicle "hit and run" accidents.

General.—Work was continued on the collaborative study of blood alcohol analyses initiated by the 1968 Conference of Toxicologists, and a further nine samples of blood were received from the Medico-Legal Laboratories, Victoria.

One hundred and one samples of detergents were submitted by the Government Tender Board for consideration and advice on their suitability for use in Government institutions.

The samples varied from the synthetic detergent mixtures to composite soap powders, laundry adjuncts, liquid soap type cleaners, steam-cleaning compounds, solvent type degreasers and preparations for highly specialised uses.

A survey to ascertain the possible exposure of wildlife to pesticides was commenced at the end of the year, and samples of liver and muscle tissue from selected fish and birds were received and examined for the Department of Fisheries and Fauna.

Samples of tomato plants, poultry feed, poultry manure and sewage sludge were examined for the Plant Research Division of the Department of Agriculture in a continued investigation into the cause of hormone type damage to tomato plants.

Following an intensive training programme by one of the Division's officers in 1969, routine examination of samples was undertaken for the Western Australian Trotting Association, and 101 samples of horse urine and 67 samples of saliva were examined for drugs.

Samples of renal fat from sheep were analysed for the Animal Division, Department of Agriculture in an experiment designed to determine the nature of the residues accumulating in animals following oral ingestion of aldrin, dieldrin and endrin at levels which would produce significant residues but not cause sub-acute or chronic toxicity. Samples of aldrin, dieldrin and endrin were first examined for purity and then administered orally to three pairs of sheep at one milligram per kilogram body weight on 25 occasions over a period of 5½ weeks. The animals, including a control which had not received any pesticide, were slaughtered 3½ weeks later and renal fat samples analysed for organo-chlorine insecticides.

Results are shown in Table 16.

TABLE 16

Sample	Aldrin	Dieldrin	Endrin
	parts per million		
1. Control	n.d.	n.d.	n.d .
2. Aldrin	0·4	22·5	n.d.
3. Aldrin	0·4	18·0	n.d.
4. Endrin	n.d.	n.d.	1·4
5. Endrin	n.d.	n.d.	6·0
6. Dieldrin	n.d.	23·5	n.d.
7. Dieldrin	n.d.	26·2	n.d.

n.d.—not detected.

No other organo-chlorine insecticides were detected, the limit for these samples being 0.01 part per million.

Of some interest is the fact that although the chemical insomers, dieldrin and endrin were given at similar dose rates, the concentration of endrin stored in the fat is much lower than that of dieldrin. This agrees with the conclusions reached by Cole et al from experiments with rats (Toxicol. Appl. Pharmacol. 1970, 16, 547).

It appears that endrin is excreted more rapidly than dieldrin via the liver, and therefore less endrin is available for storage in fat depots.

Miscellaneous samples received and examined during the year included—

- plant material for toxic substances;
- waters suspected of contamination by pesticides;
- explosives for detailed analysis to ascertain composition;
- tallow examined for compliance with trade requirements;
- hypochlorite solution assayed for available chlorine content and for stability of concentrate and diluted solutions;
- compressed air for examination to standards required for underwater swimming;
- non-excisable fermented drinks for alcohol content.

The normal enquiries for technical information and advice were received during the year, and expert evidence was tendered in various Courts as required by officers of the Division in connection with their official duties.

Mr. N. R. Houghton attended the meeting of the Food Analysis (Reference) Sub-Committee of the National Health and Medical Research Council held at Canberra in March.

Mr. F. E. Uren attended the Conference of Pesticide Chemists arranged by the Department of Primary Industry at Sydney in April, and the Conference of Scientific Officers engaged in Industrial Hygiene held at Sydney in June.

Mr. V. J. McLinden attended the Conference of Forensic Toxicologists held at Sydney in October.

INDUSTRIAL CHEMISTRY DIVISION

Introduction

Two hundred and thirty three samples were examined during the year, an increase from the 157 samples of 1969. As will be seen later, of this total 175 were peat or related materials. All these peat samples were "Public Pay" and in addition there were 5 further samples in this category and 8 samples paid for by other Government Departments.

As in previous years there has been considerable consultative work covering a wide range of materials and applications. Plastics continue to occupy a large amount of time.

Staff

1. The vacancy existing at the end of 1969 for a Chemist and Research Officer was filled by Mr. H. Kippo, a recent Associate from the W.A. Institute of Technology, who started work in February.

2. Dr. Smith delivered the first and last lectures of the "Know Your Plastics" series organised by the Plastics Institute of Australia.

Details of Work

1. Routine.

(a) Building materials.—Several samples of building materials were examined.

The abrasion or wear resistance of concrete floors is an important property and information was needed for a proprietary corrosion resistant concrete. An abrasion test was carried out to compare this special concrete with standard concrete. It was found that the abrasion resistance of the special was slightly better than the standard material.

Paint brushes frequently shed bristles in use. We were asked to examine some 6 in. brushes in which bristle shedding was much more serious than usual. The bristles were breaking off about half way down the brush and it was found in fact that many of the bristles had an area of weakness there. It was suggested that the pigs from which these bristles were collected had suffered a temporary stoppage to their growth. A similar break is shown in wool from sheep who have suffered temporary growth retardation.

There are three types of silicone masonry water repellants. The original solvent soluble type was satisfactory on bricks and stone but poor on mortar. A second type was developed with improved resistance to the alkali in mortar and also soluble in water. This second type, however, is not very effective on bricks, etc. More recently a third, solvent-soluble, type has been developed which is claimed to be satisfactory both on masonry and mortar. We were asked to compare these three types on limestone and mortar. This was done and it was found that the third type of water repellent was satisfactory on both limestone and mortar, but was not quite as efficient on limestone as the first type.

An investigation of adhesion failure of external glass mosaic tiles indicated that the likely cause was inadequate expansion joints. Recommendations were made to overcome the problem and an epoxy adhesive suggested for replacing fallen tiles.

We were asked to check the moisture content of an order for dry, dressed timber which had to comply with a specification requiring a certain maximum moisture content. A suitable percentage of the timber was tested and found to comply with the specification.

A sample of a zinc rich silicate paint was analysed for zinc and silica content.

A complaint of poor coverage by a particular brand of paint was checked by comparing the properties of the paint used with the values obtained when this brand of paint was originally tested by these Laboratories about 18 months ago. It was found that covering power was in fact substantially worse, possibly caused by a considerable reduction in paint viscosity. Titanium dioxide content was similar to that contained in an equivalent paint of another well-known brand.

We were asked to advise on whether yellow stains on a vinyl flooring had been caused by the type of adhesive used to bond the flooring to the concrete sub-floor. It was suspected that a bitumastic adhesive had been used but it was found that this was not so and the correct type of adhesive had in fact been applied.

Two proprietary paints applied to asbestos cement sheet were tested for resistance to various environments. It was thought that they might be suitable for use in areas where greater resistance might be needed. Tests applied were—

(i) resistance to UV light;

(ii) resistance to heat and steam;

(iii) resistance to certain chemicals—detergent, dilute hydrochloric acid, 5 per cent phenol and alcohol;

(iv) staining by timber.

One paint was unaffected by the UV exposure test, the other was severely affected. Both softened under the influence of heat or steam, but did not lose adhesion and did not blister or peel. One was slightly softened by alcohol and phenol but not affected by detergent and hydrochloric acid, and the other was only affected by phenol. Our attempts to develop timber stains using jarrah blocks were not too successful, but such stains can usually be removed by bleaching with sodium hypochlorite.

(b) Plastics.—Two plastic coatings were examined for resistance to certain conditions. One coating had been suggested for the walls of a room which would be subjected to frequent chemical disinfection. We had previously tested another plastic coating for the same service and it was found to resist the effects of formalin and phenol solutions. In the present case the coating failed.

The second coating was required to protect a steel holding tank from three rather complex chemical effluents. Coated steel samples were immersed in the three effluents but in each case blistering had developed more or less seriously after two weeks immersion and after four weeks active corrosion had started.

We were asked to identify some rubber gaskets, two samples from each of two suppliers. All four samples were thought to be neoprene, but in fact only one was identified as neoprene, the other three being of nitrile rubber. Field tests for distinguishing between these two types of rubber were suggested.

Two samples of rigid PVC pipe were analysed for filler content and per cent calcium carbonate in the filler. Loss in weight after immersion in three strengths of sulphuric acid was also determined.

Six samples of plastic netting, 3 of a well-known brand and 3 others, were tested for resistance to UV light. The first 3 samples were not affected by the exposure, but with the other three the colour had darkened a little and there was some reduction in strength.

(c) Miscellaneous.—In making prints of engineering and other drawings there is a method called the "True-to-Scale" process, in which the exposed sensitized paper is applied to the surface of a special gelatin coating. This coating picks up the lines, etc., of the drawing and they are then transferred to another sheet of paper to produce the print. A particular batch of sensitized paper was causing trouble by producing a build-up of deposit on the gelatin surface, which in turn produced a "dirty" print. It was found that the deposit consisted largely of cellulose fibres and it was concluded that the base paper used to produce the sensitized material was at fault.

A sample of a white incrustation was submitted from wooden pallets from a ship also carrying tolylene di-isocyanate, one drum of which had leaked. This chemical is very toxic but readily reacts with water such as moisture in the atmosphere to produce a relatively harmless product. It was originally thought that some cartons on the pallets were also affected, but this was later found not to be the case. Examination of the sample showed that there was still some free isocyanate present and the pallets were destroyed by burning.

Several samples of surgical materials were submitted for identification, one of surgical sheeting and two types of surgical overshoes. The sheeting was found to be paper coated on one side with polythene film. One type of overshoe was a composite of five layers, consisting of tissue paper/non-woven rayon/tissue paper/perforated polythene film/tissue paper. The other type of overshoe was a non-woven polythene fabric.

We were asked to test some old photographic film for storage stability. This was done and we may occasionally be asked to carry out similar tests in the future.

The literature survey on accelerated weathering, mentioned in last year's report, has been completed. However, nothing more was done on the literature search for chemicals from timber because of pressure of other work.

A sample of a resinuous material was submitted for identification. It was reported to have been found in the sub-soil in an ilmenite deposit being worked near Capel and that large quantities were present. The material was clear and of pale amber colour, roughly cylindrical and with sand grains embedded in the surface. It was found to be virtually identical with an amine-cured epoxy resin. There is some doubt about the real origin of this sample.

2. Assistance to small industry.

(a) Vegetable oil extraction.—The sponsored project mentioned in the 1969 Annual Report has now been completed.

(b) Marine protein concentrate.—Considerable further information was obtained on this process but the company sponsoring the enquiry was not able to proceed further because of shortage of funds.

(c) Rat proofing.—Advice on rat proofing was given to a chicken farm.

(d) Paints.—A problem concerning coverage of paint used on the ceiling of a new house was investigated.

(e) Paint identification.—A company was concerned by the poor adhesion of a paint applied to some heavy equipment of its manufacture. Samples of paint flakes were supplied and it was confirmed that the material was in fact an epoxy coating. Suggestions were made to explain the poor adhesion experienced.

(f) Fibreboard.—The Department of Industrial Development sponsored an investigation on behalf of two suitcase manufacturers to compare the properties of an Australian made and an imported fibreboard. They claimed that the Australian product was unsuitable and wished to import the superior product free of duty. Various properties were examined, such as impact strength, abrasion resistance, resistance to water, resistance to delamination, etc. One product was found to be superior to the other in most properties examined.

(g) Plastic tubes.—The Department of Industrial Development requested the identification of some imported disposable hospital tubes on behalf of a local company. The material of the tubes was identified as polystyrene.

(h) Montan wax.—Sixteen samples of low grade coal were examined for montan wax content for a number of companies and individuals. One company also required the determination of a number of properties and for this purpose a quantity of wax had to be prepared by solvent extraction.

(i) Dust cloths.—Specially impregnated cloths are used in the painting industry for removing dust from surfaces immediately prior to the application of the paint. On behalf of a local company importing such cloths the Department of Industrial Development sponsored work to identify the impregnant to assist the company to establish local manufacture. The type of chemical was successfully identified and advice given on a source of supply.

3. Investigational.

(a) Painting of karri timber.—The third exposure trial is still in progress. An inspection after exposure for one year showed that no panels have failed so far.

(b) Wax from peat.—A company has now taken over direct sponsorship for this work. During the year a total of 159 samples of peat were analysed for wax content. Other properties of the wax were also determined and some work done on refining. A larger extraction plant was also designed and constructed and has been used to produce quantities of crude wax for evaluation.

(c) Printers' rollers.—Some years ago this Division assisted the Government Printer in establishing the manufacture of polyurethane rubber printers' rollers for their own use. This operation has been very successful, the rollers produced being much superior to the materials previously used. However, one of the chemicals required is tolylene di-isocyanate which is, as mentioned earlier a toxic chemical and hazardous to handle. The Goverment Printer has become more and more concerned about the use of this chemical and has now asked us to prepare rollers from other elastomeric materials.

Work has been done with flexible polyvinyl chloride and some experimental rollers are now under test. In addition we are examining other possibilities such as flexible epoxies, polysulphide rubbers and possibly silicone rubbers. Also, it may be possible to replace the tolylene di-isocyanate with a less hazardous equivalent and still produce a satisfactory polyurethane rubber. The investigation is continuing.

(d) Lubricating oil recovery.—We have been asked by a major mining company which uses large quantities of lubricating oils to advise them on methods of treating used oil for re-use. Work has started and will be continued in 1971.

4. Other activities.

Scaevola spinescens.—We have continued to supply an extract of this native plant to cancer sufferers. Four collecting trips were necessary during the year to replenish our supplies.

As foreshadowed in last year's report, the Professor of Pharmacology at the University of Western Australia started a research student on the pharmacological screening of the extract. In an oral report during the year Professor Lockett advised that the first general screening test had shown the extract to possess moderate pharmacological activity. This activity appears to be associated with more than one component of the extract. This work is continuing and the initial screening phase is nearing completion.

5. Consultative.

The following items are examples of the consultative work done during the year:—

- The treatment of molybdenum ore for production of molybdenum disulphide as a lubricant additive.
- Pelletting of metaldehyde for production of snail bait and heating pellets.
- Recolouring bronze door of a city building.
- Colouring of fruit fly bait sprays for identification of trees treated. In this case a range of water and oil soluble dyes was suggested for trial and supply of samples arranged through a major dyestuffs manufacturer.
- Improvements in the surface coating of poisoned oats for rabbit control.
- Accelerated test for antioxidants in oil.
- Advice on manufacture of buoyant plastic water skis.

The above examples are only a few of the large number of enquiries received, indicating the wide range of subjects covered.

MINERAL, MINERAL TECHNOLOGY AND GEOCHEMISTRY DIVISION

General

The total number of samples registered during 1970 fell approximately 300 short of the previous year due mainly to the fact that the large number of geochemical samples was not repeated. Submissions from other branches of Mines Department, excluding geochemical traces, increased, as did submissions from other Government Departments and of subsidised work for the public. A decrease from 782 to 668 of investigations done on a confidential basis for the public was probably due to the activities of the many commercial laboratories which operated in the State during this year.

Table 17 shows the source and type of samples handled during the year. Many investigations registered include a wide range of examinations both chemical and mineralogical.

The various localities stated throughout this report are only approximate.

Despite the policy of these Laboratories to avoid competition with private laboratories, work is still accepted on a commercial basis when clients have particular reasons for requesting our report. A number of samples have been submitted by clients wishing to have umpire figures to settle disputed figures obtained elsewhere. Co-operation with commercial laboratories has resulted in consultation regarding methods of analysis on numerous occasions and the provision of analysed samples for use as standards.

Staff

Post graduate courses undertaken include a term at the Western Australian Institute of Technology on Electron Microscopy attended by 3 officers and a similar course on Electron Micro-probe analysis attended by 4 officers. Two seminars on special X-ray computer programmes conducted by Dr. B. Roof, visiting lecturer in Physics from Los Alamos, California, were attended by 3 officers. A further member of the staff attended the Fortran programming course at the University of W.A. and the safety officer attended a course on Industrial Civil Defence at the Civil Defence School, Belmont.

Mr. M. Pryce attended the seventh annual meeting of Australian Crystallographers in Sydney and at the same time visited the laboratories of the Geology Department of the Australian National University and Bureau of Mineral Resources, Canberra.

Mr. M. B. Costello attended a "Symposium on Analytical Chemistry of Uranium and Thorium" at Lucas Heights, and combined visits to C.S.I.R.O. and State Mines Department in Victoria.

In order to extend the usefulness of investigations on behalf of a mineral producing firm Mr. R. C. Morris made a visit to Adelaide and Melbourne at that firm's expense in March. The initial purpose of the visit was to use electro micro-probe equipment at Australian Mineral Development Laboratories (AMDEL) in Adelaide. The opportunity was taken to discuss metallography techniques and problems with AMDEL officers and others at the C.S.I.R.O. Laboratories of Applied Mineralogy and Mineral Chemistry, and the University Geology Department in Melbourne. Improvement of our own Laboratory facilities should follow adoption of improved thin sectioning and polishing equipment and ultimate installation of electron probe equipment.

A conference on Archean Rocks conducted in Perth by the Geological Society of Australia was attended by 4 officers.

Field trips.—Visits to mineral deposits in the field were made through the courtesy of the State Batteries. Mr. G. H. Payne made two trips, in July to Dalgaranga tantalite workings and Mt. Magnet, and in October to an alleged beryl deposit on Badja Station, which proved to be baryte, to Kathleen Hope Lead Mine and State Battery at Northampton and to a diatomite deposit at Irwin. Similarly Mr. R. S. Pepper visited deposits at Marvel Loch, Coolgardie, Kalgoorlie, Menzies and Leonora and Mr. R. W. Lindsey travelled to Sandstone, Meekatharra, and Mt. Magnet.

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Table 17

MINERAL DIVISION

	Main Roads Department	Mines Department	Public Health Department	Other Government Departments: State (a)	Other Government Departments: Commonwealth (b)	Public: Pay	Public: Subsidised	University W.A.	Total
Complete Analyses	10	13	....	....	....	2	....	....	25
Mineral Identifications	....	178	....	11	....	109	202	....	500
Minerals and Ores—									
Bauxite	....	6	....	....	....	14	95	....	115
Beryl	....	2	....	....	....	6	3	....	11
Clay (c)	1	18	....	2	....	48	61	....	130
Copper	....	9	....	....	....	25	22	....	56
Gold	....	58	....	....	....	30	37	....	125
Heavy sand	....	....	....	....	....	39	18	....	57
Iron	....	29	2	4	....	22	32	....	89
Lead	....	3	....	....	....	3	10	....	16
Lime	....	5	....	....	....	5	8	....	18
Lithium	....	2	....	....	....	10	1	....	13
Nickel	....	8	....	....	....	81	337	....	426
Phosphorus	....	29	....	....	....	3	3	....	35
Quartz (d)	....	....	....	....	....	21	15	....	36
Radioactive Minerals (e)	....	6	....	....	....	17	1	....	24
Tantalite	....	12	....	....	....	19	2	....	33
Tin	....	44	....	....	....	12	....	....	56
Titanium	....	9	....	....	....	78	5	....	92
Vanadium	....	....	....	....	....	3	21	....	24
Other (f)	....	5	....	1	....	26	7	....	39
Miscellaneous Investigations—									
Building Materials (g)	20	3	....	10	1	7	....	....	41
Calibrations (h)	....	24	1	12	16	12	....	....	65
Corrosion	6	....	1	2	....	2	....	....	11
Dusts	....	10	369	....	12	....	....	....	391
Explosives	....	8	....	....	....	....	....	....	8
Geochemistry	....	471	....	....	....	45	9	....	525
Metals and Alloys	3	....	....	3	....	....	....	6	12
Other	....	46	1	16	2	30	....	1	96
TOTAL	40	998	374	61	31	669	889	7	3,069

(a) Includes Agriculture, Industrial Development, Metropolitan Water Board, Native Welfare, Police and Public Works.
(b) Australian Broadcasting Commission, Department of Civil Aviation, Royal Australian Air Force, Royal Austral an Navy, Department of Works.
(c) Includes bentonite.
(d) Includes quartz sands.
(e) Mainly monazite concentrates.
(f) Includes antimony, bismuth, feldspar, fluorite, gypsum, manganese, salt, silver, tungsten.
(g) Mainly concrete and aggregates.
(h) Includes thermometers, pyrometers, weights.

In the course of a visit to Kalgoorlie to assess a Geochemical Laboratory for the National Association of Testing Authorities (NATA), Mr. D. Burns visited mineral occurrences at Scotia, Widgiemooltha and Kambalda. Mr. Burns also assessed for N.A.T.A. a geochemical laboratory in Belmont and Mr. G. H. Payne acted as assessor for an industrial laboratory at Rivervale.

Publications.—Publications during the year included a paper by M. Pryce in the Journal of Physics E (Scientific Instruments) entitled "A Weissenberg Goniometer for Straumanis Position Films with 8 : 1 ratio" and a paper by L. C. Hodge in the Mineralogical Magazine V37 (1970) p. 705-707 entitled "Russellite: a second occurrence".

Other professional activities of the staff include offices held in the Analytical Group of the Royal Australian Chemical Institute. Mr. M. B. Costello acted as secretary and Mr. Burns as committee member.

Equipment

Early in the year the Division took delivery of a Siemens S.R.S.1. X-ray fluorescence spectrometry unit. To date its effectiveness has been shown in scans of unknown material and comparisons, for example for police work; for major element analysis of silicate rocks; and for trace tantalum and other elements in samples of some matrices.

Necessary replacement of an old Philips-Mueller X-ray generator was made with a Philips PW1130 X-ray generator together with copper and iron target tubes. This unit is considerably more powerful than the unit it replaces with a consequent speeding up of film exposures. In addition the availability of four ports enables routine work to proceed along with long term Weissenberg exposures.

The General Electric X-ray Diffraction unit previously reported as requiring adjustments in order to pass safety requirements, is expected to be ready for use early in 1971.

Calculations within the Division have been considerably speeded up by replacement of an unserviceable mechanical calculator with an electronic one.

Visitors

Distinguished visitors to the Division with whom profitable discussions took place, included Mr. F. Ward of the United States Geological Survey and Dr. Ralph E. Grim and Mr. C. C. Harvey of Illinois, U.S.A.

Mineral Collections

The holding of specimens in the Departmental collection increased to 4,566 by the addition of 171 specimens. Of these three only were from overseas localities; vanadinite from Castle Dome Mine in Arizona; ulexite from Boron, California; and hausmannite from Langban in Sweden.

Nineteen additions were made from other Australian States due largely to satisfying cooperation by Mr. J. Halford, Geology Department, Australian National University. These included chalcocite, hematite, native copper and cuprite from the Peko Mine in Northern Territory; kaersutite from Glen Inne, N.S.W.; willemite, hedyphane, coronadite from Aroona, South Australia; roepperite, bustamite, hedenbergite, iodyrite and stolzite from Broken Hill; pyrophyllite from Pambula, N.S.W.; axinite from Nundle N.S.W.; apatite from Boolcoolmatta, South Australia; gypsum from Andanooka, South Australia; prehnite from Prospect, N.S.W.; pyromorphite from Zeehan, Tasmania; and scholzite from Reaphook Hill, South Australia.

The sample of kaersutite from Glen Inne was of sufficient uniformity to be used as an electron micro-probe standard and was accompanied by detailed analyses by courtesy of the Geophysics Department of the Australian National University.

From within Western Australia 149 specimens were added. Of these many were collected by Departmental officers on field trips or donated by private individuals or companies and represented new localities. New localities are listed elsewhere.

Major contributors to the collection have been the Geology Department of the Australian National University, Canberra, Mr. R. Adams, Electrolytic Zinc Co., Mr. A. J. Pixley of Queensland, Mr. P. J. Bridge, Mr. D. Haynes, Mr. G. Just and Mr. W. Moriarty.

The Divisions collection of standard materials has been expanded by the addition of standard rock samples G2, GSP-1, AGV-1, PCC-1, DTS-1, BCR-1 graciously supplied by the United States Department of the Interior.

Demands on the exchange collection have been net by supplying specimens for display at the Motor Show by the Department of Industrial Development. Some large specimens for display at the London office of the Tourist Development Authority were also provided. The usual requests for mineral collections for prospectors, students and schools were met until mid-year when the demand became so heavy that supply had to be discontinued.

Specific requests were satisfied for research workers at the University of Queensland for pilbarite and from the University of Munich for lump scheelite required for tungsten isotope studies and for moraesite for the Geology Department of the Australian National University. Selected specimens were also exchanged with some large scale mineral collectors.

A collection of aggregates proposed for concrete and which have been examined for potential alkali reactivity has been added to with 21 samples, raising the total to 95. Locality and mineral type are also recorded.

New Mineral Localities

Listed below are the localities from which the occurrence of the named species was recorded at the Laboratories for the first time in 1970.

(a) Kimberley Division

Azurite	13 miles West of Kununurra
Azurite	16½ miles West of Kununurra
Beaverite	13 miles West of Kununurra
Beryl	Moondooma Creek, 29 miles East South East of Oobagooma Homestead
Bindheimite	16½ miles West of Kununurra
Bournonite	13 miles West of Kununurra
Chalcocite	13 miles West of Kununurra
Chalcocite	16½ miles West of Kununurra
Chalcopyrite	Kwinana Mission
Chalcopyrite	13 miles West of Kununurra
Chalcopyrite	16½ miles West of Kununurra
Covellite	13 miles West of Kununurra
Cuprite	16½ miles West of Kununurra
Digenite	13 miles West of Kununurra
Famatinite	16½ miles West of Kununurra
Famatinite	13 miles West of Kununurra
Freibergite	13 miles West of Kununurra
Freibergite	16½ miles West of Kununurra
Galena	16½ miles West of Kununurra
Glauconite	Kwinana Mission
Hemimorphite	13 miles West of Kununurra
Jalpaite or Acanthite	13 miles West of Kununurra
Linarite	13 miles West of Kununurra
Malachite	13 miles West of Kununurra
Malachite	16½ miles West of Kununurra
Pyrite	16½ miles West of Kununurra
Pyrargyrite	13 miles West of Kununurra
Stromeyerite	13 miles West of Kununurra

(b) North West Division

Anthophyllite	White Spring on Pyramid Station
Berlinite	Gilgun Station
Cassiterite	1½ miles South of junction of Garden Creek and West Shaw River, i.e., about 12 miles South of Hillside Station
Cerussite	Talga River off Marble Bar road
Cordierite	20 miles North North West of Yinnietharra
Crandallite	High Range Lyndon Station
Galena	Talga River off Marble Bar road
Lepidolite	Stannum
Portlandite	Ripple Shoals
Turquoise	High Range Lyndon Station

(c) Murchison District

Baryte	¼ mile from Badja shearing shed
Beryl	¼ mile from Badja shearing shed
Beryl	5 miles North West Narra Tarra
Bismutite	20 miles East Gascoyne Junction
Chalcopyrite	Chesterfield
Chromite	Mt. Narryer
Chloritoid with Fuchsite	Robinson Range
Dolomite	3 miles East Mooloo Downs Homestead
Galena	Chesterfield
Ilmenite (with hematite magnetite)	Brown's soak, 30 miles South Youanmi
Sphalerite	Chesterfield
Sphalerite	Kathleen Hope LM, 5 miles North North West of Northampton
Tetrahedrite	Northampton Wheal Fortune Mine
Topaz	8 miles North Dalgaranga

(d) South West Division

Laumontite	Ravensthorpe
Microlite	Greenbushes
Monazite	10 miles North Mukinbudin
Prehnite	Lake Biddy
Stilbite	Helena Dam Site

(e) Central Division

Dolomite	Wan Away
Gersdorffite	Mt. Martin
Paratacamite	Eulaminna
Paratacamite	Murrin Murrin
Pseudorutile	Coolgardie
Talc	Nookawarra
Valleriite	Scotia
Violarite	Mt. Martin

(f) Eucla Division

Graphite	between Grass Patch and Truslove
Ixiolite	Norseman
Djurleite	Warburton Mission

An investigation of lead-silver-copper ore from Kununurra provided a number of mineral specimens recorded at these Laboratories for the first time from Western Australia. These include stromeyerite CuAgS, a mineral which is jalpaite Ag_3CuS_2 or possibly acanthite Ag_2S, and a mineral tentatively identified by microhardness, reflectance and optical properties as pyrargyrite.

Another new mineral occurrence in W.A. is crandallite $CaAl_3(PO_4)_2(OH)_5.H_2O$ from High Range on Lyndon Station.

Complete Analyses

Included amongst these samples are some examined at length though not totalled to 100 per cent.

A suite of 10 soil samples from the Shire of Shark Bay taken in connection with soil stability studies was analysed for all major elements. This was also the case with a number of rock analyses where only silica, iron and alumina bases and alkalis were required.

Norms were calculated for five rocks from Edjudina which had the following analyses.

	Basalt	Fine-grained dolerite	Amygdaloidal basalt	Carbonated andesite	Andesite
	per cent	per cent	per cent	per cent	per cent
Silica, SiO_2	48·97	49·16	57·52	54·98	53·21
Alumina, Al_2O_3	14·24	13·33	15·85	16·11	15·56
Ferric oxide, Fe_2O_3	3·29	3·05	2·20	1·13	1·92
Ferrous oxide, FeO	9·52	10·82	6·46	5·22	6·00
Magnesium oxide, MgO	7·77	7·82	4·19	5·39	4·31
Calcium oxide, CaO	12·15	9·51	4·03	5·74	7·00
Sodium oxide, Na_2O	1·41	2·32	2·98	4·30	2·92
Potassium oxide, K_2O	0·14	0·24	0·88	0·25	0·59
Combined water, H_2O+	1·52	2·36	3·26	3·16	3·30
Free water, H_2O-	0·07	0·08	0·10	0·08	0·06
Carbon dioxide, CO_2	0·01	0·01	0·80	2·73	4·16
Titanium dioxide, TiO_2	0·96	1·04	1·34	0·86	0·96
Phosphorus pentoxide, P_2O_5	0·09	0·09	0·30	0·18	0·16
Sulphur, S	(*a*)	(*a*)	(*a*)	(*a*)	(*a*)
Manganese oxide, MnO	0·17	0·19	0·11	0·09	0·11
Nickel oxide, NiO	0·02	0·01	0·02	0·01	0·01
Copper oxide, CuO	0·01	0·02	0·01	0·01	0·01
Chromium trioxide, Cr_2O_3	0·03	0·03	0·04	0·02	0·01
Lithium oxide, Li_2O	0·03	0·03	0·05	0·02	0·04
TOTAL	100·40	100·11	100·14	100·28	100·33

(*a*) less than 0·01—Analyst, P. Hewson.

A sample of white fibrous rosetted crystals from Reaphook Hill in South Australia donated to the Laboratories in connection with an investigation of cave minerals, proved to be from the second world occurrence of scholzite.

The chemical analysis and comparison with published figures for scholzite are tabulated below:

	Specimen	AM. Min. 46:1519,1961	$CaZn_2(PO_4)_2.2H_2O$
	per cent	per cent	per cent
CaO	14.5	14.29	14.2
ZnO	39.7	35.70	41.1
P_2O_5	35.0	35.99	35.8
H_2O+	9.54	....	8.9
H_2O-	0.17	....	....
H_2O	....	10.36	....
Fe_2O_3	0.63*	....	....
FeO	....	0.38	....
MnO	....	1.36	....
MgO	....	0.97	....
insol	....	0.88	....
	99.54	99.93	100.0

* total Fe, expressed as Fe_2O_3

Another mineral separated to reasonably pure state for analysis was a cordierite from 20 mile NW. Yinnietharra.

	Per cent
Silica, SiO_2	48·03
Alumina, Al_2O_3	35·4
Magnesia, MgO	13·2
Ferrous oxide, FeO	0·75
Ferric oxide, Fe_2O_3	0·11
Lime, CaO	0·16
Sodium oxide, Na_2O	0·30
Potassium oxide, K_2O	0·01
Manganese oxide, MnO	0·07
Combined water, H_2O	1·16
Moisture, H_2O-	0·64
	100·10

Analyst E. J. Tovey.

A complete analysis was made of an intergrowth of fine angular sand size particles of ilmenite and a little hematite with approximately 8 per cent of silicates. The silicates were mainly weathered feldspar, chlorites and hornblende. It was concluded that upgrading by physical methods would not be readily achieved.

Considerable attention was given to the analysis of two samples prepared as standards for use with X-ray fluorescence determination. The combination of elements presented an interesting problem for classical analysis. The analyses are as below.

A	per cent on dry basis
Copper, Cu	6·41
Lead, Pb	22·0
Zinc, Zn	5·43

B	per cent on dry basis
Iron, Fe	14·0
Nickel, Ni	6·49
Arsenic, As	5·24
Cobalt, Co	2·82
Sulphur, S	7·43

A parcel of leucoxene from current production was analysed with the following result.

	per cent as received
Ferrous oxide, FeO	0·39
Ferric oxide, Fe_2O_3	7·35
Manganese oxide, MnO	0·14
Calcium oxide, CaO	0·02
Magnesium oxide, MgO	0·05
Titanium dioxide, TiO_2	79·6
Silica, SiO_2	5·99
Alumina, Al_2O_3	1·92
Chromium trioxide, Cr_2O_3	0·09
Vanadium pentoxide, V_2O_5	0·22
Zirconium dioxide, ZrO_2	4·08

Minerals and Ores

1. Bauxite.—Considerable interest was shown in bauxite particularly in the early half of the year, and 110 samples were examined. Initially an attempt was made to screen out unacceptable material by estimating total alumina rather than the more significant "soda soluble" alumina. Subsequently a method was developed for estimation of "soda soluble" alumina from an alkaline solution by atomic absorption.

The following table shows approximate values in percentages and localities.

	Total alumina	Soda soluble alumina
Avon Loc. 18351	....	2
Banga Hill	....	4 to 6
Bindoon	....	21 to 43
Bokal	....	33
Boyup Brook	....	24
Bridgetown	14	....
Broomehill	....	25
Bruce Rock	....	15
Calingiri	....	36
Chittering	....	11 to 16
Cullalla	....	13 to 16
Cunderdin	8	....
Dangin	....	35
Dowerin	25	....
Eneabba	5 to 9	....
Goodlands	....	4
Great Eastern Highway, 64 m.	29	....
Great Eastern Highway, 69 m.	....	35
Katanning	....	9
Mahogany Creek	18	9
Mollerin	....	1 to 5
Mooliabeenie	....	23, 26, 36
Mt. Yule	17 to 25	....
Muchea	....	15
Mundaring	14	....
Narrikup	21 to 25	15
New Norcia	....	15, 21, 36, 42
Toodyay	....	16
Wellington Loc. 283	....	7
West Dandaragan	25 to 32	....
Woodanilling	32	....

2. Beryl.—Sales parcels constituted the major part of the examinations of beryl with values around 11.7 to 11.9 per cent BeO.

As usual samples were submitted which did not contain beryl and a beryl assaying 12.4 per cent BeO came from a locality incorrectly stated.

An unusual beryl with altered appearance from Greenbushes, varied from pale blue assaying 12.9 per cent BeO to white with a little kaolin assaying 12.5 per cent BeO.

A pegmatite at Roebourne contained beryl associated with bright yellow montmorillonite and illite in quartz feldspar and biotite.

Samples representing localities not earlier recorded assayed 11.8 per cent BeO from the Mt. Stewart Mica Mine and 12.9 from Narra Tarra.

3. Clays including bentonite:—There has been a considerable accumulation of data relating to clays in West Australia since the publishing of H. Bowley's "Ceramic Resources of the South West" in 1940. The weathering of the granite complexes of West Australia has provided numerous deposits of kaolin but development for ceramic uses has been limited by location and size. This year has seen a stimulation of interest in fine white clay for paper filling and in bentonitic clays, including a visit of overseas experts.

Clays examined other than white clays have been few, including a number of chromium bearing green clays prospected for nickel. A deep terra cotta clay from Kojonup shrank considerably and distorted. A set of clays of various colours submitted by an amateur potter from the south of the State were examined by differential thermal analysis.

Full mechanical and firing tests were conducted on eight clays on a commercial basis and from undisclosed localities, the sources including other laboratories and consulting geologists.

White clays submitted included samples from Beverley, Coolup, Dongara, Lake King, Meckering, Mt. Narryer, Mukinbudin, Onslow, Perenjori and Williams. Other tests made include an estimation of the pyrometric cone equivalent of a white pit clay. A clay from Mt. Magnet was tested for liquid limit, plastic limit and plasticity index, as a possible sealant for a dam. Another clay was tested by particle size analysis for load bearing properties.

This year a great impetus was given to the testing of supposed bentonites by publicity given during March to a potential commercial deposit at Forrestdale.

Bentonite is a material which is sought for a variety of uses, the main ones being as drilling mud, as a binder for foundry sands and fine iron-ore pellets and as a decolourising medium in the reclamation of oils and solvents.

The chemical constitution of the clay is not the criterion of its worth. Its desirable properties vary with the end use but in general it can be said that clays with pronounced swelling properties and high adsorption capacities find the widest use, the former for drilling muds and foundry work, the latter for decolourising.

To sort clays according to these properties we have employed the Sadlers test which gives a measure of the swelling properties and the Methylene Blue test which gives a measure of adsorption properties. High grade commercial bentonite from Wyoming has a Sadler value approaching 100 and a Methylene Blue (MB) value approaching zero, each on a scale 0 to 100.

Twelve bentonite samples were received from various sites at Forrestdale each recording a Sadlers value approximately 10 and a MB value in excess of 50. One sample reputedly from the publicised site was examined in greater detail. Its Sadler value was 20 and MB value 27. The grit material, +200 mesh size, was 47 per cent and the =2 micron fraction was only 3 per cent of the sample. X-ray diffraction showed the major minerals present as a montmorillonoid and quartz. Illite and kaolinite were relatively minor. Saponite is the most probable montmorillonoid. The magnesium content of the clay was 1.1 per cent compared with 0.08 per cent in the grit.

A further dozen samples fell in the group approximating to Sadlers 10; MB greater than 50.

Examples of variability through deposits, which necessitates great caution in sampling prospects, are four samples from an Armadale site which had Sadlers/MB values of 20/15, 15/20, 15/50, less than 10/110. From Kojonup a sample from 12 in. depth in a lake had values 95/less than 1 and from 18 in. to 20 in. values of 20/10.

Samples which showed some potential in these preliminary tests are tabulated below.

Locality	Sadlers	M.B.	Grit (+200 mesh)
Watheroo	100	0	....
Gunyidi	13	15	59
Gingin	13	10	74
Forrestdale	10	12	33
Kojonup	80	0·1	36
Kojonup	85	0·1	27
Beaufort River	10	less than 1	....

A number of other samples were examined without disclosure of locality.

4. Copper.—Fifty-six copper assays were made during the year apart from geochemical samples. Of these 18 were made without the locality being disclosed and ranged from 0.1 to 48.3 per cent. A suite of seven ores assaying 1, 2, 5, 10, 20, 40 and 60 per cent copper was prepared to calibrate an Isotope Fluorescence Analyser. The response of the instrument to these samples indicated that the filters installed in the instrument were not those appropriate to copper radiation measurement.

Samples from declared localities numbered 24 with the following percentage values: Bullsbrook 0.004; Clarks Mill (Towera Station) 1.48 to 44.5; Cue 8.69, 10.9; Fitzroy Crossing 0.62; Hammersley River 0.004; Mooloo Downs 1.36 to 1.75; Nanutarra 2.0; Northampton 0.44; Pilgangoora 0.002; Rothsay 16.2, 21.2; Springvale Station 0.24 to 1.24; Towera Station 0.44 to 1.56; Yalgoo 1.12 to 1.96; and Yalleen 6.10. Samples from Clarks Mill assayed up to 42.7 per cent sulphide copper.

A number of samples with very low copper figures were composed mainly of green epidote suspected of being secondary copper minerals.

Copper minerals were identified in samples from Hawkestone Creek, Northampton and the Warburton Ranges. This last specimen of djurleite is described under mineral identifications (selected).

5. Gold.—Once again the diversion of interest away from gold prospecting was evident in the number of samples submitted.

Of the 49 samples examined at public expense a great majority carried gold to the extent of 2 or less grains per long ton. The areas represented are Beverley, Coolgardie, Fitzgerald River, Higginsville, Hillview Station, Hyden, Lalla Rookh, Mallina, Mt. Florence, Mt. Hampton, Mullewa, Okly Panter Downs, Williambury and Willow Springs. Samples of higher values were received from Callion, 3.4 to 6.9 dwt; Olby Rocks 2 gr to 2.3 oz; Parkers Range 10 gr; Pindar 19.5 dwt to 3.5 oz; Ravensthorpe 2 dwt; Sandstone 15 dwt; and Yalgoo 1.3 oz.

Cyanidation tests to remove gold from tin-tantalite concentrates and products from a company exploring an extraction process were responsible for a number of the 40 assays done commercially. Others were from dumps being prospected, from mineral buyers offering a service to clients and other analytical laboratories not equipped for fire assay.

The general interest in gold was reflected in the receipts from State Batteries. Twenty six check assays were made for five Batteries and only five umpire assays were made for three Batteries.

An assay problem of interest concerned the fluxing of a tin-tantalite concentrate to prevent the cassiterite from reducing and so contaminating the lead button. The tin, tantalum and niobium were kept in the slag layer by omission of borax glass and addition of red lead Pb_3O_4 to the flux.

6. Heavy sands.—A great deal of prospecting attention has been paid to heavy sand this year particularly in the latter months. While the essential mineral in most heavy sands is ilmenite

they are recorded separately from occurrences of massive ilmenite and intergrowths, which are treated under titanium.

The examination given sands varied with the requirements of the person submitting the sample, from an identification of minerals present or an estimation of the total heavy mineral content to a quantitive estimation of the various heavy mineral species.

Of 57 heavy sands examined, the locality of origin was disclosed in only 15 cases as follows.

From Bolgart a sand contained 0.5. per cent ilmenite; from Buntine a sand contained 80 per cent heavy minerals mainly maghemite and hematite with quartz and feldspar; from Dongara a group of sands had heavy concentrates from 0.5 to 2.5 per cent consisting of ilmenite, leucoxene, zircon, rutile, kyanite, staurolite, magnetite and monazite; from Eneabba the heavy concentrates were 0.3 and 0.4 per cent; a Donnybrook sand contained 55 to 60 per cent ilmenite with quartz and feldspar and a small amount of magnetite, hornblende, zircon and rutile; a sand from Fitzroy Crossing contained 2 per cent heavy mineral, mainly silicates including zircon, zoisite, garnet and staurolite, with ilmenite 0.5 per cent; from Fossil Downs, a sand was largely magnetite with quartz and goethite; from Gascoyne River a heavy fraction of 13 per cent consisted of ilmenite, garnet and other silicates with some zircon and magnetite with traces of rutile, monazite and spinel; a quartz sand from Gardner River contained 13 per cent heavy minerals mainly ilmenite with magnetite, zircon, leucoxene and a trace of rutile; from Kimberley a sand assayed 37 per cent TiO_2; samples from Lake Logue contained 0.5 to 0.8 per cent heavy minerals consisting of ilmenite, leucoxene, zircon, magnetite, staurolite, hornblende, tourmaline, monazite and kyanite; a sand from Mingenew contained approximately 45 per cent ilmenite with 15 per cent zircon with quartz, rutile, magnetite and other iron oxides; from various localities around the Murchison river one sand contained 7 per cent heavy minerals mainly garnet with geothite and silicates, another contained 0.5 per cent heavy minerals mainly magnetite, iron oxides and calcite, and another had magnetite and silicates making up 0.25 per cent; two separate localities at Shark Bay varied widely. The 88 per cent heavy minerals of one was made up of 40 to 50 per cent ilmenite, 20 to 25 per cent zircon, 5 to 10 per cent leucoxene and 2 to 5 per cent of rutile. The second had 12 per cent heavy minerals consisting of ilmenite, leucoxene, zircon, staurolite and kyanite.

The numerous samples from undisclosed localities fell into much the same categories as the above consisting in some cases essentially of ilmenite and alteration products with zircon, and others where the main mineral was iron oxides, garnet or other heavy silicates. In some the main cause of interest was black organic matter.

An interesting sample amongst these was one containing coarse fragments of chalcopyrite and pyrite with a sand of ilmenite, magnetite, rutile and silicates with a trace of metallic copper; Another mainly quartz, feldspar and mica ranging from ½ inch size to fines contained garnet, pyrite, chalcopyrite with iron oxides, ilmenite, rutile, zircon and monazite; a consolidated sand has been described under Complete Analyses; a quartz sand contained 60 per cent heavy minerals, half of which were the titanium minerals, altered ilmenite, leucoxene, rutile with approximately 5 per cent zircon, 1 per cent cassiterite, and tourmaline, kyanite, staurolite, sillimanite and spinel. The zircon in the sample varied from colourless to deep pink; other samples ranged from 97 per cent heavy minerals (60 per cent ilmenite 20 per cent zircon) downwards.

Another heavy sand examined was the minus 200 mesh mill feed of a commercial plant, which was size graded.

7. Iron.—The highest assay figures for iron during the year were from metallurgical products from Engineering Chemistry Divisions upgrading experiments. These figures were 79 per cent total iron, 75.6 ferrous iron and 1.75 per cent metallic iron.

Other specimens submitted are as follows. From the Albany Jerramungup road, iron Fe 59.4 per cent; from Bulong a suspected meteorite was shown to consist of magnetite, hematite and goethite with a siliceous boxwork structure; a high grade magnetite from Cue had a little goethite, hematite and muscovite; specimens of fibrous and massive goethite were received from Duck Creek with others consisting of hematite and quartz; goethite with a little hematite and manganese oxide was received from Errabiddy; samples from Fitzroy Crossing submitted through the Native Welfare Department were a micaceous hematite assaying 68.3 per cent iron, a micaceous hematite with goethite and quartz assaying 53.5 per cent iron, and magnetite, hematite, goethite and quartz assaying 58.2 per cent iron; a goethite, quartz specimen from Gascoyne Junction had a pronounced iridescence; a sample from Kununurra assayed 66.3 per cent iron; a hematite with a little goethite and quartz assayed 65.3 per cent iron; a goethite, hematite sample from Meekatharra was of poor quality and a sample from Redmond assayed 50.2 per cent iron. From an undisclosed locality a hematite with a little goethite, muscovite and clay assayed 67.1 per cent iron.

8. Lead.—Probably the most interesting specimens of lead minerals were from undisclosed localities. Fine quartz and mica were intergrown with fine grained galena with tetrahedrite, famatinite, marcasite and a little covellite.

A specimen of cerussite and anglesite with orange patches which included litharge, came from Day Dawn.

Other areas represented were Geraldton-Northampton ranging from lead content of 65 per cent to 40 parts per million; Barker River in the King Leopold Ranges with galena part altered to anglesite in quartz with covellite and chalcopyrite; Northampton trace galena and pyrite in quartz and secondary silica; Onslow was represented by an oxidised lead ore in a gangue of quartz and iron oxides. The minerals were anglesite and cerussite with residual galena and a trace of chrysocolla. A second sample consisted of galena with minor pyrite; from Prothero a specimen was identified as pyromorphite; Williambury was the locality of a sample assaying 22.9 per cent lead; Wyloo the locality of an unusually fine grained galena.

9. Lime.—Included in this group with limestones and limesands are two burnt lime samples examined for conformity to tender specifications, one a chemical lime and the other a battery lime.

Limestones from various localities were examined as follows. Armadale, calcium carbonate 80.4 per cent, acid insoluble 14.4 per cent; Esperance, calcium carbonate 74.9, 57.9 per cent; Herdsmans Lake, a fine grained calcite; Lake Bibby Springs, a fossiliferous limestone; Marchagee, a coarse limestone including fine grained calcite nodules; Lancelin, CaO 42.6 per cent; Nabawa, a limestone; and Yanchep, a group of limestones with acid insolubles ranging from 7.04 to 28.8 per cent and carbon dioxide 29.4 to 40.1 per cent.

Limesand from Fremantle assayed 30.5 per cent CaO and from Lake Logue a sample contained fine calcite sand with organic matter and quartz.

Samples from undisclosed localities included limesands with quartz contents of 2.8 per cent to 42.7 per cent. Other samples contained calcium carbonate 81.3 to 91.3 per cent and acid insolubles 7.0 to 12.9 per cent.

10. Lithium.—With the exception of lepidolite from the Pilbara Gold Field associated with tin bearing pegmatite and assaying 1.62 per cent Li_2O, all samples for which the locality was disclosed came from the Londonderry feldspar quarry. These consisted of fresh petalite assaying 1.37 per cent Li_2O; a sales parcel of petalite assaying 4.04 per cent Li_2O and 0.10 per cent Fe_2O_3; a pink alteration product of petalite with quartz, consisting of montmorillonite, illite and kaolin coloured by a trace of manganese assaying Li_2O 1.92 per cent Fe_2O_3 0.1 per cent, and a large globular mass of lepidolite

intergrown with very minor albite assaying 1.01 per cent Li_2O.

Samples intended for use as a standards assaying Li_2O, 1.34 per cent and as checks assaying 30 ppm to less than 5 ppm were submitted by commercial laboratories.

Other samples included a petalite with 4.52 per cent Li_2O, 0.07 per cent iron, and a pegmatite consisting of lithium bearing muscovite with quartz, spodumene, albite and beryl, which assayed 0.60 per cent Li_2O.

11. Nickel.—During 1970 nickel continued to maintain more interest than any other metal and those assays done outside the large batches for many geochemical determinations numbered almost three times those of the previous year. Approximately one tenth of these were made without disclosure of locality and showed figures up to 9,000 parts per million.

The following list the nickel range in parts per million of samples from various approximate localities. The matrix of the sample is recorded in 140 cases. Albany 10; Anketell 160; Armadale 160; Ashburton Downs 130; Badera 2,200; Banga Hill, laterite 26 to 85; Bodallin 60 to 730; Bolgart 20 to 70; Beverley 35 to 170; Bindi Bindi actinolite 60 to 100; Bonny Rock 25 to 430; Boxwood Hill, goethite, 40 to 950; Boyup Brook 65; Bridgetown 40 to 4,800; Bruce Rock 60; Bullfinch 150; Carami Siding 30 to 70; Carnamah 470; Chittering 180; Corrigin 90; Cramphorne Siding, goethite, 10; Cue 50 to 3,100; Cunderdin 30; Dangin 95 to 560; Dowerin, gabbro 35 to 175; Errabiddy 2,600; Forrestonia 60 to 110; Galena 50; Garden Gully 10; Goomalling 90 to 1,100; Geraldton less than 1 to 45; Gudarra, talc 1,100; Gullewa 90; Gutha 50; Hammersley River, goethite 55 to 110; Higginsville 70; Hutt River, quartz and goethite 10; Jack Hills 40 to 80; Jildalki 80; Jingalup 45; Kalamunda, laterite 40 to 100; Kalgoorlie, hornblende 20; Katanning 40 to 100; Kennedy Ranges 45; Kent Location, hornblende 100; Kirup, epidote 80; Kojonup, soil 35; Koolanooka, variscite 60; Lake Barlee 60; Lake Biddy, opal 650 to 1,100; Lake Brown, hornblende 150; Lake Camm 30; Lake King hematite 100 to 190; Leopold Range, lamproites 200; Manjimup 65 to 1,100; Mardup Hills 85 to 310; Marvel Loch, epidote 50 to 95; Meeberrie Station 20 to 190; Meekatharra 100 to 900; Miling 4,200; Mingenew 55; Mollerin, leucoxene 50; Monjebup, basic rock 100 to 140; Moora, hornblende and ultrabasic, 10 to 4,600; Mt. Clifford 100 to 120; Mt. Florence 60; Mt. Magnet 25 to 4,000; Mt. Thirsty 490 to 790; Mukinbudin 10; Mullewa 35 to 40; Munglinup 60 to 70; Newburn 90; Newdegate, opal 320 to 1,800; New Norcia 45; Nogerup 95; Nookawarra 1,200 to 1,800; North Ironcap 80 to 140; Olby Rocks 20 to 210; Paynes Find 90 to 160; Perenjori 10 to 600; Pilgangoora 230; Pindar 80; Pindeburra, ultrabasic 1,600; Pinjarra 260; Quairading, clay, goethite 80; Ravensthorpe 130; Reedy's 4 to 8,400; Roebourne, goethite 70; Rothsay 460 to 520; Sandstone 440; Springvale Station, gossan 1,200 to 1,800; Southern Cross 240 to 400; Stakewell 360 to 1,000; Tammin, plagioclase amphibole 30 to 3,700; Toolibin 35; Towera Station 5 to 60; Tuckanarra 440; Waddi Forest, chalcopyrite 490 Walebing 100 to 920; Walpole 50 to 180; Welbungin, dolerite 30 to 140; Westonia 30; White Springs, nontronite 150; Williambury, quartz 10; Williams, epidote, feldspar 70 to 120; Wongan Hills 55 to 4,900; Waleen Station 170 to 1,800; Wubin 20 to 320; Yalgoo, oxidised copper ore 260 to 320; Yealering 590 to 1,200; Yinnietharra 55; Yorkakine, epidote 20.

Mineral specimens from Mt. Martin and Scotia were examined.

Once again specimens of high grade sulphide ore were submitted and attributed to unlikely localities.

12. Phosphate.—The only phosphate minerals identified were from undisclosed localities. A phosphate bearing quartz iron stone contained green iron phosphate minerals dufrenite and vivianite. Apatite was identified in specks in quartz, muscovite rock and two soils assayed 10.3 and 4.37 per cent phosphorus.

A series of nineteen bore samples from Gascoyne River ranged from 0.06 to 0.25 per cent P_2O_5 and six bore samples from Gnangara ranged from 0.03 to 0.11 per cent P_2O_5. Samples from a well at May River ranged from 0.02 to 5.62 per cent P_2O_5.

Other samples were from Jurien Bay assaying 7.10 per cent and from Geraldton with 0.02 per cent P_2O_5.

13. Quartz including glass sands. While some interest was shown in crushed white quartzite for ornamental aggregate the main interest was in chemically pure clear lump quartz for a Japanese market. Various specifications were quoted and examination varied from a check on the iron content to a comprehensive analysis of impurities. It is understood that a use of this quartz is in metallurgy for hardening aluminium.

Those analyses available for publication are as follows:

	SiO_2	Fe_2O_3	Al_2O_3	Na_2O	K_2O	CaO	MgO	TiO_2	MnO_2	LOI	NVR
	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
Coolgardie	99·4	....	....	....	....	....	....	....	....	....	....
Geraldton	99·8	....	....	....	....	....	....	....	....	0·040	....
Grass Valley	99·2	....	....	....	....	....	....	....	....	0·24	0·6
Grass Valley	99·4	0·08	0·33	....	....	....	....	....	....	....	....
Meeberrie Station....	96·9	0·14	....	....	....	....	....	....	....	....	....
Menzies	99·8	0·012	0·030	0·004	0·004	0·004	0·002	....	....	....	....
Mukinbudin	99·4	0·066	0·111	....	....	0·012	0·005	....	....	....	....
Mukinbudin	99·8	0·019	0·040	....	....	....	....	....	....	....	....
Mukinbudin	99·8	0·026	0·050	....	....	....	....	....	....	....	....
Mukinbudin	....	0·18	....	....	....	....	....	....	....	....	....
Welbungin	....	0·18	....	....	....	....	....	....	....	....	....

LOI—loss on ignition. NVR—non volatile residue.

A specimen of a material having the physical characteristics required for formulation of a special paint was shown to be cristobalite.

The strong interest shown in glass sands at the close of 1969 continued into 1970.

Most analyses made are not available for publication.

From Esperance (60m east) SiO_2 percentages of 99.5, 99.3, 99.4, and (6m north) 97.6 and 98.1 were recorded.

Sand from Mt. Helena after washing had an iron, Fe, content of 0.006 per cent.

A sand from Toodyay contained SiO_2 99.4, Fe_2O_3 0.02, TiO_2 0.32 and loss on ignition 0.17 per cent.

14. Radioactive minerals.—The largest amount of work associated with radio-active minerals was on sales parcels of monazite concentrates. The content of total rare earth oxides in these ranged from 55.9 to 60.5 per cent, thorium oxide from 6.88 to 7.29 per cent and the insoluble figure representing silica included in the monazite plus discrete silicate minerals, from 3.43 to 9.50 per cent. This variation in free silicates was the cause of some concern from the viewpoint of plant efficiency. The manganese oxide content of one sample was checked because of similar concern.

An interesting specimen of monazite came from Mukinbudin. In this, normal monazite was surrounded by a white alteration rim which still had the structure of monazite. The only difference revealed by X-ray fluorescence scan was a small decrease in thoria in the rim.

Individual grains submitted by a private research worker were shown to be monazite.

Other radioactive minerals examined included pulverised samples of iron ore intended to be used as standards. The percentage thoria ranged from 40 to 50 parts per million and the uranium was less than 5 parts per million in all samples.

Samples submitted for checking from a commercial laboratory ranged from 0.020 to 0.054 per cent thoria.

A sample of brown almandine garnet had yellow orange patches of fourmarierite and vandendriesscheite collectively known as gummite.

15. Tantalum and niobium.—The largest group of tantalum and niobium samples for examination this year were eleven sales parcels of concentrates. Each was assayed for Ta_2O_5 Nb_2O_5 SnO_2 and TiO_2 and in some instances for iron and lead. The content of parcels varied from Ta_2O_5 63.9 per cent, Nb_2O_5 1.6 per cent to Ta_2O_5 8.14 per cent, Nb_2O_5 66.5 per cent.

Another sales parcel was a cassiterite concentrate which carried 4 per cent tantalite.

The use of State Batteries for recovery of tantalite columbite, and consequent investigations were the source of another series of samples. A magnetic fraction from Marble Bar battery contained 0.98 per cent TiO_2 and 1.83 per cent SnO_2. A concentrate weighing 82 lb 14 oz from 9 tons of material assayed 60.3 per cent Ta_2O_5 and contained a trace amount of microlite. Other samples from the same battery (Boogardie) showed concentrates with Ta_2O_5 58.3 per cent, Nb_2O_5 7.5 per cent and tails of Ta_2O_5 0.18 per cent, Nb_2O_5 0.2 per cent.

A below value sales parcel already delivered in Perth and magnetically treated to avoid rejection was upgraded from a head value of 9.28 per cent Sn to 43.4 per cent Sn with a +100 mesh fraction of 3.24 per cent tantalum and a —100 mesh fraction of 8.02 per cent.

Estimation of tantalum and niobium content from specific gravity measurement was made on a number of known tantalites. One from Gascoyne Junction contained 85 per cent columbite of a grade containing 30 per cent Ta_2O_5 and 51 per cent Nb_2O_5. Another metamict columbite found in kaolin contained 36 per cent Ta_2O_5 and 46 per cent Nb_2O_5.

An albite pegmatite at Paynes Find had a tantalite columbite fraction amounting to 0.02 per cent.

A sample from MC 27 Dalgaranga contained 38 per cent microlite, 36 per cent altered tapiolite and tantalite and 26 per cent iron oxides and silicates and assayed 50.3 per cent Ta_2O_5, 4.55 per cent Nb_2O_5.

16. Tin.—Apart from tin estimations made in connection with tantalite parcels some commercial parcels of cassiterite were analysed, one for the elements Sn, Ta, Nb, Ti, S, Sb, Pb, Zn, Cu, W, Bi, As, Fe. Another assayed tin, Sn 66.8 per cent and iron Fe 8.06 per cent. Tin parcels from Pilbara area assayed 74.7 and 72.7 per cent tin, and associated ore samples ranged from 0.5 to 5 per cent cassiterite. A concentrate from a mineral buyer contained both nigrine and ilmenite with cassiterite.

A group of 12 samples from the Pilbara Gold Field were examined for distribution of tin in the heavy fraction. Tin in the total samples ranged from 0.002 to 0.26 per cent and in the heavy fraction from 0.51 to 69.3 per cent. A further group of 32 from the same area ranged from 0.007 to 19.3 per cent Sn. From Greenbushes field samples ranged from 80 to 1,020 parts per million associated with trace amounts of Ta_2O_5 and Nb_2O_5.

17. Titanium.—The major group of titanium bearing materials was again experimental products. New approaches in these experiments produced new analytical problems and apart from the total ferrous and metallic iron and titanium of earlier years, examinations made included manganese, free and combined carbon, alumina, silica, magnesia, sulphur, vanadium, phosphorus, chromium and nitrogen in various combinations in both oxidised and reduced materials.

Because of the difficulty of relating the oxidation states of the elements present the chemical work was accompanied by considerable mineralogical work involving polished sections and X-ray diffraction studies.

In order to extend the investigation of these products a member of the staff travelled interstate to use electron microprobe equipment. The migration of minor constituents of the raw material which accompanied various treatments, was studied.

As a result of these investigations recommendations were made for future work on the project.

A feature of the titanium bearing samples not associated with the above investigation was the number of rock samples as distinct from sands reported elsewhere. An altered basic rock from Box Hill consisting of feldspar, hornblende and chlorite assayed 3.18 per cent TiO_2 equivalent to 5 per cent ilmenite. From 12 m Hill on Coodardie Station a biotite hematite quartz rock contained 3.84 per cent TiO_2. A titaniferous magnetite from the junction of the Dale and Avon rivers assayed iron 62.7, titanium 4.54 and vanadium 0.16. On Pindeburra Station a hornblende chlorite rock contained ilmenite with magnetite. A small amount of ilmenite was present in a basic dolerite type rock from Welbungin and from Youanmi an ilmenite hematite magnetite rock assayed 20 per cent TiO_2.

Other occurrences from undisclosed localities include altered ilmenite (pseudo-rutile) as black needles in hard white clay which simple physical treatments failed to beneficiate. Also a fine grained quartzite assaying TiO_2 12.4 per cent with 10-15 per cent rutile included in the quartz and at grain boundaries. Another quartz sample had large segregations of ilmenite. TiO_2 assays of 1.98 and 2.24 per cent were obtained from a basic igneous rock and an epidotised basic rock each carrying leucoxenised ilmenite. Massive hematite-magnetite-ilmenite rocks assayed 29.2 per cent TiO_2 and 34.9 per cent TiO_2 with 0.14 per cent vanadium. A seam of pseudo-rutile in quartz assayed Fe_2O_3 36.9, TiO_2 57.8, Nb 0.15 and Ta 0.16 per cent.

A complete chemical analysis was made of a sales parcel of leucoxene, and the pyrite equivalent of sulphur in a premium grade leucoxene was estimated.

18. Vanadium.—Some interest attached to vanadium this year because of a report that commercial quantities of vanadium had been found. Apart from a titaniferous magnetite from the junction of the Dale and Avon rivers which assayed 62.7 per cent Fe, 4.54 per cent Ti and 0.16 per cent V, another from Lake Grace which assayed 58.0 per cent Fe, 12.3 per cent Ti and 0.78 per cent V, and a series of samples from east of Harvey which assayed from 3,500 to 5,100 ppm V, all samples contained less than 1,000 ppm.

Localities represented, with parts per million vanadium were: Goomalling 90; Katanning 60; New Norcia 60 to 840; Nookawarra 20; Toodyay 400 with nickel 70 and chromium 1,600; Walpole less than 100 to 230; Youanmi 600 in a titaniferous magnetite, TiO_2 20 per cent.

A normal background vanadium content of rocks quoted in geochemical literature is between 100 and 200 ppm with acid rocks around 50 ppm.

19. Miscellaneous.—Four antimony bearing samples were examined for a private analytical firm as standards representing a concentrate, Sb 60.9 per cent, an ore, Sb 1.70 per cent and two low grade ores, Sb 0.49 and 0.39 per cent.

A specimen of metallic antimony was analysed for antimony, arsenic, lead, copper, zinc and iron.

A concentrate from the Wiluna area assayed 47.7 per cent antimony.

Eight samples of bismuth minerals were examined consisting largely of sales parcels from undisclosed localities ranging from 35.9 to 67.2 per cent bismuth.

Samples from Gascoyne consisted of bismutite with a little goethite and muscovite.

One parcel assayed Bi 32.8 per cent, SiO_2 27.4 per cent, Pb 3.74 per cent, sulphur 0.86 per cent and CaO and As in parts per million.

A sample of Western Australian feldspar was examined for conformity with a buyers specifications requiring the following percentages. SiO_2 67.0 ± 0.1; Al_2O_3 17.5 ± 0.5; Fe_2O_3 0.07 ± 0.02; CaO 0.50 ± 0.25; K_2O 11.0 ± 0.05; Na_2O 2.4 ± 0.3. The local sample with Na_2O 2.92 and K_2O 12.0 per cent did not meet the specifications.

A sample of fluorite was assessed for commercial possibilities with the following results.

	per cent on dry basis
Total calcium fluoride, CaF_2	98·5
Silica, SiO_2	0·70
Effective calcium fluoride, CaF_2*	96·9
Carbon dioxide, CO_2	0·29
equivalent to	
Calcium carbonate, $CaCO_3$	0·66

*total CaF_2 minus $2\frac{1}{4}$ SiO_3

There are three principal market grades of fluorite, acid, ceramic and metallurgical. The specifications for these are fairly well defined although the requirements set by individual consumers may vary somewhat in detail.

Acid grade is the purest and must contain not more than 1.5 per cent. silica, not more than 1.0 per cent of calcium carbonate and at least 95 per cent total calcium fluoride.

For a metallurgical use, silica is detrimental as each per cent of silica present renders useless for fluxing purposes about $2\frac{1}{4}$ per cent of fluorite. Specifications therefore refer to the "effective" percentage of calcium fluoride, which is the total calcium fluoride less $2\frac{1}{4}$ times the silica percentage.

Specifications for metallurgical grade fluorite call for a minimum of 60 per cent effective calcium fluoride.

Deleterious impurities other than silica that sometimes occur in fluorite include lead, sulphides and barium sulphate.

The present sample was not of sufficient size to justify detailed trace analysis.

Samples of gypsum were received from Cardabia, Carnamah and Lake Cowan, the latter two assaying 80 and 92 per cent $CaSO_4$ $2H_2O$ respectively.

Apart from numerous dust samples one sample of ore was analysed containing 43.4 per cent Mn. Manganese oxides were examined from Coordewandy Station and both cryptomelane and pyrolusite were identified from Meekatharra.

Following work reported in 1969 to produce on a laboratory scale a free running table salt from local salt, plant scale production of a trial parcel was undertaken by the Engineering Chemistry Division. Analyses of the product gave the following figures which compare satisfactorily with those obtained in the preliminary laboratory work.

Lab. No. 7983/70

	per cent
Ca	0·12
Mg	0·12
K	0·15
SO_4	0·53
Cl	59·4
Fe	less than 0·001
Water insoluble	0·96
Moisture	0·53
Insoluble in 0·1N HCl	0·77

An investigation was commenced into possible causes of a high incidence of impurities in sodium chloride crystals from a commercial producer. The problem was characterised by a failure of produced salt to meet the required NaCl content because of a high moisture content and magnesia content. Washing tests and subsequent analysis indicated that these impurities were not on the surface but occurred as liquid (brine) inclusions within the salt crystals. Microscopic examination verified these inclusions and demonstrated the pattern in which they occurred. A survey of the literature indicated that the occurrence of brine inclusions is related to the rate of growth of the crystals rather than any inhibition of growth at points on crystal surfaces by repellant contaminants. It had been suspected that dye added to increase evaporation may have caused the inclusions but analysis for occluded dye did not support this theory.

A core taken from the salt bed in one pan was examined to see if the concentration of inclusions could be related to depth. While a variation in clarity occurred at various levels no regularity was observed which could be related a time factor.

Salt produced from crystallising pans constructed near Wyalkatchem was examined for conformity with Food and Drug Regulations. Crystals forming the bottom seal of the pans were high in magnesia because of rapid crystallisation in the preliminary stages. Further sampling is proposed as production proceeds. Brine samples from adjacent positions were compared for their magnesium content.

Scheelite concentrates for a mineral buyer assayed 8.81, 19.2 and 76.9 per cent WO_3. Another sample from an undisclosed source contained 24 per cent scheelite with hornblende, epidote, quartz and iron oxides. One scheelite concentrate submitted was heavily salted with artificial tungsten carbide.

Mineral Identifications

1. Selected.—An altered pink and green garnet from 5 mile SE of Roebourne had an X-ray diffraction pattern similar to uvarovite but the chromium content was only 0.1 per cent.

A sample of coarse sand from Brooks Mill contained a grey green xenotime, and a salmon pink semi-opaque rutile.

From High Range on Lyndon Station the aluminium calcium phosphate crandallite was recorded for the first time in Western Australia. This white mineral occurred with a radial fibrous structure.

An unexpected occurrence of hydrated lime as portlandite was recognised as fine grained agregates in a sample from Ripple Shoals. It is considered improbable that this occurrence is natural in veiw of the solubility of portlandite.

Both rutile and jarosite occurred in unusual forms in a sample from Big Bell-Cue area. The rutile was black, opaque and magnetic with a cell size identical to that of pure artificial titanium dioxide. The jarosite was biaxial and very coarsely crystalline.

A sample described as djurleite, which originated from three miles east of Warburton Range Mission was donated by Mr. D. Haynes of the Australian National University Geology Department, Canberra.

The specimen consists mainly of "chalcocite" with covellite and malachite and gangue minerals. X-ray data was not sufficient to distinguish the major copper sulphide mineral as chalcocite proper or the newly described form, djurleite ($Cu_{1.96}S$); the pattern has features common to both minerals. However the polishing behaviour of the material is consistent with that described for djurelite, in that preliminary grinding and polishing produced colour variations within the specimen, which gradually merged as polishing progressed. This feature has been noted in the past in a number of specimens reported as chalcocite from these Laboratories.

Djurleite—covellite assemblages are considered as metastable since a temperature of 60° ± 10°C for three months is sufficient to convert the mixture to digenite. In this sample the textures indicate that covellite is supergene. The specimen is in the MDC collection as MDC 4438.

The examination was concluded of minerals from Southern Cross reported in 1966 as miersite from a sample of battery tailings.

This sample was found to contain 8 ozs per ton of silver mostly in the form of silver halides. Only trace amounts were available for examination and on optical and X-ray data appeared to be AgI (Miersite) with other unidentified material.

A visit was made to the "mine" site at Gilbadji Loc. 365 outside Southern Cross in August 1967, in the company of the Marvel Loch State Battery manager. The mine was a deep pit in weathered phyllite with a large cross cutting quartz vein, but in the absence of the mine owners the location of the silver concentrations could not be established.

Thin sections prepared from a number of specimens failed to show any signs of the halides, and a concentrate from 10 lbs of selected material produced only a trace of the minerals in question. However, early in 1968 an 80 lb drum of tailings from the mine was sent in for examination.

A heavy concentrate was prepared from this sample by the Engineering Chemistry Division and further purified by micro panner and electro magnet. Heavy liquids were not used to avoid possible interaction between the halides in the sample and halogens in the liquids. Two concentrates were made, one with approximately 20 per cent impurities, the other with about 40 per cent, and a briquette with boric acid was made under 5 tons load for XRF qualitative analysis of the latter. Of the relevant elements Ag and I were major, Cl and Br minor and Cu a trace. A KCN extract from the same sample left no silver halides in the residue and contained no copper. The sample recovered from the pressed briquette showed that virtually all the silver iodide had become isotropic, whereas the original material contained a mixture of the hexagonal anisotropic form, iodyrite, as well as the cubic isotropic phase, and intergrowths of the two.

By the use of a small device fitted to a standard 5.73 cm X-ray powder camera it was found possible to prepare simulated powder patterns from single uncrushed grains. A number of isotropic grains were X-rayed and the patterns shown to be identical with those from synthetic γ—AgI. Thus the presence of AgI was confirmed in the sample in two forms, iodyrite (hexagonal) and a cubic form. From a survey of the literature on silver iodide polymorphs it appears that the cubic form is metastable unless it includes at least 15 mole per cent of copper iodide. The sample in question does not contain copper and it now seems probable that the "miersite" has formed from iodyrite by shearing stresses in the battery stamp mill and is not a natural mineral.

A pure sample was separated from a specimen of cordierite and the analysis is recorded under complete analyses.

In a collection of specimens from Bridgetown an interesting chromite was observed as a rich concentration of oxide grains in a serpentine matrix. The oxide grains are generally subhedral, usually discrete and rimmed by the serpentine but sometimes aggregated in small clumps. Individual grains consist of a central rounded core of chromite, a zone of variable width of iron enriched chromite, and finally a narrow rim of magnetite, partly altered to hematite.

Some black crystals from Greenbushes area were shown to have an X-ray diffraction pattern identical with that of the controversial "pseudorutile" of Teufer and Temple (Nature, July 9, 1966. p.180). Partial chemical analysis gave the following figures.

	per cent
Iron oxide, Fe_2O_3	36.9
Titanium dioxide, TiO_2	57.8

A number of other interesting specimens, largely, from localities outside Western Australia, were examined prior to being added to the Department Collection.

2. Miscellaneous.—The largest mineral group other than those discussed separately consisted of talc from the following localities: North of Toodyay on Bindoon Road; Moora; Calingiri; Grass Valley; Nookawarra homestead; Three Springs. The interest in talc was probably related to the search for nickel as were a number of occurrences of green epidote from Duck Creek; York; Yorkrakine; and iron free epidote from Maroonah Station; glauconite from Kwinana Mission in West Kimberley; and nontronite from Buntine and Moorine Rocks.

Graphite was submitted from four localities but Grass Patch was the only one disclosed.

Garnet was identified in samples from Barker river on Napier Downs where it occurs with staurolite, in sand from 30 m south of Murchison river, and as andradite grossularite from an unknown locality and similarly as almandine associated with minor cassiterite and rutile. Staurolite was also identified from Napier Range.

Actinolite was identified from an unknown locality as green radiating crystals, tremolite with actinolite as coarse bladed crystals from Yinnietharra, and anthophyllite from White Springs, Goodlands north of Kalannie, and Walebing.

Alunite was recorded from Westonia; massive tourmaline from Williambury and Piawaning; prehnite from Lake Grace; nephrite from the Avon valley east of Walyunga; bronzite from an undisclosed locality and hypersthene from Cunderdin; pyrite with a little pyrrhotite from Williams, from west of Harvey and with marcasite from an undisclosed locality; ferrous sulphates from the decomposition of marcasite occurred at Green Range 47 miles East of Albany.

Some interest was shown by consulting geologists in the possibility of upgrading impure kyanite deposits. One plant product examined contained approximately 65 per cent kyanite with zircon, spinel and a trace of rutile. Two quartz muscovite schists contained kyanite and another two contained sillimanite.

A sillimanite schist from Goyamin Pool contained approximately 75 per cent sillimanite with biotite.

Baryte was identified from Yalgoo; a sample assaying 94 dwt of silver was received from Mt. Magnet; microcline feldspar from Carnamah carried black radiating crystals of tourmaline; a green common opal from Newdegate had black patches of iron oxide.

Many of the above minerals were from undisclosed localities as were following minerals; fuchsite, chalcopyrite, paratacamite, magnesite, melanterite, cummingtonite, miloschite and fluorite.

Miscellaneous Investigations

1. Artificial minerals.—A number of metallic flakes in earth from Yarloop consisted of gold-coloured alloy of copper and iron and a grey alloy of zinc and iron. A metallic specimen from Fitzroy Crossing was cast iron. Other spurious minerals included carborundum.

A specimen of quartz and goethite from Northampton carried minute blue flakes which were considered to be paint.

A mineral concentrate from near Moulyinning proved to be mainly artificial tungsten carbide presumably from drilling equipment. A specimen from Menzies proved to be fire assay slag.

Another metallic specimen was essentially antimony with small amounts of lead, copper, zinc and iron. Another metal sample considered to be unnatural in its occurrence was metallic lead with adhering quartz and iron oxides, from near the Murchison river.

A further specimen was received of pumic stone which was frequently found on W.A. beaches throughout the 1960's. An amber coloured resin like material from soil at Capel had similar chemical properties to amine cured epoxy resin.

A number of artificial mineral products examined for a brick making firm consisted of mu-cordierite, mullite and cristobalite with a dark colouration due to nickel and iron oxides. The same elements coloured another product consisting essentially of plagioclase feldspar.

2. Building Materials.—With one exception the building materials examined were all concrete and aggregates and 41 samples were examined under this heading representing approximately the same number as last year

Three samples were of disrupted concrete. Deterioration of a salt shed floor was shown to be due to urea as an efflorescence in voids in the concrete probably from an earlier use of the floor. Concrete columns of the Roebourne school which were cracked by corrosion of the reinforcing, was attributed to porosity of the concrete and the presence of sulphates and chlorides. Precast exposed aggregate panels set between metal supports in the balustrading of a Government building were found to be bowing outward. These were examined to see if the cause could be expansion due to cement-aggregates reaction or the action of sulphurous fumes from an adjacent flue. Chemical and mineralogical data did not support either of these theories.

A firm experienced in concrete manufacture in South Australia submitted samples of sand, water and cement for determination of chlorides and total water soluble salts due to concern over the possible formation of efflorescence.

A mortar used to fix concrete blocks was analysed to determine the original mix so that a technique for future use could be established.

A composite of cement and blast furnace slag was examined for conformity to British Standard 146-1958 as required by the Uniform Building By-laws Committee.

An investigation was made of a suite of samples consisting of lime, sand, cement, lime mortar, cement mortar and composite mortar of known composition. The purpose of the examination was to determine the extent of usefulness of Australian Standards method A110-1957 for the determination of the original mix of set concrete when applied to mixtures containing lime. It was concluded that grinding to the specified —200 mesh introduced soluble silica from the aggregate, or possibly allowed selective loss of lime by dusting, which led to errors especially with lime and composite mortars. Crushing only to grain size (approximately 30 mesh) gave acceptable results in view of the difficulty in sampling the coarse material. The calculation of the composition of lime and composite mortars cannot be made with any confidence unless the original materials are available for analysis.

The search for suitable concrete aggregates in inland and north west areas resulted in the examination of sands and shingles from a number of localities including Coolgardie; Maitland River, Roebourne; Nanutarra, Ashburton Crossing; Gibb River, Derby; Turner River, Pilbara; Broome; and Mt. Helena.

When a full examination of mineralogy, sizing, organic matter and potential alkali reactivity has been made, a specimen is added to the Departmental collection of aggregates.

Sand in one instance was required to be examined for potential for heavy mineral recovery, for glass sand and for concrete aggregate.

A sample of insulating material examined on behalf of Public Works Architects was found to consist of a matte of organic fibres with no asbestos included.

3. Calibrations.—In this field the work was mainly pyrometry the responsibility for which was transferred to this Division in 1969. Optical pyrometers were calibrated at 5 temperatures from 1,000°C to 1,220°C and thermometers for use with the Breathalyzer were checked at 5 temperatures from 15 to 35°C and corrections were noted.

Ceramic "Buller" rings used to estimate temperature of firing in brick kilns, were fired in a muffle furnace which had been calibrated so that true temperature at various parts of the furnace could be recorded. The rings were held at known temperatures for varying periods so that the effect on their measurements of time of heating could be observed.

A large group of assay balance riders of 0.01 and 0.02 grains were calibrated.

4. Corrosion.—Corrosion products found on a cargo of barbed wire from the hold of a ship were examined to see if the nature of the corrosive agent could be established. No undeniable cause of corrosion could be stated but some possible causes were eliminated.

Corrosion on multistrand aluminium electric cable suspended near salt pans was thought to be caused possibly by perching birds. In fact no phosphate was detected in the products which were shown to be hydrated aluminium oxide with basic aluminium carbonate, basic sodium-aluminium carbonate and magnesium carbonate.

Sediment from a pump at the Badgingarra Agriculture Research Station proved to be hydrous iron oxides with some calcite.

A deposit observed in engineering practice on steel wire was simulated elsewhere by electrodeposition. The deposit produced was shown to have the X-ray diffraction pattern of α—iron.

A sample of soot from a boiler stack was found to contain carbon, iron oxide scale with iron sulphates and some free sulphuric acid.

5. Dusts and Health Hazards.—The 391 dusts and related material examined this year fell into three catagories related to health hazard in particular industries, to air pollution generally and to dust damage of equipment.

A regular thirty two samples per month were received from the monitoring gauges at Port Hedland and assayed for manganese and iron. A further gauge near the Port Hedland Drive In theatre provided five samples per month for manganese estimation.

Another gauge providing regular samples from Naval Base contained varying amounts of alumina while a gauge at Bunbury carried titanium oxide, sulphate, and acid.

Dust from Kwinana contained nickel, cobalt and iron.

Samples taken in response to particular complaints were received from Rivervale and contained lime and halite in addition to common dust constituents; from Fremantle with soot and sulphates; from Kwinana with approximately 1 per cent of phosphorus pentoxide, and from Jolimont and Subiaco with slag-like material.

A program of sampling over several months was concerned with dust evident in the Terminal Building of the Perth Airport. A feature of this dust was calcite and an isotropic material similar to that observed on another occasion where calcite-filled plastic tiles were regularly buffed.

Dust on tape spools at a TV studio was shown to be organic fibre but dust in the videotape room in addition to fibres was composed of green paint flakes, fine flakes of basic lead carbonate, organic material and metal particles. Respirable dust in the area contained lead. The source of the lead was corrosion in an air conditioning unit.

Samples from various brake lining works were examined to check the percentage of asbestos in the airborne dust.

A number of dust samples from mining operations were submitted by the Public Health Department for determination of respirable quartz in the dust. Dusts from one mineral processing plant contained approximately 80 per cent quartz though this was largely plus 5 micron material. Chemically this assessment is extremely difficult on the size of the sample available. Gross estimations have been made optically but an investigation is in hand to produce standard samples which will enable an X-ray diffraction method to be used.

Pure quartz standards of 0.12, 0.27, 0.40, and 0.53 mg per cm^2 of membrane filter have been prepared. Also prepared are mixtures 1 to 1 of quartz to feldspar, quartz to talc rock and quartz to hematite, which carry approximately the same weight of quartz per cm^2 as the standards.

Elements associated with quartz which have caused concern in dust samples are manganese and nickel. Vein material at Scotia and Kambalda checked as a possible source of quartz dust was found to be calcite.

Solid samples from commercial crushing plants and from fired bricks were also examined to see if a correlation between solid dust could be obtained. The correlation was not satisfactory.

Another group of samples received in connection with dust hazard included an asbestos of the amosite type in a mineral specimen from a cement fibre works.

Dust samples from vacuum cleaning in buildings sound insulated with sprayed fibre showed no asbestos in the dust although chrysotile was recogised in material taken from sprayed ceilings.

Dust from the breathing area of terrazzo workers which consisted mainly of calcite, contained approximately 1 per cent quartz.

Dust for use in a medical experiment was assayed for iron content.

A powdered material thought to constitute a hazard to its handlers was powdered baryte used to add weight to bulldozer tyres for increased traction. This powder contained 0.45 per cent lead partly in the form of galena.

A suspected health hazard unrelated to dust was an oil submitted for estimation of vanadium following a union complaint.

6. Explosives.—A number of samples of "explosive" ammonium nitrate were examined by British Standard method 4267:1968, Section 11 for carbon content. It was observed that the carbon figure correlated with intensity of colour, which was slightly yellow, over the range 0.002 to 0.015 per cent C. All samples fell within the suggested limit of 0.1. per cent.

A subsequent examination of "explosive" ammonium nitrate was made for total oxidisable material by the methods recommended by National Plant Food Institute, November, 1964. This figure proved to be considerably higher than the carbon figure although results by this method did not have a satisfactory degree of precision at the levels present.

An investigation is in hand to improve the method and explain the discrepancy from the carbon figure.

7. Geochemical work. The promise of increased activity in geochemical prospecting did not eventuate due to difficulties experienced in the Geological Survey Branch.

The number of samples assayed dropped to about half of the previous years, but the range of elements treated increased by the addition of the following elements, fluorine, boron, niobium, selenium, barium, chromium, manganese, phosphorus, strontium, titanium, vanadium and lithium.

One hundred and thirteen samples from Lake Yindalgooda submitted last year by the Geological Survey Branch were re-examined for selenium which ranged from less than 1 to 147 ppm. Other samples for the Geological Survey from Twin Peaks area ranged from less than 1 to 4 ppm and two groups from private surveys ranged from 0.2 to 1.2 ppm and 0.1 to 12.7 ppm selenium.

Copper, lead, zinc, molybdenum, nickel and cobalt were done on public samples from Yinnietharra, Mingenew, Swan Location, Carnamah and Northampton. Copper values from the latter locality ranged from 5 to 2,400 ppm and lead from 80 to 1,000 ppm. Other samples submitted by the public included basalt from Storm Creek in the Kimberley area with lead 20 to 280 ppm; zinc 115 to 285 ppm; copper 280 to 400 ppm; nickel 30 and cobalt 15 to 30 ppm.

Samples submitted by a private company to be used at geochemical standards assayed 40 to 50 ppm thorium and less than 5 ppm uranium.

By far the largest proportion of the geochemical work was for the Geological Survey Branch. Granites from the Perth area were assayed for bases plus the following trace elements in parts per million; lithium less than 2 to 34, strontium 65 to 340, barium 250 to 1,700, tin less than 5 to 20, copper 25 to 80, fluorine 25 to 1,700 and boron less than 2 to 3. Similarly granites from the Winburn Complex assayed in parts per million lithium less than 2 to 18, strontium 10 to 420, barium 30 to 1,200, tin less than 5 to 35, copper less than 5 to 55, fluorine 60 to 3,200 and boron less than 2 to 27. Granites from Mt. Phillips assayed lithium less than 2 to 32, strontium 15 to 370, barium 8 to 4,700, copper 20 to 360, tin less than 5 to 190, fluorine less than 5 to 1,600, boron less than 2 to 330 parts per million.

Other samples from Greenbushes assayed SnO_2 80 to 1020, Ta_2O_5 25 to 165, Nb_2O_5 10 to 105 ppm. Calcrete from Pardoo contained uranium 10 and thorium 130 to 135 ppm. From Mt. Dick opal contained nickel 200, copper 220 and cobalt 15 ppm and ochre contained nickel 640, copper 270 and cobalt 75 ppm. From Mt. Stewart samples assayed nickel 1,500 to 2,000, chromium 3,800 to 6,100, cobalt 120 to 190, copper 80 to 210 and platinum less than 0.1 ppm. From Clackline values were copper 80, nickel 60, titanium 420 and vanadium less than 100 ppm.

Samples from 80 m North of Meekatharra contained manganese 10 to 20,000; barium 5 to 310; titanium 10 to 10,200; chromium less than 5 to 5,700; phosphorus 40 to 1050; vanadium less than 5 to 300; molybdenum less than 1 to 5; fluorine less than 5 to 1,900; lead less than 1 to 200; nickel less than 5 to 1,950; strontium 2 to 90; zinc 6 to 176 and uranium less than 1 ppm.

A supposed carbonatite intrusive contained manganese 120 to 1370; barium less than 5 to 45; titanium 8200 to 16,700; chromium 130 to 515; phosphorus 145 to 320; vanadium 60 to 100; and molybdenum less than 5 to 5ppm.

An investigation of specimens of chloropal and opal from the Divisions mineral collection showed nickel contents ranging from 20 to 530 ppm.

8. Metals and alloys.—Samples of lead submitted by scrap metal dealers for use in lead joints of water mains were compared. The major impurities were tin, antimony, iron and copper in small amounts.

Another group of samples examined were prestressing steel wires for use in the Hamilton Interchange and which had shown serious pitting in an accelerated corrosion test. Chemical and microscopic examination showed that the composition of the wires conformed to the required standard and no specific reason was revealed for breakdown under accelerated stress corrosion tests.

Roman coins submitted from the History Department of the University of W.A. were largely copper alloyed with small amounts of lead, tin, silver and a trace of iron. The surface material had a high silver content indicating some coating process.

A number of samples of cadmium-magnesium alloy dissolved in aqua-regia were examined for the Physics Department of the University of W.A. The ratio of the elements varied over a considerable range.

Reinforcing steel rods which failed in fabrication were analysed for carbon, manganese, sulphur, and phosphorus. With the exception of the manganese content of one specimen the analyses were of uniform composition.

A cast iron bitumen coated sewerage main which had developed a crack in service was examined for graphitisation or evidence of fault in manufacture. The metal was in good condition and it was considered possible that the cause of the crack was mechanical shock.

9. Police exhibits.—A variety of materials were examined to establish relationship between objects. Some relationships were positively established while others were not conclusive.

In a road accident case the accused denied driving the car at the time of the accident and offered an alternate explanation of glass on his person. Glass fragments from his face and the windscreen were shown to be identical, other fragments on clothing were distinctly different.

Soils from the road surface and the underbody of a car involved in a collision were compared by mineral composition, type of clay, and grain size analysis. No essential differences were detected, nor were any minerals peculiar to the Pilbara area as was considered possible.

An X-ray fluorescence scan of mineral dust on a bottle, bricks and brick fragments showed essentially similar constituents.

Slag like material on clothing and on a welding torch could not be positively correlated, nor could sand from clothing and the base of a gas cylinder since the material examined in each instance was in no way uncommon.

Paint flakes from the inside of a safe were compared with marks on a jemmy bar. A second jemmy bar was examined and the position and composition of metal streaks on the bar were compared with marks on an aluminium door.

In a case of damage at a factory premises pigments in paint from the factory were compared with paint on clothing and at the home of the accused.

10. Other.—Other examinations made included minute crystals extracted from kidney tissue, for the Department of Pathology, at the University School of Medicine. These proved to be calcium oxalate monohydrate.

A heterogeneous collection of organic and inorganic compounds from between the railway lines on the Esperance wharf were identified. The examination was in connection wth cleaning operations.

An examination was made of wood from the packing crates of plate glass which was stained while in the crates. The sample was mainly filamentous organic material. The occurrence was noted of some forms of fungi which are known to attack glass causing permanent etch marks.

Two samples were examined in connection with the failure of a battery of alkaline accumulators (Ni/Fe) maintained as an emergency power supply. A black sludge washed from the battery was a mixture of nickel hydroxide $Ni(OH)_2$, graphite and the nickel iron oxide compound trevorite $NiFe_2O_4$. A second sample submitted was electrolyte drained from the battery to be compared with specifications for electrolyte additions. The H_2S group metals Pb, Cu, Sb, Bi and the $(NH_4)_2S$ group metals Ni, Mn, Zn and Co, collectively fell below the maximum concentration specified. Chloride and nitrogen levels were also satisfactory but sulphur, carbon dioxide and silica were each high.

Analytical Methods

1. General.—As in the past few years technical assistance has been given to new laboratories which have been established, particularly those who are working in the geochemical field. Interest has been renewed lately in the time-honoured fire assay method for determination of precious metals. The applicability of this procedure to the determination of platinum in trace amounts has added to this interest.

The Division has also acted as an umpire when anomalous figures have been produced by other analysts and also provided analysed samples to act as control samples.

2. Aluminium.—With the increased demand for soda-soluble alumina determinations on samples of bauxite, a rapid atomic absorption method was established whereby analytical results of the required accuracy could be produced rapidly and batchwise.

To check the feasibility of the method standard solutions of aluminium metal in sodium hydroxide were made and interferences by soluble silicate and sodium salts were determined. Background matrices, approximating as near as possible to bauxite samples were simulated. No significant interferences were noted.

The method is based on an initial attack of the sample with sodium hydroxide solution. The aluminium concentration of the final solution is determined by atomic absorption using the nitrous oxide-acetylene flame.

3. Ammonium nitrate.—With the increasing use of ammonium nitrate as an explosive agent the necessity for the determination of its organic carbon content has become more common. The British Standard procedure has been modified to fit in with the equipment available in the Division.

The method is based on the ignition of ammonium nitrate at 850°-900°C in purified oxygen and the carbon dioxide formed is absorbed and weighed. The train set up for the procedure is fundamentally the same as for a normal total carbon determination. As the carbon limit on ammonium nitrate is at such a low level (less than 0.05 per cent) it is vital to work with the lowest possible reagent blank. The manganese dioxide used was prepared in the laboratory as was the silver sponge, used to absorb halides. A nickel boat was also used and the magnesium oxide used to moderate the ignition was pre-ignited immediately before use.

Reproducible figures were obtained by this method but, due to the necessity for low blanks, each determination was comparatively lengthy.

Following a recent meeting of Chief Inspectors of Explosives in Perth it was decided that the total oxidisable material present in ammonium nitrate would be of more significance in assessing the degree of hazards associated with the bulk storage and transport of this material than the amount of organic carbon. A proposed method is currently under investigation.

4. Boron.—An investigation was carried out into the determination of macro amounts of boron in silicate rocks. The procedure, based on the titration of liberated boric acid with standard alkali in the presence of a polyhydric alcohol (manitol) was combined with an ion-exchange separation to give a rapid and reproducible method. The method was tested on a sample of achroite which had a boron content of 3.72 per cent.

Interest by the Geological Survey in microgram quantities of boron in granites necessitated the development of a method for this purpose. By the adaption of a method commonly used for boron in steels, satisfactory results were obtained for the concentrations encountered, usually 10 ppm or less.

The method, which is extremely sensitive depends on the formation of the boron tetraflouride ion BF_4, and the formation of a complex between this and methylene blue. This complex is then extracted with 1 : 2 dichloroethane and determined by spectrometry.

5. Palladium and Platinum.—An investigation was carried out into a method for the determination of palladium and platinum by Atomic Absorption following a concentration by fire assay into a gold prill. Interelement interferences were removed by measuring in a background solution of cadmium and copper sulphates with cadmium and copper concentrations each at 5 per cent.

Previous attempts to determine platinum by atomic absorption in acid medium had resulted in high figures due to the interelement effect.

The possibility of substituting silver for a gold carrier was also proved to be satisfactory.

The prill, silver or gold, containing the platinum or palladium after separation by fire assay procedure was treated with dilute nitric acid (1 : 4) and then with 2 ml aqua-regia and finally with 2 ml concentrated hydrochloric acid, the respective solutions being evaporated to dryness. The final hydrochloric acid treatment was repeated.

The residue was treated with 5 drops concentrated hydrochloric acid and 1 ml cadmium sulphate-copper sulphate solution and warmed gently to solution. After diluting to 7 ml with water the platinum and palladium were read by atomic absorption and compared with standards prepared similarly.

A second method by which a dithizone complex of divalent platinum was extracted into methyl isobutyl ketone proved less satisfactory than the fire assay-atomic absorption procedure, particularly for the low level detection.

6. Silica.—A method for the determination of free silica in minerals of high silica content was investigated.

The method was based on a procedure involving the solution of the combined silicates present with pyrophosphoric acid at a temperature of 250° 275°C after cleaning the sample with a nitric-hydrochloric acid treatment. The phosphoric acid solution plus residue was poured into hot water containing 20 drops of hydrofluoric acid and the insoluble residue determined after filtration and thorough washing. The purity of the free slica separated was checked by treatment with HF and sulphuric acid.

It was found that it was necessary to carry out the heating with pyrophosphoric acid in an air oven held at 260°C to prevent localised heating which occurred when a hot plate was used. In this case an insoluble metaphosphoric acid was formed rendering the method unsatisfactory. Checks by chemical analysis against synthetic standards gave satisfactory agreement.

WATER DIVISION

General

Although it was anticipated that the newly formed Division would be in its new quarters during 1970, the alterations to the old buildings have proved more extensive than anticipated and a more realistic time would be March 1971.

The Division is grateful to the Chief of the Agriculture Division and his staff who have accommodated it during this period in their cramped quarters. After transferring to the new building it is intended to build the staff from 8 to its full complement of 10 to cope with increased demands. Two new members in Messrs. J. Ollerenshaw and K. Browne joined the staff during 1970 and Mr F. Coupland transferred to the explosives Branch.

During the year the Chief of the Division, Mr. N. Platell, attended the Annual Conference of the Australasian Corrosion Association at Newcastle where he presented a paper. Mr. P. Jack is the newly elected president of the W.A. branch of the Australasian Corrosion Association and Mr. J. C. Weir the Vice President. The Water Division continues to play a very active role in other matters as well as technical.

Table 18 shows the source and number of samples received during 1970. The number of water samples handled by the Division was only slightly in excess of those in 1969 but the Division continues to play an increasing consultative role in matters associated with water and corrosion.

Table 18

WATER DIVISION

	Agriculture Department	Fisheries Department	Metropolitan Water Board	Mines Department	Native Welfare Department	Public		Public Health Department	Public Works Department	Other Government Departments		
						Free	Pay			Federal	State	
Corrosion	1	....	5	1	....	....	7	1	15	....	4	34
Miscellaneous	....	....	....	....	....	....	5	5	5	....	....	15
Water	17	23	2,016	438	14	1	697	48	1,906	8	31	5,199
Water Treatment Chemicals	....	....	28	....	....	....	....	....	....	3	....	31
TOTAL	18	23	2,049	439	14	1	709	54	1,926	11	35	5,279

A number of the more interesting investigations carried out by the Division during 1970 is included in the report.

1. Corrosion.

(a) Aluminium.—Aluminium tubes in the cooling system of a standby stationary diesel motor had perforated within 3 months although the engine had been subjected to only 15 minutes run during that period. A 10 : 1 mixture of sodium benzoate : sodium nitrate was used at the rate of 2 to 3 oz. per gallon of cooling water as specified by the suppliers. This corrosion inhibitor is satisfactory for aluminium in a mixed metal system under normal operating temperatures but is suspect in a mixed metal system at ambient temperature. The high proportion of idle period of the motor was a distinct disadvantage in this instance.

(b) Copper and alloys.

(i) Solid fuel hot water units made from copper and used in the Withers St. area of Bunbury, where there is a righ manganese content of the water, were heavily coated in the cathodic areas of the unit with a black deposit. Although manganese was absent from the anodic areas its oxide was more predominant than that of copper in these cathodic areas. Manganese is considered by some authors to promote corrosion of copper but there is insufficient evidence from this area to indicate that its deposition is due to causes other than the alkaline conditions at the cathode causing its precipitation. The role of manganese in hot water service corrosion is a subject for investigation at a future date.

(ii) Solid fuel hot water units of copper construction have been shown statistically to have a higher corrosion rate failure in eastern areas south of the Swan River in the Metropolitan area of Perth. More than 10 per cent of units sold in this area fail to reach their guarantee period of 2 years. As the water north of the Swan River is frequently more saline due to the admixture of bore water, other factors must be involved. Chlorine is a known depolariser and is generally present only in eastern areas south of the river where its concentration varies from 0.3 to 0.1 ppm. Although publications indicate that it has little effect at concentrations as high as 1 ppm this effect will nevertheless warrant investigation. Fluoridation and chlorination do increase the aggressive carbon dioxide content of the water which in turn results in a lowering of the pH by 0.2 to 0.4 units. pH values in areas north of the river are raised by aeration at the holding reservoirs and admixture with high alkalinity and high pH bore water. It is intended to carry out investigations on these effects during 1971. If shown to have significant effect then the problem could be eliminated by dechlorination at a point prior to entry from Hills areas to housing areas and a reduction of aggressive carbon dioxide content at the Hills sources by the addition of about 3 ppm of lime.

(iii) Ring mains of copper pipes for recirculating hot water under mains pressure have shown in two instances south of the Swan River in the Metropolitan area to have failed prematurely. In one instance the failure occurred within 2 years of commissioning and both were due to pitting attack. Just prior to perforation of the tubes the pits of approximately ¼ inch diameter are filled to the exact level of the original inside surface with cuprous oxide. Overlying this was a green corrosion product overlain again by a layer of black fluffy cupric oxide. Recommendations for longer life included lowering of operating temperature, reduction of aggressive carbon dioxide by soda ash addition and alteration of future dedesigns so that it is not necessary to operate under mains pressure. Because corrosion is almost linearly related to dissolved oxygen content, air elimination cannot be used in a system under 5 atmospheres pressure at 160° F where oxygen solubility is 20 ppm. The solubility under an absolute pressure of 1 atmosphere would be only 4ppm at the same temperature. One of the buildings is following our recommendation of soda ash addition and it should be possible to obtain an early indication of its effect. Dechlorination of the water prior to entry into the hot water service is another aspect which will be concurrently investigated.

(iv) A Cusilman bronze calorifier of 2,000 gallons capacity had corroded almost to the point of failure after a period of use of only 13 months. Heating was by steam coils at the bottom of the horizontal cylinder and the corrosion was mainly limited to the middle third section of the cylinder height. Contributing factors to the failure were high dissolved oxygen levels, due to the high operating pressure of approximately 40 p.s.i., and higher than recommended operating temperatures. It was not possible to ascertain whether the vessel had been stress relieved during manufacture. Alkali dosing to reduce aggressive carbon dioxide and sacrificial anodes of aluminium were included in the recommendation.

(c) Iron.

(i) A water supply drawn from a small dam filled from a flowing creek overgrown with bullrushes was causing levels of iron of 5 ppm in a service holding tank which was in turn subsequently causing staining problems. The presence of iron was at first thought to be due to seepage water into the dam but was subsequently shown by inspection to be due to corrosion of the ¾ mile, 3 inch galvanised pipe from the dam to the service tank. The free or aggressive carbon dioxide content of the dam water was 65 ppm with a pH of 5.5 and this was quite capable, with the help of oxygen, of dissolving 5 ppm of iron in its traverse to the service tank. The recommendation was to reduce the aggressive carbon dioxide to about 2 ppm by efficient aeration at the dam thereby rendering the water comparatively non-corrosive.

(ii) Mild steel end plates of water cooled tube condensers have been rapidly corroded in many systems despite inhibitor treatment. The causes have usually been due to high salts build up or insufficient inhibitor dosage. Because of this it has not been possible to obtain comparative performance of various inhibitor types. The failure of chromate-phosphate to satisfactorily inhibit corrosion at levels lower than 250 ppm, coupled with the disposal problem of chromate have led to the exclusion of this type of inhibitor in trials being conducted at various sites during the year. Inhibitors which are at present under controlled test in various systems are, molybdate-dianodic, zinc organic and filming amine.

It is hoped that by the end of 1971 the comparative worth of these three types can be assessed by inspection of the end plates.

2. Pollution.

(a) Bunbury ocean.—Over an area of approximately one square mile of ocean, which enveloped the obvious outfall area for Laporte effluent, the average iron content of the ocean water from samples taken at all depths was 0.6 ppm. Because the effluent no longer discharges directly into the ocean, but into a depression between sandhills of limesand, the outfall area is not obvious. The calculated quantity of iron in the supposed outfall area with an average depth of 20 feet was equivalent to less than two hours production of effluent and there was no accumulation of iron sludge near the ocean bottom as might have been expected from a denser material discharging into the ocean from the ocean floor. The highest level of iron at distances closer than 6 inches from the bottom was 9 ppm.

The following are possibilities for the fate of the discharged iron:—

- (i) It can be precipitated after neutralisation with limesand in the immediate surround of the discharge area. This condition can prevail for a limited number of years due to the close proximity of the ocean.
- (ii) It can channel into an underground aquifer.
- (iii) It can channel into the ocean on a confined front.
- (iv) It can channel into the ocean on a diffuse front.

The results indicate that most of the iron is being precipitated in the limesand but some is being discharged into the ocean on a dispersed front.

(b) Nitrate levels in heavily irrigated areas.—The possible ultimate fate of nitrogenous fertiliser that has not been utilised by the plant is to be leached away as nitrate if there is sufficient water to do so. Nitrate levels in heavily fertilised and irrigated areas for Sudax grass at Capel have been as high as 200 ppm in a shallow aquifer beneath the cultivated soil, and as high as 20 to 50 ppm in nearby wells. As the maximum level for water for human consumption is 45 ppm, because of its effect on babies, this is an area where continued surveillance is required.

(c) Polluted farm dams.—Because of drought conditions during 1969-70 dams were generally nearly empty and the extent of pollution due to body wastes of animals watering at these dams became more obvious. It is rarely necessary to treat such water for stock but to use this water for domestic purposes involved chlorination at breakpoint level. Unfortunately the breakpoint demand of such waters can be as high as 50 to 100 ppm of chlorine and cartage of water is generally more economically feasible for such purposes. A pamphlet "Emergency Chlorination of Farm Water Supplies" was prepared by Mr. Hughes, Chief of the Agriculture Division and published as Bulletin No. 3715 of the Agriculture Department.

3. Public Water Supplies.

(a) Treatment.—It is envisaged that in the near future approximately 12 million gallons of ground water from the Gnangara area will be treated daily to augment Perth's water reserves. The treatment plant is built to accommodate this capacity but the clarifier units at present are capable of treating only 2 to 3 million gallons daily. Jar tests and initial plant performance trials indicate that as the quality of the various bore waters is not homogeneous having varying excessive levels of iron, colour and turbidity, the treatment plant will require coagulant aids to work and tight control of these to give performance figures of 10 ft per hour upflow velocity. The water from the shallow aquifer is of similar salinity to the Hills supplies and could be charged directly into the reticulation, after treatment, without blending.

The existing system for iron removal from the Hector and Robert Street bores at the Mt. Hawthorn Treatment Plant involves incidental surface aeration and bacterial precipitation in the sumps and pipelines from the bores to the treatment plant where an additional aeration and settling period is responsible for feeding only several ppm of iron, of the original 11 ppm present, to the sand filters. Vigorous aeration at the sumps by compressed air was responsible for making more of the iron insoluble at the pipe inlet to the treatment plant but the insoluble iron was now in such a fine state that it would not settle satisfactory. Whereas the sand filters were previously loaded with only several ppm iron they were now with this additional applied aeration, loading the sand filters with 6 ppm iron. The updating of the old system warrants further investigation with chemical addition to give a more rapid settling floc.

Treatment of water supplies from country towns for turbidity, colour or taste removal included Balingup, Boyanup, Boyup Brook, Eneabba, Koorda, Manjimup, Nyabing, Pemberton, Tambellup, Wanneroo and Yornaning and these frequently involved an inspection of the site.

(b) Reticulation water from Wellington dam in newly installed P.V.C. one inch diameter pipes under the comparatively stagnant conditions of several volume changes per week took between one and two weeks before the lead content of the water was reduced to the safe level of less than 0.05 ppm. The initial level was as high as 0.30 ppm but this high level would not be expected in a normal situation. Small diameter pipes with high surface area/volume ratios and long contact times have caused these results. P.V.C. pipes manufactured for reticulation are tested for this lead aspect under Australian Standard K138-1969 and it was not expected that there would be such high levels after a preliminary rinse. Atlhough lead is a cumulative poison it is not expected that such levels, for a period of several weeks, would have an adverse effect on the consumer.

(c) Unlike water from Mundaring Weir, which contains aggressive carbon dioxide and dissolves 7-8 ppm of calcium in its 300 mile traverse through cement lined mains to Kalgoorlie, that from Millstream, after aeration at the summit tank, contains no aggressive carbon dioxide and with a positive Langelier Index is capable of depositing calcium carbonate particularly if aeration is not reduced to a minimum. See Table 19 for Millstream which supplies Dampier and Karatha after being pumped through 80 miles of approximately 20 inch diameter cement lined pipe. Needless to say after further aeration at Dampier service tanks there is likely to be deposition and encrustation on valve fittings, etc., due to increased supersaturation.

Table 19

	Mundaring	Kalgoorlie	Millstream	Dampier
pH	7·0	8·0	7·4	7·6
Saturation Index (Langelier at 20°C)	—2·5	—0·8	+0·1	+0·3
	parts per million			
Total dissolved solids	300	320	650	650
Total alkalinity (calc. as $CaCO_3$)	15	40	320	320
Calcium, Ca	8	16	75	75
Free carbon dioxide (by calculation)	3·2	0·8	25	15
Aggressive carbon dioxide	3·1	0·7	nil	nil

(d) Manganese continues to show up in underground supplies. Apart from those at Hammersley and Bunbury reported last year it had been found in a bore water from Kununurra. This means that all future drilling samples for intended town water supply will be tested for this troublesome component.

4. Miscellaneous

(a) Testing of waters for the Geological Survey for elements associated with valuable minerals still continues but it is doubtful whether it can be of any useful purpose in locating mineral ore bodies. Nearly all water samples received contain alkalinity and on aeration during sampling lose carbon dioxide causing a rise in pH and frequently formation of insoluble material. As most water samples contain suspended solids this insoluble material caused by pH rise cannot be redissolved in acid without introducting errors. "In solution" figures which are frequently as low as parts per thousand million are also subject to error because of this possible loss due to post precipitation of these elements, but if all suspended solids were included the possible error could be greater. Minerals such as zinc and copper frequently have levels of parts per million but these values can also be attributed to corrosion of galvanised iron or copper alloy pumping equipment and accessories. A notable exception to the above was a bore south of Lake Hurlstone; the lake was 10 times more saline than sea water and contained cobalt and nickel at levels of 0.4 and 0.5 parts per million respectively. The activity coefficient in such a saline water at neutral pH would allow these high levels without precipitation.

(b) There has been an increasing number of queries in relation to swimming pools both from the householder and the supplier. Their problems mostly fit into two categories.

(i) Inability to keep the water clear of algae during summer months. This is mostly the result of insufficient chlorine dosage, which for a normal household pool of 10,000 gallons capacity will cost the owner several dollars per week. Chlorine is a more effective algacide at low pH and householders are advised to keep the pH on the low side at about 7.2 to 7.4.

(ii) Formation of cloudy and coloured water apart from algae. Chlorination of a manganese bearing water was responsible for a dark colouration due to the formation of hydrated oxides of manganese in one instance but generally cloudiness was due to the water being supersaturated with respect to calcium carbonate. This supersaturation is brought about by evaporation and concentration of salts and accumulated levels of calcium due to calcium hypochlorite addition. This latter condition can also be rectified by lowering the pH.

(c) Levels of nutrients in water being leached from plots fertilised with 2 cwt of super potash and 2 cwt of urea per acre followed by irrigation with 6 inches of water, gave levels of nitrogen and phosphorus in the leachate below that expected from straight water solutions of added chemicals, whereas levels of potassium and sulphur were higher. See Table 20.

Table 20

	Level calculated from water solution of fertiliser	Level in leachate
	parts per million	
Nitrogen, N	76	36
Phosphorus, P	7	3·5
Potassium, K	30	40
Sulphur, S	11	20

(d) Water from an urn accidentally contaminated with arsenic had 3.9 ppm arsenic in it. After draining, refilling with water and boiling the level of arsenic was still 1.6 ppm. The urn was then cleaned of corrosion products by heating for a limited period with citric acid solution, draining, rinsing, refilling and boiling. It still showed arsenic at 0.1 ppm level. Although it is a water soluble component the arsenic was obviously taking part in a chemical reaction with the corrosion products at the surface and could not be readily removed by repeated rinsing and boiling with water.

(e) Taste complaints from coffee drinkers using water from a badly corroded chrome plated copper urn were accentuated after the urn had been cleansed of corrosion products by heating with 2% acetic acid. Despite repeated rinsing and heating the level of copper in the water was still high at 8 ppm and it took several days' use before it dropped to what was considered a satisfactory level of about 1 ppm. This period of higher than normal copper levels led to complaints also from tea drinkers. Subsequent testing by a taste panel of 10 showed that "white coffee" drinkers were more susceptible to this taste than "white tea" drinkers and that black coffee drinkers could not detect a taste with 6 ppm of copper. More than half the taste panel could detect "off" tastes with copper at 3 ppm. Zinc levels up to 25 ppm had no effect on taste. This taste is probably associated with the low copper levels that can be tolerated in butter without causing taste problems.

DIVISION VIII

Annual Report of the Chief Inspector of Explosives for the Year 1970

The Under Secretary for Mines

In accordance with Section 10 of the Explosives and Dangerous Goods Act 1961–1967 I submit this report on the work of the Explosives Branch for the year ending 31st December, 1970.

STAFF

During the year the staff was finally brought to the full strength as proposed in the organisation plan made in 1967 for operation of both explosives and flammable liquids. One additional clerk typist commenced in January thus completing the proposed office staff of three junior members for records correspondence and issue of licences, one full time typist-receptionist and a Senior Clerk in charge.

ACCOMMODATION

The Explosives Branch continued to operate the same premises at 10 Victoria Avenue but in May the offices were moved from the second floor to larger accommodation on the first floor. The new offices have proved quite adequate for the additional staff and the present accommodation is satisfactory in all respects.

LEGISLATION

There was no further amendment of the Explosives and Dangerous Goods Act but during the year the Act was consolidated and reprinted together with the Explosives Regulations as amended in 1969.

Nine amendments were made to the Flammable Liquids Regulations during the year. Seven were published in the *Government Gazette* on 13th April, and two in the *Gazette* for 30th July. There is nothing in these amendments to change the general effect of the regulations as originally drafted. The amendments have been made either to clarify the original intentions or to facilitate the granting of approvals in special circumstances which were not anticipated at the time of drafting. After a complete year of implementation it appears that the regulations are quite practicable and they can be applied to storages and operations throughout the whole State of Western Australia with satisfactory results to all concerned.

AUTHORISATION OF EXPLOSIVES

Four new explosives were officially authorised during the year and the definition was amended for one already authorised.

Class 2—Nitrate Mixture
Iregel (zz)

Class 3—Nitro-Compound—Division 2
Superseis Seismic Charges (zz)
Metabel (zz)

Class 6—Ammunition—Division 3
Superseis Blasting Caps (z)

MANUFACTURE OF EXPLOSIVES

Two licences were issued for manufacture of fireworks used in local displays and explosives of Class 2 are manufactured in licensed factories at Port Hedland and at Kalgoorlie. The Kalgoorlie factory is a mixing plant for nitrate mixture and is located on the Explosives Reserve. The Port Hedland factory produced 800 short tons of slurry explosive mainly for supply to the mine at Goldsworthy while the Kalgoorlie plant produced 1,057 short tons of dry nitrate mixture for supply to mines at Kalgoorlie and Kambalda.

Slurry explosives are mixed " on-site " in a mobile unit at Tom Price and a new formulation for slurry was approved and introduced this year. Since ingredients are blended together just prior to loading holes in the quarry, this operation is covered by a Licence to Manufacture Blasting Agent. Total production of all slurry explosives under this licence at Tom Price was 11,523 short tons during 1970.

Large amounts of ANFO explosive are manufactured at smaller mines and blasting operations throughout the State and 91 licences for " on-site " manufacture were issued during the year. It is impossible to estimate the quantity of explosive used in all these smaller operations but the total of all slurry and nitrate mixtures produced at Port Hedland, Kalgoorlie and Tom Price was 13,383 short tons. This quantity manufactured and used within the State is approximately five times the total of all types of explosive used annually in the whole of Western Australia prior to 1960.

(11)—90726

IMPORTATION AND SUPPLY OF EXPLOSIVES

Four Licences to Import Explosives were issued and a total of 20 Entry Permits were issued to cover special importations of explosive items not formally authorised. These items included signal lights, special appliances for oil drilling, bon-bon snaps and whaling explosives. Five shipments came from Melbourne and all followed the northern route delivering explosives direct to the ports of Broome, Port Hedland and Dampier before making the final discharge at Woodman Point. Two shipments of explosives from U.S.A. were discharged one at Wyndham and the other at Fremantle.

Throughout the year there was a steady supply of explosives and detonators from Melbourne by standard gauge rail conveyance. Some consignments were consigned to Parkeston and conveyed to the Kalgoorlie magazines while others were consigned through to the Kewdale depot from which they were further conveyed by road vehicles to Woodman Point. During 1970 about 36% of all nitro-compound explosives were consigned by rail compared with 22% for the previous year.

The total quantity of nitro-compound explosives received from all sources was considerably greater than in 1969 and the total of 2,756 short tons is of the same order as it was in 1960 before nitrate mixtures were used in this State.

Ammonium Nitrate

The quantity of ammonium nitrate shipped from overseas to north-west ports was 14,673 short tons compared with 13,369 short tons for 1969. The main source was Japan since there was none received from U.S.A. in this year. The C.S.B.P. factory at Kwinana was fully operative during the year but 1,556 short tons of nitrate prills were railed to Western Australia from the factory in New South Wales. There is still some difficulty in arranging transport for nitrate from the Kwinana factory to the north-west areas where the demand is greatest. Some consignments were arranged by State Shipping Service and some were railed to Meekatharra for further conveyance by road. It appears however, that most of the blasting in the north was done with prilled nitrate from Japan. A total quantity of 8,678 short tons of ammonium nitrate from the Kwinana factory was distributed by rail, road and ship for blasting purpose. From all the information available it appears that a total of 24,907 short tons of ammonium nitrate was used in Western Australia for blasting purposes during 1970.

Quantities Imported

The following summary shows the total quantities of explosives and prilled ammonium nitrate received in Western Australia for the year ended 31st December, 1970.

Ammonium Nitrate—	Short tons	
Shipped	14,673	
Railed	1,556	
Produced in W.A.	8,678	
		24,907
Nitro-compound Explosives—		
Shipped	1,747·1	
Railed	1,008·8	
		2,755.9
		Short tons
Marine Blasting Powder (NCN)		9·5
Nitrate Explosives, Class 2		584·25
Primers and Boosters		94·3
		Cases
Safety Fuse		1,190
Detonating Fuse		5,332
Plain Detonators		499
Electric Detonators		3,226
Whaling Explosives		60
O il-well Explosives		41
		Pounds
Blasting Powder		550
Rifle Powders		855

LICENCES AND INSPECTIONS

The following licences under the Explosives Regulations were issued and renewed during the year :

Licences to Manufacture Explosives	4
Licences to Import Explosives	4
Licences to Manufacture Blasting Agent	91
Licences to Sell Explosives	58
Licences for Premises	41
Licences for Magazines	167
Licences to Convey Explosives	87
Total Licences issued	452

Inspection of magazines and licenced premises continued on a somewhat reduced level owing to the amount of work connected with flammable liquids and the fact that all inspectors were acquiring experience in their work. Nevertheless 127 magazines and stores were inspected and 53 inspections were made of road vehicles under Licence to Convey Explosives. At Woodman Point the Magazine Keeper inspected all shipping operations and movements of explosives over the jetty both inward and outward. All vehicles leaving the Reserve with explosives were also subject to his inspection and approval. The new regulations for road conveyance have become fully effective with the appointment of additional inspectors who are now available to inspect new vehicles and ensure they are properly equipped before a licence is issued. There is keen competition for road conveyance of explosives and operators will readily place economy before safety if there is any lack of control by inspection.

EXPLOSIVES RESERVES

Woodman Point.—Normal maintenance was carried out to keep all equipment and buildings in satisfactory condition. Timber decking on the jetty was replaced by the Fremantle Port Authority and the tractor was overhauled by the Mechanical and Plant Engineer after 3½ years of continuous service. Railway lines and points were overhauled and repaired where necessary and some road surfacing was done by a contractor. There was difficulty throughout the year in securing and retaining the usual number of watchmen. Daily movements of explosives both into and out of the Reserve are now very much more numerous than they were in past years. Two agents are operating and there have been many more consignments received by rail. Minor shipping operations and a considerable increase in road conveyance have added a great deal to the duties and responsibilities of the Magazine Keeper and his staff.

Kalgoorlie Reserve.—During the year a factory building was erected on this Reserve and production of a Class 2 explosive mixture commenced. The explosive mixture is delivered by road to mines at Kalgoorlie, Kambalda and surrounding areas. The plant operates under a Licence to Manufacture Explosives but the process of manufacture is a simple operation which consists of mixing prilled ammonium nitrate with a liquid ingredient and packaging the mixture for conveyance by road.

Other Reserves.—There has been no change of circumstances affecting other Reserves which are used for explosives storage.

EXPLOSIVES DESTROYED

On fourteen occasions inspectors were called upon to destroy quantities of explosives which were unfit for further storage or for use. The quantities so destroyed varied from a few pounds to several cases. Usually they were burned under special control in remote locations. In two operations at Woodman Point, quantities of several tons were loaded to barges and towed out for dumping at sea in an approved location about 20 miles from the coast. About 310 cases of electric detonators were withdrawn from distribution by the manufacturers owing to faulty delay elements. These were suitably prepared so as to sink effectively in water and also disposed of by dumping in deep water off the coast. The Magazine Keeper carried out regular disposal of unwanted sample material and police exhibits by burning on the beach.

DISPLAYS OF FIREWORKS

Permits were issued for eleven displays of fireworks most of which were conducted by the two local manufacturers who make their own fireworks and use them for display purposes. No permit for Display of Fireworks is issued by the Explosives Branch unless the time and place are approved by the local Council and also by the Police Officer in the area. Some of the displays include aerial bombs which are projected vertically to explode at height. Such explosions are audible over a wide area and have brought complaints from residents in the area. Efforts are therefore made to restrict such displays to early hours and to secure prior approval of local authorities. There were no complaints received this year about fireworks displays.

TESTING OF EXPLOSIVES

Abel Heat Tests were made on samples from all consignments of explosives containing nitroglycerine and 1,060 samples were tested during the year at Woodman Point. Explosives delivered direct to north-west ports from Melbourne are sampled and tested by the Victorian Explosives Department before despatch. They are then accepted on satisfactory results being reported in Certificates received from Victoria.

All Safety Fuse received at Woodman Point was tested for burning time and all results were consistently within the prescribed limits.

Tests were continued throughout the year on sensitivity of slurry explosives and blasting agents. A considerable amount of work was done in cooperation with technical officers of C.S.B.P. and Farmers Ltd. on the blasting properties of mixtures made with prilled ammonium nitrate produced at the Kwinana factory. The product was found to possess satisfactory oil absorption and to be quite suitable for blasting. A number of analyses for organic carbon were made by the Government Chemical Laboratories and all results were satisfactory in being within the limit as required by shipping and harbour authorities.

ACCIDENTS WITH EXPLOSIVES

Accidents reported to the Branch were few in number this year and none was fatal. Three employees of the Metropolitan Water Supply were injured in one accident which occurred when a pneumatic drill apparently penetrated an unexploded charge. An investigation was made when several vehicles were damaged by fly-rock from a demolition job near the city area and the contractor was instructed to use blasting mat covers and to use smaller charges. An explosion occurred at the rear of premises in Hannan Street, Kalgoorlie, and it was thought to be caused by accidental detonation of mining explosives. There was, however, little damage and no person was injured.

The Department frequently received complaints of alleged damage to houses after blasting operations and these are usually investigated by the State Mining Engineer's Branch. There was, however, one instance this year which was not a mining operation and enquiries were made by the Explosives Branch. It was found that the contractor had carefully observed all statutory requirements and had followed good practice in the use of explosives. Since there was no direct evidence of damage to any property, no further action was required.

Technical officers of the Branch were called to assist police in their enquiries on six occasions when explosives were used unlawfully in the Metropolitan Area. These were generally irresponsible or malicious actions in which damage was caused to two vehicles, a telephone box and a vessel berthed at Fremantle. Evidence was obtained where possible to identify the type of explosive and to estimate the amount which was used in these outrages.

FLAMMABLE LIQUIDS REGULATIONS

The regulations became operative on 1st November, 1969 and the year 1970 was therefore the first complete calendar year of operation. There has hitherto been no such legislation in Western Australia so that part of the task has been to introduce the system to the public and to give industry an understanding and appreciation of the requirements. Some preliminary work was done in the previous year by advertisement in the press and by issue of information booklets to Councils throughout the State. A new Senior Inspector and three Inspectors however, commenced their duties between February and June in 1970, and considerable time was required to guide these officers in applying the regulations and in dealing with the many new situations which continued to arise during the year.

It is reported with satisfaction that a great deal has been achieved this year to establish the regulation and control of flammable liquids throughout the State. All inspectors have approached the task with enthusiasm and with a genuine desire to assist the public at all times and to achieve greater safety in the storgae and keeping of flammable liquids. Much work still remains to be done before all installations and storages throughout Western Australia can be brought to the required standard but very substantial results can be reported for the first year of operation.

A total of 1,121 premises were inspected and 438 advisory consultations were reported by the inspectors. An additional 61 inspections were made in connection with road conveyance. At the end of the year there were 3,961 premises registered and licensed. Applications are still being received and there are still a number of premises which have not been registered. For this reason two further announcements were inserted in the newspapers toward the end of the year.

The Oil Companies operating in Western Australia are responsible for a large proportion of all flammable liquid storages throughout the State and all companies have co-operated fully by submitting for approval all proposals and plans for new installations. They have also done a great deal to improve the older country depots which did not comply with the regulations and the up-grading of these older premises will continue since the expenditure and work involved must be spread over a reasonable period.

The Explosives Branch has augmented its staff to the full strength proposed in my report made in 1967 but the number of inspectors is much smaller than required in other smaller States. This is considered practicable because of the liaison which has been established with Department of Labour, Shire Councils and the W.A. Fire Brigades. Inspectors of the Labour Department have been instructed to observe storages of flammable liquids during their inspections and if action is thought to be required a report is made to the Explosives Branch for subsequent inspections and action. Similarly council inspectors report any local problems which require investigation and Fire Brigade inspection reports are made available to the Explosives Branch. Such co-operation has assisted the inspectors in making the best use of their time and should enable the Branch to operate with a minimum of inspectional staff.

COMMITTEES AND LECTURES

Advisory Committee on Transport of Dangerous Goods

The Chief Inspector attended meetings held at the Department of Shipping and Transport, Melbourne, on 16th and 17th April. Final discussions took place on the Draft Model Code which was subsequently published in November. The stated purpose of this Code is " to set down requirements for the transport of dangerous goods by road upon which new or amended State and Commonwealth legislation might be drafted". The Model Code is based on recommendations from the United Nations and therefore has an international significance.

Australian Port Authorities Association

The Chief Inspector attended meetings of the Dangerous Goods Sub-Committee held in Sydney on 30th and 31st July. Other members of the Sub-Committee represented the Port Authorities in each State and the Explosives Departments. The " Code for Handling Dangerous Goods in Harbours " requires constant review and amendment to meet changing conditions in Australian ports.

Main Roads Department

Lectures on " Storage, Handling and Use of Explosives " was given at a morning session of a training course for foremen of the Department.

A four-day training course on explosives was given for engineers of the Department on 24–27th August. This course was organised by Training and Safety Officers of the Main Roads Department and both the Chief Inspector and his technical officer contributed to the sessions which were held. Three days were devoted to lectures and discussions and one day to a demonstration by Mr. H. Douglas of practical blasting work in the field.

Department of Labour

Mr. H. Douglas delivered a lecture to Factory Inspectors on the subject of "Electrostatics and Explosion Hazards ".

Police Department

A lecture was given by Mr. H. Douglas to a training school for detectives. The subject of the lecture was "Explosives and Explosions ".

POLICE INVESTIGATIONS

The technical officers of the Branch were called upon by the Police Department to give expert assistance in determining the causes of explosions and outrages. In two of these occurrences brick buildings were completely wrecked by violent explosion and in each case the damage was considered to be caused by explosion of vapour from flammable liquid. Reference is made under the section of this report dealing with accidents to other occurrences which were investigated.

EXPLOSIVES CONFERENCE

The Tenth Conference of Chief Inspectors of Explosives was held in Perth from 12th to 23rd October, 1970. All States of Australia were represented and Queensland, Tasmania and New South Wales each sent two delegates. New Zealand has usually participated in the Australian Conference but was unfortunately unable to send a delegate on this occasion. For the first time a delegate attended from the Department of Labour in Papua-New Guinea where legislation is now in force for both explosives and flammable liquids.

CONCLUSION

The successful achievement of all tasks during the year is credited largely to the enthusiasm and excellent co-operation of all the staff members. Appreciation is recorded also of the assistance received in the field of flammable liquids from the Chief Officer of the W.A. Fire Brigades and his Fire Prevention Officers. Their interest in this work has continued since drafting of the regulations was first commenced and very good relations have been maintained at all times.

G. A. GREAVES,
Chief Inspector of Explosives.

2nd March, 1971.

DIVISION IX

Report of Superintendent, Mine Workers' Relief Act, and Chairman, Miners' Phthisis Board 1970

UNDER SECRETARY FOR MINES:

1. I submit for the information of the Honourable Minister for Mines my report on this Branch of the Mines Department for the year, 1970.

2. *General*

The State Public Health Department, under arrangements made with this Department, continued the periodical examination of mine workers throughout the year and mines at Kalgoorlie, Wundowie, Gosnells, Jarrahdale, Greenbushes, Bunbury, Capel, Ravensthorpe, Esperance, Norseman and Kambalda were visited by the mobile X-ray unit.

3. *Mine Workers' Relief Act*

3.1 *Total Examinations*

The examinations under the Mine Workers' Relief Act during the year totalled 4,281 and compared with 3,881 for the previous year ; an increase of 400. The results of examinations are as follows :—

Normal	3,841
Silicosis early previously normal	30
Silicosis early, previously silicosis early	394
Silicosis advanced, previously normal	....
Silicosis advanced, previously silicosis early	6
Silicosis advanced, previously silicosis advanced	....
Silico-tuberculosis, previously normal	....
Silico-tuberculosis, previously silicosis early	1
Silico-tuberculosis, previously silicosis advanced	....
Silico-tuberculosis, previously tuberculosis	....
Tuberculosis, previously normal	3
Asbestosis early, previously normal	....
Asbestosis early, previously asbestosis early	....
Asbestosis advanced, previously normal	....
Asbestosis advanced, previously asbestosis early	....
Silico-asbestosis early, previously normal	....
Silico-asbestosis early, previously asbestosis early	....
Silico-asbestosis early, previously silicosis early	....
Silico-asbestosis early, previously silico-asbestosis early	6
Silico-asbestosis advanced, previously silico-asbestosis early	....
Silico-asbestosis advanced, previously silicosis early	....
Silico-asbestosis plus tuberculosis, previously normal	....
Silico-asbestosis advanced, plus tuberculosis, previously silico-asbestosis early	....
Total	4,281

The 1970 figures, together with figures for previous years are shown on the table annexed hereto. Graphs are also attached illustrating the trend of examinations since 1940.

3.2 *Analyses of Examinations*

In explanation of the examination figures, I desire to make the following comments :—

3.2.1. *Normal, etc.*

These numbered 3,841 or 89·73% of the men examined and include men having first class lives or suffering from fibrosis only. The figures for the previous year being 3,406 or 87·77% of the men examined.

3.2.2. *Early Silicosis*

These numbered 424 of which 30 were new cases and 394 had previously been reported, the figures for 1969 being 448 and 36 respectively. Early silicosis represents 9.90% of the men examined, the percentage for the previous year was 11.55%.

3.2.3 *Advanced Silicosis*

There were 6 cases reported all of which advanced from early silicosis. Advanced silicotics represent 0·14% of the men examined, the percentage for the previous year being 0·36%.

3.2.4 *Silicosis Plus Tuberculosis*

One case was reported which was the same as for 1969.

3.2.5 *Tuberculosis Only*

Three cases were reported compared with one in 1969.

3.2.6 *Asbestosis*

There were no new cases reported.

3.2.7 *Silico Asbestosis*

Six cases were reported of which none were new cases.

4. *Mines Regulation Act*

4·1 *Total Examinations*

Examinations under the Mines Regulation Act totalled 6,378. There was an increase of 360 under this Act in 1970 as compared with 1969.

This again reflects the impetus gained from the new legislation amending the definition of " mine ". Of the total of 6,378 examined, 5,959 were new applicants and 419 were re-examinees. In addition, Provisional Certificates were issued to 748 persons in isolated country areas.

4·2 *Analyses of Examinations*

Particulars of examinations are as follows :—

4·2·1 *New Applicants*

Normal	5,951
Silicosis early	2
Silicosis early with tuberculosis	....
Tuberculosis	2
Other conditions	4
Total	5,959

4.2.2 *Re-Examinees*

Normal	419
Silicosis early	....
Silicosis early with tuberculosis	....
Tuberculosis	....
Other conditions	....
Total	419

These men had previously been examined and some were in the industry prior to this examination.

4.3 *Health Certificates Issued to New Applicants and Re-Examinees*

The following health certificates were issued under the Mines Regulation Act :—

Initial Certificates (Form 2)	6,358
Temporary Rejection Certificates (Form 3)	2
Rejection Certificates (Form 4)	6
Re-admission Certificates (Form 5)	12
Special Certificate (Form 9)	....
Total	6,378

The figures for 1969 included in that report erroneously referred to re-examinees only and the figures are now correctly shown hereunder :—

Initial Certificate (Form 2)	5,977
Temporary Rejection Certificate (Form 3)	2
Rejection Certificate (Form 4)	24
Re-admission Certificate (Form 5)	14
Special Certificate (Form 9)	1
Total	6,018

5. *Miners' Phthisis Act*

The amount of compensation paid during the year was \$9,462·00 compared with \$11,362·00 for the previous year.

The number of beneficiaries under the Act as on 31.12.1970 was 44 being 3 ex miners and 41 widows.

6. *Administrative*

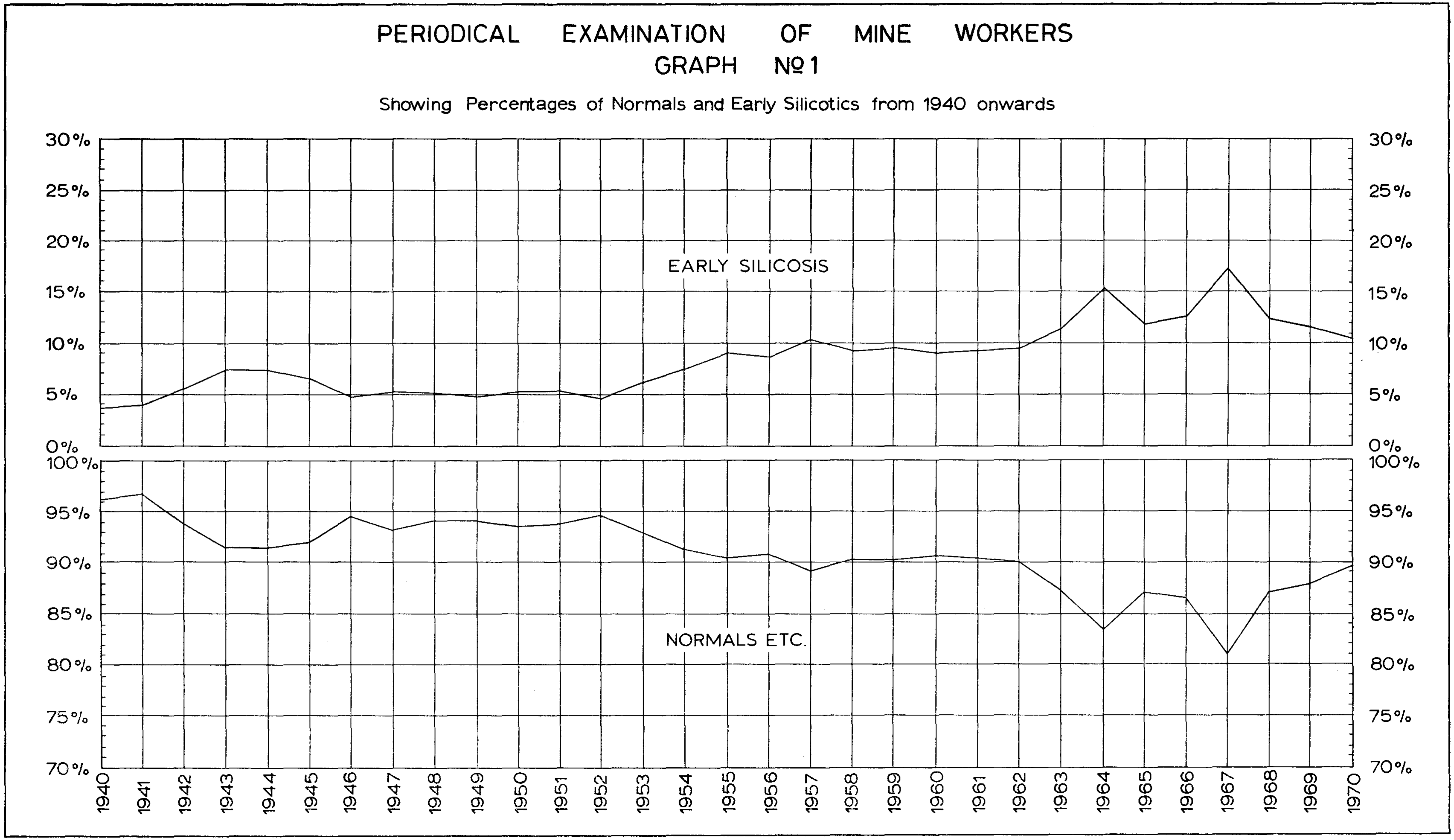
There were no administrative changes during the year.

A. L. DAY,

Superintendent, Mine Workers' Relief Act

and

Chairman, Miners' Phthisis Board.


PERIODICAL EXAMINATION OF MINE WORKERS
GRAPH Nº 1
Showing Percentages of Normals and Early Silicotics from 1940 onwards
EARLY SILICOSIS
NORMALS ETC.
30% 25% 20% 15% 10% 5% 0%
100% 95% 90% 85% 80% 75% 70%
1940 1941 1942 1943 1944 1945 1946 1947 1948 1949 1950 1951 1952 1953 1954 1955 1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970

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PERIODICAL EXAMINATION OF MINE WORKERS
GRAPH Nº 2

Showing Percentages of Silicosis Advanced, Silicosis plus Tuberculosis and Tuberculosis only, from 1940 onwards

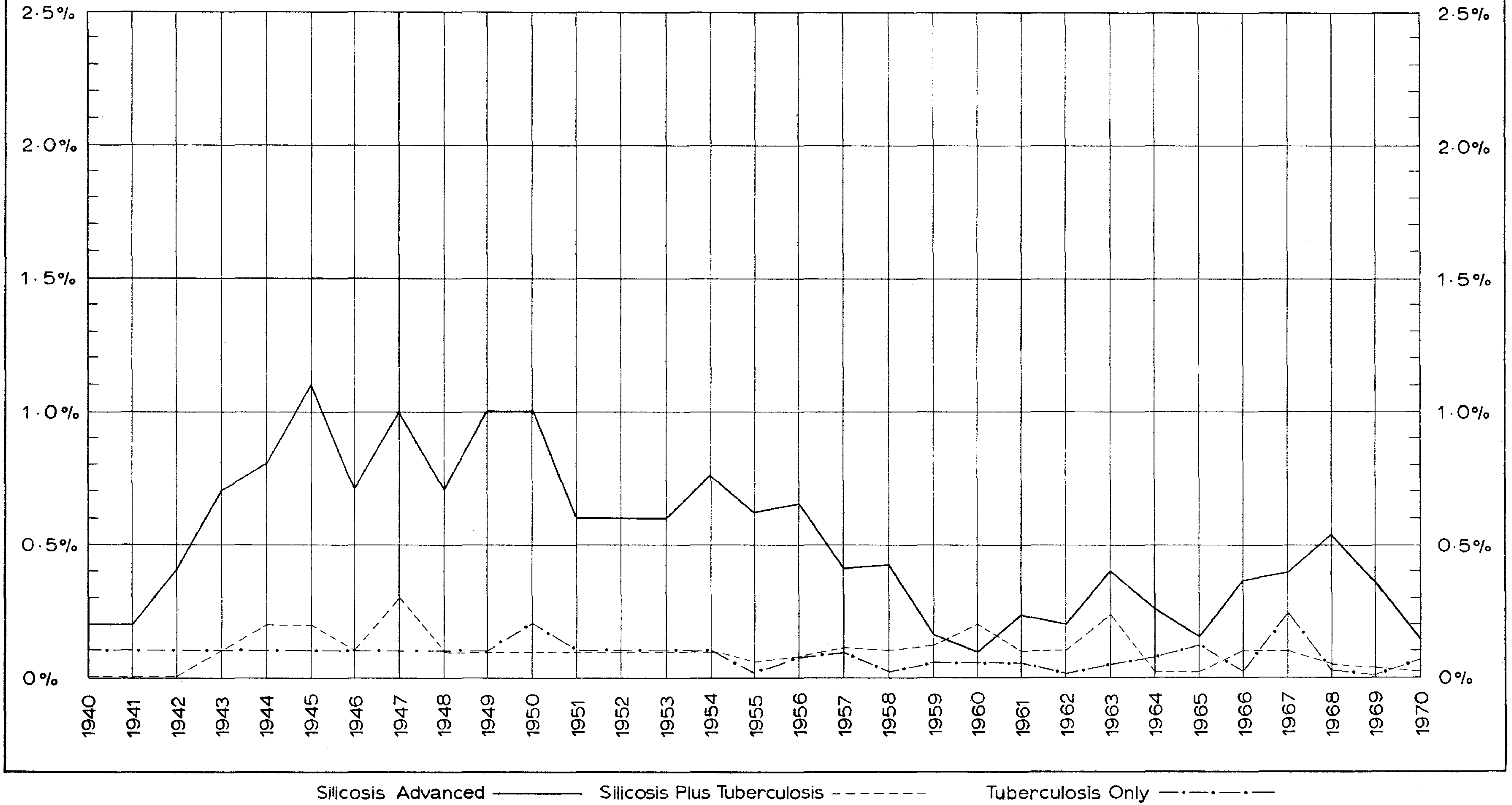

TABLE SHOWING RESULTS OF PERIODICAL EXAMINATION OF MINE WORKERS FROM INCEPTION OF EXAMINATIONS (1925).

	Normal		Silicosis Early				Silicosis Advanced					Silicosis plus Tuberculosis					Tuberculosis Only		Asbestosis									
Year	Total	Per Cent.	Previously reported as Normal etc.	Previously reported as Silicosis Early	Total	Per Cent.	Previously reported as Normal etc.	Previously reported as Silicosis Early	Previously reported as Silicosis Advanced	Total	Per Cent.	Previously reported as Normal etc.	Previously reported as Silicosis Early	Previously reported as Silicosis Advanced	Total	Per Cent.	Total	Per Cent.	Asbestosis early previously normal	Asbestosis early previously asbestosis early	Asbestosis advanced previously normal	Asbestosis advanced previously asbestosis early	Asbestosis advanced previously asbestosis advanced	Asbestosis plus tuberculosis previously normal	Asbestosis plus tuberculosis previously asbestosis	Total	Per Cent.	Total
1925 } 1926 }	3,239	80·5	....	....	459	11·4	....	....	....	183	4·5	....	....	....	131	3·3	11	0·3	....	....	....	....	....	....	....	....	....	4,023
1927	3,116	83·6	33	348	381	10·2	8	....	85	93	2·5	39	27	62	128	3·4	10	0·3	....	....	....	....	....	....	....	....	....	3,728
1928	2,977	85·5	59	303	362	10·4	3	16	79	98	2·8	18	14	10	42	1·2	4	0·1	....	....	....	....	....	....	....	....	....	3,483
1929	2,120	81·9	102	224	326	12·6	....	34	60	94	3·6	8	14	19	41	1·6	7	0·3	....	....	....	....	....	....	....	....	....	2,588
1930	2,785	81·9	136	247	383	11·3	2	22	43	67	2·0	8	60	46	114	3·3	50	1·5	....	....	....	....	....	....	....	....	....	3,399
1931	2,530	84·0	94	252	346	11·5	....	18	35	53	1·8	4	35	19	58	1·9	25	·8	....	....	....	....	....	....	....	....	....	3,012
1932	3,835	89·5	35	338	373	8·7	....	6	47	53	1·2	3	9	4	16	·4	8	·2	....	....	....	....	....	....	....	....	....	4,285
1933	2,920	86·5	57	322	379	11·2	1	15	44	60	1·8	2	9	4	15	·4	3	·1	....	....	....	....	....	....	....	....	....	3,377
1934	5,140	92·4	54	315	369	6·6	1	24	12	37	·7	6	6	....	12	·2	5	·1	....	....	....	....	....	....	....	....	....	5,563
1935	4,437	92·3	35	303	338	7·0	....	24	2	26	·6	....	5	....	5	·1	2	·0	....	....	....	....	....	....	....	....	....	4,808
1936	6,972	94·7	29	323	352	4·8	1	15	4	20	·3	3	8	....	11	·1	8	·1	....	....	....	....	....	....	....	....	....	7,363
1937	7,487	95·4	15	319	334	4·3	....	14	4	18	·2	1	10	....	11	·1	2	·0	....	....	....	....	....	....	....	....	....	7,852
1938	6,833	95·7	13	266	279	3·9	....	15	2	17	·2	1	8	....	9	·1	3	·0	....	....	....	....	....	....	....	....	....	7,141
1939	6,670	95·6	18	264	282	4·0	....	7	3	10	·1	1	9	1	11	·2	2	·0	....	....	....	....	....	....	....	....	....	6,975
1940	7,023	96·2	12	245	257	3·5	....	10	1	11	·2	....	4	....	4	·0	4	·0	....	....	....	....	....	....	....	....	....	7,299
1941	6,840	95·8	32	248	280	3·9	....	11	3	14	·2	....	....	....	....	....	7	·1	....	....	....	....	....	....	....	....	....	7,141
1942	5,469	93·9	61	264	325	5·6	....	20	5	25	·4	....	2	....	2	·0	3	·1	....	....	....	....	....	....	....	....	....	5,824
1943	3,932	91·5	63	262	325	7·6	....	25	7	32	·7	....	5	....	5	·1	4	·1	....	....	....	....	....	....	....	....	....	4,298
1944	4,079	91·5	70	270	340	7·5	....	21	14	35	·8	1	7	....	8	·2	6	·1	....	....	....	....	....	....	....	....	....	4,468
1945	3,071	92·1	54	166	220	6·6	....	26	10	36	1·1	3	2	....	5	·2	2	·1	....	....	....	....	....	....	....	....	....	3,334
1946	5,294	94·4	89	172	261	4·7	1	36	2	39	·7	3	1	2	6	·1	6	·1	....	....	....	....	....	....	....	....	....	5,606
1947	6,021	93·3	101	237	338	5·2	....	49	9	58	1·0	13	11	1	25	·3	8	·1	....	....	....	....	....	....	....	....	....	6,450
1948	4,827	94·0	24	239	263	5·1	....	18	17	35	·7	1	3	....	4	·1	5	·1	....	....	....	....	....	....	....	....	....	5,134
1949	5,162	94·0	24	239	263	4·8	....	20	31	51	1·0	3	2	1	6	·1	7	·1	....	....	....	....	....	....	....	....	....	5,489
1950	5,077	93·6	14	269	283	5·2	....	14	41	55	1·0	....	1	2	3	·1	8	·2	....	....	....	....	....	....	....	....	....	5,426
1951	4,642	93·9	13	248	261	5·3	....	9	20	29	·6	....	4	2	6	·1	4	·1	....	....	....	....	....	....	....	....	....	4,942
1952	5,073	94·6	8	234	242	4·5	....	4	31	35	·6	....	2	....	2	·1	7	·1	....	....	....	....	....	....	....	....	....	5,359
1953	4,474	93·03	74	225	299	6·22	....	8	24	32	·6	....	2	....	2	·1	2	·1	....	....	....	....	....	....	....	....	....	4,809
1954	5,142	91·33	154	275	429	7·62	....	22	21	43	·76	1	6	2	9	·1	7	·1	....	....	....	....	....	....	....	....	....	5,630
1955	4,559	90·40	63	386	449	8·90	....	9	22	31	·62	1	1	1	3	·06	1	·02	....	....	....	....	....	....	....	....	....	5,043
1956	4,600	90·78	25	401	426	8·41	....	8	25	33	·65	1	3	....	4	·08	4	·08	Segregation of asbestosis diagnoses commenced in 1959									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	....	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	3,77 0	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

MINING STATISTICS
to 31st December, 1970

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TABLE I

PRODUCTION OF GOLD AND SILVER AS REPORTED TO THE MINES DEPARTMENT DURING 1970.

(For details concerning Mines and Centres not listed see Annual Report for 1966 or previous Reports.)

(*Note.*—**Lease** numbers in brackets indicate that the holding was ***voided*** **during** the year.)

(*Note.*—* Denotes mainly derived from treatment of tailings. † Denotes mainly derived from **Lead Ore.** ‡ Denotes mainly derived from Copper Ore. § Concentrates.)

Mining Centre	Number of Lease	Registered Name of Company or Lease	Total for 1970					Total Production				
			Alluvial	Dollied and Specimens	Ore treated	Gold therefrom	Silver	Alluvial	Dollied and Specimens	Ore treated	Gold therefrom	Silver
			Fine ozs.	Fine ozs.	Tons (2,240 lb.)	Fine ozs.	Fine ozs.	Fine ozs.	Fine ozs.	Tons (2,240 lb.)	Fine ozs.	Fine ozs.
			Pilbara Goldfield.									
			MARBLE BAR DISTRICT.									
Bamboo Creek	G.M.L. 1203	Mt. Prophecy	....	....	616·00	317·57	....	....	....	4,310·55	2,357·77	110·72
		State Battery, Marble Bar	....	....	....	*213·45	21·76	....	....	12·00	*14,545·42	464·78
			Gascoyne Goldfield.									
Mangaroon Station	G.M.L. 46	Star of Mangaroon	....	....	615·75	826·47	36·44	....	3·50	3,504·50	5,403·43	100·83
			Peak Hill Goldfield.									
Peak Hill	....	Sundry Claims	....	9·46	....	....	....	61·51	410·22	35,365·35	9,030·99	5·35
			East Murchison Goldfield.									
			LAWLERS DISTRICT.									
Kathleen Valley	G.M.L. 1387	Beth Heno	....	....	4·00	·59	....	....	....	4·00	·59	....
Lawlers	G.M.L. 1363, 1364	Kim Prospecting and Development Syndicate	....	....	....	29·78	....	....	....	290·00	55·42	....
Wildara Station	G.M.L. 1404	Rowleys Find	....	....	120·00	22·39	....	....	....	120·00	22·39	....
	(1390)	Vicky Sue	....	....	25·50	10·41	....	....	....	25·50	10·41	....
	(1385)	Mangilla	....	....	52·00	30·97	....	....	....	1,675·00	1,675·53	36·18
	(1388)	Tahmoo	....	....	28·00	3·12	....	....	....	1,658·25	471·49	....
		Sundry Claims	....	....	7·50	3·87	....	143·23	....	1,527·00	784·13	29·71
			WILUNA DISTRICT.									
Mt. Keith	....	Sundry Claims	....	....	4·00	3·10	....	4·81	227·29	3,872·50	2,488·16	·99
			BLACK RANGE DISTRICT.									
Barrambie	G.M.L. 1117	Scheelite Leases	....	....	135·00	101·69	....	....	....	1,440·00	932·62	19·60

Murchison Goldfield.

MEEKATHARRA DISTRICT.

Meekatharra	G.M.L. 2013N	Prohibition	....	....	553·25	33·86	....	....	....	553·25	33·86	....
Nanadie Well	2054N	Nanadie	....	....	29·25	22·06	....	....	....	29·25	22·06	....

MOUNT MAGNET DISTRICT.

Mt. Magnet	G.M.L. 1670M	Black Cat	....	....	18·00	1·27	....	....	....	46·30	4·17	....
	1282M, etc.	Hill 50 Gold Mine N.L.	....	....	28,703·00	6,580·88	512·67	....	....	2,952,219·00	1,293,587·18	64,414·05
		Sundry Claims	....	....	30·00	·50	....	157·95	2,629·26	62,239·17	30,281·66	29·52
Paynesville	1699M	Miss Waterway	....	....	41·00	·26	....	....	....	41·00	·26	....

Mt. Margaret Goldfield.

MOUNT MALCOLM DISTRICT.

Diorite	G.M.L. 1908C	Jasper Hills	....	....	40·00	6·76	....	....	....	40·00	6·76	....
	1853C	Puzzle	....	....	210·00	77·16	....	....	....	682·50	618·23	....
Lake Darlot	....	Sundry Claims	....	....	427·50	77·39	....	129·92	914·83	12,844·87	6,973·08	45·18
Leonora	1897C	Bon Boo	....	....	523·80	212·74	....	....	....	667·30	393·97	....
	1888C	Healeys Hope	....	....	114·00	45·74	....	....	....	114·00	45·74	....
	1762C, etc.	Sons of Gwalia Ltd.	....	....	846·50	367·34	....	....	18·73	7,031,651·03	2,581,625·63	188,812·19
		Prior to transfer to present holders	....	....	....	....	....	....	....	109,081·00	55,989·21	8·66

North Coolgardie Goldfield.

MENZIES DISTRICT.

Menzies	G.M.L. 5804Z	Gladys Mary	....	....	207·50	7·54	....	....	....	589·25	24·48	....
		Sundry Claims	....	....	22·00	1·79	....	56·87	624·33	43,067·69	26,579·64	813·76
Mt. Ida	5537Z, etc.	Lake View & Star Ltd.	....	....	....	7·29	3·22	....	....	100·50	41·18	3·22
		Prior to transfer to present holders	....	....	....	....	....	....	40·77	487,579·36	248,250·96	8,505·69
		Seaton, H. L.T.T. 12/70 (1755H)	....	....	138·50	3·15	....	....	....	138·50	3·15	....

ULARRING DISTRICT.

Morleys	G.M.L. 1094U	First Hit	....	·94	....	....	....	....	83·42	5,605·00	7,444·59	11·89

YERILLA DISTRICT.

Yarri	G.M.Ls. 1126R, etc.	Porphyry (1939) Gold Mines N.L.	....	....	354·00	41·70	....	....	....	67,293·00	9,935·21	261·95
		Prior to transfer to present holders	....	....	....	....	....	....	....	30,344·50	5,448·82	507·51
		Sundry Claims	....	....	23·00	2·20	....	·87	5·93	18,382·05	6,392·40	1·40
Yilgangie	1176R, etc.	Yilgangie Queen	....	....	227·00	64·06	....	....	....	346·00	153·14	....
		Prior to transfer to present holders	....	....	....	....	....	....	·85	34,755·25	32,469·42	4,471·98

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 1970					Total Production				
			Alluvial	Dollied and Specimens	Ore treated	Gold therefrom	Silver	Alluvial	Dollied and Specimens	Ore treated	Gold therefrom	Silver
			Fine ozs.	Fine ozs.	Tons (2,240 lb.)	Fine ozs.	Fine ozs.	Fine ozs.	Fine ozs.	Tons (2,240 lb.)	Fine ozs.	Fine ozs.

Broad Arrow Goldfield.

Mining Centre	Number of Lease	Registered Name of Company or Lease	Alluvial	Dollied and Specimens	Ore treated	Gold therefrom	Silver	Alluvial	Dollied and Specimens	Ore treated	Gold therefrom	Silver
Bardoc	....	Sundry Claims	....	....	117·00	21·02	....	54·95	1,218·09	18,531·18	8,583·38	....
Broad Arrow	G.M.L. 2353W	Oversight	....	....	245·00	17·39	....	....	....	245·00	17·39	....
	2348W	Wentworth	....	....	128·00	44·34	....	....	....	128·00	44·34	....
		Sundry Claims	....	81·87	....	32·83	....	1,008·56	3,166·58	39,199·65	17,770·57	1·42
Grant's Patch	....	Sundry Claims	1·31	....	9·00	9·30	....	1·31	356·66	7,829·62	3,402·86	4·28
Ora Banda	2351W	Sand King	....	....	16·00	48·25	....	....	....	16·00	48·25	....
		Sundry Claims	....	....	94·50	90·88	....	....	467·18	17,463·55	5,288·37	....
Riches Find	2306W	Cave Hill	....	....	18·00	33·76	....	....	238·15	93·85	188·69	....

North-East Coolgardie Goldfield.

KANOWNA DISTRICT.

Mining Centre	Number of Lease	Registered Name of Company or Lease	Alluvial	Dollied and Specimens	Ore treated	Gold therefrom	Silver	Alluvial	Dollied and Specimens	Ore treated	Gold therefrom	Silver
Gindalbie	....	Sundry Claims	....	....	8·00	3·07	....	....	716·52	5,879·27	3,315·55	·01
Kalpini	G.M.L. 1591X	Bank of Kalpini	....	....	6,247·75	743·31	....	....	....	12,903·00	1,281·92	....
Kanowna	1586X	Kanowna Red Hill	....	....	760·00	35·92	....	....	....	9,866·75	1,473·27	1·94
	1585X	New Kanowna	....	....	51·00	24·04	....	....	....	122·00	166·79	....

KURNALPI DISTRICT.

Mining Centre	Number of Lease	Registered Name of Company or Lease	Alluvial	Dollied and Specimens	Ore treated	Gold therefrom	Silver	Alluvial	Dollied and Specimens	Ore treated	Gold therefrom	Silver
Karonie	....	Sundry Claims	....	....	8·50	2·10	....	....	....	515·00	159·28	....

East Coolgardie Goldfield.

EAST COOLGARDIE DISTRICT.

Mining Centre	Number of Lease	Registered Name of Company or Lease	Alluvial	Dollied and Specimens	Ore treated	Gold therefrom	Silver	Alluvial	Dollied and Specimens	Ore treated	Gold therefrom	Silver
Boulder	G.M.L.s 5345E, etc.	Gold Mines of Kalgoorlie (Aust.) Ltd.	....	....	159,463·00	42,034·08	26,451·86	....	....	6,148,431·75	1,557,231·98	467,651·11
		Prior to transfer to present holders	....	....	....	....	....	....	849·95	15,916,923·07	6,416,710·17	819,123·27
	5695E, etc.	Great Boulder Gold Mines Ltd.	....	....	....	805·54	711·81	....	1·53	16,772,306·97	7,054,405·83	1,885,035·22
	5708E, etc.	Lake View & Star Ltd.	....	....	418,203·00	98,031·03	11,942·69	....	....	21,944,234·30	6,134,106·95	689,792·59
		Prior to transfer to present holders	....	....	....	....	....	....	8·49	15,792,500·38	9,149,223·80	1,348,055·82
	5431E, etc.	North Kalgurli (1912) Ltd.	....	....	288,550·00	53,092·57	24,900·61	....	127·55	9,266,094·24	2,295,672·69	673,775·98
	5405E, etc.	North Kalgurli (1912) Ltd. (Croesus Pty. Group)	....	....	....	....	....	....	51·20	90,159·00	19,261·22	....
		Prior to transfer to present holders	....	....	....	....	....	43·99	....	4,018,629·01	2,815,959·95	97,625·03

Hampton Plains	P.P.L. 277, Loc. 50	Lake View & Star Ltd. (Pernatty)	....	....	11,869·00	734·48	....	....	....	25,070·50	1,773·82	....
		Prior to transfer to present holders	....	....	....	....	....	....	....	14,868·75	1,445·70	2·06
Kalgoorlie....	G.M.L. 6594E	Gledden South	....	....	48·75	80·78	....	....	....	129·75	158·62	....
	5510E	Golden Dream	....	....	64·75	3·59	....	....	....	784·50	45·58	....
		Prior to transfer to present holders	....	....	....	....	....	....	....	530·74	149·77	....
	6537E	Golden Key	....	....	47·00	23·73	....	....	....	116·50	148·34	....
	6630E	Golden Star	....	....	29·50	3·36	....	....	....	1,325·50	47·59	....
	6563E, etc.	Gold Mines of Kalgoorlie (Aust.) Ltd. (Mt. Charlotte)	....	....	655,859·00	88,009·00	....	....	....	2,990,006·00	413,915·05	....
		Prior to transfer to present holders	....	....	....	....	....	....	5·72	85,723·60	18,167·21	171·56
	6091E	Lesanben	....	6·87	....	....	....	....	251·79	1,446·35	1,032·09	3·88
	6485E	Maritana Hill	....	....	524·50	51·43	....	....	....	4,589·75	560·11	....
	6615E	Middle Hannans	....	....	316·50	46·91	....	....	....	903·25	124·81	....
Wombola	5497E, etc.	Daisy Leases	....	....	512·25	625·93	....	....	....	24,587·45	22,604·98	884·76
	5497E	Daisy	....	....	....	....	....	....	....	6,282·25	5,031·93	....
	5500E	Happy-go-lucky	....	....	....	....	....	....	....	2,075·25	1,675·85	....
	6413E	Kingsmill	....	....	692·00	335·47	....	....	....	692·00	335·47	....
	6684E	Maranoa	....	....	36·00	4·03	....	....	....	36·00	4·03	....
		Sundry Claims	....	....	353·75	51·53	....	....	718·13	26,829·93	14,753·93	·20
		State Battery, Kalgoorlie	....	....	....	*343·27	25·34	....	....	390·70	*41,078·00	672·37

Coolgardie Goldfield.

COOLGARDIE DISTRICT.

Bonnievale	G.M.L. 6151	Melva Maie	....	....	132·00	25·17	....	....	....	132·00	25·17	....
	5890	Rayjax	....	....	37·50	37·33	....	....	....	1,126·00	1,493·99	5·12
		Sundry Claims	....	57·95	56·50	32·90	....	....	388·21	11,598·63	5,857·89	1·11
Bulla Bulling	6035	Bernguard	....	....	566·00	19·83	....	....	....	1,426·25	209·13	....
Coolgardie	6138	Marlene	....	....	533·00	12·61	....	....	....	649·00	18·26	....
		Sundry Claims	....	....	3,022·00	289·44	....	236·14	3,044·77	90,296·94	30,176·75	1·90
Hampton Plains	P.P.L. 484, Loc. 59	Baker, T. R.	....	....	46·00	6·63	....	....	....	46·00	6·63	....
	P.P.L. 490, Loc. 48	Rennie, D.	....	1·88	....	....	....	....	1·88	116·00	45·75	....
Larkinville	....	Sundry Claims	....	....	17·00	62·04	....	....	147·20	526·03	1,106·14	....
Logans	G.M.L. 6016	Great Lion	....	....	35·00	·89	....	....	....	1,140·00	128·81	....
		Sundry Claims	....	....	22·00	2·03	....	6·88	551·62	3,553·03	3,655·73	45·29
		State Battery, Coolgardie	....	....	....	*7·67	....	....	....	771·01	*43,148·34	29·26

KUNANALLING DISTRICT.

Carbine	G.M.L. 1048S	Carbine	....	12·43	....		....	....	12·43	33·50	17·79	....
Kintore	....	Sundry Claims	....	....	49·75	7·70	....	111·91	102·70	5,498·78	2,709·43	....
Kunanalling	1052S	Catherwood	....	....	4·25	6·78	....	....	....	415·75	29·80	....
		Sundry Claims	....	....	692·50	44·30	....	216·53	994·36	17,819·77	10,351·73	21·67

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 1970					Total Production				
			Alluvial	Dollied and Specimens	Ore treated	Gold therefrom	Silver	Alluvial	Dollied and Specimens	Ore treated	Gold therefrom	Silver
			Fine ozs.	Fine ozs.	Tons (2,240 lb.)	Fine ozs.	Fine ozs.	Fine ozs.	Fine ozs.	Tons (2,240 lb.)	Fine ozs.	Fine ozs.
Yilgarn Goldfield.												
Bullfinch	G.M.L. 4535	Casas	....	....	38·25	37·60	....	....	....	61·00	48·67	2·21
Golden Valley	4427	W.A. Gold Development N.L.	....	....	3,103·10	739·22	40·17	....	....	3,103·10	739·22	40·17
		Prior to transfer to present holders	....	....	....	....	....	....	2·70	46,599·80	66,913·71	2,004·72
Hopes Hill	....	Sundry Claims	....	....	10·00	5·46	·02	21·12	97·32	4,942·87	1,488·09	2·55
Marvel Loch	4556	Apache	....	....	96·75	3·64	·11	....	....	96·75	3·64	·11
	4434	Cornwall	....	....	39·00	3·29	....	....	....	17,837·00	2,471·59	528·12
	3724	Frances Firness	....	....	107·00	29·74	....	....	591·90	23,778·25	10,507·49	306·81
Parkers Range	4508	Buffalo	....	....	25·50	4·87	....	....	10·36	1,092·50	195·32	5·62
	4512	Constance Una	....	....	3,036·00	1,737·30	....	....	....	6,116·00	4,921·92	84·50
	4589	King of the Range	....	....	21·75	2·15	....	....	....	21·75	2·15	....
		State Battery, Marvel Loch	....	....	....	*440·66	52·61	....	....	147·00	*4,548·19	2,618·28
Dundas Goldfield.												
Beete	G.M.L. 2044	Beete	....	144·31	39·00	55·45	32·63	....	169·45	62·00	67·84	38·63
Norseman	1936, etc.	Central Norseman Gold Corporation N.L.	....	....	149,772·00	50,506·34	48,966·73	....	....	4,834,304·20	2,243,052·12	1,539,061·81
	1990	Squib	....	....	41·00	2·02	·07	....	....	41·00	2·02	·07
		Sundry Claims	....	67·99	12·00	6·22	10·54	1,052·25	3,621·19	49,876·45	22,651·25	244·85
		State Battery, Norseman....	....	....	....	*145·91	30·97	....	....	427·89	*26,347·85	1,134·95
Phillips River Goldfield.												
Kundip	G.M.L. 277	Western Gem	....	....	42·00	11·23	....	....	....	563·00	128·23	....
Ravensthorpe	M.C.'s 35, etc.	Ravensthorpe Copper Mines N.L.	....	....	....	1,107·37	3,369·67	....	....	....	§20,853·85	63,844·20
		Prior to transfer to present holders	....	....	....	....	....	....	....	....	§1·99	....
South West Mineral Field.												
Lake Grace	....	Sundry Claims	....	....	35·50	18·51	....	....	....	117·25	99·95	....
Northampton Mineral Field.												
Northampton	....	Sundry Leases and Claims	....	....	....	....	†74·46	....	....	....	....	†5,286·31
State Generally.												
		Reported by Banks and Gold Dealers	5·79	....	....	86·47	....	1,200·86	1,111·85	....	1,193·74	1,140·93

TABLE II

Production of Gold and Silver from all Sources, showing in fine ounces the output, as reported to the Mines Department during the year 1970.

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
		Fine ozs.	Fine ozs.	Tons (2,240 lb.)	Fine ozs.	Fine ozs.	Fine ozs.	Fine ozs.	Fine ozs.	Tons (2,240 lb.)	Fine ozs.	Fine ozs.	Fine ozs.
Kimberley	....	....	....	....	....	....	....	....	....	....	....	....	....
West Kimberley	....	....	....	....	....	....	....	....	....	....	....	....	....
West Pilbara	....	....	....	....	....	....	....	....	....	....	....	....	....
Pilbara	Marble Bar	....	....	616·00	531·02	531·02	21·76	....	....	616·00	531·02	531·02	21·76
	Nullagine	....	....	....	....	....	....						
Ashburton	....	....	....	....	....	....	....	....	....	....	....	....	....
Gascoyne	....	....	....	....	....	....	....	....	....	615·75	826·47	826·47	36·44
Peak Hill	....	....	....	....	....	....	....	....	9·46	....	....	9·46	....
East Murchison	Lawlers	....	....	237·00	101·13	101·13	....	....	....	376·00	205·92	205·92	....
	Wiluna	....	....	4·00	3·10	3·10	....						
	Black Range	....	....	135·00	101·69	101·69	....						
Murchison	Cue	....	....	....	....	....	....	....	....	29,374·50	6,638·83	6,638·83	512·67
	Meekatharra	....	....	582·50	55·92	55·92	....						
	Day Dawn	....	....	....	....	....	....						
	Mt. Magnet	....	....	28,792·00	6,582·91	6,582·91	512·67						
Yalgoo	....	....	....	....	....	....	....	....	....	....	....	....	....
Mt. Margaret	Mt. Morgans	....	....	....	....	....	....	....	....	2,161·80	787·13	787·13	....
	Mt. Malcolm	....	....	2,161·80	787·13	787·13	....						
	Mt. Margaret	....	....	....	....	....	....						
North Coolgardie	Menzies	....	....	368·00	19·77	19·77	3·22	....	·94	972·00	127·73	128·67	3·22
	Ularring	....	·94	....	....	·94	....						
	Niagara	....	....	....	....	....	....						
	Yerilla	....	....	604·00	107·96	107·96	....						
Broad Arrow	....	....	....	....	....	....	....	1·31	81·87	627·50	297·77	380·95	....
North-East Coolgardie	Kanowna	....	....	7,066·75	806·34	806·34	....	....	....	7,075·25	808·44	808·44	....
	Kurnalpi	....	....	8·50	2·10	2·10	....						
East Coolgardie	East Coolgardie	....	6·87	1,536,569·00	284,276·73	284,283·60	64,032·31	....	6·87	1,536,569·00	284,276·73	284,283·60	64,032·31
	Bulong	....	....	....	....	....	....						
Coolgardie	Coolgardie	....	59·83	4,467·00	496·54	556·37	....	....	72·26	5,213·50	555·32	627·58	....
	Kunanalling	....	12·43	746·50	58·78	71·21	....						
Yilgarn	....	....	....	....	....	....	....	....	....	6,477·35	3,003·93	3,003·93	92·91
Dundas	....	....	....	....	....	....	....	....	212·30	149,864·00	50,715·94	50,928·24	49,040·94
Phillips River	....	....	....	....	....	....	....	....	....	42·00	1,118·60	1,118·60	3,369·67
South-West Mineral Field	....	....	....	....	....	....	....	....	....	35·50	18·51	18·51	....
Northampton Mineral Field	....	....	....	....	....	....	....	....	....	....	....	....	74·46
State Generally	....	....	....	....	....	....	....	5·79	....	....	86·47	92·26	....
Outside Proclaimed Goldfield	....	....	....	....	....	....	....	....	....	....	....	....	....
Total	....	....	....	....	....	....	....	7·10	383·70	1,740,020·15	349,998·81	350,389·61	117,184·38

TABLE III

Return showing total production reported to the Mines Department, and respective Districts and Goldfields from whence derived, to 31st December, 1970.

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
		Fine ozs.	Fine ozs.	Tons (2,240 lb.)	Fine ozs.	Fine ozs.	Fine ozs.	Fine ozs.	Fine ozs.	Tons (2,240 lb.)	Fine ozs.	Fine ozs.	Fine ozs.
West Kimberley	....	....	....	....	....	....	....	1·30	24·68	1·00	2·49	28·47	37,317·55
Kimberley	....	....	....	....	....	....	....	9,086·26	3,035·43	22,931·90	17,292·01	29,413·70	128·76
West Pilbara	....	....	....	....	....	....	....	6,339·37	374·74	24,900·96	24,353·98	31,068·09	1,910·66
Pilbara	Marble Bar	15,530·82	4,581·71	349,362·27	336,711·57	356,824·10	33,406·96	26,040·35	7,491·40	499,600·94	472,215·02	505,746·77	34,487·88
	Nullagine	10,509·53	2,909·69	150,238·67	135,503·45	148,922·67	1,080·92						
Ashburton	....	....	....	....	....	....	....	9,268·52	482·46	6,807·10	2,913·43	12,664·41	41,971·38
Gascoyne	....	....	....	....	....	....	....	698·49	121·33	3,988·50	6,299·40	7,119·22	127·75
Peak Hill	....	....	....	....	....	....	....	3,387·79	5,414·65	783,070·73	322,738·34	331,540·78	3,794·07
East Murchison	Lawlers	7,103·51	2,362·05	2,022,688·17	827,881·22	837,346·78	27,268·77	9,013·09	22,226·13	12,628,922·08	3,655,907·62	3,687,146·84	60,324·41
	Wiluna	236·48	1,254·11	8,873,653·69	1,872,323·07	1,873,813·66	10,322·32						
	Black Range	1,673·10	18,609·97	1,732,580·22	955,703·33	975,986·40	22,732·32						
Murchison	Cue	5,145·34	9,109·95	6,815,612·31	1,403,608·56	1,417,863·85	274,844·04	25,789·49	59,650·73	15,296,507·18	6,006,518·66	6,091,958·88	520,847·97
	Meekatharra	14,705·91	18,720·06	2,328,879·57	1,311,774·09	1,345,200·06	5,278·85						
	Day Dawn	3,291·61	11,341·80	2,037,710·13	1,375,648·23	1,390,281·64	169,447·42						
	Mt. Magnet	2,646·63	20,478·92	4,114,305·17	1,915,487·78	1,938,613·33	71,277·66						
Yalgoo	....	....	....	....	....	....	....	1,815·77	3,263·38	444,886·08	264,376·59	269,455·74	1,523·06
Mt. Margaret	Mt. Morgans	3,574·87	9,401·98	1,218,151·31	718,014·68	730,991·53	5,831·33	11,790·63	35,452·36	11,505,237·82	4,966,664·85	5,013,907·84	262,836·38
	Mt. Malcolm	4,067·66	16,696·03	7,758,913·27	3,074,606·61	3,095,370·30	190,814·35						
	Mt. Margaret	4,148·10	9,354·35	2,528,173·24	1,174,043·56	1,187,546·01	66,190·70						
North Coolgardie	Menzies	1,696·69	7,039·71	1,954,763·48	1,434,061·27	1,442,797·67	39,179·65	4,858·70	19,978·13	3,736,775·98	2,588,971·91	2,613,808·74	72,529·03
	Ularring	129·66	7,299·53	539,195·70	447,558·98	454,988·17	22,286·97						
	Niagara	1,718·48	1,821·77	944,525·02	528,605·23	532,145·48	5,716·17						
	Yerilla	1,313·87	3,817·12	298,291·78	178,746·43	183,877·42	5,346·24						
Broad Arrow	....	....	....	....	....	....	....	21,999·83	28,150·95	1,418,494·49	755,113·42	805,264·20	5,703·32
North-East Coolgardie	Kanowna	106,549·25	13,635·61	1,034,286·36	631,046·57	751,231·43	3,051·22	119,386·73	21,942·62	1,049,125·18	650,292·25	791,621·60	3,063·93
	Kurnalpi	12,837·48	8,307·01	14,838·82	19,245·68	40,390·17	12·71						
East Coolgardie	East Coolgardie	33,741·51	41,260·19	97,477,100·24	38,391,147·29	38,466,148·99	6,430,141·93	61,147·04	57,296·96	97,665,709·82	38,524,332·91	38,642,776·91	6,430,241·69
	Bulong	27,405.53	16,036.77	188,609.58	133,186·62	176,627·92	99·76						
Coolgardie	Coolgardie	17,212·95	22,152·05	3,018,142·97	1,548,578·54	1,587,943·54	54,478·97	18,734·84	28,035·87	3,386,537·92	1,802,613·21	1,849,383·92	55,252·03
	Kunanalling	1,521·89	5,883·82	368,394·95	254,034·67	261,440·38	773·06						
Yilgarn	....	....	....	....	....	....	....	2,198·76	6,414·14	8,296,890·22	2,445,495·11	2,454,108·01	216,475·09
Dundas	....	....	....	....	....	....	....	2,256·21	16,667·65	6,880,872·62	3,215,703·24	3,234,627·10	1,957,049·07
Phillips River	....	....	....	....	....	....	....	607·11	823·32	131,222·24	125,056·71	126,487·14	79,987·28
South-West Mineral Field	....	....	....	....	....	....	....	313·08	48·66	4,938·33	2,522·24	2,883·98	15·18
Northampton Mineral Field	....	....	....	....	....	....	....	....	....	....	....	....	5,286·31
State Generally	....	....	....	....	....	....	....	1,200·86	1,111·85	27·00	10,203·49	12,516·20	32,662·66
Outside Proclaimed Goldfield	....	....	....	....	....	....	....	....	....	....	....	....	1,259·58
Total	....	....	....	....	....	....	....	**335,934·22**	**318,007·44**	**163,787,448·09**	**65,859,586·88**	**66,513,528·54**	**9,824,795·04**

TABLE IV

Total output of Gold Bullion, Concentrates, etc., entered for export and received at the Perth Branch of the Royal Mint from 1st January, 1886.

Year	Export	Mint	Total	Estimated Value
	Fine ozs.	Fine ozs.	Fine ozs.	$A
1886	270·17	....	270·17	2,294
1887	4,359·37	....	4,359·37	37,036
1888	3,124·82	....	3,124·82	26,546
1889	13,859·52	....	13,859·52	117,742
1890	20,402·42	....	20,402·42	173,328
1891	27,116·14	....	27,116·14	230,364
1892	53,271·65	....	53,271·65	452,568
1893	99,202·50	....	99,202·50	842,770
1894	185,298·73	....	185,298·73	1,574,198
1895	207,110·20	....	207,110·20	1,759,498
1896	251,618·69	....	251,618·69	2,137,616
1897	603,846·44	....	603,846·44	5,129,954
1898	939,489·49	....	939,489·49	7,981,394
1899	1,283,360·25	187,244·41	1,470,604·66	12,493,464
1900	894,387·27	519,923·59	1,414,310·86	12,015,220
1901	923,686·96	779,729·56	1,703,416·52	14,471,308
1902	707,039·75	1,163,997·60	1,871,037·35	15,895,322
1903	833,685·78	1,231,115·62	2,064,801·40	17,541,438
1904	810,616·04	1,172,614·03	1,983,230·07	16,848,452
1905	655,089·88	1,300,226·00	1,955,315·88	16,611,308
1906	562,250·59	1,232,296·01	1,794,546·60	15,245,498
1907	431,803·14	1,265,750·45	1,697,553·59	14,421,500
1908	356,353·96	1,291,557·17	1,647,911·13	13,999,762
1909	386,370·58	1,208,898·83	1,595,269·41	13,552,548
1910	233,970·34	1,236,661·68	1,470,632·02	12,493,696
1911	160,422·28	1,210,445·24	1,370,867·52	11,646,150
1912	83,577·12	1,199,080·87	1,282,657·99	10,896,770
1913	86,255·13	1,227,788·15	1,314,043·28	11,163,402
1914	51,454·65	1,181,522·17	1,232,976·82	10,474,704
1915	17,340·47	1,192,771·23	1,210,111·70	10,280,456
1916	26,742·17	1,034,655·87	1,061,398·04	9,017,064
1917	9,022·49	961,294·67	970,317·16	8,243,292
1918	15,644·12	860,867·03	876,511·15	7,446,366
1919	6,445·89	727,619·90	734,065·79	7,237,018
1920	5,261·13	612,581·00	617,842·13	7,197,862
1921	7,170·74	546,559·92	553,730·66	5,885,052
1922	5,320·16	532,926·12	538,246·28	5,051,624
1923	5,933·82	498,577·59	504,511·41	4,464,372
1924	2,585·20	482,449·78	485,034·98	4,511,854
1925	3,910·59	437,341·56	441,252·15	3,748,640
1926	3,188·22	434,154·98	437,343·20	3,715,430
1927	3,359·10	404,993·41	408,352·51	3,469,144
1928	3,339·30	390,069·19	393,408·49	3,342,186
1929	3,037·12	374,138·96	377,176·08	3,204,284
1930	1,753·09	415,765·00	417,518·09	3,728,884
1931	1,726·66	508,845·36	510,572·02	5,996,274
1932	3,887·07	601,674·33	605,561·40	8,807,284
1933	2,446·97	634,760·40	637,207·37	9,772,508
1934	3,520·40	647,817·95	651,338·35	11,117,746
1935	9,868·71	639,180·38	649,049·09	11,404,298
1936	55,024·58	791,183·21	846,207·79	14,747,078
1937	71,646·91	928,999·84	1,000,646·75	17,487,510
1938	113,620·06	1,054,171·13	1,167,791·19	20,726,046
1939	98,739·88	1,115,497·76	1,214,237·64	23,685,928
1940	71,680·47	1,119,801·08	1,191,481·55	25,393,006
1941	65,925·94	1,043,391·96	1,109,317·90	23,702,890
1942	15,676·48	832,503·97	848,180·45	17,730,990
1943	6,408·34	540,067·08	546,475·42	11,421,338
1944	1,824·99	464,439·76	466,264·75	9,799,994
1945	5,029·38	463,521·34	468,550·72	10,021,082
1946	6,090·14	610,873·52	616,963·66	13,280,138
1947	5,220·09	698,366·29	703,886·38	15,151,148
1948	4,653·72	660,332·07	664,985·79	14,313,818
1949	4,173·14	644,252·48	648,425·62	15,925,616
1950	4,161·53	606,171·88	610,333·41	18,932,540
1951	5,589·45	622,189·64	627,779·09	19,450,686
1952	9,608·62	720,366·44	729,975·06	23,695,834
1953	5,396·30	818,515·65	823,911·95	26,598,184
1954	3,089·08	847,451·09	850,540·17	26,627,236
1955	4,091·51	837,913·72	842,005·23	26,351,118
1956	2,331·10	810,048·68	812,379·78	25,411,162
1957	2,042·27	894,638·71	896,680·98	28,076,370
1958	1,810·69	865,376·80	867,187·49	27,109,868
1959	2,321·99	864,286·87	866,608·86	27,083,858
1960	2,068·66	853,690·02	855,758·68	26,743,322
1961	2,942·58	868,902·39	871,844·97	27,413,780
1962	4,539·02	854,829·18	859,368·20	26,871,460
1963	4,665·37	795,546·34	800,211·71	25,035,372
1964	3,070·91	709,776·09	712,847·00	22,299,886
1965	2,996·56	656,440·42	659,436·98	20,722,164
1966	1,462·05	627,314·65	628,776·70	19,765,287
1967	2,743·28	573,277·73	576,021·01	18,071,924
1968	918·86	510,784·17	511,703·03	16,785,723
1969	1,413·06	463,998·56	465,411.62	17,707,219
1970	1,578·25	340,029·82	341,608·07	11,069,049
	11,605,352·54	56,457,146·35	68,062,498·89	$1,093,086,112

	1969 $A	1970 $A
Estimated Mint value of above production	1,069,933,306	1,080,609,126
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	6,904,553	7,297,782
Estimated Total	$A1,082,017,063	$A1,093,086,112
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	23,243,598	26,262,838
Gross estimated value of gold won	$A1,105,583,557	$A1,119,671,846

(12)—90726

TABLE V

Quantity and Value of Minerals, other than Gold, Reported during the year 1970

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Long Tons	Metallic Content	Value $A
		ALUMINA			
M.L. 1SA	South-West	Western Aluminium N.L.	949,987·00	....	60,799,000·00 (*l*)
		BARYTES			
M.C. 20N	Murchison	Universal Milling Co. Pty. Ltd.	45·05	....	675·75
M.C. 1102	Pilbara	Associated Minerals Pty. Ltd.	520·00	....	6,240·00
			565·05	....	(*a*) 6,915·75
		BISMUTH			
			Lbs.	Lbs.	
M.C. 51	Gascoyne	Hazlett, J. E.	1,780·00	1,196·16	5,023·87
M.C. 186	Gascoyne	Kempton, Radley and Kempton	2,000·00	576·00	1,843·20
			3,780·00	1,772·16	(*b*) 6,867·07
		BERYL			
				BeO Units	
M.L. 80 etc.	Coolgardie	Australian Glass Manufacturers Co.	9·50	111·15	3,800·00
M.C. 186	Gascoyne	Kempton Bros.	6·05	70·00	1,996·50
			15·55	181·15	(*b*) 5,796·50
		BUILDING STONE (Quartzite)			
M.C. 1158H	South-West	House, R. P.	1,516·00	....	(*c*) 7,240·00
		BUILDING STONE (Quartz)			
M.C. 2110H	South-West	Snowstone Pty. Ltd.	4,960·00	....	(*a*)(*b*) 60,682·00
		BUILDING STONE (Spongolite)			
M.C. 1062H	South-West	Worth, H.	113·50	....	1,589·00
M.C. 726H	South-West	Universal Milling Co. Pty. Ltd.	27·00	....	270·00
			140·50	....	(*a*) (*c*) 1,859·00
		CLAYS (Bentonite)			
M.C. 1042H etc.	South-West	Scott, M. E., W. T. & R. J.	97·50	....	630·00
M.C. 1720H	South-West	Dolling, H. P.	18·00	....	144·00
			115·50	....	(*a*) 774·00
		CLAYS (White Clay—Ball Clay)			
M.C. 109H	South-West	H. L. Brisbane & Wunderlich Ltd.	850·00	....	(*c*) 9,631·00
		CLAYS (Kaolin)			
M.C. 247H etc.	South-West	Linton, J. B.	187·48	....	(*a*) 1,112·74
		CLAYS (Cement Clay)			
M.C. 1018H	South-West	Swan Portland Cement Ltd.	6,654·07	....	6,263·41
M.C. 788H	South-West	Bell Bros. Pty. Ltd.	15,759·00	....	41,288·00
			22,413·07	....	(*c*) 47,551·41
		CLAYS (Fireclay)			
M.C. 1302H	South-West	Bridge, J. S.	58,086·00	....	58,086·00
M.C. 522H	South-West	Bridge, J. S. & T. D.	41,691·00	....	41,691·00
M.C. 304H	South-West	Clackline Refractories Ltd.	2,950·00	....	5,900·00
M.L. 435H	South-West	Midland Brick Co. Pty. Ltd.	6,170·00	....	3,085·00
M.C. 1114H	South-West	Midland Brick Co. Pty. Ltd.	1,993·00	....	996·50
M.L. 436H etc.	South-West	Midland Brick Co. Pty. Ltd.	13,304·00	....	6,653·50
Private Property	South-West	†Unspecified Producers	6,616·00	....	3,638·80
			130,810·00	....	(*c*) 120,050·80
		CLAYS (*Brick Pipe and Tile Clay)			
Private Property	South-West	F. W. Swaby	17,100·00	....	42,750·00
L.T.T. 16/70	Yilgarn	Nicholls, R. A.	55·00	....	825·00
Private Property	South-West	†Unspecified Producers	13,403·00	....	7,371·55
			30,558·00	....	(*c*) 50,946·55

*** Incomplete. † From Private Property not held under Mining Act.**

TABLE V.—*Quantity and Value of Minerals, other than Gold, Reported during the Year 1970—continued*

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Long Tons	Metallic Content	Value $A
		COAL			
C.M.L. 448 etc.	Collie	Griffin Coal Mining Co. Ltd.	626,191·50	....	2,639,823·48
C.M.L. 437 etc.	Collie	Western Collieries Ltd.	571,542·00	....	3,187,467·64
			1,197,733·50	....	(e)5,827,291·12
		COBALT (Metallic By-Product Nickel Mining) (h)			
				Cobalt Tons	
M.C. 150 etc.	Coolgardie	Western Mining Corporation Ltd.	....	313·88	1,123,180·00
M.C. 39W	Broad Arrow	Great Boulder Gold Mines Limited & North Kalgurli (1912) Ltd.	....	18·85	74,500·00
			....	332·73	(f)1,197,680·00
		COPPER (Metallic By-Product Nickel Mining) (h)			
				Copper Tons	
M.C. 150 etc.	Coolgardie	Western Mining Corporation Ltd.	....	2,040·74	1,977,560·00
M.C. 39W	Broad Arrow	Great Boulder Gold Mines Ltd. & North Kalgurli (1912) Ltd.	....	54·92	59,800·00
			....	2,095·66	(f)2,037,360·00
		COPPER ORE AND CONCENTRATES (g) (h)			
				Copper Units	
M.C. 35 etc.	Phillips River	Ravensthorpe Copper Mines N.L.	2,978·20	56,165·00	662,761·89
				Fine Ozs.	
		Gold and Silver content transferred to respective items	Gold	983·78	31,018·97
			Silver	2,888.04	4,713·35
		CUPREOUS ORE AND CONCENTRATES (Fertiliser)			
				Assay Cu%	
M.C. 382L	Pilbara	K. J. McPherson	*58·64	27·46	17,115·79
M.C. 1614	Pilbara	C. V. Dorph-Petersen	†14·40	17·12	3,056·29
M.L. 68P etc.	Peak Hill	Thaduna Copper Mines Co. Pty. Ltd.	466·47	18·08	94,247·00
M.C. 97P....	Peak Hill	Group Explorations Pty. Limited	22·31	27·00	5,721·60
M.C. 65P....	Peak Hill	R. Lee	13·69	12·55	1,417·03
M.C. 64P....	Peak Hill	T. L. Parkinson	24·41	19·97	4,425·61
P.A. 943P	Peak Hill	G. N. Gordon	4·07	18·73	907·00
		Silver content transferred to silver item.	603·99	19·25	(a) 126,890·32

† Also contained 40·13 fine ozs. silver valued at $49.35.
* Also contained 301·12 fine ozs. silver valued at $204.74.

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Long Tons	Metallic Content	Value $A
		FELSPAR			
M.L. 80 etc.	Coolgardie	Australian Glass Manufacturers Co.	645·00	....	(a) 9,675·00
		GLASS SAND			
M.C. 417H etc.	South-West	Australian Glass Manufacturers Co.	16,893·00	....	22,798·24
M.C. 365H	South-West	Leach, R. J.	443·00	....	1,372·00
M.C. 1074H etc.....	South-West	Ready Mix Concrete (W.A.) Pty. Ltd.	5,625·00	....	N.A.
M.C. 1191H	South-West	Silicon Quarries Pty. Ltd.	71,600·00	....	7,160·00
M.C. 619H	South-West	Westralian Sands Limited	1,008·00	....	2,716·00
			95,569·00	....	(c) 34,046·24
		GYPSUM			
M.C. 30 etc.	Yilgarn	Ajax Plaster Co. Pty. Ltd.	8,690·00	....	15,649·00
M.C. 50 etc.	Yilgarn	H. B. Brady Co. Pty. Ltd.	14,686·00	....	36,715·00
M.C. 9 etc.	Yilgarn	West Australian Plaster Mills	23,085·00	....	47,313·73
M.C. 12 etc.	Dundas	McDonald & Whitfield (Norseman Plaster works)	300·00	....	300·00
M.C. 43 etc.	Gascoyne	Garrick Agnew Pty. Ltd.	36,613·00	....	128,145·00
M.C. 612H etc.	South-West	*Gypsum Industries of Aust. Pty. Ltd	5,360·00	....	17,152·00
M.C. 1419H	South-West	*V. Forsyth	40·00	....	80·00
M.C. 485	South-West	Swan Portland Cement	1,213·11	....	2,560·15
			89,987·11	....	(a) 247,914·88

* For Agricultural Purposes.

Plaster of Paris reported as manufactured during the year being 29,508 tons from 42,453 tons of Gypsum by four Companies. Gypsum used in the manufacture of Cement = 3,090·62 tons.

TABLE V.—*Quantity and Value of Minerals, other than Gold, Reported during the Year* 1970—*continued*

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Long Tons	Metallic Content	Value $A
		IRON ORE (Pig Iron)			
			Ore Treated Tons	Pig Iron Recovered Tons	
T.R. 1258H	Yilgarn	Charcoal Iron and Steel Industry	98,640·00 Est. Av. Assay Fe % 61·00	61,537·00	3,505,910·00 (c) (d)
		IRON ORE (Ore Railed to Kwinana)			
				Av. Assay Fe %	
M.L. 2SA	Yilgarn	Dampier Mining Co. Ltd.	*1,567,216·00	61·50	11,736,080·00 (n)
		* Includes 527,102 W.L. tons shipped to Eastern States and 235,017 W.L. tons exported overseas.			
		IRON ORE (Ore Shipped to Eastern States)			
M.L. 10 etc.	West Kimberley	Dampier Mining Co. Ltd.	1,313,358·00	64·50 }	11,927,816·00
M.L. 50 etc.	West Kimberley	Dampier Mining Co. Ltd.	389,931·50	67·20 }	(n)
M.L. 244SA	Peak Hill	Mt. Newman Mining Co. Pty. Limited	479,316·00	63·00	(b)3,623,703·20
			2,182,605·50	....	15,551,519·20
		IRON ORE (Ore Exported Overseas)			
M.L. 50 etc.	West Kimberley	Dampier Mining Co. Ltd.	1,058,488·00	66·45	(b)7,211,932·57
M.L. 235SA	Pilbara	Goldsworthy Mining Limited	6,817,877·51	63·93	53,979,245·12 (b)
M.L. 4SA	West Pilbara	Hamersley Iron Pty. Ltd.	17,506,492·64	64·65	133,445,545·02 (b)
M.L. 244SA	Peak Hill	Mt. Newman Mining Co. Pty. Ltd.	10,903,659·00	62·91	82,233,735·06 (b)
M.C. 878H	South-West	Western Mining Corporation Ltd.	589,976·00	60·57	(b)4,792,154·00
			36,876,493·15	....	281,662,611·77
		IRON ORE—PELLETS (Exported Overseas)			
M.L. 4SA	West Pilbara	Hamersley Iron Pty. Ltd.	1,879,689·81	63·27	19,365,665·66 (b)
		LEAD ORES AND CONCENTRATES (g) (h)			
				Lead Tons	
M.C. 76	Northampton	G. H. & J. M. Mitchell	*143·27	77·36	16,831·15
Vic. Loc. 334	Northampton	K. D. Williams	87·50	52·89	11,470·00
M.L. 234	Northampton	Canadian Southern Cross Mines N.L.	225·82	171·13	36,478·17
			456·59	301·38	(b) 64,779·32
		* Contained 74·46 fine ozs. silver valued at $114.72. Silver content transferred to Silver Item.			
		* LIMESTONE (for Building, Burning Purposes, etc.)			
M.C. 1241H	South-West	Bellombra, M. & L.	7,431·00	....	2,229·30
M.C. 874H	South-West	Brambles Holdings Ltd.	31,644·00	....	9,403·20
M.C. 1290H	South-West	Caroleo, R. D. & Bellombra, V.	2,897·00	....	8,419·80
M.C. 1596H	South-West	Hall, H. K.	19,248·00	....	4,812·08
M.C. 713H	South-West	Franconi, D. & S.	629·60	....	851·40
M.C. 1227H	South-West	Korsunski, G.	4,559·00	....	912·80
M.C. 1071H	South-West	Koot, J. M.	1,883·00	....	4,449·00
M.C. 1443H	South-West	Koot, J. M.	561·00	....	1,348·00
M.C. 1386H	South-West	Marks, H. O.	13,832·00	....	5,746·20
M.C. 1040H	South-West	Messina, S.	420·00	....	504·00
M.C. 1105H	South-West	Moore, F. W. & E. M. Pty. Ltd.	1,818·00	....	3,616·00
Lot M1405	South-West	Parham Grazing Co.	2,726·75	....	6,816·88
M.C. 1284H	South-West	Panizza, P.	7,040·00	....	10,560·00
M.C. 2735H	South-West	Ready Lime Putty Pty. Ltd.	6,907·00	....	16,128·00
M.C. 1660H	South-West	Swan Portland Cement	239,455·82	....	301,234·83
Private Property	South-West	†Unspecified Producers	824,743·00	....	851,799·00
			1,165,795·17	....	(c)1,228,830·49
		* Incomplete. † From Private Property not held under Mining Act.			
		* LIMESTONE (for Agricultural Purposes)			
M.C. 1298H	South-West	Waroona Lime Co.	1,118·00	....	1,118·00
M.C. 50	Dundas	Esperance Lime Supply	1,846·50	....	16,175·00
M.C. 723H	South-West	Plozza, C. W. & W. A.	40·00	....	80·00
M.C. 1220H	South-West	Steer, E. J.	50·00	....	200·00
		* Incomplete.	3,054·50	....	(c) 17,573·00
		LITHIUM ORES (Petalite (h))			
				Li20 Units	
M.L. 80 etc.	Coolgardie	Australian Glass Manufacturers Co.	771·00	3,238·20	(a) 12,258·90
		MAGNESITE			
M.C. 76 etc.	Phillips River	Norseman Gold Mines N.L.	2,180·00	....	(a) 31,600·00

TABLE V.—*Quantity and Value of Minerals, other than Gold, Reported during the Year 1970—continued*

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Long Tons	Metallic Content	Value $A
		MANGANESE (Metallurgical Grade)			
				Av. Assay Mn %	
M.C. 244L etc.	Pilbara	Westralian Ores Pty. Ltd.	131,095·00	46·90	2,369,465·00
M.C. 269	Pilbara	Longreach Manganese Pty. Ltd.	25,000·00	50·00	540,692·00
M.C. 247	Pilbara	Dampier Mining Company Limited	35,188·50	52·13	764,502·00
M.C. 24	Peak Hill	Westralian Ores Pty. Ltd.	11,090·00	35·00	69,262·00
			202,373·50	47·54	(*b*)3,743,921·00
		MINERAL BEACH SANDS (Ilmenite (*g*))			
				Av. Assay TiO^2 %	
Sussex Loc. 7	South-West	Cable (1956) Ltd.	12,261·88	54·31	N.A.
M.C. 746H etc.	South-West	Ilmenite Minerals Pty. Ltd.	73,843·72	54·33	N.A.
M.L. 389Hetc.	South-West	Western Mineral Sands Pty. Ltd.	169,400·00	54·00	N.A.
M.C. 619H etc.	South-West	Westralian Sands Pty. Ltd.	112,964·42	56·57	N.A.
M.C. 516H etc.	South-West	Western Titanium N.L.	174,486·41	54·76	N.A.
M.C. 516H etc.	South-West	Western Titanium N.L. (upgraded)	7,703·72	89·26	N.A.
			542,956·43	54·83 }	5,984,388·60
		(upgraded)	7,703·72	89·26 }	(*b*)
		MINERAL BEACH SANDS (Rutile (*g*) (*h*))			
				TiO^2 Tons	
M.C. 516H etc.	South-West	Western Titanium N.L.	1,355·31	1,303·46	139,767·67
M.C. 619H etc.	South-West	Westralian Sands Ltd.	896·30	796·64	60,715·00
			2,251·61	2,100·10	(*b*) 200,482·67
		MINERAL BEACH SANDS (Leucoxene (*g*) (*h*))			
				TiO^2 Tons	
M.C. 746H etc.	South-West	Ilmenite Minerals Pty. Ltd.	5,527·23	4,855·09	307,063·89
Sussex Loc. 7	South-West	Cable (1956) Ltd.	1,898·07	1,667·49	105,069·55
M.C. 516H etc.	South-West	Western Titanium N.L.	1,113·00	990·51	51,338·00
M.C. 619H etc.	South-West	Westralian Sands Ltd.	3,592·00	3,145·00	170,700·00
			12,130·30	10,658·09	(*b*) 634,171·44
		MINERAL BEACH SANDS (Monazite (*g*) (*h*))			
				ThO^2 Units	
M.C. 746H etc.	South-West	Ilmenite Minerals Pty. Ltd.	769·89	5,190·94	104,834·64
Sussex Loc. 7	South-West	Cable (1956) Ltd.	256·61	1,730·18	34,944·86
M.C. 516H etc.	South-West	Western Titanium N.L.	1,930·93	13,679·87	254,008·07
M.C. 619H etc.	South-West	Westralian Sands Ltd.	1,735·80	11,282·70	227,815·00
			4,693·23	31,883·69	(*b*) 621,602·57
		MINERAL BEACH SANDS (Zircon (*g*) (*h*))			
				ZrO^2 Tons	
M.C. 746H etc.	South-West	Ilmenite Minerals Pty. Ltd.	6,678·25	4,349·33	178,190·95
Sussex Loc. 7	South-West	Cable (1956) Ltd.	2,226·05	1,449·75	59,697·55
M.C. 516H etc.	South-West	Western Titanium N.L.	33,463·56	22,044·89	755,254·85
M.C. 619H etc.	South-West	Westralian Sands Ltd.	18,588·16	12,167·49	515,668·00
			60,956·02	40,011·46	(*b*)1,508,811·35
		MINERAL BEACH SANDS (Xenotime (*g*))			
				Y^2O^3 lbs.	
M.C. 516H etc.	South-West	Western Titanium N.L.	55·00	28,023·48	(*b*)71,921·78
		NICKEL CONCENTRATES			
				Av. Assay Ni%	
M.L. 150 etc.	Coolgardie	Western Mining Corporation Ltd.	255,407·38	11·44	82,179,550·00
M.C. 39W	Broad Arrow	Great Boulder Gold Mines Ltd. & North Kalgurli (1912) Ltd.	10,032·46	11·43	3,344,600·00
			265,439·84	11·44	85,524,150·00 (*o*)
		NICKEL ORE			
M.C. 1288 etc.	Coolgardie	Metals Exploration N.L.	40,116·05	Av. Assay Ni% 3·05	(*c*)1,892,879·61
		OCHRE (Red)			
M.C. 26	Murchison	Universal Milling Co. Pty. Ltd.	608·54	....	(*a*) 6,085·35
		PEAT			
C.M.L. 5H	South-West	Burns, A. R. .... Bulk	858·75	....	13,740·00
		Bagged	115·50	....	7,148·00
			....	....	(*c*) 20,888·00

TABLE V.—*Quantity and Value of Minerals, other than Gold, Reported during the Year* 1970—*continued*

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Long Tons	Metallic Content	Value $A
		PLATINUM (Metallic By-Product Nickel Mining) (*h*)			
				Troy Ozs.	
M.C. 150 etc.	Coolgardie	Western Mining Corporation Ltd.	....	1,449·18	155,454·00
		PETROLEUM (Crude Oil)			
			Barrels		
1H	Ashburton	West Australian Petroleum Pty. Ltd.	16,663,905·00	....	53,710,900·00 (*m*)
		PYRITES CONCENTRATES (for Sulphur)			
				Sulphur Content Tons	
G.M.L. 5175E etc.	East Coolgardie	Gold Mines of Kalgoorlie (Aust.) Ltd.	1,398·79	630·61	(*a*) 15,765·35
		SALT			
		State Total	1,815,935·62	....	(*b*)6,476,489·00
		SEMI PRECIOUS STONES (Amethyst)			
			lbs.		
M.C. 65	Ashburton	Soklich, F. (Snr.), F. (Jnr.), D. & S.	128·00	....	100·00
		SEMI PRECIOUS STONES (Moss Opal)			
M.C. 60	Dundas	Soklich, F.	4,281·00	....	741·50
		SEMI PRECIOUS STONES (Dravite)			
M.C. 82	Gascoyne	Soklich, A.	9,360·00	....	5,132·78
		SEMI PRECIOUS STONES (Chalcedony)			
P.A. 5817W	Broad Arrow	W.A. Lapidiary & Rock Hunting Club Inc.	2,500·00	....	2,250·00
		SEMI PRECIOUS STONES (Chrysoprase)			
M.C. 50P	Outside Proclaimed	Wingelina Nickel Incorp. Aust.	56,000·00	....	37,000·00
		SILVER			
			Fine Ozs.		
		By-Product Gold Mining	414,050·62	....	649,433·66
		By-Product Lead Mining	74·46	....	114·72
		By-Product Copper Mining	4,644·63	....	7,378·08
			418,769·71	....	(*b*) 656,926·46
		TALC			
M.L. 433H	South-West	Three Springs Talc Pty. Ltd.	31,293·93	....	(*b*) 742,256·63
		TANTO COLUMBITE ORES AND CONCENTRATES (*g*) (*h*)			
				Ta_2O_5 Units	
M.C. 186	Gascoyne	Kempton Bros.	·08	2·05	230·00
M.L. 660 etc.	Greenbushes (*k*)	Greenbushes Tin N.L.	34·50	1,771·30	208,971·47
M.C. 647 etc.	Greenbushes (*k*)	Vultan Minerals Limited	16·31	113·73	11,171·90
M.L. 707	Greenbushes (*k*)	Austin & Huitson	·58	30·02	3,545·80
M.C. 35	Yalgoo	Zamen Pty. Ltd.	1·49	91·63	14,764·22
D.C. 281 etc.	Pilbara	J. A. Johnston & Sons Pty. Ltd.	14·32	195·51	4,262·00
M.C. 1033	Pilbara	C. & R. Peterson	·17	8·11	702·00
	Pilbara	Crown Lands—District Generally	1·13	33·17	2,862·52
			68·58	2,245·52	(*b*) 246,509·91
		TIN CONCENTRATES (*g*) (*h*)			
				Tons	
M.L. 660 etc.	Greenbushes	Greenbushes Tin N.L.	360·05	251·44	784,383·53
M.C. 647 etc.	Greenbushes	Vultan Minerals Ltd.	27·18	16·77	46,409·58
M.L. 707	Greenbushes	Austin & Huitson	14·39	9·49	28,522·91
D.C. 546	Pilbara	R. L. & F. J. Edwards	9·09	6·10	17,350·30
D.C. 195 etc.	Pilbara	Pilbara Tin Pty. Ltd.	106·15	74·10	244,575·09
D.C. 281 etc.	Pilbara	J. A. Johnston & Sons Pty. Ltd.	65·81	38·09	115,888·52
M.C. 1457	Pilbara	McLeod, D. W.	7·49	5·53	17,040·22
D.C. 493	Pilbara	Moolyella Tin Pty. Ltd.	6·02	4·20	13,870·51
M.C. 1203 etc.	Pilbara	Coral Bay Minerals Pty. Ltd.	3·61	2·45	6,982·38
P.A. 2893	Pilbara	Moonding, S.	15·64	11·01	33,738·48
D.C. 497	Pilbara	Henderson, J. M. & Sons	7·53	5·46	16,295·39
M.C. 691	Pilbara	Edwards, M. R.	37·22	25·85	66,980·40
D.C. 684	Pilbara	M. R. Edwards & J. B. Olive	22·83	15·71	43,772·24
M.C. 871	Pilbara	G. H. Mallett	19·11	13·77	43,005·07
D.C. 9WP	West Pilbara	F. & R. Sack & D. Adamson	11·05	7·68	21,830·51
M.C. 2158	Pilbara	Westos Minerals Pty. Ltd.	4·88	3·23	9,277·00
	Pilbara	Crown Lands—District Generally	22·04	16·07	48,165·56
	Pilbara	Crown Lands—District Generally	1·10	·66	1,544·62
	Pilbara	Crown Lands—District Generally	17·87	13·21	46,904·31
			759·06	520·82	(*b*)1,606,536·62

TABLE V.—*Quantity and Value of Minerals, other than Gold, Reported during the Year* 1970—*continued*

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Long Tons	Metallic Content	Value $A
		VERMICULITE			
M.C. 965	Yilgarn	Mineral By-Products Pty. Ltd.	299·42	....	(a) 1,796·52

REFERENCES

N.A.—Not available for publication.

(*a*) Est. F.O.R. value. (*b*) Est. F.O.B. value. (*c*) Value at Works. (*d*) Value of Mineral recovered. (*e*) Value at Pit-head. (*f*) Estimated value based on prices shown in monthly bulletins published by the Bureau of Mineral Resources. (*g*) Only results of shipments 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 of Alumina as computed by the Dept. of Mines based on prices for Alumina F.O.B. Jamaica. (*m*) Value based on the price per barrel as assessed by the Tariff Board for Barrow Island Crude Oil at Kwinana. (*n*) Nominal value. (*o*) Estimated nominal F.O.B. value based on the price of Nickel Cathodes as published from time to time in the publication " Metals Week ".

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, 1970, 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	tons	1·50	18.00
Alumina (From Bauxite)	,,	3,104,387·00	195,018,040.00
Alunite (Crude Potash)	,,	9,073·05	431,729.44
Antimony Concentrates (*a*)	,,	9,829·69	484,994.00
Arsenic (*a*)	,,	38,674·08	1,494,410.00
Asbestos—			
Anthophyllite	,,	509·35	13,547.42
Chrysotile	,,	111,034·78	987,272.20
Crocidolite	,,	152,466·74	33,496,644.98
Tremolite	,,	1·00	50.00
Barytes	,,	8,800·20	125,551.90
Bauxite (Crude Ore) (*g*)	,,	36,741·00	187,069.50
Beryl	,,	3,671·96	955,348.94
Bismuth	lb.	16,259·70	14,495.67
Building Stone (*g*)—			
Chrysotile—Serpentine	tons	4·45	106.00
Granite (Facing Stone)	,,	344·00	15,488.00
Lepidolite	,,	8·35	146.00
Prase	,,	9·50	275.00
Quartz (Dead White)	,,	1,592·23	33,914.00
Quartz	,,	5,203·23	65,975.00
Quartzite	,,	6,749·00	29,599.00
Sandstone	,,	624·00	3,744.00
Sandstone (Donnybrook)	,,	83·00	3,486.00
Slate	,,	235·00	2,115.00
Spongolite	,,	3,472·00	37,534.00
Tripolite	,,	264·00	264.00
Calcite	,,	5·00	50.00
Chromite	,,	14,419·05	416,593.50
Clays—			
Bentonite	,,	12,054·83	77,104.52
Brick, Pipe and Tile Clays (*g*)	,,	701,754·70	1,161,767.55
Cement Clays	,,	404,878·19	682,625.95
Fireclay	,,	862,689·16	1,236,001.41
Fullers Earth	,,	459·40	3,821.00
White Clay—			
Ball Clay	,,	27,424·60	179,841.60
Kaolin	,,	6,408·99	24,739.97
Coal	,,	40,343,937·79	131,866,584.82
Cobalt (Metallic By-Product Nickel Mining)	,,	510·11	1,452,925.00
Copper (Metallic By-Product Nickel Mining)	,,	3,744·48	3,030,338.00
Copper (Metallic By-Product) (*a*)	,,	(*i*) 191·50	65,375.10
Copper Ore and Concentrates	,,	305,423.80	10,244,914.03
Corundum	,,	63·15	1,310.00
Cupreous Ore and Concentrates (Fertiliser)	,,	86,692·59	3,258,917.98
Diamonds	..	(e)	48.00
Diatomaceous Earth (Calcined)	tons	520·00	15,991.00
Dolomite	,,	3,046·82	26,118.20
Emeralds (cut and rough)	carats	18,799·68	4,642.00
Emery	tons	21·15	750.00
Felspar	,,	70,970·61	529,760.06
Fergusonite	,,	·30	782.80
Gadolinite	,,	1·00	224.00
Glass Sand	,,	361,066·61	(*g*) 295,935.02
Glauconite	,,	(*h*) 6,467·00	(*f*) 300,769.00
Gold (Mint and Export)	fine ozs.	68,062,498·89	1,093,086,112.00
Graphite	tons	153·20	2,608.40
Gypsum	,,	1,253,636·98	2,799,401.97
Iron Ore—			
Pig Iron Recovered	,,	728,331·08	34,821,499.12
Ore Exported	,,	101,631,371·47	675,878,582.53
Pellets Exported	,,	4,701,697·07	48,908,709.55
Locally used Ore	,,	4,381,220·00	17,307,810.00
For Flux	,,	58,064·35	74,096.00
Jarosite	,,	9·54	75.00
Kyanite	,,	4,215·69	43,562.00
Lead Ores and Concentrates	,,	481,801·09	10,614,982.56
Limestone (*g*)	,,	5,541,082·12	5,772,347.61
Lithium Ores—			
Petalite	,,	4,994·98	77,680.10
Spodumene	,,	106·58	3,627.20
Magnesite	,,	30,765·64	334,072.86
Manganese—			
Metallurgical Grade	,,	1,615,728·56	36,756,646.48
Battery Grade	,,	2,218·25	90,860.20
Low Grade	,,	5,054·36	81,538.20
Mica	lb.	32,930·00	7,968.48

TABLE VI.—Total Mineral Output of Western Australia—*continued*

Mineral		Quantity	Value
			$A
Mineral Beach Sands—			
Ilmenite Concentrates	tons	4,102,453·62	40,473,556.41
Monazite Concentrates	,,	18,191·52	2,032,296.93
Rutile	,,	9,718·92	704,371.56
Leucoxene	,,	24,929·45	1,172,199.49
Zircon	,,	244,168·33	6,823,811.94
Xenotime	,,	67·00	79,403.01
Crude Concentrates (Mixed)	,,	155·95	1,553.00
Molybdenite	,,	77·50	1,730.00
Nickel Concentrates	,,	380,612·59	112,451,814.00
Nickel Ore	,,	40,116·05	1,892,879.61
Ochre—			
Red	,,	11,560·93	237,847.25
Yellow	,,	447·60	5,955.50
Peat	,,	2,497·55	33,602.00
Petroleum (Crude Oil)	bbls.	45,092,826·00	150,688,477.00
Palladium (By-Product Nickel Mining)	troy ozs.	320·75	9,656.00
Platinum (By-Product Nickel Mining)	,,	1,921·87	192,385.00
Phosphatic Guano	tons	11,857·06	145,420.90
Pyrites Ore and Concentrates (For Sulphur) (*b*)	,,	1,353,268·24	16,309,423.52
Quartz Grit	,,	829·50	1,400.70
Salt	,,	2,398,770·62	8,375,576.00
Semi-Precious Stones—			
Amethyst	lb.	41,418·40	15,706.29
Beryl (Coloured)	,,	200·00	100.00
Chalcedony	,,	67,420·00	8,000.00
Chrysoprase	,,	78,853·00	38,010.00
Dravite	,,	19,048·00	15,593.78
Moss Opal	,,	4,281·00	741.50
Opaline	,,	25·00	7.50
Prase	,,	8,720·00	729.50
Tiger Eye Opal	,,	120·00	194.00
Topaz (Blue)	,,	7·00	3.50
Sillimanite	tons	2·00	26.00
Silver (*c*)	fine ozs.	12,834,050·74	7,784,933.15
Soapstone	tons	565·40	3,855.70
Talc	,,	164,561·21	3,972,170.65
Tanto/Columbite Ores and Concentrates	,,	1,336·28	2,160,479.22
Tin	,,	26,985·11	19,019,184.52
Tungsten Ores and Concentrates—			
Scheelite	,,	169·18	143,424.24
Wolfram	,,	304·96	125,810.16
Vermiculite	,,	2,132·38	25,457.72
Zinc (Metallic By-Product) (*d*)	,,	2,887·75	(*j*)
Zinc Ore (Fertiliser)	,,	20·00	200.00
Total Value to 31st December, 1970		....	2,689,889,916.07

(*a*) By-Product from Gold Mining.
(*b*) Part By-Product from Gold Mining.
(*c*) By-Product from Copper and Lead Mining.
(*d*) By-Product from Lead Mining.
(*e*) Quantity not recorded.
(*f*) Value of mineral or concentrate recovered.
(*g*) Incomplete.
(*h*) Mineral Recovered.
(*i*) Assayed Metallic Content.
(*j*) Value included in Lead Value.
(*k*) Based on the price assessed by the Tariff Board for Barrow Island crude oil at Kwinana.

Footnote.—Comprehensive mineral production records maintained in the Statistical Branch of the Department of Mines show locality, producers, period, quantity, assayed or metallic content, and value of the various minerals listed above.

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TABLE VII

Showing average number of men employed above and below ground in the larger mining companies operating in Western Australia during 1969 and 1970.†

Company	1969			1970		
	Above	Under	Total	Above	Under	Total
Gold*—						
Central Norseman Gold Corporation N.L.	136	141	277	127	124	251
Gold Mines of Kalgoorlie (Aust.) Ltd. (Boulder)	317	175	492	320	145	465
Great Boulder G.M.s Ltd.§	183	118	301	....	....	....
Hill 50 Gold Mine N.L.	83	88	171	64	51	115
Lake View & Star Ltd.	337	393	730	278	277	555
Gold Mines of Kalgoorlie (Aust.) Ltd. (Mt. Charlotte)	12	112	124	12	117	129
North Kalgurli (1912) Ltd.	195	230	425	163	172	335
All other operators	518	197	715	63	29	92
State Average	1,781	1,454	3,235	1,027	915	1,942
Alumina (from Bauxite)—						
Western Aluminium N L.	906	....	906	1,165	....	1,165
Coal—						
Griffin Coal Mining Co. Ltd.	180	....	180	177	....	177
Western Collieries Ltd.	93	355	448	123	335	458
Copper—						
Ravensthorpe Copper Mines N.L.	61	63	124	62	60	122
Iron Ore—						
Charcoal Iron & Steel	7	....	7	7	....	7
Dampier Mining Co. Ltd.	446	....	446	413	....	413
Goldsworthy Mining Ltd.	335	....	335	386	....	386
Hamersley Iron Pty. Ltd.	594	....	594	791	....	791
Mt. Newman Mining Co. Pty. Ltd.	294	....	294	494	....	494
Western Mining Corporation	89	....	89	92	....	92
Mineral Beach Sands—						
Cable (1956) Ltd.	13	....	13	14	....	14
Ilmenite Minerals Pty. Ltd.	79	....	79	95	....	95
Western Mineral Sands Pty. Ltd.	40	....	40	40	....	40
Westralian Sands Ltd.	62	....	62	62	....	62
Western Titanium N.L.	145	....	145	161	....	161
Nickel—						
Great Boulder Gold Mines Limited....	....	....	....	83	53	136
Metals Exploration N.L.	....	....	....	48	37	85
Western Mining Corporation	498	315	813	672	488	1,160
Petroleum—Crude Oil—						
West Australian Petroleum Pty. Ltd.	217	....	217	166	....	166
Salt—						
Lefroy Salt Pty. Ltd.....	....	....	....	13	....	13
Leslie Salt Co.	24	....	24	43	....	43
Texada Mines Pty. Limited	91	....	91	164	....	164
All other minerals	348	8	356	319	7	326
State Total (Other than Gold)	4,522	741	5,263	5,590	980	6,570

* 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.
§ Ceased production in December, 1969.

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