Annual Report 1967

Mines

The Department of Mines Western Australia

PRESENTED TO BOTH HOUSES OF PARLIAMENT BY HIS EXCELLENCY'S COMMAND

A. A. Hall

REPORT OF THE
DEPARTMENT *of* MINES
WESTERN AUSTRALIA
FOR THE YEAR 1967

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1968

43179

To the 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 1967, together with 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, 1968.

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WESTERN AUSTRALIA

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Report of the Department of Mines for the Year 1967

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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 1967.

The estimated value of the mineral output of the State (including gold, coal and petroleum) for the year was $148,630,447 an increase of $72,667,389 compared with that for the preceding year and constitutes an all time record. This is 95.66% higher than the previous figure set in 1966.

To the end of 1967 the progressive value of the whole mineral production of the State amounted to $A1,531,398,543 of which gold accounted for $A1,047,524,121 (see Table IV at back).

Minerals other than gold and coal rose sharply in value to $125,794,021 an increase of $74,158,337 above that for 1966 to establish a new all time record 143.6% higher than the previous figure set in 1966. This huge increase was due mainly to the continued expansion of iron ore production and to a lesser extent to the increased production of alumina (from bauxite) and the commencement during the year of petroleum and nickel production.

The spectacular increase in production was reflected in royalty revenue and during the year royalty totalling $5,166,463 was collected as against $721,954 in 1966 and $450,155 in 1965.

IRON ORE

With a dramatic increase from 4,166,329 tons valued at $18,268,833 in 1966 to 9,979,459 tons valued at $67,522,532 during 1967 exported iron ore far outstripped other mineral production to become the State's leading mineral in place of gold which had held that position for the past 75 years.

Hamersley Iron Pty. Ltd. was the major producer for the year with 3,641,626 tons of Mt. Tom Price iron ore valued at $31,249,467.

Goldsworthy Mining Ltd. was a close second with 3,111,776 tons exported from the Mt. Goldsworthy deposit and valued at $26,428,889 f.o.b. Port Hedland.

Dampier Mining Co. Ltd. continued production of iron ore from Cockatoo and Koolan Islands and reported 2,216,872 tons valued at $4,757,806. Of this 64,810 tons were shipped to Japan and the remainder to B.H.P. steelworks in the Eastern States.

Dampier commenced production of Koolyanobbing iron ore in 1967 and reported 487,773 tons (valued at $965,791) of which 400,000 tons were shipped to New South Wales steelworks.

Western Mining Corporation Ltd. maintained production from Koolanooka with 521,412 tons worth $4,120,578 f.o.b. Geraldton.

Construction work for the Mt. Newman iron ore project commenced during the year and should be completed in time for production to start in 1969.

GOLD

The estimated value of gold received at the Perth Branch of the Royal Mint plus that exported in gold-bearing material was $18,071,924 a decline of $693,363 when compared with the figure for 1966 and equalled only 12.84% of the value of all minerals for 1967.

The quantity of gold advised as being received at the Perth Branch of the Royal Mint (573,277.73 fine ounces) together with that contained in gold-bearing material exported for treatment (2,743.28 fine ounces) totalled 576,021.01 fine ounces which was 52,755.69 fine ounces less than for the previous year (see Table 1(b) Part 2).

Details of gold production for the year as reported directly to the Department as distinct from that received at the Mint are set out in Table 1 at back. The total tonnage of gold ore treated was 2,531,625 being 87,391 tons less than for 1966.

The famous "Golden Mile" locality of Kalgoorlie-Boulder mining centres contained in the East Coolgardie Goldfield has to date treated a little over 91 million tons of ore for 36.98 million fine ounces of gold valued at a progressively estimated $591.63 million. These figures represent 57% of the State's reported ore tonnage and gold production.

West Australian gold included in sales on open dollar markets by the Gold Producers' Association Ltd. for the period from October, 1966 to June, 1967 totalled 405,013.8 fine ounces. The premium received therefrom in excess of Mint Value amounted to $70,569 an overall average of 17.424 cents per fine ounce. That amount, less expenses, was distributed to the producer members during 1967 and approximated 16.616 cents per fine ounce.

Subsidy payments made by the Commonwealth Government during the year under the Gold Mining Industry Assistance Act totalled $A3,597,141 an increase of $46,650 compared with the previous year. Of that amount $3,550,194 went to large producers and $46,947 went to small producers.

COAL

Coal production from Collie during the year showed an increase of 1,056 tons over that for 1966 and the overall average value per ton rose by 16 cents.

Figures for the last three years were:

	1965	1966	1967
Tons	993,741	1,061,095	1,062,151
Total Value	$4,409,972	$4,562,087	$4,764,503
Average value per ton	$4.4377	$4.2994	$4.4857
Average effective workers	760	726	694
Proportion of deep mined coal	51·15%	46·48%	46.54%

PETROLEUM
(Crude Oil)

The first commercial production of oil in Western Australia commenced on Barrow Island early in 1967 and at the end of the year 4,646,938 barrels valued at $14,853,605 had been produced.

Drilling of development wells in this oil field continued throughout the year, by the end of which the daily rate of production had increased to nearly 30,000 barrels—almost a million gallons a day.

Active exploration for oil continued in the State's sedimentary basins unfortunately without further commercial discoveries so far.

New petroleum legislation for off-shore oil search was finalised by the Commonwealth and the six Australian States during the year and is expected to considerably increase the rate of exploration of the continental shelf.

ALUMINA
(from Bauxite)

Western Aluminium again expanded alumina production from Darling Range bauxite and the nominal value of its product increased from $14,589,120 in 1966 to $24,313,500 for 1967.

Investigation of bauxite deposits in the Admiralty Gulf area of the north Kimberleys continued with some encouraging results, while exploration for other deposits in the Darling Ranges was also further pursued.

NICKEL

The Kambalda nickel mine came into production during the year marking another important mineral development in Western Australia.

To the end of the year 2,252 tons of concentrates valued at $381,628 had been produced and a decision had been made by Western Mining Corporation Ltd. to establish a nickel refinery at Kwinana.

The search for nickel was carried on with vigour throughout practically the whole State and several discoveries announced are being followed up with intensive drilling.

OTHER MINERALS

The two million dollar a year Wittenoom blue asbestos mine closed at the end of 1966 and for the first time in many years there was no production of this mineral in 1967.

This loss was offset to some extent by increased production in manganese—up $879,150 to $3,927,059 in 1967—and in tin, the output of which was valued at $2,358,771, double the 1966 yield.

Other minerals to yield over a million dollars for the year were ilmenite—$4,185,150, zircon—$1,147,908, and pyrites—$1,067,686, while pig iron worth $3,069,933 was recovered by the Wundowie Charcoal Iron & Steel Industry from Koolyanobbing iron ore.

Active exploration for all minerals continued throughout 1967 in most areas of the State and discovery of further deposits in the future is confidently anticipated together with development of new mines and expansion of existing ones.

PART 2—COMPARATIVE STATISTICS

TABLE 1

SUMMARY

Mineral Production : Quantity, Value, Persons Engaged

	1966	1967	Variation	
GOLD—				
Reported to Department (Mine Production)—				
Ore Tons	2,619,016	2,531,625	—	87,391
Gold (fine ounces)	627,052	573,445	—	53,607
Average Grade	4.788	4.530	—	.258
Persons Engaged—				
(a) Effective Workers (excluding absentees)	4,053	4,027	—	26
(b) Total Pay Roll	4,411	4,362	—	49
Mint and Export (Realised Production)—				
Gold (fine ounces)	628,777	576,021	—	52,756
Estimated Value ($A) (including Overseas Gold Sales Premium)	$19,765,287	$18,071,924	—	$1,693,363
PETROLEUM—CRUDE OIL—				
Reported to Department—				
Barrels	....	4,646,938	+	4,646,938
†Value ($A)	....	$14,853,605	+	$14,853,605
Persons Engaged—				
Effective Workers (excluding absentees)	....	229	+	229
COAL—				
Reported to Department (Mine Production)—				
Tons	1,061,095	1,062,151	+	1,056
Value ($A)	$4,562,087	$4,764,503	+	$202,416
Persons Engaged—				
Effective Workers (excluding absentees)	726	694	—	28
OTHER MINERALS—				
Reported to Department—				
Value ($A)	$51,635,684	*$110,940,416	+	$59,304,732
Persons Engaged—				
Effective Workers (excluding absentees)	2,258	2,900	+	642
TOTAL ALL MINERALS—				
Value ($A)	$75,963,058	*$148,630,447	+	$72,667,389
Persons Engaged—				
Effective Workers	7,037	7,850	+	813

* All time record.

† Based on the price of $US3.58 ($A3.196428) per bbl. assessed 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 1966 *and* 1967

Western Australia

Minerals	1966		1967		Increase or Decrease for Year Compared with 1966	
	Quantity	Value	Quantity	Value	Quantity	Value
	Tons	$A	Tons	$A	Tons	$A
Alumina (from Bauxite)	243,152·00	14,589,120	405,225·00	24,313,500	+ 162,073·00	+ 9,724,380
Asbestos (Chrysotile)	119·01	19,326	76·30	3,215	— 42·71	— 16,111
(Crocidolite)	11,464·57	2,414,906	....	....	— 11,464·57	— 2,414,906
Barytes	1,809·65	26,660	962·25	21,613	— 847·40	— 5,047
Beryl	12·63	2,992	10·97	3,682	— 1·66	+ 690
	lbs.				lbs.	
Bismuth	95·70	88	....	....	— 95·70	— 88
	Tons		Tons		Tons	
Building Stone (Granite—Facing Stone)	77·00	3,080	6·00	48	— 71·00	— 3,032
(Quartzite)	1,280·00	5,120	1,318·00	5,464	+ 38·00	+ 344
(Quartz)	....	....	207·23	4,455	+ 207·23	+ 4,455
(Quartz—Dead White)	....	....	382·00	7,742	+ 382·00	+ 7,742
(Sandstone)	248·00	1,488	42·00	252	— 206·00	— 1,236
(Spongolite)	69·00	372	633·00	8,229	+ 564·00	+ 7,857
Clays (Bentonite)	563·50	2,582	112·00	896	— 451·50	— 1,686
(Cement Clay)	23,924·00	51,536	16,814·00	36,400	— 7,110·00	— 15,136
(Fireclay)	98,487·35	169,190	86,032·45	87,910	— 12,454·90	— 81,280
(Kaolin)	150·00	900	332·45	2,164	+ 182·45	+ 1,264
(White Clay-Ball Clay)	1,012·00	7,996	739·00	5,812	— 273·00	— 2,184
(Brick, Pipe and Tile Clay)	83,091·00	126,564	82,289·00	115,050	— 802·00	— 11,514
Coal	1,061,094·65	4,562,087	1,062,150·80	4,764,503	+ 1,056·15	+ 202,416
Copper Ore and Concentrates	3,268·29	518,134	3,093·00	552,032	— 175·29	+ 33,898
Cupreous Ore and Concentrates	962·27	87,954	776·13	52,108	— 186·14	— 35,846
Diatomaceous Earth	45·50	1,955	5·00	352	— 40·50	— 1,603
Dolomite	5·00	75	....	....	— 5·00	— 75
Felspar	1,282·00	18,050	342·00	5,112	— 940·00	— 12,938
Glass Sand	28,219·00	*16,482	41,768·10	*19,909	+ 13,549·10	+ *3,427
Gypsum	41,884·00	79,873	40,078·00	77,489	— 1,806·00	— 2,384
Iron Ore (Pig Iron recovered)	54,275·00	2,865,043	54,328·00	3,069,933	+ 53·00	+ 204,890
(Ore Exported)	4,166,329·92	18,268,833	9,979,459·87	67,522,532	+5,813,129·95	+ 49,253,699
Lead Ores and Concentrates	2,681·30	104,408	909·68	96,893	— 1,771·62	— 7,515
Limestone*	577,435·70	650,666	746,777·50	802,084	+ 169,341·80	+ 151,418
Lithium Ores (Petalite)	933·00	14,124	667·00	10,477	— 266·00	— 3,647
Magnesite	135·07	1,959	1,258·48	12,224	+ 1,123·41	+ 10,265
Manganese (Metallurgical and Low Grades)	136,747·94	3,047,909	189,095·98	3,927,059	+ 52,348·04	+ 879,150
Mineral Beach Sands (Ilmenite)	470,896·12	4,621,179	429,620·24	4,185,150	— 41,275·88	— 436,029
(Monazite)	1,894·62	221,277	1,417·20	178,338	— 477·42	— 42,939
(Rutile)	576·38	40,515	400·00	28,758	— 176·38	— 11,757
(Leucoxene)	755·89	31,273	598·26	30,348	— 157·63	— 925
(Zircon)	26,497·53	851,412	29,618·18	1,147,908	+ 3,120·65	+ 296,496
Nickel Concentrates*	....	....	2,252·92	381,628	+ 2,252·92	+ 381,628
Ochre (Red)	207·00	4,140	261·00	5,220	+ 54·00	+ 1,080
			bbls		bbls	
Petroleum—Crude Oil	....	....	4,646,938·00	14,853,605	+4,646,938·00	+ 14,853,605
			Tons		Tons	
Pyrites Ore and Concentrates (For Sulphur)	76,136·22	1,023,071	78,684·89	1,067,686	+ 2,548·67	+ 44,615
	lbs.		lbs.		lbs.	
Semi Precious Stones	655·00	504	62,871·50	8,042	+ 62,216·50	+ 7,538
	Tons		Tons		Tons	
Talc	9,155·34	231,625	7,901·24	227,037	— 1,254·10	— 4,588
Tanto/Columbite Ores and Concentrates	4·71	19,691	22·75	131,680	+ 18·04	+ 111,989
Tin Concentrates	589·01	1,231,570	1,238·71	2,358,771	+ 649·70	+ 1,127,201
Tungsten Ores and Concentrates—(Scheelite)	·52	771	1·30	2,858	+ ·78	+ 2,087
(Wolfram)	....	....	·93	1,689	+ ·93	+ 1,689
Total	....	$A55,936,500	....	$A130,137,857	....	+$A74,201,357

TABLE 1 (*b*)

Quantity and Value of Gold and Silver Exported and Minted during Years 1966 *and* 1967

Minerals	1966		1967		Increase or Decrease for Year Compared with 1966	
	Quantity	Value	Quantity	Value	Quantity	Value
	Fine Oz.	$A	Fine Oz.	$A	Fine Oz.	$A
Gold (Exported and Minted)....	628,776·70	‡19,765,287	576,021·01	‡18,071,924	— 52,755·69	— 1,693,363
Silver (Exported and Minted)	223,182·96	261,271	309,476·12	420,666	+ 86,293·16	+ 159,395
Total	....	$A20,026,558	....	$A18,492,590	....	—$A1,533,968
Grand Total	....	$A75,963,058	....	$A148,630,447	....	+$A72,667,389

* Incomplete. ‡ Including Overseas Gold Sales Premium.

TABLE 2

ROYALTIES

Mineral	Rate per Ton	Royalty Collected	
		1966	1967
	Cents	$	$
Amethyst	*	....	**25.40**
Asbestos	15	1,660.50	**236.90**
Barytes	5	58.28	**74.40**
Bauxite	5	46,577.99	**99,463.11**
Bentonite	5	25.65	**8.10**
Beryl	20	4.20	**1.97**
Building Stones	10	184.50	**278.10**
Chalcedony	*	....	**7.75**
Clays	5	3,632.64	**4,965.45**
Coal	2.5	26,523.76	**28,218.04**
Diatomaceous Earth (Calcined)	15	6.23	**1.35**
Felspar	5	75.40	**18.20**
Glass Sand	5	1,434.15	**2,050.22**
Gypsum	5	1,948.20	**2,273.85**
Ilmenite Concentrates	10	37,202.45	**47,773.46**
Iron Ore	†	568,217.31	**4,446,564.43**
Leucoxene Concentrates	10	78.00	**60.40**
Limestone	5	3,518.50	**5,704.05**
Magnesite	15	16.16	**111.52**
Manganese	15	16,317.95	**26,628.75**
Mineral Phosphates	10	1.50	....
Monazite	*	826.82	**1,003.90**
Nickel	*	....	**5,146.02**
Ochre	5	....	**23.40**
Oil (Crude)	§	....	**478,826.15**
Petalite	10	88.20	**70.40**
Pyrites	10	6,943.30	**8,012.90**
Rutile Concentrates	15	72.00	**52.50**
Scheelite	*	3.94	**14.30**
Talc	‡	4,504.79	**4,717.37**
Tanto/Columbite	*	98.95	**696.09**
Tin Concentrates	20	127.23	**248.86**
Wolfram	*	....	**6.39**
Zinc Concentrates	20	....	**129.00**
Zircon Concentrates	10	1,805.50	**3,051.15**
		$721,954.10	**$5,166,463.88**

* One half per centum of the realised value F.O.R., or if exported, of the realised value F.O.B.
† Various rates according to type of ore.
‡ Various rates.
§ Provisional.

TABLE 3

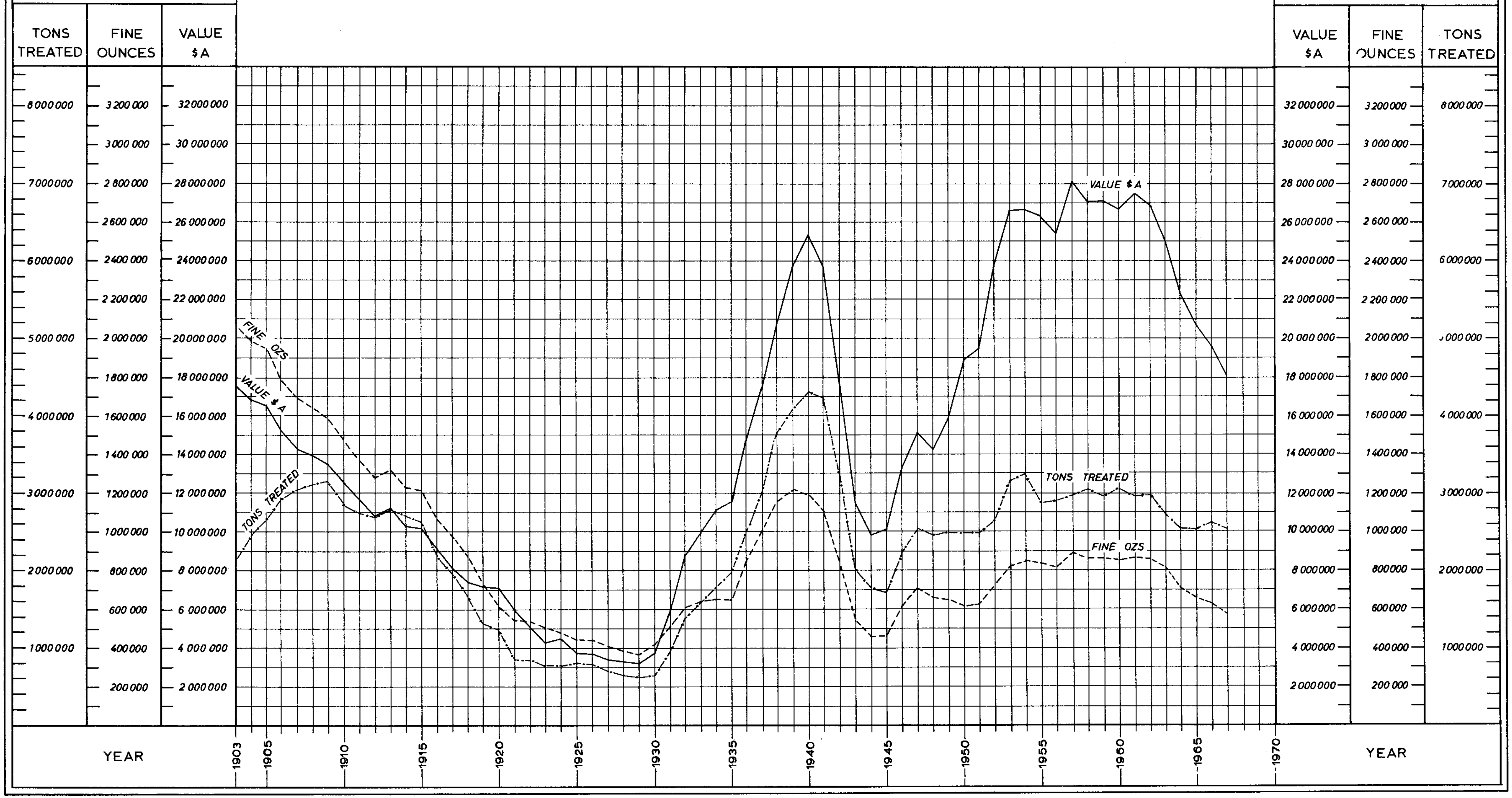
Showing for every Goldfield the amount of Gold reported to the Mines Department as required by the Regulations, also the percentage for the several Goldfields of the total reported (and the average value of the yield in pennyweights per ton of ore treated).

Goldfield	Reported Yield		Percentage for each Goldfield		‡ Average Yield per ton of ore treated	
	1966	1967	1966	1967	1966*	1967*
	Fine Oz.	Fine Oz.	Per cent.	Per cent.	Dwts.	Dwts.
1. Kimberley	18	**6**	·003	**·001**	....	....
2. West Kimberley	....	....	....	....	....	....
3. Pilbara	917	**1,351**	·146	**·236**	15·764	**18·531**
4. West Pilbara	....	....	....	....	....	....
5. Ashburton	....	....	....	....	....	....
6. Gascoyne	350	**714**	·056	**·124**	48·962	**21·636**
7. Peak Hill	6	**10**	·001	**·001**	....	....
8. East Murchison	1,044	**1,138**	·167	**·198**	9·314	**8·527**
9. Murchison	42,472	**41,632**	6·773	**7·257**	5.235	**5·134**
10. Yalgoo	7	**135**	·001	**·024**	....	**3·566**
11. Mt. Margaret	715	**1,183**	·114	**·206**	18·475	**22·093**
12. North Coolgardie	10,336	**3,121**	1·648	**·544**	7·441	**7·572**
13. Broad Arrow	2,275	**903**	·363	**·157**	5·261	**11·414**
14. North-East Coolgardie	487	**450**	·078	**·078**	15·062	**10·720**
15. East Coolgardie	461,264	**432,145**	73·561	**75·319**	4.153	**4·000**
16. Coolgardie	5,636	**1,811**	·899	**·316**	29·385	**6·523**
17. Yilgarn	1,020	**1,360**	·163	**·237**	11·124	**15·364**
18. Dundas	99,063	**86,523**	15·798	**15·080**	10·500	**9·342**
19. Phillips River†	†1,389	**1,199**	·209	**·209**	....	....
20. South-West Mineral Field	....	**35**	....	**·006**	....	**26·923**
21. State Generally	53	**39**	·008	**·007**	....	....
	627,052	**573,755**	100·000	**100·000**	4·786	**4·541**

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

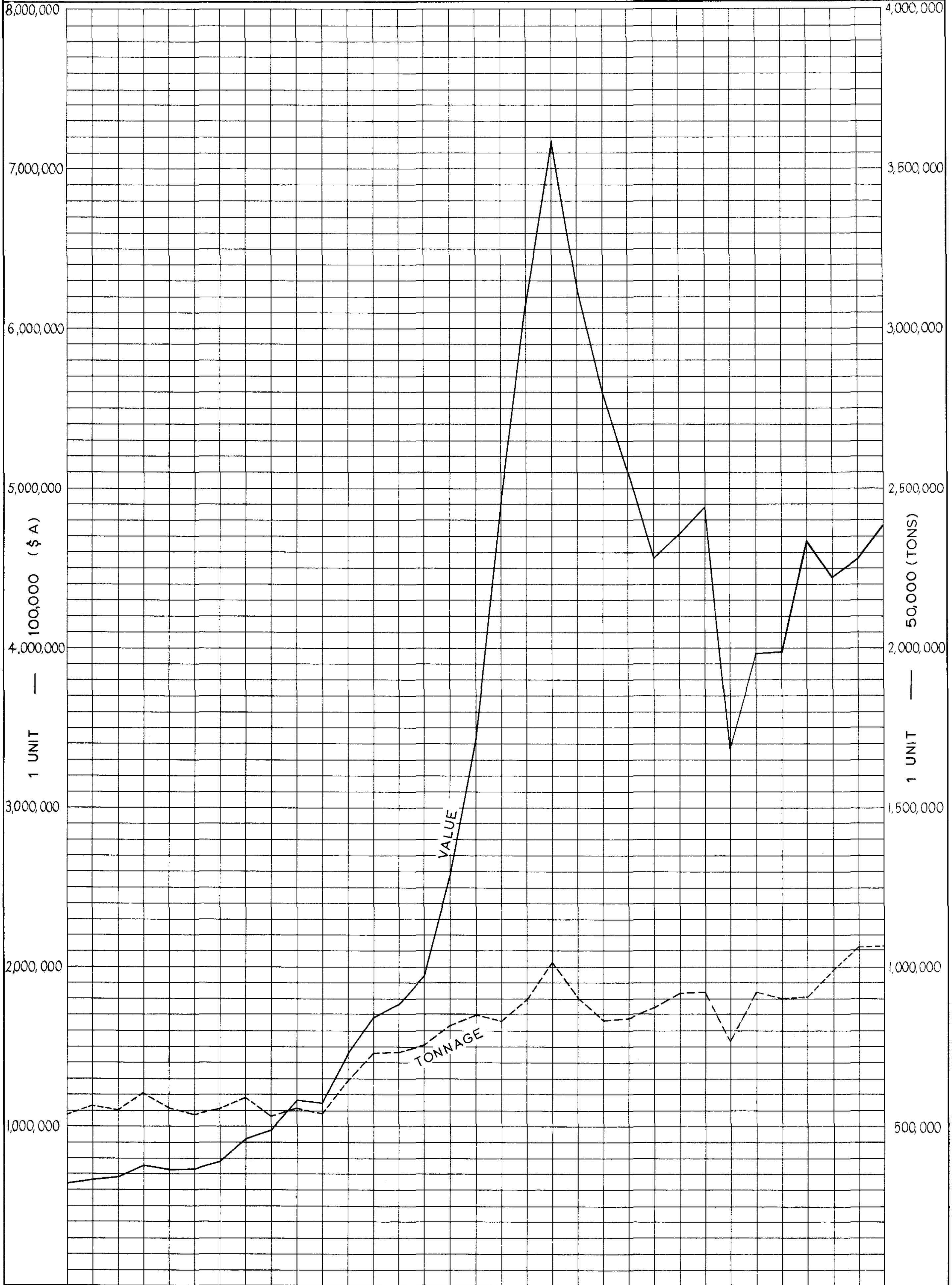
DIAGRAM OF GOLD OUTPUT

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



GRAPH OF COAL OUTPUT

SHOWING QUANTITIES AND VALUES AS REPORTED TO MINES DEPT.



YEAR	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950	1951
VALUE $ A	636,026	663,130	680,888	750,176	725,622	729,000	778,556	922,990	979,442	1,166,150	1,145,792	1,460,208	1,680,498	1,760,472	1,944,490	2,575,498	3,433,576
TONS	537188	565075	553510	604793	557535	539427	556574	581176	531546	558322	543363	642287	730506	732938	750594	814351	848475

YEAR	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967
VALUE $ A	4,914,592	6,146,146	7,177,636	6,264,148	5,595,012	5,105,310	4,560,398	4,713,064	4,878,390	3,260,518	3,961,556	3,970,120	4,678,934	4,409,972	4,562,087	4,765,503
TONS	830461	886182	1,018,343	903,792	830008	838660	870882	917434	922393	765,740	919,112	902,495	987,420	993,741	1,061,095	1,062,151

GRAPH OF TREND IN COAL OUTPUT

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

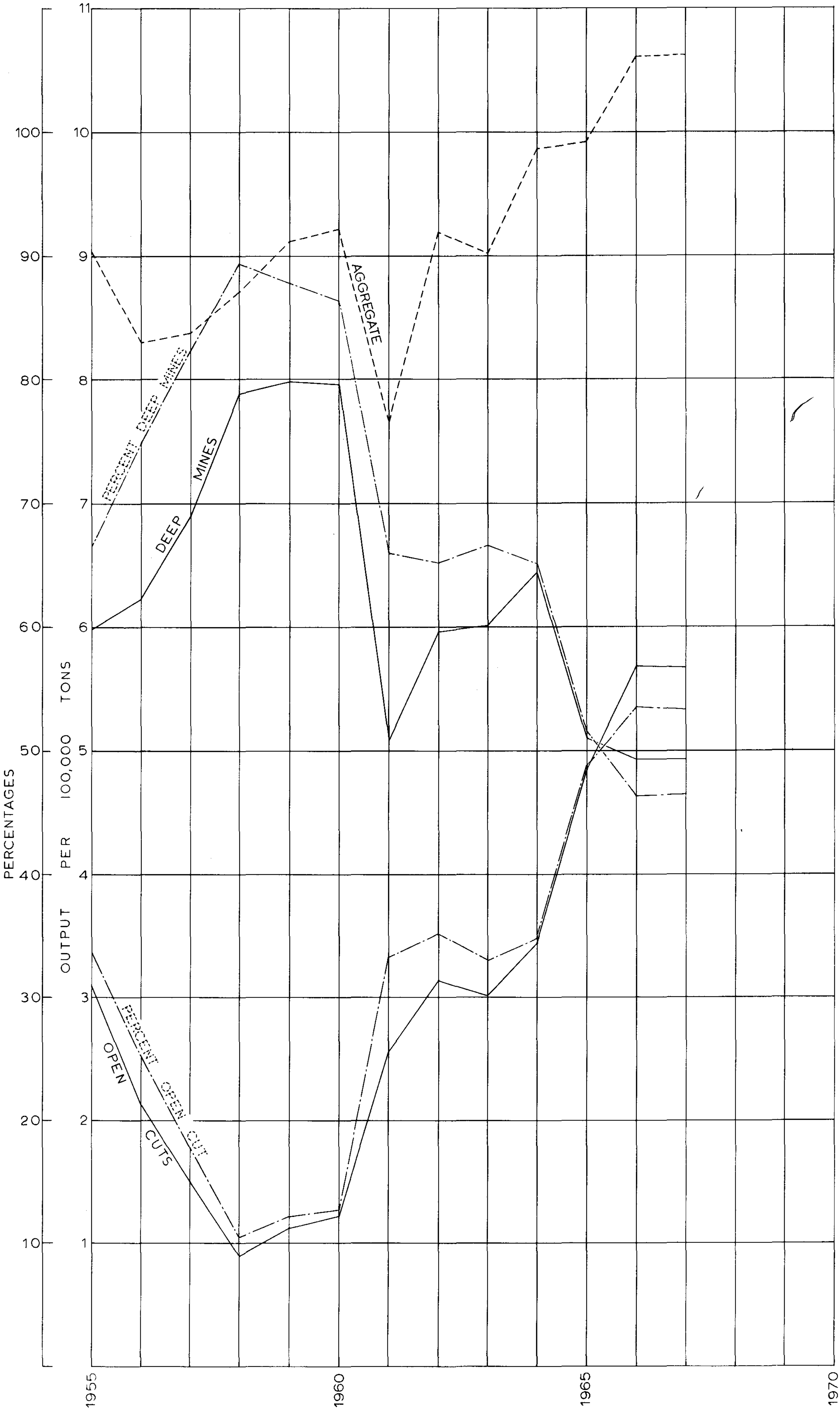


TABLE 4

Output of Gold from the Commonwealth of Australia during 1967

State	Output of Gold	Value*†	Percentage of Total
	Fine oz.	$A	%
Western Australia	576,021	18,001,355	71·75
Queensland	98,126	3,066,438	12·22
Northern Territory	72,692	2,271,625	9·05
Tasmania	34,677	1,083,667	4·32
Victoria....	11,360	354,991	1·42
New South Wales	9,946	310,812	1·24
South Australia	....	....	....
Total	802,822	25,088,888	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, 1966 *and* 1967, *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
1966	493,256	2,914,140	98	419	....	....	1,177	954
1967	494,281	2,915,567	99	410	....	....	1,206	971
Open Cut Mining—								
1966	567,839	1,647,947	....	....	209	2,717	....	....
1967	567,870	1,848,936	....	....	185	3,070	....	....
Totals—								In all Mines
1966	1,061,095	4,562,087	98	419	209	....	....	1,308
1967	1,062,151	4,764,503	99	410	185	....	....	1,530

LEASES AND OTHER HOLDINGS UNDER VARIOUS ACTS RELATING TO MINING.

TABLE 6

MINING ACT 1904.

Mining Tenements applied for during 1967 *and in force at* 31*st December,* 1967 (*Compared with* 1966).

—	Applied for				In Force			
	1966		1967		1966		1967	
	No.	Acres	No.	Acres	No.	Acres	No.	Acres
Gold—								
Gold Mining Leases	89	1,608	**105**	**2,031**	1,008	18,647	**1,030**	**19,278**
Dredging Claims	5	1,142	**2**	**600**	2	312	**5**	**939**
Prospecting Areas	450	7,963	**404**	**7,298**	343	6,135	**344**	**6,240**
Temporary Reserves	128	40,972	**35**	**130,220**	395	115,330	**439**	**129,130**
Totals	672	51,685	**546**	**140,149**	1,748	140,424	**1,818**	**155,587**
Coal—								
Coal Mining Leases	....	....	**10**	**2,880**	49	14,367	**51**	**15,011**
Prospecting Areas	....	....	**8**	**9,300**	....	....	....	....
Temporary Reserves	1	369,920	**7**	**816,800**	12	2,736,640	**11**	**1,164,320**
Totals	1	369,920	**25**	**828,980**	61	2,751,007	**62**	**1,179,331**
Other Minerals—								
Mineral Leases	145	30,509	**46**	**8,164**	184	19,750	**240**	**30,884**
Dredging Claims	81	7,206	**70**	**11,258**	422	37,497	**416**	**34,894**
Mineral Claims	534	123,418	**2,803**	**763,763**	1,574	187,022	**1,735**	**222,728**
Prospecting Areas	140	6,294	**158**	**3,224**	134	5,790	**120**	**2,425**
Temporary Reserves	241	137,818,240	**533**	**55,101,910**	353	133,037,440	**423**	**68,569,043**
Totals	1,141	137,985,397	**3,610**	**55,888,319**	2,667	133,287,499	**2,934**	**68,859,974**
Other Holdings—								
Miner's Homestead Leases	17	4,506	**5**	**975**	349	34,129	**344**	**34,109**
Miscellaneous Leases	15	169	**4**	**84**	117	1,715	**111**	**1,684**
Residence Areas	2	2	**1**	**1**	66	20	**63**	**52**
Business Areas	1	2	....	....	26	16	**24**	**20**
Machinery Areas	2	6	**1**	**5**	26	69	**27**	**77**
Tailings Areas	....	....	**1**	**2**	24	96	**24**	**94**
Garden Areas	2	10	**8**	**35**	58	180	**67**	**213**
Quarrying Areas	1	10	**25**	**463**	9	102	**23**	**360**
Water Rights	7	296	**9**	**26**	142	3,173	**143**	**3,165**
Licenses to Treat Tailings	21	....	**38**	....	35	....	**36**	....
Totals	68	5,001	**92**	**1,591**	852	39,500	**862**	**39,774**
Grand Totals	1,882	138,412,003	**4,273**	**56,859,039**	5,328	136,218,330	**5,676**	**70,234,666**

TABLE 6 (a)

SPECIAL ACTS

Leases applied for during 1967 *and in force at* 31*st December,* 1967 (*Compared with* 1966)

Mineral	Applied for				In Force			
	1966		1967		1966		1967	
	No.	Acres	No.	Acres	No.	Acres	No.	Acres
Bauxite	6	446,720	....	....	1	3,137,280	**7**	**3,137,280**
Iron	....	....	**2**	**384,000**	3	227,106	**4**	**419,106**
Salt	1	48,030	....	....	....	....	....	....
Totals	7	494,750	**2**	**384,000**	4	3,364,386	**11**	**3,556,386**

TABLE 6 (b)

PETROLEUM ACT

Permits, Licenses and Leases applied for during 1967 and in force at 31st December, 1967 (Compared with 1966)

Holding	Applied for				In Force			
	1966		1967		1966		1967	
	No.	Acres	No.	Acres	No.	Acres	No.	Acres
Permits to Explore	18	143,422,720	**6**	**43,468,800**	36	421,675,520	**37**	**417,617,920**
Licenses to Prospect	25	3,077,760	**15**	**1,662,720**	73	8,318,080	**74**	**8,360,960**
Petroleum Leases	2	128,000	....	....	....	....	**2**	**128,000**
Totals	45	146,628,480	**21**	**45,131,520**	109	429,993,600	**113**	**426,106,880**

TABLE 6 (c)

MINING ACT, 1904

Leases in Force at 31st December, 1967 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	....	....	1	5
Black Range	5	59	....	....	....	....	....	....
Broad Arrow	25	377	3	606	....	....	1	5
Bulong	4	72	....	....	....	....	1	3
Collie	....	....	49	*14,491	....	....	....	....
(Private Property)	....	....	2	*520	....	....	....	....
Coolgardie	64	1,192	73	16,913	22	1,859	6	60
Cue	2	24	....	....	6	1,233	....	....
Day Dawn	17	342	....	....	1	20	....	....
Dundas	312	6,905	....	....	19	935	....	....
East Coolgardie	307	5,444	....	....	67	3,347	62	1,168
Gascoyne	7	147	1	8	....	....	....	....
Greenbushes	....	....	58	8,773	11	588	....	....
Kanowna	3	51	....	....	12	702	....	....
Kimberley	2	34	....	....	....	....	....	....
Kunanalling	2	47	....	....	2	520	....	....
Kurnalpi	3	72	....	....	....	....	....	....
Lawlers	21	404	....	....	5	1,110	....	....
Marble Bar	45	615	4	89	2	10	8	90
Meekatharra	9	177	1	10	11	1,866	1	1
Menzies	24	444	....	....	7	740	1	10
Mount Magnet	61	938	4	38	2	30	....	....
Mount Malcolm	8	164	....	....	9	1,270	....	....
Mount Margaret	3	64	....	....	7	58	....	....
Mount Morgans	5	105	1	29	....	....	....	....
Niagara	2	29	....	....	1	20	....	....
Northampton	....	....	10	195	1	53	....	....
(Private Property)	....	....	2	36	....	....	....	....
Nullagine	11	198	....	....	2	22	3	50
Peak Hill	1	8	16	545	5	250	1	5
Phillips River	3	29	12	266	107	14,633	....	....
(Private Property)	....	....	1	297	....	....	....	....
South-West	1	24	....	....	....	....	1	2
(Private Property)	....	....	6	1,357	....	....	....	....
Ularring	10	141	....	....	1	20	....	....
West Kimberley	....	....	23	755	....	....	5	75
West Pilbara	5	74	8	108	2	11	7	142
Wiluna	....	....	5	382	17	3,879	3	11
Yalgoo	6	91	....	....	....	....	....	....
Yerilla	19	362	....	....	1	10	....	....
Yilgarn	40	609	3	141	24	923	10	57
(Private Property)	3	36	....	....	....	....	....	....
Outside Proclaimed	....	....	2	200	....	....	....	....
Totals	1,030	19,278	291	45,895	344	34,109	111	1,684

* Coal.

TABLE 6 (d)

MINING ACT, 1904

Claims and Authorised Holdings in Force at 31st December, 1967 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	8	180	....	....	45	9,492	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Black Range	6	132	....	....	3	624	4	1	....	....	....	....	....	....	....	....	....	....	....	....
Broad Arrow	40	750	....	....	12	3,377	1	1	1	1	....	....	....	....	....	....	3	8	....	....
Bulong	5	80	....	....	5	195	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Collie	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Coolgardie	92	1,644	....	....	75	18,708	4	4	....	....	1	1	....	....	2	6	5	17	....	....
Cue	23	340	....	....	10	224	4	4	....	....	....	....	....	....	....	....	1	3	....	....
Day Dawn	5	78	....	....	....	....	....	....	....	....	....	....	....	....	4	20	....	....	....	....
Dundas	26	568	....	....	47	2,190	....	....	....	....	....	....	1	5	....	....	2	12	....	....
East Coolgardie	24	375	....	....	22	6,041	31	31	....	....	1	2	12	56	7	31	11	32	4	42
Gascoyne	10	209	....	....	32	3,697	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Greenbushes	....	....	....	....	8	485	1	1	....	....	....	....	....	....	9	37	2	31	....	....
Kanowna	17	304	....	....	16	4,800	....	....	....	....	....	....	....	....	2	7	1	1	....	....
Kimberley	2	19	....	....	8	1,178	....	....	....	....	1	5	....	....	2	6	....	....	....	....
Kunanalling	11	198	....	....	5	1,210	....	....	....	....	....	....	....	....	....	....	3	25	....	....
Kurnalpi	4	96	....	....	58	17,176	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Lawlers	3	72	....	....	8	667	....	....	....	....	2	6	1	5	....	....	1	1	....	....
Marble Bar	24	501	395	32,204	345	35,451	2	2	6	6	7	21	2	10	5	10	41	1,332	11	194
Meekatharra	11	209	....	....	8	1,612	....	....	....	....	....	....	....	....	....	....	2	5	....	....
Menzies	12	156	....	....	14	2,632	....	....	....	....	1	1	....	....	3	9	5	13	....	....
Mount Magnet	31	556	....	....	2	210	....	....	....	....	....	....	....	....	12	14	3	50	....	....
Mount Malcolm	22	386	....	....	10	3,000	....	....	....	....	....	....	....	....	7	29	10	164	....	....
Mount Margaret	5	120	....	....	1	300	....	....	....	....	....	....	....	....	....	....	4	4	....	....
Mount Morgans	3	72	....	....	10	3,000	....	....	....	....	....	....	....	....	....	....	2	6	....	....
Niagara	5	120	....	....	....	....	....	....	....	....	....	....	....	....	....	....	3	6	....	....
Northampton	4	74	....	....	18	2,784	....	....	....	....	....	....	....	....	....	....	1	1	....	....
Private Property	1	20	....	....	1	10	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Nullagine	9	186	6	1,442	321	18,507	....	....	....	....	3	7	3	4	3	6	15	48	....	....
Peak Hill	3	37	....	....	61	6,451	1	1	....	....	2	8	....	....	....	....	....	....	....	....
Phillips River	....	....	....	....	42	4,087	....	....	....	....	1	2	1	2	....	....	....	....	1	5
Private Property	....	....	....	....	3	424	....	....	....	....	....	....	....	....	....	....	....	....	....	....
South-West	2	48	9	1,555	155	12,256	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Private Property	1	24	5	564	113	11,413	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Ularring	4	96	....	....	....	....	....	....	....	....	1	1	2	4	....	....	7	8	....	....
West Kimberley	....	....	....	....	5	384	....	....	....	....	2	10	....	....	....	....	1	12	3	31
West Pilbara	5	102	6	88	169	28,259	4	4	11	11	....	....	....	....	4	19	9	39	....	....
Wiluna	3	72	....	....	....	....	....	....	....	....	1	1	1	3	1	5	5	1,325	....	....
Yalgoo	13	296	....	....	22	5,407	....	....	4	1	1	5	1	5	....	....	1	10	....	....
Yerilla	2	36	....	....	34	9,820	....	....	....	....	....	....	....	....	....	....	5	12	....	....
Yilgarn	27	503	....	....	43	5,889	11	3	2	1	3	7	....	....	6	14	....	....	4	88
Private Property	1	6	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Outside Proclaimed	....	....	....	....	4	768	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Totals	464	8,665	421	35,853	1,735	222,728	63	52	24	20	27	77	24	94	67	213	143	3,165	23	360

TABLE 7

MEN EMPLOYED

Average number of Men reported as engaged in Mining during 1966 *and* 1967

Goldfield	District	Gold 1966	Gold 1967	Other Minerals 1966	Other Minerals 1967	Total 1966	Total 1967
Kimberley	....	....	....	....	....	....	....
West Kimberley	....	....	....	337	**439**	337	**439**
Pilbara	Marble Bar	30	**31**	268	**392**	298	**423**
	Nullagine	10	**10**	14	**2**	24	**12**
West Pilbara	....	2	**1**	399	**518**	401	**519**
Ashburton	....	....	....	....	**229**	....	**229**
Gascoyne	....	2	**4**	....	....	2	**4**
Peak Hill	....	1	**1**	29	**22**	30	**23**
East Murchison	Lawlers	37	**48**	....	**2**	37	**50**
	Wiluna	5	**5**	....	....	5	**5**
	Black Range	4	**7**	....	....	4	**7**
Murchison	Cue	32	**18**	1	**5**	33	**23**
	Meekatharra	7	**7**	6	**2**	13	**9**
	Day Dawn	9	**4**	....	**1**	9	**5**
	Mt. Magnet	193	**219**	....	....	193	**219**
Yalgoo	....	3	**3**	3	**3**	6	**6**
Mt. Margaret	Mt. Morgans	13	**10**	....	....	13	**10**
	Mt. Malcolm	28	**34**	....	....	28	**34**
	Mt. Margaret	12	**18**	....	....	12	**18**
North Coolgardie	Menzies	94	**55**	....	....	94	**55**
	Ularring	24	**29**	....	....	24	**29**
	Niagara	6	**9**	....	....	6	**9**
	Yerilla	10	**9**	....	....	10	**9**
Broad Arrow	....	80	**93**	....	....	80	**93**
North-East Coolgardie	Kanowna	13	**23**	....	....	13	**23**
	Kurnalpi	10	**25**	....	....	10	**25**
East Coolgardie	East Coolgardie	2,848	**2,752**	2	**2**	2,850	**2,754**
	Bulong	11	**17**	....	....	11	**17**
Coolgardie	Coolgardie	119	**155**	67	**196**	186	**351**
	Kunanalling	19	**27**	....	**3**	19	**30**
Yilgarn	....	129	**124**	16	**16**	145	**140**
Dundas	....	302	**289**	106	**114**	408	**403**
Phillips River	....	....	....	71	**95**	71	**95**
South-West Mineral Field	....	....	....	858	**1,006**	858	**1,006**
Northampton Mineral Field	....	....	....	25	**18**	25	**18**
Greenbushes Mineral Field	....	....	....	52	**60**	52	**60**
Outside Proclaimed Goldfield	....	....	....	4	**4**	4	**4**
Collie Coalfield	....	....	....	726	**694**	726	**694**
Total—All Minerals	....	4,053	**4,027**	2,984	**3,823**	7,037	**7,850**

	1966	**1967**
Minerals Other than Gold—		
Alumina (from Bauxite)	389	**526**
Asbestos	342	**2**
Barytes	7	**4**
Beryl	6	**2**
Building Stone	10	**11**
Clays	17	**21**
Coal	726	**694**
Copper	73	**97**
Cupreous Ore (Fertiliser)	26	**38**
Felspar	7	**7**
Glass Sand	3	**5**
Gypsum	13	**17**
Iron Ore	562	**1,185**
Lead	27	**20**
Limestone	21	**15**
Magnesite	....	**1**
Manganese	35	**24**
Mineral Beach Sands (Ilmenite, etc.)	322	**331**
Nickel	60	**189**
Ochre	1	....
Petroleum—Crude Oil	....	**229**
Pyrites	102	**111**
Talc	6	**7**
Tanto/Columbite	7	**12**
Tin	222	**275**
Total, Other Minerals	2,984	**3,823**

PART 3–STATE AID TO MINING.

(a) *State Batteries*

At the end of the year there were 20 State Batteries including the Northampton Base Metal Plant.

From inception to the end of 1967, gold, tin, tungsten, lead, copper and tantalite ores to the value of $39,388,374 have been treated at the State Batteries. Included in the above amount is $15,406,042 gold premium and $93,787 premium paid by sales of gold by the Gold Producers' Association Ltd. $37,958,507 came from 3,557,395¼ tons of gold ore, $220,031 from 83,833¼ tons of tin ore, $38,896 from 3,971¾ tons tungsten ore, $1,129,684 from 47,526 tons lead ore, $11,932 from 220½ tons of copper ore and $29,324 from 252 tons of tantalite ore.

During the year 25,137¼ tons of gold ores were crushed for 9,880 oz. bullion, estimated to contain 8,373 oz. fine gold equal to 6 dwts. 16 grs. per ton. The average value of sands after amalgamation was 2 dwts. 17 grs. per ton, making the average head value 9 dwts. 9 grs. per ton. Cyanide plants produced 3,624 oz. fine gold, giving a total estimated production for the year of 11,997 oz. fine gold valued at $377,267.

The working expenditure for the year for all plants was $474,249 and the revenue was $81,231 giving a working loss of $393,018 which does not include depreciation or interest. Since the inception of State Batteries, the Capital expenditure has been $1,761,276 made up of $1,402,051 from General Loan Funds; $274,409 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 $66,247 compared with $57,930 for 1966.

The working expenditure from inception to the end of 1967 exceeds revenue by $5,269,784.

(b) *Prospecting Scheme*

At the end of the year 38 men were in receipt of prospecting assistance as compared with 36 at the end of 1966.

Total expenditure for 1967 was $22,339 and refunds amounted to $2,320.

Assisted prospectors crushed 1,148 tons of ore during the year for 160 ozs. of gold.

Progressive total figures since inception of the Scheme are:

Expenditure—$957,112

Refunds—$186,469

Ore crushed—123,074 tons

Gold won—57,175 ozs.

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 increased tempo of mineral exploration in the State again created great demand for the services and assistance of the Geological Survey, particularly in providing regional geology, specialists' services, and information from the Survey's library, records and open files.

The scope of the advice and information available from this Branch of the Mines Department is well indicated by the Divisions within the Survey:

(1) Hydrology and Engineering Geology Division.
(2) Sedimentary (Oil) Division.
(3) Regional Geology Division.
(4) Mineral Resources Division.
(5) Common Services Division, which includes Palaeontology, Petrology and Geophysics.

In addition to providing assistance to the mining industry, the Survey continued to help agricultural and pastoral development in the State, particularly in relation to both surface and underground water supplies, and again assisted the general public with advice and information.

PART 4–SCHOOL OF MINES.

(a) *Kalgoorlie*

Enrolments at the School increased from 240 in 1966 to 278 in 1967 and it is hoped that the downward trend of the three previous years has been arrested.

School revenue reflected this improvement with an increase of $2,335 to a total of $14,756 for the year.

Following a review in 1966 of all courses offered for study, new ones were decided upon and the first years of the new Associateship Courses were introduced at the beginning of the 1967 academic year. The old Courses will be phased out over three years.

Modernisation of the School buildings continued with completion of Stage 1A during the year and commencement of Stage 1B.

The School continued to provide the usual services to industry and the general public and 821 gold and mineral samples were received for assay and determination.

(b) *Norseman*

Enrolments were maintained at 50 students with 124 class enrolments.

Fifteen subjects are taught at this School which fills a great need in this active mining area.

After 20 years in Kalgoorlie as Director of the School, Mr. R. A. Hobson decided to retire and his resignation as from the end of the year was accepted with regret. During his term of office Mr. Hobson devoted himself wholeheartedly to advancement of the School and the progress of its students.

PART 5–INSPECTION OF MACHINERY.

As in previous years, the work of this Branch continued to increase with the general expansion of industry in Western Australia.

Boiler registrations rose by 399 to a total of 10,095 in 1967 as compared with the previous year, and machinery groups registered, increased from 54,162 in 1966 to 56,569 this year. The latter figures include 867 lifts in operation as compared with 725 at the end of 1966.

Inspectors carried out 6,990 boiler inspections and 34,641 machinery inspections during the year as compared with 6,656 and 34,824 respectively in 1966.

The Board of Examiners granted Certificates of Competency to 136 Engine Drivers, 357 Crane Drivers and 114 Boiler Attendants—somewhat less than the numbers issued in 1966.

PART 6–GOVERNMENT CHEMICAL LABORATORIES.

The number of samples submitted to the Laboratories for analysis, determination and investigation continued to rise and 20,570 were received in 1967 as compared with 15,522 in 1966—a 33 per cent. increase.

The most prolific types of samples were Water—3,265, Soils—2,057, Wheat—2,031, Minerals—1,588, Pastures—1,431, Toxicology (human)—1,116 and Clover—1,074.

Staff increased from 110 in 1966 to 115 at 31/12/67 with provision for a further 8 to be appointed in the 1967-68 year.

Extensions to the office and laboratory at the Engineering Chemistry Division in Bentley were completed and occupied during the year.

The Laboratories continued to maintain close association with other Government Departments and to serve both State and Commonwealth Authorities as well as the general public.

PART 7—EXPLOSIVES BRANCH.

The distribution of explosives again increased throughout the State with particularly heavy use of the North West ports.

This made inspection of incoming shipments more difficult than usual but the Branch continued to carry out its fundamental function of ensuring that explosives entering W.A. complied with the State's requirements.

Very little defective explosive was found during inspections and periodic checks of ammonium nitrate importations revealed them to be of good quality and improved packaging.

Explosives Reserves at Geraldton and Port Hedland were developed with magazines, roads and fencing and new Reserves were created at Carnarvon and Onslow.

PART 8—MINE WORKERS RELIEF ACT AND MINERS PHTHISIS ACT.

Examination of mine workers for detection of silicosis, asbestosis and tuberculosis continued at the Kalgoorlie State X-Ray Laboratory, the Perth Chest Clinic and through the Mobile X-Ray Unit which visited eight gold and mineral fields during the year.

A total of 5,291 examinations were made of which 2,029 were re-examined under the Mine Workers Relief Act, 2,873 were new applicants under the Mines Regulation Act and 389 were re-examined under the latter Act.

Compensation payments under the old Miners Phthisis Act continued to decrease and totalled $13,571 to 60 beneficiaries as compared to $14,654 to 65 beneficiaries in 1966.

PART 9—SURVEY EXAMINATION AND DRAFTING BRANCH.

Surveys of mining tenements continued at a high level with a total of 465 being completed at a cost of $64,980. This work, however, could not keep pace with the tremendous number of applications being received, and at the end of the year 7,509 tenements were awaiting survey.

It is expected that this situation will gradually level itself out as the spate of applications decreases and additions to the staff are made.

This Branch continued to provide maps and technical plans for the Geological Survey, general plans for the public and also charted a record 3,957 applications for mining and oil tenements during the year.

PART 10—STAFF.

Members of the staff again met the pressures of intense mining activity, working long hours in order to cope with the tremendous volume of work which shows no sign of slackening and I am very appreciative of their efforts.

In this summary I have mentioned only main items of the Department's various activities and detailed reports of Branches are contained in Divisions II to X hereunder.

I. R. BERRY,
Under Secretary for Mines.

Mines Department,
Perth.

DIVISION II

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Report of the State Mining Engineer for the Year 1967

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Under Secretary for Mines:

I submit the Annual Report of the State Mining Engineer's Branch which has been prepared by the Assistant State Mining Engineer, the Senior Inspector of Mines and the Inspector of Mines (Drilling).

MINERALS AND OIL

The year was historic in that both the mineral nickel and oil were produced commercially for the first time in Western Australia. 2,252 tons of nickel concentrates were recorded from Kambalda for 1967 and production for the year from Barrow Island was 4,646,938 barrels of crude oil.

For most minerals it can be said that the production in 1967 remained steady with some making spectacular gains.

The production of iron ore showed the greatest increase from 4,166,329 tons in 1966 to 9,979,459 tons in 1967. Bauxite railed from Jarrahdale increased from 805,192 tons to 1,354,041 while alumina production at Kwinana increased from 243,152 tons to 405,225 tons for the year.

The total output of coal from mines at Collie increased from 1,061,095 last year to 1,062,151 tons this year. This production was the highest ever recorded on the field.

Gold production however, declined from 627,051 fine ounces in 1966 to 573,754 fine ounces in 1967. Notwithstanding this decrease, the value of production at $17,997,131 was third highest in the Mineral Output list.

The Mint value of gold was $31.25 per fine ounce but the calculated value included $67,298 distributed by the Gold Producers Association from the sale of 405,014 fine ounces at an average premium of 17.42 cents per ounce.

DRILLING SECTION

The Mines Department Drilling Section completed 31,264 feet of drilling for 1967.

Most of footage drilled was in water exploration which was carried out with holes at Busselton, Esperance, Pinjarra, Gnangara, Watheroo and Cue.

Special drilling investigations were undertaken in the Fremantle Harbour, the Narrows Bridge approach road foundations, Waroona dam foundations and test drilling of the alternative spillway site for the Ord River Dam was started.

STAFF

Retirements

State Mining Engineer — E. E. Brisbane, 23/2/67.

Workmen's Inspector of Mines — L. Cross. 1/2/67.

Appointments

State Mining Engineer — A. Y. Wilson, 5/4/67.

Special Inspector of Mines — I. W. Loxton, 28/4/67.

Assistant District Inspector of Mines — R. J. Griffin, 24/4/67.

Assistant District Inspector of Mines — D. D. Mainwaring, 6/11/67.

Workmen's Inspector of Mines — S. J. Hammond, 2/2/67.

Resignations

District Inspector of Mines — A. J. Murphy, 11/5/67.

District Inspector of Mines — J. J. Zuvich, 16/6/67.

Assistant District Inspector of Mines — R. J. George Kennedy, 27/1/67.

Transferences

Senior Inspector of Mines — J. Boyland — Kalgoorlie to Perth, 4/9/67.

District Inspector of Mines — A. W. Ibbotson — Port Hedland to Perth, 9/12/67.

A. Y. WILSON,
State Mining Engineer.

MINERAL PRODUCTION

State Mining Engineer:

Mineral production for the year 1967 is described in this report which is based on information supplied by the Statistician and Inspectors of Mines. Statistics relating to the Mining Industry are tabulated as follows:—

Table "1"—Mineral Output

Table "2"—Development Footages

Table "3"—Principal Gold Producers

TABLE 1

Mineral Output

Mineral	1966 Tons	1966 Value	1967 Tons	1967 Value
		$A		$A
Asbestos—				
Chrysotile	119.01	19,326	76.30	3,215
Crocidolite	11,464.57	2,414,905	....	....
Barite	1,809.65	26,660	962.25	21,613
Bauxite—Alumina	805,192.00	14,589,120	1,354,041.20	24,313,500
Bentonite	563.50	2,582	112.00	896
Beryl	12.63	2,992	10.97	3,682
Bismuth (lb)	95.70	88	....	....
Building Stone	1,674.00	10,060	2,588.23	26,190
Clays	206,664.35	356,186	186,206.90	247,335
Coal	1,061,094.65	4,562,087	1,062,150.80	4,764,503
Copper—				
Ore and Concentrates	3,268.29	518,134	3,093.00	552,032
Fertiliser Grade	962.27	87,954	776.13	52,108
Diatomaceous Earth	45.50	1,955	5.00	353
Dolomite	5.00	75	....	....
Felspar	1,282.00	18,050	342.00	5,112
Glass Sand	28,219.00	16,482	41,768.10	19,909
Gold (fine oz.)	627,051.74	19,702,406	573,754.67	17,997,131
Gypsum	41,884.00	79,873	40,078.00	77,489
Ilmenite	470,896.12	4,621,179	429,620.24	4,185,150
Iron Ore	4,166,329.92	18,268,833	9,979,459.87	67,522,532
Iron Ore—Pig Iron	93,740.00	2,865,043	86,401.00	3,069,933
Lead Ore and Concentrates	2,681.30	104,408	909.68	96,893
Leucoxene	755.89	31,273	598.26	30,348
Limestone	577,435.70	650,666	746,777.50	802,084
Lithium Ore—Petalite	933.00	14,124	667.00	10,477
Magnesite	135.07	1,959	1,258.48	12,224
Manganese	136,747.94	3,047,909	189,095.98	3,927,059
Monazite	1,894.62	221,277	1,417.20	178,338
Nickel Concentrates	....	....	2,252.92	381,628
Ochre	207.00	4,140	261.00	5,220
Petroleum (barrels)	....	....	4,646,938.00	14,853,605
Pyrite	76,136.22	1,023,071	78,684.89	1,067,686
Rutile	576.38	40,515	400.00	28,758
Semi-Precious Stones	0.29	504	28.06	8,042
Silver (fine oz.)	223,182.96	261,271	309,476.12	420,666
Talc	9,155.34	231,625	7,901.24	227,037
Tantalo-Columbite	4.71	19,691	22.75	131,680
Tin Concentrate	589.01	1,231,570	1,238.71	2,358,771
Tungsten Ore and Concentrates	0.52	771	2.23	4,547
Zircon	26,497.53	851,411	29,618.18	1,147,908
Totals	....	75,900,175	....	148,555,654

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
Gold—							
Murchison	Hill 50 Gold Mine N.L.	559	2,073	193	859	9,022	12,706
East Coolgardie	Lake View and Star Ltd.	....	18,815	3,355	4,304	27,227	53,701
	Great Boulder Gold Mines Ltd.	279	4,930	1,095	1,981	5,338	13,623
	North Kalgurli (1912) Ltd.	....	10,531	2,307	1,562	20,620	35,020
	Gold Mines of Kalgoorlie (Aust.) Ltd.	80	13,015	4,749	5,810	32,739	56,393
Dundas	Central Norseman Gold Corporation N. L.	....	1,156	1,325	2,175	44,901	49,557
	Total in Gold Mines	918	50,520	13,024	16,691	139,847	221,000
Copper— Phillips River	Ravensthorpe Copper Mines N.L.	180	1,703	395	246	661	3,185
Lead— Northampton	Mary Springs Lead Mine	95	130	....	....	....	225
Nickel— Coolgardie	Western Mining Corporation Ltd.	226	2,294	756	1,254	25,329	29,859
	Totals in all Mines	1,419	54,647	14,175	18,191	165,837	254,269

ASBESTOS

Old dumps at Lionel were the source of the seventy-six tons of chrysotile produced in the Pilbara. At present there are no groups actively engaged in developing or exploiting the Chrysotile or crocidolite deposits in Western Australia.

BARITE

Universal Milling Co. Pty. Ltd. obtained 740 tons from Chesterfield in the Meekatharra District. Total State production was 962 tons valued at $21,613 which included a 50 ton parcel from Gnows Nest in the Yalgoo Goldfield.

BAUXITE

Alumina production increased by 162,073 tons to 405,225 during 1967 as compared with the output for the previous year. The nominal value of this output was $24,313,500.

Western Aluminium N.L. railed to the Kwinana Refinery 1,354,041 tons of bauxite obtained from the rifle range area near Jarrahdale. To keep pace with the expansion of the alumina refinery, equipment at the mine was increased to 2x Air Track wagon drills, 3 x RB.38 shovels, 7 x Euclid R.24 trucks, 2 x Euclid front end loaders, 2 x Gradall trench diggers, a Le Tourneau LW.16 angle dozer, a D.7 bulldozer, a grader and a Euclid scraper.

Preparation of a new mining site in the Craigs Ridge area has commenced and the railway was being extended. Late in 1967 a start was made on the construction of a crushing plant at this proposed open cut operation.

BENTONITE

Only 112 tons of Bentonite were obtained from lake deposits near Marchagee as compared with 563 tons for the previous year.

BERYL

Eleven tons containing 124.57 units of Berylium oxide valued at $3,682 were obtained from the *Australian Glass Manufacturers Co. Pty. Ltd.'s* felspar quarry at Londonerry and from Lakeside in the Murchison Goldfield. No production was reported from the Yalgoo, Pilbara and West Pilbara Goldfields.

BUILDING STONE

Production from mining tenements, granted under the provisions of the Mining Act, was 2,588 tons valued at $26,190. Production included 1,318 tons of quartzite popularly known as Toodyay Stone, 589 tons of quartz from Coolgardie, Kunanalling and Mount Magnet, 42 tons of sandstone from Mount Barker, 6 tons of granite facing stone from Toodyay, and 633 tons of sawn spongolite from Ravensthorpe.

CLAYS

Reported clay production for the metropolitan area, Clackline, Glen Forrest, Mount Kokeby, Kalgoorlie and Goomalling totalled 186,207 tons valued at $247,335. Output is still in excess of the above tonnage as not all production is reported to this Department.

COAL

The total output from all mines in the Collie Coalfield was 1,062,151 tons valued at $4,764,503. This production was the highest ever recorded on the field and was 1,056 tons higher than the 1966 record output. Considerably higher tonnages could be mined if there was an increased demand for Collie coal.

Production from the Muja open cut operated by the *Griffin Coal Mining Co. Ltd.* was 567,870 tons which represented 53.5 per cent of the total output for the coalfield. At the end of the year there were approximately 413,000 tons of coal exposed at the open cut, an increase of 26,000 tons over that exposed at the comparable period last year.

The bulk of the coal output was produced from the Hebe (377,368 tons) and Galatea (71,960 tons) seams in the East Extension Area. Coal production from the Centaur seam ceased in April, following a mechanical breakdown of the 200W dragline. The total overburden removed, including forward stripping by the dragline on road excavations in advance of the cut face, was 2,769,152 cubic yards in the solid. On the basis of 1 cubic yard of coal "in situ" weighing 1 ton then the ratio of overburden removed to coal produced was 4.88 to 1.

Salvaging of equipment from the Hebe mine was completed and water allowed to rise to the vicinity of the No. 3 Left Belt Bord intersection with the main tunnel. Approximately 30,000 gallons of water per hour are being pumped from this mine over about 86 per cent. of the time. Three new International Pay-hauler 50 ton capacity trucks were purchased and put into service on overburden removal. Good standards of lighting were maintained in and around the open cut.

Western Collieries Ltd. produced 494,281 tons of coal from its two deep mines Western No. 2 and Western No. 4. A record output of 391,286 tons from Western No. 2 exceeded the previous year's record output by 1,837 tons. A considerable amount of development drivage was completed in the Main Dips and in the West Side of this mine. Drivage of the four development headings in the No. 6 West District continued satisfactorily and good progress was made on opening out No. 6 West "A" Panel and No. 6 East "A" Panel. Mining ceased in No. 3 West District following completion of work in "G" Panel where some difficulties were experienced due to adverse roof conditions. Development of most of the sumpage area between No. 6 West District and the main dips were completed and 3 of the 4 proposed pump bore holes were constructed.

At present, about 2 million gallons of water are being pumped from the mine each day. This water is used by the State Electricity Commission's Muja Generating Station. Two Melroe "Bobcat" Diesel powered front end loaders were introduced into this mine following investigations by the Company and the Mines Department.

Pillar splitting continued in widely separated areas of the Western No. 4 mine which, it is anticipated, will cease production during the latter part of 1968. The miners are being transferred to the Company's operations at Western No. 2.

There were further improvements in the standard of surface amenities on the field. A new change house was completed at Western No. 2 and a cool room facility was provided at the Muja change house.

COPPER

Ravensthorpe Copper Mines N.L. produced 3,093 tons of concentrate from 50,275 tons of ore from the Elverdton and Marion Martin mines. The concentrate contained 662 tons of copper, 1,199 fine ounces of gold and 5,131 fine ounces of silver.

Work is in progress to sink the Elverdton shaft to the No. 7 level and develop the Elverdton and Desmond lodes at that horizon.

Ore reserves were reported as 71,086 tons. Development work completed during the year included shaft sinking 180 feet, driving 1,703 feet, crosscutting 395 feet, rising 115 feet and winzing 131 feet.

Production of copper ore, for use as a trace element in fertilizers, was 776 tons as compared with 962 tons for the previous year. Grade was also slightly lower at 13.01 per cent Cu as compared with the 1966 average grade of 14.11 per cent Cu.

Notable producers of fertilizer grade ore were *M. Alac* at Ilgarari with 192 tons of 18.71 per cent ore valued at $22,014, *R. W. Shearer* at Warriedar with 402 tons of 10.14 per cent ore valued at $18,008 and *T. Lee* at Yannery Hills with 69 tons of 13.98 per cent ore valued at $4,556.

DIATOMACEOUS EARTH

Universal Milling Co. Pty. Ltd. obtained 5 tons from a deposit near Yanchep.

FELSPAR

Australian Glass Manufacturers Co. Pty. Ltd. reported the production of 342 tons from their quarry at Londonderry in the Coolgardie Goldfield. In addition, 667 tons of petalite valued at $10,477 was obtained from the same source.

GLASS SAND

Production from the Lake Gnangara deposit amounted to 14,361 tons valued at $19,909. *Ready Mix Concrete (W.A.) Pty. Ltd.* and *Burlabup Downs Pty. Ltd.* exported a total of 27,407 tons of silica sand (value not available for publication) obtained from Jandakot situated about seven miles south east of Fremantle.

GOLD

The ore treated during the year amounted to 2,531,625 tons as compared with 2,619,016 tons in the previous year. Gold recovered amounted to 573,755 fine ounces as compared with 627,052 fine ounces for 1966. Grade of ore mined was lower, recovery being 4.53 dwts. per ton as against 4.79 dwts. per ton for 1966.

The calculated value of the gold produced was $17,997,131 which included $67,298 distributed by the Gold Producers' Association from the sale of 405,014 fine ounces of gold at an average premium of 17.42 cents 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".

Gold Mines of Kalgoorlie (Aust.) Ltd., with a production of 864,931 tons of ore for a return of 152,569 fine ounces of gold at an average recovery of 3.53 dwts. per ton, was the State's leading producer. Production from the Fimiston leases was 464,297 tons yielding 100,989 ounces and from Mount Charlotte 400,634 tons yielding 51,580 ounces.

Sulphide ore reserves at Fimiston are stated as 907,500 tons at 4.8 dwts. per ton. Development was concentrated on the cross lode systems of the Perseverance and Hainault leases. Enterprise development was concentrated on Brookman lode on the 25 and 26 levels.

Western Deeps lode system exploration continued and at the end of the year the second diamond drill hole had reached 1,700 feet. Work ceased on the Paringa and Federal leases in March and preparations are in hand to close the New North Boulder and Oroya shafts.

Free milling ore reserves are stated as 5,131,000 tons at 3.6 dwts. per ton. At Mt. Charlotte work has been concentrated on developing the No. 9 level and installing a new underground crushing station. Drilling below the No. 9 level has indicated that the ore body continues to the 1,300 feet horizon.

Total development work undertaken by Gold Mines of Kalgoorlie during the year amounted to 56,393 feet made up of 80 feet of shaft sinking, 13,015 feet driving, 4,749 feet cross-cutting, 5,810 feet rising and winzing and 32,739 feet of exploratory drilling.

Lake View and Star Ltd. produced 147,133 fine ounces of gold from the treatment of 638,813 tons of ore at an average recovery of 4.61 dwts. per ton. The previous year's production was 148,130 fine ounces from the treatment of 644,625 tons.

Estimated ore reserves as at the 1st July, were 3,244,800 short tons at 4.71 dwts. per ton.

Development work completed during the year amounted to 26,474 feet. In addition, 27,227 feet of exploratory drilling was completed.

A shortage of underground miners again prevented the required increase in tonnage being produced to keep the treatment plant fully occupied. In order to create conditions more favourable to the recruitment and retention of labour a home building project was commenced involving the erection of 20 new homes for company employees.

The No. 2 power unit, the recently installed Mirrlees KVSS12 engine of 2,000 KW capacity, performed extremely well and generated about 40 per cent. of the total electric power output of the station.

The storage capacity for deslimed mill tailings used for hydraulic fill underground was increased by the addition of a third Deveraux agitator at Chaffers shaft. The Lake View section was out of production for eleven weeks when a crack developed in the main drum shaft of the winding engine.

A series of 11 ft. x 9 ft. headings were driven to connect the 2,100 feet levels of Horseshoe No. 2 and Ivanhoe shafts to the bottom of the Ivanhoe South Extended main ventilation upcast shaft. This is the first stage in the upgrading of the ventilation system of the mine.

Central Norseman Gold Corporation N.L. treated 185,224 tons for a recovery of 86,478 fine ounces of gold. Gold recovery was at the rate of 9.34 dwts. per ton as compared with the previous year's recovery of 10.49 dwts. per ton when 188,647 tons yielded 98,922 fine ounces.

Reserves of ore at the end of June were estimated to be 529,000 tons averaging 10.0 dwts. per ton.

At the Regent shaft emphasis was placed on developing the Crown reef on the Nos. 19 and 22 levels. On the Princess Royal mine the test of the Princess Royal shear north of the Royal fault on the No. 22 level was discontinued because of indifferent results, as was a test of the hanging wall shears east of the mine at the No. 10 level.

Surface diamond drilling continued throughout the year in the Princess Royal Crown and Hospital shear areas. Total footage drilled was 44,901 feet. Other development work included 1,156 feet of driving, 1,326 feet of crosscutting and 2,175 feet of rising.

TABLE 3

Principal Gold Producers

Mine	1966			1967		
	Tons Treated	Fine Ounces	Dwts. per ton	Tons Treated	Fine Ounces	Dwts. per ton
Gold Mines of Kalgoorlie (Aust.) Ltd.	849,953	158,136	3·72	864,931	152,569	3·53
Lake View & Star Ltd.	644,625	148,130	4·60	638,813	147,133	4·61
Central Norseman Gold Corporation N.L.	188,647	98,922	10·49	185,224	86,478	9·34
North Kalgurli (1912) Ltd.	364,140	70,108	3·85	356,434	65,302	3·66
Great Boulder Gold Mines Ltd.	360,417	83,129	4·61	295,894	64,410	4·35
Hill 50 Gold Mine N.L.	156,859	41,201	5·25	158,895	40,441	5·09
State Batteries	29,422	12,932	8·79	25,137	8,373	6·66
State Batteries Tailings Treatment	....	2,365	....	....	3,624	....
Other Sources	24,953	12,129	9·72	6,297	5,425	17·23
Totals in all Mines	2,619,016	627,052	4·79	2,531,625	573,755	4·53

North Kalgurli (1912) Ltd. treated 356,434 tons of ore for a recovery of 65,302 fine ounces of gold at an average recovery of 3.66 dwts. per ton. During the previous year 70,108 fine ounces were recovered from 364,140 tons of ore.

Development completed during the year included driving 10,531 feet, crosscutting 2,307 feet, rising 41 feet, winzing 1,521 feet and exploratory drilling 20,620 feet. Above average values were intersected on the No. 19 level Whitfield lode and the No. 23 level Kalgurli Cross lode.

There were nine minor occurrences of methane gas during the year. Six of these were struck in diamond drill holes and three in normal face work. All the strikes in diamond drill holes were east of the Main shaft on the Nos. 18, 19 and 20 levels.

Great Boulder Gold Mines Ltd. treated 295,894 tons of ore for a recovery of 64,410 fine ounces of gold at an average recovery of 4.35 dwts. per ton. Production for the previous year was 360,417 tons yielding 83,129 fine ounces at 4.61 dwts. per ton.

Ore reserves at the 30th June were estimated to be 1,530,160 short tons averaging 4.71 dwts. per ton. A study is being made into the feasibility of merging the gold mining interests of the Great Boulder and Lake View and Star mining groups.

Sinking of the Edwards shaft has been suspended after completing 279 feet for the year. Other development included driving 4,930 feet, crosscutting 1,095 feet, rising 1,755 feet and winzing 226 feet.

The company is at present surveying and testing, by drilling, a promising nickel deposit at Mount Martin.

Hill 50 Gold Mine N.L. at Mount Magnet treated 158,895 tons of ore for a return of 40,441 fine ounces of gold, average recovery being 5.09 dwts. per ton. This brings the total production by this company to 1,227,672 fine ounces of gold and 59,458 fine ounces of silver from 2,685,738 tons of ore treated.

The ore reserve at the 27th June was determined as 622,900 short tons at 4.7 dwts. per ton.

There was only a small amount of development undertaken off the main shaft and this consisted of driving 357 feet, crosscutting 79 feet, rising 52 feet and winzing 199 feet. All of the winze sinking was confined to the B33 winze below the No. 13 level (3,210 feet) where a No. 14 level at 3,411 feet was developed. At the Morning Star mine the principal development was the sinking of the new shaft. This shaft was advanced to 601 feet below the surface. A large building to provide change rooms, store, first aid room and office was erected adjacent to this shaft. A 80h.p. Thomson winder was also installed at the Morning Star main shaft.

In the Menzies District, *Moonlight Wiluna Gold Mines Ltd.* operating the Timoni mine at Mount Ida treated 6,334 tons of ore for a return of 2,670 fine ounces of gold. Operations at this mine ceased in March after breaking out the remaining ore reserves and emptying the stopes. During the 17 years that the company worked this mine, 231,631 fine ounces of gold was recovered from the treatment of 455,407 tons of ore.

Smaller producers of note were the *Constance Una* at Parkers Range in the Yilgarn with 764 fine ounces from 303 tons, *Star of Mangaroon* in the Gascoyne with 714 fine ounces from 660 tons, *Prophecy* at Bamboo Creek in the Pilbara with 527 fine ounces from 958 tons and the *Daisy* at Mount Monger with 418 fine ounces from 1,100 tons.

GYPSUM

Plaster manufacturers obtained their supplies of gypsum from Lake Brown, Yellowdine, Lake Cowcowing and Norseman. Plaster of Paris reported as manufactured was 23,004 tons. The 1,370 tons of gypsum used in cement manufacture was obtained from Nukarni, north of Merredin. Total production for the year was 40,078 tons valued at $77,489.

ILMENITE, LEUCOXENE, MONAZITE, RUTILE, ZIRCON

Sales of ilmenite totalled 429,620 tons valued at $4,185,150. Minerals associated with ilmenite returned $1,385,352 to the producers.

Western Titanium N.L. at Capel produced 182,211 tons of ilmenite assaying 54.57 per cent titanium dioxide, 506 tons of leucoxene, 865 tons of monazite, 400 tons of Rutile and 7,692 tons of ziron. Mining was concentrated on the section of the deposit north of the treatment plant. The face is 600 feet wide and is being advanced at the rate of about 60 feet per month; that is approximately 10 acres a year. The south end of the deposit has been refilled with tailings and the area replanted with shrubs and wildflowers. A Jones wet magnetic separator and an additional automatic oil fired drying kiln were installed during the year.

Western Mineral Sands Pty. Ltd. at Capel produced 107,990 tons of ilmenite assaying 53.73 per cent Ti02. There has been no major alteration to the mining and concentrating methods used by this company. Front end loaders dig the sand and deposit it in a bin from whence it is pumped to the concentrating plant consisting of 3 stage Reichert cones. The dry treatment plant now has eleven high intensity magnetic separators.

Westralian Oil Ltd. produced 60,199 tons of ilmenite assaying 58.24 per cent. Ti02, 482 tons of monazite, and 16,444 tons of zircon from the Yoganup deposit. Mining is in progress about 2 miles north of the concentrating plant. The ore is dug with a mechanical shovel and transported by truck to the concentrating plant. This feed contains about 30 per cent. heavy mineral and is concentrated up to 98 per cent. before transport to the dry treatment plant at Capel.

Ilmenite Minerals Pty. Ltd. and *Cable (1956) Ltd.* wholly owned subsidiaries of *Kathleen Investments (Aust.) Ltd.* produced 79,220 tons of ilmenite assaying 54.35 per cent Ti02, 92 tons of leucoxene, 70 tons of monazite and 5,482 tons of zircon. At Wonnerup, on Sussex location 7, a dredge and dragline together are mining about 35 tons per hour. The concentrate from banks of revolving cones is carted to the dry treatment plant for a recovery of about 100 tons of ilmenite per day. The suction dredge, capable of about 250 tons of sand per hour, is still operating at Stratham. The heavy minerals are recovered using Reichert concentrators and these concentrates are carted 12 miles to dry treatment plant at Bunbury for separation and stockpiling.

IRON ORE

Iron ore production exceeded ten million tons which was more than double the production for the previous year. This State, with an output valued at approximately 71 million dollars, is now the leading iron ore producer in the Commonwealth. This position is likely to be retained in the future.

Hamersley Iron Pty. Ltd. exported 3,641,626 tons of 65.30 per cent. iron ore valued at $31,249,467 f.o.b. Dampier. The company reported having mined 6,217,584 tons of high grade ore, 2,841,148 tons of low grade ore and 286,179 tons of waste rock.

The company workforce at Mount Tom Price totals 368 and at Dampier 446. These numbers will be increased as production of pellets gets under way and lump ore sales increase.

The characteristics of the Mount Tom Price ore body have resulted in the company settling on a 45 feet bench height with 9 inch diameter holes drilled on a 20 ft. x 20 ft. to a 25 ft. x 25 ft. pattern, depending on ground conditions. Ireco slurry is used as the principal explosive which is charged directly into the holes from a storage truck. Three 12 cubic yard capacity shovels load broken ore onto a fleet of twenty two 100 ton capacity KW Dart trucks for delivery to the 89 inch x 60 inch Allis Chalmers gyratory primary crusher. The ore is further crushed and screened to give two products viz.—30 mm. + 6 mm. and — 6 mm. Crushed and screened ore from the mine stockpile is delivered to Dampier over 179 miles of standard gauge (4 ft. 8½ in.) railway in either train loads comprising 1 x 2750 h.p. locomotive and 76 x 100 ton capacity ore wagons, or in double loads made up of 2 x 2750 h.p. locomotives hauling 152 x 100 ton capacity ore wagons. The travelling time each way is 6½ to 7 hours. Loading time for 152 wagons varies between 1½ and 2½ hours depending on type of load; dumping time 3 hours for lump ore and 6 hours for fines. The company has established two modern self contained townships at Dampier and Tom Price.

Goldsworthy Mining Ltd. reported the sale overseas of 3,111,776 tons of iron ore assaying 65.02 per cent. Fe and valued at $26,428,889 f.o.b. Port Hedland. The company reports that 99 persons were employed at Mount Goldsworthy on ore production and 169 employed on staff and maintenance duties. Train crews and railway control required 22 employees and at Finucane Island a total of 133 persons attended to ore handling, ship loading and maintenance.

Bench heights at the mine were reduced to 30 feet following delays brought about by excessive secondary blasting. A 40R Bucyrus Erie rotary drill is used to drill the 9 inch diameter blast holes. Two P & H 4½ cubic yard diesel electric shovels and a 150B x 7 yard electric shovel are used to load eleven 65 ton Haulpaks which transport the ore to the primary crusher at the mine. The company is attempting to reduce the dust nuisance at Mount Goldsworthy and Finucane Island. During the year, exploratory drilling totalling 12,177 feet was carried out at Shay Gap, Cattle Gorge, Strelley Gorge, Iron Mount and Rocklea.

Dampier Mining Co. Ltd. This company was responsible for the production of 2,704,645 tons of iron ore obtained from Koolyanobbing, Cockatoo and Koolan Islands. Koolan Island was the source of 64,810 tons, averaging 67.27 per cent Fe and valued at $496,729 which was exported overseas. Shipments from Cockatoo Island and Koolan Island to the Eastern States, totalled 2,152,062 tons, nominally valued at $4,261,077 or less than $2 per ton. 487,773 tons of 59.56 per cent Fe ore was railed to Kwinana from Koolyanobbing. Nominal value of this ore was $965,791.

At Cockatoo Island, no ore was shipped out during several months because of alterations being carried out to increase ore storage bin capacity. The opportunity was taken to overhaul the primary crusher and modify it by replacing the long cotton rope drive with vee belts.

The Dowd's hill or "E" deposit at Koolyanobbing was mined using an Ingersoll-Rand Drillmaster for boring and ammonium nitrate fuel oil explosive, detonated with Cordtex, for blasting the iron ore. Two P & H 6 yard electric shovels, loading into 50 ton Haulpack trucks were in use during the year. The ore crushed to 2 inches is conveyed on belts to six 2,000 tons storage bins prior to discharging directly into railway wagons.

It is expected that the blast furnace at Kwinana will be in operation early in 1968.

Western Mining Corporation Ltd. mining the Koolanooka Hills deposit exported 521,412 tons of 60.11 per cent. Fe ore valued at $4,120,578 f.o.b. Geraldton. There has been no alteration to the mining or crushing methods reported in last year's annual report. Mining on some of the upper benches has been stopped as the limit of the ore has been reached at these horizons.

The Charcoal Iron and Steel Industry at Wundowie obtained 86,401 tons of 62 per cent ore from the Koolyanobbing deposit. Pig iron produced was 54,328 tons valued at $3,069,933.

LEAD

Lead concentrate sales from the Northampton field amounted to 910 tons containing 688 tons of lead valued at $96,893 f.o.b. Geraldton. *The Mary Springs* lead mine operated by T. A. Bridson was the leading producer with 419 tons of concentrate valued at $49,583. The 100 feet level of the mine was driven 130 feet north of which 110 feet was in high grade ore. A shaft was sunk 95 feet from the surface and connected with the level at a point 35 feet from the northern end. In January, 1968, this mine was sold to Canadian Southern Cross Mines.

Fifty two feet of south drive was completed on the 114 feet level of the *Yiapa* mine. The 831 tons of ore crushed at the State Battery came principally from stoping operations above this level. Production for the year was 304 tons of concentrate containing 232 tons of lead valued at $31,527.

The *Nooka* lead mine was re-opened in August when the mine was unwatered and cleaned free of sand that had washed out of the sand filled stopes. Some underhand stoping was done at the north end below the No. 2 level. Production was 95 tons of concentrate valued at $8,337.

LIMESTONE

Reported production of limestone was 746,778 tons valued at $802,084. Total annual production would exceed the figure quoted as not all production within the State is reported. Limestone used for building purposes, road construction, agricultural purposes, flux and cement manufacture, was quarried in the metropolitan area, Wanneroo, Mount Many Peaks, Marmion, Esperance and Parry inlet.

LITHIUM ORE

Australian Glass Manufacturers Co. Pty. Ltd. obtained 667 tons of petalite from the felspar quarry at Londonderry in the Coolgardie Goldfield.

MAGNESITE

Magnesite (W.A.) Pty. Ltd. reported the sale of 1,165 tons obtained from a deposit near Esperance. *Australian Glass Manufacturers* obtained 93 tons from Coolgardie. Total production for the year was 1,258 tons valued at $12,224.

MANGANESE

Exports from Port Hedland totalled 119,413 tons of 50 per cent Mn ore valued at $2,763,275. *Westralian Ores Pty. Ltd.* was the principal producer in the Pilbara with 76,588 tons valued at $1,697,183. During the year the company reported the breaking of 68,066 tons from the Woody Woody and Ant Hill deposits. Except for 4,000 tons all of this ore was carted to the stockpile at Port Hedland.

Mount Sydney Manganese Pty. Ltd. sold 42,825 tons of manganese obtained from its several deposits at Woody Woody. Ore breaking amounted to 60,500 tons which included 4,000 tons of high silica ore for which there is a keen demand.

In the *Peak Hill Goldfield, Westralian Ores Pty. Ltd.* produced 60,860 tons from its deposit at Horseshoe and also mined 8,823 tons of ore at Mount Padbury and Mount Fraser, for *Broken Hill Pty. Ltd.* The value of the Peak Hill production was $1,163,784.

NICKEL

Western Mining Corporation Ltd. reported the sale of 2,253 tons of nickel concentrate valued at $381,628. At *Kambalda,* ore treatment commenced on the 8th June and to the end of the year, 66,409 tons of 4.57 per cent nickel ore was treated for a recovery of 15,753 tons of 13.08 per cent nickel concentrate. All of this production came from workings off the Silver Lake shaft. Ore reserves were quoted as 2,450,000 tons of 4.18 per cent nickel for the Lunnon Shoot on which the Silver Lake shaft is situated.

In addition to 25,329 feet of exploratory drilling, development work included shaft sinking 226 feet, driving 2,294 feet, crosscutting 756 feet, winzing 582 feet and rising 672 feet. Stoping was concentrated above the 400 feet level and work at the 500 feet level consisted of plat formation and development out to the ore body. An average of 189 men were employed which figure does not include contractors on building construction at the mine and townsite.

During the year, the townsite developed rapidly with the construction of 83 houses, 20 x 4 room single men's quarters, mess and canteen, supermarket, post office, country club and medical aid post.

OCHRE

The Universal Milling Co. Pty. Ltd. obtained 261 tons of red oxide from the Weld Range deposit in the Murchison.

PETROLEUM

On Sunday, April 23, the first shipment of Barrow Island crude oil for Kwinana was pumped into the 250,000 barrel capacity tanker "P.J. Adams" which was moored six miles off shore. This historic event marked the beginning of Western Australia as an oil producing State. For the producing company, *West Australian Petroleum Pty. Ltd.*, it was the culmination of 15 years of oil search. To the end of the year production was 4,646,938 barrels of crude oil valued at $14,853,605. The four companies participating in West Australian Petroleum Pty. Ltd. are as follows:—

- Ampol Exploration Ltd.—1/7 interest
- Shell Development (Aust.) Pty. Ltd.—2/7 interest
- Texaco Overseas Petroleum Company a wholly owned subsidiary of Texaco Inc.—2/7 interest
- California Asiatic Oil Company a wholly owned subsidiary of Standard Oil Company of California.—2/7 interest

The estimated recoverable oil by primary methods is 114 million barrels to be obtained from 240 wells drilled approximately 2,500 feet to the 44 feet pay zone in the Windalia sands. Two hundred wells have been completed allowing a production rate of 25,000 barrels per day. Some 25 to 30 injection and water source wells are to be drilled, to assist in maintaining production and increasing the overall output of the field by water flooding.

Major construction work completed at Barrow Island during the year included three 200,000 barrel capacity storage tanks, six miles of 20 inch diameter offshore pipeline, 2 x 14,000 barrels per hour pumping units, about 100 miles of onshore pipeline varying between 2 and 10 inches diameter, and 5 separator stations to gather and treat the oil for shipment. To provide additional storage, a fourth 200,000 barrel tank has been scheduled for construction during 1968.

PYRITE

Norseman Gold Mines N.L. railed to Perth 58,653 tons of pyritic concentrate containing 26,678 tons of sulphur valued at $875,665 f.o.r. Norseman. Superphosphate manufacturers in Western Australia have placed a final order with the company and it is expected that mining operations will cease in June, 1968.

Gold Mines of Kalgoorlie (Aust.) Ltd. forwarded to works at Fremantle 20,032 tons of auriferous pyritic concentrate containing 7,681 tons of sulphur valued at $192,021.

SEMI PRECIOUS STONES

Various rock collecting enthusiasts reported a total production of 28 tons of chalcedony, amethyst and chrysoprase valued at $8,024. The 10 tons of chrysoprase was obtained from Wingelinna in the Warburton Mining District.

SILVER

Silver as a by-product of gold and copper mining amounted to 309,476 fine ounces valued at $420,666.

TALC

Three Springs Talc Pty. Ltd. produced 7,901 tons from their open cut at Three Springs. Eight men are employed at the mine.

TANTALO-COLUMBITE

Twenty three tons of concentrate containing 1041.58 units of Ta205 valued at $131,680 were produced during 1967. The producing centres in the Pilbara were Moolyella and Wodgina with 50.45 units. At Greenbushes 991.13 units were obtained during tin mining operations.

TIN

Production for the year was 1,239 tons of concentrate containing 864.55 tons of the metal valued at $2,358,771. This output is double that for the previous year. Tin producers in the Pilbara were responsible for the production of 1,124 tons of concentrate. Greenbushes' production was 112 tons and Norseman 3 tons.

Pilbara Tin Pty. Ltd. employing 44 men at Moolyella was the State's leading tin producer with 428 tons of concentrate valued at $467,835.

Cooglegong Tin Pty. Ltd. with an average of 25 on the pay roll, reported the production of 314 tons of concentrate valued at $548,096. *J. A. Johnston & Sons Pty. Ltd.* employing 21 men reported the production of 261 tons of concentrate valued at $480,447 from deposits at Coondina and Eleys.

Other notable tin producers were the *Vultan Syndicate* at Greenbushes with 56 tons of concentrate, *Greenbushes Tin N.L.* with 54 tons, and *M.R. Edwards* at Moolyella with 43 tons.

TUNGSTEN ORE AND CONCENTRATE

Prospectors at Cookes Creek in the Pilbara and Poona in the Murchison obtained 1 ton of Wolfram containing 54.96 units of WO3 valued at $1,689. Eight tons of scheelite ore from Tindals near Coolgardie, yielded 1.30 tons of concentrate containing 89.31 units of WO3 valued at $2,858.

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

State Mining Engineer:

Hereunder I submit my report for the year ended 31st December, 1967, for the Inspection Section of your Branch.

ACCIDENTS

Fatal and serious mining accidents reported to the Department are shown below. The corresponding figures for 1966 are shown in brackets.

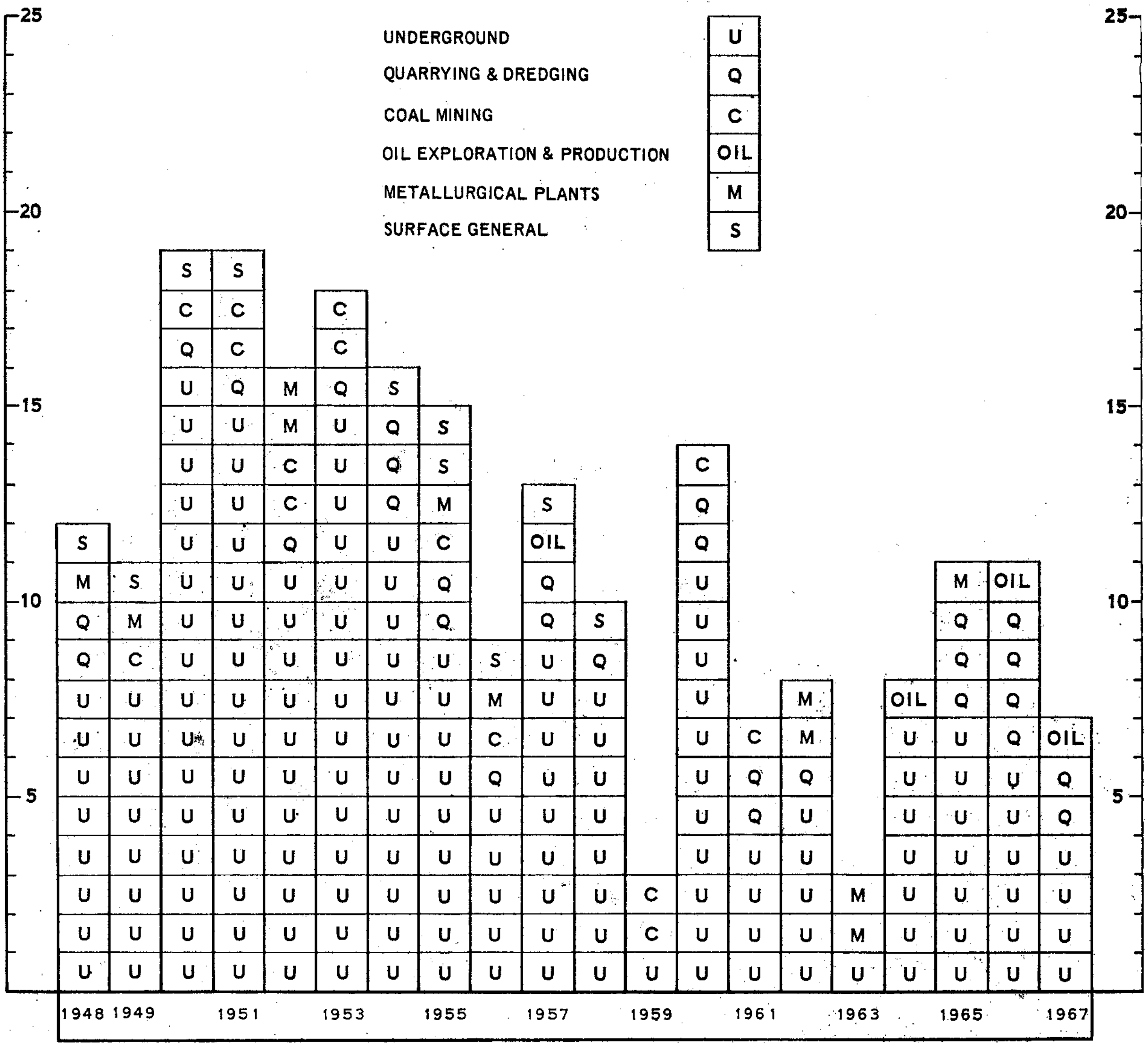
There were 7 (11) fatal and 373 (372) serious accidents.

In gold mines there were 4 (6) fatal and 217 (228) serious accidents. The number of men employed in such mines was 4,362 (4,411). The accident rate per 1,000 men was thus 0.917 (1.36) for fatal accidents and 49.74 (51.69) for serious accidents.

Other fatal accidents were rock quarries 1, iron ore 1, and oil exploration 1.

Below is a diagram showing fatal accidents segregated according to the class of mining work and extending over the past 20 years.

DIAGRAM OF FATAL ACCIDENTS
SEGREGATED ACCORDING TO CLASS OF MINING



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

TABLE A

Serious Accidents for 1967

Class of Accident	West Kimberley	Pilbara	West Pilbara	Ashburton	Peak Hill	Murchison	East Coolgardie	Coolgardie	Yilgarn	Dundas	Phillips River	Greenbushes	South West	Collie	Total
Major Injuries—Exclusive of Fatal—															
Fractures—															
Head	....	....	....	....	....	....	....	1	....	1	....	....	....	....	2
Shoulder	....	1	....	....	1	....	2	....	....	....	....	....	1	....	5
Arm	1	....	....	....	....	....	2	....	....	....	....	....	3	2	8
Hand	....	....	....	....	....	....	3	....	....	....	....	....	....	....	3
Spine	....	....	....	....	....	....	2	....	....	....	....	....	1	....	3
Rib	....	....	....	....	....	....	....	....	....	....	....	....	....	2	2
Pelvis	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Thigh	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Leg	....	....	....	1	....	....	1	....	....	1	1	....	....	....	4
Ankle	....	....	1	1	....	....	....	1	....	....	....	....	....	1	4
Foot	....	....	....	1	....	....	3	1	....	1	....	....	....	....	6
Amputations—															
Arm	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Hand	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Finger	....	....	....	1	....	....	3	....	....	....	....	....	....	2	6
Leg	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Foot	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Toe	....	....	....	....	....	....	....	....	....	....	....	....	1	....	1
Loss of Eye	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Serious Internal	....	....	....	....	....	....	2	....	....	....	....	....	....	....	2
Hernia	....	....	....	....	....	....	1	....	....	....	1	1	1	....	4
Dislocations	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Other Major	1	....	1	....	....	....	....	....	....	....	1	....	2	3	8
Total Major	2	1	2	4	1	....	19	3	....	3	3	1	9	10	58

TABLE A—continued

Serious Accidents for 1967—*continued*

Class of Accident	West Kimberley	Pilbara	West Pilbara	Ashburton	Peak Hill	Murchison	East Coolgardie	Coolgardie	Yilgarn	Dundas	Phillips River	Greenbushes	South West	Collie	Total
Minor Injuries—															
Fractures—															
Finger	1	....	....	....	....	....	9	....	1	1	....	....	....	....	12
Toe	....	....	....	1	....	....	3	....	....	....	1	....	1	....	6
Head	1	....	....	2	1	....	9	1	....	1	1	....	1	1	18
Eyes	....	....	....	2	....	1	10	....	....	2	....	....	2	1	18
Shoulder	....	....	....	1	....	....	3	....	....	....	....	....	....	3	7
Arm	....	....	....	....	....	....	6	1	....	1	....	....	2	1	11
Hand	....	....	....	5	....	1	33	....	....	3	2	1	5	8	58
Back	....	1	4	1	....	....	31	....	....	1	1	....	5	11	55
Rib	....	....	....	....	....	....	7	....	....	....	....	....	....	....	7
Leg	....	....	2	6	....	1	43	1	....	5	1	....	3	4	66
Foot	....	....	....	3	....	1	15	....	....	3	1	1	11	2	37
Other Minor	....	4	2	2	....	....	6	1	....	1	1	....	....	3	20
Total Minor	2	5	8	23	1	4	175	4	1	18	8	2	30	34	315
Grand Total	4	6	10	27	2	4	194	7	1	21	11	3	39	44	373

There were no serious accidents reported in the year under review in the following Goldfields :—

Kimberley, Gascoyne, East Murchison, Yalgoo, Northampton, Mount Margaret, North Coolgardie, Broad Arrow, North-East Coolgardie.

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

Mineral	Men Employed	Accidents		
		Fatal	Serious	Minor
Asbestos	2	....	....	....
Bauxite (Alumina)	526	....	15	35
Coal	694	....	44	231
Copper	97	....	12	47
Gold	4,362	4	217	977
Gypsum	17	....	....	....
Ilmenite	331	....	7	61
Iron Ore	1,185	1	27	196
Lead	20	....	....	....
Manganese	24	....	1	1
Nickel	189	....	5	30
Oil (Production and Exploration)	768	1	35	69
Pyrite	111	....	4	68
Tin	275	....	4	27
Other Minerals	97	....	....	....
Rock Quarries	255	1	2	....
Total	8,953	7	373	1,742

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	....	....	....	....	....	....	....	....	....	....	....	....	....	....
West Kimberley	....	....	....	....	....	....	....	....	....	....	1	4	1	4
Pilbara	....	....	....	....	....	....	....	....	....	....	1	6	1	6
West Pilbara	....	....	....	....	....	....	....	....	....	....	....	10	....	10
Ashburton	....	....	....	....	....	....	....	....	....	....	....	27	....	27
Peak Hill	....	....	....	....	....	....	....	....	....	....	....	2	....	2
Gascoyne	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Murchison	....	....	....	....	....	....	....	....	....	3	....	1	....	4
East Murchison....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Yalgoo	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Northampton	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Mount Margaret	....	....	....	....	....	....	....	....	....	....	....	....	....	....
North Coolgardie	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Broad Arrow	....	....	....	....	....	....	....	....	....	....	....	....	....	....
North-East Coolgardie....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
East Coolgardie	....	2	2	25	1	1	....	1	....	143	1	22	4	194
Coolgardie	....	....	....	2	....	1	....	....	....	1	....	3	....	7
Yilgarn	....	....	....	....	....	....	....	....	....	....	....	1	....	1
Dundas	....	....	....	....	....	2	....	....	....	10	....	9	....	21
Phillips River	....	....	....	2	....	2	....	....	....	1	....	6	....	11
Greenbushes	....	....	....	....	....	....	....	....	....	....	....	3	....	3
South-West	....	1	....	....	....	....	....	....	....	2	1	36	1	39
Collie	....	....	....	2	....	....	....	....	....	36	....	6	....	44
Total for 1967	....	3	2	31	1	6	....	1	....	196	4	136	7	373
Total for 1966	....	3	2	29	2	10	....	....	3	206	4	124	11	372

FATAL ACCIDENTS

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

Name and Occupation	Date	Mine	Details and Remarks
Reid, Edward McKenzie (Timberman)	17/3/67	Enterprise shaft of Gold Mines of Kalgoorlie (Aust.) Ltd.	With other men, Reid was descending in the cage which contained an air hose tailpiece. The tailpiece caught in the shaft timbers pulling Reid from the cage.
Fraser, Gerald (Truck-Driver)	28/4/67	Dampier Mining Co. Ltd. Koolan Island	Fraser was driving a haul-pak truck from the crusher stockpile to the Quarry when the truck was driven off the road and over the cliff face.
Forward, Harold Neil (Machine Miner)	20/10/67	Chaffers Shaft of Lake View and Star Ltd.	A seismic event in natural earth movement caused a collapse of ground in the stope and Forward was buried.
Berry, Stanley Onslow (Driller)	21/10/67	Oil Drill Site Location 5, Dongarra 8m.E.	Malfunction of "Pick-up Elevator" caused drill rod to fall and strike Berry on his head.
Smith, Ronald (Machine Miner)	2/11/67	Lake View Shaft of Lake View and Star Ltd.	Crushed by fall of rock from stope hanging wall.
Milososki, Najdenko (Labourer)	11/12/67	Mt. Newman Rail Project Port Hedland 40-mile Quarry	Deceased was holding a bar which was under tension. Apparently he lost his footing and was struck on his head by the bar when he lost his grip.
Gericevich, Ivan (Plant Operator)	25/12/67	Lake View and Star Ltd., Treatment plant	Gericevich entered a fine ore bin to rill down some fine ore. When he did make the ore rill, it buried him.

WINDING MACHINERY ACCIDENTS

Eleven accidents involving winding machinery were reported during the year.

Overwinds (3).—On the 26th January an overwind occurred at the Elverdton shaft of Ravensthorpe Copper Mines. Both the skipman and winder driver forgot that the skips were geared into No. 5 level ore pocket, and when the skipman signalled to No. 6 level and the winder driver attempted to lower his skip to that point an overwind occurred. The overwind prevention cut out switch failed. The detaching apparatus acted and the skip was suspended in the sky shaft.

On 27th June the driver had been hoisting ore from No. 11 bins at the Chaffers Shaft of Lake View and Star Ltd. He received the signal to gear into No. 25 level, and forgetting to gear out from his previous station attempted to lower a skip to No. 25 level and the opposite skip entered the sky shaft. The rope was detached and the skip suspended by the safety hook. Seventy five feet of rope was cut from the skip end.

When the driver was hoisting ore in the Oroya Shaft of Gold Mines of Kalgoorlie (Aust.) Ltd. on 20th November, he overshot the mark and the detaching hook entered the thimble and released the rope. The skip was suspended by the safety hook. The rope was cut and re-shod and repairs to the sky shaft skids were necessary.

Cage hang up—(3).—When the winder driver at Kalgurli Shaft of North Kalgurli (1912) Ltd. was giving the cage a test run through the shaft prior to lowering the 'shift' he noted an obstruction at No. 18 level and stopped the cage. Approximately 30 feet of rope was coiled on top of the cage. Investigation showed the cage was resting on a rail bearer which had been left by the previous shift after using it when removing heavy gear from the cage, 13/1/67.

On 6th February a cage 'hung up' in the South compartment of Horseshoe No. 2 shaft of Lake View and Star Ltd. when it sat on a shaft guard rail previously accidentally dropped down the shaft by the platman. The mishap resulted from the platman using the cages before making a correct shaft inspection.

An incorrectly fastened cage gate caused the cage to 'hang up' in the Croesus Shaft of North Kalgurli (1912) Ltd. on 17th February. The driver noted the unusual running and stopped the winder and no damage resulted from the mishap.

Derailment—(1).—A skip was derailed in the North Royal Shaft of Central Norseman Gold Corporation on 12th May. It was considered that spillage caused the mishap. There was no damage to the shaft or skip.

Miscellaneous—(4).—A gate broke from a cage in the Hainault Shaft of Gold Mines of Kalgoorlie (Aust.) Ltd. on 10th April. An unauthorised workman attempted to unload the cage at No. 6 level. He signalled the driver to raise the cage so that he could open he cage gate fully, but in doing so he slipped and fell, and therefore could not stop the driver from taking the cage up the shaft. The driver felt the rope vibrating and stopped his engine. The cage was found jammed in the shaft at No. 4 level. Damage to the shaft took one shift to repair.

The driver at the Oroya Shaft of Gold Mines of Kalgoorlie (Aust.) Ltd. 'geared in' too long at the end of the shift on 23rd October. As a result one skip was lowered onto the door of the spillage bin at No. 15 level and some rope was played out and kinked. The rope was cut and re-shod.

On 9th December a skip was lowered on to a temporary pentice at the 2,950 feet level of Edwards Shaft, Great Boulder Gold Mines. The pentice had been constructed for shaft repair operations and the driver had been instructed not to lower skips below 2,500 ore bin horizon. The driver however, did lower a skip slowly in single gear preparatory to 'gearing in' and forgetting the pentice he lowered the skip on to it. No damage was done.

An underground ore truck was being lowered in the Main Shaft of Great Boulder Gold Mines on 20th December when it fouled the shaft timbers. The truck was "slung" under the cage. It was necessary to cut shaft timbers to inspect and free the truck.

PROSECUTIONS

It was found necessary to prosecute one miner for firing outside the prescribed times for blasting. The prosecution was successful.

SUNDAY LABOUR PERMITS

Twenty four permits to employ labour on Sundays were issued.

Thirteen permits were issued to Gold Mines of Kalgoorlie (Aust.) Ltd. One permit, involving one Sunday was to allow specialised work in preparing a drill chamber on No. 28 level Enterprise Shaft from which to drill the "Western Deeps".

Eleven permits allowed work in the Mount Charlotte Mine on eleven Sundays for the purposes of:—Consolidating the ore passes in the main stope; rock bolting in the stope for purposes of safety; pouring concrete foundations; to commence crosscuts off the main haulage way; lowering and erecting underground crushers.

One permit provided for labour to be employed on one Sunday to allow repairs in both the K.O.T. and Oroya treatment plants.

Lake View and Star Ltd. were permitted to work one Sunday, to lower timber down the Lake View Shaft.

Three permits were issued to Central Norseman Gold Corporation N.L. to work on three different Sundays. Work allowed was:—cutting a transformer station on Regent Shaft No. 25 level, rise off Regent shaft No. 19 level main haulage way, and commence a crosscut of Regent shaft No. 22 level main haulage way.

Western Mining Corporation, Kambalda Nickel operations were granted two permits allowing the construction of a shaft pentice on one Sunday, and the removal of another shaft pentice on another Sunday.

Five permits were issued to Western Titanium N.L. allowing them to work on all Sundays during the year so that the company could increase output during a period of increased sales of ilmenite and while equipment was being installed.

AUTHORISED MINE SURVEYORS

The Survey Board issued four certificates during the year.

CERTIFICATES OF EXEMPTION (SECTION 46)

No certificates were issued during 1967.

PERMITS TO FIRE OUTSIDE PRESCRIBED TIMES (REGULATION 51)

Three permits were issued.

PERMITS TO RISE (REGULATION 64)

Forty two permits were issued for the construction of 58 rises totalling 8,331 feet. Thirty-two of the rises were made using the rising stage method.

VENTILATION

Inspections of the underground workings of all metalliferous mines throughout the State were made during the year. Dust counts and temperatures were recorded at all working places and the primary and secondary airflows received constant attention. Inspections were also made of all crushing and screening installations including metalliferous treatment plants, rock quarries, iron ore quarries, and dry treatment plants associated with the heavy mineral sands industry.

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

Throughout the year, the exhaust gases from diesel powered equipment in use underground in the Mt. Charlotte Mine, were sampled and gas concentrations determined regularly. All concentrates of the various gases recorded in both undiluted exhaust gases and diluted mine air have been well below the maximum allowable concentrations.

Eleven reports on the presence of Methane in metalliferous mines were received during the year. North Kalgurli (1912) Ltd. reported nine occurrences and Gold Mines of Kalgoorlie (Aust.) Ltd. two occurrences. All occurrences of gas encountered in the North Kalgurli Mine were of a minor nature, six being found in diamond drill holes easterly off Main Shaft between the 18 and 20 levels, and three occurrences were encountered in normal "face" work. The two reports from Gold Mines of Kalgoorlie (Aust.) Ltd. related to methane encountered, in holes being drilled for the "Western Deeps" of the Golden Mile. Several pockets were encountered, and though each was not of great volume the intersections were persistent. No methane was detected in the underground workings of the Collie Coal mines.

During the year the total number of dust samples recorded both surface and underground was 1312 at an average of 268 p.p.c.c. per sample. This shows a marked improvement over the past four years but it is felt that some of the apparent improvement is due to the fact that staff shortage prevented more testing of crushing plants.

Results of dust counts taken during the year are tabulated hereafter. Corresponding figues for 1966 are shown in brackets.

Dust Samples from	Samples Giving Over 1,000 p.p.c.c.	Total Number of Samples	Average Count
Development	3 (2)	238 (213)	219 (235)
Stoping	15 (26)	669 (647)	213 (309)
Levels	27 (25)	272 (293)	294 (342)
Surface	27 (76)	119 (341)	522 (560)
Assay Laboratories	2	14	494
Totals	74 (129)	1,312 (1,494)	268 (362)

It is pleasing to note that for the eleventh year in succession there has not been a fatal accident due to fumes or explosives. Eight alleged fuming accidents were reported and investigated. Three occurrences involved loss of time to the workman involved and resulted from each man returning to his working place too soon after firing.

In conjunction with the Department of Public Health urine samples were obtained from men employed in the lead mining industry and in gold assay laboratories.

Aluminium Therapy—Provision for the prophylactic treatment with aluminium powder was available at all gold mines, but neither management nor the work-force show much interest in this treatment for the prevention of silicosis.

GROUND VIBRATION

The Departments' sprengnether seismograph was used to check ground vibration caused by the use of explosives and by rail transport.

Seismograms were obtained from underwater blasting in the Geraldton harbour as well as from quarrying and open cast mining. Vibrations from diesel equipment used on railways were measured at Geraldton, Herne Hill, West Midland, and Spearwood.

ADMINISTRATIVE

Mines Regulation Act—Regulation 14 was amended (Government Gazette No. 5 of 18th January, 1967) following a review of wages payable to Workmen's Inspectors of Mines.

Three new mining districts—Nabberu Mining District, Warburton Mining District, and Eucla Mining District, were proclaimed mining districts. This proclamation appeared in the Government Gazette No. 84 of 6th October, 1967.

The Government Gazette No. 91 of 27th October, 1967 contained a notice altering the Districts assigned to the various Workmen's Inspectors of Mines.

Mining Act—Regulation 54 relative to the amalgamation of Dredging claims and the labour conditions applicable to such claims was amended (Government Gazette No. 22 of 3rd March, 1967). This gazette also included an amendment to regulation 55 relative to the amalgamation of Mineral Claims and the labour conditions governing such claims. The Schedule to the principal regulation was also amended by providing new Forms No. 13 and No. 14.

Regulation 98 (Government Gazette No. 74 of 6th September 1967) was amended to increase the allowable acreage for some mineral leases to 300 acres.

No amendments were made to the Coal Mines Regulation Act or the Mine Workers' Relief Act during the year under review.

J. BOYLAND,
Senior Inspector of Mines.

State Mining Engineer, Perth:

REPORT ON DRILLING ACTIVITIES FOR YEAR ENDED 31ST DECEMBER, 1967.

This year the footage completed by the Drilling Section is the highest on record. In 1959 a footage of 25,813 was done, but this year 28,604 feet were drilled being an increase of 8,755 on the total reported for 1966. This large increase is accounted for by the operations of the Mayhew 2000 rig which came into service for half the year only.

Considerable difficulty has been caused in the work by the lack of experienced and suitable labour. A large turnover of personnel has been a feature during the period and no solution to this problem is yet available. One of the difficulties appears to be the isolated localities in which our work occurs and the rough and somewhat primitive conditions under which the men live, in comparison with the mess and air-conditioned living quarters now provided by the big oil companies and iron ore developers.

New plant which came into service during the period under review was:—

(a) Mercedes-Benz diesel truck WAG 5680 fitted with an all aluminium tray body for servicing the percussion rigs.

(b) New Land Rover WAG 5022.

(c) Two new 2 berth caravans.

Our operations again were widespread ranging from Esperance to Wyndham.

No. 2 Rig (Failing M1) drilled 4,709 ft. in three holes at Watheroo for water supply investigations.

No. 3 Rig (A3000) was not used for the year and a nil footage is returned from this machine.

No. 4 Rig (A2000) was hired to Associated Diamond Drillers Ltd. for part of the year, but a nil footage is returned as it was not occupied on Departmental work.

No. 5 Rig (A2000) drilled 287 feet in four holes for the Fremantle Port Authority investigating harbour and wharf extensions.

No. 6 Rig (A2000) was hired to Pickands Mather during the year and a nil footage is returned.

No. 7 Rig (F20) was taken to Wyndham late in the year and 10 feet were drilled on spillway investigations at the Ord River Damsite for the period.

No. 8 Rig (E.500) was on hire to prospectors during the period. Administration was based at Kalgoorlie under the Senior Inspector of Mines and a nil footage is returned.

No. 9 Rig (Gemco Auger) completed 174 feet at Gnangara drilling observation holes close to water supply production bores for the P.W.D.

No. 10 Rig (Failing 750) drilled 1,374 feet in 16 holes at the Narrows bridge interchange section investigating foundation conditions for the Main Roads Department.

At Waroona 3,183 feet were drilled in 73 holes investigating dam site conditions for the P.W.D. This makes a total of 4,557 ft. completed by this plant for the year.

No. 11 Rig (Mayhew 2000) drilled 12,280 feet for the year in 10 holes. Four were sited in the Busselton area for water supply purposes.

Three holes were drilled at Capel for Western Titanium Ltd. investigating a reported occurrence of coal and 1,390 feet were completed.

At Agaton fifteen miles west of Watheroo three holes totalling 3,668 feet were drilled for water supply.

CABLE TOOL RIGS

Rig No. 1 (Ruston Bucyrus) 22 R.W. drilled 1,321 ft. in 3 holes. Hole No. 14 at Pinjarra was deepened from 190 to 677 ft. at which depth the tools were lost and after fishing operations failed the hole was abandoned. 242 feet were completed in 1 hole at Gnangara for water. At Watheroo 592 feet were drilled in Hole A6.

Rig No. 2 (R.B. 22 R.W.) completed 2,628 feet for the year. At the Narrows 1,117 ft. were done for the Main Roads Dept. Work was then transferred to Gnangara where 1,511 ft. were done on Water Supply investigation for the P.W.D.

Rig No. 3 (R.B. 22 R.W.) completed 874 feet. At Gnangara 317 feet and at Agaton 557 feet.

Rig No. 4 (R.B. 22 R.W.) drilled 1,764 feet for the year. At Gnangara 452 feet, near Esperance 779 feet, and at Cue 533 feet were drilled, all for water supply purposes.

GENERAL

As reported yearly many firms and individuals have been assisted during the period under review by the loan or hire of drilling equipment. Enquiries as to methods procedures and equipment used in the drilling industry are being received daily and advice given.

Tabulated below are details of the drilling completed for the year.

J. HADDOW,
Inspector of Mines (Drilling).

16/5/68.

TABLE SHOWING FOOTAGE DRILLED FOR YEAR ENDED 31/12/67

Rig No.	Machine	Place	Purpose	Footage	Total	Basis	Remarks
2	Failing M1	Watheroo	Water Supply	4,709	4,709	Wages	3 holes.
3	A. 3000	....	....	Nil	Nil	....	
4	A. 2000	....	....	....	....	....	Hired to Ass. D. Drillers.
5	A. 2000	Fremantle	Harbour Work	287	287	Wages	
6	A. 2000	....	....	....	....	....	Hired to Picklands-Mather.
7	F. 20	Wyndham	Dam Foundation	10	10	Wages	
8	E. 500	Kalgoorlie	....	Nil	....	....	Hired.
9	Gemco	Gnangara	Water Supply	174	174	....	Hired to P.W.D.
10	Failing 750	Narrows	Road Work	1,374	....	....	16 holes.
		Waroona	Dam Foundation	3,183	4,557	....	73 holes.
11	Mayhew 2000	Busselton	Water Supply	7,222	....	Wages	4 holes.
		Capel	....	1,390	....	....	Recoup by Western. Titanium 3 holes
		Agaton	Water Supply	3,668	12,280	....	3 holes.
			CABLE TOOL RIGS				
1	R.B.22R.W.	Watheroo	Water Supply	592	....	Wages	
		Pinjarra	Water Supply	487	....	....	
		Gnangarra	Water Supply	242	1,321	Wages	
2	R.B.22R.W.	Narrows	Road Work	1,117	....	....	
		Gnangarra	Water Supply	1,511	2,628	Wages	11 holes.
3	R.B.22R.W.	Gnangarra	Water Supply	317	....	....	2 holes.
		Agaton	Water Supply	557	874	Wages	
4	R.B.22R.W.	Gnangarra	Water Supply	452	....	....	3 holes.
		Esperance	Water Supply	779	....	....	7 holes.
		Cue	Water Supply	533	1,764	....	11 holes.
			Grand Total....		28,604		

8th February, 1968.

The Chairman,
Board of Examiners for Mine Managers' and Underground Supervisors' Certificates,
Mines Department.
Perth, W.A.

ANNUAL REPORT

Herewith I submit the Annual Report on the activities of the Board of Examiners for the year 1967.

Mining Law Examination

An examination in Mining Law for the Mine Managers' Certificate of Competency was held on April 17, 1967.

Details were as follows:—

Entries	2
Admitted	2
Pass	2

The names of the successful candidates were:—

First Class

J. W. Duggan.

K. Folwell.

Six (6) copies of the examination paper are attached. There were no entries for the Second Class examination.

Underground Supervisors Examination

The written examination was held on September 5, 1967 and applications were received from the following Centres:—

Kalgoorlie	9
Mount Magnet	4
	13

Of the thirteen (13) applications, eleven (11) were accepted and the remaining two were rejected on the grounds of not having supplied the necessary confirmation of practical experience. A further check by the Secretary revealed that in the case of Aitken (Kalgoorlie) the Secretary had been at fault in misreading the application, which in fact had supplied confirmation of experience. In the second case of Pomi (Kalgoorlie) it was found that his employers, Western Mining Corporation had been at fault in not supplying the evidence when requested by Pomi. A subsequent ruling of the Board Members admitted both of the rejected applications.

None of the applicants from Mt. Magnet possessed a First Aid Certificate, but produced a signed statement from Dr. Fitzgerald that they all possessed "sufficient knowledge of First Aid for the Underground Supervisors Certificate". The applications were accepted in view of this, but the Board felt that the proper Certificate was the desired qualification. It was resolved that the Chairman write to the Manager, Hill 50 G.M. advising him of this fact in regard to any future applications of a similar nature. All of the thirteen (13) approved applicants sat for the examination.

The results were as follows:—

Examined	13
Passed	8
Failed	4
Deferred (To sit for Mining Law only in 1968)	1

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

Boschis, A.—Kalgoorlie.
Clark, A. G.—Kalgoorlie.
Kitenbergs, J. A.—Kalgoorlie.
McKean, R. F.—Kalgoorlie.
Pomi, G.—Kalgoorlie.
Ritchie, W.—Kalgoorlie.
Gersdorf, E. H. D.—Mt. Magnet.
Williams, J. K.—Mt. Magnet.

Mine Managers' Certificates

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

First Class

R. J. George-Kennedy.
B. J. Hurley.
J. W. Duggan.
G. J. Dodge.

GENERAL

Four meetings of the Board were held during the year. At the last meeting held on September 19, 1967, Mr. Boyland moved a vote of thanks and appreciation to Mr. R. A. Hobson, Director of the School of Mines, who was retiring on December 29, 1967, after a period of twenty years in that position and many years on the Board of Examiners. Mr. Boyland's remarks were warmly seconded by the Chairman and Mr. Newman.

The Board visited the following centres during the year and examined candidates orally for the Underground Supervisors' Certificate of Competency:—

Kalgoorlie.
Mt. Magnet.

W. J. CAHILL,
Secretary, Board of Examiners.

Mines Regulation Act, 1946-61

Examination for Mine Manager's Certificate of Competency

1st Class

MINING LAW

April, 1967

Time Allowed—Three (3) Hours
Attempt Seven (7) questions from Section A
Attempt Three (3) questions from Section B

Candidates should note:—

(a) The Mining Act and Regulations may be used at the examination but NOT the Mines Regulation Act.

(b) In answering questions in Section B, reference to the appropriate Sections of the Act or to the Regulations alone will not be sufficient. Candidates must summarise the requirements of the Act and/or Regulations and must also make reference to the relevant section(s) or regulation(s).

(c) Candidates are required to pass in both sections of the paper.

SECTION A

(Mines Regulation Act and Regulations)

Attempt Seven (7) questions from this section.

Do NOT attempt more than Seven (7) questions from this section.

Marks allowed are Ten (10) per question.

What is required by the Mines Regulation Act and/or Regulations regarding the following:—

1. (a) Ladders in shafts.
   (b) Signalling in Winzes.
2. (a) Gates to Cages.
   (b) Number of men permitted to travel in a cage or skip.
   (c) Action required when a cage has been idle overnight.
3. (a) Obtaining a locomotive driver's certificate.
   (b) Riding on locomotives.
   (c) Obtaining a Hoist Driver's Certificate.
4. Misfires.

5. (a) Firing in Winzes.
   (b) Boring in Butts.

6. Safety Belts.

7. (a) Men working alone.
   (b) Drawing Ore from Shrink Stopes.

8. (a) Return Airways.
   (b) Stoppings and doors.
   (c) Ventilation of Development Ends.

9. (a) Employment of an Underground Manager.
   (b) Inspection of Mine by Manager.

10. (a) What is a Serious Accident?
    (b) What are the requirements following an accident resulting in serious injuries or apparent serious injuries?

SECTION B

(Mining Act and Regulations)

Attempt Three (3) questions from this section.

Do NOT attempt more than Three (3) questions from this section.

Marks allowed are Ten (10) per question.

11. Describe briefly the procedure necessary and the circumstances under which applications for:
    (a) Amalgamation of Leases.
    (b) Concentration of labour on Gold Mining Leases,

    can be applied for. State the number of men it is necessary to employ in each case to comply with labour conditions.

12. What action should be taken by the holder of a Mineral Lease if:
    (a) he finds gold on the lease and wishes to recover the gold.
    (b) he desires to mine some mineral other than that specified in the lease.

13. (a) A Gold Mining Lease is to be surrendered. What must the lessee do to protect his interest in the tailings on the lease?
    (b) A holder of a pastoral lease builds a dam on his property. How is he protected from miners?

14. (a) An application for a lease has been submitted in accordance with the requirements of the Mining Act. What rights does this immediately confer upon the applicant?
    (b) What are the obligations of the holder of a mining tenement regarding exploratory bore holes drilled on his property?

15. (a) What is a Mine?
    (b) Assuming the rent (if any) is paid regularly and that the required labour conditons are observed, how long can the following be held:

    Prospecting Area.

    Gold Mining Lease.

    Mineral Claim.

    Mineral Lease.

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DIVISION III

Report of the Superintendent of State Batteries—1967

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, 1967.

Crushing Gold Ores

One 20 head, five 10 head, and nine 5 head mills crushed 25,137¼ tons of ore made up of 337 separate parcels, an average of 74.59 tons per parcel. The bullion produced amounted to 9,880 ozs. which is estimated to contain 8,373 ozs. of fine gold, equal to 6 dwts. 16 grs. of gold per ton of ore.

The average value of the ore after amalgamation, but before cyanidation was 2 dwts. 17 grs. Thus the average head value of the ore was 9 dwts. 9 grs. which is 2 dwts. 16 grs. less than the previous year's average.

A total of 509 tons of tin, tungsten, and tantalite-columbite ore was also crushed at the plants that usually crush mainly gold ores. The average cost for crushing the 25,646¼ tons was $12.27 per ton, compared with 1966 when 30,455¾ tons were crushed at a cost of $10.11 per ton.

Cyaniding

Nine plants treated 19,851 tons of tailings from amalgamation for a production of 3,624 fine ozs. of gold worth $113,515. The average content was 4 dwts. 23 grs. before cyanidation, while the residue after treatment averaged 1 dwt. 7 grs. The theoretical extraction was, therefore, 74.00%. The actual extraction was 73.90%.

The tailings treated at Leonora were from clean up material from the Sons of Gwalia treatment plant. They contained charcoal and other rubbish causing low recovery.

The cost of cyaniding was $6.27 per ton, a little higher than the previous year, when 16,642 tons were treated at a cost of $5.92 per ton.

TREATMENT OF ORES OTHER THAN GOLD

Lead Ores.—During the year the Northampton State Battery crushed 3,273¾ tons of lead ore with an estimated average content of 18.23% lead. There were 17 separate parcels, giving an average of 192.57 tons of ore per parcel.

A total of 717.25 tons of concentrates was produced. The concentrates averaged 75.94% lead giving an estimated content of 544.69 tons of lead in concentrates.

2,556.5 tons of tailings were discarded. These had an average content of 2.03% lead, giving a total of 51.99 tons of lead discarded in tailings.

The recovery of lead in the concentrates was 91.28% of the lead in the ore delivered to the plant.

The cost of operating the Northampton State Battery, including administration, was $30,737.39 being $9.39 per ton of ore crushed. Revenue received was $6,547.75 being $2.00 per ton. The corresponding figures for 1966 when 5,399¾ tons of ore were crushed, were operating cost $33,518.97, $6.21 per ton, and revenue $10,803.05, $2.00 per ton.

Tin Ore.—The Marble Bar Battery crushed 3 tons of ore for 1900 lbs. of concentrates and the Norseman Battery 474 tons of ore for 2 tons 7¼ cwt. of concentrates. The total value of these concentrates was $5,984.00.

Tungsten Ore.—The Marble Bar Battery crushed 4 tons of ore for 525 lbs. of concentrates valued at $425.00.

Columbite Ore.—The Marble Bar Battery crushed 28 tons of ore for 1100 lbs. of concentrates valued at $2,819.00.

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

	1967	Grand Total
	$	$
Par Production—		
Crushing	71,134	18,019,025
Cyanidation	31,044	4,439,653
Gold Premium—		
Crushing	190,528	12,067,855
Cyanidation	82,471	3,338,187
Open Market Premium—		
Crushing	1,459	70,892
Cyanidation	631	22,895
Total Gold Production	$377,267	$37,958,507

OTHER ORES REALISED

Tin—	$	$
Ores	5,984	218,887
Residues	*Nil*	1,144
Tungsten Concentrates	425	38,896
Agricultural Copper Ore	*Nil*	11,932
Lead Concentrates	76,387	1,129,684
Tantalite-Columbite Concentrates	2,819	29,324
Total Other Ores	$85,615	$1,429,867
Grand Total	$462,882	$39,388,374

FINANCIAL

	Tons	Expenditure	Receipts	Loss
		$	$	$
Crushing (Gold Mills)	25,646¼	314,709	27,238	287,471
Crushing (Northampton)	3,273¾	30,737	6,548	24,189
Cyaniding	19,851	124,483	43,125	81,358
	....	$469,929	$76,911	$393,018

The loss of $393,018 is an increase of $25,630 on the previous year. It does not include depreciation and interest on capital.

Capital Expenditure, all from General Loan Fund, was incurred as below:—

		$	$
Cue	.... Cyanide Plant	....	1,574.35
Marble Bar	Crude Ore Bins	2,658.44	
	Plant to treat Low Grade Alluvial Tin Concentrate	7,754.28	
			10,412.82
Norseman	Jig for Tin Ore		855.30
Paynes Find	Battery Reconstruction		11,172.47
			$24,014.94

Cartage Subsidies.

	Tons	Cost
Ore carted to State Plants	12,516	$16,795

Comparative Figures for the last three years are:—

Year	State Plants				Private Plants		
	Tons Crushed	Tons Sub-sidised	Per cent. Sub-sidised	Cost	Tons Sub-sidised	Cost	Total Cost
				$			$
1965....	49,159¾	10,134	20.6	11,788	*Nil*	*Nil*	11,788
1966....	35,855½	10,442¼	29.12	14,202	*Nil*	*Nil*	14,202
1967....	28,920	12,516	43.21	16,795	*Nil*	*Nil*	16,795

Administrative

Expenditure amounted to $66,247.17 equivalent to $1.29 per ton of ore crushed and cyanided, compared with an expenditure of $57,929.54, $1.10 per ton, for 1966.

	1966	1967
	$	$
Salaries	35,058.87	42,298.74
Pay Roll Tax	7,472.19	7,458.98
Workers' Compensation	7,538.69	7,873.31
Travelling and Inspection	5,697.63	6,622.27
Sundries	2,162.16	1,993.87
	$57,929.54	$66,247.17

Staff

Engineer R. J. Sinclair retired in January after over 30 years service. For most of that time Mr. Sinclair was responsible for the designing and purchase of equipment for new installations and major alterations. His ability and thorough knowledge of all State Battery operations made him a most valued officer, and his uncomplaining efficiency under severe physical disabilities has been an example to all who knew him.

General

There was a further decrease in the amount of gold ore crushed, from 29,422 tons in 1966 to 25,137 tons in 1967. Fifteen crushing plants operated, compared to fourteen in the previous year, contributing to the considerably higher cost per ton crushed. The possibility of an early increase in the price of gold has caused a revival of interest in gold mining, and it is likely that there will be an increase in the amount of gold ore crushed in 1968.

Cyanide treatment plants operated satisfactorily. There was an increase of 3,209 tons treated, and treatment costs per ton showed a moderate increase. With a reduced amount of tailings purchased, stocks of untreated tailings were substantially reduced.

There was a further decrease in lead ore crushed at the Northampton plant, but prospects for 1968 are good. Development work is being done at the Mary Springs Mine, and big tonnages are expected in late 1968.

The amounts of tin, tungsten and tantalite ores treated were also low. With the magnetic separator plant due to start operating at Marble Bar in early 1968, the value of tin and tantalite concentrates handled should increase.

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, 1967

Number of Parcels Treated	Battery	Tons Crushed	Yield by Amalgamation: Bullion		Yield by Amalgamation: Fine Gold		Amalgamation Tailings Content		Contents of Ore-Fine Gold: Total		Contents of Ore-Fine Gold: Per Ton	
			oz.	dwts.	oz.	dwts.	oz.	dwts.	oz.	dwts.	dwts	grs.
6	Boogardie	84.00	21	18	18	11	11	20	30	11	7	7
54	Coolgardie	3,567.25	1,004	7	851	4	371	6	1,222	10	6	20
4	Cue	300.00	85	17	72	15	54	18	127	13	8	12
70	Kalgoorlie	6,303.50	2,708	16	2,295	14	681	8	2,977	2	9	11
25	Lake Darlot	2,309.00	1,257	9	1,065	14	273	15	1,339	9	11	14
13	Leonora	1,761.00	567	4	480	14	375	3	855	17	9	17
19	Marble Bar	1,537.00	1,138	10	964	18	548	0	1,512	18	19	16
41	Marvel Loch	1,711.00	1,461	16	1,238	18	262	14	1,501	12	17	13
14	Meekatharra	2,507.00	407	15	345	11	182	4	527	15	4	15
28	Menzies	1,740.00	351	13	298	0	179	17	477	17	5	12
8	Norseman	825.00	264	18	224	10	330	2	554	12	13	8
3	Nullagine	40.25	19	19	16	18	10	3	27	1	13	11
31	Ora Banda	1,157.50	314	8	266	9	80	18	347	7	6	0
14	Paynes Find	884.00	232	8	196	19	45	18	242	17	5	12
7	Sandstone	410.75	42	18	36	7	22	7	58	14	2	21
337		25,137.25	9,879	16	8,373	2	3,430	13	11,803	15	9	9

Average Tons per Parcel .... 74·59
Average Yield by Amalgamation per ton (Fine Gold) .... 6 dwts. 16 grs.
Average Head Value of Tailings per ton (Fine Gold) .... 2 dwts. 17 grs.

Schedule No. 2

DETAILS OF EXTRACTION TAILINGS TREATMENT 1967

Battery	Tons Treated	Head Value: Per Ton		Head Value: Total content	Tail Value: Per Ton		Tail Value: Total content	Calculated Recovery		Actual Recovery	
		dwts.	grs.	oz.	dwts.	grs.	oz.	oz.	%	oz.	%
Coolgardie	3,600	4	8	783.55	1	2	195.50	588.05	75.05	610.29	77.89
Cue	3,260	5	1	823.55	1	2	173.75	649.80	78.90	627.50	76.19
Kalgoorlie	4,500	2	21	643.30	0	17	157.60	485.70	75.50	483.17	75.11
Lake Darlot	4,050	4	6	848.95	0	19	159.55	689.40	81.20	686.93	80.92
Leonora	585	14	20	433.85	10	16	312.00	121.85	28.09	121.09	27.91
Marble Bar	1,254	9	6	584.65	2	9	145.85	438.80	75.05	437.83	74.89
Marvel Loch	412	5	23	123.10	1	6	26.10	97.00	78.80	102.02	82.88
Norseman	360	3	10	61.50	0	20	15.00	46.50	75.61	37.24	60.55
Ora Banda	1,830	6	14	601.30	0	23	89.55	511.75	85.11	517.82	86.12
	19,851	4	23	4,903.75	1	7	1,274.90	3,628.85	74.00	3,623.89	73.90

Schedule No. 3

DIRECT PURCHASE OF TAILINGS FOR THE YEAR ENDED 31st DECEMBER, 1967

Battery	Tons of Tailings Purchased	Initial Payment to $28 per Fine oz.
		$
Coolgardie	713.25	2,575.68
Cue	181.00	67.30
Kalgoorlie	1,727.25	2,616.69
Lake Darlot	716.25	1,316.78
Leonora	148.75	107.87
Marble Bar	1,199.75	7,517.53
Marvel Loch	398.00	2,317.69
Meekatharra	411.25	629.50
Menzies	306.00	287.90
Norseman	439.00	3,461.69
Nullagine	36.25	102.47
Ora Banda	121.00	714.15
	6,397.75	21,715.25

Schedule No. 4

STATEMENT OF RECEIPTS AND EXPENDITURE FOR THE YEAR ENDED 31st DECEMBER, 1967

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	84	658.17	582.74	502.47	1,743.38	20.75	3,145.93	648.52	5,537.83	65.93	87.25	1.04	....	5,450.58
Coolgardie	3,567¼	4,027.52	8,924.51	4,841.43	17,793.46	4.99	4,828.32	5,916.16	28,537.94	8.00	3,411.89	0.96	....	25,126.05
Cue	300	3,061.31	1,255.79	770.92	5,088.02	16.96	1,020.54	1,640.75	7,749.31	25.83	515.08	1.72	....	7,234.23
Kalgoorlie	6,303½	9,800.28	14,259.66	11,462.32	35,522.26	5.64	7,474.44	10,309.51	53,306.21	8.46	6,136.61	0.97	....	47,169.60
Lake Darlot....	2,309	3,941.25	6,939.45	2,373.15	13,253.85	5.74	2,358.21	4,224.03	19,836.09	8.59	2,635.97	1.14	....	17,200.12
Laverton	....	....	300.00	50.78	350.78	....	15.32	79.16	445.26	....	184.18	....	....	261.08
Leonora	1,761	5,358.23	8,461.59	4,534.33	18,354.15	10.42	6,016.28	4,219.51	28,589.94	16.24	2,199.84	1.25	....	26,390.10
Marble Bar	1,572	8,943.14	11,072.12	4,245.24	24,260.50	15.43	7,792.48	5,328.20	37,381.18	23.78	2,123.83	1.58	....	35,252.35
Marvel Loch	1,711	4,255.01	7,994.99	2,278.55	14,528.55	8.49	999.80	2,664.99	18,193.34	10.63	1,916.56	1.12	....	16,276.78
Meekatharra....	2,507	5,232.98	6,651.77	2,884.01	14,768.76	5.89	6,611.01	5,620.50	27,000.27	10.77	1,649.92	0.66	....	25,350.35
Menzies	1,740	4,466.01	5,887.41	2,538.12	12,891.54	7.41	2,918.86	3,586.26	19,396.66	11.15	1,804.35	1.04	....	17,592.31
Norseman	1,299	4,872.55	7,772.67	2,799.67	15,444.89	11.89	2,896.17	2,393·64	20,734.70	15.97	1,817.84	1.40	....	18,916.86
Nullagine	40¼	309.52	964.17	122.66	1,396.35	34.69	252.45	394.44	2,043.24	50.76	55.28	1.37	....	1,987.96
Ora Banda	1,157½	5,519.12	5,644.29	2,570.41	13,733.82	11.87	4,053.19	2,006.81	19,793.82	17.10	1,111.23	0.96	....	18,682.59
Paynes Find....	884	2,056.20	6,114.72	2,323.44	10,494.36	11.87	4,328.47	3,379.11	18,201.94	20.59	1,009.93	1.14	....	17,192.01
Peak Hill	....	....	....	....	....	....	....	27.44	27.44	....	....	....	....	27.44
Sandstone	410¾	1,331.90	1,186.97	383.18	2,902.05	7.07	277.47	1,007.27	4,186.79	10.19	401.87	0.98	....	3,784.92
Yarri	....	1,101.31	741.88	360.36	2,203.55	....	792.04	704.72	3,700.31	....	48.00	....	....	3,652.31
Head Office	....	....	....	....	....	....	....	....	....	....	123.50	....	123.50	....
Bambco Creek	....	....	....	....	....	....	....	46.32	46.32	....	....	....	....	46.32
Sub-Total	25,646¼	64,934.50	94,754.73	45,041.04	207,730.27	8.10	55,780.98	54,197.34	314,708.59	12.27	27,238.13	1.08	123.50	287,593.96
Northampton	3,273¾	8,492.18	5,719.52	4,536.27	18,747.97	5.73	6,202.09	5,787.33	30,737.39	9.39	6,547.75	2.00	....	24,189.64
Total	28,920	73,426.68	100,474.25	49,577.31	223,478.24	7.73	61,983.07	59,984.67	345,445.98	11.94	33,785.88	1.18	123.50	311,783.60

OPERATING LOSS : $311,660.10

Schedule No. 5

RECEIPTS AND EXPENDITURE, 1967

Cyaniding

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
		$	$	$	$	$	$	$	$	$	$	$	$	$
Coolgardie	3,600	4,009.47	8,079.62	5,101.48	17,190.57	4.77	1,195.10	4,247.34	22,633.01	6.29	7,005.02	1.95	....	15,627.99
Cue	3,260	2,192.70	9,896.89	6,347.91	18,437.50	5.66	2,893.20	4,525.73	25,856.43	7.93	7,255.11	2.23	....	18,601.32
Kalgoorlie	4,500	2,939.69	11,112.86	7,347.58	21,400.13	4.76	857.22	7,640.71	29.898.06	6.64	8,647.68	1.48	....	21,250.38
Lake Darlot	4,050	627.41	5,855.34	3,865.69	10,348.44	2.56	334.26	7,123.15	17,805.85	4.40	9,664.78	2.39	....	8,141.07
Leonora	585	....	....	643.65	643.65	1.10	....	953.13	1,596.78	2.73	1,596.78	2.73	....	....
Marble Bar	1,254	204.16	5,985.74	925.58	7,115.48	5.67	1,125.14	1,163.92	9,404.54	7.50	3,526.98	2.81	....	5,877.56
Marvel Loch	412	....	720.74	764.93	1,485.67	3.61	74.41	563.17	2,123.82	5.15	3,092.43	7.51	968.61	....
Meekatharra....	....	....	....	....	....	....	....	170.38	170.38	....	....	....	....	170.38
Norseman	360	....	740.05	546.73	1,286.78	3.57	....	131.55	1,418.33	3.94	569.47	1.58	....	848.86
Ora Banda	1,830	2,015.01	3,524.91	3,783.75	9,323.67	5.09	1,454.20	2,798.28	13,576.15	7.42	6,086.79	3.33	....	7,489.36
Totals	19,851	11,988.44	45,916.15	29,327.30	87,231.89	4.39	7,933.53	29,317.93	124,483.35	6.27	47,445.04	2.39	968.61	78,366.92
								Interest Paid to Treasury			4,320.00		4,320.00	
											43,125.04		82,686.92	
											Operating Loss		81,358.31	

STATE BATTERIES

TRADING AND PROFIT LOSS ACCOUNT FOR THE YEAR ENDED 31st DECEMBER, 1967

1966		1967	
$		$	$
	Trading Costs—		
224,911	Wages	231,805	
62,269	Stores	78,905	
72,935	Repairs, Renewals and Battery Spares	69,917	
84,194	General Expenses and Administration	93,622	
444,309			474,249
	Earnings—		
76,921	Milling and Cyaniding Charges		81,231
367,388	Operating Loss for the Year		393,018
	Other Charges—		
57,692	Interest on Capital	58,772	
26,719	Depreciation	28,283	
5,774	Superannuation—Employers Share	6,711	
90,185			93,766
457,573	Total Loss for the Year		486,784

BALANCE SHEET AS AT 31st DECEMBER, 1967

Funds Employed

31st December, 1966		31st December, 1967	
$		$	$
	Capital—		
1,378,037	Provided from General Loan Fund	1,402,051	
274,409	Provided from Consolidated Revenue Fund	274,409	
1,652,446			1,676,460
	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—		
2,271,110	Interest on Capital	2,329,883	
30,000	Advance for Purchase of Tailings	10,000	
	Other Funds—		
4,879,994	Provided from Consolidated Revenue Fund (Excess of payment over collections)		5,269,784
8,918,366			9,370,843
	Deduct—		
	Profit and Loss :		
8,102,134	Loss at Commencement of Year	8,559,707	
457,573	Loss for Year	486,784	
8,559,707	Total Loss from Inception		9,046,491
358,659			324,452

Employment of Funds

31st December, 1966		31st December, 1967	
	Fixed Assets—		
1,641,263	Plant, Buildings and Equipment	1,665,278	
1,395,925	Less Depreciation	1,424,208	
245,338			241,070
	Current Assets—		
9,937	Debtors	8,740	
71,544	Stores	76,226	
8,462	Battery Spares	9,986	
	Purchase of Tailings :		
1,833	Treasury Trust Account	21,758	
126,950	Tailings not treated	86,996	
17,277	Estimated Gold Premium	12,637	
236,003			216,343
481,341	Total Assets		457,413
	Deduct—		
	Current Liabilities :		
15,465	Creditors	23,702	
87,157	Liability to Treasurer (Superannuation—Employers Share)	93,868	
	Purchase of Tailings :		
2,783	Creditors	2,754	
17,277	Estimated Premium Due	12,637	
122,682			132,961
358,659			324,452

DIVISION IV

Annual Report of the Geological Survey Branch of the Mines Department for the Year 1967

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REPORTS

LIST OF PLATES

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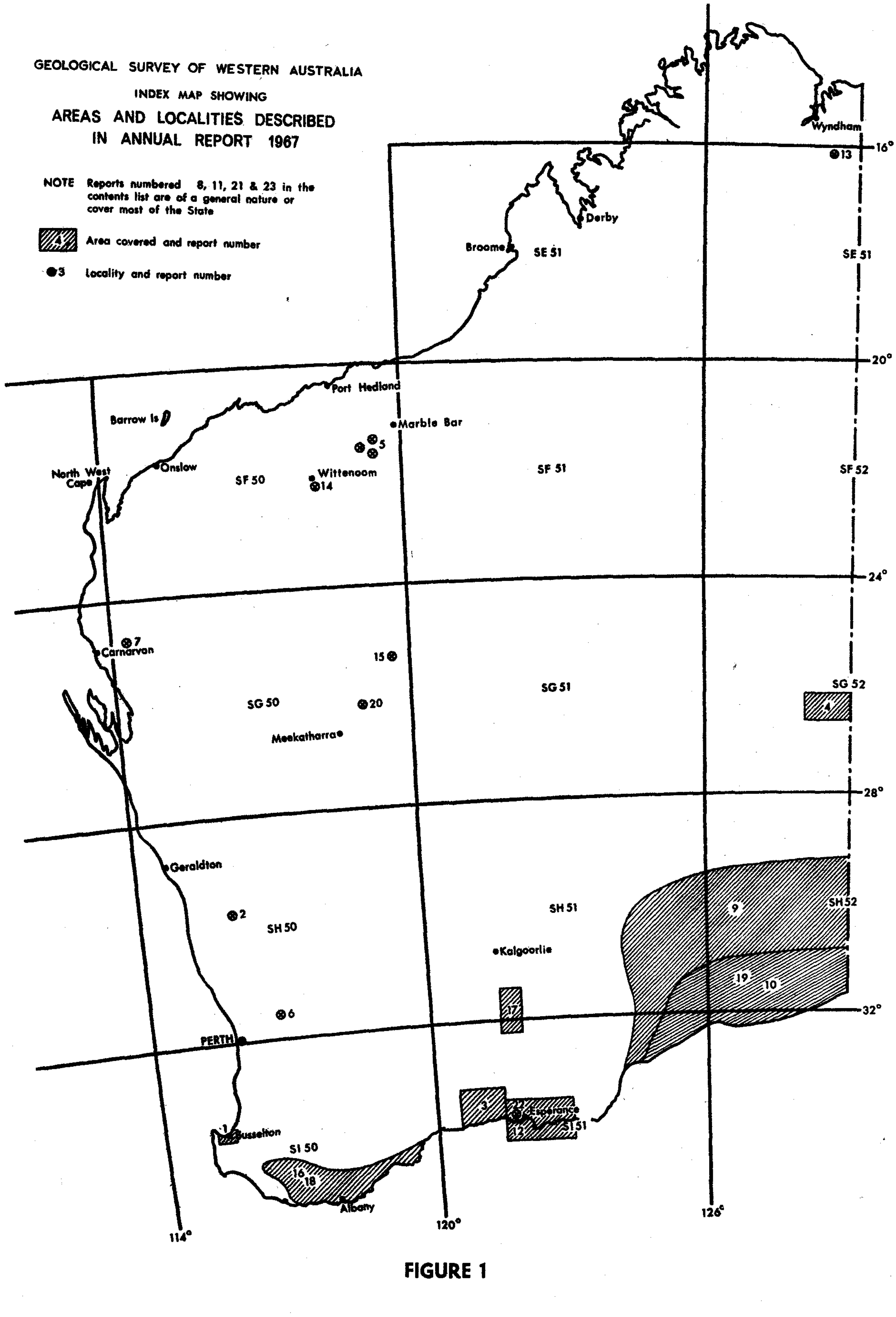

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
INDEX MAP SHOWING
AREAS AND LOCALITIES DESCRIBED
IN ANNUAL REPORT 1967
NOTE Reports numbered 8, 11, 21 & 23 in the contents list are of a general nature or cover most of the State
Area covered and report number
Locality and report number
Wyndham
Derby
Broome
SE 51
SE 51
16°
20°
24°
28°
32°
Port Hedland
Marble Bar
Barrow Is
North West Cape
Onslow
Wittenoom
SF 50
SF 51
SF 52
Carnarvon
SG 50
SG 51
SG 52
Meekatharra
Geraldton
SH 50
SH 51
SH 52
Kalgoorlie
PERTH
Busselton
SI 50
SI 51
Esperance
Albany
114°
120°
126°

FIGURE 1

DIVISION IV

Annual Report of the Geological Survey Branch of the Mines Department for the Year 1967

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 for the year 1967, together with some of the reports on investigations made for departmental purposes.

INTRODUCTION

The tempo of exploration in this State, particularly for nickel and base metals, increased again this year. The number of local, interstate, and overseas companies involved far exceeded expectations. No new ore bodies were discovered although many prospects, particularly for nickel, were examined in detail.

This unparalleled activity has created a great demand for the services and assistance of this Branch. Our field geologists, particularly those working on Precambrian areas, frequently assisted company geologists with ideas and discussions on regional geology and stratigraphy of prospect areas. Company operators usually discuss progress and methods of mineral search and rely on this Branch to provide regional geology on which they base more detailed investigations.

The Survey's library, card indexes, and open files have been continually searched and used for and by exploration companies, consultants, research workers, and the general public. Also the specialists with the Survey have been consulted on many aspects of geology affecting exploration.

The hydrogeologists and engineering geologists were used to their full capacity in the search for underground water and in the investigation of dam sites for additional water supplies, which are vital to the rapid mineral, agricultural, and pastoral development occurring within this State at present.

The increasing demand for geological investigations and services shows no sign of slackening and, as it is estimated that the value of the mineral production will rise to at least $A380 million in 1971, this demand must continue to increase rapidly.

It is considered that the specialists' activities of the Branch should expand gradually to carry out more research into problems arising out of this great period of exploration. Very few of the operating companies have the facilities or staff available for research activities. Such activities are considered necessary for developing our mineral resources even further than visualised at present.

STAFF

Six new professional positions, including a production geologist for the Sedimentary (Oil) Division and a geochemist, were approved during 1967.

As in other geological organizations some staff members have resigned to accept more lucrative positions with companies, and difficulties are being experienced in recruiting new staff. At the end of the year there were nine vacancies, although some appointments were being negotiated.

The establishment of the Geological Survey is now 47 professional, 6 clerical, and 12 general officers.

PROFESSIONAL

Appointments

Name	Position	Effective Date
H. Rutter, B.Sc. (Hons.)	Geophysicist, Grade 2	5/1/67
L. J. Peet, B.Sc.	Geologist, Grade 2	13/2/67
P. M. Hancock, B.Sc. (Hons.)	Geologist, Grade 2	3/7/67
R. Lake, B.Sc.	Geologist, Grade 2 (Temp.)	30/8/67
A. H. Pippet, B.Sc. (Hons.)....	Production Geologist	23/10/67

Resignations

J. D. Wyatt	Geologist, Grade 1	11/10/67
L. J. Peet	Geologist, Grade 2	15/12/67

CLERICAL AND GENERAL

Appointments

J. G. Neil	Geological Assistant	5/1/67
K. Gannon	General Assistant	27/11/67
R. E. Peters	Clerk	4/12/67
D. Jennings	Clerk	15/12/67

Resignations

V. D. Thornber	General Assistant	24/11/67

Transfers

F. Hargrave	Clerk	11/8/67
G. W. Wiltshire	Clerk	28/12/67

ACCOMMODATION

It became necessary during 1967 to rent part of yet another separate small building for this Branch. This was to relieve the cramped conditions existing in the library and records section. The Branch is now spread through six buildings. It is hoped that a solution to this unsatisfactory condition will be announced shortly.

Although plans have been prepared for the expansion of the core library at Dianella, building has not yet commenced.

A block of land in the suburb of Morley has been purchased for the establishment of a new store and vehicle park, when the existing area has to be vacated. Building of this new store will be required during the next financial year.

OPERATIONS

HYDROLOGY AND ENGINEERING GEOLOGY DIVISION

E. P. D. O'Driscoll (Chief Hydrogeologist), K. Berliat, F. R. Gordon, T. T. Bestow (Senior Geologists), D. H. Probert, K. H. Morgan, J. R. Passmore, P. Whincup, R. A. Farbridge, C. C. Sanders, J. L. Baxter, L. N. Wall, P. Hancock, A. D. Allen (on leave without pay at London University), and R. S. Chaturvedi (Colombo Plan Fellow).

Hydrology

Exploratory drilling in the Arrowsmith River area was completed, and a large supply of groundwater is now being pumped to Morawa township and the district en route.

At Mandurah the last of the fourteen bores is now completed and the project has been suspended.

An east-west line of deep bores was continued in the Quindalup—Busselton region. Drilling will later be extended eastward towards Donnybrook.

At Albany, one exploratory bore for the town water supply scheme was completed near Snake Hill.

The final seven bores forming part of a geophysical investigation at Neridup were drilled.

To try and augment the Northern Comprehensive Water Supply Scheme by using groundwater, exploratory rotary and percussion drilling is now being done on the central Perth Basin westward of Watheroo and Coomberdale, and will continue into 1968. Westward of the same area two successful bores were constructed for the Midlands Light Lands Committee.

For the Metropolitan Water Board several parts of an extensive shallow sand aquifer in the Lake Gnangara area have had groups of bores installed, and these are being test pumped to establish aquifer characteristics.

With the exception of a relatively small inaccessible corner, regional mapping and a bore census have been completed on the Esperance 1:250,000 geological sheet. Part of the Ravensthorpe Sheet has also been mapped, and a bore census is under way. Census work is also being done on the Perth Basin.

To assist an arid zone research project, three groups of test bores were drilled and test pumped in calcreted areas in the Cue district. The hydrology of the Cue 1:250,000 geological sheet is also being studied.

One geologist was seconded to regional mapping of the Talbot, Bentley, and Cooper 1:250,000 geological sheets, part of his duties being a hydrological assessment of the area. Mapping has also been done of a belt of Moora Group cherts along the Darling—Urella fault zone, to examine its groundwater potential.

Field surveys were made for seven government projects and 80 for private landholders. Compilation of bore records throughout the State has continued.

The draft of proposed legislation on underground water is now being prepared.

Engineering Geology

A proposed dam site at Rocky Pool on the Gascoyne River was mapped in detail and the foundations have been explored by auger drilling. Site feasibility studies included drilling and setting up piezometer tubes in several flood channels or anabranches which may be zones of reservoir leakage.

In the Kimberleys two proposed dam sites, Moochalabra Creek No. 3 for Wyndham water supply, and Arthur Creek were examined, and also two sites in the Pilbara district. Seven sites for irrigation water storage were mapped on Ferguson Brook and Joshua Brook near Dardanup, and Gemcodril work supervised on three. A new proposed spillway for the Ord River main dam site has been inspected.

A major project was the examination of the foundations of Waroona Dam, and supervision of extensive test drilling to determine leakage paths and to instal remedial works.

Some further mapping has been done on a new spillway area at North Dandalup dam site, and diamond drilling supervised.

SEDIMENTARY (OIL) DIVISION

P. E. Playford (Supervising Geologist), A. H. Pippet (Production Geologist), G. H. Low, D. C. Lowry.

During 1967 an increased part of the Division's time was occupied in the collation of oil exploration and production data, and in reviewing company exploration programmes. The Division was also called on to assist in drafting the new petroleum legislation which was enacted during the year. With the appointment of a Production Geologist, the Geological Survey now has the services of a geologist with specialised knowledge of petroleum production and conservation.

Regional mapping of the Perth Basin was continued on the Moora and Perenjori 1:250,000 Sheets. Exposures in this area consist largely of the Proterozoic Moora Group. Compilation of the Eucla Basin maps and bulletin proceeded during the year, and a brief field trip was made to complete mapping in the Point Dover area.

The Supervising Geologist spent three months in the United States and Canada working on a joint project with the Denver Research Center of the Marathon Oil Company to compare the Devonian reef complexes of the northern Canning Basin with those of western Canada.

REGIONAL GEOLOGY DIVISION

R. C. Horwitz (Supervising Geologist), J. L. Daniels (Senior Geologist), M. J. B. Kriewaldt, I. R. Williams, and J. J. G. Doepel.

Eastern Goldfields area

Geological mapping was continued on the Kurnalpi 1:250,000 Sheet and was commenced on the Menzies 1:250,000 Sheet. Both are nearly completed. A persistent stratigraphic succession has been established for the Kurnalpi Sheet, and mapping on the Menzies Sheet has linked the Kalgoorlie general area to a province to the northwest.

Gossans in Archaean sedimentary rocks have been found on both these geological sheets. The geological setting indicates that they are not primarily nickel prospects but that they could represent deposits of other base metals.

Blackstone—Warburton general area

Geological mapping was completed on the Cooper and Bentley 1:250,000 Sheets and the Talbot Sheet is well advanced. Chemical results, on samples collected last year, revealed the presence of vanadiferous magnetite on the Scott Sheet; these deposits have been further mapped on the Bentley and the Scott Sheets.

General

Mapping of the Precambrian has started on the Geraldton Sheet. Mapping of the Perth Sheet, including a revision of the geology of the Perth metropolitan area, was commenced, and mapping of the Peak Hill Sheet was continued. Liaison was maintained with field parties of the Hydrology Division during the mapping of Precambrian rocks in the southern part of the State and the islands of the Archipelago of the Recherche.

The progress of geological mapping at 1:250,000 scale to the end of 1967 is shown on Figure 2.

MINERAL RESOURCES DIVISION

L. E. de la Hunty (Supervising Geologist), J. Sofoulis (Senior Geologist), J. G. Blockley, P. C. Muhling, and J. L. Baxter.

Kimberley Division

The field work for the Kimberley mapping project, conducted jointly with the Bureau of Mineral Resources, was completed during 1967. Areas of Precambrian rocks on the Yampi, Charnley, Lennard River, and Noonkanbah 1:250,000 Sheets were mapped. Deposits of chromite, goethite, and emery were investigated.

An inspection was made of a new silver-lead-gold-copper deposit near Kununurra, in the eastern part of the Kimberley Division.

North-West Division

Brief inspections were made of several iron ore deposits in the Hamersley Iron Province, including those at Wittenoom Gorge, Mt. Lockyer, and Dales Gorge.

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

1: 250,000 OR 4 MILE GEOLOGICAL MAPPING

1967

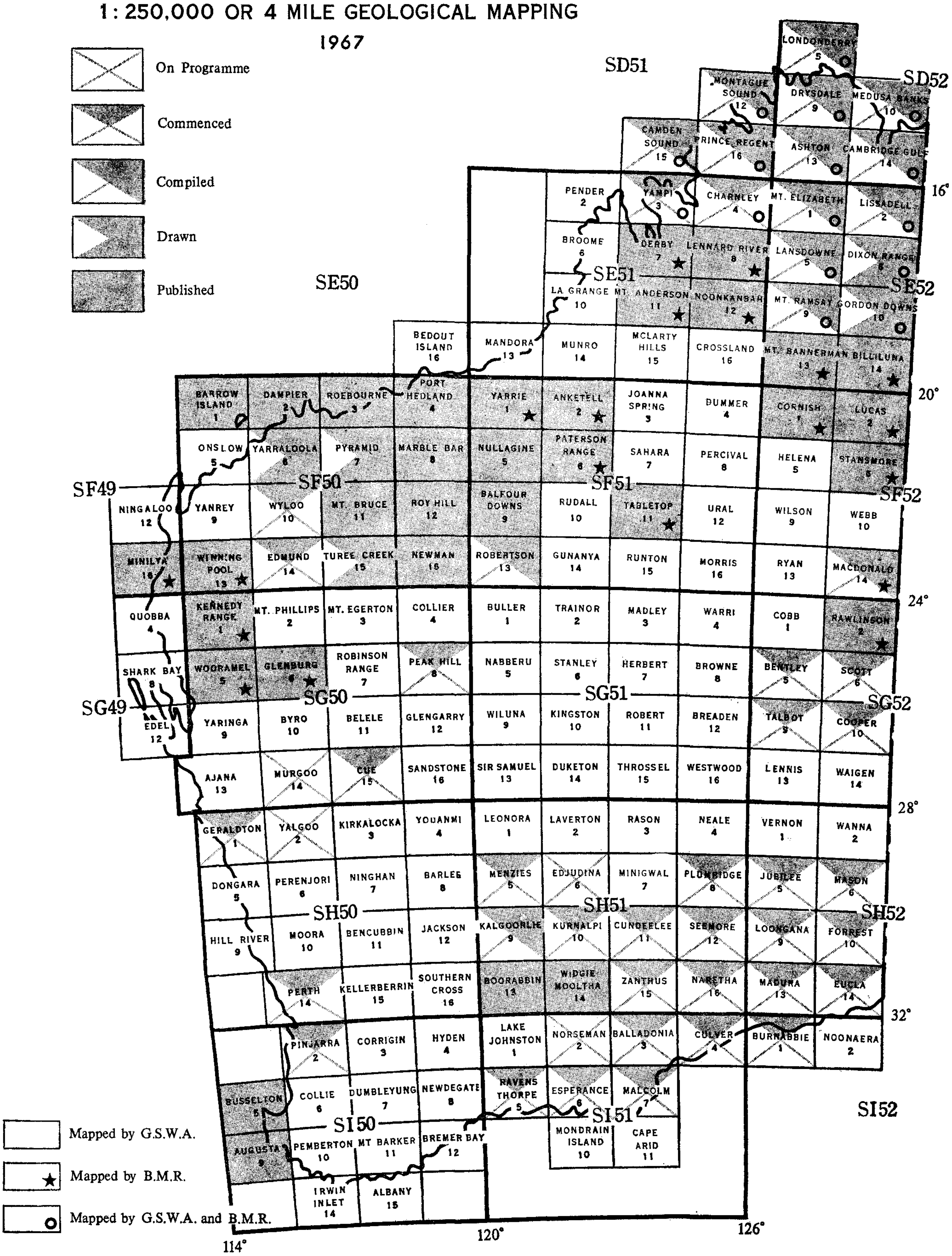


FIGURE 2

Some mapping was done on recently abandoned mineral claims for blue asbestos in the Wittenoom Gorge area, and compilation of the bulletin on blue asbestos was continued. A photographic type section of the Dales Gorge Member of the Brockman Iron Formation was prepared.

A subsidised diamond drilling programme was carried out at the Thaduna copper mine, north of Meekatharra.

Field work was continued on the mineral resources, regional geology, and hydrology of the Cue 1:250,000 Sheet.

Miscellaneous inspections were made of deposits of gold, copper, ochre, water, and a reported meteorite occurrence.

COMMON SERVICES DIVISION

Petrology (A. F. Trendall and R. Peers).

Thirty file reports were written during the year, mainly for the various Divisions of the Geological Survey, but some in response to public enquiries. The majority of these reports were the work of Miss Peers. A total of 1,230 thin-sections and 47 polished sections were prepared by the technical staff; many of these were passed directly to the collecting geologists for examination. Discussion with geologists of problems arising during such examination forms an important part of the Geological Survey petrological work.

It is a policy of the Geological Survey to avoid the divorce of detailed petrological work from the broad environment of the rocks studied; in accordance with this policy Miss Peers visited the Cue Sheet mapping party, and Dr. Trendall made a tour of field parties in the Warburton Range area, the Menzies Sheet and the Kurnalpi Sheet, in addition to spending a month in the Hamersley Range area.

During much of the year Dr. Trendall was engaged jointly with Mr. J. Blockley on the preparation of a final account of a continuing study of iron formations of the Hamersley Range area, with particular attention to the associated crocidolite. This is almost completed.

Mineralogical and chemical work by the Government Chemical Laboratories continued to complement petrological work, and this is gratefully acknowledged.

Palaeontology (A. E. Cockbain, B. S. Ingram).

Seventy-three file reports were written in 1967. These reports covered a wide variety of work and included studies of the Cretaceous of the Perth Basin, Tertiary of North West Cape and the Denmark-Esperance area, Cretaceous of the Warburton-Blackstone area, Permian of Kennedy Range dam site, and Precambrian of the Watheroo-Coomberdale area. As in 1966 the main interest of the section has been in the Mezozoic palynology of the Perth Basin and the stratigraphic palaeontology of Foraminifera and Bryozoa from the Eucla Basin. A statistical breakdown of the file reports is given below.

Reports written for	Field of Palaeontology		
	Palynology	Micropalaeontology	Macropalaeontology
Hydrogeology/Engineering	40	10	1
Sedimentary (Oil)	4	6	4
Regional Mapping/Mineral Resources	1	....	2
Miscellaneous	1	4	....

Once again, we are grateful to Mr. B. E. Balme (University of Western Australia) and Mr. G. W. Kendrick (Western Australian Museum) for their help in examining certain samples.

Geophysics (D. L. Rowston and H. Rutter).

Routine well-logging services for the Hydrology Division again dominated geophysical activities. During the year 72 logging operations, involving 42 individual drillholes with a total logged footage of 51,700 feet, were carried out. This was a significant increase over 1966 when 35 runs were made in 26 holes totalling 38,000 feet.

Normal laboratory facilities were maintained and field salinity determinations made on 700 water samples. The estimation of formation water salinities from the long normals resistivity well-logging was re-assessed; salinities in Cretaceous and younger sediments of the Perth Basin can now be determined with a minimum accuracy of ± 15 per cent.

An evaluation of the geophysical results at Esperance (1966) was made on the completion of test drilling early in the year. Notably, all the high yielding bores were in magnetic lows associated with depressions and drainages in the Archaean basement. The resistivity method can also be usefully employed to determine the thickness of sediments.

Minor geophysical investigations were made at Northampton (lead) and Big Bell (gold). An experimental resistivity survey near Cue indicated that interpretations of depth probe curves from this saline, calcrete environment, in terms of geology, can be highly speculative.

Technical Information Section (R. R. Connolly, M. E. Redman, and S. M. Fawcett).

The demand for information from companies and individuals has continued to increase. Such requests are for reports, plans, photocopies, samples, bibliographies, displays, rock and mineral identification, etc. Service is often hampered by inadequate storage and operating space.

Library loans to the staff increased to 2,429 and loans to other than staff totalled 490. This is an overall increase of 33 per cent. Requisitions to the Drafting Office for services numbered 734. Eight publications were edited, printed, and distributed, and 23 Records were prepared.

At the core library the storage capacity of the existing building has been reached and the planned extension is required to cope with samples being received.

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) Regional geological mapping of the Yampi, Charnley, Lennard River, and Noonkanbah 1:250,000 Sheets in the Kimberley Division, jointly with the Geological Survey of Western Australia.

(2) Continuation of the sampling of Precambrian rocks in the Kimberley area for age determination.

(3) Aeromagnetic survey (DC3 aircraft) of the Sir Samuel and Duketon 1:250,000 Sheets.

PROGRAMME FOR 1968

HYDROLOGY AND ENGINEERING DIVISION

Hydrology

1. Continuation of the hydrogeological survey of the Perth Basin including deep drilling.
2. Hydrogeological investigation and exploratory drilling for groundwater in the following areas:
   (a) Watheroo—north to Carnamah and south to Moora.
   (b) Albany.
   (c) Gnangara Lake.
   (d) Mandurah-Pinjarra.
   (e) Mullewa.
   (f) Ravensthorpe.
   (g) Port Gregory.
   (h) Fitzroy Crossing.
   (i) Millstream.
   (j) Horrocks Beach.
   (k) Others may be added.

3. Kimberley—hydrogeological assistance to pastoralists.
   (a) bore site selection as required
   (b) completion of the hydrogeological mapping in conjunction with the Bureau of Mineral Resources.
4. Miscellaneous minor investigations as requested by other departments and the public.

Engineering

1. Ord River Dam—northern spillway investigation.
2. Helena River—investigation of possible new dam sites.
3. North and South Dandalup dam site—further investigation.
4. Erosion studies at Bandicoot Bar Dam.
5. Moochalabra Creek—mapping of foundation area.
6. Pilbara—investigation of possible dam site.
7. Other dam site investigations for Public Works Department if staff available.

SEDIMENTARY (OIL) DIVISION

1. Maintain an active interest in the progress of oil exploration in Western Australia.
2. Continuation of the mapping programme in the Perth Basin.
3. Completion of the geological survey of the Eucla Basin.
4. Bugle Gap detailed biostratigraphic study in association with the Bureau of Mineral Resources.
5. Miscellaneous investigation as required.

REGIONAL GEOLOGY DIVISION

1. Completion of the mapping of the Kurnalpi, Menzies, Balladonia and Malcolm 1:250,000 Sheets in the Eastern Goldfields.
2. Commence the mapping of the Edjudina and Norseman 1:250,000 Sheets in the Eastern Goldfields.
3. Complete the mapping of the Talbot 1:250,000 Sheet in the Eastern Division.
4. Complete the mapping of the Geraldton and Peak Hill 1:250,000 Sheets.

MINERAL RESOURCES DIVISION

1. Continuation of the mineral survey of the Yalgoo and Murchison Goldfields.
2. Detailed investigation of the Ministerial Reserve near Rocky Dam, Kurnalpi 1:250,000 Sheet.
3. Preparation of a mineral resources bulletin on the silver-lead-zinc deposits of W.A.
4. Miscellaneous investigations as required.

PUBLICATIONS AND RECORDS

Issued during 1967

Mineral resources of Western Australia.

Bulletin 117, the geology and iron deposits of the Hamersley Range area, Western Australia.

Annual report 1966.

Geological map of Widgiemooltha 1:250,000 Sheet (SH/51-14 International Grid) with explanatory notes.

Bulletin 118, Devonian reef complexes of the Canning Basin, Western Australia.

In Press

Geological map of Pyramid 1:250,000 Sheet (SF/50-7 International Grid) with explanatory notes.

Geological map of Busselton and Augusta Sheets (SI/51-5 and SI/51-9 International Grid) with explanatory notes.

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

Geological map of Turee Creek 1:250,000 Sheet (SF/50-15 International Grid) with explanatory notes.

In Preparation

Bulletin 119, Iron Formations of the Precambrian Hamersley Group Western Australia with special reference to the associated crocidolite. Geological maps (1:250,000) with explanatory notes, the field work for each having been completed: Robertson, Kalgoorlie, Wyloo, Scott, Edmund, and sheets covering the Western Australian portion of the Eucla Basin, namely Culver, Naretha, Burnabbie, Madura, Loongana, Jubilee, Noonaera, Eucla, and Forrest.

Records Produced

1967/1 Water supplies in the East Kimberley region, by J. R. Passmore.
1967/2 Interim report on a vanadium prospect, Jameson Range, Western Australia, by J. L. Daniels.
1967/3 Hydrogeology of the Yule River area, Port Hedland town water supply, by P. Whincup.
1967/4 Explanatory notes on the Robertson 1:250,000 geological sheet, Western Australia, by L. E. de la Hunty.
1967/5 The hydrogeology of the Yampi and Lennard River 1:250,000 geological sheets, by R. A. Farbridge.
1967/6 Esperance geophysical survey, by D. L. Rowston.
1967/7 Explanatory notes on the Turee Creek 1:250,000 geological sheet, Western Australia, by J. L. Daniels.
1967/8 Notes on Ministerial Reserve 3811H near Lake Rebecca, Western Australia, by R. C. Horwitz.
1967/9 Hydrogeological features of the Gascoyne River, west of the Kennedy Range, by J. L .Baxter.
1967/10 Explanatory notes on the Kalgoorlie 1:250,000 geological sheet, Western Australia, by M. J. B. Kriewaldt.
1967/11 Big Bell mine geophysical survey, by D. L. Rowston and H. Rutter.
1967/12 The origin of blow-holes and the development of domes by exsudation in caves of the Nullarbor Plain, by D. C. Lowry.
1967/13 The mineral resources of Western Australia and their potential, by J. H. Lord.
1967/14 Geological investigations at the Kennedy Range dam site, by J. D. Wyatt (*Restricted*).
1967/15 Groundwater in the Busselton area, progress report on exploratory drilling, by D. H. Probert.
1967/16 The general geology of the Rocky Pool dam site, by J. L. Baxter (*Restricted*).
1967/17 Exploratory drilling for a water supply north of Wingellina, by R. A. Farbridge.
1967/18 Geological reconnaissance of a dam site at Bullinnarwa Pool, by F. R. Gordon (*Restricted*).
1967/19 Silver-lead-gold-copper prospect, M.C.38, Kununurra area, Kimberley Goldfield, Western Australia, by J. Sofoulis.
1967/20 Prospective dam sites on the Shaw River, Pilbara Division, by F. R. Gordon.
1967/21 Wells drilled for petroleum exploration in Western Australia, by P. E. Playford.
1967/22 Groundwater investigation in the Werillup area for the Albany town water supply, by D. H. Probert.
1967/23 Petrography and depositional environment of some Precambrian sedimentary rocks from Thaduna, Western Australia, by A. F. Trendall.

Reports in other Publications

Cockbain, A. E., 1967, *Asterocyclina* from the Plantagenet Beds near Esperance, W.A.: Australian Jour. Sci. v. 30, p. 68-69.

Horwitz, R. C., 1967, Pangaea and some units in the Precambrian and the Palaeozoic: Tectonophysics v. 4, p. 5-15.

Lord, J. H., 1967, The mineral resources of Western Australia and their potential: Royal Soc. West. Australia Jour. v. 50, p. 33-40.

Lowry, D. C., 1967, List of large collapse dolines in the Western Australian part of the Eucla Basin: Western Caver v. 7, no. 3, p. 1-7.

———1967, The origin of Eastern Cave doline, Western Australia: Australian Geographer v. 10, p. 300-302.

Lowry, D. C., and Lowry, J. W. J., 1967, Discovery of a thylacine, Tasmanian tiger, carcase in a cave near Eucla, Western Australia: Helictite v. 5, no. 2, p. 25-29.

Williams, I. R., and Sofoulis, J., 1967, The geology of the Prince Regent and Camden Sound 1:250,000 Sheet areas SD 51/16-15: Australia Bur. Mineral Resources Rec. 1967/38 (unpublished).

J. H. LORD
Director,
Geological Survey.

12th February, 1968.

GROUNDWATER IN THE BUSSELTON AREA, PROGRESS REPORT ON EXPLORATORY DRILLING

by D. H. Probert

INTRODUCTION

Between September 1966 and August 1967 an east-west line of exploratory groundwater bores was drilled in the Busselton area in the southern part of the Perth Basin. The bores were drilled to investigate groundwater occurrence in the rapidly developing coastal areas between Busselton and Dunsborough and also as part of the general investigation of the Perth Basin. Five bores ranging from 1,485 feet to 2,010 feet deep were drilled at locations shown on Plate 1.

The drilling confirmed the presence west of Busselton of major faulting beneath a strong unconformity seperating underlying older sediments of Permian and Lower Jurassic ages from an overlying blanket of South Perth Formation and Quaternary sediments. The faulting divides the western section of the basin into fault blocks of different ages. Groundwaters in the sediments west of Quindalup bore 1 are generally of poor quality and supply, and unsuitable for domestic use or irrigation. In Quindalup bores 1, 4, and 5 promising supplies of low salinity groundwater were encountered in Lower Jurassic to Lower Cretaceous sediments. This water is suitable for domestic use, but because of high bicarbonate content, some may have to be treated before being acceptable for irrigation use on clayey soils.

The bores were drilled using the Mines Department Mayhew 2000 rotary rig, with sludge samples collected every 10 feet and cores taken wherever practicable. Water samples were collected by means of Halliburton and Johnson Formation Testers and samples sent for analysis at the Government Chemical Laboratories. The bores were geophysically logged by the Geological Survey and routine palynology was carried out on selected samples. The results of chemical analyses and palynological determinations are shown in Appendices 2 and 3.

PHYSIOGRAPHY

The southern part of the Perth Basin has been divided (Lowry, 1965) into four broad physiographic regions.

The *Swan coastal plain* is a flat dune, soil, and alluvium covered plain extending northwards along the coast of Geographe Bay, bounded in the south by the Whicher scarp, and in the east by the Darling fault scarp. The plain has an average width of about 12 miles.

The *Blackwood area* is in the central section of the basin, and has a maximum elevation of about 500 feet, capped by sand and laterite and underlain by Mesozoic sediments.

The *Leeuwin—Naturaliste ridge*, which marks the western margin of the basin, has a maximum elevation of about 700 feet and is a north-south trending ridge of Precambrian crystalline rocks capped by laterite and Coastal Limestone. The ridge is bounded on the east by the Dunsborough fault.

The *Scott coastal plain* is a low lying swampy flat plain marked by scattered dune ridges.

GENERAL GEOLOGY

The southern part of the Perth Basin consists of a deep trough of sediments flanked on the east and west by Precambrian crystalline rocks of the Western Australian Shield and the Leeuwin-Naturaliste ridge. The trough continues to the north and south beneath the Indian Ocean, forming a graben between the Dunsborough and Darling faults.

Geophysical evidence suggests that a maximum thickness of 15,000 to 20,000 feet of easterly dipping sediments is present in the central and eastern sections of the basin and that this is intersected by four major, branching, north-south trending, faults having throws of up to 8,000 feet.

Lowry has described in detail the surface geology, which consists of a few scattered outcrops of Mesozoic sediments mainly masked by Quaternary deposits including alluvium, dune sands, and Coastal Limestone in the coastal plains, and sand and laterite in the Blackwood area.

Bores have intersected the sediments underlying the Quaternary sequence but mostly they are shallow and have been confined to the Lower Cretaceous—Upper Jurassic South Perth Formation, which probably blankets older sediments over a large proportion of the basin. However Sue No. 1, Alexandra Bridge No. 1 petroleum exploration wells and several coal bores in the southwest encountered Lower Permian sediments beneath the South Perth Formation, and the Abba River and Western Titanium bores encountered the Upper Jurassic Yarragadee Formation.

Quindalup bores 1 to 5

Drilling in the present part of the programme was confined to the Swan coastal plain. Bores 1 to 3 were located on the fringes of Geographe Bay 2½, 6½ and 10 miles west of Busselton respectively, and bores 4 and 5 at Wonnerup and Ruabon, 8 and 12 miles east of Busselton (Plate 1).

The bores intersected a thin veneer of Quaternary sediments overlying South Perth Formation, which in turn is separated from underlying older sediments by a strong unconformity. These sediments include those of Permian, Lower Jurassic, and Upper Jurassic ages.

The stratigraphic relationship between the bores is shown in Table 1.

Quaternary

The Quaternary sediments vary from 20 to 35 feet in thickness, forming a veneer above the South Perth Formation. In bores 1 to 3 they consist of well-sorted, fine-grained sand, marly clay, and shelly limestone of the Quindalup Dune System. In bores 4 and 5 farther inland, the sediments are poorly sorted, iron-stained sand and shelly limestone which possibly belong to the older Bassendean Dune System.

Lower Cretaceous to Upper Jurassic

Current thought on the South Perth Formation includes sediments described by previous workers as belonging to the Capel River Group and Yarragadee Formation.

In the Quindalup bores the thickness ranges from 270 feet in bore 4 to 1,180 feet in bore 5. The sediments are dominantly of continental type but rare microplankton indicate some marine influence during deposition. They are typically poorly consolidated, finely current-bedded, and lenticular. Correlation between bores is difficult and suspect, but the general dip is very gentle from east to west.

The sequence consists mainly of silt, siltstone, clay, poorly-sorted sand and sandstone containing abundant carbonaceous material, pyrite, and mica, and thin bands of lignite.

The arenaceous sediments are feldspathic, and are more consolidated with depth, making up 60 to 75 per cent of the total section.

The South Perth Formation unconformably overlies older sediments in each of the Quindalup bores.

Upper Jurassic

The Upper Jurassic Yarragadee Formation was encountered in Quindalup bores 4 and 5 and in nearby bores in the Abba River and Capel areas where it underlies the South Perth Formation.

The section is dominantly an arenaceous continental deltaic deposit containing less than 20 per cent. clay and silt. The sandstone and sand differ little from those of the overlying South Perth Formation but are typically garnetiferous and slightly more consolidated. They are generally moderately to poorly sorted, medium to very coarse in grain, and slightly feldspathic. Interbedded siltstone, clay, mudstone, and rare lignite make up the remainder.

Lower Jurassic

Lower Jurassic sediments of continental type are present between 630 and 1,930 feet in Quindalup bore 1. They consist of cross-bedded, poorly-sorted, silty to coarse-grained sand and poorly consolidated sandstone interbedded with mottled grey to red claystone, grey to green pyritic shale and siltstone. The claystone shows slickensiding and slumping.

Overlain unconformably by the South Perth Formation, the Lower Jurassic material in Quindalup bore 1 is the first observed occurrence of sediments of this age in the southern part of the Perth Basin, and is equated to the Cockleshell Gully Formation.

Permian

Permian sediments, also overlain unconformably by the South Perth Formation, occurred in Quindalup bores 2 and 3, the westernmost bores of the line.

In Quindalup bore 2 they are present between 365 and 1,807 feet, and consist of well consolidated fine to coarse-grained, slightly argillaceous sandstone containing abundant garnet, finely current-bedded, grey siltstone, 17 seams of carbonaceous shale, and poor quality dull coal ranging from 7 to 11 feet in thickness. The sandstone contains rare calcareous material.

In Quindalup bore 3 the sequence is lithologically similar except that only one 8-feet thick dull coal seam was encountered, although carbonaceous material commonly occurred as partings on bedding planes.

The Permian sequences are of different ages, that of Quindalup bore 3 being the younger of the two.

STRATIGRAPHY AND STRUCTURE

The stratigraphic relationships are shown in Plate 2, and in Table 1.

The Quaternary material forms a thin veneer over the South Perth Formation, and the maximum observed thickness of 35 feet is probably exceeded only in the Wonnerup area where gamma-ray logging of existing bores indicates a thickness of about 50 to 120 feet near the Wonnerup Estuary.

The South Perth Formation is present throughout the drilling area and ranges widely in thickness from 345 to 668 feet west of Busselton, thickening to over 1,000 feet in the Milne Street, Abba River 1, and Quindalup 5 bores. It thins again to 180 to 300 feet in the Wonnerup-Capel area. The cross-section between Abba River 1 bore and Capel (Plate 2) shows this variation, which may either be due to deposition over a deeply dissected Upper Jurassic surface or to post-Yarragadee Formation faulting. There is little concrete evidence to support the latter supposition, but differences in levels of basalt flows encountered in Quindalup bore 5 and Abba River bore 3 may either be due to depositional dip or to minor faulting. If a deep trough of South Perth sediments exists it probably is an old erosional channel which may extend as far east as the Whicher scarp, and possibly be related to basalt occurrences in the area.

The variation in thickness of the South Perth Formation illustrates the strong unconformity which separates these beds from the underlying strata. Below the unconformity three major north-south trending faults with throws of several thousand feet have been proved by the drilling. These include the Wirring and Busselton faults inferred from previous gravity and seismic surveys, and a fault postulated by Lodwick from seismic data. The faults divide the area beneath the unconformity west of Busselton into four blocks containing Upper to Lower Permian, Lower Permian, Lower Jurassic, and Upper Jurassic sediments. The block between the Wirring and Busselton faults is uplifted with respect to the others, which are normal east block down.

The Yarragadee Formation is present east of Busselton in Quindalup bores 4 and 5, Abba River bores 1 and 3, and in bores at the Western Titanium mining pit at Capel. No bores have penetrated the full succession of the Jurassic sediments which reach a maximum observed thickness of 1,615 feet in Quindalup bore 4.

Lower Jurassic sediments in Quindalup bore 1 are of similar lithology and age to the Cockleshell Gully Formation in the Hill River area, but the arenaceous sediments appear to be generally coarser in grain. The Lower Jurassic sediments are restricted in occurrence to the fault block immediately west of Busselton and nothing is yet known of their extension to the south.

Lower Permian coal-bearing sediments in Quindalup bore 2 are probably Upper to Lower Artinskian in age. The lower part of the section contains similar spore assemblages to the lower Artinskian coals of the Collie and Irwin River areas and to those encountered at 8,866 feet in WAPET's Sue No. 1 well. In this part of the basin these sediments are confined to the wedge-shaped block between the Wirring and Busselton faults.

The Permian sediments in Quindalup bore 3 appear younger than those in bore 2 and have been tentatively dated as early Upper Permian to Upper Artinskian. They lie between the Dunsborough and Wirring faults and their southward extent is not known.

OCCURRENCE OF GROUNDWATER

Groundwater was present in sediments of all ages and was sampled wherever possible by formation testers. The water samples were used by D. L. Rowston as controls for the estimation of salinities from resistivity logging. These results are shown on bore completion reports and on Plate 1.

Quaternary aquifers

Small supplies of groundwater are available from the thin veneer of Quaternary sediments. The water varies from stock to domestic quality and

TABLE 1

STRATIGRAPHIC SUCCESSION IN QUINDALUP BORES (EAST TO WEST)

Age	Formation	Bore 3 (feet)	Bore 2 (feet)	Bore 1 (feet)	Bore 4 (feet)	Bore 5 (feet)
Quaternary	Recent sediments and Quindalup and Bassendean Dune Systems	0–32	0–20	0–22	0–35	0–22
Lower Cretaceous to Upper Jurassic	South Perth Formation	32–700	20–365	22–630	35–305	22–1180
Upper Jurassic	Yarragadee Formation	Not present	Not present	Not present	305–1920	1180–2010
Lower Jurassic	Cockleshell Gully Sandstone equivalent	Not present	Not present	630–1930	....	....
Early Upper Permian	....	700 to 1485	Not present			
Artinskian	....		365–1807			

Correlation based on lithology, palynology, and geophysical data.

usually contains high H_2S and bicarbonate. Bores near the coast and tidal drainage channels are subject to saline intrusion. The sediments form a useful source of domestic and garden water in coastal cottages in and around Busselton.

South Perth Formation aquifers

The aquifers of the South Perth Formation are lenticular and contain groundwater of variable quality and supply. Lowry (1965) has summarised bore census data for the Busselton area and gives the following relationship between bore depth and frequency:

Table 2

Bore depth (feet) (average 60)	No. of bores
31–50	123
51–70	123
71–100	66
101–150	37
>150	10

These sediments are the most important source of groundwater for farmers, particularly the shallow glauconitic sands near Quindalup. Generally bores are sited for convenience, and as the beds are very lenticular the landholder continues drilling until he obtains water. Most supplies are sub-artesian, yielding 200 to 1,000 gallons per hour, and range from good stock to domestic quality, although saline groundwater has been encountered in some areas west of Busselton.

West of Busselton on the fringes of Geographe Bay, groundwater in the South Perth Formation of Quindalup bores 1 to 3 is generally of poor quality. In bore 1 thin layers of stock quality groundwater are intercalated with layers ranging in salinity from 8,000 to 20,000 ppm TDS. In bore 2 the quality is uniformly poor, avering about 14,000 ppm TDS. Farther west the quality improves to 450 to 1,500 ppm TDS.

Between Quindalup bore 1 and Capel, domestic quality groundwater is obtained at depths of 50 to 1,000 feet from the South Perth Formation. A little saline groundwater has been met near the coast at shallow depths but generally the supply and quality improves with depth. Supplies are generally good ranging from 200 gph in shallow bores to over 30,000 gph in bores 500 to 1,000 feet deep. Near the coast the bores flow.

Yarragadee Formation aquifer

Sediments of the Yarragadee Formation were encountered 305 and 1,920 feet in Quindalup bore 4, and between 1,180 and 2,010 feet in Quindalup bore 5. They have also been encountered in the Abba River bores 1 and 3 and in the Western Titanium works at Capel. In the Wonnerup area the sequence is dominantly arenaceous and formation testing suggests that large quantities of domestic quality groundwater (200 to 400 ppm TDS) are available. In the Capel area, bores produce 20,000 to 25,000 gallons per hour from similar but more argillaceous beds. In the Abba River area, poor results obtained in drilling the three Abba River bores probably reflect bad drilling techniques.

Cockleshell Gully Formation (?) aquifers

The Lower Jurassic sand and sandstone in Quindalup bore 1 contain domestic quality groundwater between 670 and 720 feet and between 952 and 1,520 feet. Between 720 and 950 feet and below 1,520 feet the salinity increases to about 2,000 ppm TDS.

Formation testing of these sands indicates that they contain good supplies which are possibly artesian.

Permian aquifers

The well consolidated Upper and Lower Permian sandstones in Quindalup bores 2 and 3 vary greatly in porosity and permeability. They contain groundwater ranging from good to poor stock quality (1,300 to 8,800 ppm TDS) and are probably of poor supply.

CHEMICAL CHARACTERISTICS OF THE GROUNDWATER

Standard chemical analyses were obtained for most of the deeper bore samples in the Busselton-Capel area, and the results are shown in Appendix 3. Appendix 4 shows calculated sodium adsorption ratios, calcium—magnesium ratios, and residual sodium bicarbonate.

In the Busselton—Capel area most groundwater has a salinity of less than 600 ppm TDS and only west of Busselton, in the South Perth, Lower Jurassic, and Permian formations, do some salinities exceed this figure.

The two main groundwater sources, the South Perth and Yarragadee Formations, contain low salinity water of very similar characteristics. They have a pH ranging from 6.3 to 7.6, contain high concentrations of dissolved iron, and are typically low in calcium, magnesium, and fluoride ions. Variation lies mainly in the bicarbonate—chloride ion content of the South Perth Formation aquifers. These show a decrease in the bicarbonate—chloride ratio from east to west, which appears to be related to the incidence of old calcareous dune systems on the Swan coastal plain. The calcium—magnesium ratio shows little variation although there is a general trend of increase from east to west, indicating westerly groundwater movement.

The Yarragadee Formation aquifers show primary salinity, and both calcium-magnesium and bicarbonate-chloride ratios increase from east to west across the basin, indicating groundwater movement to the west. The bicarbonate ion content also decreases with depth and is possibly related to intake from overlying dune areas. The bicarbonate content is, with one possible exception, marginal to high, and untreated groundwater is generally unsuited for use in the irrigation of clayey soils. The exceptional groundwater, which probably belongs to the Yarragadee aquifer system, was in Yoganup bore 1 in the eastern section of the Swan coastal plain at the base of the Whicher scarp. This water has a low pH and very low bicarbonate content and suggests that groundwaters at the eastern margin of the coastal plain near the Whicher scarp may be more suitable for irrigation use.

RECHARGE

Only limited data are yet available on static water levels. Between Busselton and Yoganup two distinct water levels are present in the Yoganup bores and Quindalup bores 4 and 5, suggesting different potentiometric surfaces for the South Perth and Yarragadee aquifer systems. These have average downward gradients from east to west of 4 and $2\frac{1}{2}$ feet per mile respectively over most of the plain, but rise towards the Whicher scarp.

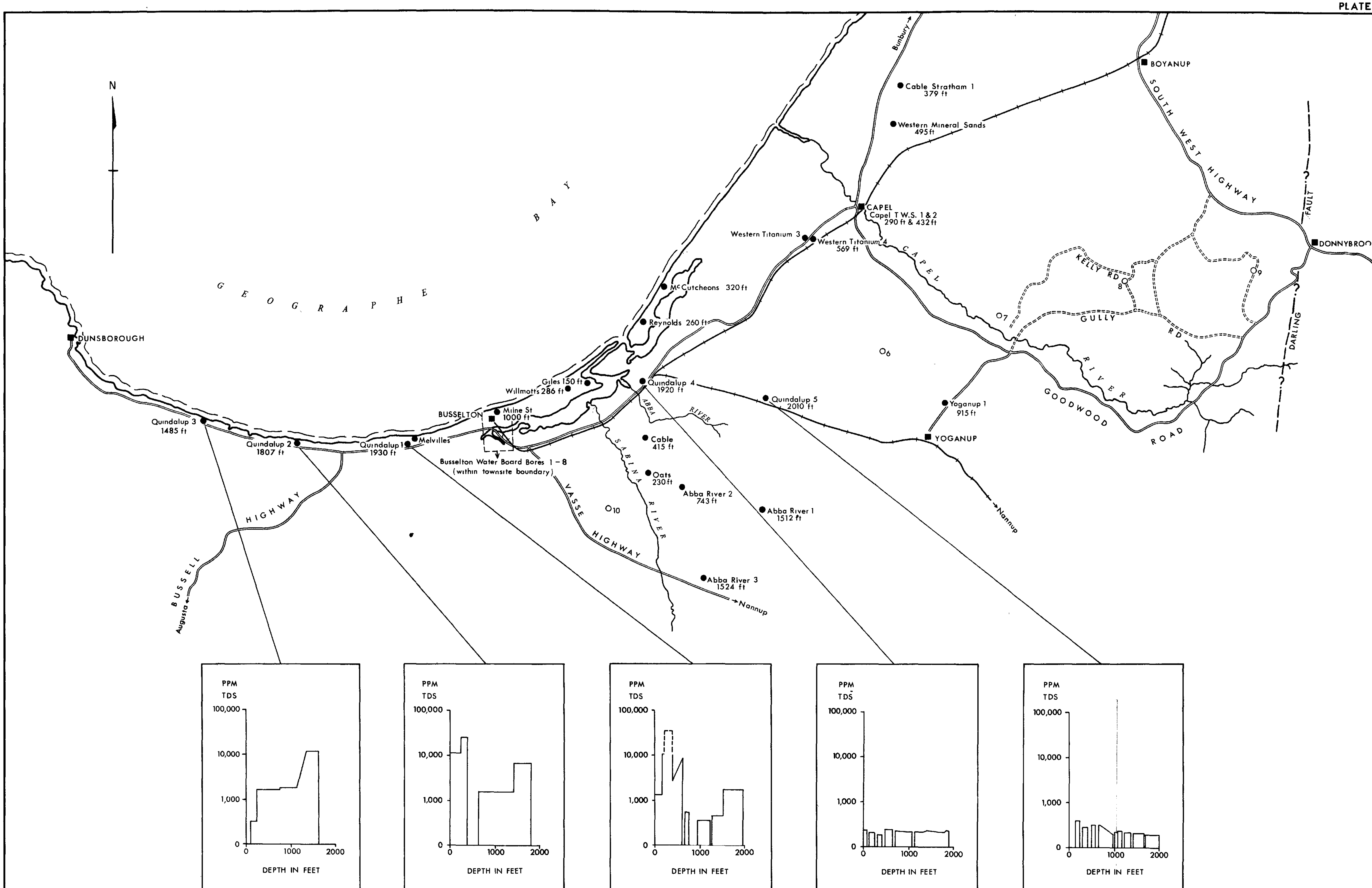
Data from levels, lithology, and chemical analyses suggest that recharge of the South Perth aquifers is mainly by direct infiltration of rainfall and river water from the Swan coastal plain. The recharge is selectively governed by topography and the lenticular nature of the sediments, particularly in the areas west of Busselton where saline groundwater is present in both the South Perth Formation and Permian strata.

The Yarragadee Formation probably receives groundwater from the elevated areas between the Darling fault and the Swan coastal plain, although some direct recharge may occur if areas of shallow Upper Jurassic sediments are present in the eastern sections of the plain.

AVAILABILITY AND USE OF GROUNDWATER

At present a maximum of about 10 million gallons per day of groundwater is extracted from the Yarragadee and South Perth aquifer systems for stock, domestic, town supply, and industrial purposes in the Busselton-Capel areas. It is not possible to estimate the total amount of groundwater available in this area but probably 20 million gallons could be extracted safely without depleting supplies.

PLATE 1



LEGEND

Main road	
Forestry road	
Railway	
● Quindalup 3 1485 ft	Existing water bores (showing depth)
O7	Proposed water bores

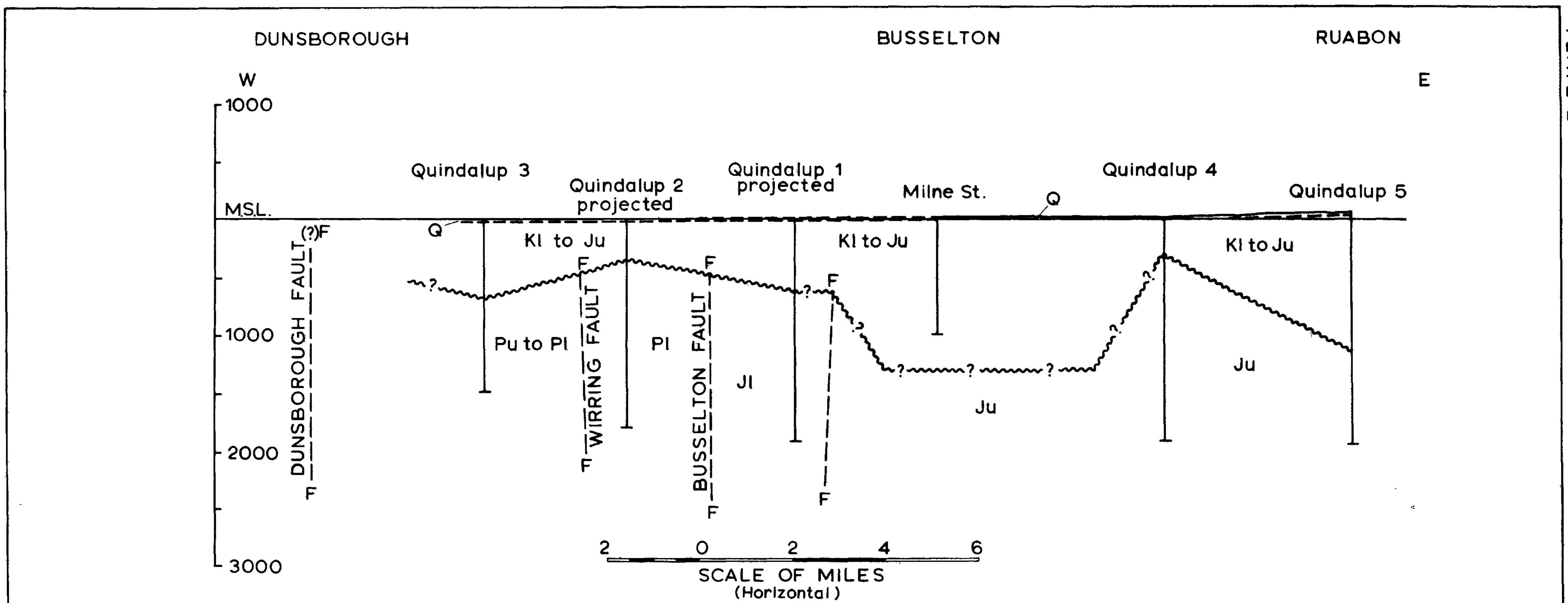
1 0 1 2 3 4 5
SCALE OF MILES

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

PLAN OF BUSSELTON AREA
SHOWING
EXISTING AND PROPOSED DEEP WATER BORES
AND
GROUNDWATER SALINITIES OF QUINDALUP BORES

TO ACCOMPANY REPORT BY D.H. PROBERT 1967

7226



STRATIGRAPHIC SECTION FROM DUNSBOROUGH TO RUABON

REFERENCE

Q	Quaternary	Quindalup Dune System Spearwood Dune System Bassendean Dune System Coastal Limestone
Kl to Ju	L. Cretaceous to U. Jurassic	South Perth Formation
Ju	U. Jurassic	Yarragadee Formation
Jl	L. Jurassic	Cockleshell Gully Formation equivalent
Pu to Pl	Early U. Permian to L. Artinskian	
Pl	U. to L. Artinskian	

Unconformity

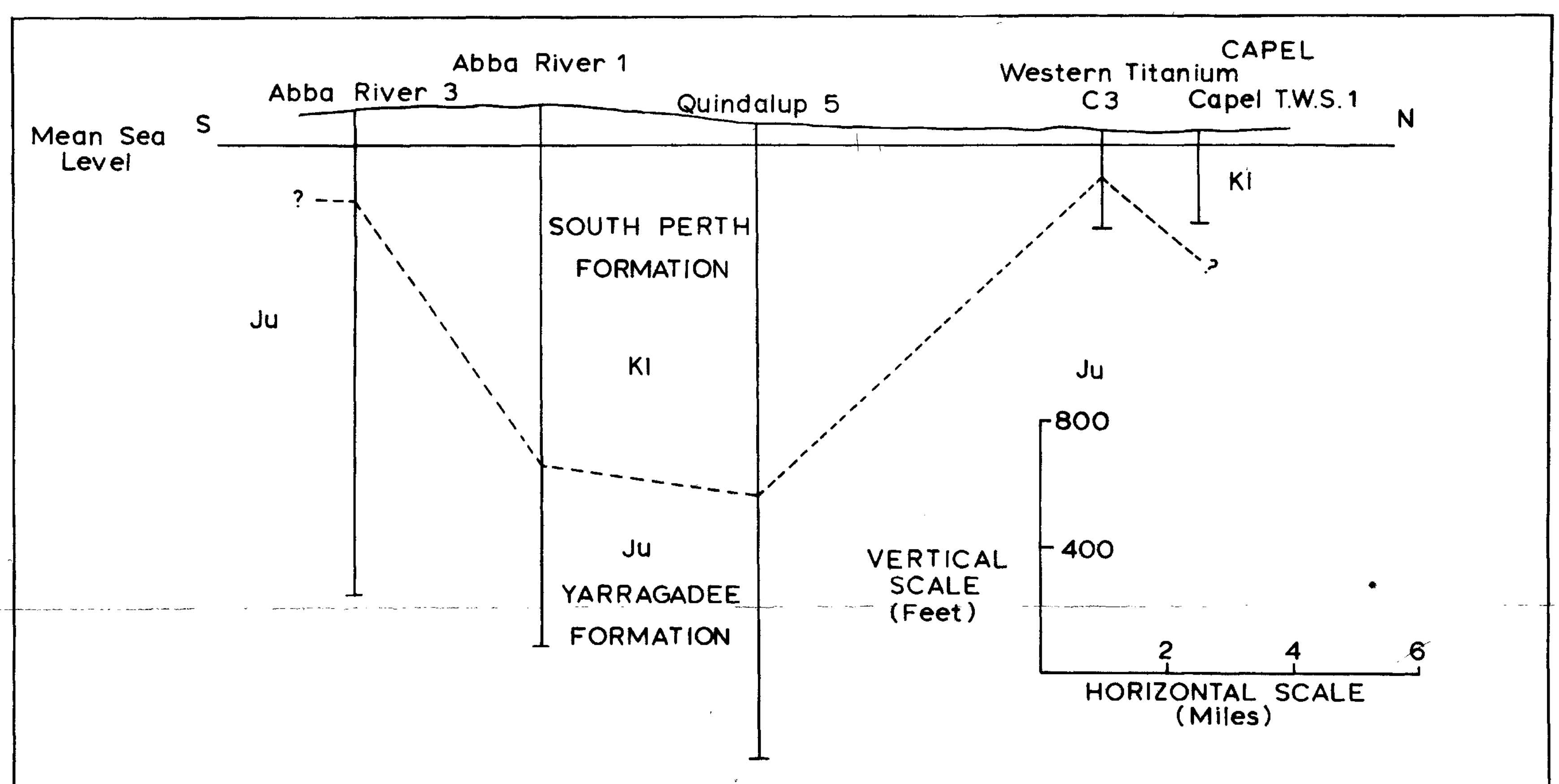
F—— Fault

Potentiometric surface South Perth Formation(?)

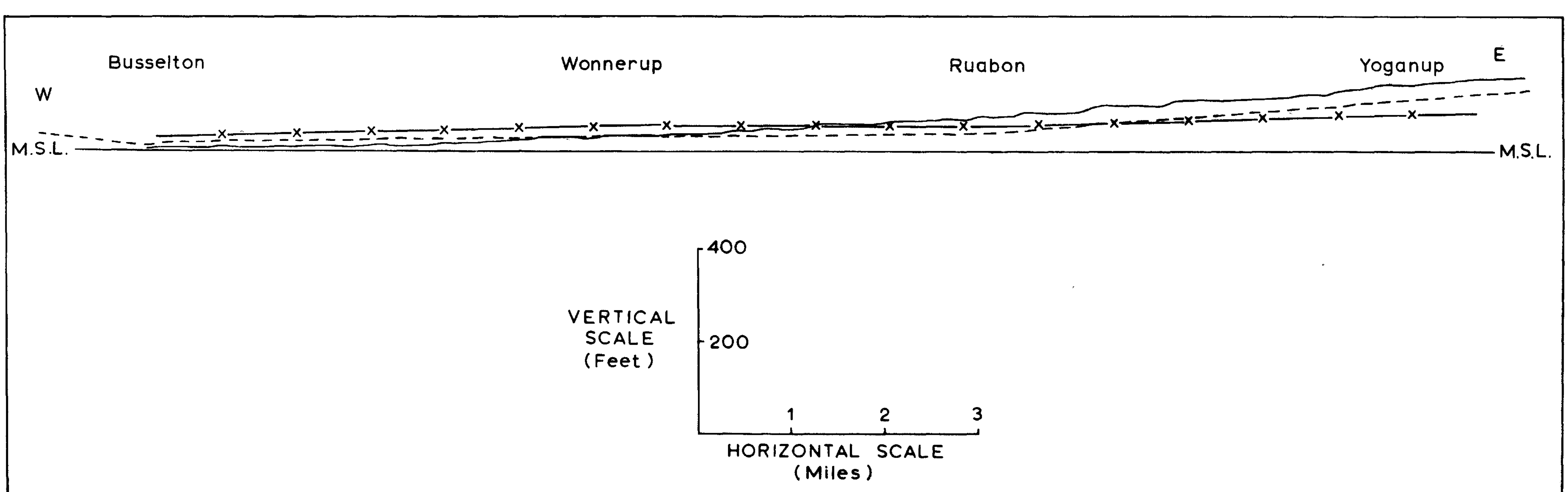
x——x Potentiometric surface Yarragadee Formation(?)

Ground surface

Surfaces based on limited topographic and hydrologic data



STRATIGRAPHIC SECTION BETWEEN CAPEL AND ABBA RIVER 3 BORE



TENTATIVE POTENTIOMETRIC SURFACE BETWEEN BUSSELTON AND YOGANUP

To accompany Report by D.H.Probert, 1967

7227

All low salinity waters are suitable for domestic use, but the waters of the Jurassic and deeper South Perth aquifers contain moderate concentrations of bicarbonate ions which would make them unsuitable for the irrigation of heavy clay soils and use in some industries without treatment. Appendix 4 shows the relationship of sodium adsorption ratios and residual bicarbonate (Eaton, 1950). Calculations based on Handa (1964) indicate that the groundwater could be made suitable for irrigation by the application of between 0.2 and 0.6 tons of gypsum per acre foot of water used.

CONCLUSIONS AND RECOMMENDATIONS

The drilling has shown that large supplies of low salinity groundwater are available from Lower Cretaceous and Upper Jurassic sediments east and north of Busselton. This groundwater is suitable for domestic and some industrial use, but as usual in groundwaters from this area, has a high iron content. Some of the groundwaters also contain moderate concentrations of bicarbonate ions which make them unsuitable for use in irrigation without treatment. This should be no great problem.

West of Busselton the groundwater in sediments underlying the near coastal strip is of marginal to very poor quality, and between Busselton and the Busselton fault, moderate to low salinity groundwater suitable for domestic use was encountered only in the Lower Jurassic sediments. Small quantities of domestic to stock quality groundwater are present in shallow Quaternary sands or in low lying areas underlain by Lower Cretaceous sediments east of Geographe Bay. These supplies are too small and irregular to be of great value other than for farming purposes.

Plate 1 shows the location of five drill-holes proposed for the second stage of the programme. Four bores continue in a line between Ruabon and Donnybrook and will investigate the stratigraphy and hydrological potential of the eastern section of the Swan coastal plain and the elevated area of Mesozoic sediments between Yoganup and Donnybrook. A further bore is proposed to investigate the presence of groundwater between the Sabina and Vasse Rivers, 5 miles southeast of Busselton, where poor and conflicting results were obtained during the drilling of the Abba River bores in 1958.

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Appendix 1

LIST OF DEEP BORES IN THE BUSSELTON—CAPEL AREA

Bore	Depth (feet)	Remarks
G.S.W.A. Quindalup 1	1930	8 in. casing to 504 feet
2	1807	Plugged, capped and abandoned
3	1485	Plugged, capped and abandoned
4	1910	10 in. standpipe to 80 ft.; bore capped
5	2010	Plugged, capped and abandoned
G.S.W.A. Abba River 1	1712	Abandoned
2	743	Abandoned
3	1524	Abandoned
Busselton Water Board 1	470	Drilled 1908, abandoned 1960
2	480	Abandoned 1938
3	560(?)	Abandoned
4	163	Bore in use
5	495	Bore in use
6	363	Bore in use
7	555(?)	Bore in use
8	490(?)	Bore in use
Milne Street	1000	Bore in use
Western Titanium 1	351	Bore in use
2	572	Bore in use
3	632	Bore in use
No bore 4 drilled		
5	569	Bore in use
Westralian Oil Capel 1	193	Bore in use
Westralian Oil Yoganup 1	915	Bore abandoned
2	361	Bore abandoned
Western Mineral Sands Capel 1	496	Bore in use
2	498	Bore equipped
Capel town water supply 1	290	
2	432	
Oats bore	320	Wonnerup-Ruabon area
Cable (1956) Ruabon	450	
Cable (1956) Stratham	450	
McCutcheon's bore	320	Wonnerup area
Vasse coal bore 1	159	Drilled 1892-1900 (bores 1–6)
2	143	
3	269	
4	476	
5	656	
6	330	
Blums bore	297	Bore in use
Reynolds bore	200	Bore in use
Wilmotts bore	286	Bore in use

Appendix 2

PALAEONTOLOGICAL DETERMINATIONS IN THE BUSSELTON—CAPEL AREA

Quindalup Bore 1

feet	
22	Quaternary—Recent
110	Lower Cretaceous: South Perth Formation
140	Lower Cretaceous: South Perth Formation (?)
270	Lower Cretaceous—Upper Jurassic: South Perth Formation
507	Barren
620–650	Lower Jurassic: Cockleshell Gully Formation equivalent (?)
926–934	Barren
1266	Lower Jurassic: Cockleshell Gully Formation equivalent (?) (1266–1900)
1580	
1680	
1690	
1820	
1900	

Quindalup Bore 2

feet	
110, 170, 310, 380	Lower Cretaceous (possibly Uppermost Jurassic ?): South Perth Formation
500, 630, 820, 960	Lower Permian—Upper Artinskian (?)
1190, 1300, 1450, 1730, 1800	Lower Permian—Lower Artinskian

Quindalup Bore 3

feet	
75, 315, 400, 505, 640	Lower Cretaceous (Aptian—Neocomian): South Perth Formation
840, 1140, 1165–1170, 1282, 1289, 1484	Early Upper Permian to Lower Permian (Upper Artinskian ?)

Quindalup Bore 4

feet	
60	Lower Cretaceous—Uppermost Jurassic: South Perth Formation
310–316	Upper Jurassic: Yarragadee Formation
405	Barren
1098	Upper Jurassic: Yarragadee Formation
1240–1250	Upper Jurassic: Yarragadee Formation
1620–1627	Barren

Quindalup Bore 5

feet	
88, 90, 202	Lower Cretaceous: South Perth Formation
343, 484	Barren
556, 585	Lower Cretaceous: South Perth Formation
620	Aptian—marine (?): South Perth Formation
1051	Lower Cretaceous: South Perth Formation
1055	Barren
Sludge 1190	Lower Cretaceous: South Perth Formation
1337, 1340	Upper Jurassic: Yarragadee Formation

Western Titanium Capel Bore C3

feet	
195, 210, 244, 260, 309	Upper Jurassic: Yarragadee Formation

Western Titanium Capel Mining Pit

feet	
30	Sample taken from mining area 30 feet below ground level Lower Cretaceous—Upper Neocomian to Lower Aptian—marginal marine

Milne Street Bore (Busselton)

feet	
150, 160, 300	Lower Cretaceous—Neocomian to Aptian
550, 690, 946, 970	Lower Cretaceous, probably samples poor

Capel Town Bore 1

feet	
30	Quaternary, probably Pleistocene
70	Lower Cretaceous—Aptian to Neocomian marine
270	Lower Cretaceous—Neocomian

Appendix 3

CHEMICAL ANALYSES—BUSSELTON-CAPEL AREA

Bore	Depth (feet)	pH	ppm TDS Evap.	ppm TDS Cond.	NaCl	Hardness $CaCO_3$	Alkalinity	Ca	Mg	Na	K	Fe	HCO_3	CO_3	SO_4	Cl	NO_3	Fl	SiO_2 ppm
Melville	15	....	1330	1440	764	579	403	143	54	248	6	0·1	491	....	88	464	<1	ND	6
Quindalup 1	460–510	6·9	....	17,000	11,000	....	....	....	....	....	....	....	....	....	....	....	....	....	....
	935–1025	8·3	640	730	274	76	225	24	4	202	6	?	274	....	61	166	1	ND	5
	1180–1250	7·5	1450	1700	1110	176	205	31	24	484	18	0·4	250	....	90	675	....	ND	8
	1455–1580	8·1	....	19,700	18,100	....	....	CONTAMINATED SAMPLE											
	1680–1770	7·3	2720	3010	2160	216	233	39	29	933	24	<0·1	284	....	185	1310	3	ND	6
Quindalup 2	238–310	....	....	42,000+	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
	834–884	12·0	....	3680	1710			CONTAMINATED SAMPLE											
	1670–1700	7·3	....	8930	7650	....	....	....	....	....	....	....	....	....	....	....	....	....	....
	1670–1700	7·1	....	8930	7650	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Quindalup 3	275–315	7·9	1270	1470	941	171	90	60	5	404	18	<0·1	110	....	168	571	1	ND	9
	1050–1080	8·3	1280	1440	913	93	155	34	2	442	10	<0·1	189	....	124	554	ND	ND	18
	1390–1485	7·5	8850	8850	7840	1980	65	721	43	2840	53	<0·1	79	....	634	4760	<1	ND	9
Quindalup 4	326	6·3	200	220	120	41	50	5	7	53	11	<0·1	61	....	14	73	3	ND	16
	530–560	7·1	330	340	120	66	158	20	4	96	10	<0·1	192	....	25	73	1	ND	12
	1370–1400	7·6	420	420	166	83	181	20	8	109	20	<0·1	220	....	21	101	<1	ND	13
Quindalup 5	695–763	7·3	520	540	194	43	210	11	4	174	12	<0·1	256	....	59	118	1	ND	16
	1057–1105	6·7	310	340	140	74	122	15	9	75	18	<0·1	149	....	18	85	<1	ND	16
	1338–1392	6·7	330	370	178	87	112	17	11	79	16	<0·1	137	....	15	108	<1	ND	17
	1926–1955	6·5	270	310	152	71	85	12	10	63	17	<0·1	104	....	14	92	<1	0·2	18
	1929–2000	6·8	310	350	163	65	105	13	8	84	16	<0·1	128	....	23	99	<1	0·2	18
Busselton Water B.5	585	....	240	....	....	....	....	12	9	49	14	8	54	....	10	95	3	0·25	18
Milne Street	350–620	6·6	190	218	....	....	....	9	7	39	15	0·1	82	....	11	55	<1	ND	ND
	750–1000	7·6	272	361	....	....	....	44	7	37	14	0·1	181	....	12	54	0·2	ND	12
Giles (Wonnerup)	150*	6·5	250	260	148	64	48	14	7	52	9	0·1	58	....	4	90	<1	0·3	24
Willmott (Wonnerup)	286*	6·3	380	400	270	77	43	13	11	94	9	0·1	52	....	19	164	<1	0·4	28
Reynolds (Wonnerup)	200*	6·3	200	230	124	49	48	5	9	44	14	0·1	58	....	10	75	<1	0·4	18
McCutcheon (Wonnerup)	320	7·3	220	250	124	64	67	6	12	53	6	0·1	82	....	14	75	<1	0·3	21
Oats (Ruabon)	320*	5·9	530	630	428	103	40	10	19	145	9	0·1	49	....	22	260	<1	0·4	26
Cable(1956)(Ruabon)	450*	6·2	220	240	135	41	48	5	7	55	12	0·1	58	....	13	82	<1	0·4	17
Western Titanium Capel 3	622*	6·7	220	240	92	56	90	11	7	48	20	(13) 0·1	110	....	16	56	<1	0·3	14
Western Titanium Capel 4	569*	6·6	220	240	92	52	90	11	6	49	21	0·1	110	....	16	56	<1	0·3	13
Capel Town Bore 1	289½*	6·1	380	380	....	83	35	11	13	83	15	16	43	....	17	166	ND	ND	17
Westralian Oil (Capel)	193*	6·1	280	340	206	73	48	13	10	67	15	0·1	58	....	14	125	<1	0·2	14
Western Mineral Sands	495*	7·2	210	230	101	55	72	9	8	42	19	0·1	88	....	13	61	<1	0·3	16
Cable (Stratham)	379*	7·0	230	250	110	54	76	10	7	50	18	1	92	....	15	67	<1	0·4	15
Westralian Oil	915*	4·6	420	460	331	64	5	4	13	102	15	0·9	6	....	16	201	<1	0·1	37

* Total depth of bore.

Appendix 4

CHEMICAL CHARACTERISTICS OF GROUNDWATER

No.	Bore	Depth (feet)	Calcium magnesium ratio rCa/rMg	Sodium adsorption $\frac{Na^+}{\sqrt{\frac{(Ca^{++}+Mg^{++})}{2}}}$	Residual sodium bicarbonate
1	Melville	10	1·6	4·5	....
2	Quindalup 1	935–1025	4·0	10·1	6
3	Quindalup 1	1180–1250	0·8	16·3	1·1
4	Quindalup 1	1680–1770	0·4	27·5	0·6
5	Quindalup 3	275–315	7·5	13·5	....
6	Quindalup 3	1050–1080	8·0	20·0	3·0
7	Quindalup 3	1390–1485	10	27	....
8	Quindalup 4	326	0·4	3·5	0·3
9	Quindalup 4	530–560	3·3	4·0	3·8
10	Quindalup 4	1370–1400	1.5	5·1	3·0
11	Quindalup 5	695–763	1·7	11·0	6·6
12	Milne Street	550–620	0·8	2·4	....
13	Milne Street	750–1000	3·8	0·8	0·4
14	Busselton 5	407–495	0·8	2·6	....
15	Quindalup 5	1057–1105	0·9	2·9	0·9
16	Quindalup 5	1926–1955	0·7	3·2	0·6
17	Quindalup 5	1929–2000	1·0	3·3	1·6
18	Yoganup 1	915	0·2	5·6	....
19	McCutcheon's	320	0·3	2·9	0·1
20	Western Titanium 3	622	1·0	2·8	1·3
21	Western Titanium 4	569	1·1	2·9	1·5
22	Cable Ruabon	415	0·7	2·6	0·2
23	Oats	230	0·3	6·2	....
24	Giles	150	1·2	2·8	....
25	Western Mineral Sands, Capel	495	0·7	2·4	....
26	Willmotts	157–286	0·7	4·6	....
27	Reynolds	154–174	0·3	2·7	0·1
28	Cable Stratham	379	0·9	8·6	0·9
29	Westralian Oil Capel	192	0·8	3·4	....
30	Capel Town water supply 1	289	0·5	4·0	....

PROSPECTS FOR UNDERGROUND WATER SUPPLIES FOR CARNAMAH TOWNSHIP

by P. Whincup

ABSTRACT.

In the Carnamah district, groundwater suitable for the town supply is available only from Quaternary sand overlying chert of the Proterozoic Moora Group. Groundwater in the chert is too brackish to be of use.

Exploratory drilling of an area of Quaternary sand adjacent to the present pumping field is recommended.

INTRODUCTION

Carnamah is a northern wheatbelt town on the Geraldton Highway, 188 miles north of Perth. It has a population of about 370.

Water is supplied to the town from a catchment which yields an average 3 million gallons per annum, and from shallow sands at Winchester, 7 miles south of the town. Overabstraction from these sands has resulted in a marked increase in groundwater salinity and it has become necessary to locate additional supplies. The Moora Group, a sequence composed mainly of chert and orthoquartzite which provides water for several towns about 50 to 75 miles south of Carnamah, crops out near Winchester. Accordingly a hydrogeological investigation has been made of these rocks in the Carnamah area at the request of the Public Works Department, the primary object being to delineate their extent and assess the groundwater potential. Geological mapping with an associated groundwater census was done between 4th and 13th April, 1967.

A more detailed geological investigation of the Moora Group has been completed recently by G. H. Low and L. N. Wall and some of their results are incorporated.

TOPOGRAPHY

The major control on the topography is geological. The Mt. Scratch Siltstone and the Permian Nangetty Formation form the flat, low-lying saline areas on the west and probably underlie the Yarra Yarra salt lakes. These flats are succeeded to the east by a narrow zone of low, rounded hills and ridges of the Moora Group, succeeded in turn by gently undulating granite hills. In general the natural surface rises from west to east. Intermittent saline creeks drain westerly towards the large Yarra Yarra saline system. The average annual rainfall is about 15 inches, and ranges between 4 inches and 29 inches.

GEOLOGY

Rocks exposed are of Archaean, Proterozoic, and Permian age with overlying Quaternary alluvium.

Archaean

The Archaean is represented by a massive, medium-grained, porphyritic granite often well-jointed and intruded by dolerite dykes. Generally it either crops out or occurs at shallow depth and weathers to a coarse feldspathic sand with the typical kaolinitic weathering profile often being absent.

Proterozoic

The *Moora Group* type section near Coomberdale is subdivided by Logan and Chase into four formations. Near Carnamah no subdivision is possible as only the Coomberdale Chert appears to be present. This is a sequence of chert, chert breccia, and orthoquartzite, often well-bedded and dipping at about 30 degrees to the west. Occasional interbedded siltstone appears towards the west.

The chert contains colonial organisms resembling stromatolites (*Collenia*) which reflect the original calcareous nature of the sediments. Several caves have also been preserved, one directly south of points 4 and 5, while there are several sink holes in the yellow sand area which trends eastwards from points 15 and 79. (See Plate 3.)

The contact between the Archaean and the overlying Moora Group is either faulted or, less commonly, unconformable. The Moora Group is intruded by dolerite dykes and its structure is complicated by the north-south faulting shown on Plate 3. Farther south Low and Wall (pers. comm.) have found evidence of northeast-trending shear zones with associated minor multi-directional faults and shear zones. They are postulating similar faulting near Winchester but this has not been shown on either of the accompanying plates.

The chert is white, yellowish and reddish and weathers to yellow clay and sand. Extensive tracts of yellow sand, such as immediately south and east of Winchester, overlie clay and chert. The sand varies in thickness from a few inches to perhaps 20 feet and may have been derived from the chert by illuviation of the clay fraction.

The *Mt. Scratch Siltstone* is a purple-reddish, well-bedded siltstone which dips very steeply to the west. It may be in faulted contact with the Moora Group. Only one very thin dolerite dyke was seen to intrude it.

Permian

The *Nangetty Formation*, exposed only in the extreme northwest of the area, is a white to reddish, fine-grained, very poorly sorted tillite containing occasional boulders of granite and chert. It is flat-lying and unconformably overlies the Mt. Scratch Siltstone.

Quaternary

The Quaternary alluvial sediments are mainly sandy and may in many instances be derived from the Moora Group cherts. Near Winchester several south-westerly trending sandy washes mark drainage lines from the Moora Group, while coarse, sandy colluvium is often found near granite outcrops. North of Carnamah at point 84, the origin of a narrow belt of sand parallel to the adjacent salt lake is uncertain.

HYDROLOGY

Groundwater characteristics are closely related to the geology and will be discussed accordingly. Reference should be made to the points marked on Plate 3.

Archaean

Water in the granite and weathered granite is in most instances too saline for domestic use. Domestic quality water occurs only in the coarse sandy colluvium near granite hills, usually in poor supply and at shallow depth. Thus No. 18 is an 18-foot well which produces 600 gallons of 500 ppm water per day. Several bores have been drilled to intersect joints in the unweathered rock; for example, No. 72 was drilled 90 feet into granite and yielded 1,500 gpd of 3,255 ppm water.

Water from the granite is in poor supply and too saline for domestic use.

Proterozoic

The *Moora Group*, between Moora and Watheroo, occasionally yields large supplies of fresh water from fractures in the chert. Near Carnamah however it yields only brackish water and where recharge is very slight, as near points 103 and 104, the salinity may be as high as 11,000 ppm. Recharge is either by runoff from the granite or by infiltration of water from the overlying yellow sand. Bores 39 and 40 which are both located on a creek draining nearby granite, yield 4,000 to 5,000 gpd of 2,200 to 2,500 ppm water from the chert. An adjacent abandoned bore No. 38 does not benefit from this recharge and produced water too saline even for stock use.

In the yellow sand areas, the fresh water often found at shallow depths may extend into the upper weathered chert profile. However the quality deteriorates rapidly with depth as illustrated by the following salinity data obtained from a Public Works Department bore in the present pumping field.

Depth (feet)	Salinity (ppm)
25	350
35	1,650
45	2,100
60	5,700

Moora Group rock, weathered in situ, was encountered at about 25 feet in this bore.

Yields from the chert may be quite high. The Main Roads Department pump 30,000 gallons per day from a water-filled cave in the chert, on high ground about half a mile south of points 4 and 5, the water salinity being 4,300 ppm. In no instance was domestic quality water noted in the Moora Group and therefore its development for a town water supply cannot be recommended.

The reason for the higher groundwater salinity at Carnamah than at Moora is not readily apparent in a restricted investigation such as this. It could be a result of lower rainfall and topography and hence poorer recharge conditions at Carnamah.

The *Mt. Scratch Siltstone* yields only very saline water.

Groundwater in the Permian Nangetty Formation is similar to that in the Mt. Scratch Siltstone. Well No. 109 situated on a slope above the salt lakes became too saline and was abandoned.

Quaternary

Domestic quality water is generally evailable from shallow soaks and wells in the yellow sand areas south and east of Winchester. Several examples are cited below:

No.	Depth (feet)	Water level (feet)	Salinity (ppm TDS)
4	9	6	550
5	?4	?2	980
13	10	4	900
15	8	4	200
50	3	surface	210
51	2	surface	500
78	6	3	140

No. 79 which is closer to the salt lakes, and at 17 feet is slightly deeper, has a salinity of 6,000 ppm. On Plate 4 it is apparent that there are several larger soaks and lakes in the sands but as they are subject to considerable evaporation during the summer months they are usually saline. Alongside the lakes however the groundwater is again of good quality. The lake shown on Plate 4 directly south of the sand ridge has a salinity of 12,800 ppm whereas the water in a soak excavated by the Main Roads Department about 20 yards north of the lake has a salinity of only 1,340 ppm.

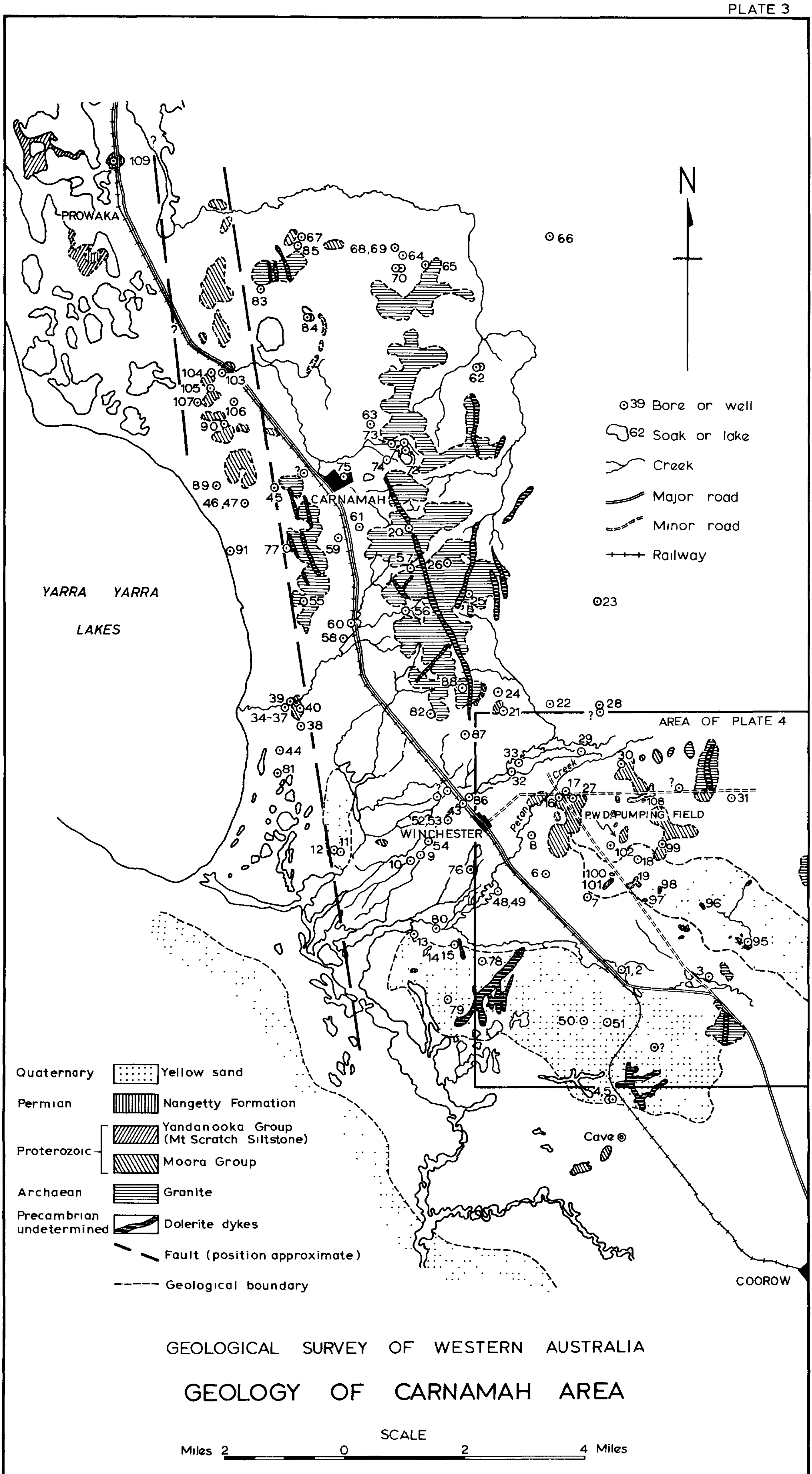
Small supplies of fresh water are also obtained from the stringers of sand which mark drainage lines from the Moora Group rocks near Winchester. Nos. 9, 10, 43, 52, 53, 54, and 86 all have salinities less than 750 ppm.

Two bores north of Carnamah, indicated by No. 84, yield small supplies of fresh water at a depth of 15 feet in the narrow strip of sand parallel to the lake.

The *Public Works Department pumping field* shown on Plate 4 is located in a yellow sand filled depression about 7 miles south of Carnamah and 2 miles east of Winchester. The yellow sand overlies Moora Group chert. The chert crops out to the east and west and a sand ridge cuts off the depression to the south. Several small salt lakes mark the main northerly-trending drainage line.

About 100 shallow auger holes have been drilled in the vicinity of the pumping field, permitting the Public Works Department to draw approximate surface and water table contours. Present production is from five or six spear points, of average depth 20 to 25 feet, centred near the bore with salinity 2,280 ppm. The depth to the water table in the centre of the depression is about 5 to 10 feet, and yields from individual spear points vary from 100 to 200 gph. The direction of groundwater movement is apparently to the north and northwest towards the large southwesterly-draining Petan Creek. Water is actually pumped towards Petan Creek from spear points in the northerly salt lakes in order to prevent the encroachment of salt water into the pumping field. Near the southern end of the depression the groundwater is moving slowly towards the sand ridge. The estimated rate of movement, from hydraulic gradients and an assumed hydraulic conductivity of 100 feet per day, is about 0.05 feet per day.

During the drilling programme in early 1961 it was noted that after 4.18 inches of rain had fallen in one week, water levels generally rose by about one foot nine inches. This indicates that after heavy showers, all the rainfall and much of the runoff from the flanks of the depression find their way to the water table. Unfortunately rainfall is usually light and well dispersed and may vary annually from 4 to 29 inches. Working on the average annual rainfall of 15 inches, Public Works Department engineers have calculated that recharge to the yellow sand is of the order of 5 million gallons per annum. Vollprecht (1962) estimated that in the 130 acres of the pumping field only 2 inches of the average annual rainfall



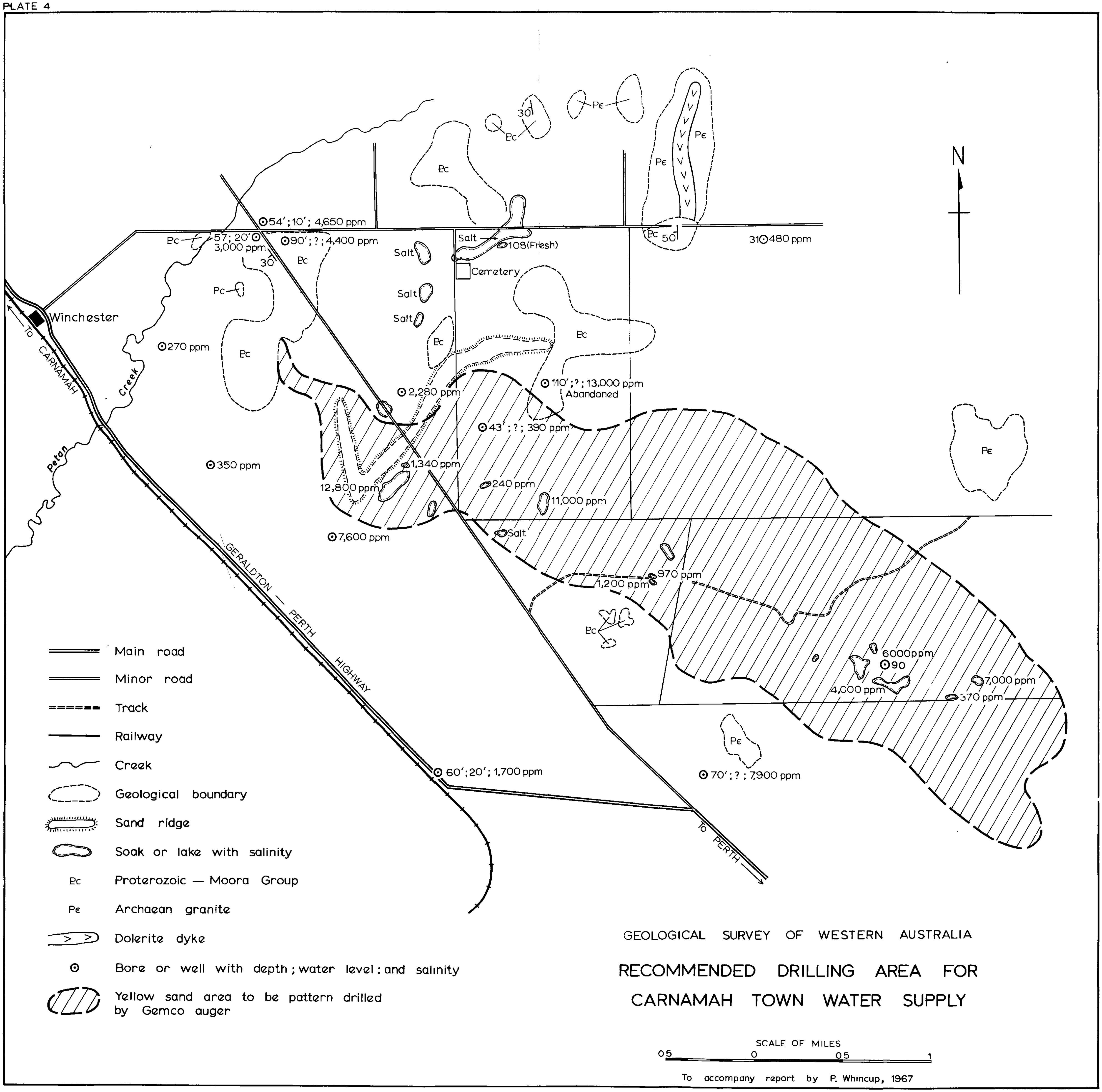
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

GEOLOGY OF CARNAMAH AREA

To accompany report by P. Whincup, 1967

7087

PLATE 4


Winchester
To CARNAMAH
Creek
Petan
GERALDTON — PERTH HIGHWAY
To PERTH
Cemetery
Salt
108 (Fresh)
54'; 10'; 4,650 ppm
57; 20' 3,000 ppm
90'; ?; 4,400 ppm
31 480 ppm
270 ppm
350 ppm
2,280 ppm
110'; ?; 13,000 ppm Abandoned
43'; ?; 390 ppm
1,340 ppm
12,800 ppm
240 ppm
11,000 ppm
7,600 ppm
970 ppm
1,200 ppm
6000 ppm
90
4,000 ppm
7,000 ppm
370 ppm
60'; 20'; 1,700 ppm
70'; ?; 7,900 ppm
N
Main road
Minor road
Track
Railway
Creek
Geological boundary
Sand ridge
Soak or lake with salinity
Pc Proterozoic — Moora Group
Pє Archaean granite
Dolerite dyke
Bore or well with depth; water level: and salinity
Yellow sand area to be pattern drilled by Gemco auger
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
RECOMMENDED DRILLING AREA FOR CARNAMAH TOWN WATER SUPPLY
SCALE OF MILES
0.5 0 0.5 1
To accompany report by P. Whincup, 1967

9781

reached the water table. This is an annual recharge of 5.5 million gallons and is roughly equivalent to the Public Works Department estimate.

Subsequent abstraction has gradually risen to the present figure of approximately 6.5 million gallons per annum, an annual overdraw of more than one million gallons. This has resulted in a lowering of water levels and a drastic twofold increase in salinity between March 1966 and 1967 to a value of 1,800 ppm. It is therefore a matter of some urgency that additional groundwater supplies be located.

Additional groundwater supplies

The Moora Group cherts are not a prospective source of domestic water. The only possibility is to locate additional yellow sand areas similar to that already being used, and it will be noted on Plate 4 that such an area occurs south and east of the present pumping field. There are numerous soaks and small lakes in the sands, which although they are saline, indicate the presence of a fairly extensive, shallow, water table aquifer. It is suggested that the sands be pattern-drilled with a Gemco auger drill to test their thickness and the groundwater quality. The best results will undoubtedly be obtained in the lower lying areas where the accumulations of yellow sand are greatest; on the higher ground many of the Gemco holes may be dry, as the water table there is deeper and chert may be encountered at shallow depths.

Two additional spear points have already been equipped.

However the sands are not a reliable groundwater source as their recharge is completely dependent on the annual rainfall and their safe yield in times of drought will fall appreciably. Alternative more distant supplies may eventually have to be sought.

CONCLUSIONS AND RECOMMENDATIONS

The Moora Group cherts near Carnamah yield only brackish water and are unsuitable for development as a town water supply. Domestic quality groundwater is available only from shallow yellow sand overlying the chert, and is already utilised east of Winchester. It is recommended that a similar yellow sand area, adjacent to and south-east of the pumping field, be test drilled for additional groundwater supplies. The high salinities of soaks and lakes in the sands are a result of direct surface evaporation and do not reflect the general groundwater quality. However the salinity does increase quite markedly with depth and drilling should be stopped when saline water is encountered. Recharge to the sands is by direct infiltration of rain and hence is very variable.

Thus, as a short term prospect, the additional shallow sand area is probably adequate, but eventually the location of a more reliable water supply for the town will become necessary.

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HYDROGEOLOGY OF THE EASTERN PART OF THE RAVENSTHORPE 1:250,000 GEOLOGICAL SHEET

by C. C. Sanders

ABSTRACT

A hydrogeological assessment of the eastern part of the Ravensthorpe 1:250,000 geological sheet area was made during regional mapping. There is groundwater of stock and occasionally of domestic quality near the coast, and also where Quaternary soils overlie Tertiary sediments in the southeastern part of the sheet. Elsewhere the groundwater is generally saline.

INTRODUCTION

Geological mapping and an associated groundwater census was carried out on the Ravensthorpe Sheet area during 1967 as a continuation of the hydrogeological assessment of the Esperance Sandplain. This area is undergoing very rapid farm development from virgin land, and as farms are new, there is a paucity of groundwater information. The bores so far constructed are mainly concentrated on well developed properties in the south-eastern corner adjoining the Esperance 1:250,000 geological sheet area. Usable groundwater mainly comes from Eocene siltstone and spongolite which are thinly draped over Precambrian granitic gneiss in the southern third of the sheet.

TOPOGRAPHY AND RAINFALL

The major topographic control is geological. Sofoulis (1958) divided the Ravensthorpe area into three distinct divisions on physiographic grounds.

The *Hinterland Division* (Salinaland of Jutson, 1934) has internal drainage, the foci being the salinas and dry lakes in the northernmost part of the sheet and on the adjoining Lake Johnston Sheet area. The rainfall is generally less than 14 inches per annum.

The northern boundary of the *Intermediate Division* is determined by the limits of the river systems which drain into the Southern Ocean. The southern boundary is a low escarpment which leads down to a narrow coastal plain.

A mantle of white to grey sand and sometimes red loamy soils supports low scrub and mallee, typical of the Esperance Sandplain. The area is deeply dissected in the vicinity of the pronounced drainage system, the rivers assuming youthful characteristics in their lower reaches where they cut Eocene rocks. Steep-sided, gorge-like valleys 100 to 150 feet deep and capped with breakaways 10 to 30 feet high are common, especially on the Oldfield River.

Rainfall over the division declines from about 22 inches per annum near the coast to 14 inches per annum at the northern limit. It is only after heavy and lengthy downpours that river flow occurs. Throughout most of the year rivers are dry except for disconnected pools. These are generally saline or brackish, though some pools are known to remain fairly fresh through the summer drought period.

The *Coastal Division* is a narrow plain covered by vegetated sand dunes and long limestone ridges. Rainfall ranges from 22 to 25 inches per annum.

GEOLOGY

Morgan (pers. comm.) believes that the Esperance Sandplain is a fossil archipelago which existed in Eocene times when the sea level was nearly 1,000 feet higher than at present. The plain is now a dissected plateau covered by Quaternary soils.

The underlying basement of granitic gneiss is exposed as "islands" through the soil cover and in the dissected river valleys (Plate 5). Associated with the gneiss are dyke rocks, which have undergone high-grade metamorphism and are now represented by hornblende granulite (amphibolite). These rocks are severely deformed and crossfolded but show a general south-westerly foliation trend.

North of the Esperance-Ravensthorpe road the basement rocks lie about 15 feet beneath the Quaternary soil mantle. South of the road thin Tertiary sediments no greater than 150 feet thick, unconformably overlie the gneiss.

During Eocene times the sea covered most of the present south coast region, and in the Esperance-Ravensthorpe area siltstone and spongolite were deposited in a marine archipelago similar to the Archipelago of the Recherche. High gneissic islands were only thinly covered by sediment and, with erosion since Eocene times, are seen today as inliers protruding through the Tertiary and Quaternary cover. The spongolite is richly fossiliferous, but most carbonate parts are now replaced by opaline silica. Solution cavities and sink holes are common.

The Quaternary soils are divisible into two distinct units which are developed over the Precambrian and Tertiary rocks: red sandy loam over limestone, and sand over pisolites and yellow clay.

The *red sandy* loam forms a plain over gneiss in the northern part of the Sheet. It is an ancient soil horizon which continues inland from the sand and pisolite soils. In places the loam is stripped away by wind action exposing a cemented limestone and sometimes a silcrete sub-horizon.

The *sand horizon* covers most of the area and consists of white to grey siliceous soil over pisolite and yellow clay, the sand ranging in thickness from a few inches to a few feet. Pisolite has formed near the base of the sand and in areas of strong wind erosion it has been exposed to form patches of usable gravel. The yellow clay sub-horizon underlies the pisolite zone and results from weathering of the upper surface of the Eocene sediments; it is present therefore only in the southern part of the Sheet.

HYDROLOGY

Groundwater characteristics are closely related to the geology.

Gneiss is the predominant rock type, and the ground water overying it is very saline, because of the low permability of the rock itself, and availability of soluble salts resulting from the decomposition of basic minerals. However, stock quality water occasionally occurs within coarse, sandy colluvium found in shallow depressions and drainage lines, and in zones of deeply weathered gneiss. These occurrences are rare.

Rainwater runoff from the basement rocks tends to become quickly saline. A field salinity test 30 miles inland on the Lort River immediately after heavy rain, registered a salt content of 18,000 ppm TDS. Salinity measurements on water in the lower reaches of the river made some days later after widespread rains gave similar values.

Farmers working properties on the banks of the Young River report that the river is normally saline except after flash floods. When these floods occur, the rivers rise and fall very quickly and fresh water is occasionally trapped in semi-permanent rock pools. This water slowly becomes saline due to evaporation and salt uptake from the confining rocks, but it generally remains of stock quality until late summer.

The denudation of large tracts of land in the area for pasture improvement, especially where the sandplain overlies gneiss, is likely to lead to a severe salt problem in the future. The natural vegetation is probably highly salt tolerant, and the deep root system of some shrubs would tend to prevent the upward movement of saline water resting on the gneiss. The planting of extensive areas with shallow rooted pastures such as most clovers, is liable to lead to salting due to a rise of the salt water table. The root system may also not be deep enough to prevent wind erosion, particularly in late summer, when pasture is in a poor condition. A suggested remedial measure would be the reafforestation of paddock boundaries and road verges, using deep-rooting, salt tolerant trees. In areas still to be developed farmers should clear selectively, leaving untouched as much natural vegetation as possible. The planting of pasture around numerous clumps of trees is advisable.

Eocene sediments, which unconformably overlie the Precambrian bedrock, are the most important aquifers in the south coast region. The northern limit of their extent on the Ravensthorpe Sheet area is about the Esperance-Ravensthorpe road, except in the area adjacent to the Esperance Sheet. Even there, the sediments have been eroded out a few miles north of the road. They occur in well drained, elevated, and high rainfall ports of the sheet.

The Tertiary rocks are of variable thickness, but sufficient information is not yet available to accurately predict depth to bedrock at any particular locality. Islands of granitic gneiss commonly protrude through the sediment mantle and these further complicate any estimate of thickness. The functioning bores in the area generally tap water from zones between 30 and 80 feet below ground level. This interval can probably be regarded as the target zone for groundwater.

Water of variable quality occurs sporadically throughout the Eocene sediments, generally resting on the regionally saline groundwater body. These accumulations normally occur under sandy depressions, at the base of drainage channels, and as a result of rainfall runoff from hills of bedrock entering permeable sections of Eocene sediments. The latter intake environment is the most important in the Neridup area, east of Esperance, where granitic hills shed less saline water than the gneissic hills on the Ravensthorpe Sheet.

Sandy sink holes are the best surface indication of permeable strata within the Eocene sediments. Subsidence results from leaching of the carbonate fraction from the underlying rocks by percolating rainwater.

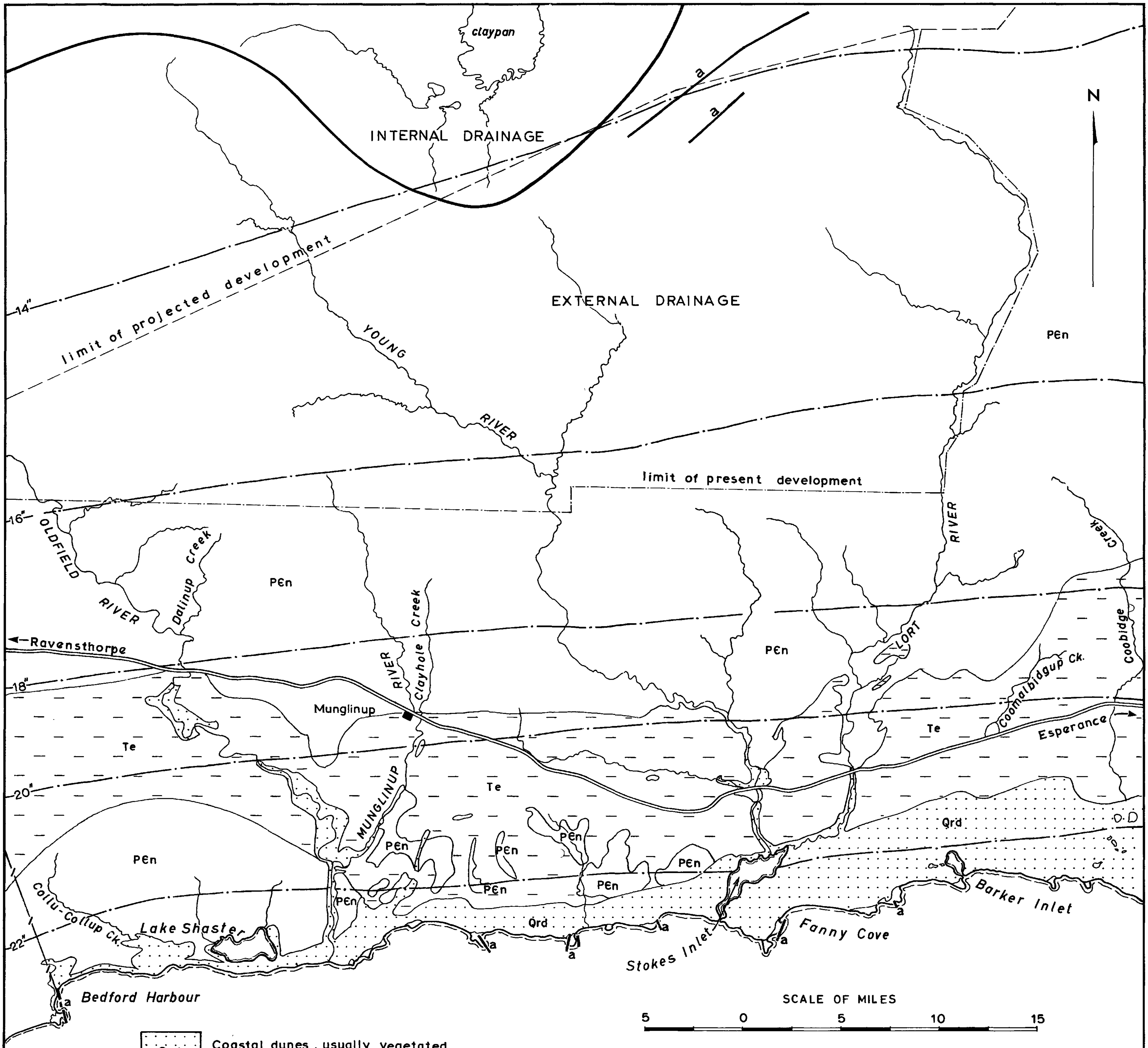
Intake occurs over the whole area of Tertiary rocks through sink holes and drainage channels. Depressions which hold water throughout the year are common but are considered poor sites for usable groundwater, as they indicate perching of the surface water on bedrock or impermeable saline clay.

Bores sunk into the Eocene rocks often silt up after some years, due to an influx of fine-grained sediment. This may be overcome by inserting a fine gravel packing around the bore screen or spear.

Alluvial flats and benches on the Young and Oldfield Rivers are a possible source of good quality groundwater. They are fairly common in the lower reaches of the rivers, but as yet have not been tested. Intake to these alluvial zones would be from rainfall and occasional flash floods.

The *coastal dune system* is a potential source of potable groundwater. The system occupies the narrow coastal plain adjoining the inland Precambrian plateau. The dunes are vegetated and often attain a height of 300 feet, although over a large area the interdune flats are at an elevation of 50 feet or less above sea level. Rainfall runoff from the dunes can be expected to collect in the interdune flats and soak downwards into the underlying sand and limestone. The effect is more pronounced where the dunes have been cemented to ridges of hard limestone.

The coastal area of the Ravensthorpe Sheet is mainly gazetted as faunal reserve, but even so, watering points could be established in this area for use by farmers during summer or in times of drought.



Qrd	Coastal dunes, usually vegetated and alluvium along river channels
Te	Siltstone and spongolite mostly overlain by Quaternary soils
PЄn	Gneiss with rare coarse-grained granite; mostly overlain by yellow clay, pisolite and surface white sand
a	Amphibolite dyke; intrudes gneiss
	Isohyet in inches

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SUBSURFACE GEOLOGICAL SKETCH MAP
of the
EASTERN PART OF THE RAVENSTHORPE SHEET AREA

To accompany report by C.C.Sanders,1967

7214

CONCLUSIONS AND RECOMMENDATIONS

The gneissic basement rocks of the Ravensthorpe Sheet generally yield saline water, although brackish water may occur in deeply weathered zones and in sandy colluvium. Supplies from these accumulations are small.

Domestic and stock quality groundwater is available from Eocene siltstone and spongolite which are thinly draped over gneiss in the southernmost part of the Sheet. Bore sites should be selected in sandy depressions and drainage channels where recharge is greatest. The groundwater is usually encountered at depths between 30 and 80 feet below ground level.

Alluvial flats and benches on the Young and Oldfield Rivers should yield usable groundwater. Also, semi-permanent rock holes in the rivers occasionally hold water of stock quality until late summer.

The coastal dune system which lies mainly within Crown Land is a suitable environment for the accumulation of potable groundwater. As yet, this source has not been tapped. Farmers in the area should be advised on the necessity to conserve natural vegetation as a means of controlling a rise in the salt water table, which is expected to occur on the Sandplain with continual clearing. Planting of salt tolerant trees on paddock boundaries and road verges is a remedial measure suggested for those areas already cleared.

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DRILLING FOR WATER IN COBB DEPRESSION, NORTH OF WINGELLINA

by R. A. Farbridge

ABSTRACT

The results of drilling suggest that there is a potentially important groundwater source in Phanerozoic sedimentary rocks in the Scott 1:250,000 Sheet, about 55 miles north of Wingellina.

Yields of 10,000 to 13,500 gph of water with salinity of 1,000 to 2,000 ppm have been obtained, although samples analysed have salt contents above those acceptable for human consumption.

Further testing will be necessary to evaluate aquifer potential and the suitability of the water for industrial and domestic purposes.

INTRODUCTION

There is current mineral exploration in the Warburton-Blackstone region for vanadium, nickel, and copper. The region is arid, the surface waters are ephemeral, and little is known of the groundwater potential.

Any mineral exploitation would require large water supplies close to the ore bodies.

LOCATION

This remote area, approximately 1,100 road miles from Perth, is near to the junction of the boundaries of Western Australia, South Australia, and the Northern Territory.

Formed tracks link the mining camps with Giles meteorological station and with Warburton mission.

The tested area is about 55 miles north of Wingellina on the Giles road, where the latter crosses an extensive dune field.

GEOLOGY

Phanerozoic sediments are found in a shallow east-west trough which rests upon the Precambrian rocks of the Musgrave block (Horwitz and others, 1967).

Flat-lying porcelanous siltstone, kaolinitic sandstone, and conglomerate crop out as low rubbly breakaways or mesas. Superficially the sediments may be silicified and lateritised.

Well-rounded polished pebbles have been found on ironstone gravel surfaces, which are thought to overlie Phanerozoic sediments. The limits of the Phanerozoic rocks, based on surface evidence, are shown in Plate 6.

A reconnaissance gravity survey (Lonsdale and Flavelle, 1962) established an extensive gravity low termed the Cobb gravity depression, which can be traced into the south Canning Basin.

The position of the -95 mg gravity anomaly coincides roughly with the presumed centre of the sedimentary trough, as deduced from surface evidence by the Geological Survey of Western Australia in 1966. Subsequently, Southwestern Mining which was advised to test these sediments for water supplies, sited and drilled three bores.

BORE DATA

Bores drilled by: Southwestern Mining.

Date: 12th April 1967 to 15th April 1967.

Plant: Drillmaster.

Method of Testing: Drum measurement of water expelled by compressed air during drilling.

Logged by: H. R. Butler.

Bore No.	Depth (ft.)	Present S.W.L. (ft.)	Water cut (ft.)	Salinity (ppm)	Supply (gph)	Aquifer(s)
D57	350	73·5	90	1,075	10,000 at 350′	Phanerozoic sandstones
D58	93	55·5	83	Not analysed	Soak	Weathered acid gneiss
D59	400	127·5	80	2,013	13,500 at 400′	Phanerozoic sandstones

DRILLING RESULTS

Bores D57 and D59 were both successful, D57 being drilled on the centre of the Bouguer anomaly. D58 encountered chlorite schist and acid gneiss at shallow depth.

Bore D57, drilled to 350 feet, cut a section of interbedded ferruginous clayey sandstone, white medium to coarse sandstone, and minor ferruginous sandy clay. The groundwater was confined, possibly by a ferruginous clay seal. Bore D59 penetrated 400 feet of light-grey or ferruginous partly conglomeratic sandstone with clayey sand and clays; the groundwater was apparently unconfined.

The drill cuttings from Bore D59 showed that much of the clastic material was derived from igneous — metamorphic terrains. (Australian Mineral Development Laboratories Rept. MP 2976/67 *in* West. Australia Geol. Survey file 121/1967, p. 42).

A palaeontological examination of drill cuttings failed to find any evidence of their age (Cockbain, 1967).

WATER ANALYSES

(Analyses by N.T. Administration Animal Industry Branch)

	D57	D59
Hardness:		
Total	318 ppm	824 ppm
Carbonate	173	189
Non-carbonate	145	635
Analyses:		
Chloride	275	695
Sulphate	178	431
Bicarbonate	211	230
Nitrate	65	43
Fluoride	1·4	1·5
Carbonate	Nil	Nil
Sodium	205	320
Potassium	36	47
Calcium	39	112
Magnesium	65	133
pH	7·8	7·9
Total dissolved salts	1,075	2,013
Remarks :	Chemically suitable for adult consumption. Unsuitable for children under 1 year due to high nitrate.	Chemically unsuitable for human consumption due to high Mg^{++}, Ca^{++}, SO_4^{--}

CONCLUSIONS

The drilling suggests that large supplies of underground water may exist in an extensive sedimentary trough.

The bores were drilled with an air percussion rig, and hence the quoted supplies represent water which was forced to the surface by a compressor unit. They cannot be regarded as having been effectively tested.

There are no data on water salinity changes with depth, and salinities quoted may be of water derived from several aquifers in the same bore.

Because the water salinity from Bore D59 is high (2,013 ppm) and the water is unsuitable for human consumption, salinities in any further bores must be tested during drilling.

Successful development of these water-bearing beds may assist the exploitation of the known nickel prospects of Wingellina and the vanadium prospects of the Jameson Range.

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PROSPECTIVE DAM SITES ON THE SHAW RIVER, PILBARA DIVISION

by F. R. Gordon

INTRODUCTION

In 1966 the Public Works Department requested a geological reconnaissance of eight prospective dam sites in the Pilbara area for possible use by heavy industry such as an iron ore pelletizing plant at Port Hedland or Roebourne.

Three of the sites, North Pole, North Shaw, and Hillside, were situated on the Shaw River. Site examination of North Pole occupied a day, in the company of Messrs. K. C. Webster and C. Ion of the P. D. & I. Branch of the Public Works Department. North Shaw and Hillside were examined in a day for each.

A light aircraft flight, chartered by P. W. D., provided a quick perspective of all the locations.

GENERAL PHYSIOGRAPHY

The Shaw River in its upper course traverses the Nullagine Plateau in a young valley with deep gorges and ravines. On leaving Nullagine rocks, it flows across wide plains largely composed of granite, and therefore has the appearance of an old river. On the plains there are long and narrow ridges of hard rocks such as dolerite, in which water gaps have been cut, as at the Hillside site. The middle reaches of the Shaw are in rugged country consisting of sandstone, conglomerate, and jaspilite. Both North Shaw and North Pole sites are located at river constrictions in this area.

NORTH POLE DAM SITE

The North Pole site (Plate 7) is located on the Marble Bar 1:250,000 Sheet (SF/50-8) at latitude 21° 05′ S and longitude 119° 17′ E, and is approximately 4 miles northwest of the battery at the North Pole mining centre. Access is gained from the Port Hedland-Marble Bar road at a point 68 miles from Port Hedland, thence by bush track 30 miles to near the North Pole centre, followed by a 3-mile walk down creek and river bed to the site.

The site is topographically favourable as there is a reasonably wide storage basin immediately upstream of the river constriction. There is a deeply incised creek on the upstream edge of each abutment, and valley depth and straightness suggest the presence of a fault or major unconformity striking at right angles to the river direction. The course of the Shaw River is also at right angles to the general strike of the quartzite and sandstone beds that occur as strike ridges, and thus form valley constrictions. Local deformation resulted in a folded structure with joints nearly at right angles to the river bed on the right hand bank. The rock is a well-bedded quartz sandstone, and the joints dip to the north at angles between 25° and 45°. A minor joint set at right angles to the main folding is parallel to the river, but no leakage is expected (Plate 10A).

On the left hand bank the beds strike nearly parellel to the river and have a steep to vertical dip. The bedding planes are about 6 inches apart in a coarse, metamorphosed sandstone. The visible joints are an easterly striking set with vertical dip, and flat joints that dip at 30° to the north or downstream. The rock on this abutment is mainly a siliceous pebble conglomerate with inclusions of banded iron formation and a grey to ferruginous red weathered matrix. There is a thin mantle of scree on the abutment where thin-bedded rocks have weathered, and massive boulder conglomerate beds are exposed at the foot of the abutment.

The effective height of the dam is governed by a small saddle on the ridge forming the left abutment, about 330 feet above river bed. While the strike of the bedding on this abutment favours the passage of water, the joints are reasonably well closed, and flat sheet jointing is probably of equal significance. The valley slopes on both abutments are quite steep.

NORTH SHAW DAM SITE

The North Shaw site is in the gorge of the Shaw River, 5 miles northwest of the North Shaw mining centre, on the Marble Bar 1:250,000 Sheet

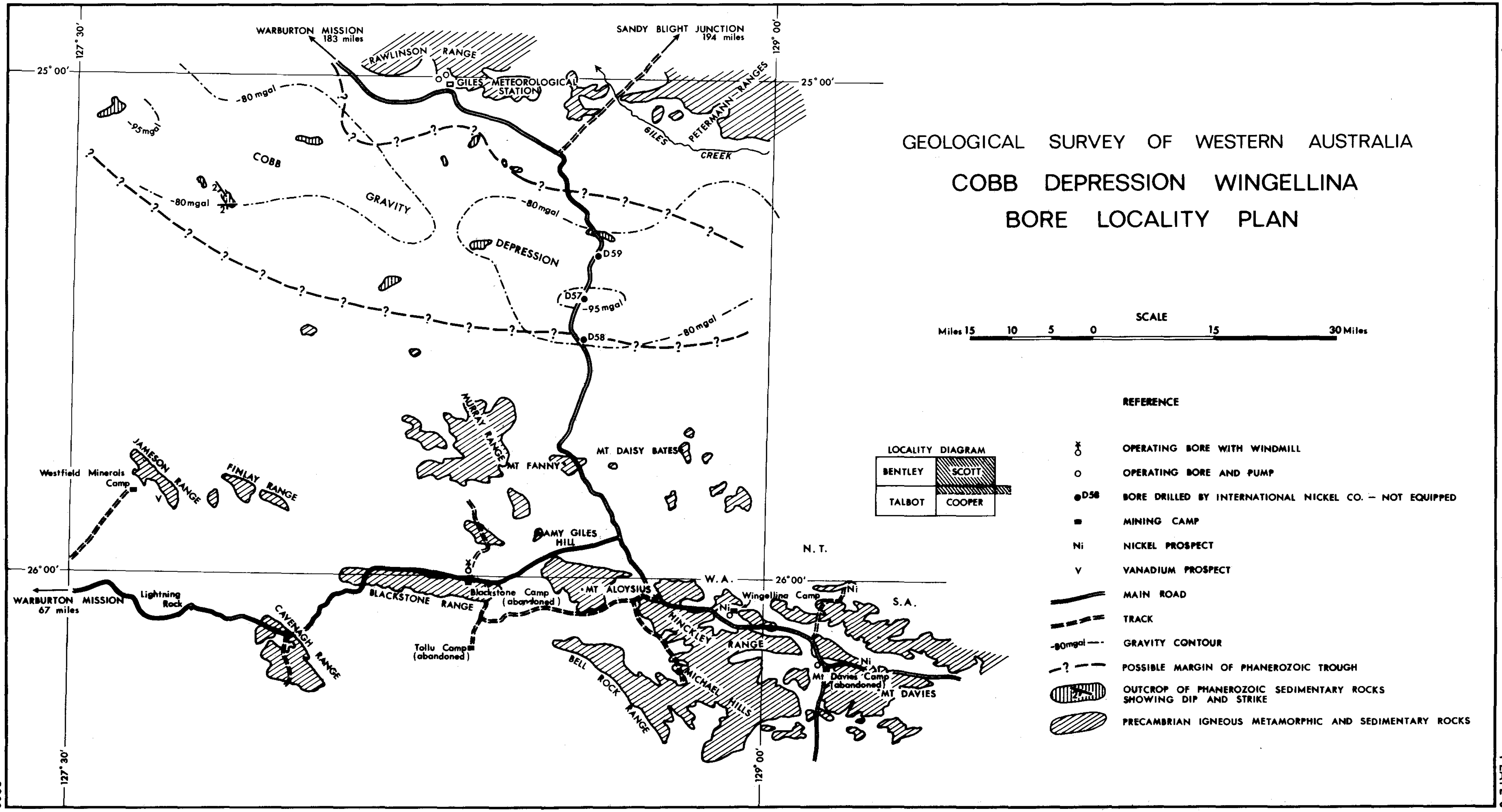
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
COBB DEPRESSION WINGELLINA
BORE LOCALITY PLAN
SCALE
Miles 15 10 5 0 15 30 Miles
REFERENCE
OPERATING BORE WITH WINDMILL
OPERATING BORE AND PUMP
D58 BORE DRILLED BY INTERNATIONAL NICKEL CO. – NOT EQUIPPED
MINING CAMP
Ni NICKEL PROSPECT
V VANADIUM PROSPECT
MAIN ROAD
TRACK
-80mgal GRAVITY CONTOUR
POSSIBLE MARGIN OF PHANEROZOIC TROUGH
OUTCROP OF PHANEROZOIC SEDIMENTARY ROCKS SHOWING DIP AND STRIKE
PRECAMBRIAN IGNEOUS METAMORPHIC AND SEDIMENTARY ROCKS
LOCALITY DIAGRAM
BENTLEY
SCOTT
TALBOT
COOPER
WARBURTON MISSION 183 miles
SANDY BLIGHT JUNCTION 194 miles
RAWLINSON RANGE
GILES METEOROLOGICAL STATION
PETERMANN RANGES
GILES CREEK
25° 00'
127° 30'
129° 00'
26° 00'
-80 mgal
-95 mgal
COBB
GRAVITY
DEPRESSION
D59
D57
D58
MURRAY RANGE
MT FANNY
MT DAISY BATES
JAMESON RANGE
FINLAY RANGE
Westfield Minerals Camp
AMY GILES HILL
N. T.
W. A.
S. A.
WARBURTON MISSION 67 miles
Lightning Rock
CAVENAGH RANGE
BLACKSTONE RANGE
Blackstone Camp (abandoned)
Tollu Camp (abandoned)
MT ALOYSIUS
Wingellina Camp
HINCKLEY RANGE
BELL ROCK RANGE
MICHAEL HILLS
Mt Davies Camp (abandoned)
MT DAVIES
Ni

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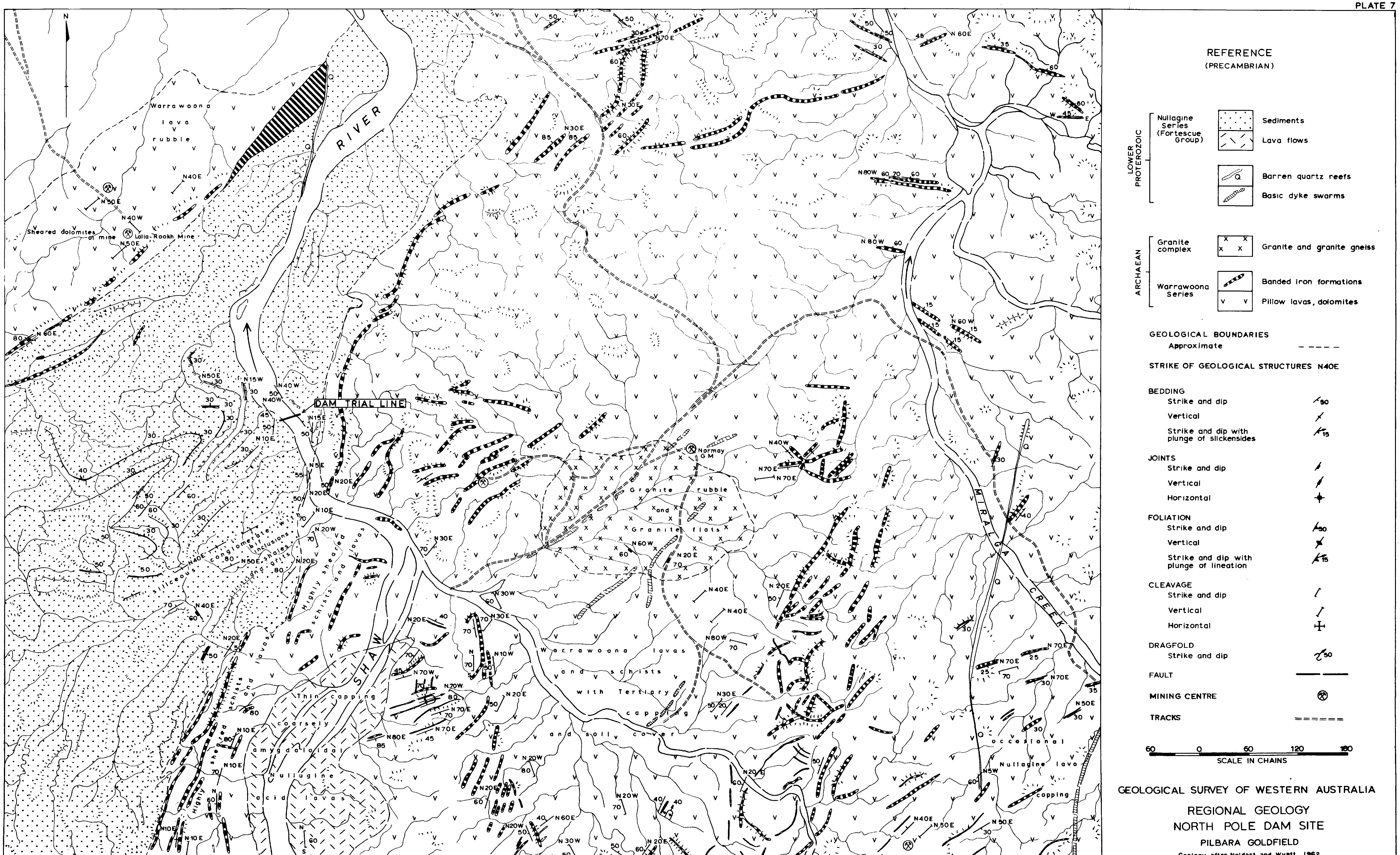
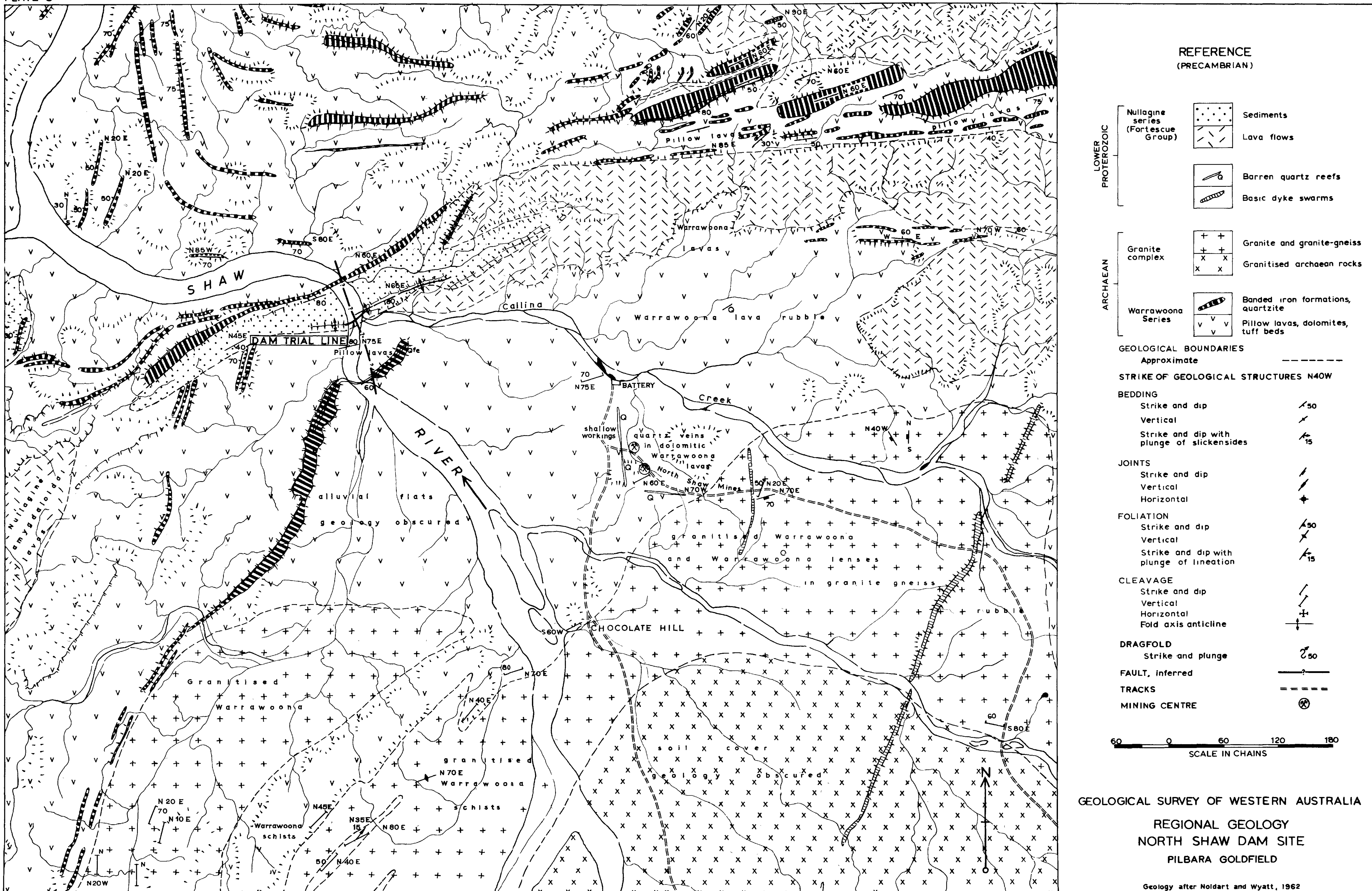
PLATE 6

PLATE 7


REFERENCE
(PRECAMBRIAN)
LOWER PROTEROZOIC
Nullagine Series (Fortescue Group)
Sediments
Lava flows
Barren quartz reefs
Basic dyke swarms
ARCHAEAN
Granite complex
Granite and granite gneiss
Warrawoona Series
Banded iron formations
Pillow lavas, dolomites
GEOLOGICAL BOUNDARIES
Approximate
STRIKE OF GEOLOGICAL STRUCTURES N40E
BEDDING
Strike and dip
Vertical
Strike and dip with plunge of slickensides
JOINTS
Strike and dip
Vertical
Horizontal
FOLIATION
Strike and dip
Vertical
Strike and dip with plunge of lineation
CLEAVAGE
Strike and dip
Vertical
Horizontal
DRAGFOLD
Strike and dip
FAULT
MINING CENTRE
TRACKS
60 0 60 120 180
SCALE IN CHAINS
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
REGIONAL GEOLOGY
NORTH POLE DAM SITE
PILBARA GOLDFIELD
Geology after Noldart and Wyatt, 1962
Warrawoona lava rubble
RIVER
SHAW
Sheared dolomites at mine
Lalla Rookh Mine
DAM TRIAL LINE
Normay G.M.
Granite rubble and Granite flats
MIRALGA CREEK
Warrawoona lavas and schists with Tertiary capping and soil cover
Highly sheared schists and lavas
Siliceous N40E conglomerate with inclusions of shales and grits
Thin capping coarsely amygdaloidal Nulllagine acid lavas
Highly sheared schists and lavas
occasional Nullagine lava capping

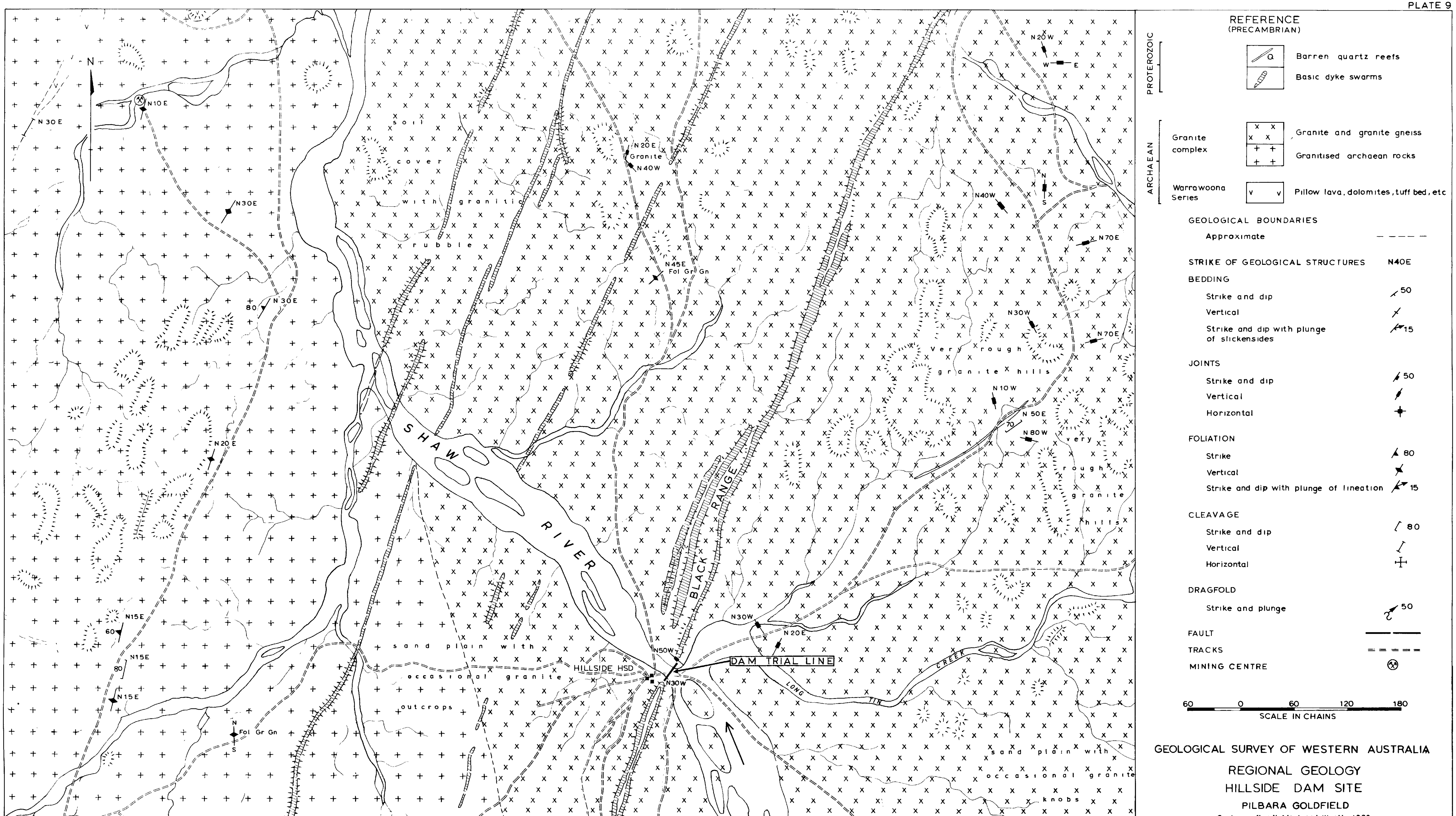
9868

PLATE 8

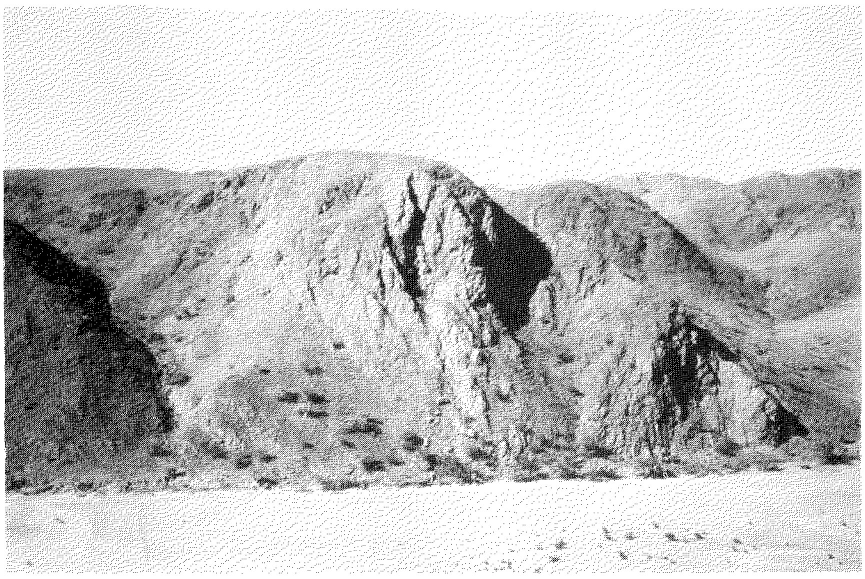

REFERENCE
(PRECAMBRIAN)
LOWER PROTEROZOIC
Nullagine series (Fortescue Group)
Sediments
Lava flows
Barren quartz reefs
Basic dyke swarms
ARCHAEAN
Granite complex
Granite and granite-gneiss
Granitised archaean rocks
Warrawoona Series
Banded iron formations, quartzite
Pillow lavas, dolomites, tuff beds
GEOLOGICAL BOUNDARIES
Approximate
STRIKE OF GEOLOGICAL STRUCTURES N40W
BEDDING
Strike and dip
Vertical
Strike and dip with plunge of slickensides
JOINTS
Strike and dip
Vertical
Horizontal
FOLIATION
Strike and dip
Vertical
Strike and dip with plunge of lineation
CLEAVAGE
Strike and dip
Vertical
Horizontal
Fold axis anticline
DRAGFOLD
Strike and plunge
FAULT, inferred
TRACKS
MINING CENTRE
SCALE IN CHAINS
60
0
60
120
180
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
REGIONAL GEOLOGY
NORTH SHAW DAM SITE
PILBARA GOLDFIELD
Geology after Noldart and Wyatt, 1962
SHAW
RIVER
Callina
Creek
DAM TRIAL LINE
BATTERY
CHOCOLATE HILL
Pillow lavas
Warrawoona lavas
Warrawoona lava rubble
shallow workings
quartz veins in dolomitic Warrawoona lavas
North Shaw Mines
alluvial flats
geology obscured
granitised Warrawoona and Warrawoona lenses in granite gneiss
rubble
Granitised Warrawoona
granitised Warrawoona schists
Warrawoona schists
soil cover
geology obscured
Nullagine amygdaloidal lavas
N

9869

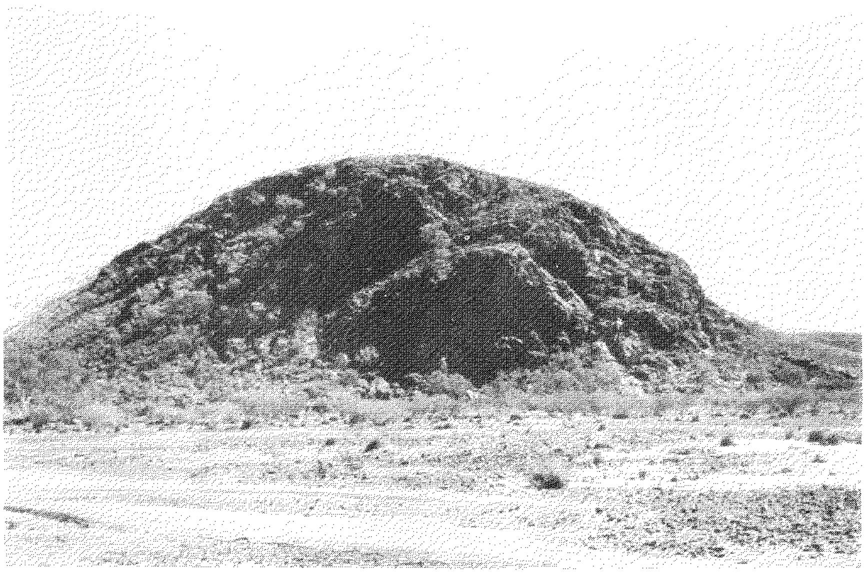
PLATE 9


REFERENCE
(PRECAMBRIAN)
PROTEROZOIC
Barren quartz reefs
Basic dyke swarms
ARCHAEAN
Granite complex
Granite and granite gneiss
Granitised archaean rocks
Warrawoona Series
Pillow lava, dolomites, tuff bed, etc
GEOLOGICAL BOUNDARIES
Approximate
STRIKE OF GEOLOGICAL STRUCTURES
N40E
BEDDING
Strike and dip
Vertical
Strike and dip with plunge of slickensides
JOINTS
Strike and dip
Vertical
Horizontal
FOLIATION
Strike
Vertical
Strike and dip with plunge of lineation
CLEAVAGE
Strike and dip
Vertical
Horizontal
DRAGFOLD
Strike and plunge
FAULT
TRACKS
MINING CENTRE
60 0 60 120 180
SCALE IN CHAINS
SHAW RIVER
BLACK RANGE
LONG TIN CREEK
DAM TRIAL LINE
HILLSIDE HSD
soil cover with granitic rubble
Very rough granite hills
very rough granite hills
sand plain with occasional granite outcrops
sand plain with occasional granite knobs
Fol Gr Gn
Granite
N10E
N30E
N20E
N40W
N45E
N15E
N20W
N70E
N30W
N10W
N50E
N80W
N50W
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
REGIONAL GEOLOGY
HILLSIDE DAM SITE
PILBARA GOLDFIELD
Geology after Noldart and Wyatt, 1962

9870



A. North Pole Dam Site, right abutment viewed from left abutment; F1190.



B. North Shaw Dam Site, the anticlinal folding forming the left abutment, and the faulting and large joint openings are shown; F1191.

C. Hillside Dam Site, large joint openings in the dolerite; F1192.

(SF/50-8) at latitude 21° 18′ S, longitude 119° 20′ E. Access is gained from Pilga homestead, 35 miles from Marble Bar on the Hillside road, thence by bush track 13 miles north, followed by a 3-mile walk downstream.

The site is in a band of sedimentary rocks of the Proterozoic Nullagine Series flanked by quartzite and banded iron formation (Plate 8).

The first constriction of the Shaw River at the commencement of the gorge is superficially attractive, but the banded iron formation of the right abutment is folded and large gapes have developed, which would certainly allow heavy leakage through the thin ridge (Plate 10B). Furthermore, Callina Creek breaches the reservoir rim a mile east of the site, and this gap is almost as wide as the main river valley.

The second constriction which constitutes the proposed dam site, is formed by the breaching of an anticlinal ridge of boulder and pebble conglomerate. There appears to be a slight displacement of about 200 yards of the right abutment in a downstream direction with respect to the left abutment. Air-photo interpretation indicates that the anticlinal ridge forming the right hand abutment and reservoir rim has been displaced by a north-northeasterly striking fault at a position 1½ miles east of the site. The movement has been west block (abutment) to the north. The hinge line is in the present position of the river. A zone of breakage or of minor faulting may be expected in the river bed, transecting the foundation area of the dam.

The right abutment rises steeply from the sandy river channel to 212 feet above it, then rises gently. The rock, a boulder and pebble conglomerate, is extremely competent and is sheeted on bedding planes which are from 1 to 10 feet apart, and there is often a gap of from 1 to 6 inches between the beds and occasionally an overhang. The fold axis strikes at 085° and plunges at 20° to the west. From the crest of the ridge a breccia-filled fault zone about 6 inches wide follows the direction of the fold axis down to river level. Two joint sets, in addition to bedding set, are present; one strikes 065° and dips south at 75° to 90°. These joints are open to 1 inch and are about 20 feet apart. The other joint set strikes 175° and dips at 65° to 75° to the west.

The left abutment is likewise dominated by widely separated, open-bedding joints that have an anticlinical form (Plate 10B). Some of the gapes are up to 12 inches wide, and the fold axis appears to be horizontal and strikes 110°. The abutment is further broken by three faults that are parallel to the ridge, and are vertical or steeply dipping. The result is that the left abutment is composed of a number of huge blocks of conglomerate, averaging about 15 feet in thickness and of great structural integrity within each block.

It is apparent that leakage would take place through the left abutment and immediate reservoir rim, but to a lesser extent through the right abutment. The problem of rendering the gaping conglomerate beds watertight is relatively simple because of the separation and size of the openings.

There is probably some faultng of the rock in the river bed, and this will probably be a path of leakage.

HILLSIDE DAM SITE

Hillside dam site is on the Shaw River, ½ mile southeast of Hillside homestead, on the Marble Bar 1:250,000 Sheet (SF/50-8, sheet 108) at latitude 21° 43′ S, longitude 119° 24′ E. Access is from the Marble Bar—Hillside road, ¼ mile distant from which a new road runs through the dam site to J. A. Johnstone's tin workings immediately upstream, and to the mining village 4 miles to the north.

The site is one of the few constrictions of the middle reaches of the Shaw River and is formed by the breaching of a long narrow ridge of dolerite, known as Black Range. This dyke has an exposed length of approximately 50 miles and is almost continuous, with minor breaks and displacements. It is prominent topographically and rises to about 200 feet above the granite plain. The dyke trends north-northeast and the Shaw River flows north-westerly through the water gap.

In the vicinity of the right abutment the Black Range ridge is composed of three dolerite dyke bodies, separated by granite, and has a total width of about 1,500 feet. At the actual water gap there is only one dyke and the ridge has a width of about 350 feet (Plate 9). The water gap is about 700 feet across, and there are occasional dolerite outcrops showing through alluvium. A bore 22 feet deep has been sunk on the proposed centre line, yielding a good supply of water for a tin treatment plant, immediately upstream (Whincup, 1966). From the river bed the right abutment rises steeply for 120 feet to the crest of the range, which then rises gently to the north-northeast.

The coarse-grained quartz dolerite is highly jointed. The major division is from flatly dipping joints (horizontal to a 10° dip southwesterly) that have an average incidence of 1 every 6 feet, and are open from 1 to 12 inches. There are two other sets; (1) 038° strike, dip 70° northwest with an incidence of 1 every 10 feet, and (2) strike 125°, vertical dip, incidence 1 in 10 feet (Plate 10C). It is impossible to tell if the blocks visible in the abutment are in situ or not, but it is highly likely that the joint openings were all filled with calcite, and thus any exposure showing open joints has settled and the blocks have rotated to some extent. It is likely that all openings above ground water level are open, or partly so.

The left abutment consists of two dolerite dykes enclosing a horse of granite, but in every other respect it is similar to the right abutment.

Although there are zones of intense jointing alternating with zones of comparatively little mechanical division, the expectation is that the right abutment will transmit large quantities of water.

COMPARISONS AND CONCLUSIONS

It is assumed that all sites are topographically satisfactory and that the reservoir rim is complete in each case. Table 1 shows a comparison of the three.

Table 1

COMPARISON OF SHAW RIVER DAM SITES

	North Pole	North Shaw	Hillside
1. Foundations	Sandstone and conglomerate beds	Conglomerate beds	Quartz dolerite
2. Effective height	300 feet	200 feet	120 feet
3. Structure	Deflected strike ridge	Anticlinal ridge	Dyke
4. Leakage	Little expected	Large on left abutment	Large on right abutment
5. Adverse faulting	....	Probably in river bed	....
6. Other defects	Poor access	....	Floods tin mine
7. Advantages	....	....	....
8. Storage	Valley flat and valley	Wide valley flats	Flat plain
9. Distance to Port Hedland	72 miles	85 miles	110 miles

On the evidence available, the North Pole dam site is the only site on the Shaw River worth further consideration.

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RAILWAY CUTTINGS IN ROCK

by F. R. Gordon

INTRODUCTION

Although the basic methods used to determine the stability of slopes are the same for open pits and for railway cuttings, the approach to safety is fundamentally different. In an open pit operation certain risks are justified with the expectation that slope failure will possibly only involve further excavation. Also many pit operations are of limited duration with constantly changing wall positions. A railway cutting has a normal engineering life expectancy of 100 years, during which time the batters are not altered, and should remain stable.

Even a minor slope failure on a rail cutting could be catastrophic because of the fixed line; whereas a road allows for manoeuverability of vehicles which usually carry fewer passengers. A blocked road usually causes less delay because of alternate routes or by-passes.

Railway construction for development was common at the turn of the century, and the present building of iron ore railways has coincided with the development of rock mechanics, the new phase of engineering and geology. The necessity for flat grades for modern trains has meant that deep cuttings are imperative, while improved methods of stripping, drilling, blasting, and haulage have lowered the cost of rock excavation and made the construction of deep cuttings feasible. It is against the background of the construction of a standard gauge railway which will carry iron ore in Western Australia that aspects of rock cuttings are viewed.

The railway is under construction between Kalgoorlie, through the iron ore deposits of Koolyanobbing, to Fremantle and Kwinana on the coast, a distance of about 390 miles. Most of the cuttings evaluated are situated in the Avon Valley Deviation which follows a natural transportation route along the valley of the Swan-Avon River, through dissected topography of the Darling Range between Northam and Upper Swan (Plate 11).

GEOLOGICAL SETTING

Rock Types

The two main elements of the geology are the Precambrian basement complex of the Darling Range and fault scarp, and the Tertiary and Recent superficial deposits mantling both the sedimentary sequences of the Perth coastal plain and the weathered Precambrian rocks of the Darling Range and scarp.

The main rock types of the Precambrian are: a granite-gneiss-amphibolite suite; a banded granite gneiss suite hybridized in part; intruding batholithic granite; pegmatites and quartz veins; quartz dolerite intrusions; metasedimentary quartzite and schist of the Jimpeding Series (Prider, 1944) in the vicinity of Toodyay.

Geomorphology

The mature valley of the Swan-Avon River system has a fall of 450 feet in 60 miles, and follows foliation or bedding structure except in a few gorge areas where control is from shears or big joints. Generally the valley is asymmetric in cross section, with physical weathering of sheet jointed structures dominant on the northern side and chemical decay of rock dominant on the southern side. Down-cutting by the river has resulted in some exposure of rock in the valley bottom, partly mantled by alluvium. A typical cross section is shown in Figure 3.

Jointing

The dominant joint sets are sheet joints conforming to the topography, and joints following the bedding or foliation.

Sheet joints not only dominate the mechanical division of the rocks, but often have a profound effect on chemical weathering by channelling the movement of groundwater, and rock decay often results in the production of thick bands of clay between layers of fresh granite. Sheet joints may also limit water movement by an impervious lower joint surface, resulting in complex layering, with clay passing abruptly to fresh granite (Figure 4), rather than the transitional sequence resulting from prolonged chemical weathering (Table 1 and Figure 5).

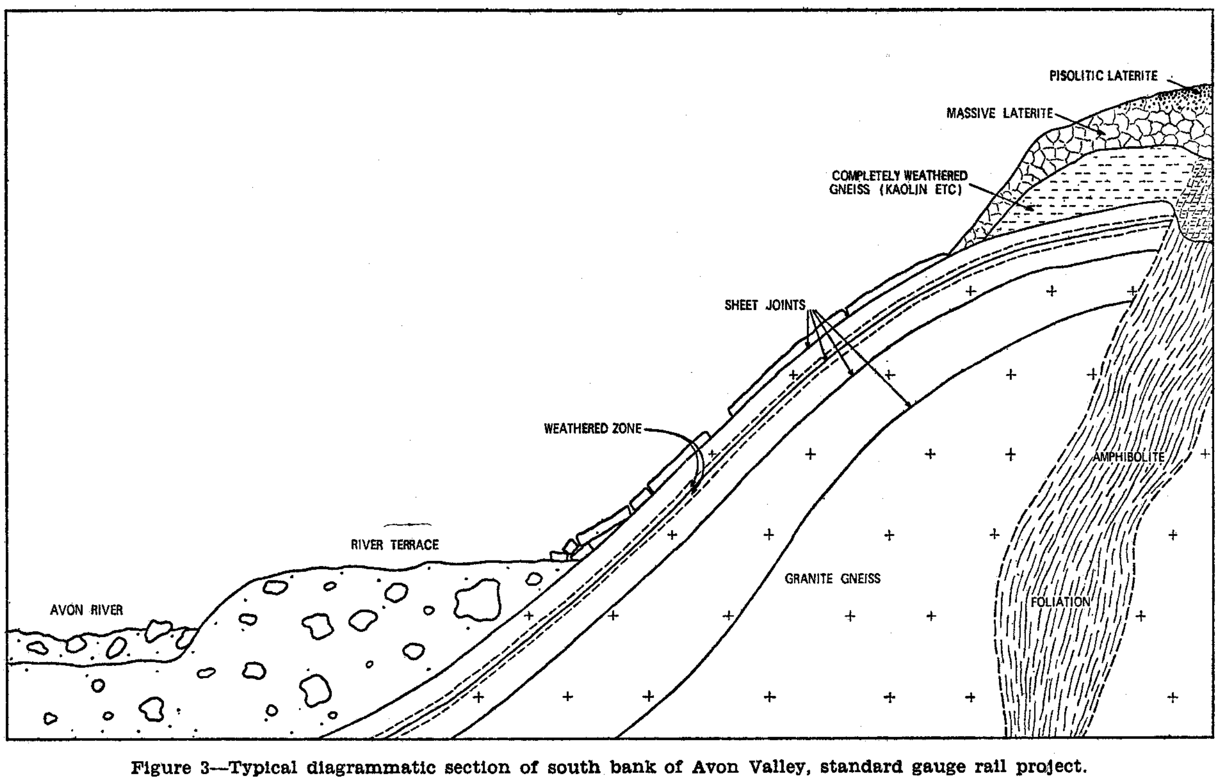

Figure 3—Typical diagrammatic section of south bank of Avon Valley, standard gauge rail project.

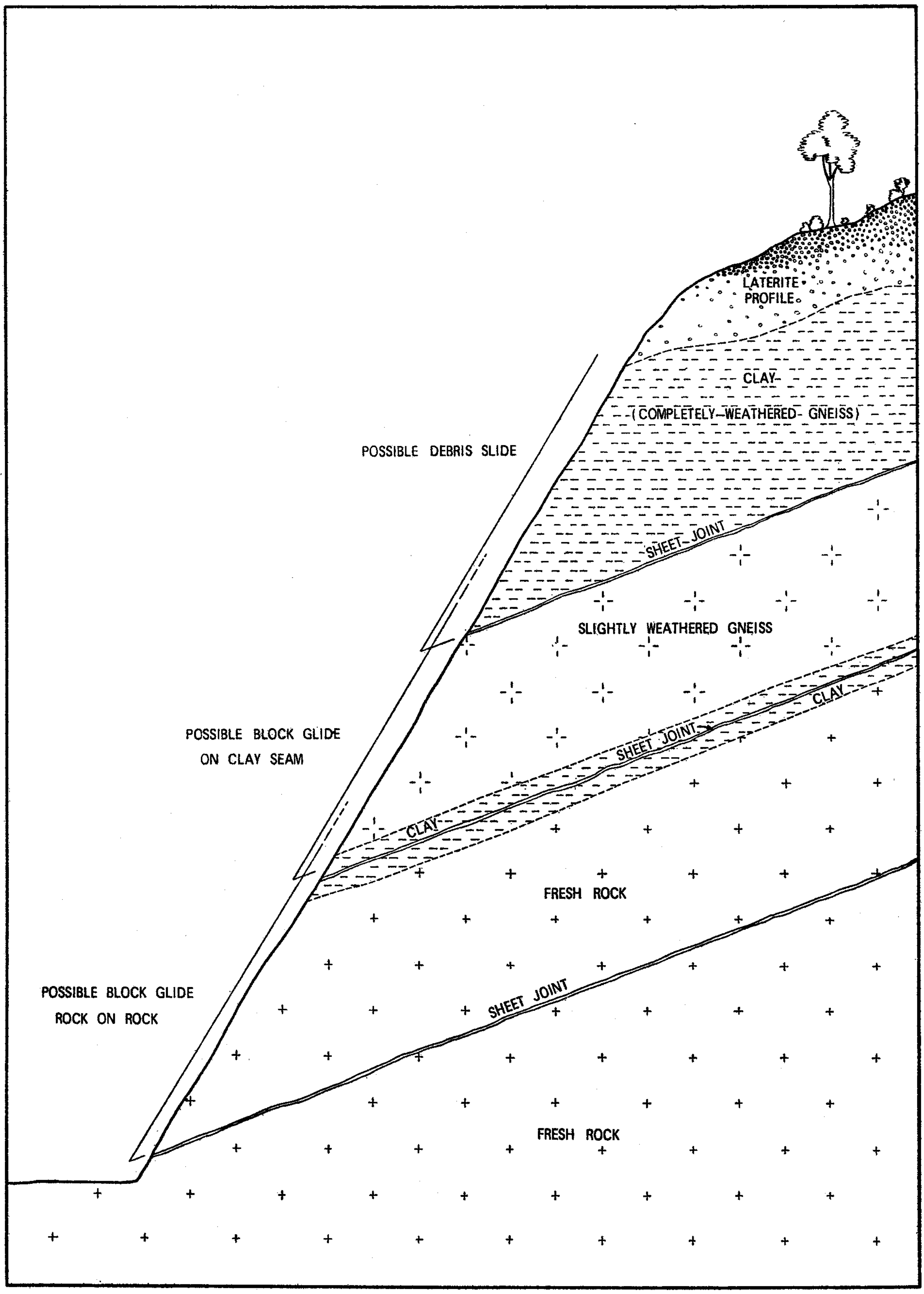

Figure 4—Diagrammatic section showing conditions of instability in cuttings resulting from sheet joints, standard gauge rail project.

SLOPE STABILITY

Rock and soil mechanics

There has been some discussion as to the precise point in a weathered sequence when soil mechanics methods are not valid and where rock mechanics techniques should be employed.

In the cuttings of the Avon Valley Deviation it was found that no guide lines could be fixed, that the stability of some sequences of highly weathered rocks of the kaolin phase (Gordon, 1964) were dominated by relict geological structures, and that the stability of some blocks of fresh rock was governed by the soil properties of joint-filling material. The interface between the two disciplines was often found to extend from ground level to Formation Level, a depth of as much as 120 feet, and even in isolated places where a clear-cut division was apparent, variations of rock type and depth of weathering allowed little lateral extension. Most of the stability problems were encountered in this interface zone.

Type of slope failure

The various types of slope failure encountered are classified according to the inherent geological defect, rather than to the physical form of the failure. The effects of construction methods on stability have been discussed elsewhere (Gordon, 1966) and this aspect is noted only incidentally. Many of the types of slope failure have developed after excavation, that is, long after a decision has been made on the overall angle of the batter. Each of these problems is an individual one, and in most instances the underlying geological cause was not discerned during the initial site examination. To this extent the unstable areas represent partial failures of the investigation and design methods employed, as failure in a railway cutting must be classified as the failure even for one individual block. It is conceded that the calculation or pronouncement of a stable slope angle is an overall approximation, although it is possibly the most essential part of exploration and design phases. Experience to date indicates that the most comprehensive site examination possible under any economic limits would not discern all the possible types of failure.

Sheet joints

One of the most serious difficulties in the investigation stage concerned the presence and influence of folded geological structures or of large, curved, and spoon-shaped joint surfaces. The latter are of common occurrence as sheet joints in the granite terrain, and the non-planar structures often contain clay partings. Mathematical expression of such features in rock mechanics calculations is difficult, moreover empirical judgments are apt to err, as the general attitude of the sheet joints was connected with topography at the time of formation, which is not necessarily the same as the present scene.

The rock type, attitude of geological structures, and the amount and nature of other types of jointing all have a bearing on the configuration and prominence of sheet joints. A dominant joint pattern usually means that the sheet joints, which are formed later than joints of tectonic character, are absent or are not prominently developed. Where the continuity of the granite gneiss is interrupted by dolerite dykes, which are usually well jointed, the sheet joints continue, displaced along one of the flat pre-existing cooling joints. Sheet joints are not well developed in areas where the older amphibolite-gneiss suite has been folded, with the protection of joints in the more brittle gneiss. The sheet joints dipping into the cut were invariably on the uphill or highest side.

The following types of slope instability are a direct result of the presence of sheet joints:

(1) debris falls of completely weathered rock above a joint plane,

(2) block glide of rock on clay as a sheet joint replacement,

(3) block glide of rock on rock on an over-step joint plane.

These three cases are illustrated in a section (Figure 4).

If the joint plane is dipping steeply enough, then unstable conditions exist in all three cases. The presence of clay as a joint filling or as a seam adjacent to the sheet joint, means that the critical angle for sliding is much less than if the joint opening were clear and the sliding mass was rock over rock. Terzaghi, (Muller, 1959) assumes a frictional angle of 15° for rock layers with clay partings, and of 25° if there are no clayey flakes. This sliding angle is independent of the angle of the batter.

In essence, the stability of the blocks lying on the sheet joint planes depends on their dip into the cut, which is broadly related to the topography of the hill or spur being cut. The most steeply dipping, and thus the most potentially dangerous joints, are usually found on the flanks of the hill rather than in the centre, unless the cross section profile has a considerable cross fall. Although this happens occasionally, most of the hillslopes involved in cutting slope at 10° to 25° across the direction of the cutting. The critical issue then is the presence or absence of clay in the joint opening, and this varies in individual joints, making it almost impossible to assess the conditions of stability by conventional site exploration.

Once the cutting had been opened up, the exposure of the seams of clay dipping into the cutting and overlain by large masses of fresh rock meant that an assessment of stability had to be made, and remedial measures instituted if there were danger of rock slides. Remedial works were usually restricted to pinning or anchoring, as large-scale removal was not practicable because of topography and a need to retain berms.

Cross joints

Strongly developed open joints that intersect the walls of a cutting in plan between 45° and 90° may be a cause of weakness, as the explosive force from blasting may be channelled along the joint openings giving considerable overbreak. Well developed cross joint sets that are not parallel may also channel the explosive effect, leaving a toe.

Intersection of two cross joints is a situation often allowing block gliding. The usual condition is that the joints dip in opposite directions, with the intersection open to the top. Bedding planes dipping at 55° and striking across a cutting and intersected by occasional major points dipping at 60° in the opposite direction, frequently allowed large blocks to slide in the Windmill Hill Cutting.

Folding

Folding of granite gneiss has usually caused local breakage and deformation, and this condition allows rock falls from the batter. In areas of metasediments, where schists are often enclosed in quartzites, there has been destructive bedding slip on deformation, allowing the development of drag folds and fracture cleavage in the less competent schists.

In the Windmill Hill cutting, folding of Precambrian metasediments has produced a structural terrace of tremolite-biotite schist enclosed in quartzite. Two series of rock slides occurred during construction, the first as a consequence of the geological structure, the second as a result of the construction methods used in remedial works.

The sequence of events of the first series of rock slides is shown in Plate 12. The presence of a band of tremolite-biotite schist enclosed in quartzite had been inferred during preliminary route reconnaisance because of the lack of outcrop or scatter. The structural terrace was exposed during excavation of the bottom lift, where the folding had induced intense fracture cleavages in the tremolite-biotite schist. This had resulted in the production of lens shaped pieces of schist separated by mica flakes. The exposure of this material containing moisture, and the development of groundwater head were facts which caused alarm when noticed during a geological inspection, and

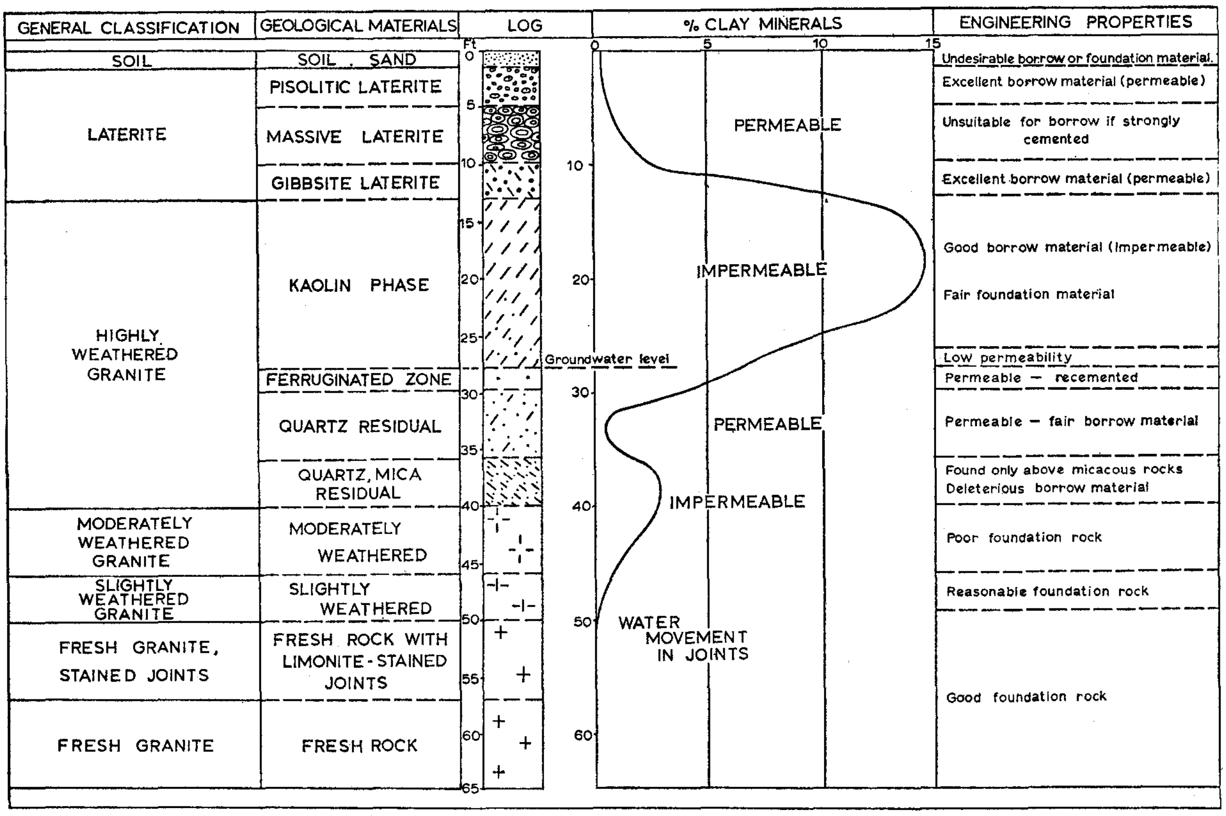

Figure 5—Weathering profile of granitic rocks.

the cutting was cleared of men and machine immediately. Two hours later phase 2 of the sliding occurred, followed by the others in order of undermining, and the whole fallen mass moved as a debris slide following heavy rains, one month later.

It was apparent that if the structural terrace were of significant extent, then a major problem of stability of quartzite sliding on crushed decomposed mica, was involved. The structure was determined by diamond and air track drilling before the excavation of the lowest lift was authorized. The rockslide area in the schist was to be battered back at 35°, and the three top lifts were successfully shapped by dozer when the contractors decided to remove the lower slice by drilling and blasting. The 35°-55°-90° template used to set the angle of the air track drills was wrongly marked with the result that the holes were drilled at 55° to 60°, and on blasting, the slope failed again, proving that the first collapse was not unique. The slide was cleared and the slopes were cut down by a small dozer at 30° for the bottom batter and 35° for the remainder.

Fault zones

The nature and size of a fault or shear zone and the rock type involved is important in determining any deleterious effect on the stability of a cutting. The direction and attitude that a fault makes with the length of a cutting is however of critical importance. The most dangerous situation is found when thin clay filled crush zones strike along the cutting and dip into it at flatter angles than the batter. It would be fortuitous if such a structure were detected under the conditions of a thick weathered mantle. As the strike of the fault makes greater angles with the cutting, the problems lessen, and only the stability of the crush zone itself becomes of concern. If the crush zone is wide and ravels, remedial work is necessary. Faults striking across the cutting may be important, however, if they are intersected by other faults or prominent joints in a conjunction that would aid block gliding or rockfall (Plate 13A).

Rock weathering

The soils resulting from the in situ decomposition of granitic rocks vary widely in properties according to the depth of weathering, and to the nature of the original rock. At the ground surface a fairly uniform laterite residual reveals few characteristics of the underlying rocks and the differences due to changes in rock types only become more apparent under the laterite mantle. The weathering profile is shown in detail in Table 1, and it is apparent that the more or less horizontal stratification resulting from weathering does not persist as the mineral character of the granite gneiss complex changes laterally. In extreme cases in banded granite gneiss with vertical foliation, outcrops or quartzose granite or massive amphibolite are found immediately adjacent to 60 to 80 feet of completely weathered rock (Gordon, 1963). Deep downcutting of the Avon-Swan River through the weathering profile and the presence of sheet joints are important modifiers.

The weathering of dolerite dykes is found to be a function of the strike. There are two dominant strikes for the dykes, easterly and north-northeasterly. The more northerly trending dykes appear to be the more resistant to weathering and often form the spine of a ridge, while the easterly dykes are often weathered to depths of 20 to 30 feet.

Figure 5 is a geological diagram of one of the cuttings illustrating the variety of rock types, and the complexity of the profile of chemical weathering developed on them. These elements and the mechanical division of the rock by joints make it almost impossible to get an accurate geomechanical picture of the site before construction commences.

The variable depth and nature of weathering mean that overshooting will occur unless the blasting pattern is altered (Plate 13B). It also means that the initial site exploration would need to be exhaustive, in order to effectively assess the optimum slope angle for the batters.

INFLUENCE OF BEDDING AND FOLIATION PLANES

When stratified or foliated rock is inclined towards a free face, especially at a flatter angle than the face, the decreased shear strength of the rock is liable to result in sliding. Such gross structures can be recognised in the reconnaissance stage and the batter angles can be adjusted to contain them.

In some of the minor cuttings near Northam, close to the Avon River, moderately weathered granite gneiss with steeply inclined foliation planes was exposed at ground level. The foliation joint planes in the upper 10 feet or so were filled with debris and this area was impermeable. Excavation of the cuttings intersected open water-bearing planes, and saturation of sub-base filling, mud boils, and settlement occurred. Deep interceptor ditches on the uphill side of the cutting and use of coarse rock fill instead of weathered rock sub-base were methods used to overcome these problems. A similar seepage problem occurred at 49 miles 25 chains where ground water was confined in flatly dipping foliation planes of amphibolite schist. Vertical, well-jointed quartz reefs acted as natural channels, and springs developed in the cutting floor after excavation (Gordon, 1966).

MAINTENANCE

Chemical and mechanical weathering of rocks exposed in a cutting are often sufficiently rapid to allow debris and rock falls in the first year of maintenance. Post-excavation relaxation or rebound is thought to occur in the deeper rock cuts and this appears to be conditioned by the method of blasting (Gordon, 1966). In Cut No. 2 well-jointed amphibolite and gneiss that are moderately weathered have deteriorated notably in a period of two years, and debris falls are frequent.

Pyrite mineralisation is a notable feature at the base of Horseshoe Hill cutting below the former ground water level. Where abundant pyrite crystals are disseminated in the altered amphibolite matrix, there has been wholesale deterioration of the rock by chemical oxidation, and subsequent debris falls.

The rock cuttings were designed with a 10-foot wide berm sloping into the hill at 1 in 12, placed every 30 or 40 feet vertical height of the cutting. The benches were meant to be continuous to allow access for clearing of accumulated debris. The shaping of the benches proved most difficult, and the outer angle was often lost due to shattering from 2, 3, or 4 adjacent blasts (Gordon, 1967). The corner between the toe of a slope and the bench, also proved difficult to shape correctly, either from under or overshooting. If the toe is undershot the efficacy of the bench is impaired, and remedial work which can only consist of trimming, usually oversteepens the lower part of the slope above, and weakens it at its weakest point.

DRAINAGE AND WATER PROBLEMS

Many of the cuttings had distinctive and often troublesome seepage patterns, and before remedial works were commenced, the various types of geological conduits were classified. These were: (1) sheet joints, (2) foliation joints, (3) bedding joints, (4) quartz veins, (5) variations in rock type (Gordon, 1966). The seepage trouble resulted in debris falls from cutting walls, and springs in the floors, saturation of the sub-base and the formation of mud boils.

Most of the cuttings were situated about half way up the gently sloping left bank of the Avon River. A small range of hills of bare granite gneiss forms the crest of the valley wall, and erosion in the valley has meant that the normal weathering sequence is truncated. The cuttings were deep enough to expose slightly weathered rock below the impervious weathered zone, and below the zone where joint openings were filled with weathering products.

A serious stability problem at Windmill Hill was partially caused by the development of a high piezometric head during construction, where a band of relatively impervious weathered schist was enclosed in open jointed quartzite. As the cutting advanced towards the schist which acted as a water barrier, the groundwater level in the excavated quartzite adjusted to formation level. At the time of collapse there was a differential head of 30 feet between the quartzites on either side of the schist, which caused it to collapse into the cutting, commencing in an area of fracture cleavage (Plate 12).

Fortunately in the two deepest cuttings near the Darling scarp, the ground water level was in gneiss with open limonite-stained joints, below the zone of deleterious weathering.

METHODS OF SITE EXPLORATION

With the benefit of hindsight, it is profitable to review methods of site exploration, and to suggest possible improvements to fit the cases developed in this paper.

At the completion of the reconnaissance survey, the depth and length of cutting are usually known, and these constants can be related to three initially important variables in the determination of safe batter slopes, which are (1) the mechanical condition of the rock, (2) the amount of chemical weathering, (3) spatial relationship of geological weaknesses to the cutting. The first step in the design stage should be precise geological mapping of the cutting area, followed by a rock mechanics joint survey. These studies should be supplemented by the drilling of exploratory holes with an air-track type drill, at a spacing of not more than 5 chains, the hole to be taken down to formation level, and the cuttings to be examined on the site by a geologist. Any anomalies should be diamond drilled.

The batter slopes may then be assessed and the cutting laid out on the assumption that the worst conditions apply from top to bottom unless other information is available. The initial cut in overburden is thus of maximum width. As the top lift is removed, the joint pattern should be reassessed as greater amounts of less weathered rock is revealed. The batter slopes for the remaining lifts are then determined, and if this is steeper than the initial figure, the width of the top bench is made correspondingly greater.

This however may involve a difficult contractural point, where the contractor could claim for compensation for less work and loss of profit. If there are indications of deleterious geological structures or of weathered rock at depth, more detailed investigation is needed including diamond drilling. One of the most necessary measurements is to determine the cross section profile of the rock spur or hillside as well as its shape as intersected by the length of the cutting. This is to give an idea of the possible dip angles of the sheet joints, if developed in the area.

Finally the geomechanical properties of the various rock types and their distribution must be considered in the light of the excavation method proposed, of which the blasting pattern in probably the most important factor.

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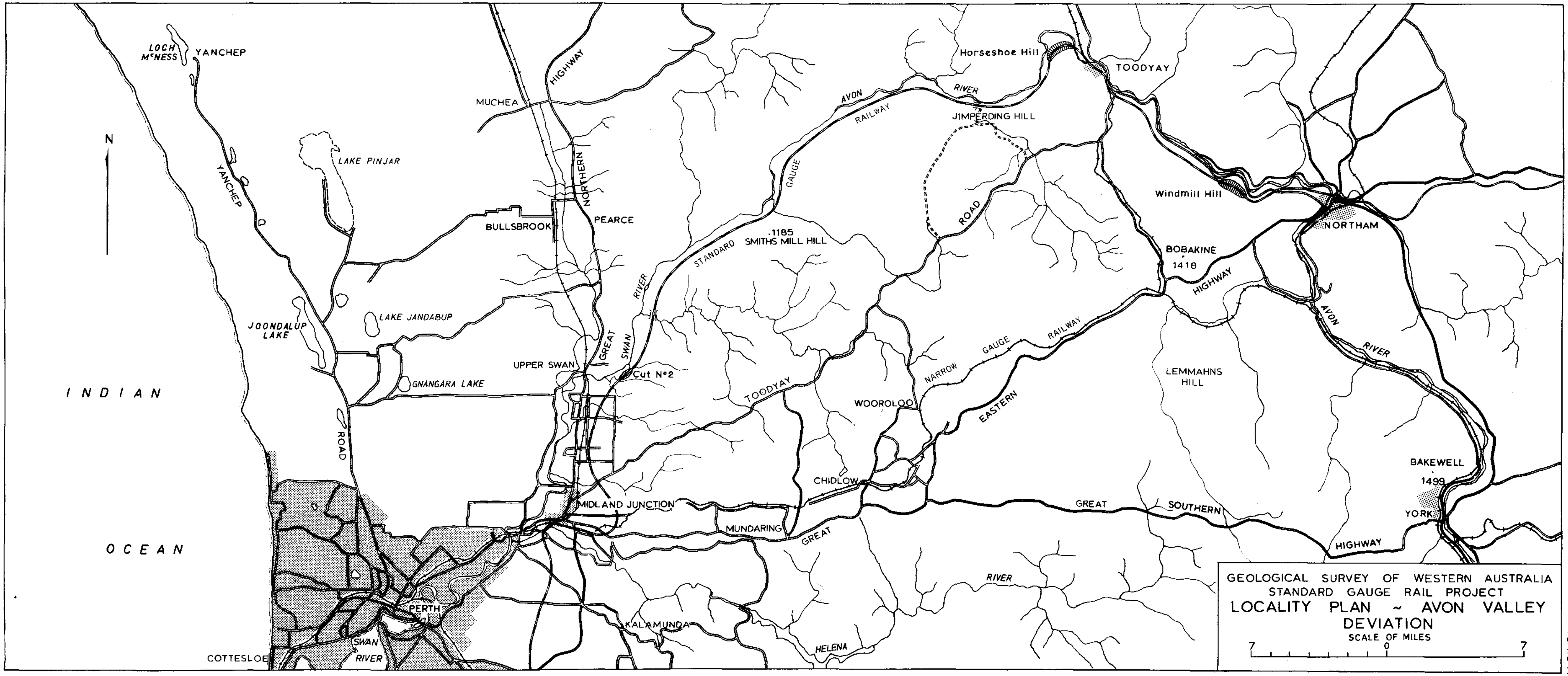
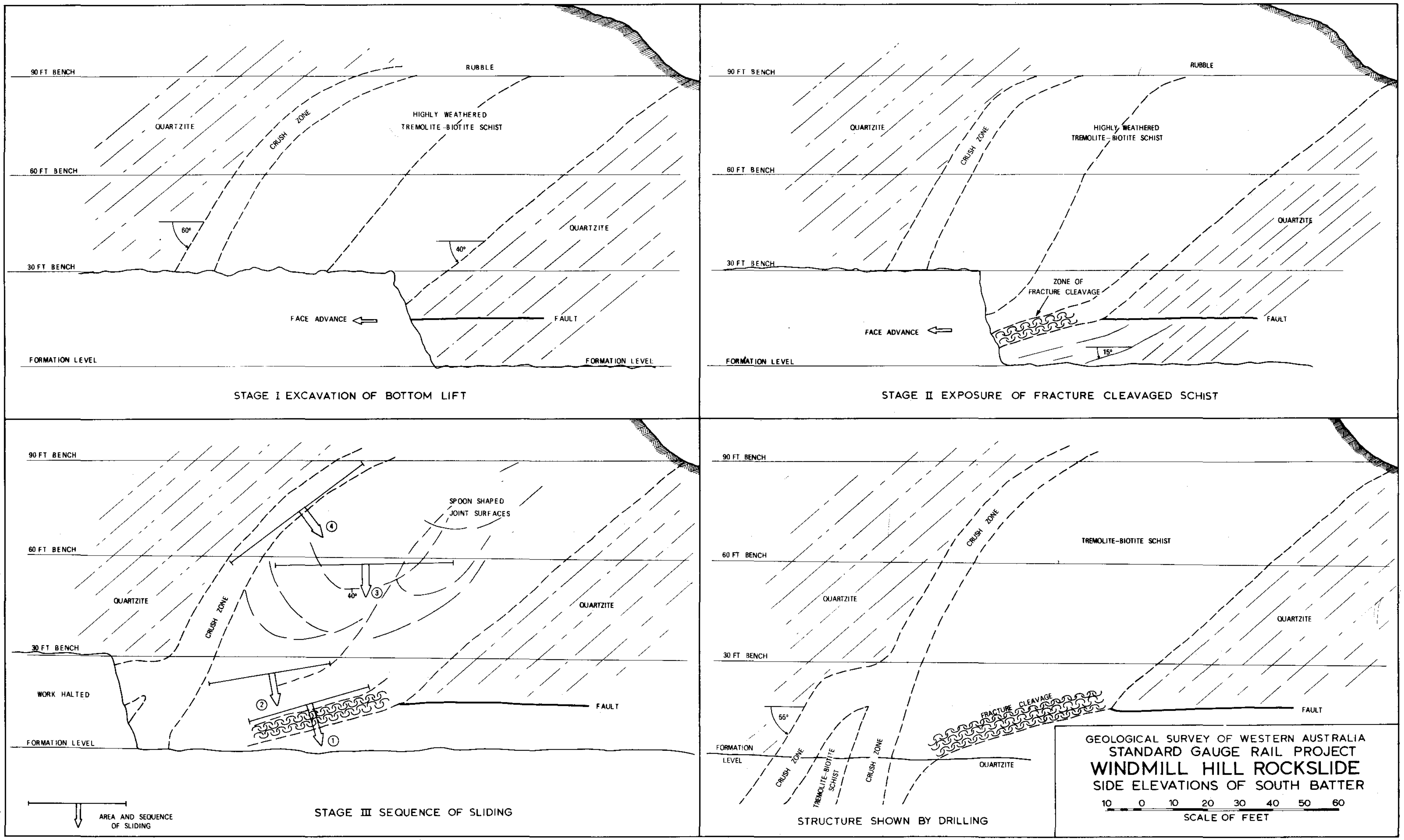


PLATE 11

1886

PLATE 12



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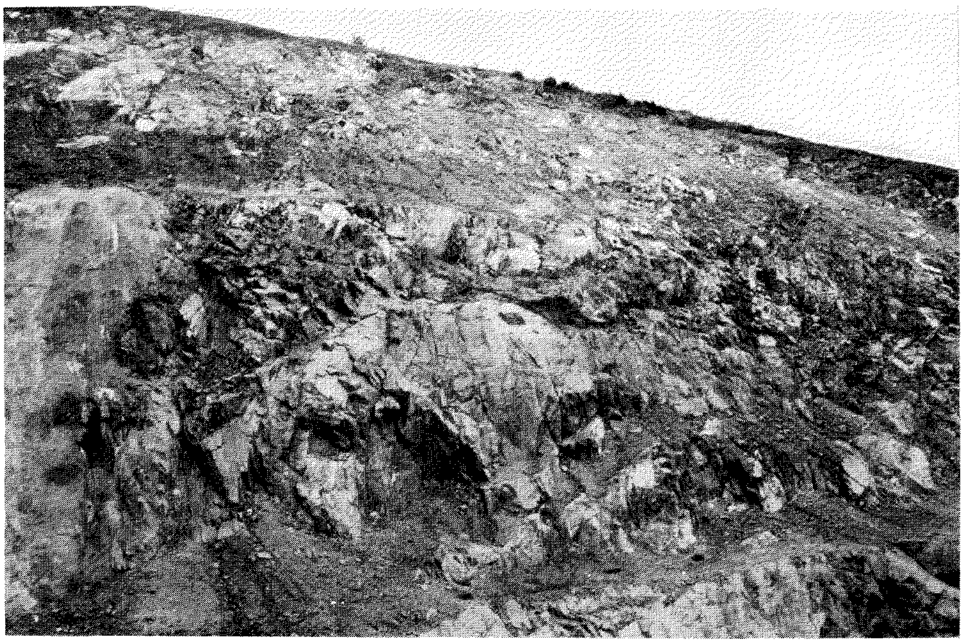
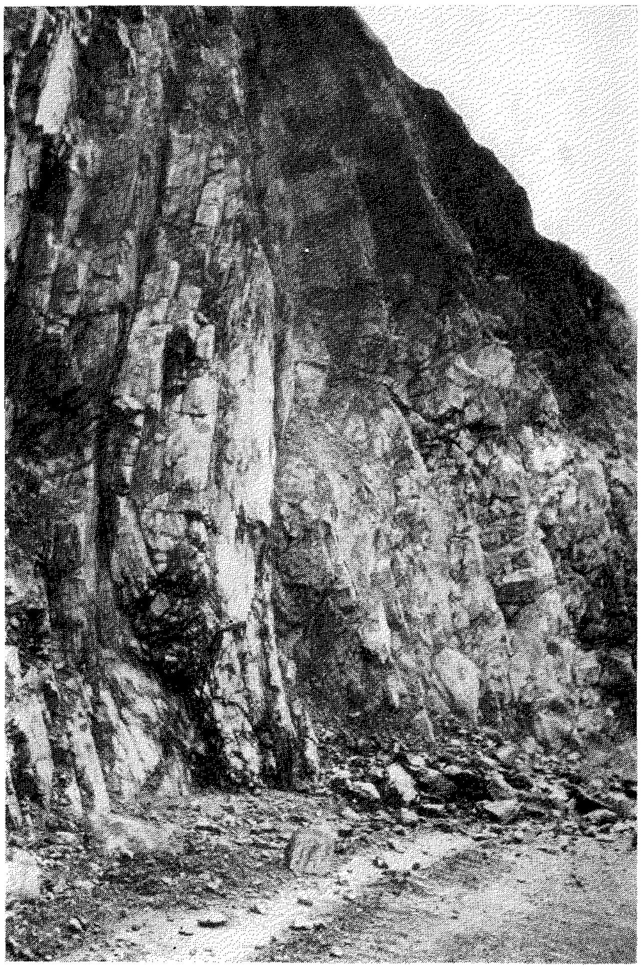


A. No. 2 rock cut showing conjunction of fault and sheet joint to give unstable conditions; F 1193.



B. Overshooting the toe of batter, No. 2 rock cut; F 1194.

GENERAL GEOLOGY OF THE ROCKY POOL DAM SITE

by J. L. Baxter

INTRODUCTION

Rocky Pool dam site, 37 miles upstream from the mouth of the Gascoyne River, was investigated during 1967 by geological mapping and auger drilling.

The river has incised its own flood plain to a depth of between 20 and 30 feet, exposing cliffs of sedimentary formations which form the abutments.

During peak flows, the floodwaters are not confined to the main channel, but spill into distributaries to the north and south of Rocky Pool. Two distributaries to the south, which become one channel away from the river, and a distributary to the north will have to be sealed, depending on the position of the wall. These are lower than the full storage level of the dam, understood to be R.L. 160 feet.

Regional and plane table mapping, and the supervision of a preliminary Gemco auger drilling programme at the dam site were conducted during 1967 by J. D. Wyatt, J. L. Baxter, and P. Hancock. R. Passmore inspected the hydrology of the river channel, and its distributaries downstream of the dam site in 1967, siting preliminary bores for the establishment of piezometers.

Mapping was completed by Baxter at a scale of 20 chains to an inch on air photos, taken as part of an erosion study of the Gascoyne River. The two river banks over a distance of 7,200 feet and a width of 4,000 feet were plane tabled by Wyatt and Baxter at a scale of 100 feet to an inch.

GEOLOGY

Geological mapping of the dam site and surrounding area has been completed at scales of 100 feet to an inch and 20 chains to an inch. The former is presented at 400 feet to an inch as Plate 14 showing also survey lines A, B, D, and F. A contour map at a scale of 1:12,000 and vertical interval 5 feet was supplied by the Department of Lands and Surveys (Rocky Pool Project G87).

Table 1.

STRATIGRAPHIC COLUMN

Age	Thickness (ft.)	Geological formation	Map unit	Description
QUATERNARY	0–25	River sand	Qra	Sand and silt, unconsolidated
	0–20	Superficial deposits	Qrr	Silt, sand, gravel unconsolidated
	2–6	Boulder scree	Qrt	Pebbles and boulders
	0–6	Eluvium	Qrs	Indurated sand and clay partly derived from in situ weathering
UNCONFORMITY				
QUATERNARY or Tertiary	0–200	Sandstone	Tqe	Well bedded sandstone with minor conglomerate
UNCONFORMITY				
TERTIARY	5–20	Red siltstone	Tk	Ferruginous siltstone
	10–80	White siltstone	Ts	White silty sandstone
CRETACEOUS	13–50	Green clay	Kut	Green calcilutite
	?150	Blue clay	N.M.	Blue calcilutite

NOTE—N.M. means not mapped.

QUATERNARY

River sand

Sand is deposited in the larger tributaries, and in the main channel of the Gascoyne River. It is red-brown to white, fine to coarse-grained, unconsolidated sand up to 25 feet thick. On the banks of the river there is deposited a thin veneer of silty sand which is only a few inches thick.

Superficial deposits

Superficial eolian and fluvial deposits of silt and sand have been formed on the banks of the river. These deposits are in the form of dunes and levee material, not more than 20 feet thick. Thin bands of coarser pebbly wash are deposited through the sands.

Boulder scree

Boulder scree slopes on the banks of the Gascoyne River, particularly in the vicinity of the "B" line, are composed of conglomerate.

Eluvium

Red-brown, silty sand, partly derived from induration of soils and partly from weathering of the underlying rock unit, has formed eluvial deposits. These deposits occur as a thin cover over weathered outcrop.

A sandy bed with some silt and clay is found overlying the green clay in the vicinity of survey station 181. The unit may be a localised sandy lens which has been leached, or a weathering product of the green clay; however in this mapping it has been included with eluvium.

TERTIARY OR QUATERNARY

Sandstone

Extensive areas of sandstone crop out upstream of the "D" line, and downstream from the "A" line. The unit is a brown silty sandstone containing beds of grit and conglomerate. It is underlain disconformably by a red siltstone. A prominent, near horizontal, parting with a frequency range of 1 per 3 to 12 inches is common. The sandstone contains numerous irregular circular patches of limonitic pisolites in a sandy matrix. The maximum measured section, measured upstream of the "D" line, is 200 feet.

The sandstone in the banks of the river near line "A" has few bands of conglomerate. It is principally a sandstone with minor gritty bands. In the vicinity of Bore 45 the sandstone is thin and overlies red siltstone; here distinction in mapping is difficult.

In the vicinity of the "D" line the sandstone contains numerous pebbly bands. The sandstone overlies a silicified, lateritised siltstone in this area indicating an appreciable time break between the deposition of the two units.

The sandstone is poorly consolidated, and is not suitable for rock fill, or rip-rap. It may be useful as unselected fill.

TERTIARY

Red siltstone

The red siltstone is best exposed on the right bank at the Rocky Pool constriction, where it ranges in thickness from 10 to 20 feet.

Jointing is irregular, although perfectly formed polygonal shrinkage cracks are common. Exfoliation partings, or sheet joints, parallel to the ground surface, have resulted in the formation of slabs of rock a few inches thick and up to 2 feet in diameter. On the right bank of the river, in the vicinity of station 109, the surface is covered with large masses of rock up to 6 x 6 x 8 feet.

The contact between the red siltstone and the underlying white siltstone shows many variations. In places, particularly at the pool, the contact is gradational, with nodules of red siltstone in the underlying white siltstone, and vice versa. The accessory minerals tourmaline and zircon are common to both the red and white siltstone. In other places the contact between the two siltstones is sharp.

White siltstone

The white siltstone varies in thickness from 10 feet to more than 80 feet. The thickest section of the siltstone occurs south of Rocky Pool in Bore 2.

There are sandy and clayey bands within the siltstone unit, and some of the sandy beds have purple staining due to the presence of ferruginous minerals.

The contact between the white siltstone and the green clay is either conformable, or disconformable. This is best observed at a small plunge pool in the vicinity of station 251.

The white stiltstone is a relatively soft plastic rock. Measurement of dip and strike is difficult because the rock becomes desiccated on exposure to the atmosphere, forming a poorly consolidated fragmental material broken by many small, open, irregular cracks.

The white siltstone is poorly to well consolidated and is not suitable as rock fill, and its use as a core material will be limited by the shrinkage properties.

Green and blue clay

The green clay crops out in the core of an anticline at the dam site, and the blue clay is observed only in drillholes.

The best exposure is in the banks of the river in the vicinity of the "B" line, where cliffs capped by conglomerate have green clay exposed in the scree slopes.

The rocks are foraminiferal calcilutites correlated biostratigraphically with the Cretaceous Toolonga Calcilutite within the Carnarvon Basin.

The green clay is highly plastic, frequently gypsiferous, and desiccates on exposure to air. It is considered unfavourable as an impermeable core material as it will tend to slip under pressure, but no other suitable material is known to occur in the vicinity of the dam site.

STRUCTURE

The geological structure of the Rocky Pool area is that of a northward plunging asymmetric anticline with its axis striking approximately 020°, the flanks dipping to the east at 8° to 17°, and to the west at 2° to 5°. Green clay is exposed in the core of the anticline, and siltstone, sandstone, grit and conglomerate on the flanks (Plate 15).

A lineament on the photos bearing approximately 017° cuts the sequence at the "D" line. This lineament is not well defined by outcrop, but Bores 29 and 33 show different sections, and therefore the feature is probably a fault. There are air photo indications of a second fault downstream from this, bearing aproximately 030° and cutting the axis of the anticline beneath the river.

Both northwest and southwest from Rocky Pool deep flood channels leave the river course. These channels have in them between 1 and 40 feet of wash deposited over rock. The channel to the south will have to be sealed if a dam is built on the river, however the northern channel will not affect a dam site east of the "B" line.

HYDROLOGY

The Gascoyne River is a sand-filled channel, the sand being of variable thickness. Islands in the channel are up to 25 feet high. Rocky Pool, located at a constriction in the river, is a semi-permanent pool, which remained full throughout 1967, after cyclonic rain in January and small winter rains.

The detailed hydrology of the river and the anabranches and distributaries downstream from Rocky Pool has been generally studied by Baxter and will be investigated further with water level recorders established in 1967.

SITE APPRAISAL

The preliminary investigation programme is now completed. The work done so far indicates that Rocky Pool dam site would be a difficult one on which to build and operate a dam. The basin formed by the dam would be large and shallow, which is a disadvantage in an area where evaporation is approximately 8 feet per year and considerable increase in salinity could be expected as a result. Leakage though the sands on the flanks of the reservoir would occur. The proposed wall is appoximately 3,500 feet long, and would have its foundation on plastic green clay. The overlying white siltstone is an unsuitable foundation as it contains beds of unconsolidated permeable sands. The impermeable green clay would be slippery, and the dam would have to be keyed into the formation. The structure would have to withstand the large peak flows of flash floods, common with cyclonic rains.

Material for construction of a dam would be difficult to obtain, and it is suggested that experiments with the available material, and with mixing of the material, be planned. Filter zone material could be obtained from the river bed sands. The green clay or the white siltstone may be suitable as core material; however three is a possibility that core will have to be mixed from these two units. Unselected fill could be obtained from a white siltstone and a sandstone. Rip-rap is the least likely material to be found in the area, and though the red siltstone may be of some use, it would possibly break up with persistent wave action. Concrete aggregate may be obtained by sieving and washing the sands in the river bed.

Two types of river flow are common, flash floods, which have a high flow rate, and low flow, which can be only a trickle. Scouring by the high flows may cause erosion problems at the wall, and siltation from flows will need constant attention.

The left bank of the river is a wide flood plain flanked by low sand dunes. A prominent depression, south of the main channel, has 40 feet of sand deposited in it, and will require sealing if the reservoir is to be watertight. In the vicinity of the "A" line the green clay is approximately 60 feet below the surface, and is overlain by white siltstone. This site is considered unsuitable as the white siltstone contains a bed of unconsolidated sand 10 to 15 feet thick through which water flows under hydrostatic pressure. This bed would be difficult to seal. In the vicinity of the "B" line, the contact between the green clay and the overlying white siltstone slopes away from the river, and will have to be tested for outflow.

The river sands in the existing channel are of variable thickness, and a noticeable feature is the variation in salinity of the water in the sands, suggesting lenticular aquifers. This may mean that the surface of the green clay in the river is irregular, or that the sand deposits in the channel are divided by deposits of impermeable silt. This should be investigated more fully by auger drilling in the river, and possibly a seismic traverse along the trial centre line of the dam.

The plain on the right bank of the river also has a depression which will only act as an offtake channel if the dam is built in the vicinity of the "A" line. The right bank has extensive flats of conglomerate and sandstone, which will have to be stripped before building a dam. The green clay is generally closer to the surface than on the left bank.

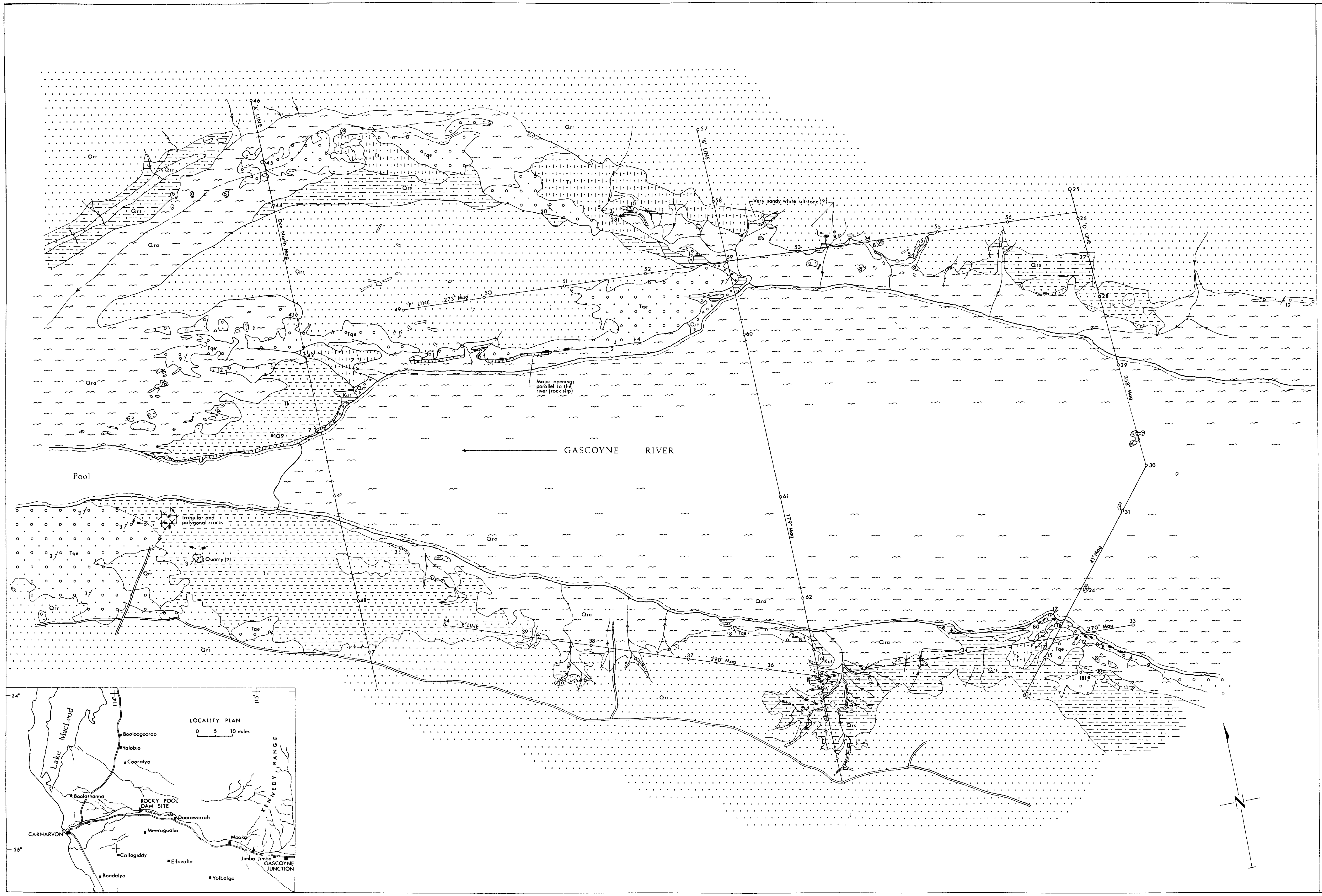
RECOMMENDATIONS

Seismic traversing across the dam site in the vicinity of the "B" line would give an estimate of the depth to green clay. The survey should include a traverse upstream of the "D" line to attempt to determine the exact position and attitude of the fault.

A trial centre line should be drilled to determine the depth and quality of the foundation material. Drilling of the fault in the vicinity of the "D" line may reveal its characteristics.

Laboratory tests are needed to determine if suitable construction material can be obtained from siltstone, sandstone, and clay, or whether some of these materials will require mixing.

Concrete aggregate may be obtainable from the sand in the river by screening and washing.



REFERENCE

QUATERNARY	Qra	Alluvium coarse to medium grained quartz sand
	Qrr	Superficial deposits silts, sands, gravel, unconsolidated
	Qrt	Boulder scree
	Qrs	Eluvium indurated sand and clay partly derived from in situ weathering
		Unconformity
TERTIARY OR QUATERNARY	Tqe	Sandstone well bedded sandstone with minor conglomerate
		Unconformity
TERTIARY	Tk	Red siltstone lateritised siltstone
	Ts	White siltstone white silty sandstone
		Disconformity or Unconformity
CRETACEOUS	Kut	Green clay green calcilutite

12 Bedding — strike and dip

80 Jointing — strike and dip

Outcrop boundary

181 GSWA survey station

A46 PWD Gemco auger drillhole

Tracks

Depression showing depth

Zone of earth slide

SCALE OF FEET

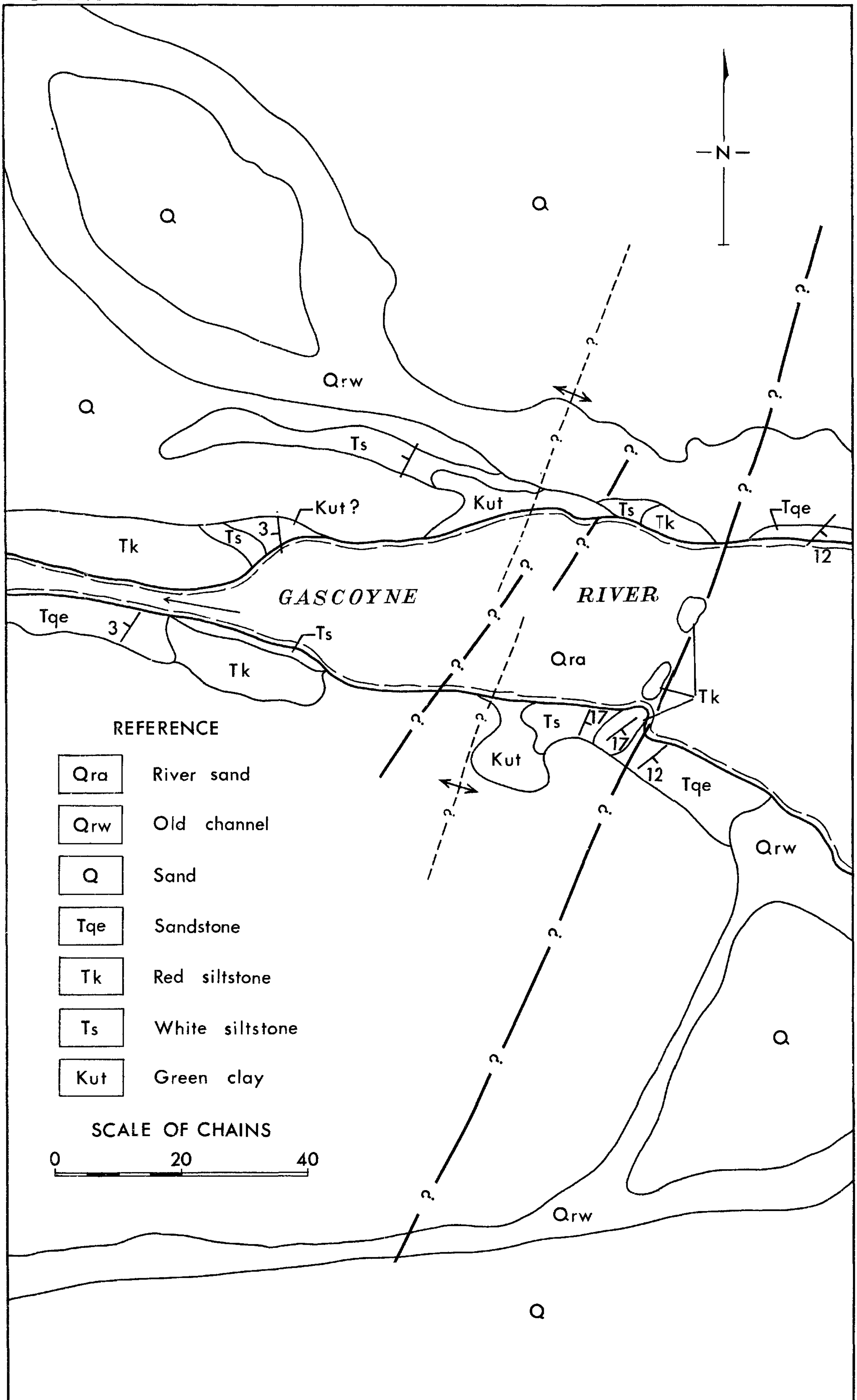
0 200 400 600 800 1000 1200 feet

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

GEOLOGICAL PLAN
ROCKY POOL DAM SITE
SHOWING GEMCO AUGER DRILL HOLES

Geology by J.D.Wyatt & J.L.Baxter 1967

To accompany Report by J.L.Baxter



GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

ROCKY POOL DAM SITE
SIMPLIFIED STRUCTURAL PLAN

To accompany Report by J.L. Baxter

9966

THE SEARCH FOR OIL IN WESTERN AUSTRALIA IN 1967

by P. E. Playford and G. H. Low

INTRODUCTION

The principal event during the year was the commencement of commercial production from the Barrow Island oilfield. The first oil shipment was loaded on the tanker *P. J. Adams* on April 23, thus marking the successful culmination of more than 16 years of activity by West Australian Petroleum Pty. Ltd. in this State.

The amount of exploratory drilling declined during 1967 as compared with the previous year. A total of 17 test wells and 11 stratigraphic wells were completed, and 1 test well and 2 stratigraphic wells were drilling on December 31. The total footage amounted to 115,970 feet. This compares with 25 test wells and 9 stratigraphic and structure wells completed in 1966 for a total of 180,850 feet of drilling. In 1967 163 development wells (totalling 403,205 feet) were completed on Barrow Island, compared with 5 (totalling 11,503 feet) the previous year.

A new oilfield was discovered at Pasco Island during 1967, and two wells were completed there as potential producers. Another gas well was completed at Dongara; the other wells were abandoned as dry holes. The previous year 11 wells had been completed in the State as potential producers.

Geophysical activity during the year was at a slightly higher level than in 1966. Seismic operations amounted to 53.4 party months (land) and 15.0 party months (marine) in 1967, compared with 51.35 party months (land) and 20.18 party months (marine) in 1966. During the year 14.25 party months of gravity and 6,478 line miles of aeromagnetic surveys were conducted, compared with 5.5 months of gravity and 2,700 line miles of aeromagnetic surveys in 1966. Field geological work increased from 9 geologist-months in 1966 to 22.5 in 1967.

OIL HOLDINGS

The positions of permits to explore and licenses to prospect in Western Australia at the end of 1967 are shown in Plate 16. Details of these concessions are as follows:

Permits to Explore

No.	Area (Square Miles)	Expiry Date of Current Term	Holders
27H	31,650	31/12/67 (renewal applied for)	West Australian Petroleum Pty. Limited
28H	26,040	31/12/67 (renewal applied for)	do. do. do.
30H	123,020	31/12/67 (renewal applied for)	do. do. do.
106H	11,800	28/9/68	Westralian Oil Limited
127H	13,450	28/3/68	Alliance Oil Development Australia N.L.
151H	14,200	7/2/68	Beach-General Exploration Pty. Ltd.
152H	11,650	7/2/68	do. do. do.
153H	13,050	7/2/68	do. do. do.
172H	6,150	30/3/68	Alliance Petroleum Australia N.L.
173H	12,250	30/3/68	do. do. do.
174H	6,100	30/3/68	do. do. do.
175H	6,050	30/3/68	do. do. do.
177H	6,050	30/3/68	do. do. do.
193H	2,750	5/2/68	Hawkstone Oil Co. Ltd., BP Petroleum Development Australia Pty. Ltd.
205H	16,700	17/9/68	Alliance Petroleum Australia N.L.
213H	104,000	20/6/68	Woodside (Lakes Entrance) Oil Co. N.L. B.O.C. of Aust. Ltd., Shell Development (Aust.) Pty. Ltd.
217H	17,600	30/5/68	West Australian Petroleum Pty. Limited
221H	44,800	28/7/68	Australian Aquitaine Petroleum Pty. Limited, Arco Ltd.
225H	8,000	20/7/68	West Australian Petroleum Pty. Limited
226H	34,700	6/4/68	do. do. do.
227H	11,400	6/4/68	do. do. do.
228H	2,900	13/5/68	do. do. do.
232H	3,000	20/6/68	B.O.C. of Australia Ltd., Shell Development (Aust.) Pty. Ltd., Woodside (Lakes Entrance) Oil Co. N.L.
233H	6,800	10/2/68	West Australian Petroleum Pty. Limited
235H	19,400	21/1/68	Canadian Superior Oil (Aust.) Pty. Ltd.
236H	2,600	3/2/68	Abrolhos Oil No Liability, BP Petroleum Development Australia Pty. Ltd.
238H	1,190	9/1/68 (renewal applied for)	B.O.C. of Australia Ltd., Shell Development (Aust.) Pty. Ltd., Woodside (Lakes Entrance) Oil Co. N.L.
240H	11,850	14/6/68	Coastal Petroleum N.L.
241H	11,850	14/6/68	do. do.
242H	11,850	14/6/68	do. do.
243H	11,850	14/6/68	do. do.
251H	4,228	29/6/68	West Australian Petroleum Pty. Limited
253H	5,200	28/12/68	Westralian Oil Limited
254H	12,100	14/2/69	Tenneco Australia Inc.
259H	12,930	1/2/69	West Australian Petroleum Pty. Limited
260H	5,860	19/4/69	do. do. do.
261H	3,000	19/4/69	do. do. do.

Licenses to Prospect

102H	195·551	13/1/68	West Australian Petroleum Pty. Limited
103H	200·00	20/5/68	do. do. do.
104H	197·867	6/6/68	do. do. do.
105H	196·032	14/8/68	do. do. do.
106H	195·779	11/9/68	do. do. do.
107H	200·00	25/2/68	do. do. do.
108H	200·00	22/1/68	do. do. do.
109H	200·00	22/2/68	do. do. do.
111H	150·00	4/6/68	do. do. do.
114H	67·00	27/10/68	Alliance Oil Development Aust. N.L.
115H	200·00	5/11/68	West Australian Petroleum Pty. Limited
117H	200·00	10/9/68	do. do. do.
118H	117·687	29/9/68	do. do. do.
119H	109·032	12/1/69	do. do. do.
120H	195·984	30/11/67	Westralian Oil Limited
121H	120·00	11/7/68	West Australian Petroleum Pty. Limited
122H	113·418	11/7/68	do. do. do.
123H	113·232	11/7/68	do. do. do.
124H	112·528	20/4/68	do. do. do.
125H	112·477	20/4/68	do. do. do.
126H	200·00	8/2/68	do. do. do.
127H	200·00	18/1/68	do. do. do.
128H	182·00	8/3/68	do. do. do.
129H	200·00	8/3/68	do. do. do.
130H	189·929	28/3/68	do. do. do.
132H	200·001	13/5/68	do. do. do.
133H	200·001	13/5/68	do. do. do.
135H	106·197	17/5/68	do. do. do.
136H	190·765	17/5/68	do. do. do.
137H	8·830	17/5/68	do. do. do.
138H	89·037	17/5/68	do. do. do.
140H	198·750	17/5/68	do. do. do.
141H	188·941	17/5/68	do. do. do.
142H	193·350	17/5/68	do. do. do.
143H	198·133	17/5/68	do. do. do.
144H	193·104	17/5/68	do. do. do.
145H	187·411	17/5/68	do. do. do.
146H	187.032	17/5/68	do. do. do.
147H	188·953	17/5/68	do. do. do.
148H	200·00	9/6/68	do. do. do.
149H	200·00	14/7/68	do. do. do.
150H	200·00	18/10/68	do. do. do.
151H	194·367	5/7/68	do. do. do.
153H	196·00	18/10/68	do. do. do.
154H	160·20	Renewal applied for	Beach-General Exploration
155H	193·75	18/10/68	West Australian Petroleum Pty. Limited
156H	189·269	Application pending	do. do. do.
157H	188·973	15/2/68	do. do. do.
158H	196·00	20/3/68	do. do. do.
159H	196·00	20/3/68	do. do. do.
160H	195·871	20/3/68	do. do. do.
161H	196·129	20/3/68	do. do. do.
162H	196·00	20.3/68	do. do. do.
163H	200·00	20/3/68	do. do. do.
164H	199·997	20/3/68	do. do. do.
165H	200·00	20/3/68	do. do. do.
166H	133·841	13/3/68	do. do. do.
167H	160·520	13/3/68	do. do. do.
168H	186·473	13/3/68	do. do. do.
169H	200·00	20/3/68	do. do. do.
171H	190·00 (provisional)	13/4/68	do. do. do.
172H	199·697	21/6/68	do. do. do.
173H	190·00 (provisional)	9/8/68	do. do. do.
174H	190·00 (provisional)	28/7/68	do. do. do.
175H	200·00	10/8/68	do. do. do.
176H	188·968	27/9/68	do. do. do.
177H	200·00 (provisional)	20/12/68	do. do. do.
179H	197·00 (provisional)	21/3/69	do. do. do.
180H	195·00 (provisional)	21/3/69	do. do. do.
181H	200·00	9/2/69	do. do. do.
182H	200·00	6/2/69	do. do. do.
183H	74·455	30/3/69	do. do. do.
184H	200·00	4/4/69	do. do. do.
185H	199·672	26/7/69	do. do. do.
186H	200·00	14/8/69	do. do. do.
187H	200·00	13/8/69	do. do. do.
188H	111·117	27/7/69	do. do. do.
189H	200·00	13/8/69	do. do. do.
190H	100·00	2/10/69	do. do. do.
191H	200·00	16/10/69	do. do. do.
192H	130·00	Application pending	do. do. do.
193H	190·458	Application deferred	do. do. do.
194H	193·620	Application deferred	do. do. do.
195H	200·00 (provisional)	Application pending	do. do. do.
	Applied for 3/1/68	....	do. do. do.

Petroleum Leases

1H	89·4	2/2/88	do. do. do.
2H	110·6	2/2/88	do. do. do.

DRILLING

The positions of wells drilled for petroleum exploration in Western Australia to the end of 1967 are shown on Plates 17 to 19. Drilling was carried out during the year in the following permits:

PERMIT TO EXPLORE 27H

Permit to Explore 27H is held by West Australian Petroleum Pty. Ltd. and covers part of the Perth Basin. The company completed 6 test wells (Badaminna No. 1, Cockburn No. 1, Dongara Nos. 4 to 6, and North Erregulla No. 1), and two stratigraphic wells (Bookara Nos. 2 and 3) on this permit during the year.

Dongara No. 4 was drilled 1¼ miles north of Dongara No. 2, and was completed as a gas producer in the Lower Permian Irwin River Coal Measures over the interval 5,639-5,642 feet. Gas was also recovered from a drill-stem test of the "Basal Triassic Sandstone". This was the fourth producing well to have been completed on the Dongara gas field. Two subsequent holes, Nos. 5 and 6, were dry and have been abandoned.

North Erregulla No. 1 was drilled to further evaluate the Cockleshell Gully Formation in the Erregulla area. It was abandoned as a dry hole, but small quantities of oil were obtained from drill-stem tests of the Kockatea Shale and the "Basal Triassic Sandstone" at depths of 9,580-9,613 feet and 10,535-10,570 feet respectively.

Further detais of the wells drilled on Permit 27H during the year are as follows:—

Badaminna No. 1

Type: Test well.
License to Prospect: 182H.
Latitude and longitude: 31° 20′ 30″ S, 115° 40′ 02″ E.
Elevation: G.L. 120 feet, R.T. 136 feet.
Commenced: 31st January, 1967.
Completed: 24th February, 1967.
Total depth: 8,000 feet.
Bottomed in: Lower Jurassic.
Status: Dry, plugged, and abandoned.

Bookara No. 2

Type: Stratigraphic well.
Latitude and longitude: 29° 09′ 59″ S, 114° 54′ 30″ E.
Elevation: G.L. 31 feet, R.T. 36 feet.
Commenced: 24th August, 1967.
Completed: 9th September, 1967.
Total depth, 2,500 feet.
Bottomed in: Precambrian.
Status: Dry, plugged, and abandoned.

Bookara No. 3

Type: Stratigraphic well.
Latitude and longitude: 29° 06′ 27″ S, 114° 53′ 14″ E.
Elevation: G.L. 102 feet, R.T. 107 feet.
Commenced: 15th September, 1967.
Completed: 24th September, 1967.
Total depth, 1,764 feet.
Bottomed in: Precambrian.
Status: Dry, plugged, and abandoned.

Cockburn No. 1

Type: Test well.
License to Prospect: 180H.
Latitude and longitude: 32° 08′ 02″ S, 115° 44′ 05″ E.
Elevation: G.L. 8 feet, R.T. 24 feet.
Commenced: 17th May, 1967.
Completed: 30th June, 1967.
Total depth: 10,020 feet.
Bottomed in: Lower Jurassic.
Status: Dry, plugged, and abandoned.

Dongara No. 4

Type: Test well.
License to Prospect: 111H.
Latitude and longitude: 29° 13′ 46″ S, 114° 58′ 49″ E.
Elevation: G.L. 201 feet, R.T. 216 feet.
Commenced: 27th February, 1967.
Completed: 24th March, 1967.
Total depth: 5,963 feet.
Bottomed in: Lower Permian.
Status: Gas well, completed over the interval 5,639-5,642 feet in Irwin River Coal Measures. Production test on a ¼-inch choke yielded 1.4 mmcf/day.

Dongara No. 5

Type: Test well.
License to Prospect: 111H.
Latitude and longitude: 29° 11′ 14″ S, 114° 58′ 54″ E.
Elevation: G.L. 91 feet, R.T. 105 feet.
Commenced: 19th October, 1967.
Completed: 3rd November, 1967.
Total depth: 5,933 feet.
Bottomed in: Lower Permian.
Status: Dry, plugged, and abandoned.

Dongara No. 6

Type: Test well.
License to Prospect: 190H.
Latitude and longitude: 29° 11′ 41″ S, 114° 56′ 16″ E.
Elevation: G.L. 81 feet, R.T. 94 feet.
Commenced: 12th December, 1967.
Completed: 31st December, 1967.
Total depth: 5,115 feet.
Bottomed in: Precambrian.
Status: Dry, plugged, and abandoned.

North Erregulla No. 1

Type: Test well.
License to Prospect: 150H.
Latitude and longitude: 29° 14′ 44″ S, 115° 19′ 34″ E.
Elevation: G.L. 533 feet, R.T. 547 feet.
Commenced: 4th October, 1967.
Completed: 25th November, 1967.
Total depth: 11,300 feet.
Bottomed in: Lower Permian.
Status: Oil show, plugged and abandoned. Drill stem tests of the interval 9,580-9,613 feet in the Kockatea Shale recovered 20 gallons of oil, and of the interval 10,535 to 10,570 feet in the "Basal Triassic Sandstone" recovered 8 gallons of oil.

PERMIT TO EXPLORE 28H

Permit to Explore 28H is held by West Australian Petroleum Pty. Ltd. and covers part of the Carnarvon Basin. The company completed 4 test wells (Chargoo No. 1, Gnaraloo No. 1, Kennedy Range No. 1 and Muiron No. 1) and two stratigraphic wells (Locker No. 1 and Peak Island No. 1) during the year, and one test well (Sandy Point No. 1) and one stratigraphic well (Observation Island No. 1) were still drilling at the end of the year. All the wells were dry. Details are as follows:

Chargoo No. 1

Type: Test well.
License to Prospect: 141H.
Latitude and longitude: 23° 35′ 51″ S, 113° 55′ 51″ E.
Elevation: G.L. 75 feet, R.T. 80 feet.
Commenced: 14th October, 1967.
Completed: 20th October, 1967.
Total depth: 1,404 feet.
Bottomed in: Lower Permian.
Status: Dry, plugged, and abandoned.

Gnaraloo No. 1

Type: Test well.
License to Prospect: 140H.
Latitude and longitude: 23° 40′ 38″ S, 113° 47′ 28″ E.
Elevation: G.L. 152 feet, R.T. 157 feet.
Commenced: 30th October, 1967.
Completed: 10th November, 1967.
Total depth: 1,646 feet,
Bottomed in: Carboniferous.
Status: Dry, plugged, and abandoned.

Kennedy Range No. 1

Type: Test well.
License to Prospect: 153H.
Latitude and longitude: 24° 29′ 50″ S, 114° 59′ 19″ E.
Elevation: G.L. 968 feet, K.B. 980 feet.
Commenced: 1st December, 1966.
Completed: 23rd January, 1967.

Total depth: 7,305 feet.
Bottomed in: Lower Permian.
Status: Minor gas show, plugged and abandoned.

Locker No. 1

Type: Stratigraphic well.
License to Prospect: 173H.
Latitude and longitude: 21° 43′ 16″ S, 114° 45′ 35″ E.
Elevation: G.L. 9 feet, R.T. 12 feet.
Commenced: 13th June, 1967.
Completed: 10th July, 1967.
Total depth: 2,512 feet.
Bottomed in: Triassic.
Status: Dry, plugged, and abandoned.

Muiron No. 1

Type: Test well.
License to Prospect: 185H.
Latitude and longitude: 21° 39′ 04″ S, 114° 21′ 18″ E.
Elevation: G.L. 16 feet, R.T. 30 feet.
Commenced: 1st December, 1967.
Completed: 26th December, 1967.
Total depth: 5,857 feet.
Bottomed in: Jurassic.
Status: Dry, plugged, and abandoned.

Observation No. 1

Type: Stratigraphic well.
License to Prospect: 195H.
Latitude and longitude: 21° 44′ 28″ S, 114° 32′ 12″ E.
Elevation: G.L. 16 feet, R.T. 30 feet.
Commenced: 31st December, 1967.
Status: Drilling at 72 feet on 31st December.

Peak Island No. 1

Type: Stratigraphic well.
License to Prospect: 191H.
Latitude and longitude: 21° 36′ 17″ S, 114° 30′ 23″ E.
Elevation: G.L. 16 feet, R.T. 30 feet.
Commenced: 17th October, 1967.
Completed: 23rd November, 1967.
Total depth: 7,026 feet.
Bottomed in: Jurassic.
Status: Dry, plugged, and abandoned.

Sandy Point No. 1

Type: Test well.
License to prospect: 192H.
Latitude and longitude: 22° 25′ 50″ S, 113° 47′ 46″ E.
Elevation: G.L. 366 feet, R.T. 378 feet.
Commenced: 30th November, 1967.
Status: Drilling at 7,117 feet on 31st December.

PERMIT TO EXPLORE 30H

Permit to Explore 30H is held by West Australian Petroleum Pty. Ltd. and covers part of the Canning Basin. The company completed two dry test wells (Blackstone No. 1 and May River No. 1) in this area during 1967. Details are as follows:

Blackstone No. 1

Type: Test well.
License to Prospect: 124H.
Latitude and longitude: 17° 35′ 14″ S, 124° 21′ 01″ E.
Elevation: G.L. 202 feet, R.T. 213 feet.
Commenced: 23rd July, 1967.
Completed: 12th October, 1967.
Total depth: 10,005 feet.
Bottomed in: Lower Ordovician.
Status: Dry, plugged, and abandoned.

May River No. 1

Type: Test well.
License to Prospect: 181H.
Latitude and longitude: 17° 14′ 50″ S, 124° 05′ 01″ E.
Elevation: G.L. 56 feet, R.T. 67 feet.
Commenced: 6th June, 1967.
Completed: 1st July, 1967.
Total depth: 5,505 feet.
Bottomed in: Precambrian.
Status: Dry, plugged, and abandoned.

PERMIT TO EXPLORE 217H

Permit to Explore 217H is held by West Australian Petroleum Pty. Ltd. and covers the northeastern part of the Carnarvon Basin. The company drilled 3 test wells (Pasco Nos. 1 to 3) and 7 stratigraphic wells (Airlie No. 1, Mardie No. 1, Sholl Island No. 1, Trimouille Nos. 1, 1A, and 1B and Yarraloola No. 1) on the permit during the year. A further stratigraphic well, Peedamullah No. 1, was still drilling at the end of the year. Pasco Nos. 1 and 3 were completed as oil wells, the others were dry.

The Pasco discoveries are at the southeastern end of the unnamed island immediately south of Pasco Island, 6 miles south of Barrow Island. The discovery well yielded 449 barrels per day of oil on a production test of the interval 5,742 feet to 5,744 feet in an Upper Jurassic sandstone. The well also flowed gas at 3 million cubic feet per day from a drill-stem test over the interval 5,663 feet to 5,725 feet. The second well was dry, but Pasco No. 3 was also completed as an oil well over the interval 5,980 to 5,984 feet. A production test of this interval flowed at about 90 barrels per day.

Details of the wells drilled on this permit area are as follows:

Airlie No. 1

Type: Stratigraphic well.
License to Prospect: 163H.
Latitude and longitude: 21° 19′ 30″ S, 115° 09′ 55″ E.
Elevation: G.L. 16 feet, R.T. 30 feet.
Commenced: 11th September, 1967.
Completed: 5th October, 1967.
Total depth: 7,279 feet.
Bottomed in: Upper Jurassic.
Status: Dry, plugged, and abandoned.

Mardie No. 1

Type: Stratigraphic well.
Latitude and longitude: 21° 20′ 54″ S, 115° 42′ 54″ E.
Elevation: G.L. 16 feet, R.T. 21 feet.
Commenced: 20th July, 1967.
Completed: 16th August, 1967.
Total depth: 728 feet.
Bottomed in: ? Palaeozoic.
Status: Dry, plugged, and abandoned.

Pasco No. 1

Type: Test well.
License to Prospect: 158H.
Latitude and longitude: 20° 58′ 19″ S, 115° 19′ 30″ E.
Elevation: G.L. 25 feet, R.T. 39 feet.
Commenced: 20th April, 1967.
Completed: 25th May, 1967.
Total depth: 6,230 feet.
Bottomed in: Upper Jurassic.
Status: Oil well, completed over the interval 5,742 to 5,744 feet in the Upper Jurassic. A production test flowed 449 barrels oil/day on ¼-inch choke; gas/oil ratio not measured. A drill-stem test of the interval 5,663 to 5,725 feet flowed gas at 3.0 mmcf/day.

Pasco No. 2

Type: Test well.
License to Prospect: 158H.
Latitude and longitude: 20° 57′ 41″ S, 115° 19′ 20″ E.
Elevation: G.L. 12 feet, R.T. 26 feet.
Commenced: 11th June, 1967.
Completed: 19th July, 1967.
Total depth: 8,009 feet.
Bottomed in: Upper Jurassic.
Status: Minor shows of oil and gas. Plugged and abandoned.

Pasco No. 3

Type: Test well.
License to Prospect: 158H.
Latitude and longitude: 20° 58′ 05″ S, 115° 19′ 51″ E.
Elevation: G.L. 33 feet, R.T. 50 feet.
Commenced: 24th July, 1967.
Completed: 16th August, 1967.

Total depth: 8,041 feet.
Bottomed in: Upper Jurassic.
Status: Oil well, completed over the interval 5,980 to 5,984 feet in the Upper Jurassic. Production test flowed about 90 barrels oil/day on ¼-inch choke.

Peedamullah No. 1

Type: Stratigraphic well.
License to Prospect: 187H.
Latitude and longitude: 21° 24′ 26″ S, 115° 37′ 50″ E.
Elevation: G.L. 18 feet, R.T. 23 feet.
Commenced: 24th December, 1967.
Status: Drilling at 525 feet on 31st December.

Sholl Island No. 1

Type: Stratigraphic well.
License to Prospect: 159H.
Latitude and longitude: 20° 57′ 00″ S, 115° 53′ 50″ E.
Elevation: G.L. 16 feet, R.T. 30 feet.
Commenced: 7th January, 1967.
Completed: 27th January, 1967.
Total depth: 4,172 feet.
Bottomed in: Lower Permian.
Status: Dry, plugged, and abandoned.

Trimouille No. 1

Type: Stratigraphic well.
License to Prospect: 161H.
Latitude and longitude: 20° 24′ 11″ S, 115° 34′ 09″ E.
Elevation: G.L. 16 feet, R.T. 30 feet.
Commenced: 12th February, 1967.
Completed: 19th March, 1967.
Total depth: 7,990 feet.
Bottomed in: Lower Cretaceous.
Status: Minor oil show, plugged and abandoned.

Trimouille No. 1A

Type: Stratigraphic well.
License to Prospect: 161H.
Latitude and longitude: 20° 24′ 11″ S, 115° 34′ 09″ E.
Elevation: G.L. 16 feet, R.T. 30 feet.
Commenced: 21st March, 1967.
Completed: 3rd April, 1967.
Total depth: 2,250 feet.
Bottomed in: Tertiary.
Status: Minor oil show, plugged and abandoned.

Trimouille No. 1B

Type: Stratigraphic well.
License to Prospect: 161H.
Latitude and longitude: 20° 24′ 18″ S, 115° 34′ 16″ E.
Elevation: G.L. 12 feet, R.T. 16 feet.
Commenced: 20th May, 1967.
Completed: 2nd June, 1967.
Total depth: 750 feet.
Bottomed in: Tertiary.
Status: Dry, plugged, and abandoned.

Yarraloola No. 1

Type: Stratigraphic well.
License to Prospect: 186H.
Latitude and longitude: 21° 25′ 07″ S, 115° 45′ 52″ E.
Elevation: G.L. 58 feet, R.T. 63 feet.
Commenced: 27th November, 1967.
Completed: 20th December, 1967.
Total depth: 892 feet.
Bottomed in: Carboniferous.
Status: Dry, plugged, and abandoned.

PERMIT TO EXPLORE 228H

Permit to Explore 228H is held by West Australian Petroleum Pty. Ltd. and is farmed out to French Petroleum Co. (Aust.) Pty. Ltd. and Australian Aquitaine Petroleum Pty. Ltd. It is situated in the central Perth Basin. One well, Beharra No. 2, was drilled on the permit during the year. Details are as follows:

Beharra No. 2

Type: Test well.
License to Prospect: 177H.
Latitude and longitude: 29° 30′ 55″ S, 115° 01′ 15″ E.
Elevation: G.L. 92 feet, R.T. 107 feet.
Commenced: 11th January, 1967.
Completed: 28th January, 1967.
Total depth: 6,313 feet.
Bottomed in: Lower Permian.
Status: Dry, plugged, and abandoned.

PERMIT TO EXPLORE 251H

Permit to Explore 251H is held by West Australian Petroleum Pty. Ltd. and is farmed out to Gewerkschaft Elwerath. This company drilled one dry well, Yulleroo No. 1, on the concession during 1967. Details are as follows:

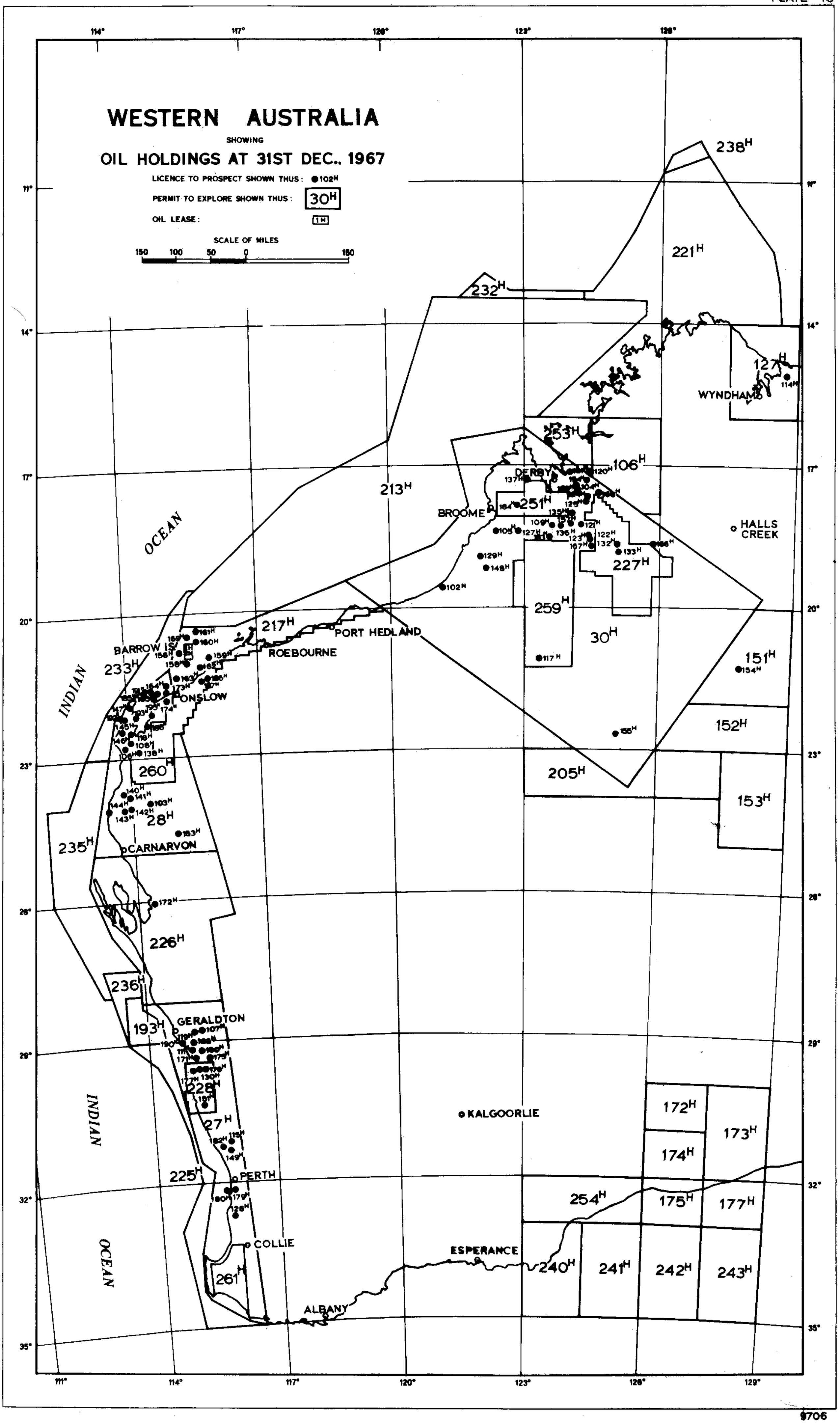
Yulleroo No. 1

Type: Test well.
License to Prospect: 184H.
Latitude and longitude: 17° 51′ 16″ S, 122° 54′ 25″ E.
Elevation: G.L. 164 feet, R.T. 181 feet.
Commenced: 21st May, 1967.
Completed: 13th November, 1967.
Total depth: 15,018 feet.
Bottomed in: Upper Devonian.
Status: Minor gas show, plugged, and abandoned.

PETROLEUM LEASE 1H

The following table summarises the development wells completed on Barrow Island (Petroleum Lease 1H) during 1967:

Well	R.T.	G.L. or F.F.*	T.D.	Commenced	Completed
A18	99	FF 89	2560	28/6/67	1/7/67
A38	54	FF 144	2517	30/12/67	2/1/68
B14	74	FF 64	2405	5/7/67	8/7/67
B15	63	FF 53	2308	7/9/67	16/9/67
B16	78	FF 67	2345	29/7/67	3/8/67
B21	63	FF 53	2511	20/8/67	23/8/67
B23	56	FF 45	2415	27/8/67	31/8/67
B25	53	FF 42	2290	6/12/67	15/12/67
B32	48	GL 37	2414	19/11/67	24/11/67
B34	49	FF 37	2427	24/11/67	28/11/67
E12	155	FF 145	2348	6/4/67	10/4/67
E16	135	FF 125	2636	15/12/67	19/12/67
E21	204	FF 194	2312	19/3/67	23/3/67
E23	119	FF 108	2365	27/12/67	30/12/67
F12	142	FF 132	2303	24/1/67	30/1/67
F16	183	FF 172	2344	20/1/67	25/1/67
F18	148	FF 138	2403	24/3/67	28/3/67
F21	165	GL 155	2336	1/2/67	4/2/67
F23	213	FF 203	2350	10/1/67	14/1/67
F27	148	FF 138	2342	12/3/67	18/3/67
F32	162	FF 152	2316	6/1/67	9/1/67
F34	176	FF 165	2318	13/1/67	18/1/67
F38	100	FF 90	2275	23/12/67	26/12/67
F41	187	FF 176	2307	5/2/67	10/2/67
F43	112	FF 101	2228	2/1/67	5/1/67
F54	135	FF 125	2885	2/3/67	12/3/67
F61	114	FF 184	2277	11/2/67	15/2/67
G12	126	FF 115	2456	8/7/67	12/7/67
G14	122	FF 112	2427	4/8/67	6/8/67
G18	180	FF 169	2403	24/2/67	27/2/67
G21	124	FF 114	2548	1/8/67	3/8/67
G23	98	FF 87	2457	16/8/67	19/8/67
G25	130	FF 120	2428	10/8/67	13/8/67
G27	145	FF 135	2402	21/3/67	24/3/67
G32	109	FF 99	2487	24/7/67	27/7/67
G34	144	FF 134	2457	13/8/67	16/8/67
G36	169	GL 158	2396	28/3/67	5/4/67
G38	184	FF 174	2415	15/3/67	20/3/67
G41	141	FF 131	2525	17/8/67	20/8/67
G43	126	FF 115	2420	31/8/67	3/9/67
G45	134	FF 123	2338	27/6/67	29/6/67
G47	183	FF 172	2350	12/3/67	15/3/67
G52	130	FF 119	2488	13/7/67	17/7/67
G54	160	FF 149	2427	17/7/67	20/7/67
G56	165	FF 154	2396	6/4/67	8/4/67
G57	163	FF 153	2357	13/6/67	19/6/67
G58	148	FF 138	2309	28/2/67	6/3/67
G61	143	FF 132	2555	10/8/67	13/8/67
G63	126	FF 115	2454	7/8/67	10/8/67
G65	160	FF 149	2397	20/7/67	24/7/67
G67	134	FF 124	2310	22/2/67	27/2/67
G72	157	FF 146	2496	12/7/67	15/7/67
G74	140	FF 130	2436	8/7/67	11/7/67
G78	104	FF 94	2257	17/2/67	21/2/67
G81	99	FF 89	2470	20/6/67	23/6/67
G83	91	FF 81	2403	1/7/67	5/7/67
G84	91	FF 81	2390	3/9/67	12/9/67
G85	90	FF 79	2310	24/6/67	27/6/67
G87	80	FF 70	2215	7/3/67	12/3/67
H18	81	FF 71	2548	6/8/67	10/8/67
H47	105	FF 95	2575	14/8/67	17/8/67
H58	140	FF 130	2545	4/8/67	7/8/67
H78	141	FF 130	2619	24/7/67	29/7/67
K18	164	FF 154	2518	12/12/67	15/12/67
K25	196	FF 186	2547	5/12/67	9/12/67
K27	172	FF 162	2561	28/11/67	3/12/67
K38	179	FF 169	2487	27/12/67	30/12/67
K45	190	FF 180	2518	9/12/67	12/12/67
K47	194	FF 183	2517	3/12/67	6/12/67
K56	142	FF 131	2457	30/12/67	4/1/68
K72	140	FF 130	2547	25/8/67	27/8/67
K74	164	FF 154	2488	22/8/67	24/8/67
K76	163	FF 153	2487	5/7/67	8/7/67
K78	183	FF 172	2417	24/3/67	27/3/67
K81	107	FF 97	2607	28/7/67	31/7/67
K83	119	FF 109	2487	19/8/67	21/8/67


WESTERN AUSTRALIA
SHOWING
OIL HOLDINGS AT 31ST DEC., 1967
LICENCE TO PROSPECT SHOWN THUS: ●102H
PERMIT TO EXPLORE SHOWN THUS: 30H
OIL LEASE: 1H
SCALE OF MILES
150 100 50 0 150
INDIAN OCEAN
BARROW IS.
ONSLOW
ROEBOURNE
PORT HEDLAND
BROOME
DERBY
WYNDHAM
HALLS CREEK
CARNARVON
GERALDTON
PERTH
COLLIE
ALBANY
ESPERANCE
KALGOORLIE
238H
221H
232H
127H
213H
253H
106H
251H
227H
259H
30H
217H
233H
151H
152H
205H
153H
260H
28H
235H
226H
236H
193H
228H
27H
225H
261H
172H
173H
174H
254H
175H
177H
240H
241H
242H
243H

9706

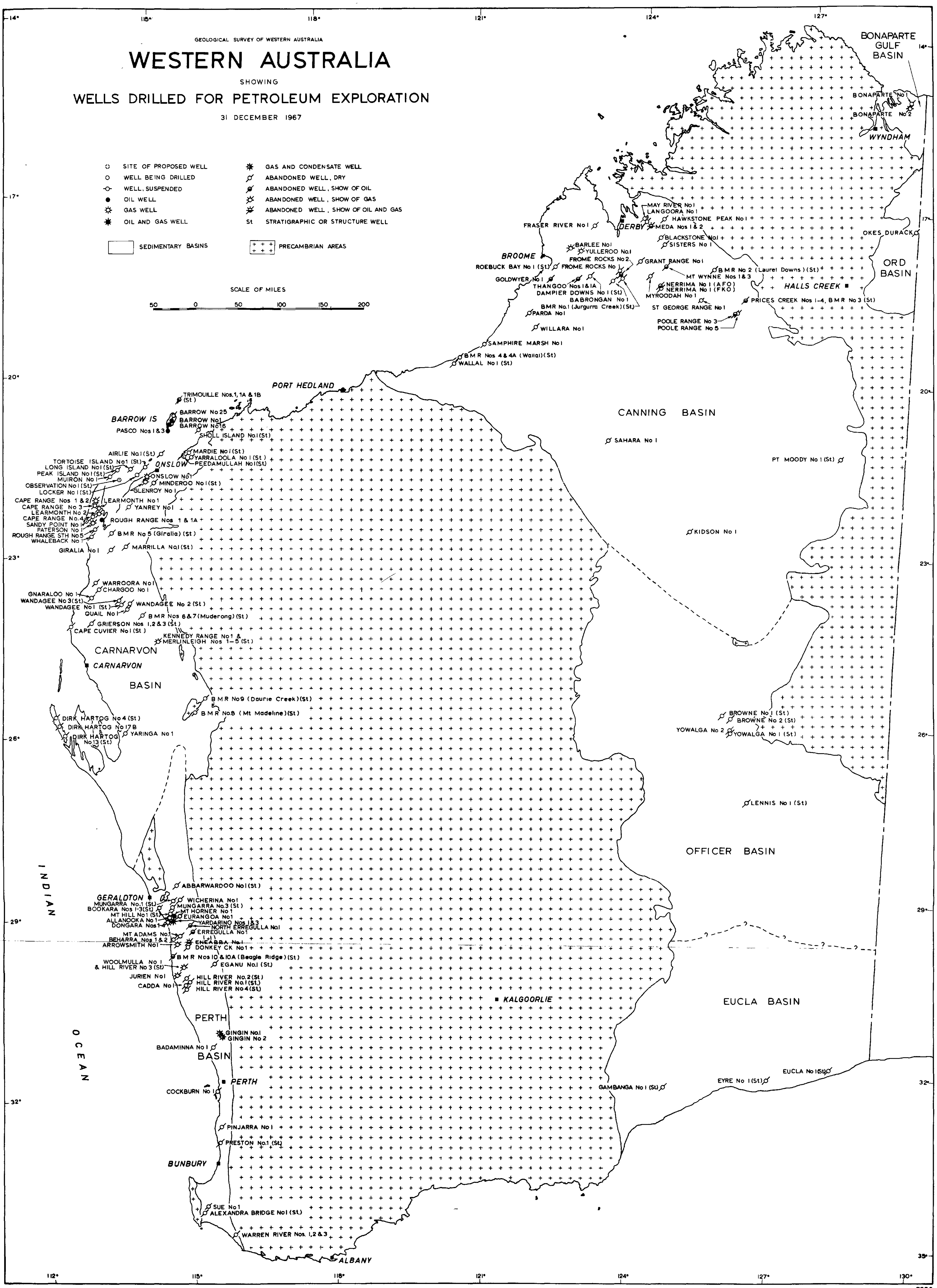
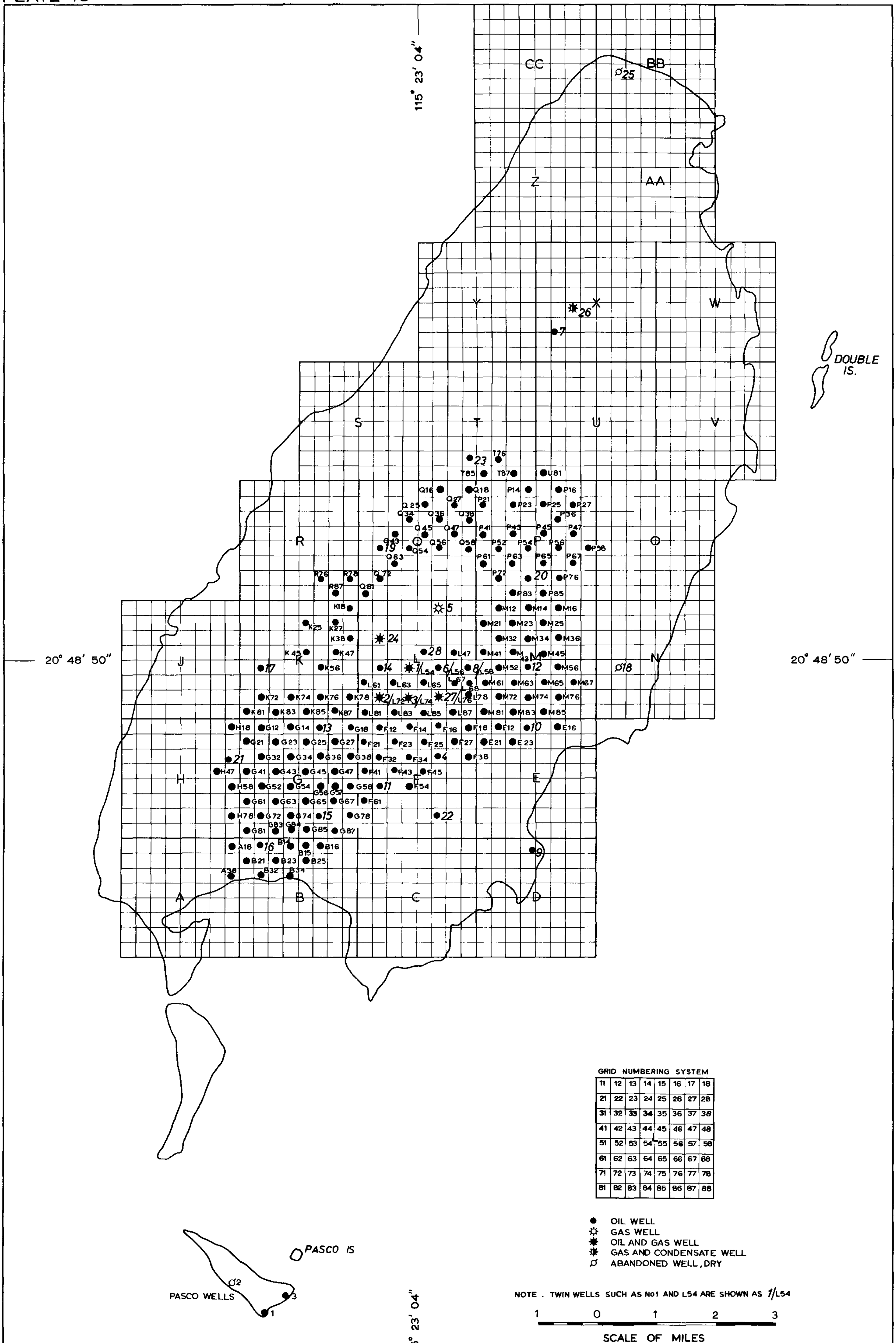


PLATE 17

9653

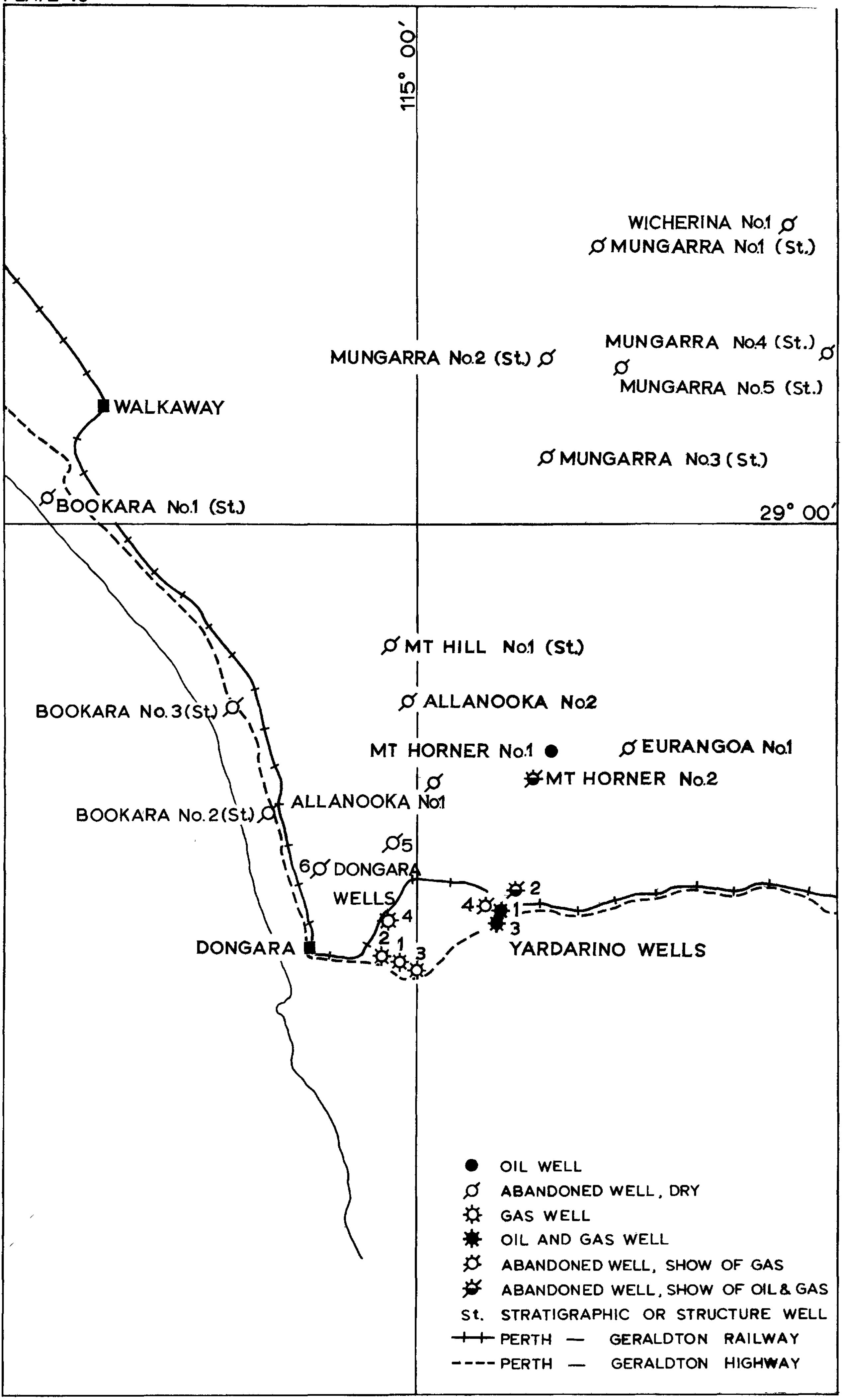
PLATE 18



BARROW ISLAND AREA
SHOWING WELLS DRILLED FOR PETROLEUM

9994

PLATE 19



DONGARA AREA

SHOWING WELLS DRILLED FOR PETROLEUM

0 4 8

SCALE OF MILES

9655

Well	R.T.	G.L. or F.F.*	T.D.	Commenced	Completed
K85	161	FF 151	2519	2/7/67	5/7/67
K87	193	FF 183	2434	27/2/67	2/3/67
L47	170	FF 160	2455	18/5/67	21/5/67
L54	180	FF 170	2400	9/2/67	13/2/67
L56	218	FF 207	2505	22/5/67	25/5/67
L58	220	FF 210	2466	30/5/67	3/6/67
L61	194	FF 184	2434	19/2/67	22/2/67
L63	190	FF 179	2406	12/2/67	16/2/67
L65	209	FF 199	2404	29/1/67	9/2/67
L67	201	FF 191	2456	25/4/67	29/4/67
L68	190	FF 180	2456	17/9/67	22/9/67
L72	164	FF 154	2348	10/1/67	15/1/67
L76	227	FF 217	2408	25/1/67	29/1/67
L78	173	FF 163	2426	9/4/67	12/4/67
L81	155	FF 144	2371	15/2/67	19/2/67
L83	138	FF 128	2300	16/1/67	23/1/67
L87	182	FF 172	2434	29/3/67	1/4/67
M12	195	FF 184	2502	4/6/67	9/6/67
M14	162	FF 151	2528	10/6/67	13/6/67
M16	134	FF 123	2560	24/6/67	26/6/67
M21	151	FF 140	2440	14/5/67	17/5/67
M23	145	FF 134	2488	5/6/67	8/6/67
M25	173	FF 163	2564	23/4/67	16/5/67
M32	150	FF 139	2440	11/5/67	14/5/67
M34	112	FF 102	2457	2/6/67	5/6/67
M36	123	FF 113	2547	11/6/67	14/6/67
M41	152	FF 141	2485	8/5/67	11/5/67
M43	159	FF 148	2487	27/5/67	30/5/67
M45	122	FF 112	2488	8/6/67	11/6/67
M52	150	FF 139	2517	3/5/67	6/5/67
M56	129	FF 119	2548	14/6/67	17/6/67
M61	162	FF 152	2456	22/4/67	25/4/67
M63	175	FF 165	2457	29/4/67	3/5/67
M65	122	FF 112	2564	16/4/67	19/4/67
M67	101	FF 190	2516	30/5/67	2/6/67
M72	177	FF 166	2455	16/4/67	22/4/67
M74	136	FF 126	2472	20/4/67	23/4/67
M76	142	FF 132	2501	10/4/67	16/4/67
M81	170	FF 160	2426	13/4/67	16/4/67
M83	161	FF 150	2494	2/4/67	5/4/67
M85	136	FF 126	2548	29/6/67	2/7/67
P14	147	FF 137	2487	19/9/67	23/9/67
P16	168	FF 158	2577	4/9/67	6/9/67
P21	208	FF 198	2547	9/10/67	12/10/67
P23	196	FF 185	2550	17/5/67	23/5/67
P25	177	FF 166	2577	15/9/67	19/9/67
P27	135	FF 125	2578	29/10/67	31/10/67
P36	155	FF 144	2577	31/8/67	3/9/67
P41	192	FF 181	2576	6/10/67	9/10/67
P43	189	FF 178	2578	9/10/67	12/10/67
P45	134	FF 124	2577	12/9/67	15/9/67
P47	139	FF 128	2578	7/11/67	9/11/67
P52	195	FF 184	2548	4/10/67	9/10/67
P54	140	FF 130	2578	28/9/67	1/10/67
P56	112	FF 102	2548	28/9/67	29/9/67
P58	109	FF 99	2578	20/12/67	22/12/67
P61	172	FF 161	2547	1/10/67	4/10/67
P63	152	FF 142	2517	17/10/67	20/10/67
P65	124	FF 114	2548	13/10/67	17/10/67
P67	122	FF 111	2577	20/10/67	22/10/67
P72	167	FF 156	2517	25/9/67	28/9/67
P76	113	FF 103	2547	28/8/67	31/8/67
P83	165	FF 155	2519	20/6/67	23/6/67
P85	133	FF 122	2547	17/6/67	20/6/67
Q16	190	FF 180	2547	4/11/67	11/11/67
Q18	179	FF 169	2576	21/10/67	25/10/67
Q25	150	FF 139	2534	29/10/67	1/11/67
Q27	198	FF 187	2547	16/10/67	22/10/67
Q34	144	FF 134	2541	1/11/67	4/11/67
Q36	167	FF 157	2578	23/10/67	28/10/67
Q38	211	FF 200	2577	3/10/67	6/10/67
Q43	185	FF 175	2557	25/10/67	29/10/67
Q45	165	FF 154	2548	22/9/67	25/9/67
Q47	227	FF 217	2547	12/10/67	15/10/67
Q54	204	FF 193	2547	16/11/67	19/11/67
Q56	215	FF 205	2547	11/11/67	16/11/67
Q58	187	FF 177	2548	12/10/67	14/10/67
Q63	163	FF 153	2487	19/11/67	22/11/67
Q72	136	FF 126	2458	22/11/67	24/11/67
Q81	142	FF 131	2487	25/11/67	28/11/67
R76	130	FF 120	2494	24/5/67	29/5/67
R78	135	FF 125	2518	28/11/67	1/12/67
R87	208	FF 197	2576	1/12/67	4/12/67
T76	171	FF 160	2642	4/11/67	6/11/67
T85	191	FF 180	2638	17/9/67	20/9/67
T87	168	FF 157	2567	7/9/67	12/9/67
U81	165	FF 154	2578	9/11/67	13/11/67

* FF = First flange. Datum adopted for the Barrow wells is 18·54 feet above mean sea level, or 23·44 feet above Indian spring low-water mark.

GEOPHYSICAL OPERATIONS

Gravity

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

Company	Permit	Basin	Party Months
West Australian Petroleum Pty. Limited	27H	Perth	2·5
do. do. do.	30H	Carnarvon	4·0
do. do. do.	217H	Carnarvon	2·0
Australian Aquitaine Petroleum Pty. Ltd.	151H	Canning	0·8
do. do. do.	152H	Canning	4·0
do. do. do.	205H	Canning	0·4
French Petroleum Co. (Aust.) Pty. Ltd.	259H	Canning	3·0

Seismic

During 1966 seismic surveys were conducted in the Perth, Carnarvon, Canning, Bonaparte Gulf, and Eucla Basins. This work was distributed as follows:

Company	Permit	Basin	Party Months
West Australian Petroleum Pty. Limited	27H	Perth	1·5 (marine) 11·0 (land)
do. do. do.	28H	Carnarvon	3·0 (marine) 10·0 (land)
do. do. do.	30H	Canning	2·0 (land)
do. do. do.	217H	Carnarvon	3·0 (marine) 1·0 (land)
do. do. do.	225H	Perth	0·5 (marine)
do. do. do.	233H	Carnarvon	0·5 (marine)
Tenneco Australia Inc.	175H	Eucla	0·5 (marine)
do. do.	177H	Eucla	0·255 (marine)
do. do.	240H	Eucla	0·120 (marine)
do. do.	241H	Eucla	0·188 (marine)
do. do.	242H	Eucla	0·145 (marine)
do. do.	243H	Eucla	0·045 (marine)
do. do.	254H	Eucla	0·142 (marine)
Union Oil Development Corp.	261H	Perth	3·5 (land)
Marathon Petroleum Australia Ltd.	260H	Carnarvon	6·5 (land)
Gewerkschaft Elwerath	251H	Canning	2·0 (land)
Australian Aquitaine Petroleum Pty. Ltd.	151H	Canning	0·8 (land)
do. do. do.	152H	Canning	4·0 (land)
do. do. do.	205H	Canning	0·4 (land)
French Petroleum Co. (Aust.) Pty. Ltd.	259H	Canning	11·0 (land)
Arco Limited	221H	Bonaparte	4·0 (marine)
Canadian Superior Oil (Aust.) Pty. Ltd.	235H	Carnarvon	1·0 (marine)

Magnetic

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

Company	Permit	Basin	Line Miles
West Australian Petroleum Pty. Limited	28H	Carnarvon	1,167
do. do. do.	217H	Carnarvon	3,830
do. do. do.	233H	Carnarvon	1,481

GEOLOGICAL OPERATIONS

Field geological studies were carried out by oil exploration companies in the Carnarvon and Canning Basins. Details are as follows:

Company	Permit	Basin	Geologist Months
West Australian Petroleum Pty. Limited	30H	Canning	2
do. do. do.	217H	Carnarvon	1
Australian Aquitaine Petroleum Pty. Ltd.	151–153H	Canning	13·0
French Petroleum Co. (Aust.) Pty. Ltd.	259H	Canning	6·5

PRODUCING OPERATIONS

West Australian Petroleum Pty. Ltd. was granted Petroleum Leases 1H and 2H in January, 1967, covering the onshore and offshore areas respectively of the Barrow Island License to Prospect. Drilling during the year was confined to Lease 1H on the island itself. Two rigs were used to drill 163 development wells.

The first shipment of oil from Barrow Island was loaded on April 23, and by the end of December a total of 4,648,217 barrels of oil had been shipped. The average production during the year rose from 8,700 barrels a day in April to 25,700 barrels a day in December. It is predicted that when all the the primary 80-acre-spacing development wells are completed production will exceed 30,000 barrels a day.

Two water-injection wells were drilled in the central part of the field, together with one water-supply well. This pilot water-flood programme was designed to check laboratory studies of secondary recovery from the Windalia reservoir. A total of 26 water-injection wells have now been programmed for 1968.

Production details are summarised in the following tables.

OIL AND GAS PRODUCTION, 1967

Company	Petroleum Lease and Field	Reservoir	Production	
			Oil (bbl)	Gas (mcf)
West Australian Petroleum Pty. Limited	1H Barrow Is.	Windalia	4,729,013	2,829,095
		Jurassic 6200	8,894	52,326
		Jurassic 6600	53,850	156,323
		Jurassic 6700	191,349	225,763
Total			4,983,106	3,263,507

OIL AND GAS DISPOSAL, 1967

	Oil (bbl)	Gas (mcf)
Total production	4,983,106	3,263,507
Used in drilling	5,835	....
Field fuel	6,716	25,575
Gas flared	....	3,237,932
Percentage field utilization	0·25%	0·78%
Percentage gas flared	....	99·22%
Oil shipments	4,646,948	....

TERTIARY STRATIGRAPHIC UNITS IN THE EUCLA BASIN IN WESTERN AUSTRALIA

by D. C. Lowry

ABSTRACT

The Tertiary stratigraphy of the Eucla Basin in Western Australia has been revised as a result of a recent study. Two previously described units, the Wilson Bluff Limestone and Nullarbor Limestone, are defined more precisely, and the Hampton Conglomerate is amended to Hampton Sandstone. Four new units are proposed. They are the Toolinna Limestone, a bryozoan Upper Eocene limestone in the southwest of the basin; the Abrakurrie Limestone, a bryozoan Lower Miocene limestone which underlies the Nullarbor Limestone near the centre of the basin; the Mullamullang Limestone Member, an algal limestone at the base of the Nullarbor Limestone; and the Colville Sandstone, a Lower Miocene sandstone in the northern part of the basin.

INTRODUCTION

This paper gives definitions and preliminary descriptions of new stratigraphic units, and refines the definitions of existing units. A bulletin of the Geological Survey describing the stratigraphy of the Eucla Basin in greater detail is in course of preparation.

The Eucla Basin is occupied by a thin, almost horizontal sheet of Cretaceous and Tertiary strata. The foundations of the Tertiary stratigraphy were laid by Tate (1879) who measured a section at Wilson Bluff and recognised, in ascending order, a "White Polyzoal Limestone", a "Yellow Polyzoal Bed", and a "Crystalline Limestone". Some later workers grouped all the limestone as "Eucla Limestone", which they believed to be of Eocene (Maitland, 1911) or Miocene age (Maitland, 1919; Teichert, 1947; Fairbridge 1953). Others recognised the presence of beds of several ages: Crespin (*in* King, 1949) recorded Lower Miocene, "Upper Middle Miocene", and Upper Cretaceous, while Glaessner (1953) recognised Lower Miocene and "Late Eocene". Singleton (1954) named the upper "crystalline" limestone the Nullarbor Limestone and the lower chalky limestone the Wilson's Bluff Limestone, ignoring Tate's "Yellow Polyzoal Bed". Singleton's nomenclature has been widely used (McWhae and others, 1958; Ludbrook, 1958a, 1958b, 1963), although Ludbrook (1958a) supported the validity of Tate's three-fold subdivision, and pointed out that the confusion was largely due to lack of geological field work, and the neglect of Tate's observations.

Singleton (1954) failed to specify a type section for the Nullarbor Limestone and Wilson Bluff Limestone, but this ommission was corrected by McWhae and others (1958), who selected Wilson Bluff as the type section for the Wilson Bluff Limestone, and by Ludbrook (1958a), who favoured Tate's section at Wilson Bluff as the type section for both units. Unfortunately Tate did not specify precisely where his section was measured, but it seems likely that it was a composite section with the lower part measured beneath the Wilson Bluff trigonometrical station and the upper part measured about 100 yards to the west. The section is a poor one because in the upper part the exposures are either obscured or almost inaccessible. The best place to measure a section on the bluff is at its eastern end, 1.2 miles east of the trigonometrical station, and this is taken as the type section. The section lies in South Australia, about 2 miles east of the border with Western Australia.

Tate's "Yellow Polyzoal Bed" is now recognised as a distinct formation and is here named the Abrakurrie Limestone. Fairbridge (1953) recorded "*Lithothamnium* (algal) reefs" at Madura Pass, but this outcrop is part of an extensive biostrome which is here named the Mullamullang Limestone Member of the Nullarbor Limestone. Teichert (1947, p.115) examined corals from near Forrest which he described as "reef-building", and Fairbridge (1953) seems to have used this report as the basis for proposing the name "Forrest Reef Limestone Member". However it appears that Teichert used "reef-building" as a synonym for colonial, because I have found colonial corals scattered in the limestone near Forrest, but no sign of true reef development, and I therefore regard the name as invalid. The name Toolinna Limestone is proposed here for beds in the southwest of the basin which are laterally equivalent to the Wilson Bluff Limestone but which are sufficently distinct lithologically to warrant the status of a formation. For similar reasons the name Colville Sandstone is proposed for beds in the north of the basin which are laterally equivalent to the Nullarbor Limestone.

Singleton (1954) placed the Nullarbor Limestone and Wilson Bluff Limestone in the Eucla Group, omitting the Hampton "Conglomerate". However it is in keeping with the Australian Code of Stratigraphic Nomenclature to include in a group all the formations of a major depositional cycle, so the Hampton "Conglomerate" is here included in the Eucla Group, along with the Toolinna Limestone, Abrakurrie Limestone, and Colville Sandstone.

There has been little faulting in the Eucla Basin, and the formations are nearly horizontal. The thickest drilled sections of both the Tertiary and Cretaceous beds are in the Madura area, and marine seismic surveys indicate that the beds continue to thicken gently southwards across the continental shelf. The stratigraphic relations of formations of the Eucla Group are presented diagrammatically in Figure 6, and a cross section of part of the basin is shown in Plate 20.

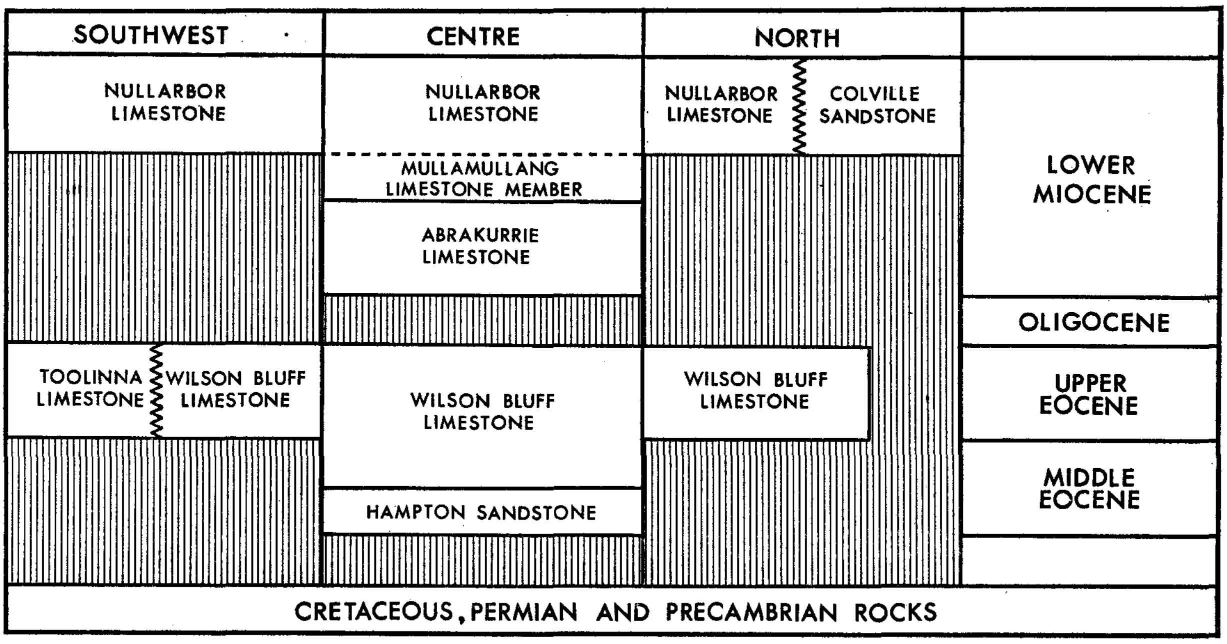


Figure 6—Stratigraphic relations within the Eucla Group, in the southwest, central, and northern parts of the Eucla Basin.

HAMPTON SANDSTONE

The name "Hampton Conglomerate" was given by Fairbridge (1953) to the sandstone, calcareous sandstone and conglomeratic sandstone underlying the Tertiary "Eucla Limestone" in the Madura 1 bore. The name is apparently derived from the adjacent Hampton Range.

Type section

The type section is that encountered over the interval 903 feet to 928 feet 6 inches in the Madura 1 bore (31° 54′ 35″ S, 127° 00′ 20″ E). Fairbridge (1953) cited the interval 903 feet to 927 feet 3 inches, the combined intervals of the samples described by Maitland (1904). However, the driller's log indicates that the bed from 927 feet 3 inches to 928 feet 6 inches should also be included in this unit. The name is amended here to Hampton Sandstone because sandstone is the dominant lithology. The enclosing strata are Wilson Bluff Limestone above and Madura Shale beneath.

Lithology

The samples held by the Geological Survey of Western Australia comprise a lime-cemented medium to coarse-grained sandstone with iron-stained rounded to subrounded quartz grains from the interval 903 feet to 904 feet 8 inches, and medium to coarse-grained subangular to rounded iron-stained quartz sand from the interval 904 feet 8 inches to 927 feet 3 inches. Maitland (1904) described the lower sample as "coarse quartz, sand and gravel", but there is only about 5 per cent. conglomeratic material in the existing sample. The driller's log records:

903 feet-905 feet: very hard limestone conglomerate.

905 feet-927 feet 3 inches: coarse brown water-worn granite sand.

927 feet 3 inches-928 feet 6 inches: hard crystalline boulders.

Thickness

The thickness in the Madura 1 bore is 25 feet 6 inches according to the driller's log.

Distribution

The Hampton Sandstone does not crop out, and its extent is known only from bores. It was recorded in Eyre No. 1 to the south and Gambanga No. 1 to the west, but not in bores on the Trans Australian Railway to the north. Eastwards, it probably extends into South Australia, but if so, it is discontinuous because it was not present in Alliance Eucla No. 1.

Stratigraphic relations

The unit is overlain, probably conformably, by Wilson Bluff Limestone, and is underlain disconformably by the Cretaceous Madura Shale. It may pass laterally into the "Pidinga Clays and Sands" in South Australia (Ludbrook, 1958a).

Fossils

Casts of pelecypods are present in the sample from the interval 903 feet to 904 feet 8 inches.

Age

The Hampton Sandstone is probably the same age as the overlying lower part of the Wilson Bluff Limestone, that is, Middle Eocene (Ludbrook, 1963).

WILSON BLUFF LIMESTONE

The name "Wilson's Bluff Limestone" was introduced by Singleton (1954) for chalky bryozoal limestone that underlies "crystalline" limestone in the Eucla Basin. The name was amended to Wilson Bluff Limestone by McWhae and others (1958).

Type section

The type section has not been accurately defined previously and it is here defined as the section exposed at the east end of Wilson Bluff (31° 41′ S, 19°, 02′ E.), 1.2 miles east of the trigonometrical station. The top of the formation is about 167 feet above sea level and is marked by an upward change from a hard white limestone with brachiopods to a friable porous bryozoan limestone. The formation extends below sea level and the base is not exposed.

The exposure on the west wall of Abrakurrie Cave (31° 39′ 20″ S, 128° 29′ 20″ E) is nominated here as a reference section because the contact with the overlying formation is better exposed and more accessible than at Wilson Bluff. The top of the formation in the cave is also marked by an upward change from a white hard limestone with large brachiopods to a yellow, friable, coarse, bryozoan limestone. The boundary lies about 159 feet beneath the surface of the plateau, and the formation extends below the lowest accessible part of the cave.

Lithology

The beds at Wilson Bluff are white chalky bryozoan limestones with chert nodules and minor glauconite.

Thickness

The type section is 167 feet thick, and the reference section 80 feet thick. In neither section is the base of the formation exposed. The thickest section drilled is in Eyre No. 1, which penetrated 1,073 feet of Tertiary limestone (Ludbrook, 1960) of which the lower 950 feet (approximately) is Wilson Bluff Limestone.

Distribution

The Wilson Bluff Limestone is developed throughout most of the Eucla Basin. It extends northwards beyond the Trans Australian Railway and eastwards into South Australia. Near the western margin of the basin it passes laterally into the Toolinna Limestone.

Stratigraphic relations

The Wilson Bluff Limestone overlies (probably conformably) the Hampton Sandstone in the Madura area, and disconformably overlies the Madura Shale in the northern part of the basin. To the west and southwest the upper part of the formation grades laterally into the Toolinna Limestone. It is overlain by the Abrakurrie Limestone in most areas, and the contact is interpreted as a slight disconformity where it is seen in Cocklebiddy Cave and in caves near Wilson Bluff. In the northern part of the basin, for example at Haig Cave (30° 45′ S, 126° 23′ E), the Abrakurrie Limestone is absent and the Wilson Bluff Limestone is overlain by Nullarbor Limestone.

Fossils

The Wilson Bluff Limestone contains a rich fauna of bryozoans, pelecypods, echinoids, brachiopods, and foraminifers.

Age

Foraminifera indicate an Upper Eocene age for the upper part of the formation, and a Middle Eocene age for the lower part (Ludbrook, 1963).

TOOLINNA LIMESTONE

The name Toolinna Limestone is proposed here for porous bryozoan limestone that crops out in the southwestern part of the Eucla Basin. The name is taken from Toolinna Cove.

Type Section

The type section is the cliff at Toolinna Cove (32° 44′ S, 125° 01′ E), from about 60 feet above sea level to the top of the cliff. The lower part of the section was measured at the southwestern end of the cove, and the upper part along a precarious path up the cliff face. The beds in the lower 60 feet are regarded as Wilson Bluff Limestone, but the upper beds are designated as a separate formation because they are distinctly better sorted and coarser than the chalky beds at Wilson Bluff. The two lithologies are interbedded at Toolinna Cove, with the chalky beds dominant at the bottom and the porous beds dominant higher up. The boundary was chosen as the base of a thick current-bedded limestone bed which disconformably overlies a chalky bed at about 60 feet above sea level. The disconformity has a relief of at least 5 feet, but is probably of only local significance.

Lithology

The unit is a thick-bedded bryozoan limestone, and is commonly current-bedded. It is generally a medium to coarse-grained calcarenite, but in places the bryozoan fragments are large enough to form a fine calcirudite. In the lower 100 feet the beds are porous and friable, but in the upper part they are weathered to a hard tightly-cemented limestone.

Thickness

The type section is 180 feet thick, and the unit is thought to thicken to the southwest.

Distribution

The unit is exposed in the west and southwest of the basin, and it is possibly present in the subsurface in the north, close to the Eocene shoreline.

Stratigraphic relations

The echinoids and foraminifers clearly show that the Toolinna Limestone is laterally equivalent to the upper part of the Wilson Bluff Limestone.

Near Mount Ragged in the extreme southwest of the basin, the unit grades laterally into the Plantagenet Beds, and rests unconformably on Precambrian rocks. It is overlain disconformably by Abrakurrie Limestone towards the centre of the basin, and by Nullarbor Limestone towards the margin.

Fossils

The fossil content is similar to that of the Wilson Bluff Limestone, except that the planktonic foraminifers found in the chalky limestone are generally absent from the porous Toolinna Limestone. Crespin (1956) recorded numerous foraminifers in samples from a well near Booanya Rock in beds now regarded as Toolinna Limestone.

Age

Foraminifera indicate an Upper Eocene age (Crespin, 1956).

ABRAKURRIE LIMESTONE

The name Abrakurrie Limestone is proposed here for the yellowish bryozoan limestone overlying the Wilson Bluff Limestone and underlying the Mullamullang Limestone Member of the Nullarbor Limestone in the central part of the Eucla Basin. The name is taken from Abrakurrie Cave. The unit was first described at Wilson Bluff by Tate (1879) as the "Yellow Polyzoal Bed", but it has not been formally named or defined before and the opportunity is taken here to select a type section superior to that at Wilson Bluff.

Type section

The type section is the western wall of Abrakurrie Cave (31° 39′ 20″ S, 128° 29′ 20″ E). The upper limit is the contact with algal limestone (Mullamullang Limestone Member) about 51 feet below the surface of the plateau, and the lower limit is the contact with hardened white limestone with abundant brachiopods (Wilson Bluff Limestone) about 159 feet below the plateau.

Lithology

The Abrakurrie Limestone is a medium to coarse-grained yellowish bryozoan calcarenite. The lower part is porous and friable, but weathering has made the upper part hard and tightly cemented. In places near the centre of the basin, for example at Twilight Cove and Mullamullang Cave, it is current-bedded. The lithology is very similar to the Toolinna Limestone, but preliminary studies by G. M. Philip indicate that each formation has a distinct echinoid fauna which can be used to distinguish them.

Thickness

The unit is 105 feet thick in Abrakurrie Cave, and is more than 322 feet thick in Mullamullang Cave. It was probably thickest south of Madura, but much has been removed by Pleistocene marine erosion. The depth to the base of the formation is unkown in the Madura area because it extends beneath the water table in caves, and in bores it is not possible to pick accurately the boundary with the Wilson Bluff Limestone.

Distribution

The unit is developed around Madura in the centre of the basin. It extends to Point Dover in the southwest, and beyond Wilson Bluff in the east. It probably does not extend as far north as the Trans Australian Railway.

Stratigraphic relations

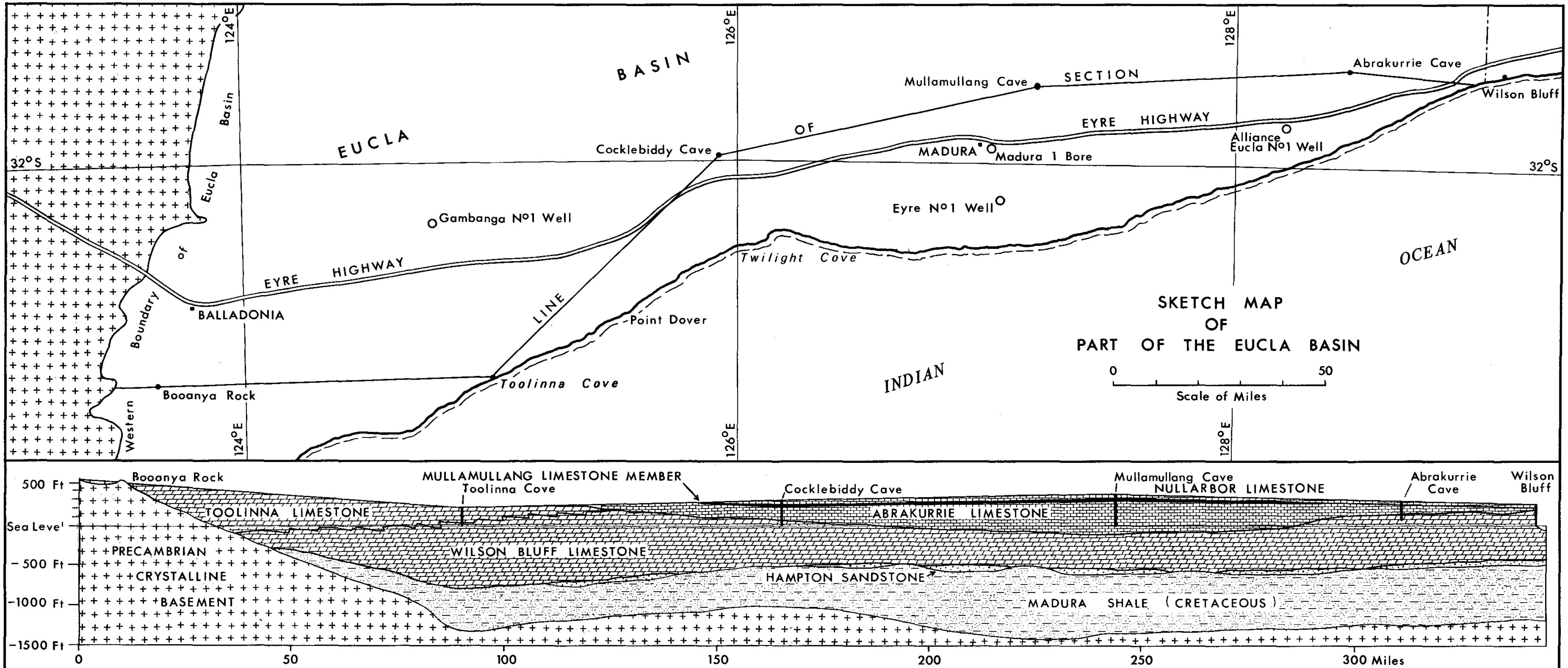
The Abrakurrie Limestone disconformably overlies the Wilson Bluff Limestone, and is overlain with apparent conformity by the Mullamullang Limestone Member.

Fossils

The unit contains abundant bryozoans, echinoids, pelecypods, and brachiopods.

Age

Echinoids indicate an Oligo-Miocene age (Philip, written communication, 1966), but typical Oligocene foraminifers are absent, and a lower Miocene age seems most likely.



VERTICAL EXAGGERATION X 100

SECTIONS EXPOSED AT EACH LOCALITY ARE INDICATED BY A HEAVY VERTICAL LINE

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

DIAGRAMMATIC CROSS SECTION OF THE EUCLA BASIN IN WESTERN AUSTRALIA

PLATE 20

9952

NULLARBOR LIMESTONE

The term Nullarbor Limestone was introduced by Singleton (1954) for hard "crystalline" limestone which overlies the Wilson Bluff Limestone in the Eucla Basin. Ludbrook (1958a) nominated Wilson Bluff as the type section. Singleton's characterisation of the Wilson Bluff Limestone as chalky and friable and the Nullarbor Limestone as hard and tightly cemented was an over-simplification which led to the general belief that the Eucla Basin was everywhere covered by Nullarbor Limestone. The Toolinna Limestone and Abrakurrie Limestone are porous and friable where unweathered, but they also become hard and tightly cemented where subjected to prolonged weathering. For example the upper part of the scarp between Point Culver and Wilson Bluff is formed by 50 to 100 feet of hard, tightly cemented limestone which has the appearance of a single continuous formation, but this apparent uniformity is caused by weathering, the top of the scarp being formed in various places by Nullarbor Limestone, Abrakurrie Limestone, and Toolinna Limestone.

At Wilson Bluff, the bottom of the zone of weathering lies within the Abrakurrie Limestone, and Singleton (1954) apparently included the upper tightly cemented part of that formation in the Nullarbor Limestone and the lower friable part in the Wilson Bluff Limestone. However later workers have restricted the name Nullarbor Limestone to the foraminiferal calcarenite at the top of the cliffs and this practice is continued here.

Type section

The type section adopted is that exposed at the eastern end of Wilson Bluff, where the unit extends from the top of the Abrakurrie Limestone (239 feet above sea level) to the top of the cliffs. This section is a poor one because the formation lies within the zone of surface weathering ,and both the textural details of the limestone and its contact with the underlying formation are obscure. A reference section is nominated here as the 58 feet of foraminiferal and algal limestone exposed in the doline of Mullamullang Cave (31° 43′ S, 127° 14′ E), between the Abrakurrie Limestone and the surface of the plateau.

Lithology

The Nullarbor Limestone is a hard, tightly cemented, poorly-sorted calcarenite. Foraminifers and comminuted algae and echinoids are the most prominent constituents. Near the centre of the basin, the formation includes a biostromal algal limestone which is designated the Mullamullang Limestone Member.

Thickness

The unit is 46 feet thick at its type section at Wilson Bluff. Its thickness is very variable because it is the uppermost unit of the marine Tertiary sequence in the Eucla Basin, and its present thickness depends to a large extent on the amount of post-Miocene erosion. The thickest measured section in Western Australia is 75 feet in Haig Cave, but it is somewhat thicker in parts of South Australia, being 80 feet thick in Warbla Cave, 15 miles northeast of Wilson Bluff.

Distribution

The Nullarbor Limestone forms the surface of some 25,000 square miles of the Eucla Basin. It has been removed from the Roe Plains south of Madura by Pleistocene marine erosion (Ludbrook, 1958b), and from the southwestern part of the plateau by subaerial erosion.

Stratigraphic relations

The Nullarbor Limestone overlies the Abrakurrie Limestone with apparent conformity. The boundary is sharp, but there is no evidence of a period of erosion between deposition of the two formations. In the centre of the basin, the basal part is termed the Mullamullang Limestone Member, and in the northern part the formation grades laterally into the Colville Sandstone.

Fossils

The formation commonly contains abundant moulds of pelcypods and gastropods. There are scattered colonial corals near Forrest, and coralline algal nodules in the central part of the basin.

Age

Benthonic foraminifers indicate a Lower Miocene age (Ludbrook, 1963).

MULLAMULLANG LIMESTONE MEMBER OF THE NULLARBOR LIMESTONE

The name Mullamullang Limestone Member is introduced here for the algal limestone that is developed at the base of the Nullarbor Limestone near the centre of the Eucla Basin. The name is taken from Mullamullang Cave.

Type section

The type section is that exposed in the doline of Mullamullang Cave (31° 43′ S, 127° 14′ E). The unit overlies hard bryozoan limestone of the Abrakurrie Limestone 58 feet below the surface of the plateau, and grades up into foraminiferal calcarenite about 37 feet below the plateau.

Lithology

The member is an algal limestone composed of nodules of coralline algae of the *"Lithothamnium"* type, enclosed in a poorly-sorted foraminiferal calcarenite.

Thickness

The unit is 21 feet thick in its type section, and reaches a thickness of about 35 feet where it is exposed on the Hampton Range, 25 miles southwest of Madura.

Distribution

The member occurs near the centre of the Eucla Basin, extending from Wilson Bluff on the east to beyond Cocklebiddy Cave on the west. The unit does not extend as far north as the railway.

Stratigraphic relations

The Mullamullang Limestone Member overlies the Abrakurrie Limestone with apparent conformity, and it grades up into the overlying part of the Nullarbor Limestone.

Fossils

Calcareous algae of the *"Lithothamnium"* type are dominant (see Figure 4 *in* Ludbrook, 1958b). The matrix contains comminuted algae, small algae, and foraminifers.

Age

The unit contains *Austrotrillina howchini,* a characteristic Lower Miocene foraminifer.

COLVILLE SANDSTONE

The Colville Sandstone is proposed here for the beds of sandstone with minor claystone, limestone, and conglomerate that crop out in the northern part of the Eucla Basin. The name is taken from Lake Colville, 17 miles east of the type section.

Type section

The beds exposed in an east-flowing creek (21° 31′ S, 126° 23′ E) on the western side of a major depression 110 miles northwest of Loongana are taken as the type section.

Lithology

The dominant lithology of the type section is a medium-grained quartz sandstone. Thin calcarenite interbeds occur near the top and the bottom of the sequence. In other areas the formation also contains minor glauconitic sandstone, sandy shelly calcarenite, claystone, and conglomerate.

Thickness

The type section is 62 feet thick and the thickest known section of 77 feet is exposed in a creek 45 miles to the east. The base is not exposed in either section, and the maximum thickness is unknown.

Distribution

The Colville Sandstone is developed around the northern margin of the Eucla Basin.

Stratigraphic relations

The beds overlie tillite of probable Permian age near Lake Gidgi and the Carlisle Lakes, and surround an inlier of Proterozoic rocks near Lake Ilma (formerly "Lake Ell"). The beds grade laterally into the Nullarbor Limestone, and they are overlain by a variety of Quaternary deposits.

Fossils

The most common fossils are the heavy-shelled pelecypods *Ostrea* sp. and *Spondylus* sp.

Age

Marginopora vertebralis occurs at the base of the type section and *Austrotrillina howchini* has been found elsewhere. The beds are therefore Lower Miocene, the same age as the Nullarbor Limestone.

ACKNOWLEDGEMENTS

Fossils collected during the field work are being studied as follows: echinoids, Professor G.M. Philip; molluscs and brachiopods, Dr. N. H. Ludbrook; and Foraminifera, Bryozoa, and other groups, Dr. A. E. Cockbain. Some of their preliminary palaeontological data have been used in this report.

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THE ORIGIN OF BLOW-HOLES AND THE DEVELOPMENT OF DOMES BY EXSUDATION IN CAVES OF THE NULLARBOR PLAIN

by D. C. Lowry

ABSTRACT

Narrow circular vertical shafts called blow-holes are common surface features in the limestone of the arid to semi-arid Nullarbor Plain. Blow-holes are formed by roof domes of shallow caves migrating upwards until they reach the surface. The domes develop in the vadose zone by frittering of the rock by exsudation.

INTRODUCTION

The Nullarbor Plain is a stony treeless plain in the centre of an arid to semi-arid plateau of Tertiary limestone on the southern coast of Australia. This paper describes only the Western Australian plain, but the remarks on the genesis and morphology are believed to apply equally well to blow-holes in the adjoining part of South Australia. The name Nullarbor Plain strictly applies only to the treeless plain, but it is often used to include the scrub-covered area to the south, and sometimes (for example Jennings, 1963) to include the whole of the limestone plateau.

DESCRIPTION OF BLOW-HOLES

Blow-holes are circular vertical shafts 1 to 6 feet in diameter and 5 to 35 feet deep. The surface of the plateau has a relief of about 20 feet, and consists of gentle rises with boulders and rare pavements of limestone, and intervening flat areas of accumulated clay. Blow-holes are found both on clay flats where they are set in a conical depression in the clay, and on rises where some are set in limestone pavements. Most of the shafts that are large enough to enter, are either blocked at the bottom by clay and rubble or lead to cramped rubbly caves. A few lead to larger caves, for example, Thylacine Hole, which covers an area of more than 2 acres.

DISTRIBUTION

Blow-holes occur over the entire treeless plain and also in the scrub-covered area between the plain and the scarp that marks the southern edge of the plateau. Vehicle tracks criss-cross the plain, and by noting the frequency with which blow-holes are seen alongside the track it is possible to make a rough estimate of the areal density of blow-holes as well as the limits of their distribution. The data are plotted on Plate 21 and it suggests that there are 10,000 to 100,000 blow-holes scattered over an area of about 20,000 square miles.

ROCK HOLES

Rock holes are another surface feature of the Nullarbor. They are roughly circular basins set in limestone pavements, and they hold water after rain. Pavements are often pock-marked with solution pans a few inches deep, and the pan in the lowest part of the pavement becomes preferentially enlarged because of the greater ponding of water. When the holes are big enough to hold water for a week or two after rain the rate of enlargement is probably increased further by the activity of algae and also by the scratching of men and animals trying to reach the last of the water.

PREVIOUS THEORIES OF ORIGIN OF BLOW-HOLES

The earliest account of the blow-holes is probably that of Tate (1879, p. 111) who recorded "perpendicular vents called blow-holes up which there rushes on hot days a violent wind". Numerous other authors have mentioned them, and two possible origins have been proposed: Bolam (1923) suggested that they were formed by rock holes being deepened until they broke through into a cave, whereas King (1949) believed that the shafts were formed by corrosion and corrasion by descending vadose waters, presumably by the enlargement of a crack at the intersection of two vertical joints. Jennings (1963) also favoured this view and recorded conchoidal hollowings on the walls which he believed to be the evorsional sculpturing of turbulent vadose water. It is conceivable that a few blow-holes were formed in the manner suggested by Bolam, but the great majority have features irreconcilable with either theory. A third theory is proposed herein; that they are formed by domes in the roofs of shallow caves migrating upwards until they reach the surface.

SALIENT FEATURES OF BLOW-HOLES

Blow-holes have the following features:

Although aerial photographs commonly show a general joint-controlled pattern of elongate ridges of exposed limestone and intervening flat areas of colluvial clay, the rock outcrops rarely show jointing on a small scale. Instead the upper 10 to 15 feet of limestone is broken by irregular anastomosing cracks and seams of kankar and clay. The cracks are irregular in both horizontal and vertical exposures, and it seems unlikely that the intersection of two cracks could be rectilinear and vertical as would be necessary to initiate a blow-hole. Blow-holes rarely lie on cracks in limestone pavements, and instead most of them have circular rims unaffected by cracks (Plate 23A).

Some blow-holes occur in areas where the limestone is buried by colluvial clay up to 5 feet thick. The freshness of the exposure of the clay in the crater around these blow-holes shows that there is rapid erosion of the clay at the present time (Plate 23B). The clay appears to have once formed a continuous sheet over the top of the blow-holes, and it is difficult to see how they could have been formed by solution by vadose water.

Rock holes are not as common a feature as blow-holes, and they are restricted to large limestone pavements without cracks that would allow the seepage of water. Blow-holes on the other hand are not restricted to such pavements.

Rock holes often have irregular margins, for example Undawidgi Rock Hole in Plate 23C. Blow-holes however are usually markedly circular. A few rock holes are markedly circular and parallel-sided, but these may well be blow-holes that have become blocked by clay so that they now hold water.

Several blow-holes have little or no drainage entering them because they occur on ridges (for example, Plate 23A). Where blow-holes do receive surface drainage, it is not possible to demonstrate whether the drainage system developed as a result of the blow-hole, or vice versa.

Blow-holes commonly descend more than 10 feet before opening out into a cave, whereas no rock holes observed were more than 4 or 5 feet deep.

These features and their congruity with each of the possible origins are listed in Table 1. The conclusion is that the blow-holes have broken through to the surface from beneath and that their distribution is unrelated to jointing or surface drainage.

Table 1

FEATURES OF BLOW-HOLES AND ROCK HOLES, AND THEIR CONGRUITY WITH POSSIBLE BLOW-HOLE ORIGINS

Features	Possible origin		
	Deepened rock hole	Joint opening	Enlarged cave roof dome
Blow-holes rarely occur on joints	yes	no	yes
Some blow-holes are covered by clay	no	no	yes
Rock holes are restricted to large rock pavements ; blow-holes are not	no	yes	yes
Rock holes often have irregular shapes ; blow-holes are circular	no	?no	yes
Some blow-holes receive little drainage	no	no	yes
Rock holes are shallower than blow-holes	no	yes	yes

ROOF DOMES IN CAVES OF THE NULLARBOR PLAIN

If blow-holes break through from beneath, an examination of quarries and caves should reveal incipient blow-holes that have not reached the surface. In fact, almost all the shallow caves that are entered by way of a blow-hole have domes in the roof which would become blow-holes if they extended further upwards. These domes have received very little attention by previous writers on Nullarbor caves: Tate (1879, p.111) seems to be the only writer to mention them. He recorded that the roof "in many places rises nearly to the surface in the form of inverted pot holes". The walls of the domes are close to vertical and the tops are approximately hemispherical. They range in diameter from 6 inches to 6 feet, and are usually in the range 18 inches to 3 feet. The walls have concentric sculpturing due to the truncation of subhorizontal layers of clay, kankar, and limestone having differing resistances to weathering. The "evorsional" sculpturing on the walls of blow-holes is probably usually due to the same cause.

Three widely separated caves can be used to illustrate the occurrence of domes. Decoration Cave lies at the northern limit of the Nullarbor Plain, 50 miles northeast of Forrest. A blow-hole 2 feet in diameter leads to a chamber 60 feet long, 25 feet wide, and 8 feet high. The chamber has a flat earth floor 35 feet below the surface, and the walls are covered with old calcite stalactites and flowstone. The entrance shaft (Plate 24A; Figure 7) has several domes connected with it, and the roof near the entrance shaft has a cluster of domes. It appears that a cluster of domes migrated upwards until the central one reached the surface.

A second example is Lynch Cave near Loongana (see Figure 8). The entrance is a blow-hole and like the entrance of Decoration Cave, there are several domes associated with it. The cave has an abundance of old calcite stalactites and flowstone, some of which are truncated by domes. This shows that these domes formed later than the calcite, and are one of the last-formed features of the cave.

Telegraph Cave, 24 miles east of Caiguna, is small (Figure 9) and has numerous domes. The entrance is partly the result of collapse, and it is likely that it was caused by weakening of the rock by a cluster of domes reaching almost to the surface.

It might be argued that domes are only associated with caves large enough to enter, or that domes only form after the cave develops an entrance. These possibilities can be discounted by examining some of the quarries along the Eyre Highway and the Trans-Australian Railway. The best exposures are in the Loongana quarry where there are domes developed above small cavities in porous rubbly limestone (Plate 24B).

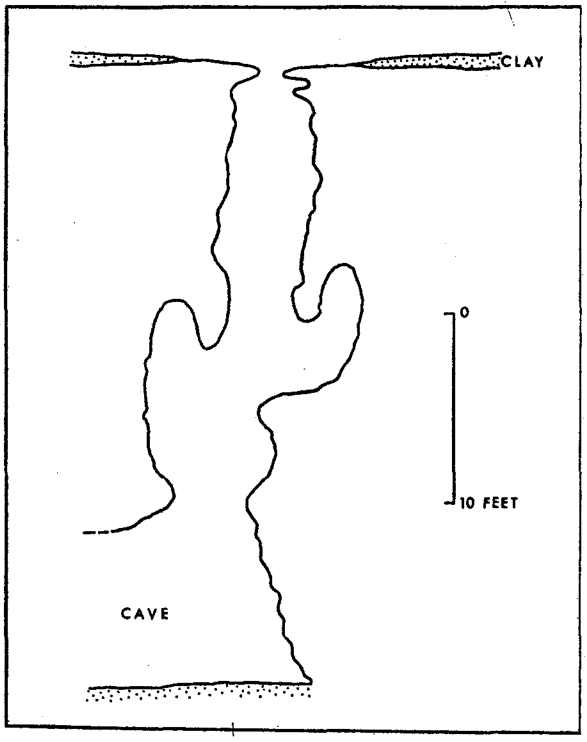


Figure 7—Vertical section of entrance to Decoration Cave.

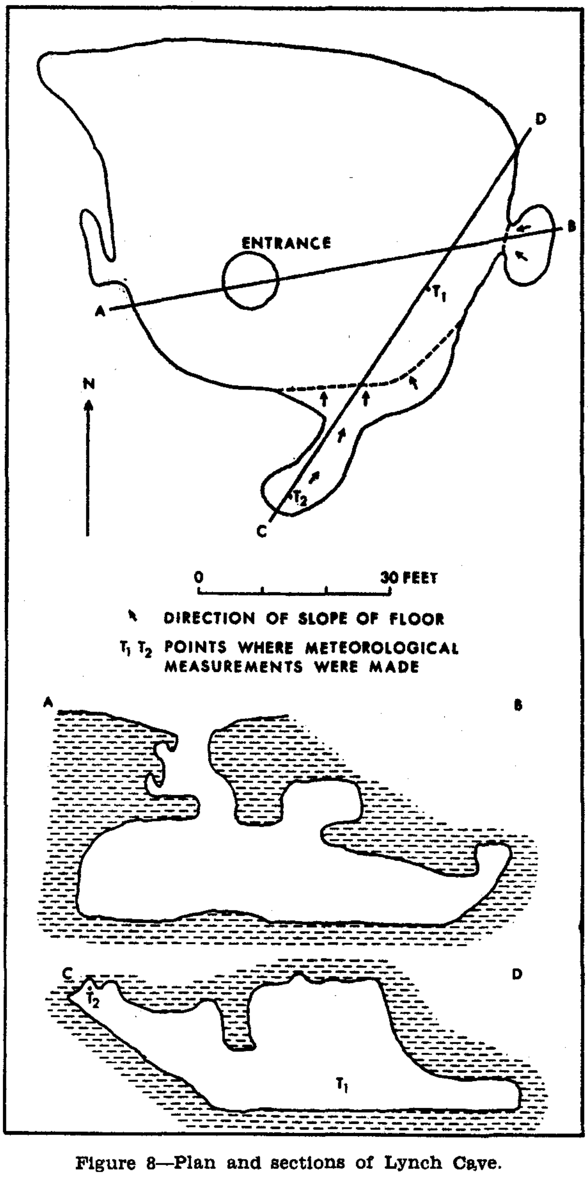


Figure 8—Plan and sections of Lynch Cave.

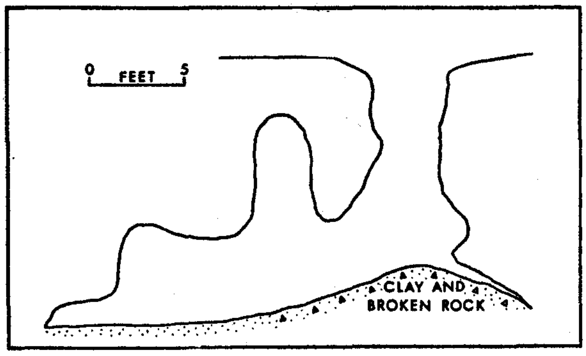


Figure 9—Vertical section of Telegraph Cave.

DEVELOPMENT OF THE DOMES

If blow-holes are formed by the upward migration of domes, the problem is to find the mechanism. Domes have been recorded in the roofs of limestone caves elsewhere in the world, but none of the postulated origins fits the domes in the roofs of caves of the Nullarbor Plain. Probably the best known description of roof domes is that of Bretz (1942) who showed that the domes he studied were caused by solution by water in the phreatic zone. This theory cannot account for the domes described above: truncation of calcite formation and fresh erosion around the entrances of some blow-holes shows that the domes have developed relatively recently, yet the water table is at present about 300 feet below the plain and it is most unlikely that it could have been near the surface of the plain during the development of the domes.

King-Webster and Kenny (1958) believed that colonies of bats excavated domes in the roofs of caves in Trinidad, but this cannot apply to domes in the small shallow caves of the Nullarbor Plain because bats rarely live in them, and there are no guano piles beneath the domes.

Solution by vadose water as postulated by Bretz (1942) for dome-pits in caves in North America is eliminated because the tops of the domes have no visible fissures, and the walls of the domes are dry.

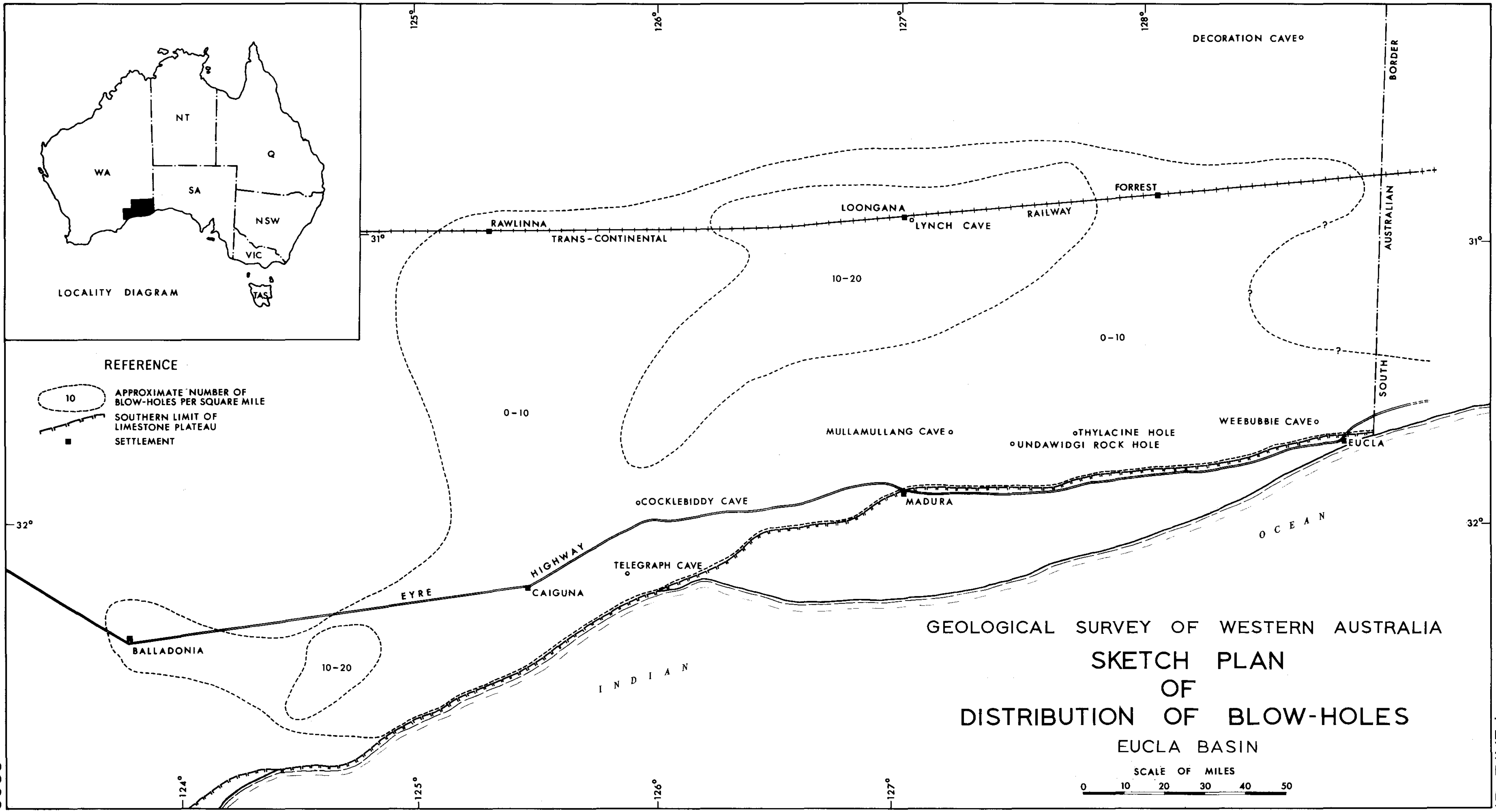
There do not appear to be any other published theories that can explain the development of domes in Nullarbor caves, and it is proposed here that the domes form by the frittering of the rock by the process of exsudation.

EXSUDATION

Exsudation (see Hume, 1914; Jutson, 1918) is the process whereby the surface grains of a rock are wedged off by the growth of crystals in pores near the surface. The crystals grow because of evaporation of saline interstitial water. Buckley (1951) discussed the force exerted by a growing crystal, and cited several examples of rock disintegration caused by it.

Exsudation has an important modifying influence on the morphology of deep caves of the Nullarbor Plain. Jennings (1963) recorded scalloping ("tafoni") on the walls of Weebubbie Cave, and Lowry (1964) recorded similar weathering occurring at the present time in Cocklebiddy Cave and suggested that it was due to exsudation. Recently-discovered Mullamullang Cave shows very great modification by exsudation; for half a mile from the entrance the floor is covered with drifts of dust, sand, and rock flakes (Anderson, 1964) which I believe to be frittered from the roof. Wigley and Hill (1966) also recorded minor exsudation features in other parts of the cave. Thus exsudation is well-established in the deep caves, and it seems to be the most probable mechanism for the development of domes in the shallow caves.

There are at least three requirements for exsudation to take place in caves: the rock must be sufficiently porous; the interstitial fluid saline; and evaporation occur at the rock surface, that is, the



GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SKETCH PLAN OF DISTRIBUTION OF BLOW-HOLES

EUCLA BASIN

PLATE 21

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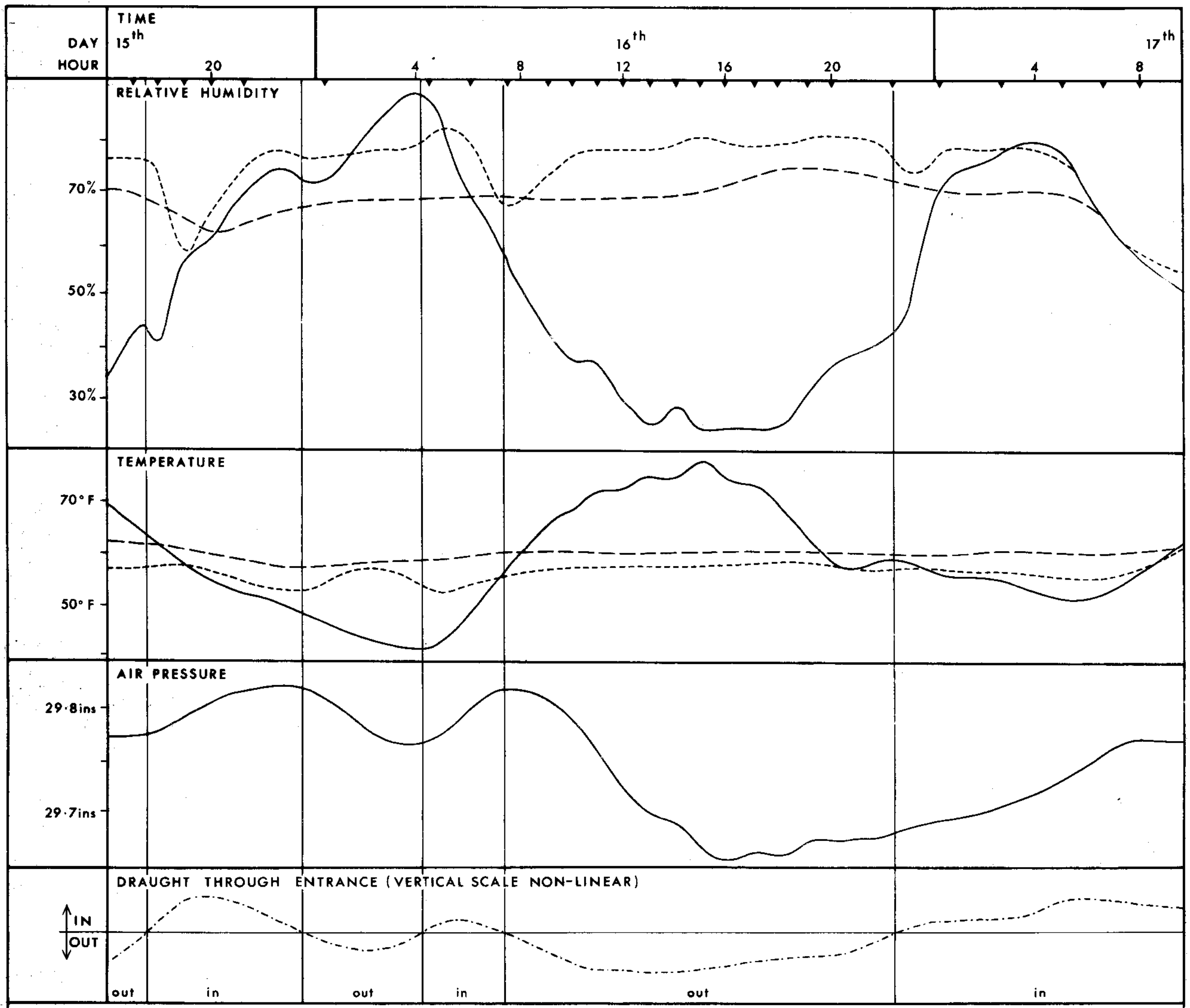
PLATE 22

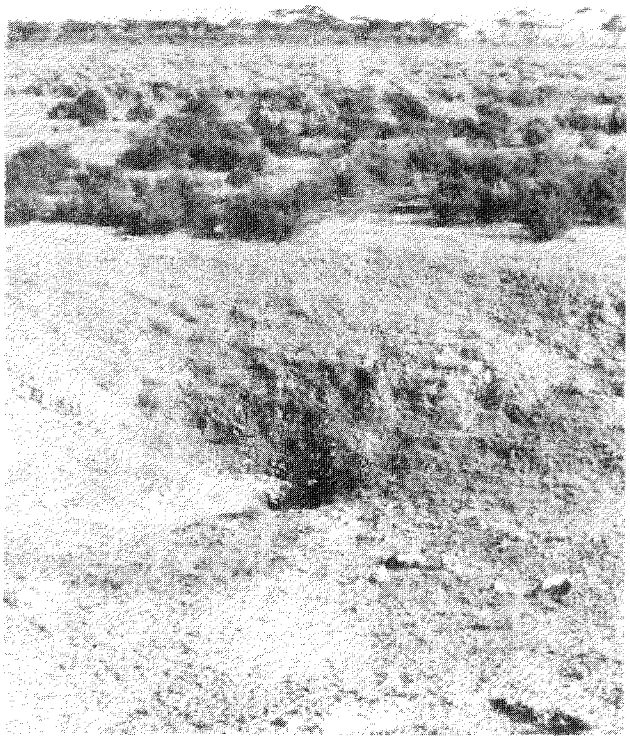


METEOROLOGICAL DATA FROM LYNCH CAVE 15-17th OCTOBER 1966

REFERENCE
- TIMES AT WHICH MEASUREMENTS WERE MADE
- MEASURED OUTSIDE CAVE
- MEASURED IN MAIN CHAMBER; POINT T_1 IN FIGURE 8
- MEASURED IN DOME; POINT T_2 IN FIGURE 8

9928

A. Typical blow-holes situated on a limestone ridge. Note the circularity of the rims; F 1177.



B. Blow-hole surrounded by a rapidly eroding layer of clay 3 feet thick; F 1178.

C. Undawidgi Rock Hole showing irregular margins and a typical large limestone pavement; F 1179.

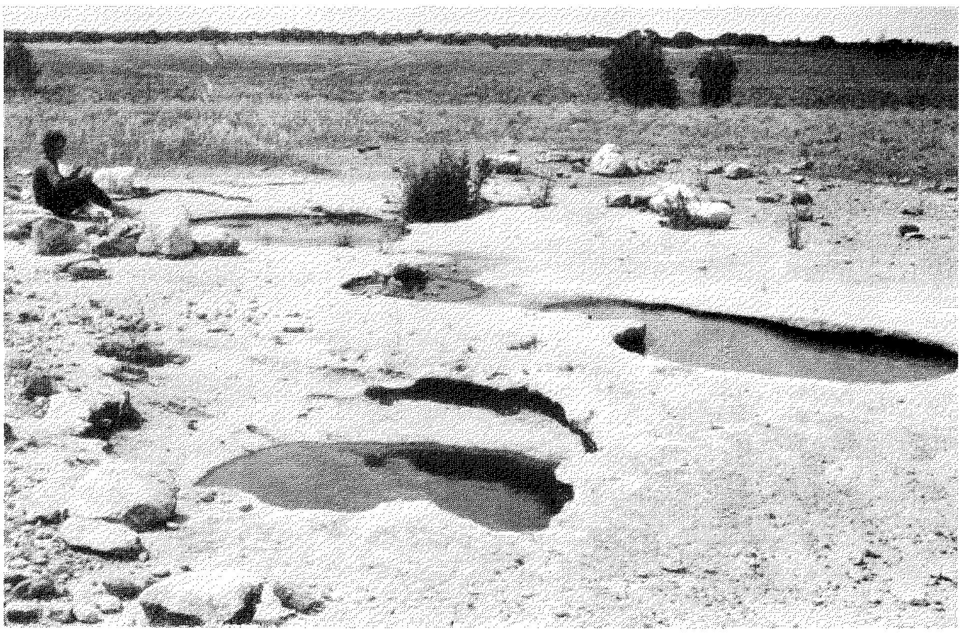
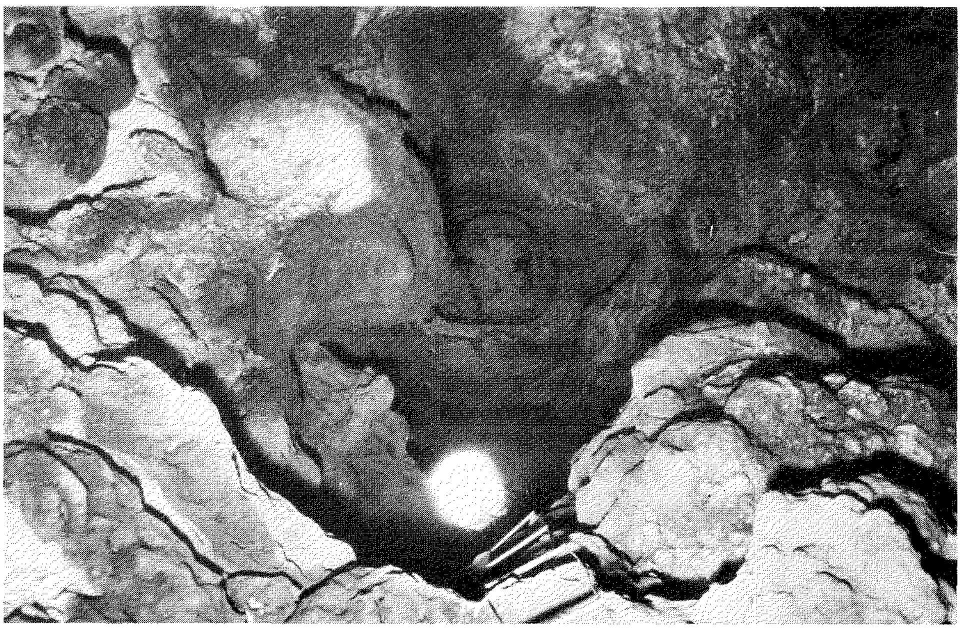
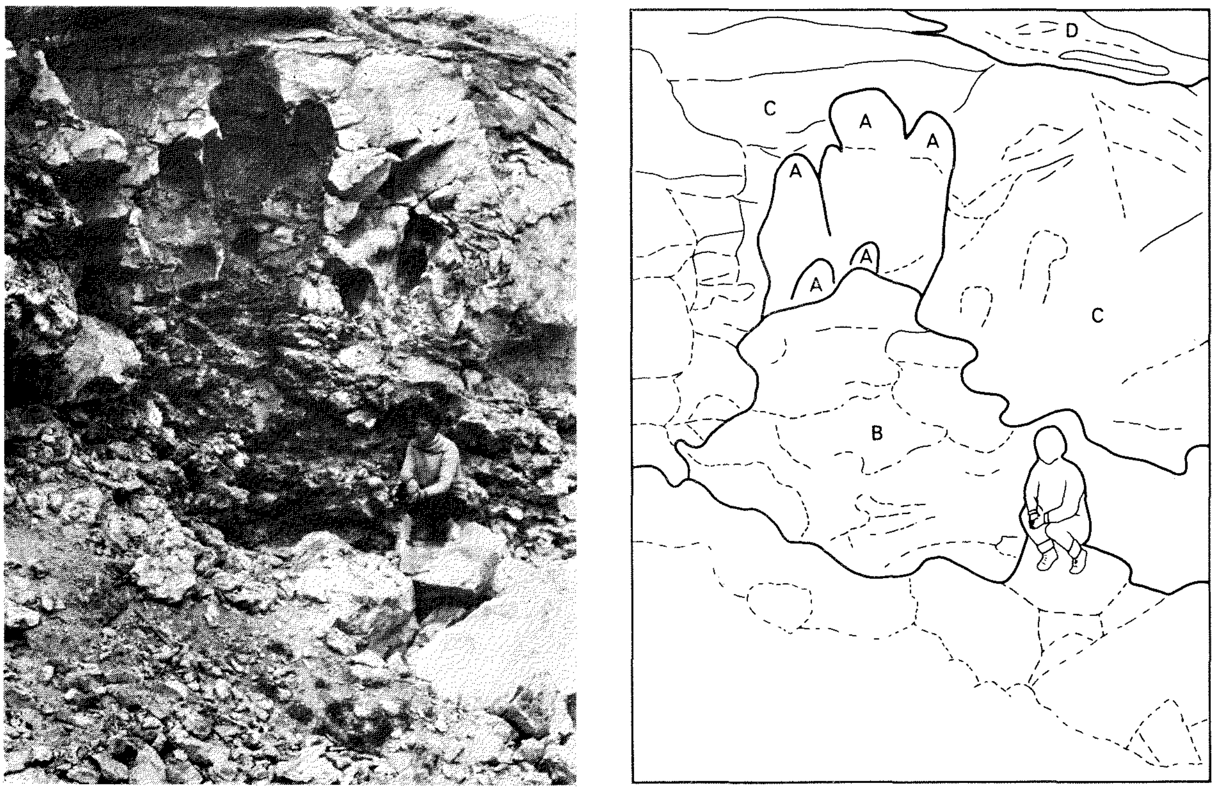


PLATE 24



A. View looking up Decoration Cave blow-hole entrance. Ladder rungs are 6 inches wide. The dome appears in section in Figure 7; F 1181.



B. Loongana Quarry. A cluster of domes (A) are developed above a zone of porous rubbly limestone (B). Note the irregular jointing of the limestone (C) and the superficial layer of clay and kankar (D); F 1183.

air is not saturated with water vapour. These requirements are met by the conditions in the shallow caves of the Nullarbor Plain.

The limestone in which most of the domes are developed (the Nullarbor Limestone) is usually described as crystalline, but I believe that the limestone is porous and permeable enough to allow sufficient movement of water through the rock to supply the growing crystals. A thin-section of the wall of one of the domes in Lynch Cave showed that the rock had a porosity of about 5 per cent.

Rainfall on the Nullarbor Plain varies from about 12 inches near the coast to about 7 inches near the Trans-Australian Railway. This low rainfall results in the accumulation of cyclic salts in the soil (notably halite and gypsum), and water seeping into the underlying rock can be expected to be saline. This is confirmed by the occurrence of halite deposits in some of the caves.

Evaporation at the surface of the dome can also be expected because there exists a widespread shallow zone of small interconnected cavities in which there are air movements. This will be discussed in detail in the next section.

One implication of the exsudation hypothesis is that one could expect to find a cone of disintegrated rock beneath each dome. It must be admitted that such a cone is present in only a few instances (one example is beneath a shallow dome in Thylacine Hole, 25 yards southwest of the entrance). It is possible that flood waters, and perhaps strong draughts are responsible for removing debris beneath other domes. Solution by vadose water is probably ultimately responsible for removal of the debris; otherwise there would be a serious room problem created by the frittered rock occupying more space than the solid rock from which it was derived.

AIR MOVEMENTS IN SHALLOW CAVES

The limestone of the Nullarbor Plain, in an interval about 10 to 40 feet below the surface, is riddled with tubes and small interconnected cavities. Jennings (1963) believed these tubes were the result of phreatic solution, but while this may be true for some tubes, I believe that many are due to solution by root exudates (Wall and Wilford, 1966), and that some other tubes and the irregular rubbly cavities are due to disintegration and solution of the rock in the vadose zone. Whatever the origin of the cavities, there are several indications that they are interconnected and ubiquitous.

One striking indication is the common occurrence of draughts in blow-holes. The draughts are estimated to reach 20 or 30 mph and give the blow-holes their name. The air pressure fluctuates under the combined influence of changing weather patterns, and a cyclical twice-daily change. Data presented in Plate 22, and in Wigley and others (1966) show that the daily fluctuations amount to about 0.1 inches of mercury (about 4 millibars). They claimed that the estimated volume of caves required to generate the observed draughts, is usually much greater than that accessible to exploration, and that this extra volume was due to the intergranular porosity of the limestone. They seem to have overlooked the more likely explanation that the extra volume is due to the small cavities mentioned above. The small cavities are found over the entire plain and are not restricted to the vicinity of blow-holes. Patches of rocks riddled with small cavities are exposed in dolines, coastal cliffs, and quarries (for example the Loongana quarry, Plate 24B). Furthermore, most percussion bores drilled on the Nullarbor Plain develop draughts before they reach a depth of 40 feet (Mr. M. Walsh, pers. comm.).

Little is known of the humidity of the air in the cavities, and thus it is uncertain how much evaporation can occur. Substantial evaporation must occur in cavities surrounding existing blow-holes, because there is a daily exchange of a large volume of air; the air blown out being more humid than the air sucked in. This is well shown by the data from Lynch Cave (Plate 22). However it is not certain that there is movement of air in cavities remote from blow-holes and other places where the zone of cavities is clearly connected with the atmosphere. It might be argued that in remote cavities, air movement would be so slight that the humidity would be high and exsudation negligible. This would mean that domes would develop only in the vicinity of existing blow-holes, and the exsudation hypothesis could not explain the development of the first blow-holes. This problem is not insuperable because it is quite likely that there is a small amount of air movement through the cracks and partly-blocked root holes that are seen in many limestone outcrops and which could well connect with cavities beneath. One indication that evaporation does occur throughout the cavities of the plateau is given by the data from Lynch Cave. During the observations there was a period when air blew out of the cave for 15½ hours instead of the average period of about 8 hours. The air blowing out reached a relative humidity of 78 per cent. 3 hours after the period commenced, and it remained virtually constant for the remainder of the period suggesting that the air in the cavities had that humidity for a great distance around the cave.

This evidence all points to a widespread shallow zone of cavities with air movements favourable to exsudation.

AGE OF THE BLOW-HOLES

The limestone plateau emerged from the sea at the end of the Lower Miocene, and weathering produced a thick residual clay with a kankar horizon near the surface. Jessup (1961) studied soils in South Australia and believed that during the Pleistocene there was a period of wind erosion when calcareous clay was blown from the Nullarbor Plain eastwards into South Australia. Jessup did not try to correlate this event with an absolute or glacial chronology, but it seems likely that it was about the middle of the Pleistocene. Over much of the plateau the limestone is covered by thick residual clay and kankar but in the centre (the treeless Nullarbor Plain) and in the south there are numerous outcrops of limestone. This is very likely the source of Jessup's wind-blown clay. Blow-holes are virtually restricted to areas where the limestone surface has been exposed by this erosion. It seems likely that exsudation in caves would commence once the limestone surface was exposed and the air could move through the cracks. If so the domes would have started developing in approximately the middle Pleistocene. Another indication that blow-holes are no older than middle Pleistocene is that all skeletal remains found in caves with blow-hole entrances are of species of animals known to have lived on the mainland of Australia or Tasmania in historic times. Blow-holes are believed to have formed until the present time. As indicated earlier, several blow-holes appear to have broken through to the surface relatively recently, and the process of exsudation is believed to be occurring at present.

THE SHAPE OF THE DOMES

One remaining problem for the exsudation hypothesis of dome formation is to find the mechanism whereby domes grow upwards instead of there being a general disintegration of the cave roof and walls. Two possible mechanisms are apparent. If the water from the surface is in the form of a vertical seepage confined to a small duct or zone, only the rock dampened by it will undergo exsudation and the dome will work back along the seepage towards the surface. Alternatively, warm air might collect in initial pockets in the roof so that evaporation occurred faster there than in the rest of the cave. The temperature of the rock walls of the cave would be roughly the mean daily or perhaps mean annual surface temperature, and warm air could accumulate either by the cave sucking in hot air during the day, or by sucking in cold air at night which would be warmed by the walls.

There are some observations which support the latter mechanism. In Lynch Cave, the air temperature was measured over a 40 hour period in the main chamber (at Point T_1 in Figure 8) and in a dome in the southern corner of the cave (at Point T_2). The data (Plate 22) show that the air in the dome was consistently warmer than in the

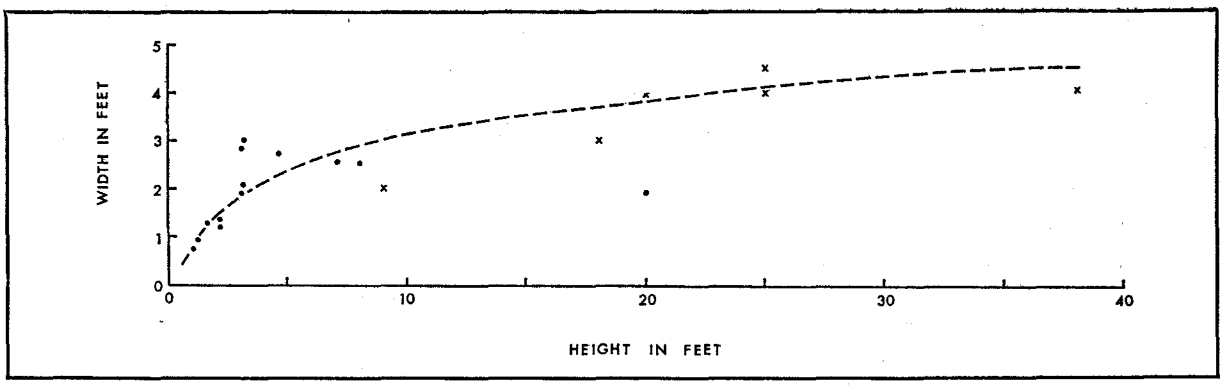


Figure 10—Plot of heights and widths of blow-holes (x) and domes (·).

main chamber. Similarly in Thylacine Hole, the air in a dome near the entrance felt significantly warmer than the air in the cave beneath the dome. However, the air in domes in many other caves was not noticeably warmer than in the rest of the cave, and it is not certain that trapping of warm air is a general characteristic of domes.

One feature of domes which might be indicative of the mechanism of their growth is the ratio of height to width. The few measurements that were made are plotted in Figure 10, and they seem to indicate that the height to width ratio increases as the dome grows. The processes of seepage and evaporation are potentially so complex that the significance of the ratio is not clear, although it would probably make a fruitful topic for further study.

ACKNOWLEDGEMENT

Dr. A. Richards kindly provided the whirling hygrometer used for humidity measurements.

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PROVISIONAL SUBDIVISIONS OF THE PRECAMBRIAN IN WESTERN AUSTRALIA, 1967

compiled by R. C. Horwitz

The accompanying chart (Plate 25) of provisional sub-divisions of the Precambrian in Western Australia is a revision of that published in the 1966 Annual Report. The chart emphasises the groupings in time of igneous events and sedimentation in Western Australia.

The previous geographic divisions of Phillips River and South West areas are deleted and replaced by a South Coast area and Perth Basin area. Some granites between Esperance and Israelite Bay appear to be analogous to those of Albany, dated at about 1,000 m.y. Areas surrounding the Perth Basin are characterised by repeated periods of folding and igneous activity throughout time.

STRUCTURAL LAYERING OF THE ROCKS OF THE ARCHIPELAGO OF THE RECHERCHE

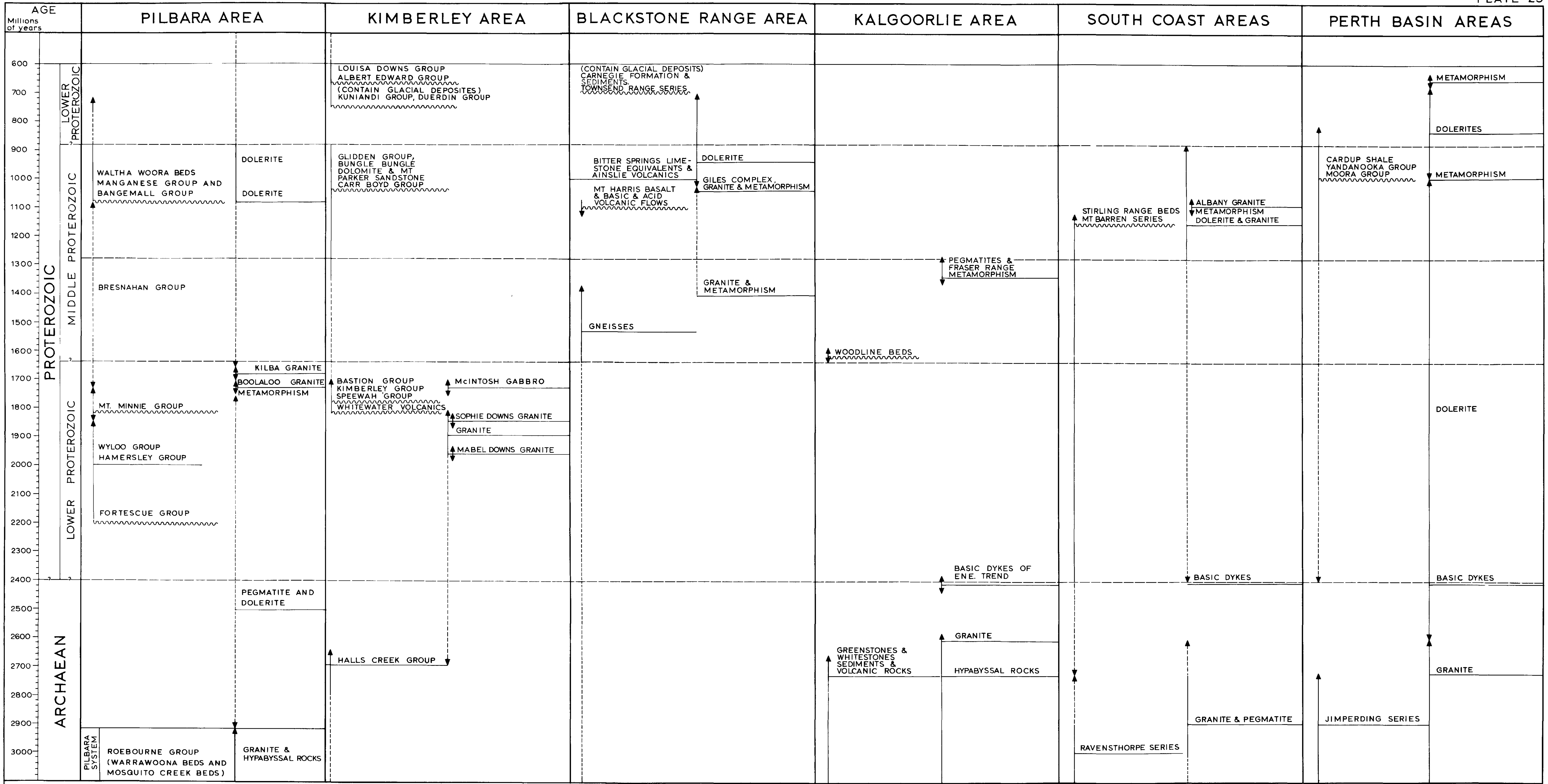
by K. H. Morgan, R. C. Horwitz and C. C. Sanders

ABSTRACT

The Archipelago of the Recherche, and adjoining mainland along the south coast of Western Australia, are made up of crystalline rocks that are believed to be Precambrian. Granite sheets and metamorphic rocks are layered and folded in a broad southwest plunging anticlinorium.

INTRODUCTION

The Archipelago of the Recherche is off the south coast of Western Australia near the port of Esperance. The one hundred or more small islands and rocks of the Archipelago are dotted along the continental shelf for over 100 miles.



AGE OF UNIT

PROPOSED
PROPOSED (UNIT RESTS WITH A BASAL UNCONFORMITY)
PROBABLE RANGE WITHIN WHICH THE UNIT MAY FIT
POSSIBLE RANGE WITHIN WHICH THE UNIT MAY FIT
TENTATIVE POSITION OF TIME BOUNDARY

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

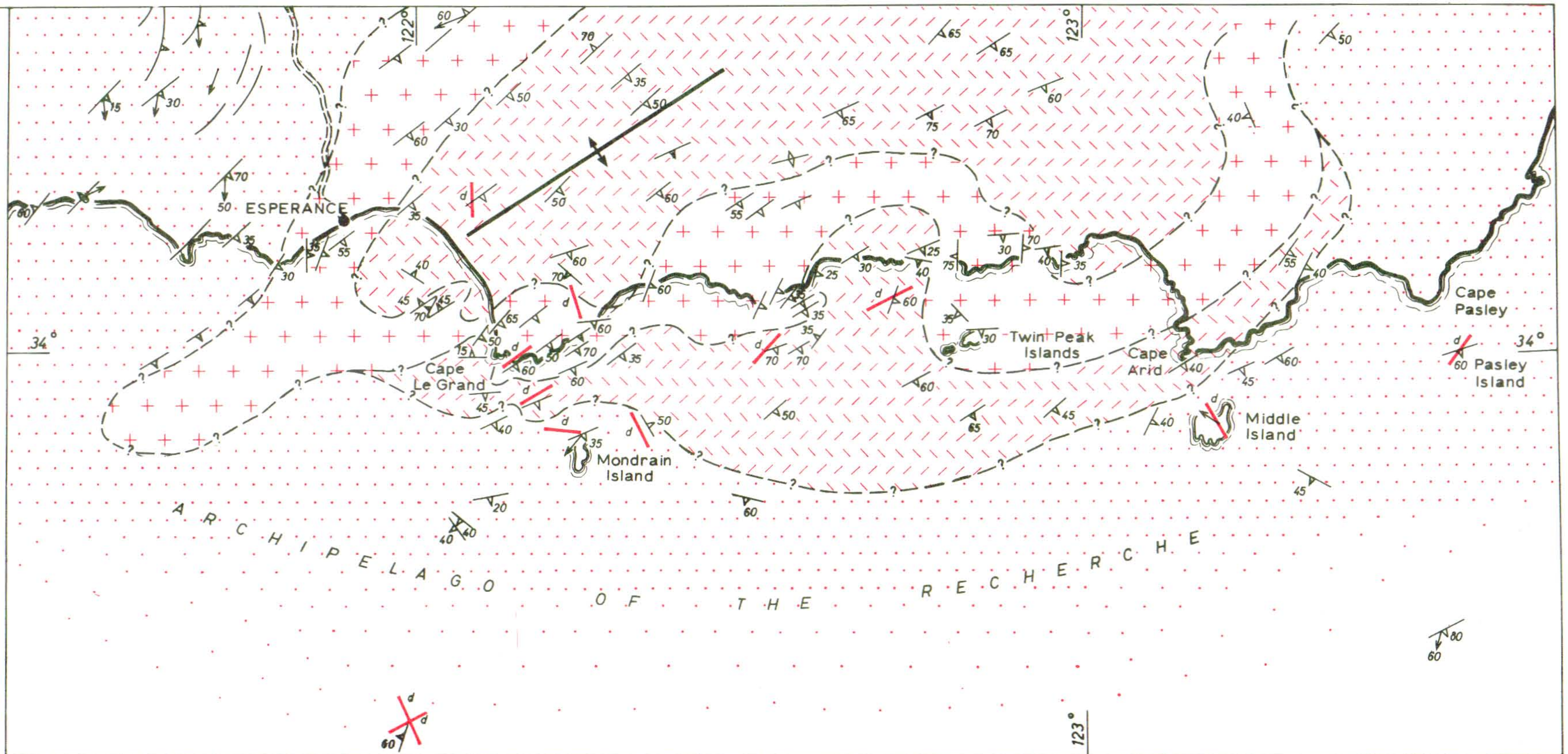
PROVISIONAL SUBDIVISION OF THE PRECAMBRIAN IN WESTERN AUSTRALIA 1967

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SKETCH MAP OF SOLID GEOLOGY OF THE ARCHIPELAGO OF THE RECHERCHE REGION

15 0 15 30

SCALE OF MILES



REFERENCE

- d — Basic dykes
- Strike and dip of foliation or of gneissic banding
- Direction and plunge of mineral lineation or of small fold axis.

LEGEND

- Mixed gneisses with numerous bands of basic and acid metamorphic rocks
- Lath granite
- Gneiss; bands of granite of different texture and numerous bands of metamorphic origin
- Lath granite

PLATE 26

1996

The rocks of these islands are mainly crystalline and are believed to be Precambrian. To the east, some islands are capped by calcarenite which has been soaked by bird guano, leading to the development of phosphate deposits. These have been described by Woodward (1908, 1917) and by other geologists in unpublished reports.

Fairbridge and Serventy (1954) have given accounts of the physiography and rock types on these islands but little was known previously on the regional geology of the Precambrian of the Archipelago.

In April 1967, a week was spent in visiting several of the islands by boat and an ordered layered sequence of igneous and metamorphic rocks was recognised in the crystalline Precambrian rocks.

PRECAMBRIAN

The accompanying sketch map (Plate 26) shows the solid geology of the Archipelago of the Recherche and the adjoining coastal area. In the ocean, strike and dip symbols denote an island that was visited; they were measured on lath-feldspar foliation in granites, and on compositional banding in gneisses.

The rocks are arranged in a layered sequence and folded. The deepest rock exposed is a grey porphyritic biotite granite with two feldspars, one of which is an alkali feldspar which is commonly in large pink laths.

Above this granite are gneisses made up of bands of granite of varying tone and texture with metamorphic rocks in large and small rafts.

Higher in the structural layering, lath granite is more abundant and, to the east of Esperance, there is a homogeneous sheet of granite which is about 15,000 feet thick. This homogeneous sheet is not developed to the west of Esperance where several bands of lath granite alternate with varitextured crystalline rocks.

Above this granite there are mixed gneisses with numerous bands of metamorphic rocks, including hypersthene and garnet-bearing rocks. The bands are commonly basic, such as on the mainland coast 25 miles west of Esperance, or on Pasley Island, where field relationships indicate that the basic rocks are altered sills. On Middle Island there are granular quartz rocks which could be altered vein rocks.

Dolerite dykes cut the mixed gneisses. They are rarer in the lower part of the layering and very scarce in the granites. North of Cape Le Grand, basic dykes cut granite but they can be traced in the granite to some disconnected basic xenoliths. The dolerite and the granite are thus considered to be broadly contemporaneous.

The Precambrian history of the region can be summarised as follows:

(1) Deposition of sedimentary rocks and intrusion of basic igneous rocks. The age of this assemblage is believed to be Archaean because it appears to be the extension of the 2,800 m.y. old gneisses of the Oldfield River region to the west (dated by Richards and others, 1966) and with the Archaean rocks of the Norseman region, to the north.

(2) Regional metamorphism of these rocks. The age of this metamorphism is not known; it could be Middle Proterozoic.

(3) Intrusion of granite and, possibly towards the end of this igneous phase, intrusion of dolerite dykes. This igneous activity is tenatively assigned to the younger part of the Middle Proterozoic because it is equated with the Albany Granite on the grounds of similarity in rock types, trends, and relationship, and of provincial unity. The Albany Granite is dated by Turek and Stephenson (1966) as about 1,100 m.y. old.

(4) Folding in a broad anticlinorium.

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SILVER-LEAD-GOLD-COPPER PROSPECT, M.C.38, KUNUNURRA AREA, WESTERN AUSTRALIA

by John Sofoulis

ABSTRACT

Silver-lead-gold-copper mineralisation of M.C.38 is associated with lenticular quartz reefs intruding fractures within Hart Dolerite. Development on the mineralised reefs is insufficient to allow any accurate estimation of the amount and grade of ore available. Low-grade mineralisation may be distributed over a large proportion of the quartz reefs and it is likely that some of the reef sections could contain concentrations suitable for selective mining. The prospect could prove to be a profitable concern for small syndicate operation but the limited size of reefs and patchy distribution of ore are not suited to company scale operations. Silver, lead, and associated mineralisation similar to that of M.C.38 has been recorded from several other localities in the Kimberley Goldfield region. Although none of the deposits are economic, they indicate a widespread occurrence of this type of mineralisation and suggest further areas for future prospecting.

INTRODUCTION

Seven lenticular quartz reefs, some of which contain patchy silver-lead-gold-copper and minor zinc mineralisation are included in M.C.38, pegged by Mr. P. Costeo in June 1967. The claim is about 13 miles west of the Kununurra townsite in the East Kimberley district.

A geological inspection of M.C.38 was made by the writer in October 1967.

LOCATION AND ACCESS

M.C.38 lies in flat to gently undulating country adjoining the all-weather bitumen road that links Kununurra (the centre for the Ord Irrigation Scheme) with the port of Wyndham. The claim turn-off is 10 miles by road west of the western abutment of Bandicoot diversion dam, and the main excavations on the claim are about 600 feet north of the road. The road distance from M.C.38 to Wyndham is approximately 52 miles. The area lies within the Cambridge Gulf 1:250,000 Geological Sheet SD/52-14.

GENERAL GEOLOGY

The geology of the region has been described by Dow and others (1964), and by Plumb and Veevers (1965). Proterozoic rocks referred to the Valentine Siltstone and Lansdowne Arkose of the Speewah Group comprise the main stratigraphic units exposed near the claim area. These formations are folded along northeast lines and have low to moderately steep dips to the southeast or northwest. The Speewah Group is commonly intruded as definite stratigraphic levels by extensive dolerite sills referred to the Hart Dolerite of post-Kimberley Group age (Upper Proterozoic).

The quartz reefs of the claim area are emplaced within a persistent sill of Hart Dolerite found in the basal part of the Valentine Siltstone. This sill is reported to be up to 6,000 feet thick in the adjacent Lissadell 1:250,000 Sheet area, (Plumb and Veevers, 1965).

Minor faulting, shearing, and jointing has affected the Hart Dolerite and associated sediments. A major fault west of the Dunham and Ord Rivers, known as the Ivanhoe fault, lies approximately 4 miles east of the claim. It dislocates both Proterozoic and Palaeozoic rocks and is defined by a prominent scarp of northeast trend. The quartz reefs of M.C.38 occupy faults and joints within the Hart Dolerite, and may be related to the same Palaeozoic or post-Palaeozic period of tectonism. Significant lead - zinc - silver mineralisation of Palaeozoic or post-Palaeozoic age has been recorded from the West Kimberley area (Halligan, 1965).

DOLERITE HOST ROCKS

The Hart Dolerite is the host rock for the mineralised quartz reefs. It forms low rocky outcrops, pavements, and loose rounded boulders. The loose boulders are associated with red loamy soil adjacent to outcrops, or with black soils related to drainage lines. Dolerite in adjacent areas forms low, rounded boulder-strewn hills generally less than 50 feet high. Most of the dolerite boulders and outcrops are fresh, dark green, crystalline rocks ranging from fine to medium-grained dolerite and quartz-dolerite to coarse-grained gabbro and probably granophyre. Plumb and Veevers (1965) described dolerite from this area containing andesine or labradorite and pigeonite or diopsidic augite. Magnetite is a common accessory whilst olivine, biotite, quartz, epidote, and hypersthene may also be present as minor constituents.

Sheared Hart Dolerite crops out within the claim area marginal to the intrusive quartz reefs. Elsewhere the dolerite is hard, fresh, and massive with a prominent ophitic or sub-ophitic fabric. No sulphide minerals were observed in fresh dolerite specimens although lead and silver mineralisation was detected in an assay of oxidised dolerite taken from a contact zone (Sample 12819). Elsewhere in this region the Hart Dolerite locally contains small amounts of pyrite and chalcopyrite.

MINERALISED QUARTZ REEFS

Several discrete lenticular quartz bodies with west-northwest to northwest trend are emplaced within the Hart Dolerite of the claim area and crop out over a distance of some 900 feet to form an echelon series aligned northwesterly (see Plate 27). These lenticular reefs range from small bodies 70 feet long and 10 feet wide to 200 feet long and 50 feet wide.

All of the reefs crop out as low pavements and solid bodies with up to 4 feet of relief, and have prominent joints parallel with their strike or at right angles to contacts with Hart Dolerite. A pre-existing fault or fracture pattern within the Hart Dolerite has provided suitable openings for the quartz intrusions (and subsequent mineralising fluids), and has been the dominant control for quartz reef distribution.

The lenticular quartz reefs are tabular or dome-like bodies, possibly connected in depth, and with irregular walls that range in dip from vertical to 30 degrees northeast. Usually the contacts are well defined and knife-sharp, but some are zones up to 2 feet wide and consist of quartz interlayed with dolerite and assimilated dolerite. Minor xenoliths are also present, and a larger block 20 feet long and 6 feet wide is included in the quartz reef of the southeastern part of the claim area.

All of the reefs consist of milky white massive quartz, commonly discoloured at the surface by orange-brown limonite staining. Blue-grey quartz crystals form interlocking half-rosettes growing inward from the walls of vugs and irregular openings. These crystalline growths are interlayed with white massive quartz to give a composite banding or layering effect. Some of the openings may have been up to 12 inches wide but most are lined with quartz crystal growths and the voids are now partly or completely filled.

The quartz reefs are separately designated on Plate 27 as reefs A-G.

MINERALISATION

Significant mineralisation was observed only in reefs B, C, D, E, and F. The mineralised sections of the quartz reefs include silver, lead, gold, and copper, with minor amounts of antimony and zinc. The most common minerals are galena (lead sulphide), cerussite (lead carbonate), anglesite (lead sulphate), malachite (copper carbonate), and the yellow ochreous mineral bindheimite (a hydrous antimonate of lead). Neither gold, silver, nor zinc minerals were observed megascopically. Silver is probably associated with the lead minerals and is found in argentiferous tetrahedrite disseminated with the galena ores. Accessory copper minerals include azurite, chrysocolla, and a few grains of bornite, covellite, and chalcopyrite. An examination of crushed analytical material showed that the main zinc mineral is hemimorphite with a little sphalerite.

These complex silver-lead-gold-copper ores are not confined to any defined lode but are found as fine disseminations and as irregular enriched patches distributed within the quartz reefs. The more significant patches of mineralisation are indicated on Plate 27.

Most of the enriched ore is associated with the crystal-lined vugs described above, the ore material filling or partly filling the remaining spaces between the quartz crystal growths. Secondary copper minerals (mainly malachite) also occur in vugs as well as forming thin coatings along joints and partings of surface or near-surface layers. Below the surface layers the copper mineralisation is weaker and the copper minerals are mainly chalcopyrite, covellite, and bornite, found as minor disseminations with galena. The galena is disseminated in the quartz or may be in massive form or in coarse cubic crystals and bunches (up to 18 inches across) often with curved crystal faces.

Yellow ochreous bindheimite is associated with copper and lead carbonates (and partly altered galena) in some of the more oxidised surface ores.

DEVELOPMENT

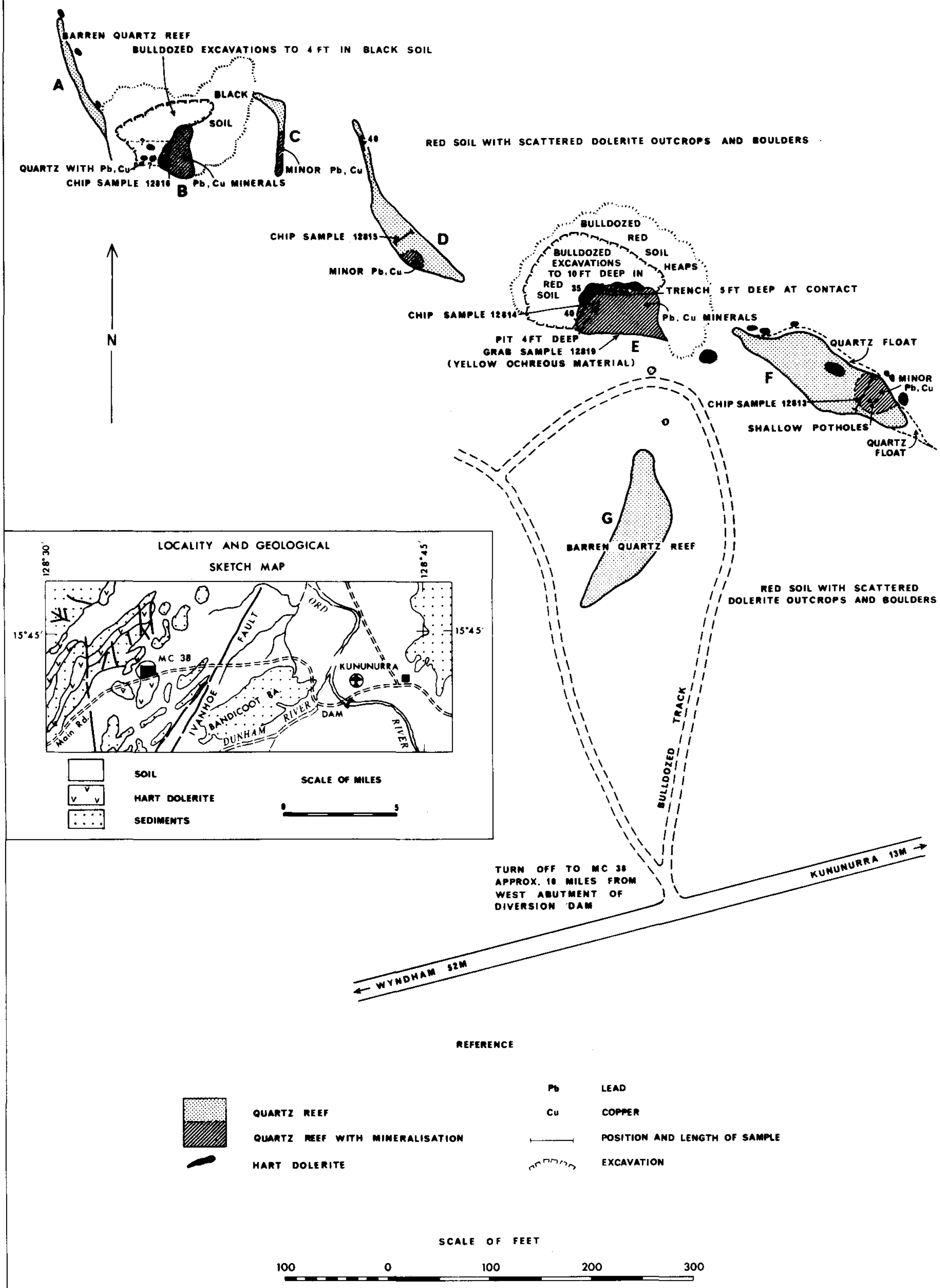
The claim holder and one employee are currently working the claim. A bulldozer was used in the removal of overburden and scrubby growth, and in the construction of an access track from the bitumen road. Some black soil and red soil patches marginal to some of the mineralised sections of the quartz reefs were excavated to 10 feet deep to expose the irregularly dipping walls of ore bodies B and E, and some trenches have now been opened up on the best mineralised sections. Several shallow trenches, potholes, and small costeans scattered over other mineralised parts of the quartz reefs have been merely exploratory diggings for locating zones of more concentrated mineralisation.

Approximately 120 tons of silver-lead-gold-copper ore have been won from the claim and are stockpiled at the site ready for shipment. The ore has been hand-sorted into two separate piles of approximately 60 tons which represent first and second grade ore. Most of this ore was won from small gossanous surface-enriched zones and deeper cuts (to 5 feet deep) sunk into the mineralised sections of quartz reefs B and E.

SAMPLING AND ASSAY RESULTS

Samples collected from M.C.38 were analysed by the Government Chemical Laboratories. Samples 12816 and 12814 were 20-foot chip samples taken from the exposed sections of the quartz reefs B and E. These reefs have provided most of the ores so far produced from this claim. Samples 12815 (20 feet) and 12813 (40 feet) were further chip

PLATE 27



GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SKETCH PLAN OF QUARTZ REEFS M C 38 KUNUNURRA AREA, KIMBERLEY GOLDFIELD

BASED ON TAPE AND COMPASS SURVEY, J. SOFOULIS, OCTOBER, 1967.

9960

Table 1
ASSAY RESULTS M.C.38 KUNUNURRA

G.S.W.A. No.	Locality	Type of Sample	Silver Ag per long ton oz	dwt	grn	Gold Au per long ton oz	dwt	grn	Copper Cu per cent. on dry basis	Zinc Zn per cent. on dry basis	Lead Pb per cent. on dry basis	Calculated Value per long ton $Aust.*
12813	Reef F	40 ft. chip	7	14	22		2	5	.37	1.25	8.87	40
12814	Reef E	20 ft. chip	15	4	7	1	7	14	.78	.27	4.98	76
12815	Reef D	20 ft. chip		16	10		2	14	.84	.05	1.03	15
12816	Reef B	20 ft. chip	11	4	19		2	10	.51	.23	10.40	48
12817	1st grade ore dump	Random chips	96	4	14	1	1	14	4.04	.76	34.80	286
12818	2nd grade ore dump	Random chips	28	16	14	1	2	0	1.75	.74	11.70	112
12819	Margin of Reef F	Grab sample	1	4	19			6	.18	.11	5.93	16

* Values approx., based on B.M.R. Metal and Mineral Prices as at 3/10/67 : Ag 154.4c/troy oz., Au $31.25/troy oz., Cu $1,000/ton, Zn $256/ton, Pb $210/ton. Assays : Government Chemical Laboratories, Perth.

samples taken across the width of the poorly mineralised sections of bodies D and F. The positions of all samples are shown in Plate 27.

Samples 12817 and 12818 were chip samples taken from the two hand-sorted stockpiles classified by the claim holder as first and second grade ores. Some yellow, ochreous, kaolinitic material (Sample 12819), locally showing relic ophitic fabric and believed to be decomposed Hart Dolerite, was included in the sampling as some of it was considered to be the yellow ochreous material (bindheimite) normally associated with oxidised lead ores. A geiger counter was used to test the yellow powdery material, the ore dumps, and mineralised portions of quartz reefs, but no significant radioactivity was detected.

Assay results are listed in Table 1.

Based on these assay results, hand-sorted ores from mineralised zones of reefs E and B, and stockpiled as first and second grade, have a mineral content equivalent to a calculated value of $285 and $112 per ton respectively. If a deduction of $30 to $50 per ton is allowed for production, handling, freight, and treatment costs, similar hand-sorted ores from reefs E and B would furnish a profit provided that equivalent grades could be maintained.

Sampled ore bodies D and F cannot be regarded as economic on the quoted assay values, because the disseminated nature of the contained mineralisation does not lend itself to concentration by hand-sorting methods. However it is considered that much of these low-grade ores could be beneficiated mechanically and upgraded by crushing, screening, and gravity concentration to yield a saleable product.

Some of the other untested reefs of this claim, and possibly some of the sheared dolerite marginal to the reefs, may contain sufficient disseminated mineralisation for beneficiable ore.

OTHER PROSPECTS

Recent publicity given to M.C.38 has been mainly responsible for a number of claims being taken up on adjoining dolerite ground. Some of these locally contain small quartz reefs (up to 60 feet long and 15 feet wide) which have lead and copper showings similar to the reefs of M.C.38. However, because of the patchy distribution of mineralisation and limited size of reefs, none of the occurrences are considered to be economic, although small amounts of payable concentrates could be extracted as a part-time venture.

Blatchford (1927) reported on a quartz vein (associated with a granophyric phase of the Hart Dolerite) which contained silver-lead-copper mineralisation in the Speewah locality of the adjacent Lissadell 1:250,000 Sheet area. Preliminary investigations into the concentration and treatment of this ore were conducted by Moore (1927). However the prospect (known as Martin's, or Durack and Martin's Silver-Lead Prospect) was too small to be of economic significance, and the temporary reserve (T.R.457H) was allowed to lapse.

Further galena mineralisation (with associated fluorite) was reported from 5 miles north-northwest of the old Speewah homestead and from other areas in the East Kimberley. According to Dunnett and Plumb (1964), none of these deposits have economic potential.

Massive barite and a little copper mineralisation are found 6 miles west of M.C.38, in a vertical fault zone of quartz-breccia cutting Antrim Plateau Volcanics, 0.2 of a mile east of the 46-mile post (Wyndham-Kununurra road). This fault zone is up to 5 feet wide and is traceable northwesterly from the road for approximately half a mile.

Although the occurrence is not economic the common association of barite with silver-lead-zinc deposits suggests that the major faults shown on the Cambridge Gulf and Lissadell geological sheets could be worthy of more intensive prospecting.

CONCLUSIONS AND RECOMMENDATIONS

Silver-lead-gold-copper mineralisation of M.C.38 is associated with lenticular quartz reefs intruding fractures within Hart Dolerite. Development on the mineralised quartz reefs is as yet insufficient to allow any accurate estimation of the amount and grade of ore available.

Surface indications, and small cuts and openings already made, suggest that although the quartz reefs are well defined, they are discontinuous in plan (and probably in depth) and that their contained mineralisation is patchy and irregular.

Low-grade mineralisation may be distributed over a large proportion of the quartz reefs and it is likely that some reef sections could contain concentrations suitable for selective mining.

High-grade ore is indicated from assays of the hand-sorted ore dumps derived from ore bodies E and B, and a high assay was obtained from the wall zone of ore body E. Although rich patches are present, there does not appear to be any defined zone capable of yielding a large quantity of direct shipping ore.

Concentration by hand-sorting or mechanical processes would therefore be necessary to maintain grades comparable with those already produced. The lower grade reefs with disseminated mineralisation are not amenable to hand-sorting and would require mechanical benefication to produce a saleable product.

The principal ore metal is expected to be lead (from galena) with variable gold and silver content and small amounts of copper and zinc.

A drilling programme would be required to delimit the mineralised sections of the quartz reefs or to prove high-grade zones suitable for selective mining.

The prospect could prove to be a profitable concern for a small syndicate operation but the limited size of reefs and patchy distribution of ore would not be suitable for company scale operations.

Suggested development would be to trench across the width of the mineralised sections to get an appreciation of grade and potential of these sections, as well as to provide workable faces for future open cut or selective mining operations.

The sale of ore to visitors and tourists is a profitable sideline which could develop with increased activity associated with the construction of the Ord River dam.

Silver-lead and associated mineralisation similar to that of M.C.38 has been recorded from several other localities in the East Kimberley region. Although none of the deposits are economic, they indicate the widespread occurrence of silver-lead-gold-copper-zinc mineralisation, and a possibility of finding a large deposit. Areas recommended for further prospecting are the major faults or shears cutting basic rock formations such as Hart Dolerite, Carson Volcanics, and Antrim Plateau Volcanics. These major faults and shears are shown on the available geological maps of the region.

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STRATIGRAPHY OF THE DALES GORGE MEMBER OF THE BROCKMAN IRON FORMATION, IN THE PRECAMBRIAN HAMERSLEY GROUP OF WESTERN AUSTRALIA

by A. F. Trendall and J. G. Blockley

ABSTRACT

A composite type section 466.25 feet thick is selected for the basal Dales Gorge Member of the Brockman Iron Formation, in the Precambrian (about 2,000 m.y. old) Hamersley Group of Western Australia. The type section consists of diamond drill core from three holes and is illustrated completely by continuous strip photographs at a scale of one fifth. The member is divided into 33 numbered macrobands: macrobands BIF0 to BIF16 are made up of cherty iron formation banded (into mesobands) on a scale of inches; they alternate with macrobands S1 to S16, which are generally thinner and consist of shale, chert, and siderite. Within its outcrop area of about 20,000 square miles the macrobands are easily distinguishable in the field, and some criteria to assist recognition are given. Additional photographs show that mesoband correlation is simple where diamond drill core is available; the greatest distance between drillholes is 51 miles. In natural exposures mesoband correlations have been made over 185 miles using the photographic type section, and quality of exposure rather than stratigraphic discontinuity is thought to be the limiting factor. The publication of such a detailed type section is justified only by the unusual lateral continuity of lithostratigraphic detail. Previously published work on the Dales Gorge Member is related to the type section, and it is suggested that all future work should specify stratigraphic position by reference to the equivalent position on the type section in feet above the base. Most of the type section will be permanently stored by the Geological Survey of Western Australia; some, included in the core of an additional section (analogous to a paratype in biological taxonomy) will be housed in the United States National Museum, Washington. Blue asbestos has been mined from the Dales Gorge Member, and it is the host for all of the larger iron ore bodies of the Hamersley Range area, including Mt. Tom Price and Mt. Whaleback, together containing over 1,000,000,000 tons of high-grade hematite.

INTRODUCTION

Between 1961 and 1966 extensive diamond drilling was carried out in the lower part, now called the Dales Gorge Member, of the Brockman Iron Formation, by the Australian Blue Asbestos Co. under subsidy from the Western Australian Government. The drilling formed part of a crocidolite exploration programme and comprised 60 holes in the Wittenoom Gorge area (lat. 22° 10′ S, long. 118° 20′ E.), 10 holes at Yampire Gorge, about 15 miles to the east-southeast, and 2 holes at Junction Gorge, about 35 miles farther in the same direction. Between 1964 and 1967 the Geological Survey of Western Australia pursued a special study of the geology of crocidolite in the Hamersley Range area, and core from the drilling contributed valuable evidence. The progress of the study has been reported by Trendall (1965; 1966a), by Ryan and Blockley (1965), and by Blockley (1967); a final report is in preparation (Trendall and Blockley, in preparation). This present paper is concerned solely with the stratigraphy of the Dale Gorge Members; its purposes are:

(1) to define the Dales Gorge Member in accordance with the requirements of the Australian Code of Stratigraphic Nomenclature (Geological Society of Australia, 1964),

(2) to provide a continuous photographic record of the core designated as the type section. This is intended to act as a display of the lithology of the member, a means of precise but simple specification of stratigraphic position within it, and as a means of stratigraphic location either in core or in field exposure,

(3) to record the positions, within the member, of selected features which are identifiable on the ground, or of which descriptions have already been published.

It is specifically *not* our purpose to provide here a full description of the lithology, petrography, chemistry, or diagenetic development of the Dales Gorge Member. Nor do we discuss its general geological significance; an account of the general geology of the Hamersley Range area has been given by MacLeod (1966) and a recent summary has also been provided by Trendall (1968).

PREVIOUS DEFINITIONS

The Brockman Iron Formation of the Hamersley Group was formally defined by MacLeod and others (1963, p. 48-9), with a type locality at Mt. Brockman (lat. 22° 28′ S, long. 117° 18′ E), and a measured thickness of about 2,200 feet some 30 miles to the south-southwest. Ryan and Blockley (1965) later divided the formation into five members. They named the lowest of these the Dales Gorge Member, with a type section in Wittenoom Gorge.

Although Ryan and Blockley's establishment of the Dales Gorge Member was not made in a type of publication acceptable for formal definition by the Australian Code of Stratigraphic Nomenclature the name has already appeared in acceptable publications (Trendall, 1966a; 1966b) and in other restricted but publicly available forms (Daniels, 1967). Nevertheless, for our present purposes the Dales Gorge Member is accepted as a currently informal name and is here formally defined as would be required for an original appearance (Geological Society of Australia, 1964, paragraphs 19, 21, 22, and 28); the definition below supersedes all others, and accurately defines the base of the Brockman Iron Formation.

PRESENT DEFINITION

The Dales Gorge Member is defined as the basal member of the Brockman Iron Formation (MacLeod and others, 1963). It usually forms about a quarter of the full thickness. It consists of magnetite-bearing, cherty banded iron formation, iron-rich shales including tuffaceous stilpnomelane varieties, and banded chert-siderite rocks. Massive riebeckite and crocidolite occur locally.

TYPE SECTION

The composite type section of the Dales Gorge Member is here selected as the core between 856.95 and 1,298.6 feet drilling depths in Hole 47A (lat. 22° 20′ S, long. 118° 14′ E) of the Australian Blue Asbestos Co.'s drilling at Wittenoom Gorge, continuing down from 303.5 to 328.75 feet in Hole Y1 (lat. 22° 25′ S, long. 118° 27′ E) at Yampire Gorge; except that the parts of Hole 47A between 1,052.9 and 1,063.0 feet (mainly the S11 macroband, 269.5 to 259.85 feet from the base of the type section) and 1,227.65 to 1,230.25 feet (within BIF3 macroband, 94.9 to 92.4 feet from the base of the type section) are replaced by 375.6 to 385.25 feet and 540.8 to 543.3 feet respectively of the core of Hole EC10 (lat. 22° 20′ S, long. 118° 20′ E).

The core forming this type section is completely illustrated at an approximate scale of one fifth by Plates 28 to 36 of this paper, with footages marked upwards from the designated base. Although comparative photographs are included of representative core lengths from the two overlying members of the Brockman Iron Formation informally defined by Ryan and Blockley (1965), successively the Whaleback Shale Member and the Joffre (formerly Mindy Mindy) Member, these are not formally defined here.

RECOMMENDED SPECIFICATION OF STRATIGRAPHIC POSITION

We have reluctantly used the foot rather than the metre as our basic length unit since all previously published literature on Hamersley Range area stratigraphy has done so, as well as all drilling logs and records. However, a division of feet into tenths rather than inches is not only neater (Figure 11), but is easier to accommodate to the scale variation of the photographs. We therefore suggest that in future work stratigraphic position within the Dales Gorge Member be specified by reference to correlative position on the photographic type section here provided, and that this in turn be specified by its distance above the base in feet and tenths. An accuracy of a twentieth of a foot may be necessary at times, but no finer subdivision is normally needed. Examples appear throughout this paper. It should be noted that a 5 in the second decimal place does not imply a greater accuracy than one twentieth of a foot.

DERIVATION OF NAME

The member is named from Dales Gorge (lat. 22° 28′ to 29′ S, long. 118° 33′ to 35′ E) where clean exposures of the lower part of the member in the floor and sides of the gorge form possibly the finest natural exposures of Precambrian banded iron formation in existence.

LITHOLOGY AND SUBDIVISION

Ryan and Blockley (1965) based their subdivision of the member on the analysis by Trendall (1965) of company drilling records. He (p. 56) defined three scales on which the iron formation could be described as banded:

Coarse *macrobanding:* alternations, on a scale of feet, between two constrasted lithologies, banded iron formation and "shale". The term "shale" was used as an abbreviation of "shale with subordinate cherts and carbonate", and it was later emphasized (Trendall, 1966b), p. 1453) that the term was a provisional one. In the field such macrobands are normally intensely weathered and on hillsides are marked by grassy talus slopes between cliffs of resistant banded iron formation (Plate 37D).

Medium-scale *mesobanding:* the conspicuous striped succession of chert, magnetite, and other types, with an average thickness of less than an inch, within the banded iron formation macrobands, clearly displayed on Plates 28 to 36.

Small-scale *microbanding:* an alternation, within chert mesobands only, of regularly repetitive laminae of even thickness (usually in the range 0.5 to 2.0 mm) defined by a greater or lesser content of some iron-rich mineral within the chert. Microbands are not distinguishable at the scale of this type section.

It is not our present purpose to describe in greater detail the lithology or petrography of any of the constituents of these three scales of banding.

Trendall (1965, Plate 32) represented 31 macrobands in the lower part of the Brockman Iron Formation: 16 "shale" macrobands, consecutively numbered upwards, separated by 15 similarly numbered banded iron formation macrobands, such that banded iron formation 1 overlay "shale" 1, and so on. In our present definition of the Dales Gorge Member we follow Ryan and Blockley (1965) in accepting and extending this macroband subdivision, by adding banded iron formation 0 as a basal macroband below Trendall's "shale" 1, and by adding banded iron formation 16 as a topmost macroband above Trendall's "shale" 16. The positions of these 33 macrobands in the type section of Plates 28 to 36 are marked on the Plates and are summarised in Figure 11.

Accurate macroband boundaries must be arbitrary, and we have chosen to accept the appearance and disappearance of magnetite as marking the lower and upper limits of BIF macrobands. These limits are not always those that would be closen by a field geologist working on weathered exposures and using mainly broad textural and compositional differences between macroband types.

We find that terms of the form "S13 macroband" and "BIF2 macroband", usually abbreviated to "S13" and "BIF2", are convenient designations of the macrobands, and we therefore propose to abandon the unsatisfactory term "shale".

LIMITS AND STRATIGRAPHIC RELATIONSHIPS

The lower and upper boundaries of the Dales Gorge Member are marked clearly on Plate 28 (0 feet) and Plate 36 (466.25 feet) respectively. The member overlies the Mt. McRae Shale with perfect conformity. Cherty iron formation occurs in the upper part of this shale, and to this extent the boundary is arbitrary, but it has been selected at the base of a thick banded iron formation macroband at a point approximating to where a field geologist would map the junction of the Mt. McRae Shale and the Brockman Iron Formation following MacLeod and others (1963) and using gross topographic expression as a guide. This is well shown by Plate 37C. The Whaleback Shale Member (Ryan and Blockley, 1965, informal name) overlies the Dales Gorge Member with perfect conformity. The Whaleback Shale Member has chert in its lower part, but the top of the Dales Gorge Member is similarly selected at an accurately determinable level approximating to a common major topographic expression of stratigraphy.

DISTRIBUTION AND THICKNESS

Since the type section is composite its thickness of 466.25 feet represents the true thickness of the member at no specified locality. Trendall (1965) studied thickness variations of 31 macrobands with a mean total thickness of 366.4 feet, in selected boreholes in the Wittenoom area, and also gave details of the effect of stratigraphic sample size in assessing thickness variation. Ryan and Blockley (1965, Table 2) reported a mean thickness of 452.2 feet for all 33 macrobands representing measurements over the whole outcrop area. The thickest section so far measured is one of 607 feet at Mt. Brockman (lat. 22° 28′ S, long. 117° 18′ E) and the thinnest one of 280 feet at Seven Mile Creek (lat. 23° 13′ S, long. 117° 33′ E). The average regional thickness variation of the Dales Gorge Member is of the order of 7 feet per mile, but random local variation of the same order is superimposed on the regional pattern.

A smoothly curved line encircling the present outcrop of the Brockman Iron Formation and extending no more than 10 miles outside it, encloses an area of about 20,000 square miles, with a maximum extent in latitude of 20° 53′ to 23° 30′ South and in longitude 116° 03′ to 120° 30′ East. This is the minimum depositional area of the Dales Gorge Member. A similar smooth curve encircling the outcrop of the basal Marra Mamba Iron Formation of the Hamersley Group encloses 33,000 square miles, and the formation-scale continuity of the Hamersley Group makes it more reasonable to accept this as a closer approach to the original Dales Gorge Member depositional area. However, the Marra Mamba Iron Formation has a crudely crescentic outcrop, and if the depositional area is assumed to have extended between the horns of the crescent an area close to 50,000 square miles must be accepted.

LATERAL STRATIGRAPHIC CONTINUITY

MacLeod and others (1963) drew attention to the remarkable lateral persistence of all formations of the Hamersley Group. All 33 macrobands of the Dales Gorge Member are, given adequate exposure (Plate 37 D), easily distinguishable in the field over almost the entire outcrop area. Within BIF macrobands the ease with which individual mesobands (mainly cherts) can be correlated depends partly on the quality of material available and partly on the character of the mesoband sequence in the restricted thickness chosen for the attempt. In Plate 37, A to C, selected lengths of the type section are reproduced next to equivalent lengths of core from other holes in the Wittenoom Gorge area and also from two holes at Junction Gorge, 51 miles east-southeast of Hole 47A, the main contributor to the type section. It will be appreciated from these photographs firstly that we accept subjective lithological mesoband correlation, and secondly that the standard of correlation between bore-holes 51 miles apart is not sensibly inferior to that between boreholes 6 miles or less apart.

When core is not available, field mesoband identification can be achieved using the photographed type section and working outwards from the more easily identified macroband boundaries. A high standard of exposure is essential, together with some experience of the effects of surface processes on lithology. We have compared in detail the natural exposures of the upper part of BIF0 (roughly 33 to 44 feet on the type section) at Dales Gorge, at Woongarra Gorge (lat. 22° 52′ 30″ S, long. 117° 07′ 30″ E; 92 miles west-southwest of Dales Gorge), and on the foreshore at James Point (lat. 20° 58′ S, long. 116° 10′ E; about 185 miles northwest of Dales Gorge and 145 miles north-northwest of Woongarra Gorge). Some cherts or closely associated chert groups in this section are sufficiently distinctive for confident identification. Three examples are: the thick chert with a thin central magnetite parting at 36.3 to 36.8 feet, the group of three thin cherts at 39.9 to 40.0 feet, and the grey (on the photograph) chert group at 42.9 to 43.2 feet. By using such distinctive cherts as markers, and by measuring systematically between them, other cherts on the type section, which lack any identifying characteristic, can be correlated with equal confidence. However, where there are groups of poddy cherts, as at 40.3 to 40.6 feet, individual chert correlation is not possible.

In summary, we believe that mesoband correlation over the entire outcrop area of the Dales Gorge Member falls little below the standard which the examples of Plate 37, A to C demonstrate to exist over a distance of 51 miles. The publication of a photographic type section on the scale of that presented here is justified only by the spectacular continuity of the detailed lithostratigraphy of the Dales Gorge Member; potentially some 10,000 knife-sharp lithological boundaries are correlatable in all parts of the 20,000 square mile area.

AGE

The age of the Woongarra Volcanics, a higher formation of the Hamersley Group, was given by Leggo and others (1965) as about 2,100 m.y. The base of these lavas lies some 3,000 feet (excluding sills) above the top of the Dales Gorge Member. Later detailed work by P. A. Arriens has revised the earlier age to a date very close to 2,000 m.y. (personal communication). If Trendall's (1965, p. 64)) estimate of 2,000 years per foot of iron formation is accepted, and if there is a negligible time gap between the Woongarra Volcanics and the sediments on which they rest, then the Dales Gorge Member was deposited in the interval between 7 and 6 m.y. prior to this age.

SOME CRITERIA FOR FIELD RECOGNITION

Where it is exposed with the clarity and completeness illustrated in Plate 37D, it is easy from Figure 11 to relate macrobands BIF0 to BIF16 to the exposed cliffs, while the intervening S1 to S16 macrobands can be similarly counted upwards, with their thicknesses proportional to the heights of the grassy slopes. During field work over several years it has become possible to identify many macrobands by some individual peculiarity other than simple thickness where the Dales Gorge Member is poorly or partially exposed. Although it is not possible to list all such characters, a few of which received informal field names, their great importance in the field makes it useful to record some of the more striking ones.

The "bed of holes"

Below the base of BIF0 the black shale visible in Plate 28 is about 2.5 feet thick. It is underlain by about 3 feet of cherty iron formation, 1 foot of shale and then by the upper part of a thicker band of iron-poor banded chert. Roughly central in the 3-foot thick band of cherty iron formation, and over a thickness of about 6 inches, carbonate nodules weather out to give ovoid holes about ½-inch long and 1 to 3 inches apart, elongate along the bedding. This "bed of holes" is an extremely reliable regional indicator of the base of BIF0, which lies about 4 feet above it.

Maculate bands

Of the four maculate bands in BIF1, MB1 to MB4, defined and described by Trendall (1966a) MB1 fortuitously appears clearly on the type section at about 48.4 to 49.1 feet (Plate 28). MB1 is persistently maculate and a useful regional confirmatory criterion of S1 just beneath it. It is recognisable at Woongarra Gorge, although immaculate at James Point.

The "adit-roof riebeckite"

The Yampire Gorge crocidolite mine (lat. 22° 23′ 15″ S, long. 118° 27′ 30″ E) of West Australian Blue Asbestos Fibres Ltd. was abandoned in 1946. Several adits at this easily accessible locality are cut into the lower part of BIF2 and are roofed by a conspicuous mesoband of tough massive blue riebeckite about 0.5 feet thick, the "adit-roof riebeckite", which appears at 77.5 to 77.95 feet on Plate 29. It is variously represented by a massive riebeckite or by a flat-modified chert (Trendall, 1965) in the Hamersley Range area.

The "three-chert shale" (S3)

The S3 macroband characteristically has three central chert mesobands (Plate 29, 86.0 to 86.85 feet). These are a reliable field indicator of S3 throughout the Dales Gorge Member outcrop area; before the numerical macroband nomenclature was used it was referred to informally as the "three-chert" shale".

The S4 breccia

Although it appears only inconspicuously on the type section, between 110.35 and 112.3 feet (Plate 30), the central part of S4 in the Wittenoom-Yampire-Dales Gorge area consists of a coarse breccia 1 to 2 feet thick, graded upwards. The angular fragments are of chert and shale and some reach a length of several feet. S7 and S16 are also locally brecciated, but to a lesser degree. The limits of the area of brecciation in S4 are not precisely known. The early name Calamina Member for S4 is now abandoned.

The Yampire Riebeckite Zone

BIF0 to BIF5, the lowermost six macrobands of banded iron formation, locally have abundant mesobands of massive riebeckite, and together constitute the Yampire Riebeckite Zone. Riebeckite is particularly abundant in BIF1 to BIF3 in the central part of the Hamersley Range.

The Junction Gorge Riebeckite Zone

This zone comprises BIF12 to BIF16, and is again locally characterised by abundant massive riebeckite mesobands.

The Calamina cyclothem

In some macrobands (notably BIF12 at roughly 295 to 301 feet, BIF15 at about 382 to 390 feet, and BIF16 at roughly 429 to 435 and 444 to 452 feet) there is a strongly cyclic sequence in which thick cherts are separated by thin magnetite-rich bands, with about 2 cycles to the foot. It forms a useful field criterion of recognition, as it is emphasized by weathering. It is proposed to call this cyclothem the Calamina cyclothem (Trendall and Blockley, in preparation).

The central parting of BIF16

BIF16 often lies at the top of cliffs, below a recessive smooth slope of the Whaleback Shale Member. Its identity can easily be checked by the presence of a thin, roughly central parting, which does not normally cause any break of slope in the vertical (joint-face) cliff. It is caused by a stilpnomelane-rich mesoband which appears at 439.9 to 440.1 on the type section (Plate 35).

RELATIONSHIP OF PUBLISHED WORK TO TYPE SECTION

Since the nomenclature set out here is a modification of the earlier scheme of Ryan and Blockley (1965), itself a modification of that of Trendall (1965), there is no difficulty in relating the new type section to these publications. The various nomenclatures of Finucane (1939, 1964) and of the Australian Blue Asbestos Co. are related by the later report of Trendall (1966a, Plate 34). The descriptions of parts of the Dales Gorge Member by LaBerge (1966) were separately related to the present scheme by Trendall (1966b); the illustrations of S13 in that discussion (Figures 1 and 3) can be followed clearly on our present type section (320 to 328 feet), the idea of which was then referred to (Trendall, 1966b, p. 1454). The chert from which spherical bodies were photographed for publication by LaBerge (1967, p. 336 and Plate 3) must be in BIF13 close to 348.8 feet, but closer identification is not possible.

Although MacLeod and others (1963) did not subdivide the Brockman Iron Formation, MacLeod (1966, p. 73) later referred to the special significance of the lower 500 feet of the formation for hematite mineralisation, and (ibid., p. 105) referred to the shale above this limit at the Mt. Whaleback Shale Member. We propose to designate this member the Whaleback Shale Member in a future publication (Trendall and Blockley, in preparation). MacLeod was clearly well aware of the special status of that part of the Brockman Iron Formation below this shale, the part we now call the Dales Gorge Member, although he found it unnecessary to name it formally. The application of our type section is well illustrated by the fact that, without knowing the drillhole number of the core in MacLeod's (1966) Figure 16, we were able to identify the chert sequence in the central row of core (roughly marked 260 to 261 feet, and between 2.25 and 0.2 inches from the right hand edge of the photo) as that appearing between 318 and 319 feet on the type section, in BIF12.

It should be noted that the "Brockman Iron Formation" of Campana and others (1964, p. 6), consisting of "sixteen massive, hematite-rich layers (slightly magnetic at intervals) separated by more shaly partings and reaching an aggregate thickness of 400 feet", is the Dales Gorge Member, *not* the Brockman Iron Formation.

REPOSITORY OF SECTIONS

Type Section

The photographed type section, with the exceptions of 92.4 to 94.9 feet and 259.85 to 269.5 feet is stored by the Geological Survey of Western Australia.

Other Sections

All the recovered core from Hole EC10 (lat. 22° 20′ S, long. 118° 20′ E.), representing 46.5 to 357 feet on the photographed type section, and comprising 301.5 feet of core, is stored by the United States National Museum, in Washington. Of this, 375.6 to 385.25 feet and 540.8 to 543.3 feet drilling depth form part of our designated type section. The stratigraphically equivalent intervals from Hole 47 (about 10 feet distant from 47A) will be stored with Hole 47A in Perth.

A large part of the core from Hole 63 (lat. 22° 19′ S, long. 118° 17′ 30″ E), representing approximately 42 to 289 feet, 344 to 361 feet and 436 to 466.25 feet on the type section, and comprising some 260 feet of core, is stored in the Department of Economic Geology of Adelaide University, South Australia; there are several shorter gaps in this core.

In addition to these two holes stored outside Western Australia, the Geological Survey of Western Australia also holds about 75 feet of core from Hole JG1, the furthest hole from Wittenoom, representing a span of about 47.5 to 120.5 feet on the type section; about 218 feet of core from JG2, equivalent to about 85.5 to 202.5 and 335 to 448 feet on the type section; and 314 feet of core from Hole 51 (lat. 22° 19′ S, long. 118° 18′ E) at Wittenoom, representing a span of 47 to 356 feet on the type section. This last hole has several broken sections, and has been extensively used for thin-sectioning and chemical analysis.

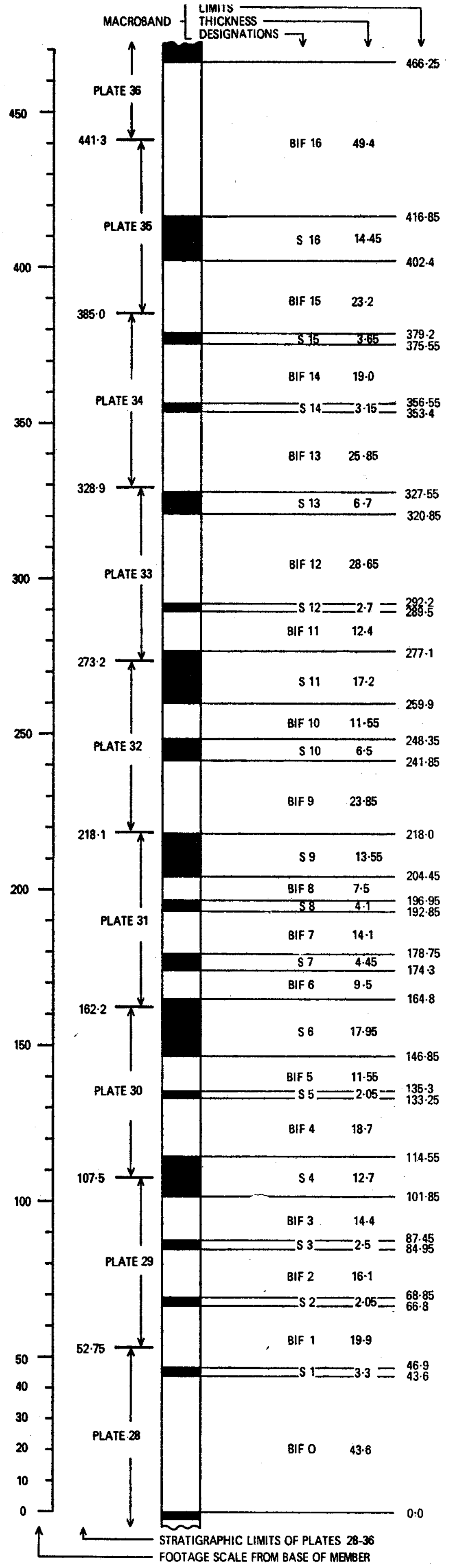


Figure 11—Summary of macrobands in the type section of the Dales Gorge Member. Black represents a mixture of shale, chert, and siderite; plain white is banded iron formation.

CAPTIONS FOR PLATES

Note: The photographs of Plates 28 to 36 are of NX core, with a nominal diameter of 2⅛ inches. To reduce parallax curvature all the core of Hole No. 47A was photographed with a 135 mm lens on 35 mm film from a point 12 feet vertically above each tray, with four frames to a tray. A 50 mm lens was used for Holes Y1 and EC10. Prints were made at a scale of one third and a slice about a tenth of an inch wide was cut from each side of the core photographs to give a final strip ½-inch wide for mounting and reduction x3/5 for a published scale of about x1/5. White marks were painted on the core one foot apart so that slight inaccuracies in photographic processes would not matter. Thus the scale varies slightly above and below x1/5, in order to maintain the accurate relationship of the marked footages with true core length.

Plate 28 (opposite). The lowermost part of the type section of the Dales Gorge Member, with footages marked upwards from the base at 0 feet. This point defines both the base of the Dales Gorge Member of the Brockman Iron Formation and the top of the underlying Mt. McRae Shale. This Plate includes the BIF0, S1 and part of the BIF1 macrobands, the boundaries of which (see text) are marked. The poorer conditions of photography of the core from Hole Y1, below 24.4 feet, accounts for a change in appearance at this point. In general, paler mesobands in the BIF macrobands are chert, and darker mesobands are QIO (Trendall, 1965) or magnetite. MB1 of Trendall (1966, p.76-78), with the drill passing close to a macule core, is conspicuous between about 48.4 and 49.1 feet.

Plates 29-35. The successive upward continuation of the type section of the Dales Gorge Member, with marked footages continuing from Plate 28. Refer to Figure 11 for the footage limits of each Plate and its coverage of the macrobands; macroband limits are also marked on the Plates. The main mesobands of massive riebeckite are marked by the letter R; although they have a bright blue colour in contrast with the black, dark grey, or dark green of the shales, the two rocks appear identical in these photographs.

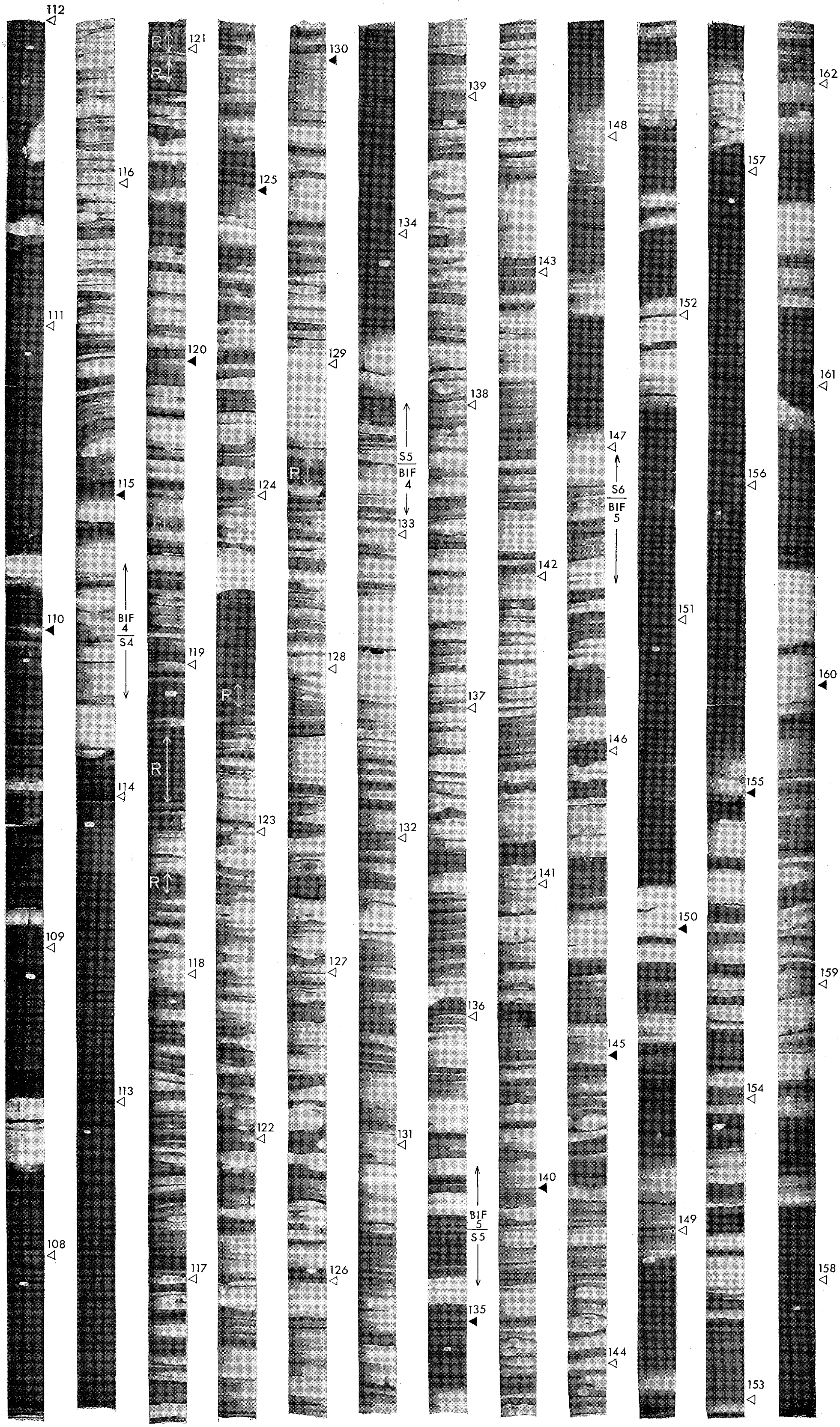
Plate 36. The six left-hand columns are the uppermost part of the type section of the Dales Gorge Member, with the top (also the base of the Whaleback Shale Member) at 466.25 feet. The two central columns represent typical material from the Whaleback Shale Member, between approximately 719 feet (top of right-hand column) and 728 feet drilling depths in Hole 47A. The dark green or black shale and siderite has scattered white cherts. The close lithological resemblance between this and some macrobands of the Dales Gorge Member, for example S6, is obvious. The two right-hand columns, from approximately 544.5 (top of right-hand column) to 553 feet in the same hole, show the rather different lithology of the overlying Joffre Member. Many of the cherts are either red (hematite) or blue (riebeckite). Both the Joffre Member and Whaleback Shale Member are illustrated at the same scale as the Dales Gorge Member.

Plate 37. A, B, C:— In these three groups of three stratigraphically equivalent sections of the Dales Gorge Member the type section core is reproduced on the left of each group at the same scale as in the earlier Plates. The central and right-hand columns in each group are from equivalent levels of drill-holes at Eastern Creek and Junction Gorge, about 6 and 51 miles to the east-southeast respectively. Type section footages are marked on the type section itself in B and C. In B they are marked also on the right-hand column, to illustrate the recommended use of the type section to specify stratigraphic position after correlation. In A, type section footages are marked only on the right-hand column. The black lines between columns provide a correlative framework only. Careful comparison will reveal many details which can be correlated between columns; in some places there is closer resemblance across 51 miles than across 6 miles.

D:— Cliff exposure of the Dales Gorge Member on the northeast face of the prominent un-named hill about 2 miles north of Mt. Tom Price: photograph taken from Tom Price water supply tank, looking southwest. Macroband expression is clear between the base of the member (marked in three places by an arrow lettered B) and its top (similarly marked T in two places).


BIF
0
Mt
McRae
Shale
47A
Y1
BIF
1
S1
R
S1
BIF
0

PLATE 29 52·75 – 107·5 FEET


112
116
115
BIF 4 / S4
110
114
111
109
113
108
121
120
119
118
117
R
125
124
123
122
130
129
128
127
126
134
S5 / BIF 4
133
132
131
139
138
137
136
BIF 5 / S5
135
143
142
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148
147
S6 / BIF 5
146
145
144
152
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149
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154
153
162
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160
159
158


166
165
BIF 6 / S6
164
163
171
170
169
168
167
176
175
S7 / BIF 6
174
173
172
180
179
BIF 7 / S7
178
177
185
184
183
182
181
190
189
188
187
186
194
193
S8 / BIF 7
192
191
199
198
BIF 8
197
S8
196
195
204
203
202
201
200
208
207
206
205
S9 / BIF 8
213
212
211
210
209
218
S9
217
216
215
214

218·1 — 273·2 FEET

PLATE 32

PLATE 33 273·2–328·9 FEET


333
332
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342
341
340
339
347
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345
344
343
352
351
350
349
348
BIF 14 / S14
356
355
S14 / BIF 13
353
361
360
359
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357
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S15 / BIF 14
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BIF 15 / S15
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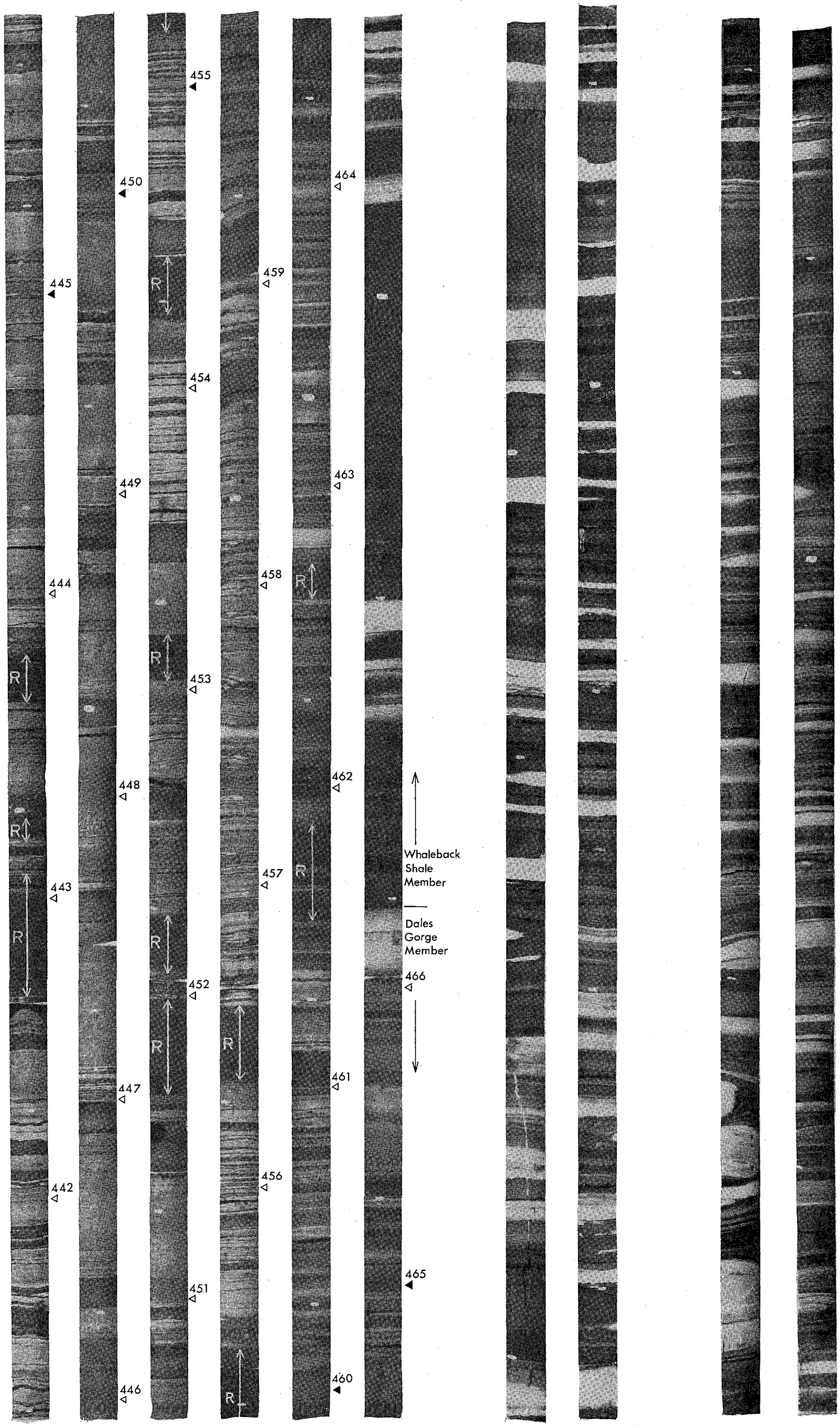
PLATE 35 385·0–441·3 FEET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Whaleback
Shale
Member
Dales
Gorge
Member
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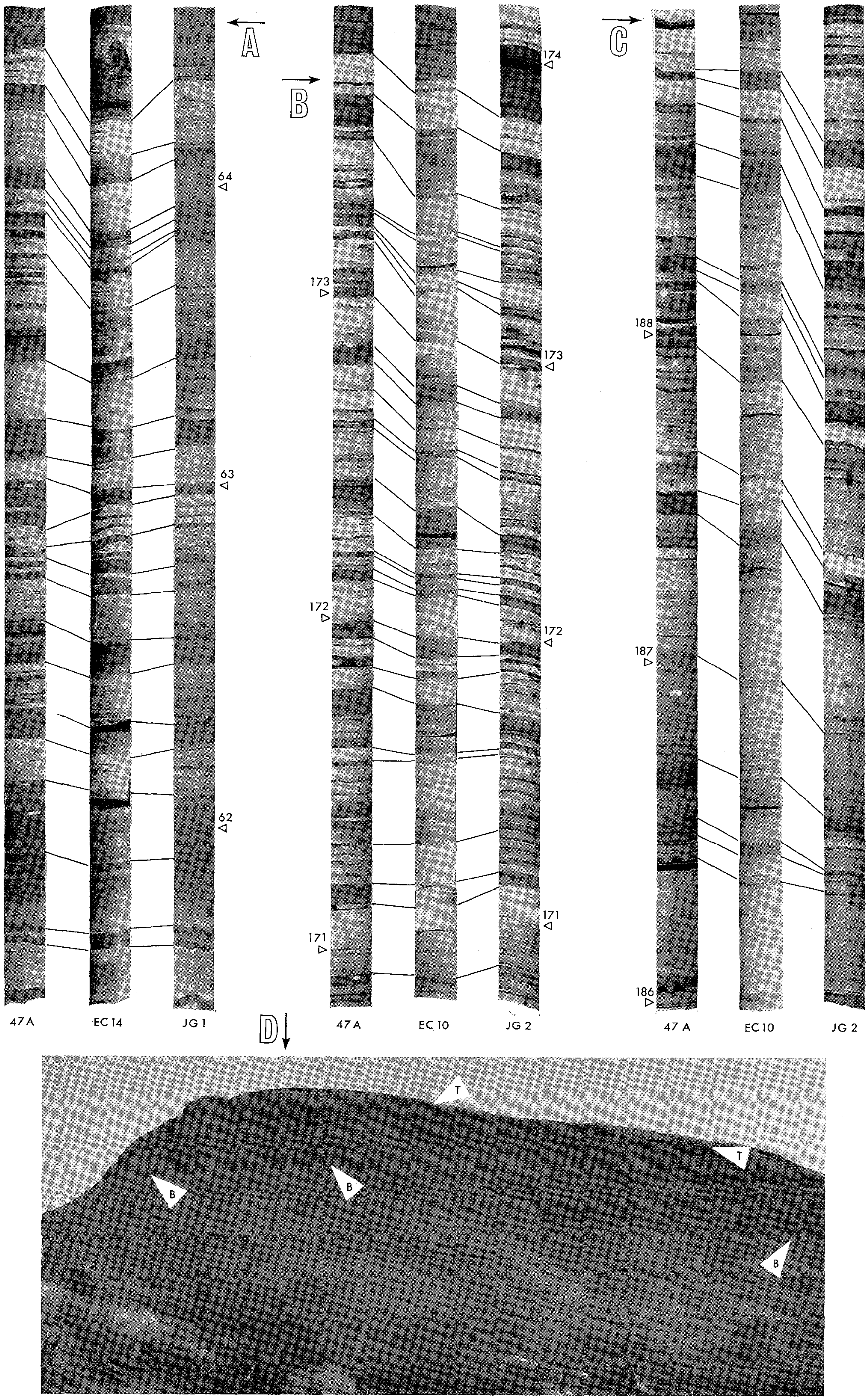
PLATE 37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62
47A
EC14
JG1
B
174
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47A
EC10
JG2
C
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187
186
47 A
EC10
JG 2
D
T
T
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ECONOMIC GEOLOGY

Crocidolite

The Dales Gorge Member locally contains blue asbestos deposits which are in part stratigraphically controlled. Although a full account of these is in preparation (Trendall and Blockley, in preparation) it is appropriate to note here the positions of the lower and upper mined seams at Wittenoom Gorge (Trendall, 1966b, Plate 34) at 49 to 50.5 feet and 69 to 70.5 feet.

Iron ore

The Dales Gorge Member is the host for the major hematite-geothite ore bodies of the Hamersley Iron Province (MacLeod, 1966, p. 73), including those of Mt. Tom Price and Mt. Whaleback, with a combined tonnage well in excess of one thousand million tons of high-grade ore. At Mt. Tom Price the macrobands can clearly be traced through the ore, and the ghost stratigraphy of the Dales Gorge Member here is of potential use both in structural mapping of the ore and in grade control in mining, as well as in allowing an accurate assessment of total volume change during the conversion of iron formation to hematite ore.

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DIAMOND DRILLING AT THE THADUNA COPPER MINE, PEAK HILL GOLDFIELD, WESTERN AUSTRALIA

by J. G. Blockley

ABSTRACT

At Thaduna, a copper lode about 2,000 feet long and 10 feet wide has been mined within a fault zone cutting Middle Proterozoic greywacke and siltstone. Ore shoots within the fault are controlled by split-shear structures developed on S-bends along the fault. Most of the mining has been confined to the oxidised part of the lode and several diamond drilling programmes have been aimed at testing the underlying sulphides. This drilling has shown that supergene sulphides averaging about 3.5% copper exist to depths ranging from 400 feet in the central part of the lode to 150 feet near the ends, but that the primary sulphide zone below this averages less than 1% copper and nowhere contains more than 2% copper. It is concluded that supergene enrichment is not taking place in the alkaline conditions of the present arid climate, but probably dates back to a more pluvial period in the Tertiary.

INTRODUCTION

Between November 1966 and June 1967, the British Metal Corporation Pty. Ltd. drilled 10 diamond drillholes totalling 3,148 feet at the Thaduna copper mine. This drilling was subsidised on a dollar for dollar basis by the Mines Department, and the Geological Survey was asked to provide geological guidance for the work. Initially, assistance was given on the siting of the drillholes and examining sections of drill core sent to Perth. Later, British Metal Corporation requested a geological appraisal of the drilling programme with calculations of ore reserves. To collect sufficient information for this, several days were spent at Thaduna with B.M.C. staff, sampling and surveying the open cuts, and logging the remaining drill cores.

Before the present work the Thaduna lode had been tested by three other drilling programmes, between 1953 and 1964. The results of these were made available by the British Metal Corporation and used in the overall assessment of the lode's potential.

The objects of this report are to describe the geology and ore controls of the Thaduna mine, and to record for future reference the locations and results of all drillholes put down to test the lode. Calculations of ore reserves and core logs of the holes cannot be published at present, but are available to anyone entitled to the information.

ACCESS AND FACILITIES

The Thaduna copper mine is situated at latitude 25° 30′ S, longitude 119° 43′ E. It is 130 miles by road from Meekatharra, the nearest rail head, and 35 miles east of the Great Northern Highway. Two graded gravel roads from the mine join the highway 90 miles and 106 miles respectively from Meekatharra. There is also a road connection to Wiluna, 90 miles to the southeast.

There are no postal services at the Thaduna mine, communication being by way of the Royal Flying Doctor Service radio network. Mail has to be collected from Meekatharra.

The Thaduna Copper Mines N.L. company has constructed a serviceable airstrip 3 miles southeast of the mine. The strip can take aircraft to the size of a D.C.3, but cannot be used after heavy rain.

Water for domestic and mining purposes is obtained from surface catchments and an underground bore situated in a creek bed. The surface water dries up during periods of drought and the mine then relies entirely on the bore which produces about 600 gallons per hour of rather brackish water.

Useful timber is scarce in the vicinity of the mine. Because of this, and the prevalence of termites, most construction is done in steel.

HISTORY OF MINING AND DRILLING

The Thaduna copper lode was originally found by prospectors looking for gold. It was first reported in 1942 and worked in a small way by Mr. E. A. Wright as the Nabberu copper mine. Later, E. A. Walsh worked the deposit until 1953.

In 1952, Anglo-Westralian Mining Pty. Ltd. took an option on the property and carried out a programme of costeaning and diamond drilling. The option was relinquished in 1953 after two drillhole intersections had returned poor results.

The present company, Thaduna Copper Mines N. L., was formed in 1955 to work the leases. This company set about mining the lode by open-cut methods and soon became one of the State's largest producers of oxidised copper ore. It maintained this position until production ceased in 1966. All the company's production of 28,389 tons of ores and concentrates containing 2,244.64 tons of copper was sold to manufacturers of superphosphate as copper trace-element additive. The average tenor of the ore mined fell from about 6 to 7 per cent. to 3 to 4 per cent. during this period of production. In 1962, the company installed a flotation plant of a design suggested by the Kalgoorlie School of Mines in order to upgrade their product and increase its unit price and marketability.

In 1960 to 1962 the company carried out some deep mining from a shaft sunk in the floor of the northern open cut. Two shoots were mined from this shaft, each to a depth of about 160 feet. The stope on the Big Lode shoot was directly underneath the open cut and broke through in one place. The stope on the Black Lode shoot was just west of the open cut and broke through to the surface, apparently as the result of a collapse. Deep mining was abandoned when the workings collapsed after flooding.

New Consolidated Gold Fields (A/sia) Pty. Ltd. obtained an option on the Thaduna mine in 1962 and drilled 10 holes on the leases in the two following years. Eight of these holes were designed to test the known lode and two, GD9 and 10, were on a geochemical anomaly to the north. This work was done in conjunction with a regional geological, geochemical and geophysical survey. New Consolidated Gold Fields abandoned the option in 1966 after deep drillholes at Thaduna had shown the low grade of the primary mineralisation and after regional work had failed to find significant reserves of secondary ore.

Thaduna Copper Mines N.L. is now largely owned by the British Metal Corporation. The object of the present drilling was to prove sufficient supergene ore to justify capital expenditure on the mill, and thereby increase its efficiency in dealing with the graphite rich chalcocite ore.

In the four exploratory programmes carried out at Thaduna since 1953, 32 holes totalling about 14,000 feet have been drilled. Severe deflection of the deeper holes has been a constant problem, and two were abandoned when it became obvious that they would miss the lode. New Consolidated Gold Fields completed one deep hole only by constant wedging over the last few hundred feet. Most holes turn into the bedding of the sediments and this usually means that they curve to the south. The deflection can be compensated to some extent by starting the holes on a bearing north of the required azimuth, but if this is carried too far, the drill cuts the bedding planes in the opposite sense, and the holes then deflect to the north.

GEOLOGY OF THE THADUNA LEASES

Previous work

The only published account of the geology of the Thaduna copper mine has been given by Low (1963, p. 112-117). Unpublished reports for Anglo-Westralian Mining Pty. Ltd. and New Consolidated Gold Fields (A/sia) Pty. Ltd. are now held by the British Metal Corporation and were made available to the Geological Survey. Rowston (1964) has reported on geophysical work done in the Thaduna area.

Stratigraphy and rock types

The copper mineralisation at Thaduna is in Precambrian rocks correlated by Horwitz (1966) with the Middle Proterozoic Bangemall Group. Four mappable stratigraphic units can be recognised on the leases, two of siltstone and two of greywacke. The lower siltstone unit, which is of undetermined thickness, is known only at the northern end of the leases beyond the area included on Plate 38. It is exposed in geochemical sample holes and in two diamond drillholes. Overlying this unit is the lower greywacke unit which consists of 2,500 feet of interbedded coarse, medium and fine-grained greywacke intercalated with beds of siltstone up to 100 feet thick. The upper 800 feet of the member is mainly of medium to coarse-grained greywacke which crops out more boldly than the finer-grained lower part.

The upper siltstone member is about 200 feet thick and is a good marker bed. Although its outcrop is poor, it forms a distinctive red-clay soil liberally covered with white quartz scree which can be traced through the leases. The upper greywacke unit is about 300 feet thick and comprises mainly medium to coarse-grained sediments with but few beds of siltstone. East of the mine area, it is overlain by more siltstone.

Lithologically the two greywacke units are almost identical, although the lower one has more intercalations of shale and siltstone. The rocks are made up of angular fragments of shale, lava, feldspar, and sparse, rounded quartz grains. Much of the fragmental rock material is probably of volcanic origin, the rocks being essentially resorted tuff (Trendall, 1967). The greywackes range from coarse turbidite with fragments 1½ to 2 inches across, to fine siltstones. The composition remains much the same regardless of the grain size. In good exposures the greywackes show many sedimentary structures such as cross-bedding, graded bedding, scours, slumps, and sedimentary breccias. Ripple marks and raindrop patterns are also found, but are much less frequent. In all, there is seldom any difficulty in determining the facings in well exposed greywacke.

The siltstone units consist of finely laminated purple shale and siltstone. The purple colour is due to fine hematite particles and is characteristic of many rocks within the Bangemall Group. The siltstone beds are finely cross-bedded and often show fine slump structures.

Although the foregoing description applies to the Thaduna leases, the whole copper-bearing belt from Lee's mine (M.C. 65P) 2 miles to the southwest, to the Green Dragon (M.L. 69P) 3½ miles northeast is underlain by similar rocks.

STRUCTURAL GEOLOGY

Folding

The Proterozoic sediments in the vicinity of the Thaduna mine have been folded about axes trending at 040° to 050° and plunging at 10 to 15° northeast. The folds are asymmetric with axial planes dipping at about 70° northwest.

Two synclines and one anticline have been established within the area of the leases while a second anticline is known to the southeast.

The westernmost fold, a syncline, has its west limb overturned, but the other folds are normal. The present tentative interpretation of the regional geology, is that the Thaduna mine is near the axis of a major anticlinorium which is flanked on its western side by overturned "drag" folds, but which has more open folds near its crest. On this interpretation, the rock assemblage seen on the leases is therefore the oldest which crops out in the area.

Faulting

Three sets of faults are known in the copper-bearing area about the Thaduna mine. The major set trends at about 340° and has had a strong influence on the drainage pattern of the area. The other sets, striking north and east respectively, seem to be subsidiary to the major faulting. Mineralisation has been observed in faults of each set.

The copper lode on the Thaduna leases is within the prominent Thaduna fault, the best known example of the northwest trending set of faults. This fault has a measured displacement of 500 feet horizontally and about 200 feet vertically. The northeast block has moved northwest and down. The block of country west of the Thaduna fault has been tilted sufficiently to the west to bring the fold axes to a horizontal position.

WALL ROCK ALTERATION

At Thaduna, the rocks within 50 feet of the lode are hydrothermally altered. Chlorite has been produced by the reaction of the original hematite and clay components, resulting in a marked colour change from purple to green. Calcite, introduced during the alteration, has considerably softened the sediments, allowing the wall rocks to weather deeply. Near the lode, the wall rocks are impregnated with graphite and are consequently coloured grey or black. In the weathered zone, the wall rocks consist mainly of kaolin.

MINING GEOLOGY

The Thaduna copper lode is within the Thaduna fault. It is about 2,000 feet long and averages about 10 feet wide. In places, copper has penetrated into the wall rocks increasing the total width of mineralisation to a maximum of 70 feet. In this report the term "lode" is used to refer to mineralised material within the crush zone of the fault, whether or not it contains significant copper. The term is not used for mineralised wall-rock, although at times the copper content of this may approach an economic grade.

Composition of the lode

For convenience of core logging and description, five types of lode material have been recognised, but graduations between the types are common.

(1) Graphitic schist: soft, black, very fissile material composed chiefly of carbon and crushed rock.

(2) Graphitic breccia: breccia with black, angular pieces of country rock set in a matrix of carbonates and crushed rock.

(3) Quartz-filled breccia: breccia with angular rock fragments, usually black, set in a matrix of quartz with minor carbonates.

(4) Siliceous lode: hard, dense, flinty quartz which is often grey or brown and may contain some rock fragments.

(5) Quartz: normally a typical, white, reef quartz.

The copper minerals present are: chalcopyrite and bornite in the primary zone; chalcocite and a little covellite in the secondary sulphide or supergene zone; and cuprite, malachite, azurite, and chrysocolla in the oxidised part of the lode.

There is insufficient information to calculate average grades of copper in all three zones. However, the richest lode material found to date in the primary zone contains only about 1.5 per cent. to 2 per cent. copper while the richer supergene ore averages 8 to 10 per cent. and the better oxidised ore 6 to 8 per cent. copper. The average grade of all oxidised ore won is about 4 per cent. copper which is higher than the average for supergene ore encountered in the drilling.

The mineral paragenesis of the lode can be set out as follows:

Zone	Minerals Present	Lower Limit of Zone
Near surface	Chrysocolla....	10–20 feet
Oxidised zone	Malachite + azurite cuprite	50–150 feet
Supergene zone	Chalcocite (+ covellite)....	300–400 feet
Primary zone	Chalcopyrite + bornite	

Despite the great depth of weathering found in the drillholes, only the upper few feet of the lode has been reduced in grade by surface leaching. It seems that in the prevailing alkaline weathering conditions copper cannot be transported far in solution. The mineral paragenesis shows that the present copper carbonates and oxides have resulted from the oxidation of supergene chalcocite. In fact in any shoot, there is little change in the grade of copper between the oxidised and supergene zones, indicating that there has been little migration of the copper during the present weathering processes. However, the fact that both the oxidised and supergene zones are both considerably richer in copper than the primary zone, shows that in the past there must have been considerable concentration of copper during oxidation of the lode. This suggests that the groundwaters of the time must have been much more acid than those affecting the lode at present. But the primary sulphide content of the lode is very low; (in fact the acid-producing mineral pyrite is quite rare), so the acidity probably derived from more abundant vegetation flourishing in a wetter climate. If so, then it is likely that the supergene copper zone is no younger than Tertiary in age.

The most characteristic feature of the Thaduna lode, and indeed of the other copper lodes worked in the same field, is the presence of carbon, either as the amorphous form, or as graphite. The carbon seems to have been introduced hydrothermally into the shear zone along with the copper minerals. The possibility of a carbonaceous sediment having been dragged along the shear is discounted for the reasons that:

(1) no primary carbon-bearing sediments have been recognised near the mine, either on the surface or in any of the drillholes;

(2) the wall-rocks of the lode are impregnated with carbon in a manner suggesting that it has been carried outwards from the lode channel;

(3) all the lodes in the Thaduna area carry a similar amount of carbon, suggesting it has a common deep-seated source rather than a local origin.

Although the carbon in the lode resembles graphite in its macroscopic properties, tests made on it during geophysical surveys of the area have shown it to be mainly amorphous carbon. The term "graphite" however has been retained in the rest of this report, partly because of local usage, and partly because it imparts a much more accurate description of the material as seen in the field.

Ore controls within the lode

Where seen south of the mine workings, the Thaduna fault is a simple, tight shear with only patches of copper mineralisation. Within the leases however, the fault swings through a large S-bend on which are superimposed smaller bends of the same type. On these bends, the shear splits into two or more branches and the intervening country rock is veined and brecciated.

Although the whole width of the resulting breccia zone may be mineralised, the ore shoots are usually restricted to the most intensely crushed parts. At the south end of the lode, two such shoots have been worked where the split sections of the main fault rejoin on either side of an S-bend. This situation is illustrated diagrammatically in figure 12. Here the fault A-D bends and splits between B and C. The section between B and C consists of large, broken slabs of country rock, but due to the wide separation of the marginal shears there has been little crushing of the rock. At a point such as B or C, the wedge of rock between the shears has been subjected to considerable stress in comparison to its bulk, and has been crushed. It is at these positions that the enrichments of copper are found.

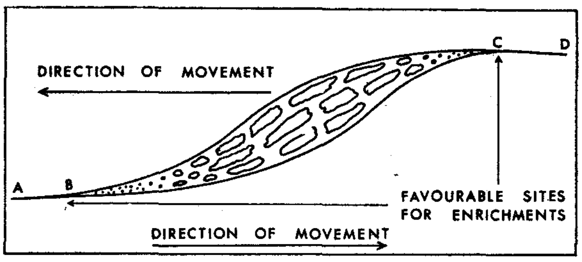

Figure 12—Diagram illustrating favourable positions for ore shoots on a split shear structure.

The better grade ore worked at Thaduna is almost always in "graphite schist" or "graphitic lode". Lode with a high content of silica seldom contains high-grade copper mineralisation. As all of the ore worked to date owes its copper content to secondary enrichment, it is likely that this process has taken place preferentially in the less siliceous and hence more permeable parts of the fault zone.

At the north end of the open cuts, two shoots known as the "Big Lode" and the "Black Lode" respectively, have been mined to a depth of about 160 feet. The controls of these shoots are not as apparent as with those to the south mainly because the present collapsed, waterfilled workings cannot be closely examined. From previous examinations, made when the workings were in a better condition, it is thought that the two shoots are on separate branches of the Thaduna fault. The Black Lode shoot is on the main through-going branch of the fault while the Big Lode is on an eastern branch which dies out to the north. The movement on this branch seems to have been taken up on link shears which join it to the western part of the structure. The shoots may have formed where these link-shears intersect each of the two branches.

THE DIAMOND DRILLING PROGRAMME

Drilling done by New Consolidated Gold Fields in 1963 to 1964 showed the existence of good-grade chalcocite ore beneath the open cuts at depths of 350 to 400 feet below the surface. However, the holes intersecting the secondary sulphide ore were too widely spaced for reliable determination of the reserves, so the British Metal Corporation decided to drill a further 10 holes. Eight of the holes were planned to intersect the lode at about 200 feet vertical depth, and two were laid out to cut the more interesting central part at a depth of about 400 feet. Another three holes, financed entirely by B.M.C. are planned to test the extensions of the lode along strike.

The present drilling programme was laid out with the object of trying to prove a large body of supergene enriched ore. Consequently, no deliberate attempt was made to intersect each of the shoots known in the open cuts and it is therefore possible that the drillholes may have straddled some shoots. However, as the object of the programme was to prove an ore body suitable for open-cut mining, the policy of placing the holes at equal intervals to get an average grade for the whole lode was justified. Any deliberate attempt to intersect only the higher-grade shoots would have made the results impossible to interpret and useless for the aim of the project.

Table 1 gives the results of all holes drilled on the lode to date and the positions of the intersections in plan and section are shown in Plates 38 and 39. On these plates, holes drilled by the British Metal Corporation are shown as BD15 to 24. This numbering follows on from that used by New Consolidated Gold Fields who drilled 14 holes in the Thaduna area. Those holes of New Consolidated Gold Fields which are in the compass of the present report are shown on the plates with the prefix GD. The two intersections obtained by Anglo-Westralian Pty. Ltd. are shown on the longitudinal projection with the prefix AW. As the collar positions of these holes are uncertain, they have not been shown on the plan. Thaduna Copper Mines drilled several shallow holes, which are shown on the plates with the prefix TH. Apart from TH7 the positions of these holes are known only approximately.

The results of drilling and channel sampling can best be interpreted as indicating a series of North-pitching shoots within the lode. Holes GD2 and BD20 intersect one such shoot which is centred on channel sample S7 in the open cut. The mine manager, Mr. A. Rieck, reports that the shoots worked from the shaft in the northern open cut also pitched to the north. Individual shoots are in the order of 150 to 200 feet long and range in grade from 6.5 per cent. to 10 per cent. copper.

The average grade up the upper 200 feet of the lode as calculated from the drilling and sampling results, and excluding some very low-grade sections, is about 3.5% copper. Sufficient ore is indicated to justify a small open-cut mining venture if the high price of copper is maintained and the problems associated with concentrating the copper sulphides can be overcome.

Secondary enrichment extends to a depth of 350 to 400 feet in the central part of the lode, but is less than 150 feet deep at the south end and is also decreasing at the north end.

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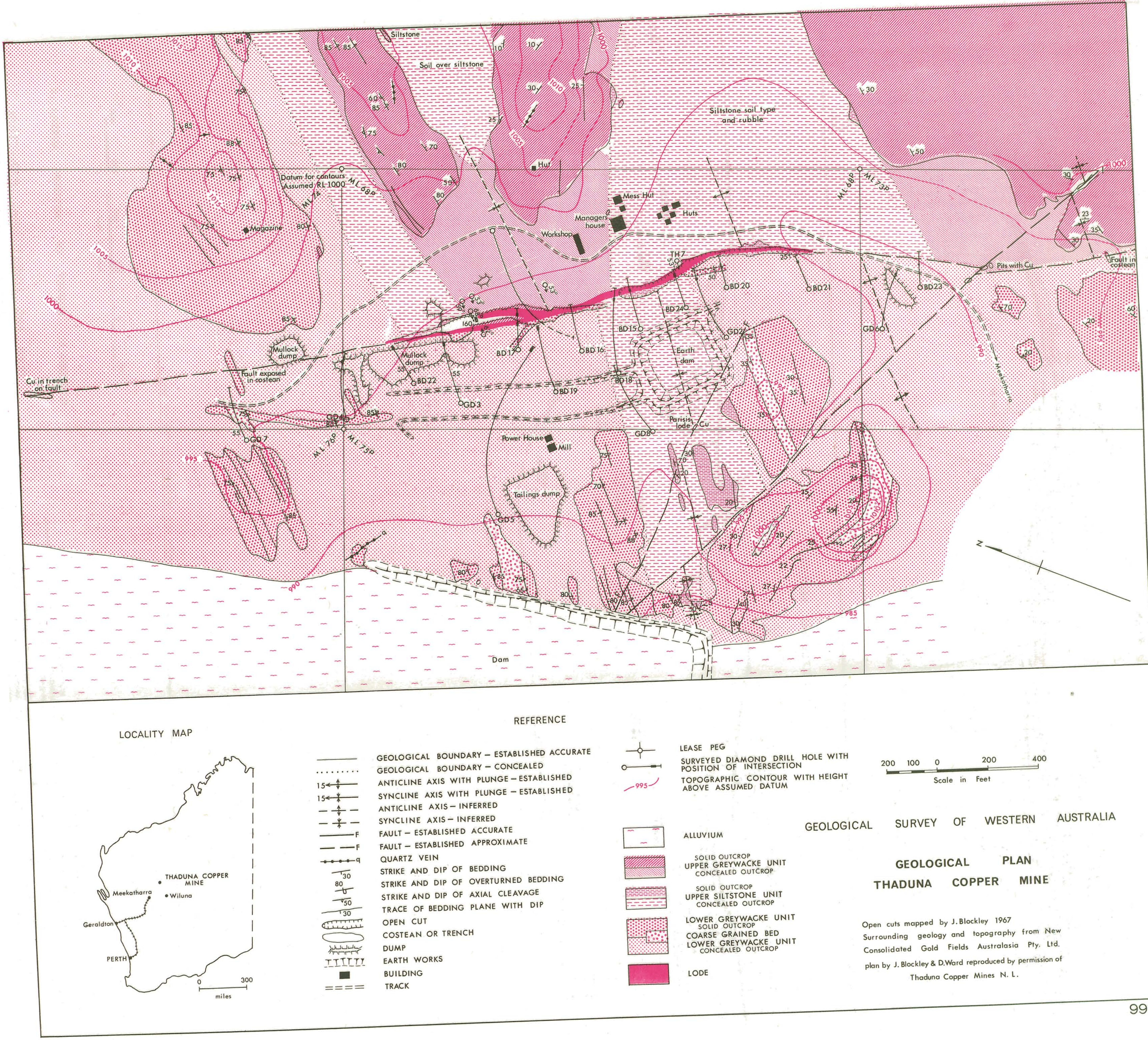
Siltstone
Soil over siltstone
Siltstone soil type and rubble
Datum for contours Assumed RL 1000
Magazine
Hut
Mess Hut
Managers house
Huts
Workshop
Pits with Cu
Fault in costean
Mullock dump
Cu in trench on fault
Fault exposed in costean
Earth dam
Parisis lode Cu
Power House
Mill
Tailings dump
Dam
Meekatharra
LOCALITY MAP
THADUNA COPPER MINE
Meekatharra
Wiluna
Geraldton
PERTH
0 300 miles
REFERENCE
GEOLOGICAL BOUNDARY – ESTABLISHED ACCURATE
GEOLOGICAL BOUNDARY – CONCEALED
ANTICLINE AXIS WITH PLUNGE – ESTABLISHED
SYNCLINE AXIS WITH PLUNGE – ESTABLISHED
ANTICLINE AXIS – INFERRED
SYNCLINE AXIS – INFERRED
FAULT – ESTABLISHED ACCURATE
FAULT – ESTABLISHED APPROXIMATE
QUARTZ VEIN
STRIKE AND DIP OF BEDDING
STRIKE AND DIP OF OVERTURNED BEDDING
STRIKE AND DIP OF AXIAL CLEAVAGE
TRACE OF BEDDING PLANE WITH DIP
OPEN CUT
COSTEAN OR TRENCH
DUMP
EARTH WORKS
BUILDING
TRACK
LEASE PEG
SURVEYED DIAMOND DRILL HOLE WITH POSITION OF INTERSECTION
TOPOGRAPHIC CONTOUR WITH HEIGHT ABOVE ASSUMED DATUM
ALLUVIUM
SOLID OUTCROP
UPPER GREYWACKE UNIT
CONCEALED OUTCROP
SOLID OUTCROP
UPPER SILTSTONE UNIT
CONCEALED OUTCROP
LOWER GREYWACKE UNIT
SOLID OUTCROP
COARSE GRAINED BED
LOWER GREYWACKE UNIT
CONCEALED OUTCROP
LODE
200 100 0 200 400
Scale in Feet
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
GEOLOGICAL PLAN
THADUNA COPPER MINE
Open cuts mapped by J. Blockley 1967
Surrounding geology and topography from New Consolidated Gold Fields Australasia Pty. Ltd.
plan by J. Blockley & D. Ward reproduced by permission of Thaduna Copper Mines N. L.

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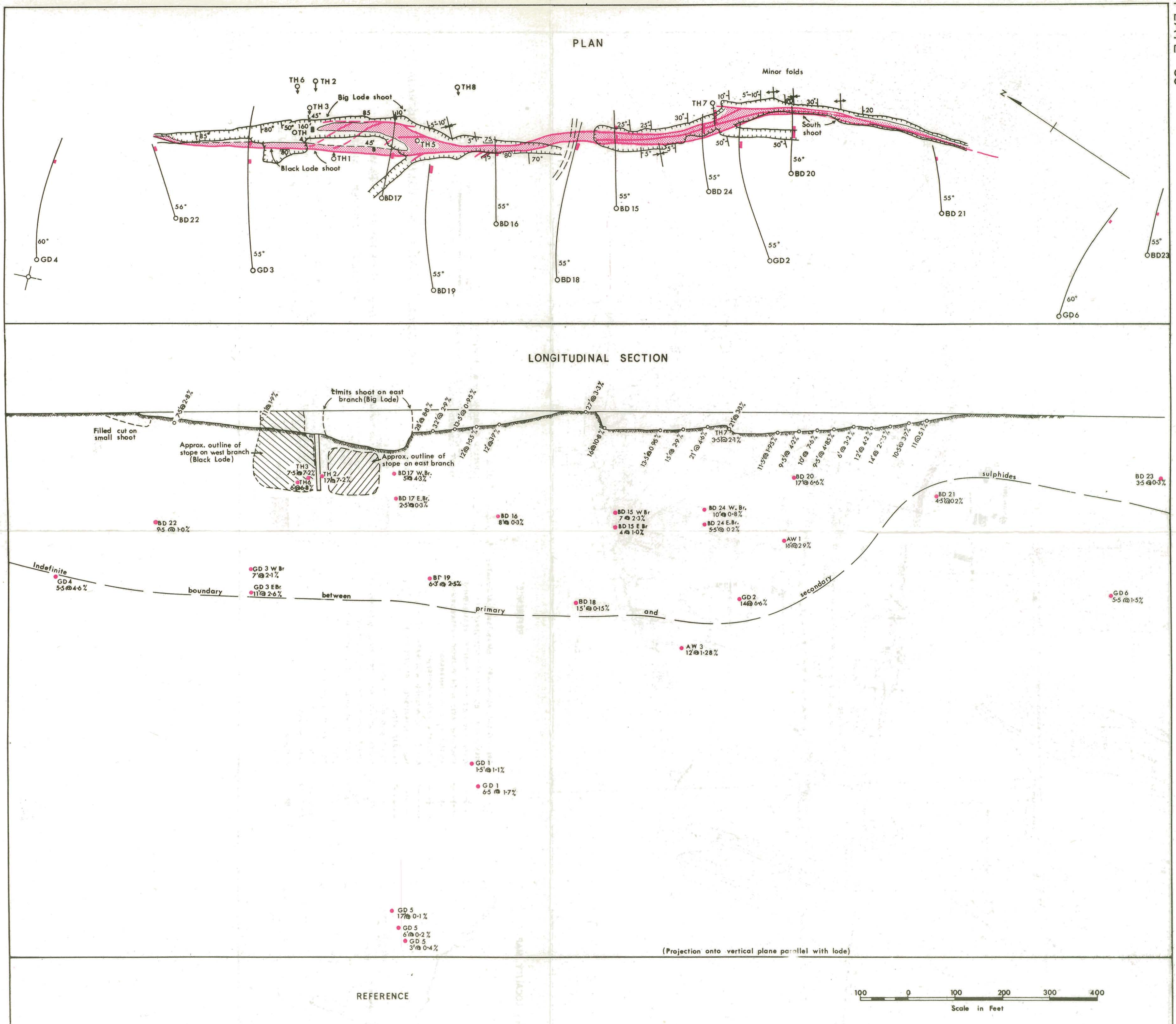
PLATE 39



GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

PLAN AND LONGITUDINAL PROJECTION THADUNA COPPER MINE

Showing geology of the open cuts and locations of diamond drill intersections and channel samples

9933

Table 1

SUMMARY OF DIAMOND DRILLING RESULTS

Hole No.	Drilled by*	Date	Collar		Lode Intersection		Assays better sections				Final depth (ft.)	
			Bear.	Dep.	From (ft.)	To (ft.)	From (ft.)	To (ft.)	%Cu	Hor. Width (ft.)		
AW1	A.W.	1953	....	....	....	....	....	....	2·9	16	....	Poor core recovery
AW2	A.W.	1953	....	....	....	....	....	....	....	....	635	Abandoned due to severe deflection
AW3	A.W.	1953	....	....	....	....	....	....	1·28	12	....	In primary sulphide
TH1	T.C.M.....	1959	....	62°	0	15	0	15	Trace	....	160	
TH2	T.C.M.....	1959	....	53°	162	190	162	190	7·2	17	190	
TH3	T.C.M.....	1959	....	68°	141	161	141	161	7·2	7½	171	
TH4	T.C.M.....	1959	....	90°	....	....	....	....	....	....	90	No lode intersected
TH5	T.C.M.....	1959	....	90°	0	120	0	120	7·15	....	120	Drilled vertically down lode
TH6	T.C.M.....	1959	....	59°	170	182	170	182	6·8	6	185	
TH7	T.C.M.....	1959	....	53°	20	56	20	56	5·5	20	70	Oxidised lode
					60	66	60	66	2·1	3½	....	Graphite lode
TH8	T.C.M.....	1959	....	53°	....	....	....	....	....	....	201	No lode intersected
GD1	N.C.G.F.	1963	230°	55°	761	956	761½	762½	14·9	0·3	956	Hole deflected badly and was running nearly
							890	894½	1·13	1½	....	parallel to the lode when stopped; primary
							932½	956	1·67	6½	....	sulphides
GD2	N.C.G.F.	1963	050°	55°	460·7	482·9	463·5	482·9	6·6	14	550	Secondary sulphides
GD3	N.C.G.F.	1963	055°	55°	341·7	346·7	341·7	346·7	1·8	3·5	598	Oxidised copper minerals
					395·0	404·7	395·0	404·7	2·06	7	....	West branch of lode } Secondary and primary
					459·0	474·0	459·0	474·0	2·65	11·0	....	East branch of lode } sulphides
GD4	N.C.G.F.	1964	055°	60°	402·0	415·5	407·0	415·6	4·6	5·5	517	Secondary and primary sulphides
GD5	N.C.G.F.	1964	060°	63°	1234·5	1265	1234·5	1265	0·09	17	1351	} Primary sulphides
					1291	1302	1291	1302	0·19	6	....	} Hole running near-parallel to this lode
					1326	1344	1326	1344	0·42	3	....	}
GD6	N.C.G.F.	1964	079½°	60°	425·5	434	425·5	434	1·54	5·5	500	Primary sulphides
GD7	N.C.G.F.	1964	035°	60°	402·7	430·3	402·7	430·3	0·01	18·5	481	Disseminated pyrite in lode
GD8	N.C.G.F.	1964	040°	65°	....	....	....	....	....	....	736	Abandoned due to deflection after several wedging attempts
GD9†	N.C.G.F.	1964	050°	60°	449	556	....	....	....	....	752	Lode comprises quartz-filled breccia—no copper
GD10‡	N.C.G.F.	1964	040°	60°	405	412	405	412	0·62	4·0	502	Oxidised copper minerals
					432	450	432	450	0·32	12·0	....	Oxidised copper minerals
BD15....	B.M.C.....	1966	058°	55°	261	279	254	266	2·35	7·0	351	Includes some mineralised wall rock in assay section
					296	302	295	302·5	1·0	4·5	....	
BD16....	B.M.C.....	1966	058°	55°	259	272	259	272	0·3	8·2	320	
					290·5	304	Barren	....	....	....	....	
BD17....	B.M.C.....	1966	069°	55°	159	168·2	157	162	2·4	3·0	285½	
					224	228	224	228	0·3	2·2	....	Poor recovery in lode
BD17A	B.M.C.....	1967	....	....	155	170	153·5	162	4·35	4·9	226	Secondary sulphides
					219	226	Not assayed					Wedged from BD17 at 130 feet
BD18....	B.M.C.....	1967	054°	55°	471	523	487	508	0·15	15·0	587	
BD19....	B.M.C.....	1967	053°	55°	431·5	446	431	440	2·5	6·3	458	Secondary sulphides
BD20....	B.M.C.....	1967	053°	56°	196·5	231	196·5	219·5	6·65	19	253	Secondary sulphides
BD21....	B.M.C.....	1967	053°	55°	205	214·3	205	211	0·2	4·5	250	Pyrite in lode
BD22....	B.M.C.....	1967	041°	56°	274	286	272	289	1·03	9·5	294	Primary and secondary sulphides
							273	279	2·25	3·3	....	
BD23....	B.M.C.....	1967	068°	55°	154	159	154	159	0·3	3·5	250	Oxidised
BD24....	B.M.C.....	1967	051°	55°	232·5	241	232·5	251	0·8	10	297½	Oxidised
					247	259	Not assayed					
					275	286	275	286·5	0·2	5·5	....	Oxidised

* A.W. = Anglo-Westralian Corporation Pty. Ltd.
T.C.M. = Thaduna Copper Mines N.L.
N.C.G.F. = New Consolidated Gold Fields (A/sia) Pty. Ltd.
B.M.C. = British Metal Corporation Pty. Ltd.
† GD9 sited on a geochemical anomaly 1,775 feet north of GD7.
‡ GD10 sited on a geochemical anomaly 1,200 feet north of GD7·

THE NAUTILOID CIMOMIA IN THE PLANTAGENET GROUP

by A. E. Cockbain

ABSTRACT

The Upper Eocene nautiloid *Cimomia felix* (Chapman), of which *C. yorkensis* McGowran is a junior synonym, is described and figured from the Plantagenet Group in the Denmark-Esperance area. The five specimens come from four widely scattered localities and are all of small size.

INTRODUCTION

Nautiloid cephalopods were first discovered in the Plantagenet Group by Jutson and Simpson (1916). The form they found has subsequently been named *Aturia clarkei* Teichert. More recently, Glenister and Glover (1958) have described *Teichertia prora* Glenister, Miller and Furnish from these strata. A third species was recorded, but not figured, by Chapman and Crespin (1934) as *Nautilus geelongensis*. What is probably the same species was identified by Teichert (*in* Clarke and Phillipps, 1955, p. 22) as "fairly close to the Victorian *Nautilus balcombensis* Chapman or *Nautilus geelongensis*".

This latter nautiloid from Western Australia has not been described or figured and the purpose of this note is to rectify this omission.

SYSTEMATIC PALAEONTOLOGY

Phylum MOLLUSCA
Class CEPHALOPODA
Subclass NAUTILOIDEA
Order NAUTILIDA
Superfamily NAUTILACEAE
Family HERCOGLOSSIDAE
Genus CIMOMIA Conrad, 1866

Type species:
Nautilus burtini Galeotti 1837.
Cimomia felix (Chapman) 1915.
Plate 40; Figure 13.

1915 *Nautilus felix* Chapman, p. 357, pl. 6 fig. 14, pl. 7 fig. 15.

1934 *Nautilus geelongensis* (Foord); Chapman and Crespin p. 125.

?1955 "close to . . . *Nautilus balcombensis* Chapman or *Nautilus geelongensis*"; Teichert *in* Clarke and Phillipps p. 22.

1959 *Cimomia felix* (Chapman); McGowran p. 443 pl. 65 figs. 1-7, text fig. 10.

1959 *Cimomia yorkensis* McGowran p. 445 pl. 66 figs. 6-8; text fig. 11.

Material: From the Western Australian Museum collection,

65.1: from Lort River.

64.21: from Esperance.

67.353a: from Plantagenet Location 5293, 22 miles from Albany along Mt. Manypeaks road.

From the National Museum of Victoria collection (Jutson collection; *N. geelongensis* (Foord) of Chapman and Crespin 1934, p. 125), P26128 A & B: from near Albany.

Dimensions (in mm):

Specimen No.	65·1*	64·21*†	67·353a*	P26128A†	P26128B†
Maximum diameter	34·0	....	21·5	....	....
Maximum width	33·0	....	17·5	....	....
Height of last chamber	15·5	....	9·0	....	....
Height of impressed area	6·0	....	4·5	....	....
Chamber length	4·0–7·5	approx. 5·0	2·0–3·2	....	approx. 6·0
Umbilicus diameter	2·0	....	1·5	....	....
No. of chambers in final whorl	Body chamber +11	Body chamber +4	16	Body chamber +1	5·0

* Specimen distorted; axis of coiling is at 82° to plane of coiling in 65.1 and 67.353a and at a slightly larger angle in 64.21.

† Incomplete specimens.

Description: All specimens are preserved as internal moulds: the description is based on those in the W.A. Museum collection. Conch small, expanding fairly rapidly. Umbilicus small; it is impossible to determine whether or not it is perforate. Body chamber takes up about $\frac{1}{3}$ of a volution in 65.1 (incomplete specimen) and one third to one half volution in 64.21. Whorl cross section broadly rounded ventrally, sides slightly flattened, umbilical walls steep. Siphuncle not preserved. Surface of internal mould smooth; in 65.1 there is a faint ridge on the mid-ventral line of the final chambers, in 67.353a, there is a shallow groove in this position. Suture line (Figure 13) slightly sinuous with broad ventral saddle and shallow lateral lobe; a small but distinct lateral saddle is present in the umbilicus in early chambers and on the umbilical shoulder in later chambers. Dorsal suture unknown.

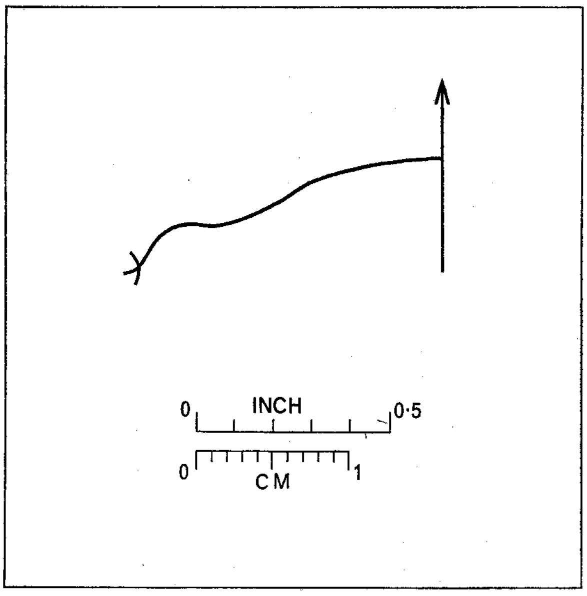


Figure 13—*Cimomia felix;* suture line form final whorl of specimen 65.1

Remarks: The only slightly sinuous suture line of these specimens suggests that they belong to the genus *Cimomia* rather than *Eutrephoceras*. Two Australian Tertiary species of *Cimomia* are known, namely *C. felix* (Chapman) and *C. yorkensis* McGowran. The main differences between these two species (McGowran 1959, p.446) are in height/width ratio of mature chambers, perforation of umbilicus, and position of subcentral siphuncle; in view of the known variability of these features in nautiloid populations it seems best to recognise only one species and suppress *C. yorkensis* as a synonym of *C. felix*. This is borne out by published figures (McGowran 1959, pl.65 figs. 2 & 3) showing the variation in chamber cross-sectional shape in young specimens of *C. felix*. The Plantagenet Group specimens closely resemble the young specimens from the Tortachilla Limestone figured by McGowran (1959, pl.65 fig. 1, 2). The only other published figures with which the Plantagenet Group specimens may be compared, are of young (and atypical) paratypes of *Cimomia tenuicosta* Glenister, Miller & Furnish (1956, pl.53 fig. 5, 6, 7) from the Upper Cretaceous Miria Marl in the Carnarvon Basin. It is possible that these paratypes do not belong to *C. tenuicosta;* the suture line resembles that of *C. felix* although the chamber cross section is more globose and lacks the lateral flattening of *C. felix*.

It is not clear what is the significance of the small size of the Plantagenet Group material. All five specimens studied come from a variety of lithologies (limestone, hard and soft siltstone). These nautiloids seem to be consistently smaller than other Australian Tertiary nautiloids previously described. Whether they are all young specimens or represent a new, small-sized species, cannot be established from the material available.

Stratigraphical range: In addition to the specimens from the localities mentioned above *C. felix* probably occurs near Quaalup homestead on the Gairdner River. The species is thus known throughout the Plantagenet Group outcrop in the Denmark-Esperance area.

Cimomia felix is of Upper Eocene Age, being known from the Tortachilla Limestone, Blanche Point Marls, and Browns Creek Clay (McGowran, 1959; Ludbrook, 1967). The Plantagenet Group is known to be of Upper Eocene age from dating by Foraminifera (McTavish, 1966; Cockbain, 1967). The presence of *C. felix* in the Plantagenet Group would support this Upper Eocene age.

ACKNOWLEDGEMENTS

I wish to thank Dr. T. A. Darragh of the National Museum, Melbourne and Mr. G. W. Kendrick of the Western Australian Museum for making available for study the specimens under their care.

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PLATE 40

Cimomia felix (Chapman)

Left: Specimen No. 65.1 from Lort River.

Right: Specimen No. 67.353a from Plantagenet Loc. 5293.

EOCENE FORAMINIFERA FROM THE NORSEMAN LIMESTONE OF LAKE COWAN, WESTERN AUSTRALIA

by A. E. Cockbain

ABSTRACT

Three formations (Norseman Limestone, Cowan Dolomite, and Princess Royal Spongolite), in part laterally equivalent, crop out on the margins of Lake Cowan and are here designated the Eundynie Group. The original Miocene dating, on the basis of Bryozoa, of the Norseman Limestone has been questioned recently. Upper Eocene Foraminifera are identified for the first time from the Norseman Limestone and enable it to be correlated with the Toolinna Limestone, Wilson Bluff Limestone, and Plantagenet Group.

INTRODUCTION

There are several small outcrops of rocks, usually assigned to the Tertiary, around the margin of Lake Cowan. The main rock types are limestone (silicified in part), dolomite, and spongolite; they have been named—Norseman Limestone (Gregory, 1916), Cowan Dolomite (Fairbridge, 1953), and Princess Royal Spongolite (Glauert, 1926) respectively. A variety of fossils has been recorded, chiefly from the Norseman Limestone; most of these fossils were referred to Victorian species and a Miocene age assigned to the beds. More recently, with the recognition of the Upper Eocene age of the Plantagenet Group, the Lake Cowan Tertiary rocks have been placed in the Eocene. However, no palaeontological evidence has been published to substantiate this age. The purpose of this paper is to record an Upper Eocene fauna from the Norseman Limestone.

STRATIGRAPHY

The accompanying sketch map (Plate 41) shows the known Tertiary outcrops in the vicinity of Lake Cowan. An attempt has been made to place each outcrop in its correct formation on the basis of published evidence. Previous workers have considered the three formations to be in stratigraphic sequence:

(3) Princess Royal Spongolite

(2) Cowan Dolomite

(1) Norseman Limestone

The evidence for this succession is tenuous. Clarke and others (1948, p. 90) state that ". . . two small fossiliferous outcrops (Norseman Limestone) . . . underlie the unfossiliferous (Cowan) dolomite". The field evidence is equivocal and as the Norseman Limestone and Cowan Dolomite are at about the same elevation, and the dip, whilst not measured, is low, the two formations could be in part laterally equivalent. Concerning the Princess Royal Spongolite, Clarke and others (1948, p. 93) write ". . . The relation of the spongolite to the dolomite has not been seen but the base of the spongolite is about level with the top of the dolomite". On the other hand Hooper (1959, p. 8) concludes . . . "Thus the spongolite and shell bed limestone (i.e. Norseman Limestone) may be regarded as lateral facies laid down more or less at the same time".

In the absence of detailed mapping of the Tertiary rocks the relationship of these three formations cannot be determined with certainty. However it appears likely that they are, in part, lateral equivalents, with the Norseman Limestone being the nearshore facies and the Princess Royal Spongolite a more offshore (although not necessarily deeper water) facies. The spongolite occurrence at Princess Royal is at a slightly higher elevation than the surrounding Tertiary rocks and hence the Princess Royal Spongolite must overlap the Norseman Limestone and Cowan Dolomite. Whether the carbonate unit needs different names for the fossiliferous and unfossiliferous parts, future mapping must decide. It is here proposed that the Norseman Limestone, Cowan Dolomite, and Princess Royal Spongolite be referred to collectively as the "Eundynie Group".

PREVIOUS WORK ON PALAEONTOLOGY OF THE LAKE COWAN GROUP

Of the three formations, the Cowan Dolomite is unfossiliferous, the Princess Royal Spongolite consists almost entirely of sponge spicules, and the Norseman Limestone is richly fossiliferous in places.

Lists of fossils from the Princess Royal Spongolite have been published by Hinde (1910, p. 9-20), Chapman and Crespin (1934, p. 126), Glauert (1926, p. 61), and Clarke and others (1948, p. 93), although most of these records are repetitions of those given by Hinde. Hinde (1910) stated that the formation was younger than the Cretaceous but was unable to be more specific on the evidence of the sponges.

The Norseman Limestone fauna has been recorded by Campbell (1906, p. 22), Maitland (1907, p. 61; 1908, p. 153), Gregory (1916, p. 320), Chapman and Crespin (1934, p. 126), Clarke and others (1948, p. 90-97), Crespin (*in* Clarke and others 1948, p. 99-100), and Hooper (1959, p. 4-6).

In determining the age of the deposit considerable reliance was placed on the Bryozoa by both Gregory and Crespin, who referred them to Victorian and South Australian species formerly believed to be of Miocene age. Since many of the sponge determinations are unreliable (de Laubenfels, 1953), and, as the Bryozoa require re-examination in the light of both modern bryozoan taxonomy and current views on Victorian Tertiary stratigraphy, there is no point in repeating these faunal lists here.

FORAMINIFERA FROM NORSEMAN LIMESTONE

Examination of samples, in the Geological Survey collection, of Norseman Limestone from the type locality of the formation about 20 chains north-east of ML1, Norseman (Norseman run 4, photo 5475, quadrant C, x co-ord. 2.34, y co-ord. 0.36), enabled the following foraminifers to be identified: *Bolovina* sp. *Amphicoryna hirsuta* (d'Orbigny), *Quinqueloculina* spp., *Cibicides perforatus* (Karrer), *Elphidium* cf. *omotoensis* Dorreen, and *Spirillina* sp. The age of the limestone cannot be determined from this fauna.

In July 1967, samples were collected from Hooper's (1959) locality 3 on the southern side of Lake Cowan some 7 miles south-southeast of Binneringie homestead. The succession at this locality consists of a basal shelly limestone about two feet thick resting on Precambrian rocks and overlain by bryozoan limestone. Total thickness is estimated to be about 30 feet. The byrozoan limestone is current-bedded in places and the strata dip eastwards at a low angle. Hooper (1959) recorded two shell beds at this locality but only one was noted in the present investigation.

A small creek marks the junction between limestone and Precambrian rocks. To the east, another creek cuts across the limestone outcrop. In both creeks the limestone is sufficiently weathered to disaggregate readily and a well-preserved fauna of Foraminifera and Bryozoa has been obtained. Sample F6675, collected from the eastern creek (Widgiemooltha Run 16 photo 5721, Quadrant C, x co-ord. 3.60 y co-ord. 0.55) has yielded the following foraminifers:

Species	Other Records		
	Tep	Tew	Tet
Lamarckina turgida Dorreen		(x)	(x)
Elphidium ex. gr. *ingressans* Dorreen	(x)	(x)	
Discorbis finlayi Dorreen	x	x	
Reusella cf. *finlayi* Dorreen			x
Stomatorbina torrei (Cushman & Bermudez)	x	x	x
Gyroidinoides cf. *zelandica* (Finlay)		x	(x)
Cibicides perforatus (Karrer)		x	?
C. vortex Dorreen		x	x
Anomalinoides sp.		x	
Asterigerina sp.			(x)
Sherbornina atkinsoni Chapman	x		
Crespinina kingscotensis Wade	x		
Globigerina cf. *praeturritillina* Blow & Banner		x	
Operculina sp.	x		
Bolivinella sp.	x		x

Tep Plantagenet Group (Quilty *in* Hodgson and others, 1962; Cockbain, 1967).
Tew Wilson Bluff Limestone (Crespin, 1956; G.S.W.A. collections).
Tet Toolinna Limestone (Crespin, 1956; G.S.W.A. collections).
(x) Record of genus only.

Other records of these foraminifers in southern Western Australia are as indicated above.

AGE

The fauna is similar to that of the Plantagenet Group, Wilson Bluff Limestone, and Toolinna Limestone. All three formations are usually considered Upper Eocene in age with the Wilson Bluff Limestone extending down in the Middle Eocene. Significant species for correlation purposes are *Sherbonina atkinsoni* and *Crespinina kingscotensis* both of which occur in Ludbrook's (1963) Tortachilla microfaunule.

The closest faunal similarities are with the Booanya Rock fauna recorded by Crespin (1956) from rocks now assigned to the Toolinna Limestone (Lowry, 1968). *Globigerina* cf. *praeturritillina* is poorly preserved and has a very coarsely ornamented spiral side, but closely resembles *G. praeturritillina* identified by Dr. N. H. Ludbrook from the Wilson Bluff Limestone at Wilson Bluff (G.S.W.A. sample 14266B). This species is characteristic of the Upper Eocene according to Blow and Banner (1962) although Jenkins (1967) shows it extending into the Oligocene in New Zealand. The balance of evidence suggests that the Norseman Limestone is of Upper Eocene age.

ENVIRONMENT

Abundant *Elphidium* and the presence of robust and ornamented species such as *Lamarskina turgida* suggest shallow-water nearshore conditions. The single, aberrant, specimen of *Globigerina* does not conflict with this interpretation. Sponge spicules are very rare and in view of the proximity of spongolite outcrops this is somewhat surprising. Presumably conditions were such that sponges did not live in the nearshore environment.

Lithology and fauna suggest that the Norseman Limestone correlates most closely with the Toolinna Limestone. From this evidence, and from Morgan's (1966) map of the salt-lakes drainage system, it is probable that the Eundynie Group was deposited in an arm of the Upper Eocene sea which connected with the open water conditions of the Eucla Basin.

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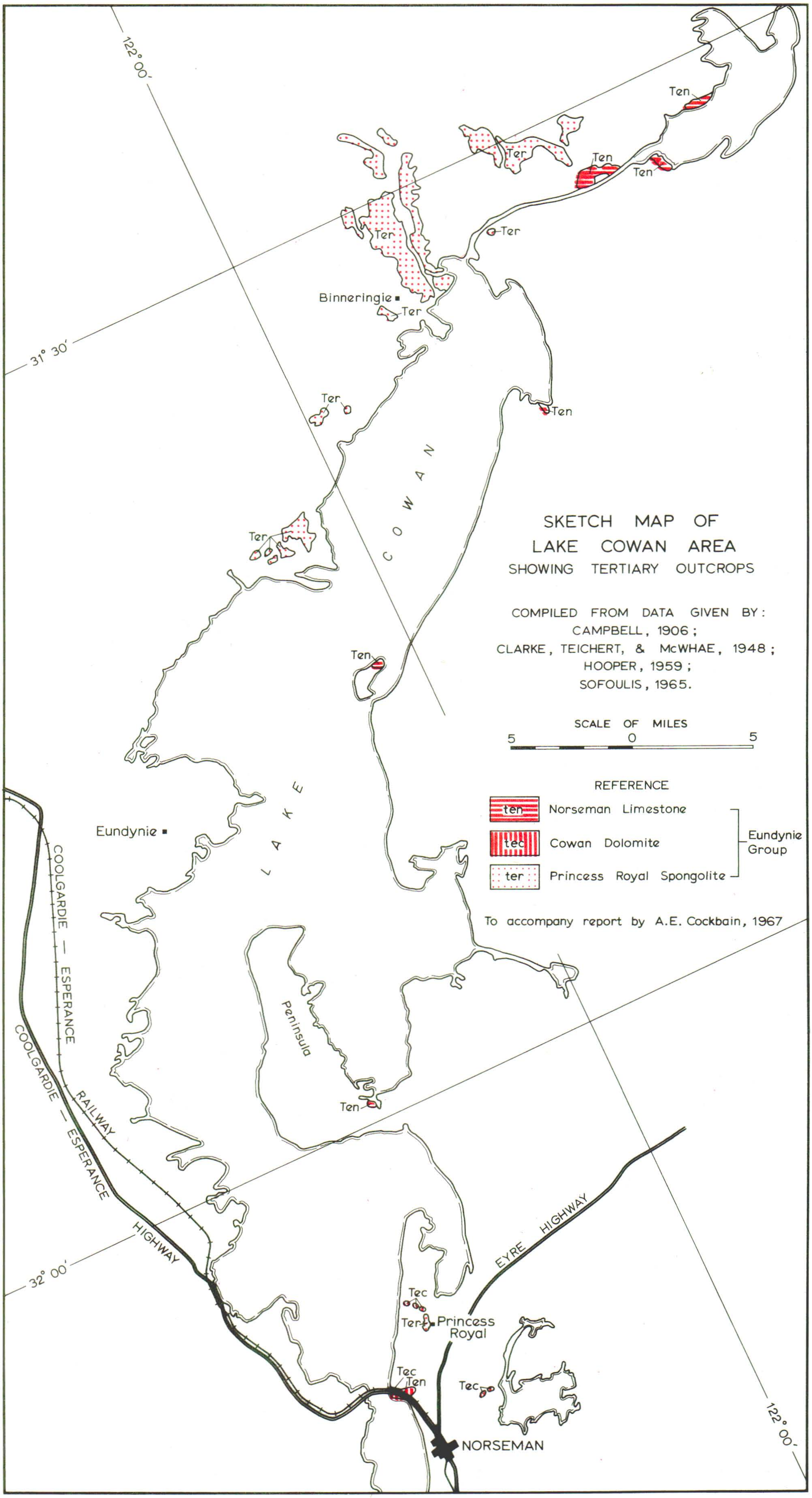
SKETCH MAP OF
LAKE COWAN AREA
SHOWING TERTIARY OUTCROPS
COMPILED FROM DATA GIVEN BY:
CAMPBELL, 1906;
CLARKE, TEICHERT, & McWHAE, 1948;
HOOPER, 1959;
SOFOULIS, 1965.
SCALE OF MILES
5
0
5
REFERENCE
ten Norseman Limestone
tec Cowan Dolomite
ter Princess Royal Spongolite
Eundynie Group
To accompany report by A.E. Cockbain, 1967
122° 00′
31° 30′
32° 00′
LAKE COWAN
Binneringie
Eundynie
Peninsula
Princess Royal
NORSEMAN
COOLGARDIE — ESPERANCE RAILWAY
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THE STRATIGRAPHY OF THE PLANTAGENET GROUP, WESTERN AUSTRALIA

by A. E. Cockbain

ABSTRACT

The Plantagenet Group in the Denmark-Esperance region consists of two new formations, the lower Werillup Formation of dark-coloured siltstone, sandstone, and lignite (including the thin Nanarup Limestone Member) and the upper Pallinup Siltstone of light-coloured siltstone and spongolite. Foraminifera from the Werillup Formation and nautiloids from the Pallinup Siltstone suggest an Upper Eocene age and hence correlation with the Eundynie Group and part of the Eucla Group.

INTRODUCTION

The Plantagenet Beds were defined by Jutson and Simpson (1916, p.24) as a series of marine beds forming " . . . a low plateau to the north and northeast of Albany" and containing "abundant sponge spicules". The beds are now known to extend from Nornalup Inlet in the west to some 100 miles east of Esperance where they pass laterally into the Toolinna Limestone (Lowry, 1968). This region along the south coast of Western Australia will be referred to as the "Denmark-Esperance region" in this paper.

A type section for the Plantagenet Beds has never been designated and the only detailed description of the strata was given by Clarke and Phillips (1955). The purpose of this paper is to revise the stratigraphy of the Plantagenet Beds, define and describe two constituent formations, the Werillup Formation and the Pallinup Siltstone, and change the name of the unit to Plantagenet Group.

PREVIOUS WORK

The original published description of the Plantagenet Group by Jutson and Simpson (1916) is, from internal evidence, a summary of their paper read before the Royal Society of Western Australia in October 1915 but not published until 1917. Prior to these papers the most important work was by Brown (1873, the relevant part of which is quoted by Maitland, 1899) and Maitland (1899, 1907) who described the Plantagenet Group between Albany and Cape Riche. A very full account of all the then-known outcrops of the Plantagenet Group was given by Clarke and Phillips (1955) who also summarised previous work on these beds. Subsequent stratigraphical work has been published by Sofoulis (1958) for the Ravensthorpe area, and Kay and others (1963) for the Bremer Bay area.

Palaeontologically, the Plantagenet Group has attracted considerable attention, especially because of the rich sponge fauna it contains. The most important works are by Chapman and Crespin (1926, 1934), molluscs and sponges; de Daubenfels (1953), sponges; Teichert (1944), Glenister and others (1956), Glenister and Glover (1958), Cockbain (1968), nautiloids; McTavish (1966), Cockbain (1967), foraminifers; Quilty *in* Hodgson and others (1962), foraminifers and echinoids; Cookson (1954), Balme and Churchill (1958), palynomorphus. Prior to 1953 the Plantagenet Group was assigned to the Miocene; however the presence of *Aturia clarkei* suggested an Upper Eocene age to Glaessner (1953). Later work (McTavish, 1966; Cockbain, 1967, 1968) has tended to substantiate this age.

GENERAL STRATIGRAPHY

The Plantagenet Group was laid down on an uneven surface of Precambrian granite, gneiss, schist, and quartzite. Observations along the Pallinup River valley show that there is at least 200 feet of relief on this surface; evidence from boreholes would no doubt increase this figure. The beds are horizontal and are very rarely faulted. The abundance of sponge remains in the Plantagenet Group has been emphasised, and although spongolite is an important constituent, a variety of rock types occur, including sandstone, siltstone, limestone, conglomerate, clay and lignite.

Two major lithological units can be recognised in the Plantagenet Group: an upper unit of light coloured sandy siltstone and spongolite, and a lower unit of dark coloured siltstone, sandstone, carbonaceous clay, and lignite.

The stratigraphical nomenclature can be formalised as follows:

Plantagenet Group
- Pallinup Siltstone; white brown, red siltstone and spongolite, maximum thickness 200 feet.
- Werillup Formation; dark grey siltstone, maximum thickness 160 feet.

Descriptions of these formations are given below. The location of sections mentioned in the text is shown in Plate 42 and the measured sections are drawn in Plate 43.

WERILLUP FORMATION

The name Werillup Formation is proposed for the dark-coloured sandstone and siltstone with occasional lignite occurring in the Denmark-Esperance region. The formation is named after a trigonometrical station some 4 miles west of Princess Royal Harbour, Albany. The lignite in the Fitzgerald River area was referred to as the "Fitzgerald Brown Coal Series" by Blatchford (1930) and whilst this name has priority over "Werillup Formation", it was not adequately defined and it is suggested that the term be allowed to lapse.

Type section: The type section is between 56 and 193 feet in Werillup 3 borehole situated 30 chains southwest of Albany prison. The formation rests on weathered granite and is overlain by Quaternary sand in the type section. Cuttings from this bore are stored in the core library of the Geological Survey.

Lithology: The Werillup Formation consists of grey and black clay, siltstone, sandstone, lignite, and carbonaceous siltstone. Bryozoan limestone at Nanarup quarry is here placed in the Nanarup Limestone Member.

Stratigraphical relationships: At its type section the Werillup Formation is underlain by Precambrian granite, the upper 67 feet of which is weathered to a white and grey clay. In all localities where the base of the formation is present it rests on Precambrian rocks.

Distribution and thickness: The formation is 132 feet thick at the type section and reaches a maximum known thickness of 160 feet in the Albany Aerodrome Bore. The Werillup Formation has a patchy distribution. Lignites have been recorded from Nornalup Inlet, Denmark, Fitzgerald River, and Esperance. Dark grey siltstone and sandstone with occasional carbonaceous siltstone also occurs in boreholes near Neridup, northeast of Esperance.

Palaeontology: The lignites contain microplankton, spores, and pollen which have been recorded by Cookson (1954) and Balme and Churchill (1959). Siltstone from the Neridup boreholes have yielded an abundant fauna of foraminifers, including the genus *Asterocyclina* (Cockbain, 1967), and bryozoans.

Age and correlation: The foraminifer fauna is of Upper Eocene age (Cockbain, 1967) and correlates with Ludbrook's (1963) "Tortachilla microfaunule". Formerly two microfloral assemblages based on the presence or absence of *Proteacidites pachypolus* were considered to occur in the lignites (Balme and Churchill, 1959). This species is now known to range from Upper Palaeocene to Upper Eocene (Harris, 1965), and Ingram (1967) believes these microfloras to be of Upper Eocene age. At the present time there is no evidence to suggest that the Werillup Formation (and hence the Plantagenet Group) is older than Upper Eocene.

The foraminifer fauna suggests correlation of the formation with the Norseman Limestone (Eundynie Group), Toolinna Limestone, and upper part of the Wilson Bluff Limestone (Eucla Group). In South Australia, the closest correlative formation is the Tortachilla Limestone. Eocene clays and lignites are also known from South Australia in the Pidinga Formation, Knight Group, and in lateral equivalents of the North Maslin Sand.

Condition of deposition: The Werillup Formation contains both marine and non-marine strata. There is no consistency in the stratigraphical sequence of marine and non-marine beds. The sporadic distribution of the formation and the presence of lignite and non-marine clays indicates that the beds were laid down in isolated hollows in the underlying Precambrian surface. Peat swamps were flooded by the sea and in some cases an area became landlocked and swamp conditions developed after an initial marine phase. The transgressing sea laid down silt, sand, and clay. A prolific shallow water fauna of foraminifers and bryozoans lived in the sea which, on the evidence of the tropical genus *Asterocyclina*, was warm along this coast in Upper Eocene times (Cockbain, 1967).

NANARUP LIMESTONE MEMBER OF THE WERILLUP FORMATION

The name "Nannarup Limestone" *(sic)* was used, without definition, by McTavish (1966) following unpublished work by Quilty (*in* Hodgson and others, 1962). The unit is here defined as the Nanarup Limestone Member of the Werillup Formation to refer to the brown and white bryozoan limestone occurring in Nanarup lime quarry.

Type section: The type section is taken as the beds of limestone exposed in Nanarup lime quarry, (Mt. Barker run 8, photo serial no. 2944, quadrant D, x co-ord 1.31, y co-ord 0.73; Jan. 1965 photography). The base and top of the member are not exposed.

Lithology: The Nanarup Limestone Member comprises brown and white friable bryozoan limestone.

Stratigraphical relationships: Contacts with other formations are nowhere exposed. The member is placed in the Werillup Formation because of its fauna (see below) and its low altitude (approximately 30 feet above sea level); the Werillup Formation is well developed at the base of the Tertiary sequence in the Albany area.

Distribution and thickness: The member is known only from its type section where it is 15 feet thick.

Palaeontology: The limestone has yielded a good fauna of foraminifers, echinoids, bryozoans, brachiopods, and molluscs which have yet to be determined in full. The benthonic foraminifers and echinoids are recorded by Quilty (*in* Hodgson and others, 1962) whilst some remarks on planktonic foraminifers are given by McTavish (1966).

Age and correlation: An Upper Eocene age has been assigned to the fauna by McTavish (1966) and the foraminifers belong to the "Tortachilla microfaunule". The close similarity between the fauna of the Nanarup Limestone Member and that from the Werillup Formation in the Neridup boreholes is the main basis for assigning the member to the Werillup Formation.

Conditions of deposition: The fauna of the Nanarup Limestone Member suggests that the member was deposited in a shallow marine environment. Possibly local conditions caused a temporary lull in detrital deposition, enabling a shelly carbonate rock to form.

PALLINUP SILTSTONE

The name Pallinup Siltstone is proposed for the light coloured, frequently banded siltstone and spongolite commonly occurring throughout the Denmark-Esperance region. These are the rocks which are usually considered typical of the "Plantagenet Beds". The formation is named after the Pallinup River. Maitland (1907) referred to the Pallinup Siltstone in the Albany-Cape Riche area as the "Cape Riche beds" and the "Warriup beds", but the names were not defined, have not been used subsequently and should be allowed to lapse.

Type section

The type section is exposed in a cliff on the north side of Beaufort Inlet about one mile upstream from the mouth of the Pallinup River (Bremer Bay run 11, photo serial no. 5581, quadrant A, x co-ord 1.95, y co-ord 0.5; January 1958 photography). The section extends from river level up to the top of the cliff.

Lithology

The Pallinup Siltstone typically consists of white, brown or red siltstone, and spongolite. Well-developed burrowings are present at several levels in the type section. The basal beds tend to be somewhat sandy, as in the type section, and in the upper part the rocks may be laminated and sponge-bearing. In the Fitzgerald River and Ravensthorpe area, spongolite makes up a large portion of the formation and should probably be named as a member of the Pallinup Siltstone. East of Esperance, the Pallinup Siltstone is a siltstone with moulds of molluscs and bryozoans abundant in places; all carbonate appears to have been leached out of the rocks.

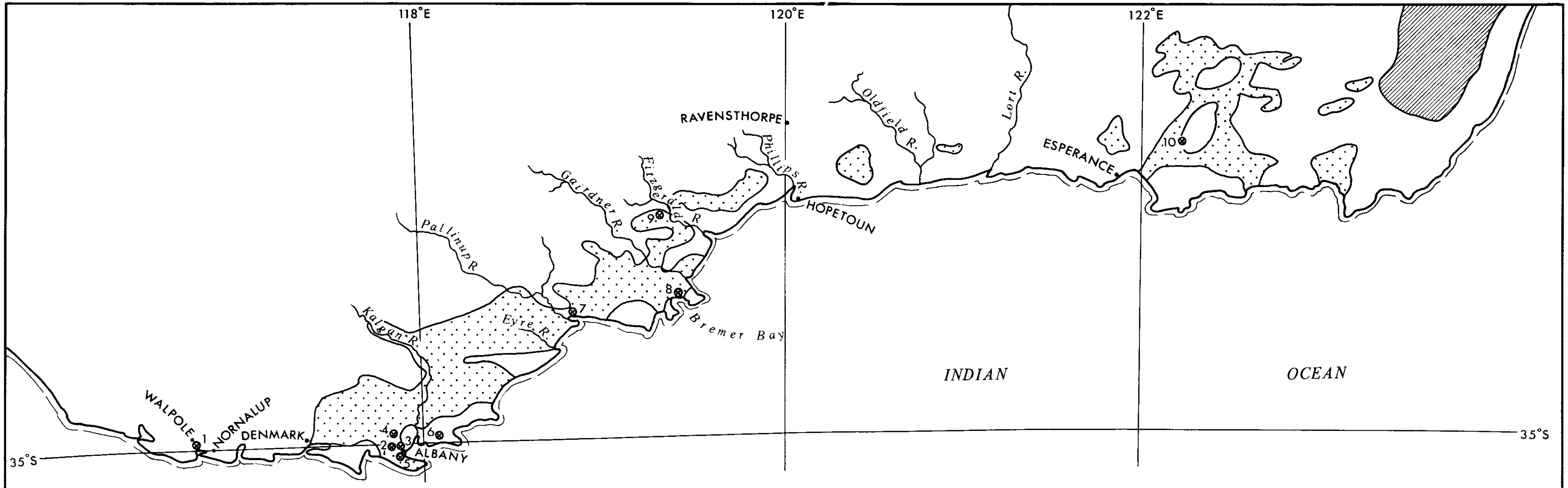
Stratigraphical relationships

The base of the Pallinup Siltstone is not exposed at its type section. In the Neridup boreholes the Werillup Formation is conformably overlain by yellow-brown silty sandstone of the Pallinup Siltstone. The Albany Aerodrome bore, although not logged in detail, shows brown clay and siltstone of the Pallinup Siltstone (well exposed in Stoke's Brick Yard and near Cuthbert) overlying sand and clay with fossil wood which is assigned to the Werillup Formation. In the Fitzgerald River area the Pallinup Siltstone must overlie the Werillup Formation although the contact has not been seen. Elsewhere the Pallinup Siltstone rests directly on Precambrian rocks. There is a thin pebble bed at the base in some exposures in the Fitzgerald River area. Near the mouth of the Eyre River a thin shelly silty sandstone lies on tope of Precambrian gneiss. At Hummocks Beach, Bremer Bay, siltstone is underlain by 15 feet of boulder conglomerate (Kay and others, 1963) resting on a sloping surface of Precambrian rock.

Distribution and thickness

The formation is 153 feet thick at the type section. The maximum known thickness of 200 feet occurs in the Albany Aerodrome bore, although greater thickness will probably be measured in the Bremer Bay to Ravensthorpe area.

The Pallinup Siltstone outcrops from north of Walpole, where a good fauna of molluscs and sponges have been found recently (G. W. Kendrick, pers. comm., Feb. 1967) to about 100 miles east of Esperance where the formation passes laterally into the Toolinna Limestone of the Eucla Basin. The formation extends at least as far north as the southern edge of the Stirling Range, there being good exposures of sponge-bearing white, brown and red siltstone in the Kalgan Valley east of Kendenup. There are records of plant remains and sponge-bearing siltstone to the north of the Stirling Range which probably indicate a northerly extension of the Pallinup Siltstone.



LEGEND

Eucla Group

Plantagenet Group

• Towns

⊗ Location of measured sections in Plantagenet Group

SCALE OF MILES

0 40 80

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

LOCALITY MAP OF MEASURED SECTIONS IN THE PLANTAGENET GROUP

To accompany report by A. Cockbain, 1967

PLATE 42

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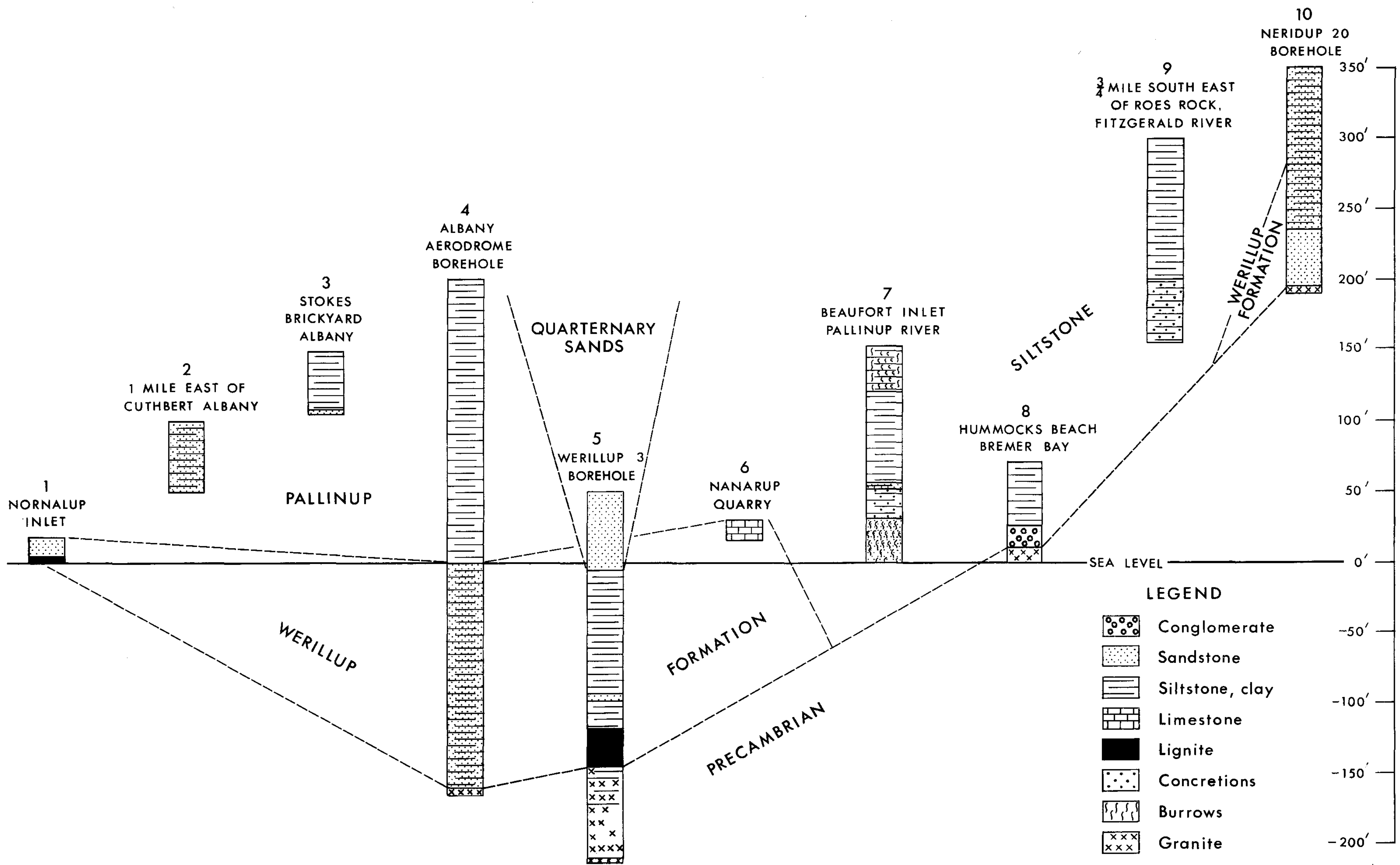
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

MEASURED VERTICAL SECTIONS IN THE PLANTAGENET GROUP OF DENMARK–ESPERANCE REGION

PLATE 43



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Palaeontology

Most of the fossils listed by Chapman and Crespin (1934) as coming from the Plantagenet "Beds" in fact come from the Pallinup Siltstone. Preservation is frequently poor, and many of the fossils occur as internal and external moulds. Molluscs, sponges, and bryozoans are the most abundant fossils; nautiloids are rare, but stratigraphically useful. Foraminifers are also rare in the Pallinup Siltstone, but are known from the Jerdacuttup River north of Hopetoun (G.S.W.A. palaeontology collection) and the Bremer River (Glenister and Glover, 1958).

Age and correlation

The nautiloids *Aturia clarkei, Teichertia prora,* and *Cimomia felix* (see Teichert, 1944; Glenister and others, 1956; Glenister and Glover, 1958; Cockbain, 1968) have been recorded from the Pallinup Siltstone. All three genera occur in Upper Eocene or Middle and Upper Eocene strata elsewhere in Australia and together suggest an Upper Eocene age for the formation.

Lithologically the Pallinup Siltstone correlates with the Princess Royal Spongolite (Eundynie Group) and from its stratigraphical position it is laterally equivalent to the Toolinna Limestone and upper part of the Wilson Bluff Limestone. Spongolites are not known in the Eastern States, but the Pallinup Siltstone is of the same age as the Blanche Point Marls and Buccleuch Group of South Australia.

Conditions of deposition: The Pallinup Siltstone was laid down in a shallow transgressive sea because the formation overlaps the Werillup Formation and comes to rest on the Precambrian. Sand, sometimes pebbly, was the first deposit of this sea, with boulders occuring around areas of steeply sloping Precambrian basement. As the sea deepened, silt was laid down. Where terrigenous material was negligible and sponges throve, the sediment was extremely rich in sponge spicules. Eastwards, shelly material became abundant as the margins of the region of carbonate deposition in the Eucla Basin were approached.

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STRATIGRAPHICAL PALYNOLOGY OF CRETACEOUS ROCKS FROM BORES IN THE EUCLA BASIN, WESTERN AUSTRALIA

by B. S. Ingram

ABSTRACT

The Madura Shale in Madura No. 1, Eyre No. 1, and Gambanga No. 1 boreholes is subdivided into three microfloral assemblage zones of Neocomian—Aptian—Albian—Cenomanian, and Senonian age, and correlated with Cretaceous formations in the Perth Basin. All strata are marine except for non-marine Neocomian—Aptian beds (containing the first record of *Crybelosporites stylosus* in Western Australia) at the base of Madura 1 and Gambanga No. 1.

INTRODUCTION

The existence of Cretaceous strata in the Eucla Basin has been known since 1910 when R. Etheridge, Jr., in a letter to A. G. Maitland, recorded *Aucella hughendenensis* and *Maccoyella corbiensis* from the Loongana (or No. 3) bore, although the identifications were not published until 5 years later (Maitland, 1915). The lower Cretaceous age suggested by these pelecypods was long accepted as the age of all sediments below the Tertiary rocks of the Eucla Basin (see, for example, McWhae and others, 1958, p. 118).

Ludbrook (1958, 1960) showed that a much wider range of Cretaceous strata was present using evidence from arenaceous foraminifers and also suggested correlation on lithological grounds with Perth Basin formation. She commented, however (1958, p.111), that ". . . palynological study of the core in this bore (Madura 1) should be undertaken to confirm the correlations . . . ". The present work was carried out with this comment in mind.

Cretaceous strata do not crop out in the Western Australian part of the Eucla Basin and all information comes from boreholes. Pertinent boreholes are Madura 1, Loongana (or No. 3), both drilled by the Western Australian Public Works Department in 1902 and 1907 respectively, and Eyre No. 1 and Gambanga No. 1, drilled as oil exploration wells by Exoil Pty. Ltd. in 1959 to 1960.

Fairbridge (1953) proposed two formations, the Madura Shale and Loongana Conglomerate, for the Cretaceous strata in the Eucla Basin. The latter was defined as the sand and conglomerate in Loongana bore, between 1,260 and 1,314 feet. The Madura Shale was inadequately defined by Fairbridge (1953) and was placed in the Tertiary (p.X/9) and, on a later page, in the Cretaceous (p.XI/9). Subsequently McWhae and others (1958, p. 118) selected the type section in Madura 1 bore as ". . . between 927 feet and 2,041 feet (the total depth of the bore)". In fact the total depth is 2,101 feet, but since the lithology below 2,041 feet is similar to that above, all strata between 927 and 1,101 feet are here assigned to the Madura Shale.

The samples studied for this paper come from the Madura Shale in Madura 1, Eyre No. 1, and Gambanga No. 1 boreholes. The position of these bores is shown on the accompanying map (Plate 44). Portions of all available cores were treated by routine palynological methods and the important palynomorphs identified in each assemblage are recorded in Table 1. The material available for study from Madura 1 represents only a fraction of the original, as the bore was cored throughout, but it appears that only representative samples of each major rock type were kept. Frequently it is only possible to locate a sample within a 300-foot interval of the bore.

PALYNOLOGICAL ASSEMBLAGE ZONES

Three Cretaceous palynological assemblage zones can be recognized in these bores. The assemblages correspond closely to those from the Gingin Chalk and associated greensand, the Osborne Formation, and the South Perth formation in the Perth Basin. The exact position of these assemblage zones within the European Stages is uncertain (see Ingram, 1967). The following table summarises these assemblage zones and correlates them with the age units suggested by N. H. Ludbrook.

Ludbrook, 1958	Ludbrook, 1960	Palynological units	
Santonian	post-Cenomanian	Senonian	
?Cenomanian-Albian	? Cenomanian Albian ? Albian	Albian-Cenomanian	
Aptian	....	Marine	Neocomian-Aptian
		Non-marine	

The correlation of these units in the three bores is shown on Plate 45. The palynological assemblage zones are defined on microplankton, and spores and pollen grains. A chart showing the distribution of some of the genera and species identified is given as Table 1. The main features of each assemblage zone are discussed below.

Senonian

All samples of Senonian age are marine and hence contain few spores and pollen grains. However some samples contain several species of *Proteacidites*, indicative of a late Upper Cretaceous or younger age. Microplankton present include several species previously recorded only from Upper Cretaceous strata in the Perth and Carnarvon Basins, for example:

Dinogymnium westralium (Cookson and Eisenack).

Deflandrea tripartita (Cookson and Eisenack).

Odontochitina cribropoda (Deflandre and Cookson).

Nelsoniella aceras (Cookson and Eisenack).

N. tuberculata (Cookson and Eisenack).

Albian-Cenomanian

The microfloras in the Albanian-Cenomanian assemblage zone are very similar to those from the Osborne Formation in the Perth Basin. For example, species of the microplankton *Diconodinium* and *Gonyaulacysta*, spores and pollen grains such as *Gleicheniidites* (at least three species), *Laevigatosporites*, and *Hoegisporis* (a restricted Albian-Cenomanian form) occur and all are common also in the Osborne Formation.

Microplankton species present which are only known from Albian-Cenomanian strata include:

Odontochitina striatoperforata (Cookson and Eisenack).

Gonyaulacysta edwardsi (Cookson and Eisenack).

Diconodinium dispersum (Cookson and Eisenack).

D. glabrum (Eisenack and Cookson).

Neocomian-Aptian

Lower Cretaceous assemblages are present below about 1,960 feet in Madura 1 and in Cores 8 and 9 (1,200 to 1,229 feet) in Gambanga No. 1. The section in Madura 1 can be divided into marine (1,960 to 2,049 feet) and non-marine (below 2,049 feet). The Lower Cretaceous in Gambanga No. 1 is non-marine, correlating with or possibly even older than, the non-marine section in Madura 1.

The two diagnostic microplankton in the marine section are *Dingodinium cerviculum* (Cookson and Eisenack and *Muderongia mcwhaei* (Cookson and Eisenack), both of which appear to be restricted to Upper Neocomian-Aptian strata in Australia (Evans, 1966).

Spores and pollen grains are more diverse in this unit including mainly Lower Cretaceous forms although some extend into the Jurassic. Species include:

Cicatricosisporites australiensis (Cookson).

Coronatispora telata (Balme).

Crybelosporites stylosus Dettmann.

Dictyophyllidites crenatus Dettmann.

Dictyotosporites complex Cookson and Dettmann.

Lycopodiumsporites circolumensis Cookson and Dettmann.

Many other species, including species of long ranging genera such as *Tsugaepollenites, Ischyosporites, Contignisporites* and *Aequitriradites*, are also present.

STRATIGRAPHICAL COMMENTS ON SOME OF THE SPECIES

Microplankton

The microplankton genera are arranged in alphabetical order.

DICONODINIUM Eisenack and Cookson

A genus commonly abundant in the Osborne Formation and common in a few samples from the Albian-Cenomanian assemblage zone. Two of the species recorded here (*D. dispersum* (Cookson and Eisenack) and *D. glabrum* (Eisenack and Cookson) appear to be restricted to Albian-Cenomanian strata in Western Australia (Eisenack, 1964).

DINGODINIUM Cookson and Eisenack

Dingodinium cerviculum Cookson and Eisenack

A common, widespread dinoflagellate which is considered to be restricted to late Neocomian-Aptian throughout Australia (Evans, 1966) and also in Germany (Alberti, 1961). In the Perth Basin it occurs only at the top of the South Perth Formation, where the formation is marine (Edgell, 1964).

DINOGYMNIUM Evitt, Clarke and Verdier

Fossil dinoflagellates previously referred to *Gymnodinium* Stein are now placed in this genus.

Dinogymnium westralium (Cookson and Eisenack)

This species, and a few specimens of an indeterminate species of *Dinogymnium*, were recorded in samples from the upper assemblage zone unit. Evitt, Clarke, and Verdier (1967, p. 5) comment: "this genus is highly characteristic of Upper Cretaceous marine strata", and consider the few records outside of Upper Cretaceous can be attributed to reworking.

In Western Australia *D. westralium* has been recorded previously from the Korojon Calcarenite and the Molecap Greensand (Deflandre and Cookson, 1955; Cookson and Eisenack, 1958).

DEFLANDREA Eisenack

A common genus with over 40 species. According to Manum and Cookson (1964, p. 31) it "has its main distribution in Upper Cretaceous and younger beds". Core 6 in Gambanga No. 1 has a particularly rich assemblage of *Deflandrea* species, several of which appear to be undescribed. *D. tripartita* Cookson and Eisenack, which occurs in some samples of the upper assemblage zone, has been recorded only from the Upper Cretaceous of Western Australia (Cookson and Eisenack, 1960) and Victoria (Cookson and Eisenack, 1961).

GONYAULACYSTA Deflandre

Gonyaulacysta edwardsi (Cookson and Eisenack)

This species is said by Sarjeant (1966, p. 130) to range from Aptian to Turonian in Australia but has only been seen by the author in the Osborne Formation in the Perth Basin. It occurred only in the middle assemblage zone in this study.

Core 20 in Eyre No. 1 contains an abundance of large specimens of this genus (including *G. edwardsi*) which would be well worth taxonomic study.

MUDERONGIA Cookson and Eisenack

Muderongia mcwhaei Cookson and Eisenack

Has a restricted range from Upper Neocomian to Aptian (Evans, 1966).

NELSONIELLA Cookson and Eisenack

The only three species of this genus described by Cookson and Eisenack, 1960, are all from Western Australian Upper Cretaceous strata. The two recorded in this study (*N. aceras* and *N. tuberculata*) came from the upper assemblage zone.

ODONTOCHITINA Deflandre

Odontochitina cribropoda Deflandre and Cookson

A distinctive species, again with a recorded occurrence restricted to the Upper Cretaceous in Western Australia and also in the Nelson Bore, Victoria (Cookson and Eisenack, 1960, p. 7).

Odontochitina striatoperforata Cookson and Eisenack

This species has only been recorded from Albian-Cenomanian strata in Australia (Cookson and Eisenack, 1962). It is very similar to *O. costata* described by Alberti (1961) from the Cenomanian-Turonian of Germany.

Spores

Only one species is considered worthy of comment.

CRYBELOSPORITES Dettmann

Crybelosporites stylosus Dettmann

This species is considered by Dettmann (1963) to be restricted to the lower Neocomian in south-eastern Australia. Evans (1966, p. 10) notes it "is not a common fossil" and "more records of the species" occurrence are needed to indicate whether it is a reliable Cretaceous marker. The presence of *C. stylosus* in Madura 1 and Gambanga No. 1 is the first record of the species in Western Australia. It has not been seen in the numerous Neocomian samples which the author has examined from the Perth Basin.

CONCLUSIONS

Palynological study of some Cretaceous sections in the Eucla Basin has shown that three microfloral assemblage zones can be determined, with a marked similarity to Perth Basin assemblages. This basically supports the stratigraphy as envisaged by Ludbrook (1958, 1960) although some of her boundaries are changed and Lower Cretaceous strata are recognized in Gambanga No. 1. This is based largely on the presence of *Crybelosporites stylosus* Dettmann, recorded for the first time in Western Australia.

Bore	EYRE No. 1	EYRE No. 1	GAMBANGA No. 1	GAMBANGA No. 1	GAMBANGA No. 1	GAMBANGA No. 1	MADURA 1	MADURA 1	MADURA 1	MADURA 1	MADURA 1	MADURA 1	MADURA 1	MADURA 1	MADURA 1	MADURA 1	MADURA 1	MADURA 1	MADURA 1	MADURA 1
Sample Depth (feet)	1400–1420	1220–1230	1209–1229	1200–1209	1055–1065	910–920	2049–2101	2015–2049	1979–1991	1978–1979	1960–1978	1839–1978(B)	1839–1978(A)	1775–1839	1523–1775	1486–1523	1471–1486	1104–1470	968–988	963–968
Registered No.	F6720	F6719	F6718	F6717	F6716	F6715	F6714	F6713	F6712	F6711	F6710	F6709	F6708	F6707	F6706	F6705	F6704	F6703	F6702	F6701
MICROPLANKTON																				
Odontochitina cribropoda Deflandre & Cookson						×													×	×
O. porifera Cookson						×														
Deflandrea tripartita Cookson & Eisenack		×																		×
D. serratula Cookson & Eisenack		×																		
D. balmei Cookson & Eisenack					×	×														
D. sp. cf. D. acuminata Cookson & Eisenack						×														
D. spp.						×														×
Dinogymnium westralium (Cookson & Eisenack)						×													×	×
D. sp. indet.																				×
Diconodinium pelliferum (Cookson & Eisenack)																				×
Palambages (?algae)						×														×
Nelsoniella aceras Cookson & Eisenack		×				×													×	
N. Tuberculata Cookson & Eisenack																			×	
Xenikoon australis Cookson & Eisenack		×																		
Palaeohystrichophora infurorioides Deflandre		×				×														
Gonyaulacysta edwardsi (Cookson & Eisenack)	×												×					×		
G. sp. cf. G. apionsis (Cookson & Eisenack)													×				×			
G. spp.	×											×								
Odontochitina striatoperforata Cookson & Eisenack	×												×					×		
Microdinium ornatum Cookson & Eisenack																		×		
Ascodinium parvum (Cookson & Eisenack)					×	?										×		×		
A. acrophorum Cookson & Eisenack	×																			
Diconodinium dispersum (Cookson & Eisenack)					×											×	×			
D. glabrum Eisenack and Cookson					×								×			×				
D. multispinum (Deflandre & Cookson)					×								×							
Fromea amphora Cookson & Eisenack					×			×	?							×				
Muderongia sp. cf. M. tetracantha (Gocht)								×				×	×		×					
Diplofusa sp. cf. D. gearlensis Cookson & Eisenack	×																			
Veryhachium spp.					×				×				×			×		×		×
Dingodinium cerviculum Cookson & Eisenack								×	×	×	×	×								
? Canninginopsis sp.												×								
Chlamydophorella nyei Cookson & Eisenack	×										×	×								
Pterodinium cornutum Cookson & Eisenack											×									
Muderongia mcwhaei Cookson & Eisenack								×	×											
Gen et sp. indet. Forma A Eisenack & Cookson							?		×											
Gonyaulacysta muderongensis (Cookson & Eisenack)									×											
SPORES AND POLLEN GRAINS																				
Proteacidites spp.		×																	×	×
Gleicheniidites spp.		×			×	×								×		×	×	×	×	×
G. circinidites (Cookson)								×	×	×	×		×	×		×		×		
Laevigatosporites sp.																×	×	×	×	×
Hoegisporis sp.																×	×			
Microcachyridites antarcticus Cookson			×	×	×		×	×	×	×	×	×	×	×	×	×	×			
Plicatella sp.																×				
Cicatricosisporites sp. cf. C. hughesi Dettman								×	×						×	×				
Inaperturopollenites limbatus Balme					×					×			×							
Ceratosporites equalis Cookson & Dettmann										×		×								
Tsugaepollenites spp.							×		×		×									
Lycopodiumsporites circolumensis Cookson & Dettmann				×			×	×	×		×									
Cicatricosisporites australiensis (Cookson)							×													
Crybelosporites stylosus Dettmann			×	×			×													
Coronatispora telata (Balme)							×													
Dictyotosporites complex Cookson & Dettmann							×													
Dictyophyllidites crenatus Dettmann			×				×													
Aequitriradites sp.			×	×																
Ischyosporites sp.			×	×																
AGE UNITS	Albian—Cenomanian	Senonian	Neocomian—Aptian	Neocomian—Aptian	Albian—Cenomanian	Senonian	Neocomian—Aptian	Neocomian—Aptian	Neocomian—Aptian	Neocomian—Aptian	Neocomian—Aptian	Neocomian—Aptian	Albian—Cenomanian	Albian—Cenomanian	Albian—Cenomanian	Albian—Cenomanian	Albian—Cenomanian	Albian—Cenomanian	Senonian	Senonian

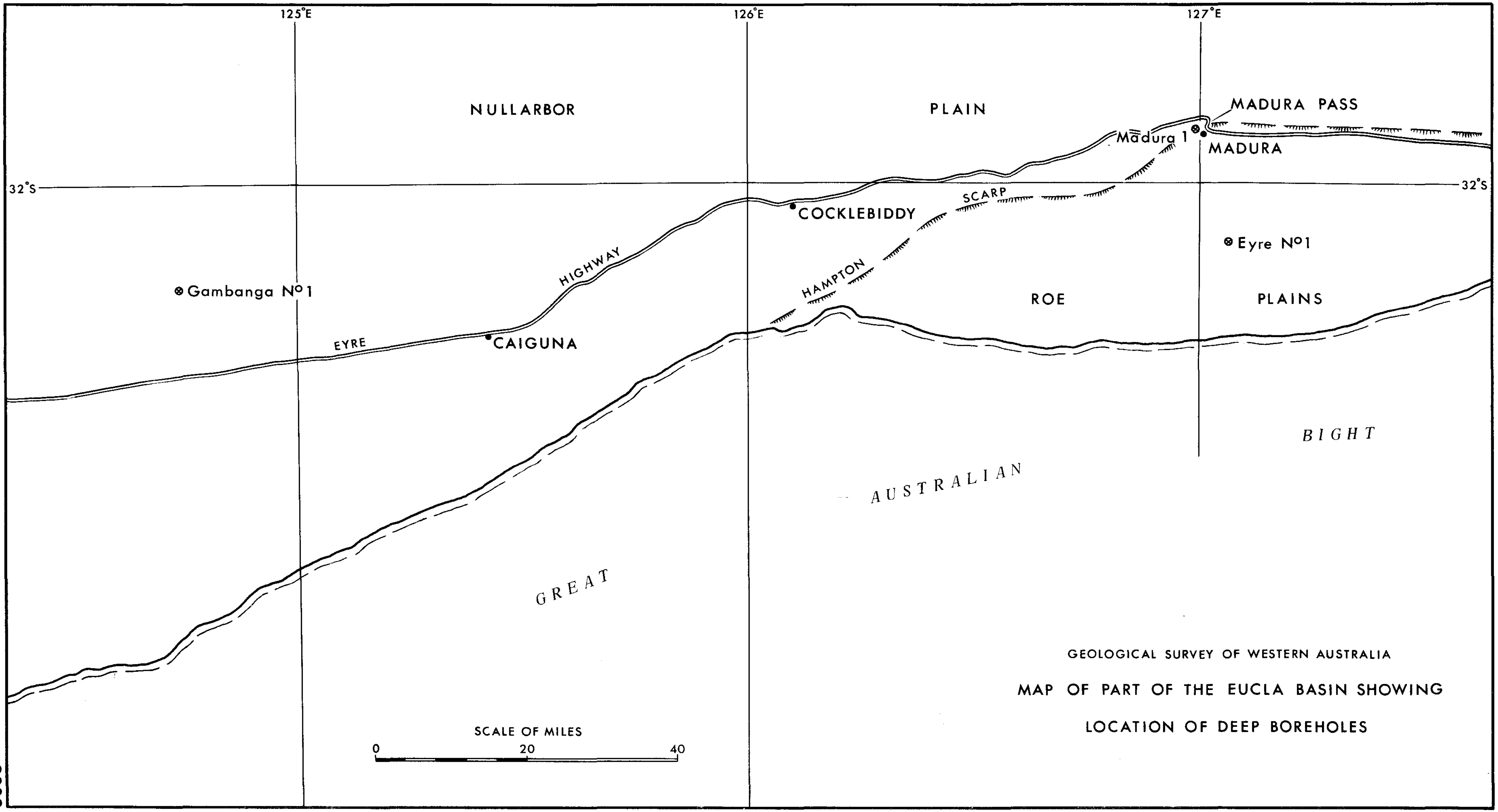
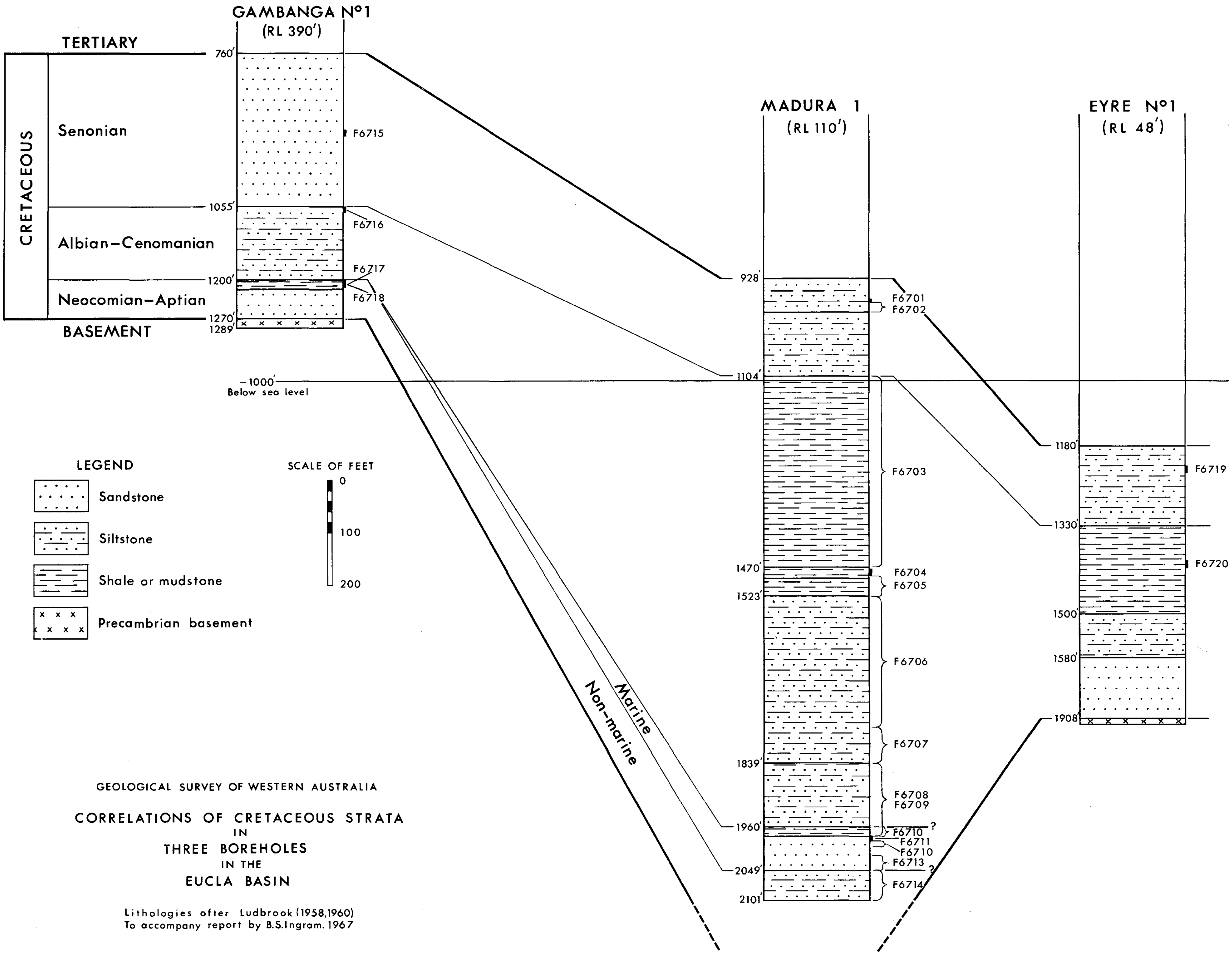


PLATE 44

6866



GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

CORRELATIONS OF CRETACEOUS STRATA
IN
THREE BOREHOLES
IN THE
EUCLA BASIN

Lithologies after Ludbrook (1958, 1960)
To accompany report by B.S. Ingram. 1967

0666

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A METEORITE FRAGMENT FROM DOOLGUNNA STATION, MEEKATHARRA DISTRICT, WESTERN AUSTRALIA

by W. N. MacLeod

ABSTRACT

A fragment of a chondritic meteorite has been recovered from a claypan near the southern boundary of Doolgunna Station in the Meekatharra District. The fragment weighs 20 grams and is the only piece found during an intensive search of the area.

The claypan, from which the fragment was recovered, bears some resemblance to a large meteorite explosion crater with a flat floor at a lower level than the surrounding country and an almost completely encircling sand dune. However, it is not considered to be a crater and it would appear likely that the meteorite has been carried into the claypan by aborigines.

LOCALITY OF THE FIND

The claypan in which the meteorite was found is situated a few miles beyond the southern boundary of Doolgunna Station at latitude 25° 56′ S and longitude 119° 18′ E. This point is approximately 75 miles northeast of Meekatharra, the nearest town (see Plate 46).

From the southern part of the State the most convenient access is via the Great Northern Highway as far as the Doolgunna turn-off near Milepost 558. From Doolgunna homestead, which is 6 miles from the highway, the Diamond Well Station road is followed south for 22 miles. The claypan lies 2 miles west from this point and a vehicle with 4-wheel drive is required to negotiate the heavy drift sand over this final 2-mile approach. The circular peripheral dune completely hides the depression which cannot be seen until the summit of the dune is mounted.

The fragment was recovered on November 3rd, 1967 when I visited the depression in the company of Mr. Deane Davies of Doolgunna Station. Several weeks previously Mr. Davies had come across the depression by chance and had been impressed with the unusual circular form and distinctive vegetation pattern. I had observed the depression on aerial photographs and had noted the resemblance of the feature to a meteorite crater. However, such depressions are common on sand plains and develop over zones of higher water table as a result of progressive calcification of the soils and deflation by wind. Another depression, similar in form to the one in which the meteorite was found, lies about 3 miles to the north.

The floor of the depression is almost circular in plan with a maximum diameter of 1,600 feet. It supports a thick stand of desert oaks and is a pleasant shady oasis in contrast to the barren surrounding sand plain. The floor of the depression, which is almost perfectly flat, is between 6 and 10 feet lower than the general sand plain level and is made up of powdery calcareous soil and clay in which gilgai structures are common. The encircling dune forms an almost perfect amphitheatre except for a narrow breach on the northern side. The dune is composed of reddish brown and yellow quartz sand with a minor content of ironstone fragments and occasional kankar nodules. The dune is highest near the southern perimeter of the depression where it rises about 30 feet above the floor and 20 feet above the outside plain. It is asymmetrical in section with the steeper slope of between 10 to 15° on the outside and a gentler slope of about 5° on the inside down to the level floor of the depression.

There are no outcrops of any type of rock within or around the depression with the exception of kankar sheets and nodules near the breach in the dune at the northern end and in some zones around the gently sloping inner wall of the dune. The nearest exposures of hard rocks occur at Juderina Spring, about 5 miles west of the depression. Archaean granite and gneiss cut by basic dykes and quartz reefs crop out near the spring and probably underlie much of the extensive sand plain in which the depression is situated.

Despite the absence of any nearby outcrops, an assortment of stones was found in the depression in the grove of trees near the southern side. These included fragments of basic dyke rocks, amphibolites, quartz, and siliceous ironstone. These were lying loose on the surface scattered over a zone about 100 yards wide. Most of the fragments had been chipped and shaped and some had clearly been used as grinding stones. The place would appear to have been a tribal stonemason's "workshop", and it can be reasonably assumed that most of these stones have been carried into the site by natives. Small piles of stones from the excreta of emus are also common in the depression.

The meteorite fragment was recovered from the assortment of loose stones lying on the surface in the southern part of the depression. Under these circumstances it seems most likely that the fragment has been carried there by natives together with the other terrestrial stones, and the point of fall could be many miles distant.

The depression was revisited on November 27th and 28th and a very thorough search made of the area within and around the depression for more meteoritic material. None was found and a similar search of the northern depression, 3 miles distant, and the intervening sand plain proved equally fruitless. Magnetometer traverses were run across the southern depression in the hope of detecting anomalous zones which could correspond to buried meteorite material, and to check the possibility that the depression may actually be an ancient meteorite crater now infilled with sand and clay. No anomalies were detected and the variations could be attributed to normal magnetic gradients in the rocks beneath the sand plain. Pits were sunk in the floor of the depression and on the inner flank of the dune without disclosing any further rock or metorite fragments and conforming that the stones found on the surface had not been washed out of the underlying soil.

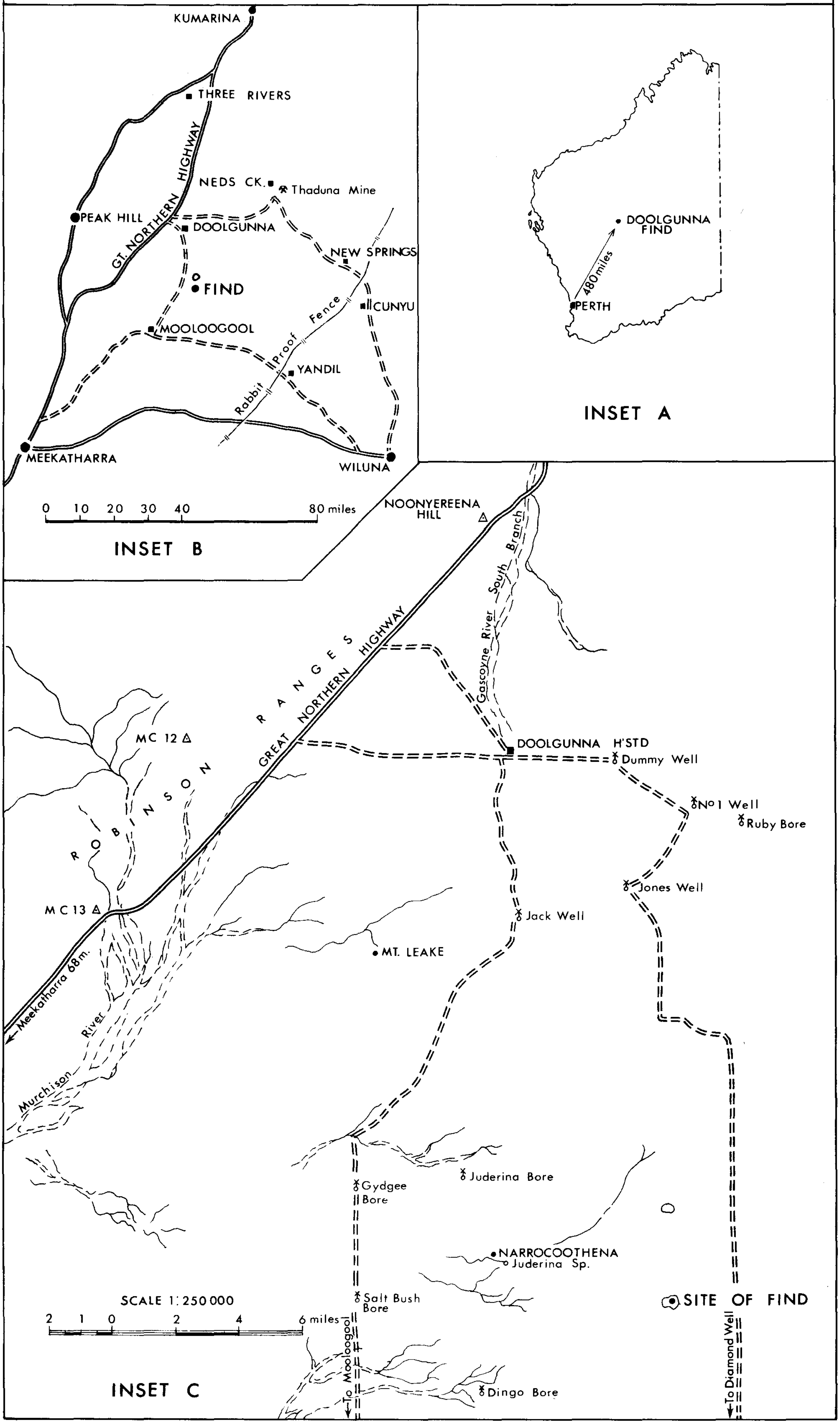
DESCRIPTION OF THE METEORITE

The meteorite fragment is rhomboidal in shape and originally measured between 1.5 and 2 cm in diameter. When recovered the fragment weighed 20 grams but thin and polished sections have been cut for microscopic examination leaving a residual piece of 14 grams. The specific gravity is 3.37.

The surface is dark reddish brown with a thin coating of iron oxides which have probably developed during terrestrial weathering. Although the surface is pitted and rough there is little indication of fusion; flow lines are not apparent and there are no obvious signs of ablationary grooving or pitting. Shallow cracks extend across the full width of some faces. Both the angularity of the fragment and its rough hackly surface suggest that it may be one of many small stones produced by the disintegration of a larger body on entry into the atmosphere. There are many recorded instances of large stony meteorites breaking into thousands of small fragments during passage through the atmosphere. Accordingly a wider search for more fragments within this district would seem to be justified. Plate 47 A to C shows the external appearance of the meteorite fragment.

The meteorite has the following approximate mineralogical composition: olivine, 50 per cent.; orthopyroxene (hypersthene), 30 per cent.; nickel-iron and iron oxides, 20 per cent. There is a minor content of small clear plagioclase grains. The ferromagnesian silicate minerals are aggregated into chondrules in a mesostasis composed of small grains of olivine and orthopyroxene and the nickel-iron alloy. The composition and texture of the stone places it in the most common category of meteorites, the olivine-hypersthene chondrites.

LOCALITY PLAN OF THE DOOLGUNNA METEORITE FIND



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A

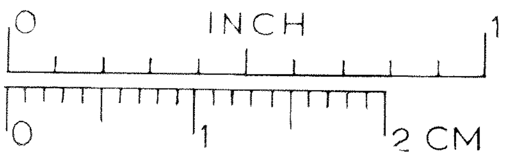
F 1195

B

F 1196

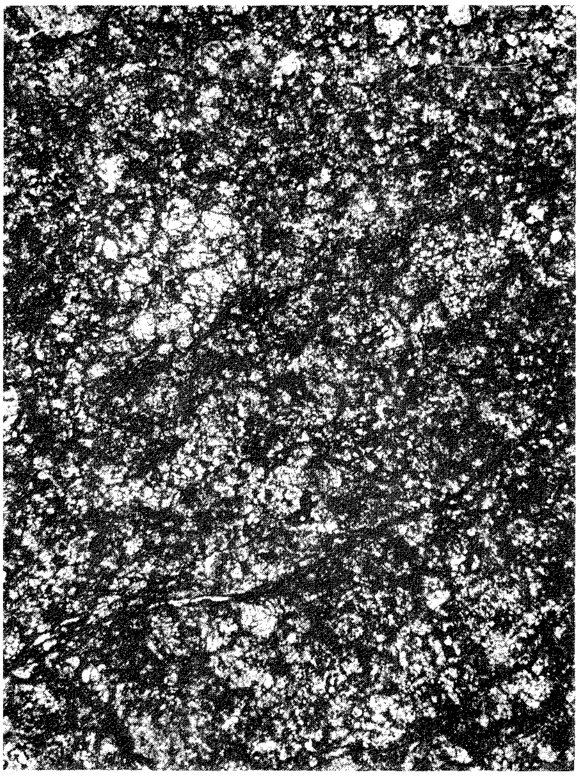
C

F 1197



Photographs of the meteorite showing the hackly surface and irregular cracks.

D



Thin-section of the meteorite. Light-coloured areas are chondrules of olivine and orthopyroxene and dark areas correspond to nickel-iron and iron oxides. The large chondrule left of centre is composed entirely of olivine grains in random orientation and the chondrule in the extreme upper left is composed of bladed orthopyroxene (Magnification—8 diameters); F 1198.

E

Polished section of the meteorite viewed in reflected light. Nickel-iron forms the isolated white blebs. Iron oxides in broad veins and fine veinlets (light grey) cut the dark grey groundmass of silicate minerals. (Magnification—202 diameters); F 1199.

The chondrules generally range in diameter between 0.5 mm and 1.5 mm with the largest of the order of 2.5 mm and grading down to small monomineralic blebs of 0.2 mm. The majority of chondrules are made up of euhedral to subhedral olivine grains; a few are composed entirely of bladed, radiating crystals of hypersthene, whilst some contain both minerals, although in these cases the olivine is predominant and the orthopyroxene occupies a central position in the chondrule. The groundmass of the stone is made up of small grains (0.01 to 0.1 mm) of olivine and hypersthene with scattered and isolated subrounded grains of nickel-iron and occasional grains of clear plagioclase. The olivine crystals show a development of iron oxide and iron staining along cleavages but otherwise are unaltered.

A striking feature of the stone which is most apparent on examination of a polished section is the intricate net-veining of the entire stone by anastomosing veins and veinlets of iron oxides. These are probably a mixture of goethite and maghemite. From the complex penetrative relationships with all other constituents it is inferred that the iron oxides were the last minerals to form. Their distribution suggests a forcible injection into a shattered and cracked medium and it is a matter of surmise whether the shattering was developed during terrestrial or spatial impact. The iron oxides form continuous broad veins traversing and enclosing the chondrules and groundmass silicates, and penetrating along intergranular boundaries as a continuous network of fine veins.

The stone is sufficiently magnetic to be picked up by a small hand magnet. As the nickel-iron content amounts to little more than 5 per cent. of the volume it is thought that some of the magnetism is accountable to the presence of maghemite in the veins.

Typical textural and compositional features of the meteorite are illustrated in Plate 47 D and E.

PRECAMBRIAN ROCKS ENCOUNTERED DURING DRILLING IN THE MAIN PHANEROZOIC SEDIMENTARY BASINS OF WESTERN AUSTRALIA

by R. Peers and A. F. Trendall

ABSTRACT

The structural development of Western Australia during Phanerozoic times has produced the "basin and swell' structure typical of many shield continents; an inevitable consequence is that much Precambrian geology of potential interest is hidden. Thirty-three geologically recorded boreholes in the main Phanerozoic sedimentary basins of Western Australia have reached Precambrian rocks; 30 of these have been drilled since 1957 in the course of oil exploration. This paper is a compilation and summary of all information on the nature of the Precambrian rocks thus encountered, and includes a brief discussion of the signifiance of the information for Precambrian geology. In general, this is slight, but some possibilities for future work are noted, and one probable Precambrian sequence from the Officer Basin is well represented by preserved core, and is of interest for paleogeographic interpretation.

INTRODUCTION

In most stable ("shield") regions of the present continents Phanerozoic sedimentary basins are separated by broad areas of Precambrian rocks. In Africa this has been aptly called "basin and swell" structures (Holmes, 1965, p. 1053-6); the western part of Australia has a closely similar structure. An important problem associated with it, as yet unresolved anywhere, is that of the genetic relationship between the Phanerozoic basins and the structure of the underlying Precambrian rocks: when and how, during the Precambrian, were the structures initiated which led to the sinking of the Phanerozoic basins in their present positions. Evidence for the solution of this problem must come mainly from detailed studies of the structural history of the Precambrian areas, but any continental-scale reconstruction of such history will involve postulated correlations across, and beneath, the Phanerozoic basins. Any direct evidence concerning the Precambrian rocks below these basins is therefore valuable.

During the last 60 years, 33 geologically documented boreholes have penetrated Precambrian rocks beneath the major Phanerozoic basins of Western Australia; 30 of these were drilled during petroleum exploration since 1957. Although descriptions of the rocks encountered in many of these holes are publicly available, some are not, and none have been collected and listed in a convenient form. The purposes of this paper are:

(1) to list all boreholes in the main Phanerozoic basins of Western Australia which penetrated to Precambrian rocks, and to show their locations on a single map;
(2) to provide brief descriptions of the Precambrian rocks encountered;
(3) to indicate where further information or material is available;
(4) to discuss briefly the signifiance of the described material for Precambrian geology.

Very many boreholes drilled for water relatively close to basin edges are not included in this compilation, since no material has been recovered, recorded, or preserved from them. Boreholes in the Collie basin (Low, 1958) are also excluded, since this is small enough for Precambrian geology to be more reliably predictable from mapping around its perimeter.

One borehole, Fraser River No. 1 well of WAPET, is omitted because it is controversial. The dolerite and gabbro intersected at this locality (lat. 17° 25′ 04″ S, long. 123° 09′ 39″ E) between 10,056 and 10,132 feet were considered at the time of drilling to be intrusive, on the evidence of thermal metamorphism of the overlying Carboniferous sedimentary rocks and of cross-cutting glassy doleritic veins in the 1,000 feet above the main igneous body (J. E. Glover, *in* Campbell, 1956). Closely similar dolerite in Barlee No. 1, some 40 miles southwest and stratigraphically similar, later gave a K-Ar age of 196 m.y. (Harding, 1967, quoted in Veevers, 1967), compatible with its intrusive relationship, but dolerite from Fraser River No. 1 itself has yielded an age of 830 m.y. (White, 1962). As a result of the direct conflict of these two separate types of evidence no confident age can yet be assigned to the gabbro in which drilling in Fraser River No. 1 well ceased.

Many of the rock descriptions are modified from consultants' reports; attributions are noted with each. Those lacking attributions are by Miss Peers, while Dr. Trendall wrote the discursive and introductory sections, and initiated and supervised the compilation.

ACKNOWLEDGEMENTS

We are indebted to Alliance Petroleum Australia N. L., French Petroleum Company (Australia) Pty. Limited, and West Australian Petroleum Pty

Limited (WAPET) for permission to include unpublished information in this report. Thanks are due to Dr. J. E. Glover for useful discussion, and we acknowledge the invaluable help of Mr. M. H. Johnstone, of WAPET, without whose advice and co-operation this compilation could not have been accomplished.

SUMMARY OF AVAILABLE INFORMATION

The positions of the 33 boreholes with which this report is concerned are shown in Plate 48, together with the positions and accepted limits of the five main basins—Perth, Carnarvon, Canning, Officer, and Eucla, in clockwise rotation from the south-west. In Table 1 the name and exact co-ordinates of each hole are listed, together with the name of the exploration company or organisation, the depth of the hole, depth to the Precambrian, and other appropriate information.

DESCRIPTIONS OF THE PRECAMBRIAN ROCKS

PERTH BASIN

Allanooka No. 2

GARNET GNEISS (core 3: 3,278-3,283 feet)

Hand specimen: Grey and coarse-grained, with a faintly developed foliation; contains quartz, kaolinised feldspar, and pink garnet.

Thin-section: The predominant minerals are quartz and slightly kaolinised microcline which includes blebs and stringers of plagioclase. Grains of one mineral have been completely altered to masses of minute flakes of a colourless, highly birefringent mineral. The original mineral may have been cordierite or plagioclase but the presence of pale yellow pleochroic haloes indicates that it was almost certainly cordierite. Garnet is the characterising mineral but other minerals include brown biotite, chlorite, calcite, pyrite, zircon, sphene, leucoxene, and apatite. The texture is allotriomorphic granular with a faint foliation due to a tendency toward preferred orientation of flaky minerals and elongation of quartz and feldspar. (Description modified after J. E. Glover *in* reference below) .

Further information: see Burdett (1965).

Arrowsmith No. 1

GRANITE (cuttings only: 11,290-11,294 feet)

Minerals identified from a grain mount of cuttings include microcline, quartz, sericitised plagioclase, reddish-brown biotite, and zircon.

Further information: see Elie (1965a).

Beharra No. 1

GNEISS (cuttings only: 6,735-6,740 feet)

Minerals identified from a grain mount of cuttings include microcline, quartz, sericitised plagioclase, and reddish-brown biotite.

Further information: see Cooper and Sweeney (1967).

Bookara No. 1

GARNET-CORDIERITE GNEISS (core 1: 914 feet-914 feet 10 inches)

Hand specimen: A grey, medium-grained, gneissic rock with a weak foliation.

Thin-section: The predominant minerals are quartz with numerous two-phase inclusions, plagioclase, garnet, and cordierite. The plagioclase is andesine which is altered particularly along margins to sericite and chlorite and forms minor myrmekite when in contact with potassium-feldspar. The cordierite shows abundant twinning and its alteration which is strongest along grain margins, proceeds inwards along irregular channels throughout the crystals. The alteration products consist of pinite and an isotropic mineral. Small amounts of potassium feldspar with plagioclase inclusions, and flakes of reddish-brown biotite occur. Other minerals include pyrite, ilmenite altering to leucoxene, apatite, and zircon. Texturally this rock may be described as allotriomorphic granular with minor myrmekite developed between andesine and the potassium feldspar. (Description modified after J. E. Glover *in* reference below).

Further information: see Jones (1965).

Bookara No. 3

BIOTITE GARNET GRANITE (core 3: 1,762 feet)

Hand specimen: The rock is a medium-grained pink and grey granite composed of quartz, feldspar, red garnet, and biotite.

Thin-section: The texture is allotriomorphic granular. The predominant feldspar is an unaltered microcline which perthitically includes spindles of plagioclase. Grains of plagioclase elsewhere in the rock are now represented by a mixture of alteration products including chlorite, albite, sericite and calcite. Almandine garnet forms irregular grains up to 5 mm in diameter which are sieved by quartz inclusions. Abundant irregular grains of quartz with numerous two-phase inclusions occur. Biotite flakes are common and are pleochroic with X = pale brown, Y = orange, and Z = dark orange. Other minerals include zircon, leucoxenized sphene, and pyrite.

Further information: see Bowering (1967).

B.M.R. No. 10A (Beagle Ridge)

GARNET GNEISS (core 14: 4,852-4,862 feet)

Hand specimen: This is a medium-grained gneiss with well-developed foliation.

Thin-section: Plagioclase, quartz, microcline, and garnet are the predominant minerals. The plagioclase is andesine and is extensively altered to sericite and chlorite. Abundant two-phase inclusions occur in the quartz grains, and stringers of plagioclase are included in the unaltered microcline. The garnet, which is pink, forms subhedral grains which are extensively altered to chlorite. Some garnets are virtually pseudomorphed by chlorite. Other minerals include flakes of a red-brown biotite altering to chlorite, muscovite, zircon, kaolinite, and pyrite. The texture is allotriomorphic granular, with a preferred orientation of the flaky minerals and an elongation of quartz and feldspar grains.

Further information: see MacTavish (1965).

Cadda No. 1

GNEISS (cuttings only: 9,160-9,165 feet

Minerals identified from grain mount of cuttings include microcline, quartz, mildly sericitised plagioclase, muscovite, red garnet, and red-brown biotite.

Further information: see Elie (1956b).

Dongara No. 6

GRANITIC GNEISS (sidewall core, 5,100 feet)

Hand specimen: An off-white, very friable rock composed of quartz grains in a matrix made up of argillaceous material and small flakes of a soft white mineral.

Thin-section: The rock consists mainly of quartz grains, a micaceous mineral and abundant argillaceous material. The quartz grains range in diameter from 0.05-2 mm and commonly form interlocking aggregates which have a crude preferred orientation of elongation. The micaceous mineral may be altered biotite. Most of the remainder of the rock consists of brown argillaceous material. Other minerals in the rock include calcite, zircon, brown tourmaline, and minor pyrite and limonite.

Positive identification of this rock is difficult because of its alteration. The fabric resembles that of granitic gneiss, and the mineralogy is consistent with that of a weathered granitic gneiss. (Description modified after J. E. Glover *in* reference below.)

Further information: see Lehmann (1968).

Geraldton Municipal Bore

GRANITE (cuttings only: 1,408-1,453 feet)

Minerals identified from a grain mount of cuttings include sodic plagioclase, quartz, microcline, brown biotite, zircon, and an opaque mineral.

Further information: Geological Survey of Western Australia file No. 500/1897, Boring for Water in the Geraldton District.

Jurien No. 1

GRANITIC GNEISS (core 16: 3,365-3,366 feet)

Hand specimen: The rock is light-grey, medium-grained and well foliated.

Thin-section: The predominant minerals are microcline, quartz, plagioclase, and mica. Microcline is mostly clear and unaltered, but contains blebs and stringers of plagioclase and quartz. The plagioclase grains are zoned with an inner highly altered core of oligoclase and an outer clear rim of albite. The alteration products include sericite and carbonate. Three varieties of mica are present, a pale greenish brown, moderately pleochroic mica, minor brown biotite, and muscovite. Sillimanitic needles and rods occur oriented parallel to the plane of foliation of the mica, and are most abundant in the micaceous bands. Other minerals include pyrite, zircon, and tourmaline as rare accessories. The texture is allotriomorphic granular with preferred orientation of mica and sillimanite to give a marked foliation. (Description modified after J. E. Glover *in* reference below).

Further information: see Pudovskis (1964b).

Sue No. 1

GARNET QUARTZ-PLAGIOCLASE-HORNBLENDE-GRANULITE (core 35: 10,018-10,028 feet)

Hand specimen: The rock is dark-grey and is made up of anhedral porphyroblasts of pink garnet up to one centimetre in diameter in a medium-grained groundmass of hornblende, feldspar, and quartz with some pyrite.

Thin-section: The rock has a granulitic fabric and is composed of pale yellow-green to olive-green hornblende and partly altered albite. The albite has altered to a cloudy grey aggregate of chlorite, sericite, and probably some clay minerals. Hornblende is altered locally to penninite and epidote. Quartz is an important constituent and other minerals include apatite, opaque iron oxide, pyrite, and zircon. The rock is cut by a narrow vein of prehnite containing cloudy aggregates of a very fine-grained mineral, probably sphene.

GNEISSIC BIOTITE GRANITE (core 36: 10,096 feet)

Hand specimen: The rock is medium to coarse-grained and composed of feldspar, quartz, and biotite.

Thin-section: The fabric of the rock ranges from hypidiomorphic granular to allotriomorphic granular. The most abundant minerals are clear microcline, kaolinised and sericitised calcic oligoclase, and quartz. Red-brown biotite is common and alters in places to pale-green chlorite. Other minerals include a little muscovite and calcite, a few grains of opaque iron oxide, apatite, and zircon. (Descriptions modified after J. E. Glover *in* reference below).

Further information: see Williams and Nicholls (1966).

Woolmulla No. 1

SHEARED MUSCOVITE APLO-GRANITE (core 12: 9,212-9,218 feet)

Hand specimen: This specimen is a slightly mineralised sheared leucocratic muscovite granite cut by a narrow pegmatite vein.

Thin-section: The rock is medium-grained holocrystalline, and has a poorly developed foliation. It has an even-grained granitic texture in which all constituents, other than pyrite, occur as interlocking anhedra. It consists, in order of abundance, of completely sericitised feldspar, water-clear microcline, quartz often showing undulose extinction due to strain, muscovite flakes, irregular patches of secondary calcite, pyrite euhedra, and very rare grains of apatite. The pegmatite vein is composed of quartz, feldspar, and minor pyrite. (Description modified after R. T. Prider *in* reference below).

Further information: see Pudovskis (1964a).

CARNARVON BASIN

Yanrey No. 1

QUARTZ-MUSCOVITE SCHIST (core 8: 1,395-1,413 feet)

Hand specimen: This rock is a pale grey, medium-grained schistose rock with a very strong foliation.

Thin-section: The bulk of the rock is composed of muscovite, quartz, plagioclase, and microcline. The plagioclase is unaltered except for a slight dusting of kaolinite whereas the microcline is intensely kaolinised and altered to chlorite. Quartz forms clear irregular grains. Muscovite is abundant, occurring as flakes and aggregates throughout the rock. It is the arrangement of the muscovite which gives the rock its schistosity. Chlorite also occurs in patches some of which appear to be pseudomorphous after garnet because they are bounded by a relict crystal outline. Minor accessory minerals include pyrite and apatite. The texture is allotriomorphic granular with a distinct schistosity due to the alignment of muscovite flakes.

Further information: None. Data and sample for above description kindly supplied by West Australian Petroleum Pty. Limited.

CANNING BASIN

B.M.R. No. 3 (Prices Creek)

BIOTITE SCHIST (core 7: 656 feet)

Biotite schist with numerous thin quartz lenses parallel to the schistosity. The schist itself contains little quartz and the biotite has been chloritised. The quartz lenses are of coarse-grained anhedral quartz with some inclusions of biotite. The quartz has been highly strained and fractured.

BIOTITE-QUARTZ SCHIST (core 8: 686 feet)

Fine-grained biotite-quartz schist, which is a lighter colour and contains more quartz (70%) than the other schists. It contains granular disseminated pyrite which in some places is parallel to the schistosity. Biotite is common and is concentrated parallel to the schistosity, which produces thin lined structure in hand specimen; these bands may represent original bedding.

HORNFELS (core 9: 686-690 feet)

This is a fine to medium-grained hornfels consisting of granoblastic grains of quartz, microcline, microperthite, albite, small flakes of biotite, some muscovite, granular pyrite, and magnetite. In some places the texture becomes finer and distinctly schistose, producing a quartz-feldspar-biotite schist, poor in opaque minerals.

HORNFELS (core 10: 693 feet)

Fine-grained quartz-biotite hornfels composed of equant grains of quartz and minor albite forming a mosaic with elongate flakes of green-brown biotite and pale-green muscovite oriented parallel to the foliation. Other minerals include microcline, magnetite, epidote, and pyrite, with glomeroblastic garnet. (Descriptions modified after R. D. Stevens *in* reference below.)

Further information: see Henderson (1963).

B.M.R. No. 4A (Wallal)

MYLONITIZED PORPHYRITIC BIOTITE GRANODIORITE or *CRUSHED BIOTITE-QUARTZ-OLIGOCLASE GNEISS* (core 9: 2,224-2,228 feet)

Hand specimen: This is a grey sheared gneissic rock containing light grey lenses rich in feldspar.

Thin-section: The rock is composed mainly of altered sodic plagioclase (albite-oligoclase) and quartz, with accessory epidote, biotite, chlorite and pyrite, and rare leucoxene, zircon, and apatite. The plagioclase is sericitised and epidote is a subordinate product of its alteration. The grain-size of the feldspar is fairly even, and is about 0.1 mm; that of quartz is less even, but about the same order of average size. Biotite has been broken up into small shreds which are admixed with quartz and feldspar. (Description modified after W. B. Dallwitz *in* reference below.)

Further information: see Bastian (1963).

Goldwyer No. 1

GRANITE (core 20: 4,717-4,720 feet)

Hand specimen: A medium-grained pink and grey granite.

Thin-section: The fabric is allotriomorphic granular. Microcline, the predominant feldspar forms lightly kaolinised phenocrysts up to 3 mm long. The plagioclase is oligoclase occurring as smaller less common grains which are mildly altered to kaolinite and sericite. Quartz forms irregular grains which are quite unaltered. Other minerals include muscovite, a greenish-brown biotite, chlorite, secondary carbonate, and minor apatite, zircon, and magnetite.

Further information: see Elliott (1959).

Hawkstone Peak No. 1

METAMORPHIC QUARZITE (core 20: 3,895 feet)

Hand specimen: This rock is a pinkish-grey, medium-grained quartzite with fine fracture planes which appear to be constant in direction and which are now infilled by carbonate.

Thin-section: Most of the rock is composed of a tightly interlocking mosaic of quartz grains of average grain diameter about 0.2 mm. These tend to be slightly elongated in the direction of the foliation. Minor iron oxide occurs along fractures and grain margins and occasional thin veins of cryptocrystalline carbonate cut irregularly across the quartzite. Rare zircon grains occur. The fabric is allotriomorphic granular with a very weak foliation. (Description modified after G. R. Pearson *in* reference below.)

Further information: see Gardner (1963a).

Langoora No 1

QUARTZ-CHLORITE-BIOTITE-CALC SCHIST (core 11: 5,239-5,258 feet, top part of core)

Hand specimen: The rock is grey-green and has a rough foliation due to bands with concentrations of dark grey-green mica. Calcite makes up the bulk of the rock and lenses of quartz are present.

Thin-section: Granular calcite in grains elongate parallel to the general schistosity constitutes most of the rock. Anhedral quartz grains poikiloblastically enclose finely granular calcite. Quartz grains form aggregates parallel to the schistosity. Other minerals include biotite, pyrite and a black opaque

CALCITE-MICA-CHLORITE-QUARTZ SCHIST (core 11: 5,239-5,258 feet, middle part)

Hand-specimen: The rock is dark grey-green and foliated with narrow bands and lenses of calcite.

Thin-section: The rock is made up of lenticular bands of different mineralogical composition and texture. The thickest bands are composed of angular, granular, quartz, pale-green mica, chlorite, brown biotite, a black opaque mineral converted to hematite, and minor oligoclase, leucoxene, and apatite. The texture is lepidoblastic. Thinner, well-defined bands of quartzite and granular calcite are intercalated between the schist.

QUARTZ-MICA-CALC SCHIST (core 11: 5,239-5,258 feet, lower part)

Hand specimen: The rock is light grey-green with with a pronounced foliation due to parallelism of dark green mica and grey siliceous bands.

Thin-section: About 70% of the rock is made up of granular calcite. The mica is pale yellow-green and concentrated in bands. Other minerals include chalcedonic quartz, a black opaque mineral, and a little pyrite and sphene.

QUARTZ-HORNBLENDE SCHIST (core 11: 5,239-5,258 feet, bottom)

Hand specimen: The rock is dark grey-green, massive to poorly schistose, and cut by narrow carbonate veinlets.

Thin-section: Prismatic hornblende showing a strongly preferred orientation is the dominant mineral of the rock. Quartz grains are generally elongated parallel to the hornblende rods. Other minerals include brown biotite, black iron ore grains, rare apatite and pale brown sphene. The rock is cut by a narrow vein of carbonate and pyrite. (Descriptions modified after J. E. Glover *in* reference below).

Further information: see Gardner (1963b).

May River No. 1

ACTINOLITE SCHIST (core 7: 5,434-5,451 feet)

Hand specimen: This rock is dark-grey, fine-grained and has a strong foliation but weak schistosity. It is cut by secondary veinlets of calcite and quartz with which is associated minor sulphide mineralisation.

Thin-section: The predominant minerals are actinolite, quartz, calcite, and biotite. Actinolite forms irregular blades oriented parallel to the foliation and averaging 0.05 mm in length. It is pleochroic with X = very pale green, Y = pale green, and Z = pale bluish-green. The biotite also forms ragged blades which are scattered through the rock and are distinctly pleochroic in shades of brown. Plagioclase and clear quartz grains form a groundmass mosaic of average grain diameter 0.04 mm. Other minerals include epidote, sphene, calcite, and the opaque sulphide.

The secondary veinlet which cuts the hand specimen is composed of quartz, calcite, and epidote of average grain diameter 0.5 mm, with scattered irregular grains of the opaque sulphide mineral (pyrite?).

Further information: None. Data and sample for above description kindly supplied by West Australian Petroleum Pty. Limited.

Meda No. 1

QUARTZITE (core 25: 8,685-8,694 feet)

Hand specimen: This is a medium-grained pale grey quartzite with minor cross-cutting veinlets of calcite.

Thin-section: It is composed almost entirely of irregular grains of quartz of 0.5 mm average grain diameter. The quartz is quite unaltered but has marked strain extinction. A number of cross-cutting veinlets of calcite and chalcedony penetrate the rock. Accessory minerals include sphene and zircon. The texture is allotriomorphic granular.

CHLORITE-CALC SCHIST (core 26: 8,744-8,755 feet)

Hand specimen: This is a greyish green schistose rock cut by veinlets of carbonate.

Thin-section: It is made up of irregular grains of quartz of 0.1 mm average grain diameter, abundant pale green chlorite, minor muscovite, sodic plagioclase, and abundant calcite in patches and veinlets. Accessory minerals include zircon and tourmaline, and a leucoxenised opaque mineral (ilmenite?). The texture is schistose.

Further information: see Pudovskis (1962).

Parda No. 1

SCHIST (core 66: 5,868 feet)

Hand specimen: The rock is light-grey to white, and soft. It contains a little quartz and effervesces slightly in cold dilute HCl.

Thin-section: The rock is composed mainly of a mixture of clay minerals, muscovite, and quartz.

Calcite and a little limonite are present. Despite the strong alteration of the rock, it still possesses a pronounced lepidoblastic texture.

GNEISS (core 5: 6,017-6,024 feet)

Hand specimen: The rock has a gneissic texture and is made up of bands composed mainly of chlorite separated by bands of coarsely granular quartz and altered feldspar.

Thin-section: The rock consists mainly of lepidoblastic lenses of biotite which has been largely converted to chlorite, separated by granoblastic aggregates of quartz and feldspar. Muscovite is a common associate of the chlorite. Albite and microcline can be recognised in places, but much of the feldspar has been altered to a mixture of calcite and a colourless flaky mineral which may be sericite or a clay mineral. Small veins of the latter mineral traverse the rock. A little pyrite is present. (Descriptions modified after J. E. Glover *in* reference below.)

Further information: see Williams (1965).

Samphire March No. 1

GRANITE (core 12: 6,668 feet)

Hand specimen: This rock is a medium-grained pink, green, and black granite.

Thin-section: The predominant minerals are quartz, plagioclase, and microcline. The quartz forms irregular, clear grains with undulose extinction and narrow veinlets of carbonate along fracture planes. Plagioclase is zoned from andesine to albite and slightly altered to sericite and carbonate. The microcline grains include irregular patches of plagioclase and quartz. Flakes of biotite are strongly pleochroic with X = pale yellow, Y = olive green and Z = dark brown, are altering to chlorite and are associated with minor hornblende. Other minerals include ilmenite, sphene, zircon, and apatite. The texture is allotriomorphic granular.

Further information: see Johnstone (1961).

Thangoo No. 1A

PHYLLITE (core 9: 5,236-5,266 feet)

Hand specimen: This rock is dark grey with closely spaced, very thin, light-coloured beds. It has a slightly silky lustre and is cut by pyritic quartz-carbonate veinlets.

Thin-section: It consists mainly of fine-grained quartz and feldspar dusted with fine-grained graphite. Biotite is abundantly and uniformly distributed throughout the rock and is altered to pale green chlorite. The carbonate veinlets consist of a granular aggregate of carbonate, and quartz with minor amounts of pyrite and chlorite. (Description modified after Dallwitz, and after Prider, *in* reference below).

Further information: see Pudovskis (1960).

67 Mile Bore (Derby-Lennard Road)

METAMORPHOSED CALCAREOUS SILTSTONE (core from 2,613 feet)

Hand specimen: This is a fine-grained, pink and grey, well-balanced metamorphic rock.

Thin-section: Bands, composed almost entirely of fine-grained muscovite arranged parallel to the foliation, with minor quartz, calcite, and magnetite, alternate with bands in which quartz predominates. Minor biotite is associated with the muscovite, and scattered grains of bluish green tourmaline occur.

BIOTITE-CALCITE-QUARTZ ROCK (core from 2,772 feet)

Hand specimen: This rock is medium-grained with irregular bands of quartz and calcite alternating with bands of biotite.

Thin-section: The white bands are composed of an irregular mosaic of quartz and calcite with minor scattered flakes of muscovite. The dark bands are almost entirely composed of biotite flakes which are pleochroic with X = very pale green, Y = pale green, and Z = green. Minor grains of a sulphide mineral occur.

QUARTZ (core at 2,793 feet)

Hand specimen: This sample is composed entirely of white quartz.

Thin-section: The whole thin-section is composed of a single grain of quartz, presumably part of a vein.

CHLORITE-BIOTITE SCHIST (core from 3,012 feet)

Hand specimen: This is a black, schistose rock with scattered grains of sulphide.

Thin-section: It is composed of green and brown biotite and green chlorite which are arranged in flakes parallel to the foliation. Other minerals occurring in minor quantities include quartz, pyrite euhedra, and apatite crystals. The texture is lepidoblastic.

Further information: see Playford (1960).

OFFICER BASIN

Browne No. 1

BROWNE EVAPORITES (435-1,269 feet, cuttings only)

Further information: see Jackson (1966).

Browne No. 2

BROWNE EVAPORITES (860-960 feet, cuttings only)

Further information: see Jackson (1966).

Lennis No. 1

LENNIS SANDSTONE (614-2,009 feet, cuttings only)

OFFICER VOLCANICS (2,009-2,016 feet, cuttings only)

Further information: see Jackson (1966).

Yowalga No. 1

LENNIS SANDSTONE (1,502-2,011 feet, cuttings only)

Further information: see Jackson (1966).

Yowalga No. 2

(See Discussion for further comment on the stratigraphic relationships of the rocks whose descriptions follow; these are a representative sample of the fifteen descriptions given in the reference appended.)

ALTERED BASALT (core 3: 2,423 feet)

Hand specimen: The rock is brown with small pink phenocrysts and numerous dark green amygdales.

Thin-section: The rock is amygdaloidal with phenocrysts of altered iron-stained plagioclase in a groundmass of feldspar laths, opaque iron oxide grains, and interstitial pale green serpentine. There are also a few phenocrysts of a mineral now completely transformed to hematite and serpentine; this mineral was probably ferromagnesian. The amygdales range up to 8 mm in diameter and are composed of serpentine, chlorite, and possibly nontronite. This is an altered, amygdaloidal, slightly porphyritic volcanic rock containing sodic plagioclase. It may represent a basalt which has undergone extensive deuteric alteration, possibly followed by weathering.

THOLEIITIC BASALT (core 4: 2,764 feet)

Hand specimen: This rock is fine-grained and dark grey.

Thin-section: The rock is made up mainly of plagioclase and clinopyroxene, and the fabric ranges between intergranular and subophitic. The plagioclase laths are zoned from bytownite to labradorite near the margins. Most of the coarser grains of pyroxene are augite. The smaller grains are pigeonite, which is altered to uralite and stained by hematite. Other minerals in the rock include hematite grains and interstitial patches of chlorite and a poorly crystallised mineral which may be K-feldspar, and which includes needles of apatite.

Chemical analysis: A sample of this rock analysed at the Government Chemical Laboratories gave the following result:

	Weight per cent.
SiO_2	52.90
Al_2O_3	15.63
Fe_2O_3	2.80
FeO	6.79
MgO	6.62
CaO	9.13
Na_2O	1.81
K_2O	1.20
H_2O+	1.18
H_2O-	0.82
CO_2	0.02
TiO_2	0.89
P_2O_5	0.06
FeS_2	0.07
Cr_2O_3	0.01
V_2O_5	0.06
NiO	0.02
CoO	0.01
MnO	0.14
TOTAL:	100.16

Analyst: J. R. Gamble.

The composition is very typically tholeiitic (cf. Turner and Verhoogen, 1960: Table 15, p. 208).

QUARTZ SANDSTONE (core 5: 2,793 feet)

Hand specimen: This rock is red-brown with light grey-green patches, and contains rounded quartz grains and minute mica flakes. It effervesces locally in cold dilute HCl.

Thin-section: It is made up mainly of poorly sorted, subangular to rounded quartz grains ranging in diameter from 0.1 mm to 1.5 mm. Other clastic grains include dolomite and partly silicified dolomite rock, chalcedony, sandstone, plagioclase, microcline, quartzite, volcanic rock, and other fine-grained lithic fragments. Cement includes clay minerals, anhydrite, hematite, carbonate, muscovite, biotite, and chlorite. The rock is a clastic sediment deposited in an evaporitic environment under oxidising conditions.

MICACEOUS SILTSTONE (core 5: 2,797 feet)

Hand specimen: The rock is red-brown and is made up of alternating slightly cross-bedded bands up to 2 mm thick of silty argillaceous material.

Thin-section: The bands are composed mainly of angular silty quartz and clay-sized minerals. The bands of silty quartz also contain hematite grains and thin lenses, muscovite and brown biotite flakes, and rare microcline grains. The bands of clay-sized material also contain abundant, very fine silty quartz, muscovite, biotite, and grains and narrow lenses of hematite. The specimen is cut by several thin veins of anhydrite. This rock was deposited in a neutral to oxidising environment. The presence of anhydrite veins indicates evaporitic conditions in the sequence.

CHALCEDONY-ANHYDRITE ROCK (core 7: 2,931 feet)

Hand specimen: The rock is grey, and contains numerous irregularly shaped, pale brown to off-white patches up to a centimetre in diameter. The specimen does not effervesce in cold dilute HCl.

Thin-section: The rock is composed mainly of anhydrite (the grey areas of the hand specimen) and chalcedony (the pale brown to off-white patches). The anhydrite grains are subhedral to euhedral and range from 0.015 to 0.1 mm in length. The chalcedony forms pale brown flaring masses. Quartz is also present and both chalcedony and quartz enclose isolated grains of anhydrite and dolomite . There are numerous argillaceous and dolomitic patches and schlieren in the rock. They contain irregularly shaped aggregates, of minute pyrite crystals. Isolated dolomite rhombs, pyrite crystals, and pale green chlorite grains occur throughout the rest of the rock. This rock is evidently the product of an evaporitic environment.

Chemical analysis: A sample of this rock was analysed at the Government Chemical Laboratories with the following result:

	Weight per cent.
SiO_2	32.39
Al_2O_3	4.10
Fe_2O_3	0.97
FeO	1.21
MgO	2.24
CaO	22.65
Na_2O	0.23
K_2O	1.01
H_2O+	1.38
H_2O-	0.56
CO_2	4.09
TiO_2	0.16
P_2O_5	0.20
SO_3	28.12
FeS_2	0.65
V_2O_5	0.02
NiO	0.01
CoO	0.01
MnO	0.19
C	0.16
TOTAL	100.35

Analyst: J. R. Gamble.

Further information: see Jackson (1966).

DOLOMITIC SILICIFIED SANDSTONE (core 8: 3,237 feet)

Hand specimen: The rock is grey, fine to medium-grained, and thoroughly indurated.

Thin-section: It is made up mainly of an interlocking mosaic of quartz grains which range in diameter mainly between 0.2 mm and 0.3 mm. Ghost outlines of rounded to sub-rounded clastic cores are visible in a few grains. The rock is a fairly well-sorted sandstone which has been partly cemented by authigenic quartz, dolomite, and a rare mineral which is probably an authigenic sulphate. Also present are a few rounded grains of green tourmaline, chert, microline, and plagioclase.

SILTY SHALE (core 8: 3,239 feet)

Hand specimen: The rock is red-brown and finely laminated with thin alternating silty and argillaceous beds.

Thin-section: It is composed of thin alternating bands of angular silty quartz and clay-sized material. Most of the bands are less than one millimetre thick, and all are impregnated with hematite. Muscovite and green biotite are found throughout the rock, and the flakes are almost invariably parallel to the bedding. (All Yowalga No. 2 descriptions modified after J. E. Glover *in* reference below.)

Further information: see Jackson (1966).

EUCLA BASIN

Eucla No. 1

GRANITE (cuttings only: 720-725 feet)

Minerals identified from a grain mount of cuttings include microline, quartz, sericitised plagioclase, biotite, chlorite, and hematite.

Further information: see Stach (1964).

Eyre No. 1

GNEISSOSE GRANITE (core 23: 1,715 feet 4 inches to 1,715 feet 9 inches)

Hand specimen: The rock is light grey, medium-grained and foliated with numerous well-aligned microline phenocrysts up to 2 cm long.

Thin-section: Microline, quartz, and oligoclase are the predominant minerals. Microline forms both phenocrysts and irregular grains in the groundmass, and commonly includes oriented spindles of plagioclase. The oligoclase is lightly sericitised and commonly forms a graphic intergrowth with quartz. Numerous acicular crystals (rutile?) are included in the oligoclase and are oriented in three directions oblique to the twin planes. Quartz occurs as irregular grains with a marked strain extinction and numerous two-phase inclusions. A reddish-brown biotite is common and is partly altered to chlorite. Other minerals include calcite, apatite, zircon, and an opaque iron oxide. The texture is allotriomorphic granular.

Further information: see Shiels (1960a).

Gambanga No 1

PYROXENE-BEARING GRANITE (core 10: 1,279 feet)

Hand specimen: This is a grey, medium-grained gneissic rock with a distinct foliation due to the alignment of the platy minerals.

Thin-section: The predominant minerals are quartz, plagioclase, and orthoclase, and the texture is allotriomorphic granular. The plagioclase is fresh, unaltered oligoclase forming irregular grains which are not well twinned. Quartz occurs as irregular grains and as a myrmekitic intergrowth with plagioclase along the grain boundaries. Numerous two-phase inclusions occur in the quartz. The predominant feldspar is orthoclase, which forms mildly kaolinised and sericitised grains with numerour fine spindle-shaped inclusions of plagioclase. Orange-brown biotite is abundant occurring as scattered flakes. An orthopyroxene forms ragged grains which are extensively altered to chlorite and a dark green hornblende. Accessory minerals include zircon, apatite, and magnetite.

Further information: see Shiels (1960b).

Transcontinental Railway Bore 4

BIOTITE GRANITE (core: un-numbered, unknown depth, but below 940 feet)

Hand specimen: This is a very weathered and crumbly medium-grained, pink and grey granitic rock.

Thin-section: The texture is allotriomorphic granular, and the main consituents are quartz, microcline, plagioclase, and biotite. The microcline is completely fresh except for minor secondary calcite developed along fracture planes, and a slight dusting of kaolinite. The predominant plagioclase grains are so completely altered to sericite, clay minerals, and chlorite as to preclude more specific identification. However, smaller plagioclase inclusions in microcline are quite unaltered and were identified as oligoclase. The quartz is extensively fractured and exhibits a marked strain extinction. Calcite is developed along the fracture planes. Minerals which are the products of alteration (probably both deuteric and weathering) include pale green chlorite, olive green biotite, muscovite, and calcite. Euhedral magnetite grains have been altered to hematite.

Further information: see Maitland (1915).

DISCUSSION

A glance at a geological map of almost any large region is enough to show the difficulty of geological extrapolation away from mapped areas, particularly of older rocks. The geology of the sub-Phanerozoic surfaces of Western Australian basins may be guessed at by continuing structural trends, outcrop areas, unconformities, metamorphic gradients, and so forth. However, there are no reliable rules to be applied, capable of forecasting such known phenomena as the abrupt cut-off of linear geological trends which are continuous for hundreds of miles. Another almost insuperable difficulty is that, to be of use for extrapolation on the scale required, any trend must be so broad and general as to be highly subjective, while an objective and uninterpreted map of the Precambrian of Western Australia would be more confusing than helpful.

Some attempt must nevertheless be made to select some broad features of the Precambrian geology which may be expected to persist under the Phanerozoic basins, and on whose actual extrapolation the data listed above may thus give some clue. The Precambrian information on Plate 48 represents the minimum possible framework for discussion here. It is diagrammatised from the map of Horwitz (1966), with age data from Compston and Arriens (1968). All ages are rounded to the nearest 100 m.y., and many important features, which on this conceptual scale are details, are omitted entirely. Therefore this selective sketch map is not intended to replace reference to the sources referred to (which list further authorities) for those seeking a review of the Precambrian geology of Western Australia, nor should the rounded dates on this map be quoted without reference to Compston and Arriens' paper.

The salient features marked on the plate are as follows:

(1) The largely gneissic and granitic Yilgarn Block in the southwest; the western part seems to be distinctly older than the eastern part, but no geological boundaries are yet relatable to this division.

(2) Marginal metamorphic or magmatic overprints of the Yilgarn Block. These include: to the southeast the Fraser Range granulites; to the south the slightly younger Albany Granite; on the west the off-lying Leeuwin—Naturaliste and Greenough blocks, and a narrow strip of uncertain significance close to Perth.

(3) The stable Pilbara Block, farther north, which seems to be roughly coeval with the western part of the Yilgarn Block.

(4) The Mt. Bruce Supergroup, which dips gently off the southern and eastern margins of the Pilbara Block. The uppermost part (the Wyloo Group) is altered and intruded by granites in the western part, around the western termination of the overlying Bangemall Group.

(5) The Bangemall Group sediments, which lie unconformably upon folded Mt. Bruce Supergroup to the north, and on the Yilgarn Block to the south.

(6) The Kimberley Block, which comprises mainly a thick and only gently folded clastic sequence including the Kimberley Group. This sequence lies unconformably upon the Lamboo Complex.

(7) The Lamboo Complex, which consists of mixed metamorphosed older rocks and granites of ages just older than that of the sedimentary succession of the Kimberley Block. The two arms of the Lamboo Complex, the King Leopold Mobile Zone on the west and the Halls Creek Mobile Zone to the east, have histories of continuous movements before and after sedimentation and granite intrusion.

(8) Between the eastern side of the Halls Creek Mobile Zone and the Warburton—Blackstone area, in the north-south strip of country adjacent to the Northern Territory and South Australia borders, the Precambrian geology is complex, and insufficiently well known for useful generalised trends to be suggested. It includes younger Precambrian correlatives of the Adelaide System, with glacigene sediments, and acid volcanics in the Warburton—Blackstone area with an age of about 1,100 m.y. (Compston and Nesbitt, 1967).

In the Perth Basin the data compiled contain no surprises. Taken as a group the nine holes clustered south of the Greenough Block yielded much the rocks that would be expected from a random sample of the block itself (see Jones and Noldart, 1961, for a summary). Similarly the granulite and granite from Sue No. 1 are entirely similar to many rocks of the Leeuwin—Naturaliste Block (R. C. Horwitz *in* Lowry, 1965).

The schist from Yanrey No. 1, in the Carnarvon Basin, is less easily matched with the immediately adjacent Precambrian. There are two possible interpretations. It is possible that the metamorphism of the Wyloo Group around the western extremity of the Bangemall Group outcrop (Daniels, pers. comm.) continues to increase in grade westwards; the lithology of the Yanrey rock is entirely consistent with its identity as part of the Wyloo Group which reached garnet grade and suffered later retrograde metamorphism. But it is also possible that the discontinuity in Precambrian lithology which evidently runs north-south between the Greenough and Leeuwin—Naturaliste blocks continues northwards through the eastern side of the Carnarvon Basin and separates the Yanrey site from the adjacent Precambrian.

In the Canning Basin the six holes closest to the northeastern edge all yielded rocks which have close counterparts within the adjacent Lamboo Complex. It is the remaining five holes, between and including B.M.R. No. 4A and Thangoo No. 1A, that seem to offer the greatest promise of useful information. The rocks encountered in these holes may, as a group, be matched petrographically either with the Pilbara Block, the Lamboo Complex, or the granites and metamorphic rocks between Lake Disappointment and the Paterson Range, marked on Plate 48 by a question mark about 200 miles south of the group.

Yowalga No. 2, in the Officer Basin passed through the following succession between 1,335 and 3,246 feet (Jackson, 1966):

	Thickness in feet
Lennis Sandstone	1,055
Officer Volcanics	385
Babbagoola Formation	471

The Lennis Sandstone consists of arkosic and feldspathic sandstones; no examples are described here. Two descriptions of the basalts which comprise the Officer Volcanics are given above, as well as examples of sandstone, siltstone, shale, and an evaporite from the lithologically mixed Babbagoola Formation. No unequivocal evidence for the age of this succession is given by either palaeontological or isotope evidence, and the surface correlation of the Lennis Sandstone tentatively accepted by Jackson *via* a suggestion of Wells (1963) is not itself sufficient evidence for a reliable age. Daniels (personal communication) suggests that, on the simplest structural interpretation of the Warburton Range area, the Yowalga No. 2 succession may be expected to be younger than any of the Precambrian sequences exposed there; until further evidence is forthcoming there is more reason to accept than to reject a Precambrian age.

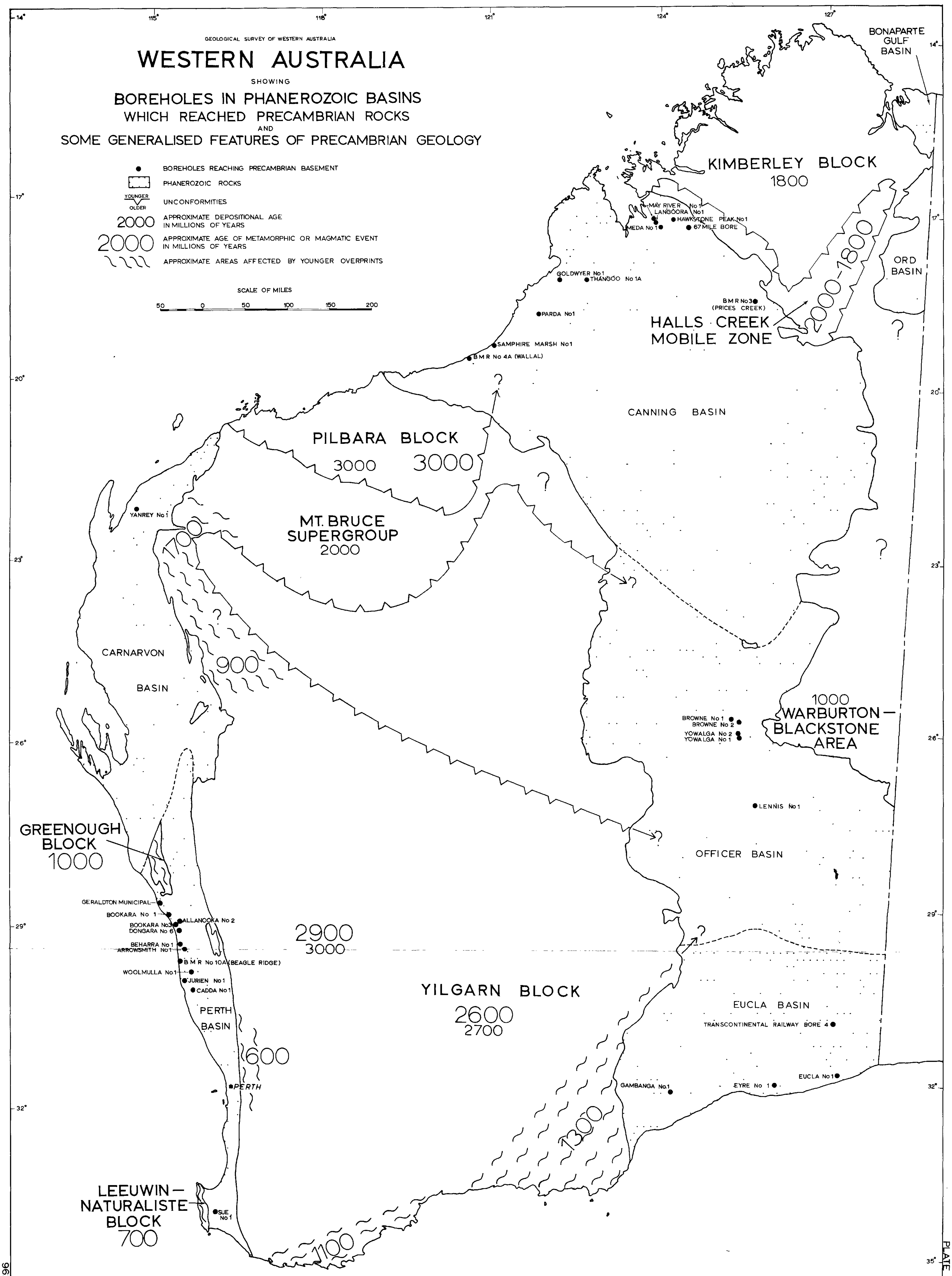
In the Eucla Basin the recovered rocks are similar to those associated with the overprinted metamorphic and magmatic activity along the southeastern edge of the Yilgarn Block.

In summary, none of the recovered material solves important Precambrian problems, but there is a real possibility that some of it may be a worthwhile object for future study. In particular, additional isotope analyses may well resolve present doubts concerning the Precambrian or younger age of the lowest rocks in Fraser River No. 1 (see Introduction) and also concerning the Officer Volcanics in Yowalga No. 2. Isotope analyses could also be fruitful in the series of holes across the northern Canning Basin, which span a time gap of over 1,000 m.y. (not indicated by Veevers, 1967, Fig. 4). A single K-Ar determination from Samphire Marsh No. 1 in this series, gave an age of 484 m.y. (White, 1962); this seems most likely to represent Ordovician weathering, the effect of which may be less apparent if the total rock Rb-Sr method were used. However, any future work on these lines should also take into account the possibility that some terminal "basement" rocks logged (and here accepted) as Precambrian may be large boulders in Phanerozoic sediments; this possibility exists at B.M.R. No. 4 (pers. Comm. M. H. Johnstone) and Goldwyer No. 1 (pers. comm. P. E. Playford). The problem of the Yanrey material is also potentially solvable from isotope analysis. We hope that by tabulating the available material in this compilation we have increased the likelihood of future work on it.

Table 1

WELLS DRILLED INTO PRECAMBRIAN ROCK OF SEDIMENTARY BASINS IN WESTERN AUSTRALIA TO THE END OF 1967

Basin	Name	Type	Location		Ground level elevation (feet)	Total depth (feet)	Depth to Precambrian (feet)	Drilled for	Year completed	Material recovered	Well completion report description
			Latitude (S)	Longitude (E)							
PERTH	Allanooka No. 2	Oil test	29° 06′ 00″	114° 59′ 36″	218	3,300	3,232	Wapet	1965	Core	Yes
	Arrowsmith No. 1	Oil test	29° 36′ 38″	115° 06′ 55″	168	11,306	11,218	F.P.C.	1965	Cuttings	No
	Beharra No. 1	Oil test	29° 29′ 10″	115° 00′ 45″	74	6,744	6,695	F.P.C.	1966	Cuttings	No
	Bookara No. 1	Strat.	28° 59′ 28″	114° 45′ 50″	65	926	863	Wapet	1965	Core	Yes
	Bookara No. 3	Strat.	29° 06′ 27″	114° 53′ 14″	107	1,764	1,560	Wapet	1967	Core	No
	B.M.R. No. 10A (Beagle Ridge)	Strat.	29° 49′ 38″	114° 58′ 30″	15	4,862	4,794	B.M.R.	1960	Core	No
	Cadda No. 1	Oil test	30° 20′ 15″	115° 12′ 45″	256	9,000	9,169	F.P.C.	1965	Core	No
	Dongara No. 6	Oil test	29° 11′ 41″	114° 56′ 16″	94	5,115	5,053	Wapet	1967	Cuttings & SWC	Yes
	Geraldton Municipal	Water	28° 46′ 40″	114° 36′ 30″	unknown (approx. 122)	1,453	1,435	State Govt.	1940	Cuttings	No
	Jurien No. 1	Oil test	30° 08′ 40″	115° 02′ 54″	30	3,366	3,208	Wapet	1962	Core	Yes
	Sue No. 1	Strat.	34° 03′ 54″	115° 19′ 04″	269	10,097	10,021	Wapet	1966	Core	Yes
	Woolmulla No. 1	Oil test	30° 01′ 24″	115° 11′ 28″	382	9,224	9,097	Wapet	1963	Core	Yes
CARNARVON	Yanrey No. 1	Oil test	22° 15′ 16″	114° 34′ 57″	45	1,413	1,383	Wapet	1957	Core	No
CANNING	B.M.R. No. 3 (Prices Creek)	Strat.	18° 38′ 00″	125° 54′ 00″	518	694	654	B.M.R.	1956	Core	Yes
	B.M.R. No. 4A (Wallal)	Strat.	19° 44′ 12″	120° 44′ 28″	27	2,228	2,224	B.M.R.	1958	Core	Yes
	Goldwyer No. 1	Oil test	18° 22′ 47″	122° 22′ 58″	259	4,720	4,660	Wapet	1958	Core	No
	Hawkstone Peak No. 1	Oil test	17° 14′ 45″	124° 24′ 26″	161	3,897	3,855	Wapet	1962	Core	Yes
	Langoora No. 1	Oil test	17° 18′ 07″	124° 06′ 48″	69	5,299	5,240	Wapet	1962	Core	Yes
	May River No. 1	Strat.	17° 14′ 50″	124° 05′ 01″	56	5,505	5,387	Wapet	1967	Core	No
	Meda No. 1	Oil test	17° 24′ 00″	124° 11′ 30″	88	8,809	8,663	Wapet	1958	Core	No
	Parda No. 1	Oil test	18° 56′ 08″	122° 00′ 34″	335	6,256	5,830	Wapet	1965	Core	Yes
	Samphire Marsh No. 1	Oil test	19° 31′ 08″	121° 10′ 51″	16	6,664	6,610	Wapet	1958	Core	No
	Thangoo No. 1A	Oil test	18° 21′ 52″	122° 53′ 09″	559	5,429	5,100	Wapet	1960	Core	Yes
	67 Mile Bore (Derby-Lennard Road)	Water	17° 57′	124° 49′	....	3,012	2,528	State Govt.	1910	Core	No
OFFICER	Browne No. 1	Strat.	25° 51′ 15″	125° 48′ 58″	1,489	1,269	435	Hunt	1965	Cuttings	No
	Browne No. 2	Strat.	25° 56′ 00″	125° 57′ 45″	1,588	960	860	Hunt	1965	Cuttings	No
	Lennis No. 1	Strat.	27° 17′ 00″	126° 21′ 00″	1,362	2,016	614	Hunt	1965	Cuttings	No
	Yowalga No. 1	Strat.	26° 10′ 12″	125° 58′ 00″	1,554	2,011	1,502	Hunt	1965	Cuttings	No
	Yowalga No. 2	Oil test	26° 10′ 12″	125° 58′ 00″	1,550	3,246	1,335	Hunt	1966	Core	Yes
EUCLA	Eucla No. 1	Strat.	31° 52′ 15″	128° 13′ 21″	40 (app.)	728	702	A.O.D.	1964	Cuttings	No
	Eyre No. 1	Strat.	32° 07′	126° 58′	48	1,719	1,708	Exoil	1960	Core	No
	Gambanga No. 1	Strat.	32° 16′	124° 50′	390	1,279	1,282	Exoil	1960	Core	No
	Transcontinental Railway Bore 4	Water	30° 52′	128° 25′	520 (app.)	996	940(?)	State Govt.	1910/11	Core	No



GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
WESTERN AUSTRALIA
SHOWING
BOREHOLES IN PHANEROZOIC BASINS
WHICH REACHED PRECAMBRIAN ROCKS
AND
SOME GENERALISED FEATURES OF PRECAMBRIAN GEOLOGY
BOREHOLES REACHING PRECAMBRIAN BASEMENT
PHANEROZOIC ROCKS
YOUNGER
OLDER
UNCONFORMITIES
2000 APPROXIMATE DEPOSITIONAL AGE IN MILLIONS OF YEARS
2000 APPROXIMATE AGE OF METAMORPHIC OR MAGMATIC EVENT IN MILLIONS OF YEARS
APPROXIMATE AREAS AFFECTED BY YOUNGER OVERPRINTS
SCALE OF MILES
50 0 50 100 150 200
BONAPARTE GULF BASIN
KIMBERLEY BLOCK
1800
MAY RIVER No 1
LANGOORA No 1
HAWKSTONE PEAK No 1
MEDA No 1
67 MILE BORE
2000-1800
ORD BASIN
GOLDWYER No 1
THANGOO No 1A
B M R No 3 (PRICES CREEK)
HALLS CREEK MOBILE ZONE
PARDA No 1
SAMPHIRE MARSH No 1
B M R No 4A (WALLAL)
CANNING BASIN
PILBARA BLOCK
3000
3000
MT. BRUCE SUPERGROUP
2000
YANREY No 1
1700
900
CARNARVON
BASIN
1000
WARBURTON — BLACKSTONE AREA
BROWNE No 1
BROWNE No 2
YOWALGA No 2
YOWALGA No 1
LENNIS No 1
OFFICER BASIN
GREENOUGH BLOCK
1000
GERALDTON MUNICIPAL
BOOKARA No 1
ALLANOOKA No 2
BOOKARA No 3
DONGARA No 6
BEHARRA No 1
ARROWSMITH No 1
B M R No 10A (BEAGLE RIDGE)
WOOLMULLA No 1
JURIEN No 1
CADDA No 1
2900
3000
YILGARN BLOCK
2600
2700
PERTH
BASIN
600
PERTH
EUCLA BASIN
TRANSCONTINENTAL RAILWAY BORE 4
EUCLA No 1
GAMBANGA No 1
EYRE No 1
1300
LEEUWIN — NATURALISTE BLOCK
700
SUE No 1
1100
PLATE 48
9631

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* Reports listed as unpublished and marked with an asterisk are not available for public examination; unpublished reports not so marked are available for reference at the Bureau of Mineral Resources, Canberra, and the Geological Survey of Western Australia.

EXPERIMENTAL GEOPHYSICAL METHODS IN GROUNDWATER SEARCH NEAR ESPERANCE

by D. L. Rowston

ABSTRACT

Experimental geophysical investigations in the Esperance Plains area during 1966 indicated that the magnetic resistivity, and electromagnetic methods can be usefully employed in the search for groundwater. The methods were used to determine the depth to granitic bedrock, the bedrock relief, and probable variations in the salinity of the groundwater in a number of relativity simple environments. Twenty-six percussion bores were drilled to test the initial geophysical interpretations and to evaluate the methods generally.

The magnetic anomalies are attributed mainly to the bedrock relief and can delineate major depressions and probable drainages; most of the productive test bores were sited in magnetic lows.

The results of the resistivity mapping and depth probes were not entirely satisfactory because of high electrode contact resistances and instrumental shortcomings. However, drilling substantiated that accurate depths to bedrock can be obtained and there is a possible correlation of the deeper layer resistivities with groundwater salinity. The resistivity mapping results were influenced by near-surface variations. The electromagnetic method was similiarly affected but in areas where the surface conditions were homogeneous, the magnitude of the imaginary component increased negatively with the increase in groundwater salinity.

INTRODUCTION

The Geological Survey of Western Australia is engaged in the study of the regional geology and hydrology of the Esperance 1:250,000 Sheet between latitude 33° and 34° S and longitude 121° 30′ and 123° E. Part of this Sheet, the Esperance Plains (see Plate 49) has received special hydrological study because of rapid agricultural expansion and the urgent demand for underground water supplies. Bores are frequently preferred to dams because of costs and saline surface conditions.

Although many of the factors influencing groundwater accumulation and salinity are now better understood, several problems still remain. Experimental geophypsical surveys were made in selected areas during 1966 to determine whether or not some of these problems could be resolved. Percussion drilling was carried out concurrently on geophysical anomalies to assist interpretation and to evaluate the methods.

The Esperance Plains comprise about 3,000 square miles of gently undulating sandplain country to the north and east of the Esperance township. The Archaean granitic basement is overlain by marine and terrigenous sediments of Eocene age, and Recent eolian deposits. The granitic rocks crop out sporadically as monadnocks and form the only prominent physical features away from the coast. A thin veneer of sand and laterite and the general paucity of outcrop prevents any reliable estimate of the thickness of Eocene sediments or of their lithology, and to attempt to elucidate these unknowns was an objective of the geophysical work.

The annual rainfall is reliable but rapidly decreases from 27 in. on the coast to 18 in. at the north margin of the plains. Generally the decrease in rainfall is accompanied by an increase in the salinity of the groundwater as demonstrated by the isohyet and isohalsine contours on Plate 49. Any isohalsine contour indicates the predominant salinity only, and locally there are large departures from this value; the range of salinities that may be encountered in a small area are exemplified by the current drilling data. Thus another of the objectives was to define the least saline groundwater within a particular area.

With the exception of a few streams along the immediate coastal strip, drainage is internal and ephemeral; the drainages are poorly defined and frequently terminate in small saline swamps or lakes. Bores are commonly sited along these drainages on the assumption that the present day channels correspond to ancient drainages which have been infilled with permeable fluvial deposits.

The granitic hills constitute excellent sources of recharge and, provided there is a reasonable thickness of sediments, good quality water can sometimes be obtained from bores around their peripheries. However, many of the properties are devoid of granite outcrop or distinct drainage lines and successful bore siting is largely a matter of luck.

GEOPHYSICAL METHODS AND TECHNIQUES

Magnetic, resistivity, electromagnetic, and self-potential methods were used during the surveys. The first two have been widely used in hydrological investigations but the others are not usually employed for this purpose. The general theory and application of these methods is well described in the standard texts such as Parasnis (1962) and need no reiteration. However some explanation of the reasons for using them in this environment and some of the assumptions made in the interpretation of the results is warranted.

MAGNETIC

Magnetic anomalies may be attributed to either variations in the magnetic susceptibility of different rocks or, assuming a uniform susceptibility for the bedrock and non-magnetic sediments, related to the bedrock relief. Despite the lack of susceptibility information it was hoped that depressions and drainages in the Archaean basement would be indicated.

An ABEM torsion magnetometer Type MZ-4, accurate to about two gammas, was used to measure local variations in the vertical component of the earth's field. Diurnal corrections were applied in the usual manner but the limited extent of the work precluded corrections for regional effects.

RESISTIVITY

Depth probe and resistivity mapping techniques were employed to determine the depth to bedrock, the general bedrock configuration, and probable sub-surface lithology; it was also possible that the mapping could define the salinity pattern. The inherent ambiguity of the interpretation of resistivity results is well known. For instance a zone of low apparent resistivity may be due to a sand containing saline water or a clay layer which is almost impervious; high resistivities could indicate shallow bedrock, fresh water sands, or dry material above the water table. The more geological information available the better the chance of resolving the ambiguities.

Interpretation of the Wenner array depth probes was made by curve matching using standard two-layer type curves with Hummels' extension to the multi-layer case. High contact resistances and erratic readings at the larger electrode intervals sometimes prevented a reliable estimate of the depth to bedrock. However, even in these instances, the resistivities of the layers above bedrock are useful. The unit electrode spacing used in the mapping technique was restricted to 50 feet by the accurate readability of the instrument; readings were often as low as 0.10 ohms.

The resistivity measurements were made with a Tellohm Resistivity Meter. Although salt water was used at all electrode points the contact resistances were commonly above 2,000 ohms.

ELECTROMAGNETIC

The electromagnetic method was used to test whether subsurface conductivity variations could be related to changes in the lithology or in the salinity of the groundwater. Whilst giving much the same information as the resistivity mapping technique it has the advantage that no direct electrical contact with the ground is required.

An ABEM E.M. Gun equipment with frequencies of 440 and 1,760 cycles per second was used for the work. According to the manufacturers, coil separations of 100 and 150 feet gave depths of investigation ranging down to about 100 feet.

SELF-POTENTIAL

Potential measurements were made with a Sharpe VP-6 millivoltmeter because of the possibility that differences in concentration of salts in solution or of groundwater movement could generate small potentials. When readings over three areas failed to detect other than erratic potentials the method was abandoned.

DRILLING

A Mines Department Ruston Bucyrus percussion rig was used to drill 26 bores as a follow up to the geophysical work. The bores were sited to test a combination of geophysical anomalies rather than those obtained by any one method. All holes were drilled to bedrock and regular sludge samples collected for logging, and water samples were taken for salinity determinations and chemical analyses. Lithological logs and completion reports were prepared by K. H. Morgan who also supervised the drilling.

The borehole information proved invaluable in modifying the original interpretations of the geophysical indications and in evaluating the methods.

AREAS INVESTIGATED

The four main areas studied were parts of Neridup Locations 169, 14, and 159, and Esperance Location 1445 to the west of the highway; these locations are shown on Plate 49. All of the properties lie north of the 24 in. isohyet where surface water salinities are generally greater than 5,000 ppm TDS. The groundwater potential is largely unknown and many bore failures are reported. The localities were selected to give a variety of test conditions.

At Neridup Location 169 a flat tract of country of about 150 acres in the southwest corner of the property and adjoining a low granite dome was studied. Recharge from the granite made this a prospective area, provided there was a reasonable thickness of sediments. Although isolated clay pans were scattered throughout the area there were no obvious drainages or other features to aid bore siting.

A more detailed survey over about 75 acres was made at Neridup Location 14. The grid lies between a prominent granite hill near Condingup Peak and a low sand ridge to the west. The shallow depression so formed was considered to have excellent groundwater potential and the survey here was to test the ability of the geophysical methods to define salinity variations.

Twelve private bores had been put down at Neridup Location 159; many of these were dry, a few yielded very small supplies of saline (10,000 ppm) water and one produced about 50 gallons per hour of domestic quality water. A strip of ground along the southern slope of an elongate granite ridge from which adequate recharge could be expected was investigated.

The survey at Esperance Location 1445 covered about ¾ square mile and was made to determine the speed with which an area could be adequately investigated. Because of the apparent success of the magnetic method in delineating drainages, work was restricted to this method supported by minor electromagnetic traversing. There are no granite outcrops but two producing bores in one corner struck granite at depths of 25 feet and 60 feet.

DISCUSSION OF RESULTS

For the purposes of this discussion typical geophysical results from Locations 14 and 159 have been selected to demonstrate the efficacy of the work.

At Location 169, although there was excellent agreement between the geophysical anomaly patterns from all methods and the follow up drilling, the thin layer of clayey sediments precluded groundwater concentrations. Drilling verified the indicated basement depressions but none of these contained other than seepage quantities of groundwater of about 14,000 ppm TDS.

An interesting magnetic low was obtained at Esperance Location 1445 but this anomaly has not been tested by drilling.

NERIDUP LOCATION 14

The topographic depression in the southeastern corner of Neridup Location 14 is controlled by Archaean basement rocks which flank the western and southeastern margins of the geophysical grid. The basement rocks are, in the main, concealed by a typical granitic weathering profile capped by pisolitic laterite. Test drilling revealed that the central trough contains up to 160 feet of terrigenous and marine sediments of Eocene to Recent ages. Although the sedimentary sequence is highly variable, the lithology generally includes a thick siltstone or cemented silty sand containing porous porcellanite and opaline silica, about 30 feet of fossiliferous silts and sands, 20 feet of grey sand, and decomposed granite and fresh bedrock. The sequence is overlain by a few feet of silty sand with some lateritic pisolite. The siltstone is the only bed that is laterally persistent; the underlying strata are commonly heterogeneous and the fossiliferous bed is sometimes absent.

At the conclusion of the geophysical work eight percussion holes were sited to test the geophysical interpretation and anomalies. With the exception of the two holes, 17 and 18, that were drilled to verify shallow granite on the ridge, all bores encountered groundwater. The wide range of groundwater salinity, from 1,800 to 9,800 ppm TDS, emphasises one of the major problems in selecting boresites. This variability within a small area is common over much of the Esperance Plains.

Water was struck generally at between 50 and 60 feet and a static level of 50 feet was observed in all but bore 25 where the rest level was at 45 feet. Estimated yields ranged from 200 to 2,000 gph with most around 1,000 gph. Groundwater supplies are available from most of the sedimentary rocks including the siltstone which has a significant secondary porosity due to the porcellanite bands. Contrary to the usual pattern there is no pronounced increase in salinity with depth in any of the bores.

The main geophysical results from this investigation together with the relevant information from the test bores are shown on Plate 50.

Magnetic

The magnetic vertical force contours relative to the arbitrary base station 1N/100 are shown on Plate 50 together with the appropriate drilling and depth probe data.

The simple magnetic pattern was interpreted initially as due to a bedrock depression elongated in a northeasterly direction across the grid. Steep gradients indicated shallow granite beneath the sand ridge in the west and northwest, and the gradual increase in intensity from the minimum (-300 gammas) towards the southeast again suggested a probable thinning of the sediments.

The percussion drilling subsequently verified this interpretation but showed that the deepest part of the depression was displaced to the east of the magnetic low. The shallowing of the bedrock towards the southeast is not as gradual as inferred from the contours although the depth differences between bores 25 and 14 are accompanied by a minor steepening of the gradient. The magnetic results thus give a broad and qualitative picture of the bedrock relief.

Resistivity

The results of the resistivity mapping are shown as contours on Plate 50, which also includes the layer resistivities determined from the depth probes. The granitic bedrock resistivity which tends towards infinity has been omitted.

The depths to bedrock estimated from the satisfactory depth probes, and those found by drilling, show reasonable agreement although it was not possible to site the bores to specifically test these results. At bores 16, 17, and 18 where depth probes were made, the estimated and drilling depths to bedrock agree very well.

The reliability of some of the resistivity mapping results is open to question because of the high electrode resistances. In particular the anomalies centred about 7N/600 and 11N/800 which occur over dry lateritic soils are considered due mainly to surface inhomogeneities.

There is an obvious correspondence between the mapping and depth probe second layer resistivities. The latter correlate with about 30 feet of silty sand and clay which directly underlie the soil and it is inferred that the mapping results are largely influenced by variations in composition, porosity, and amount of saturation of this layer. As water was not struck above 50 feet in any of the bores it is unlikely that a direct correlation between groundwater salinity and the resistivity mapping can be established. Even if this layer is saturated by capillarity from below, the salinity would be diluted by rainfall intake and not representative of the main aquifer salinity.

The resistivities of the third layer, where identified, show a broad correlation with the groundwater salinity but there is insufficient data to assess this relationship quantitatively. In general the lower resistivities correspond to relatively saline water; for instance the third layer values along line 17N are lower than those in the southeast corner of the grid where fresher water was encountered.

Despite the unsatisfactory results in the area the resistivity method has promise; an instrument with greater power and a lower range would overcome many of the difficulties and allow larger spacings to be used in the mapping technique. Accurate depth probe curves could define the layer boundaries and the depths to bedrock.

Electromagnetic

A rigorous interpretation of electromagnetic results is far more complex than that of the resistivity method and normally involves consideration of both real (in-phase) and imaginary (out-of-phase) components to correctly define variations in resistivity. However, at Location 14 the real component was seriously affected by changes in the coil separation and topography and was, without correction, unsuitable for presentation. The imaginary component contours are shown on Plate 50.

Positive anomalies are attributed to high resistivities and, conversely, negative ones to zones of relatively low resistivity. Thus the e.m. results should be, and are, very similiar to the resistivity mapping pattern. The most noticeable discrepancy is at bore 16 sited in a zone of high resistivity whereas the electromagnetic contours indicate a low resistivity and agree with the depth probe at this point. Several feet of laterite was logged at the top of bore 16 and the high mapping resistivity is probably erroneous due to poor electrode contacts.

There is reasonable agreement between the magnitudes of the imaginary component and the second layer resistivities but no apparent relationship with the salinity of the groundwater, except that the 9,800 ppm salinity of bore 26 coincides with a strong negative anomaly, and that of 25 (1,800 ppm) coincides with a zero contour. The salinities of bores 13, 14, 15, and 16 are completely at variance with a possible correlation; the lower salinities in 14 and 16 occur with strong negative anomalies.

This suggests that the e.m. anomalies, like the resistivity mapping variations, originate in the near surface layers, and that the depth penetration is limited. Even if the penetration was down to the theoretical 100 feet calculated for 1,760 cps and 6 ohm-m, it would be almost impossible to segregate the secondary field effects at depth from the strong surface anomalies. The method could be used for selecting sites with relatively low salinity prospects if the water table was very close to the surface.

NERIDUP LOCATION 159

Geophysical work at this locality was restricted to the magnetic and electromagnetic methods; unreliable resistivity results due to extremely high contact resistances and erratic potentials were obtained in early testing and these methods were discontinued.

The magnetic and electromagnetic imaginary component contours are given on Plates 51 and 52 respectively. At the conclusion of the geophysical work six bores were drilled to test the field interpretation and salinity distribution, and the relevant data is summarised on the contour plans.

Three of the boreholes yielded groundwater and the main purpose of this survey, to locate an adequate supply in an area where earlier boring had been comparatively unsuccessful, was accomplished. However the borehole information raised several problems concerning the interpretation of magnetic data and hydrology which have not been satisfactorily resolved.

Magnetic

The vertical force contours, plotted relative to the base station 2W/00, delineate part of an interesting magnetic low which is elongated east-west and roughly parallel to the granite outcrop just north of the grid (Plate 51). No attempt was made to trace the continuation of the anomaly to the east. The magnetic low was interpreted simply as a depression in the granitic bedrock and as such was predicted to channel groundwater with possible movement towards the east.

The first three bores, 19, 20, and 21, substantiated the interpretation but 22, drilled on a magnetic high attributed to shallow granite, continued to 155 feet before encountering bedrock.

From the geophysical viewpoint the contradiction of bore 22 complicates the interpretation. Whilst the intensity gradient to the north of the magnetic low can still be ascribed to the relief of the granite, the southern maximum is less readily explained. None of the tentative explanations can be supported by fact. An increase in the magnetic susceptibility of the bedrock, perhaps because of a basic dyke, would account for the magnetic high but the bottom hole sample from bore 22 did not contain fresh bedrock or any other indication of increased bedrock basicity. The anomaly could also be due to a channel cut through magnetic sediments and subsequently refilled with non-magnetic material but a careful examination and planning of the bore samples failed to reveal any trace of magnetite or ilmenite, and this theory was ruled out.

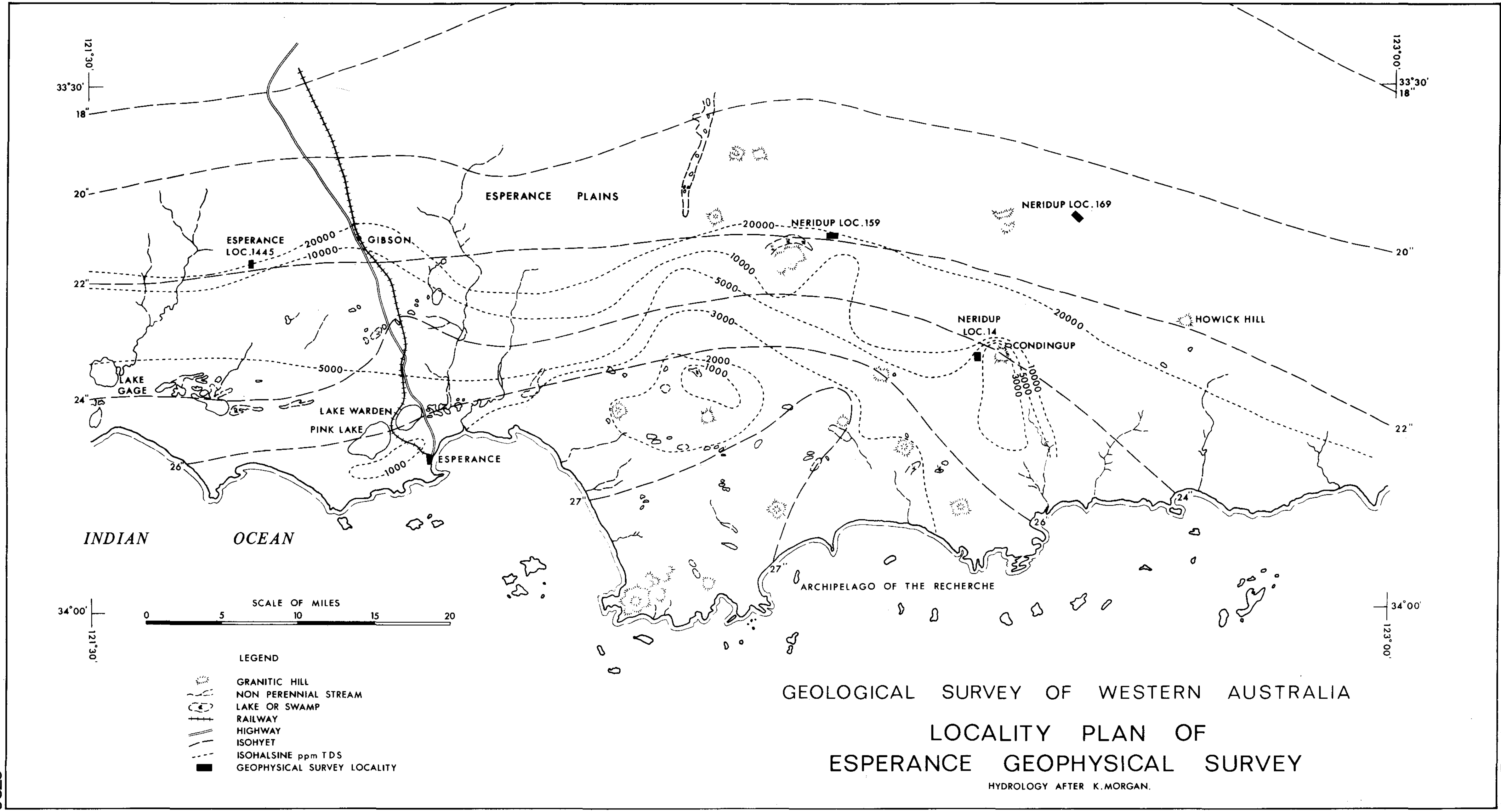
In the absence of a depression in the bedrock the reason why the groundwater should be restricted to the magnetic low is an enigma.

Electromagnetic

The electromagnetic contours on Plate 52 appear to be mainly related to variations in the underground water salinity and, to a lesser degree, to the surface distribution of dry sand, laterite, and silty sand.

With the exception of the pronounced negative anomaly in the southwest corner of the grid, the contours west of line 00 are zero or positive and denote high resistivities. Most of this part of the grid is covered with fine dry sand and, to the north, lateritic soils. The laterite extends to the east of Line 00 and north of the zero contour. The remainder of the eastern part corresponding to the negative e.m. zone is occupied by silty sand. This zone becomes increasingly negative towards the east and culminates with the strongest negative indications over a number of small clay pans. The negative anomaly in the southwest is also associated with a clayey surface layer.

Typically the surface material is only two or three feet deep and is underlain by about 30 to 40 feet of yellow silty sandstone, 30 feet of brown sandstone, about 40 feet of grey clayey fossiliferous sandstone or siltstone, and weathered granite. Water was struck from about 30 feet downwards in bores 20, 21, and 23; bore 22, which is shown as dry, contained seepage water of 3,900



GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

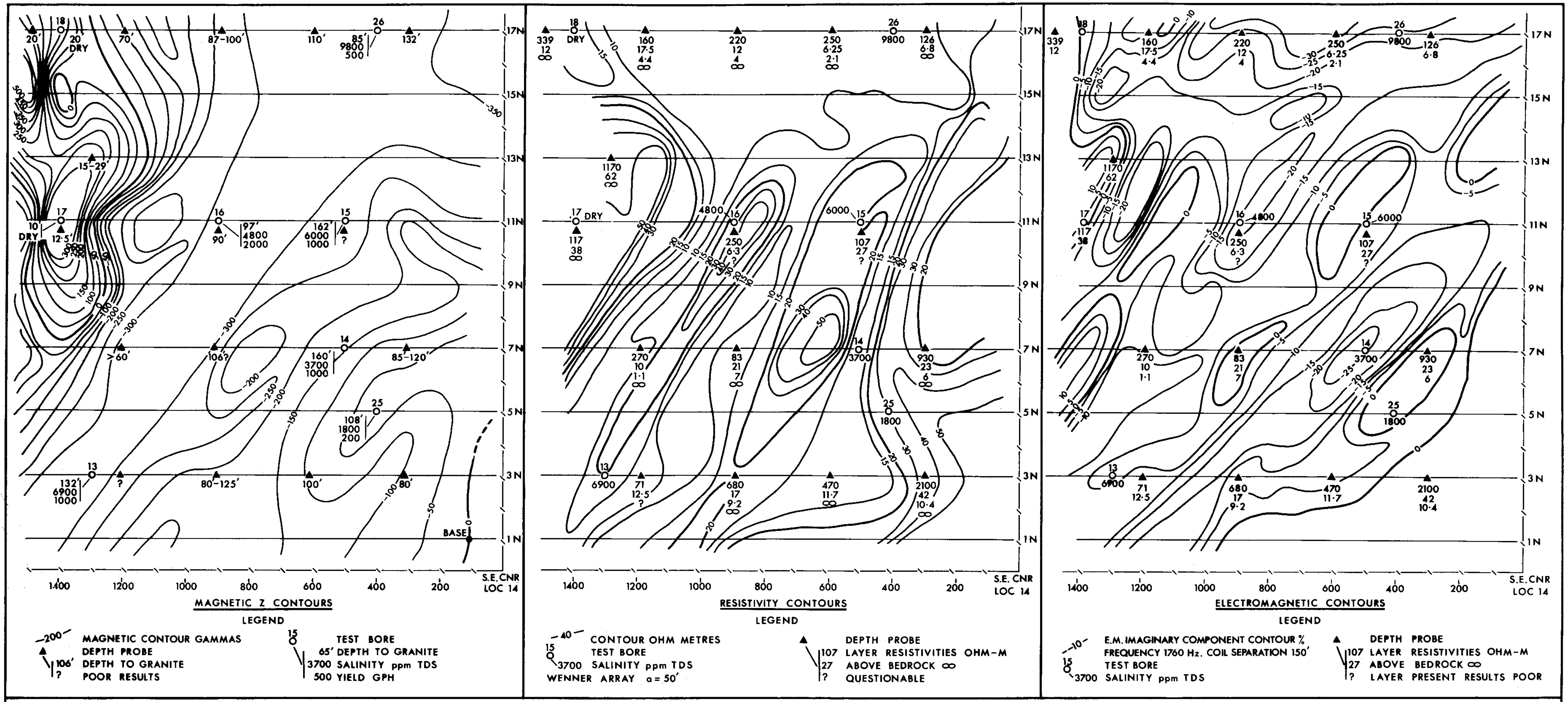
LOCALITY PLAN OF ESPERANCE GEOPHYSICAL SURVEY

HYDROLOGY AFTER K. MORGAN.

PLATE 49

9782

PLATE 50



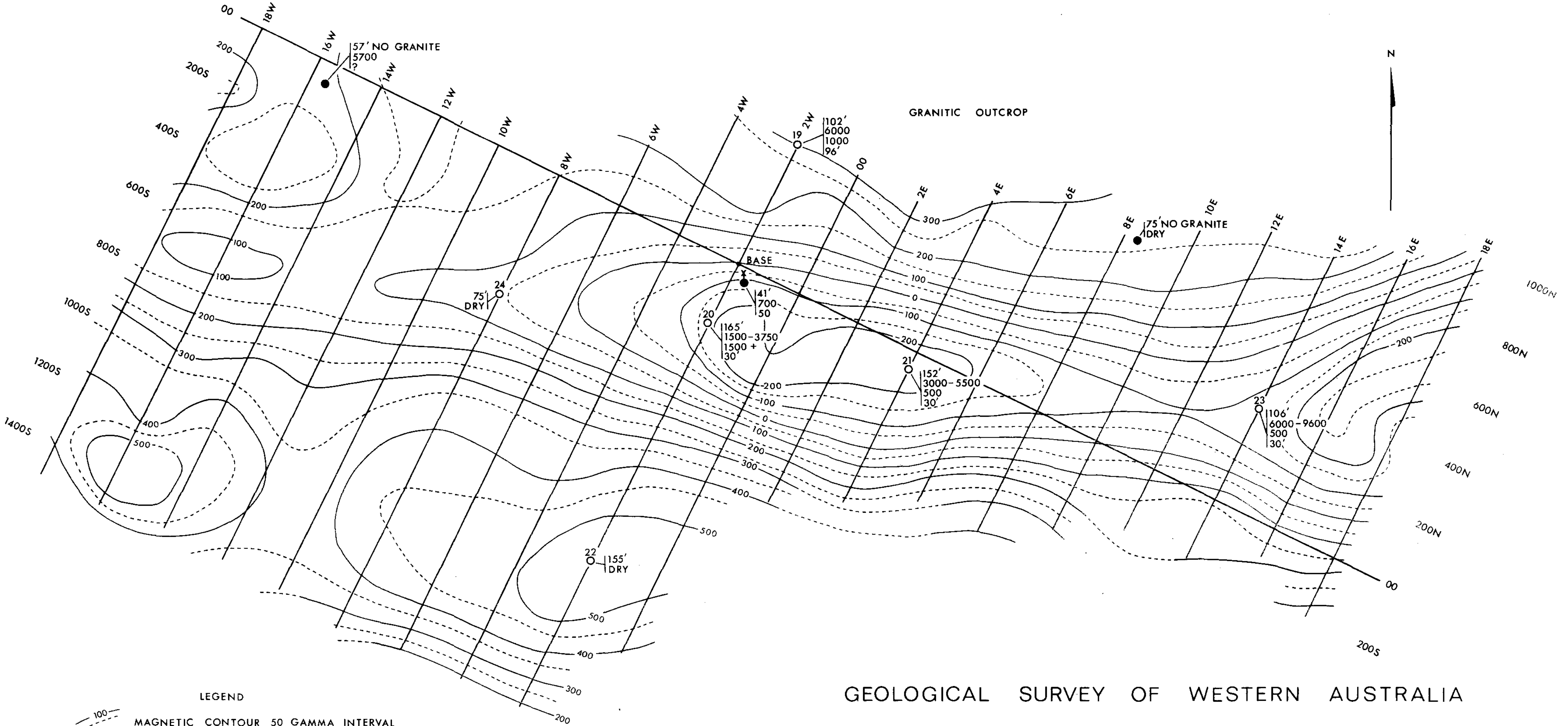
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

0 200 400 600 800 1000 FT.

TO ACCOMPANY REPORT BY D. L. ROWSTON. 1967

PLAN OF PART OF NERIDUP LOC 14 SHOWING MAGNETIC, RESISTIVITY AND ELECTROMAGNETIC CONTOURS

4182



LEGEND

- MAGNETIC CONTOUR 50 GAMMA INTERVAL
- ● PRIVATE BORE
- ○21 TEST BORE NERIDUP No 21
- 152' DEPTH TO GRANITIC BEDROCK
- 3750 WATER SALINITY ppm TDS
- 500 ESTIMATED YIELD GALLONS PER HOUR
- 77' WATER CUT
- MILL

0 200 400 600 800 1000

SCALE OF FEET

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

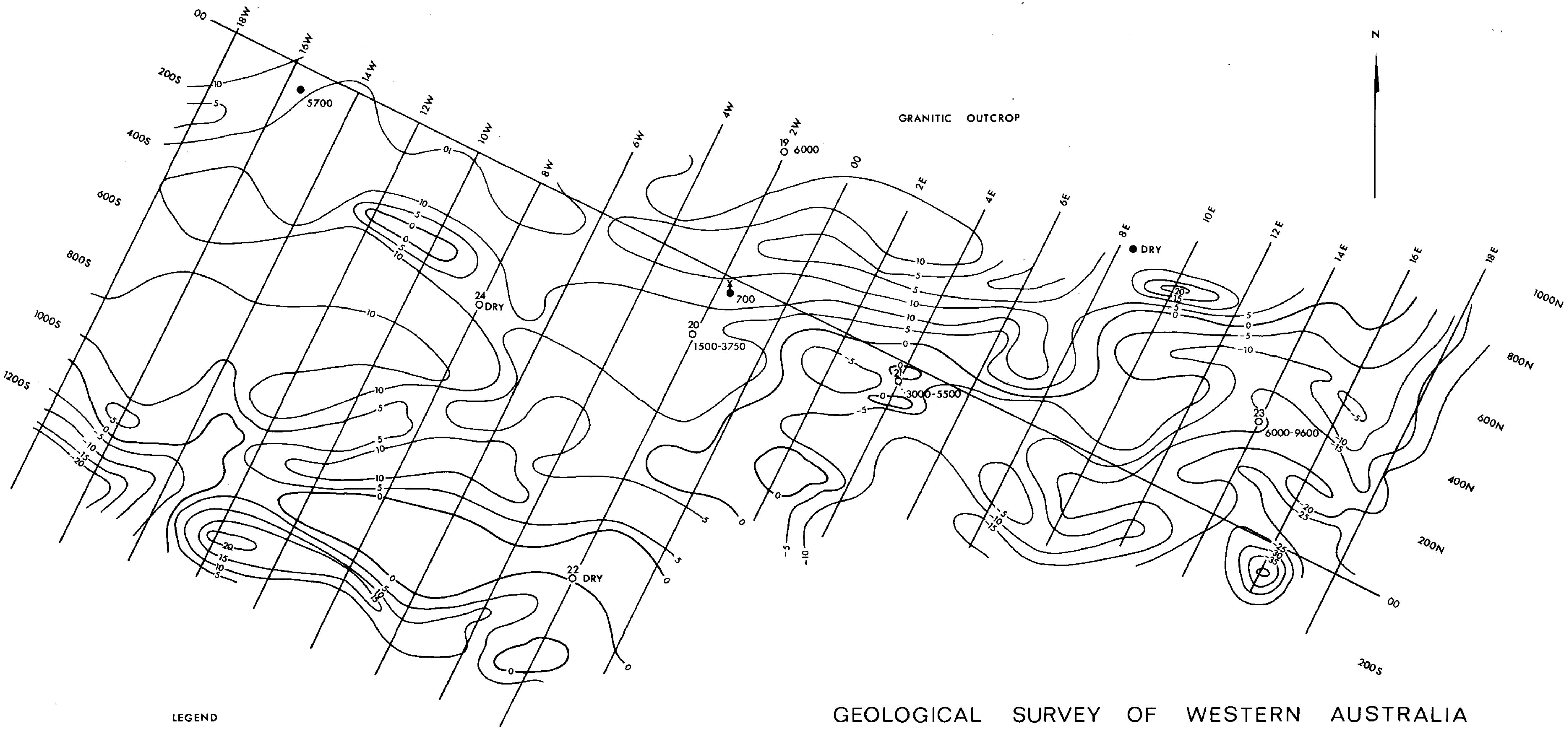
PLAN OF PART OF NERIDUP LOC 159 SHOWING MAGNETIC Z CONTOURS

TO ACCOMPANY REPORT BY D. L. ROWSTON. 1967

PLATE 51

9786

PLATE 52



LEGEND

E.M. IMAGINARY COMPONENT CONTOUR %
FREQUENCY 1760 Hz COIL SEPARATION 150 FT

PRIVATE BORE

TEST BORE

SALINITIES ppm TDS

0 200 400 600 800 1000

SCALE OF FEET

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

PLAN OF PART OF NERIDUP LOC 159 SHOWING ELECTROMAGNETIC CONTOURS

TO ACCOMPANY REPORT BY D. L. ROWSTON. 1967

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ppm quality between 22 to 28 feet. Yield from this surface layer amounts to only 50 gph as does the supply from the mill (reputed 700 ppm); the main yield of up to 1,500 gph comes from the lower aquifer and generally below 60 feet.

There is a strong correlation between the e.m. results and the salinity of this near surface groundwater, but it is not possible to establish a quantitative relationship because of the small number of water samples. It is sufficient to say that the more negative the e.m. results the more saline the groundwater. The effects of the water encountered in bore 19 and the private bore at about 16W/50S may be neglected because the depths at which water occurs are beyond the range of the equipment.

The salinity distribution is considered to be mainly controlled by localised surface recharge to the aquifers in the vicinity of bore 20. The outcrop catchment provides, in the main, sheet runoff over the impervious lateritic clay fringing the granite to the sandy soil at the foot of the slope. To the east of bore 20 the surface material is relatively clayey and most of the run-off is dissipated by surface drainage. Some replenishment is also supplied from the weathered granitic layer and this more saline water (6,000 ppm in bore 19), together with the marine environment, probably accounts for the higher salt content in the lower water horizon. The gradual increase in groundwater salinity to the east typifies the normal pattern down a drainage from the source of recharge.

The problem of the dry bores, 22 and 24, has yet to be resolved satisfactorily. These bores encountered the same strata as bore 20 and are only 600 feet away. There is no evidence to suggest a break in continuity of the horizontal beds and it is difficult to explain why these bores failed to yield other than seepage quantities of groundwater. Bore 21, 600 feet east of 20 and with the same lithology, yielded better than 500 gph.

CONCLUSION AND RECOMMENDATIONS

The magnetic, resistivity, and electromagnetic methods were moderately successful in underground water investigations in the Esperance Plains. The self-potential method failed to give any worthwhile results.

The specific problems, which were to determine the depth to granitic bedrock, the general bedrock topography, and to define relatively the least saline groundwater, were resolved albeit with some reservations. None of the methods can detect water directly or indicate the probable yield; these can only be found by drilling.

Notably, all of the test bores that yielded useful supplies of underground water were sited in magnetic lows. The magnetic patterns generally were attributed to variations in the granitic bedrock relief and thus the lows are minima ascribed to bedrock depressions or drainages. Shallow granite is usually indicated by steep magnetic gradients. Of the 26 holes put down in the three areas only one, bore 22 at Location 159, completely contradicted the magnetic prediction. On the evidence of this bore the magnetic anomaly at Location 159 must be due in part to a change in the magnetic susceptibility of the granitic bedrock, and therefore not all anomalies can be considered due only to bedrock relief. In view of the lack of susceptibility data the method can only be used to give a qualitative picture of the bedrock configuration.

Applications of the resistivity techniques, depth probes, and mapping, were seriously affected by high contact resistances in both dry sand and lateritic soils. The addition of salt water does not entirely overcome the problem and general use of the method in the Esperance area is restricted by local conditions. In addition a high-power instrument capable of reading accurately down to 0.01 ohm is necessary for reliable results. The 50-foot electrode spacing used for the mapping was quite satisfactory in the shallow bedrock environment at Location 169 but larger spacings are required elsewhere to minimise local surface inhomogeneities and to measure main aquifer resistivities. Accepting these limitations, depth pobes can be used to provide estimates of the depths to bedrock. The layer resistivities show promise of direct correlation with the salinity of the underground water but further work is required to ratify this possibility.

The results of the electromagnetic work also show that the variations in conductivity may be related qualitatively to water salinity provided the water table is within about 30 feet of the surface and the surface lithology homogeneous. This method has the advantage over resistivity work that no direct electrical contact with the ground is required but it is also seriously affected by near surface variations which mask indications from depth. These near surface effects are inherent with a dipole primary field source and restrict the use of the E. M. Gun equipment to areas where the surface layers are fairly uniform, such as at Location 159. Other electromagnetic methods using large horizontal loops or long grounded cables for the primary field array would probably give better results. Although not tested at Esperance, the seismic refraction method could accurately determine the thickness of sediments and the basement relief.

If geophysical methods are used for further prospecting for underground water at Esperance the following practical approach is suggested.

A rapid magnetic survey should be made to broadly define depressions in the Archaean bedrock. These probable depressions should then be investigated by a pattern of depth probes to find the depths to bedrock and verify the interpretation of magnetic data. At the same time the resistivities of layers at or below about 50 feet could give some indication of the groundwater salinity distribution; on the assumption that the sediments are laterally homogeneous the lower resistivities would indicate the more saline localities.

Resistivity mapping, which requires at least four men for efficient operation, and the electromagnetic method, are not advocated unless surface conditions are suitable.

Although the hydrological aspects of the drilling results will be dealt with in more detail in a separate report, some mention of them is justified here. The belief that fresher supplies are obtained from near the areas of recharge is supported by the drilling data. However the influence of recharge can be quite local as exemplified by bores 16, 25, and 15 at Location 14 and bore 20 at Location 159. The salinity of the formation water does not always increase with the depth of a bore and thus larger supplies of the same quality water may sometimes be obtained by continuing drilling. On the evidence from Location 159 the surface aquifers is capable of yielding only about 50 gph whereas supplies up to about 1,500 gph can be pumped from the bottom aquifer.

Whilst most of the highest yielding aquifers are sandstone or fossiliferous marine beds, good supplies can be obtained from apparently impervious siltstones, particularly where they are intercalated with porcellanite and opaline silica bands. For example these beds at Location 14 are capable of yielding 500 gph and similar strata elsewhere should not be neglected or a bore abandoned because of hard drilling.

REFERENCE

Parasnis, D. S., 1962, Principles of applied geophysics: London. Methuen.

WATER SALINITIES FROM RESISTIVITY WELL LOGS

by D. L. Rowston

ABSTRACT

An empirical method of estimating formation water salinities from R_{64}'' long normal resistivity well logs has been developed and used effectively in the Perth Basin of Western Australia. Salinities can be determined with an accuracy of ± 15% or better for aquifers in the relatively unconsolidated Mesozoic and younger sediments. Estimates in older strata may be unreliable.

INTRODUCTION

The Geological Survey of Western Australia has used a Widco well logger, Model XMVA-12, to obtain hydrogeological data from exploratory water bores drilled in the Perth Basin since the end of 1963. The logger is equipped to provide gamma ray, point resistivity (PR), normals resistivity (R_{16}'' and R_{64}''), potential (SP), caliper, and temperature measurements to depths of 2,500 feet.

The electrical and gamma ray logging has been particularly useful in rotary drilled holes. In addition to the normal identification of lithology and stratigraphic correlations, an empirical method has been developed whereby formation water salinities can be estimated fairly reliably from the R_{64}'' normals restivity logs. Although developed independently the method had been described previously by Jones and Burford (1951). In view of its successful application locally, the method is considered worthy of reiteration because of possible interest to other investigators who are unable to employ more sophisticated logging techniques. It is not suggested that it can be applied elsewhere categorically; in Western Australia the method has been refined over a period of four years and is reassessed continually as more data comes to hand.

The Geological Survey has been engaged in a systematic study of the hydrology of the Perth Basin for some years. A series of exploratory bores have been drilled across the Basin from the coast to the Darling Scarp at Busselton, Mandurah, Pinjar, and Gingin (Plate 53) with more localised patterns at Arrowsmith and, currently, at Watheroo. The bores are generally about 2,000 feet deep and penetrate relatively unconsolidated Cainozoic to Mesozoic sediments. Permian rocks have been encountered in a few bores. Artesian to subartesian aquifers occur in the Quaternary, Cretaceous, and upper Jurassic sediments whereas the Permian strata are generally too tight to yield large supplies. The water quality is highly variable and the hydrological pattern further complicated by shallow faulting, sea water encroachment, and local recharge conditions.

WELL LOGGING

Well logging is now carried out as a matter of routine to augment water sample and lithological data obtained during the course of drilling. In rotary drilled holes, gamma ray, SP, PR, R_{16}'', and R_{64}'' logs are recorded; the first run is usually made at 1,000 feet and the final run at total depth.

Originally the potential log was to be used to determine formation water salinities according to the standard procedure detailed by Schlumberger (1962). But potential logs obtained in the relatively shallow and fresh water environment are frequently unusable because of drift, and the comparatively small potentials generated by the low resistivity contrast between formation water and drilling fluid. Attempts to enhance the magnitude of the potentials by increasing the mud salinity resulted in erratic and unrepetitive logs. The SP logs are still used qualitatively to indicate whether the formation water is more, or less, saline than the drilling fluid. Potentials negative with respect to the shale line denote water salinities higher than that of the mud and conversely positive potentials indicate less saline water.

With the failure of the SP method to estimate water salinity, recourse was made to the calibrated R_{64}'' normals resistivity log as the next most prospective function. Existing logs showed that excellent repetition with different runs in the same hole was possible, despite variations in mud resistivity and other hole parameters.

OUTLINE OF METHOD

The estimation of formation water salinity from the R_{64}'' log is based on the fundamental relationship propounded by Archie (1942), namely:

$$Rt = \frac{F\ Rw}{S_w^n} \qquad (1)$$

where RT = true formation resistivity.
F = formation resistivity factor.
Rw = resistivity of formation water.
S_w^n = fraction of pore volume of sediment occupied by interstitial water.

The relationship can be simplified by assuming that the formation is 100 per cent. water saturated and contains no hydrocarbons. Under these conditions, $S_w^n = 1$ and

$$Rt = Ro = F\ Rw \qquad (2)$$

where Ro = formation resistivity when 100 per cent saturated with water of resistivity Rw.

These conditions are considered quite tenable for shallow sediments in the Perth basin.

With equation (2) accepted, values for Ro and F are required to resolve Rw and thus the formation water salinity.

(a) Ro is measured directly from the long normal R_{64}'' log, that is

$Ro = R_{64}''$

and equation (2) becomes

$$R_{64}'' = F\ Rw \qquad (3)$$

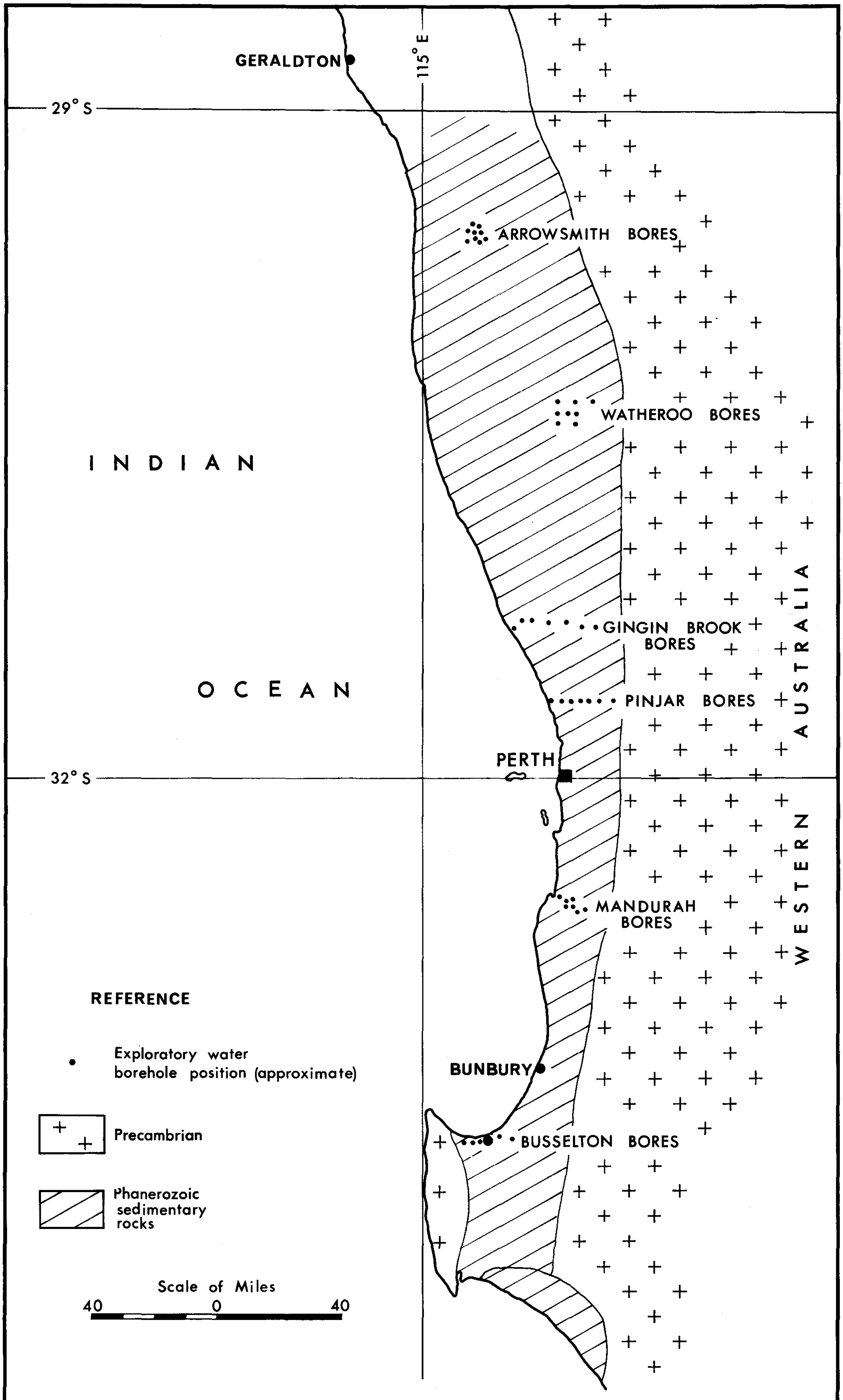
(b) F is obtained empirically from (3) by measuring Rw of a control water sample from the bore and using the R_{64}'' reading corresponding to the interval sampled. Temperature corrections, either Rw to the temperature of the formation of both Rw and R_{64}'' to 20°C are applied.

This value for F is then used with the R_{64}'' readings to determine Rw for other clean sands in the bore. Rw is entered on a resistivity versus salinity chart to the appropriate temperature curve and the salinity read off. The conversion chart used by the Geological Survey has been constructed from a great number of water sample analyses by the Government Chemical Laboratories and gives total dissolved salts (TDS) directly instead of the standard NaCl equivalent.

PROBLEMS AND LIMITATIONS

On theoretical grounds there are numerous objections to the assumption that R_{64}'' is equivalent to Ro and to the application of F to other clean sands, even within a particular formation. These objections are debated thoroughly by Patten and Bennett (1963) and only a brief discussion of the more salient points is warranted here. The empirical nature of the method is emphasised and, despite theoretical considerations to the contrary, it can be used to determine salinities to within about ± 15 percent in Mesozoic and younger sediments in the Perth Basin.

The discussion is based on hydrogeological data from about 18 bores totalling some 27,000 feet where reliable calibrated resistivity logs were recorded.



GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

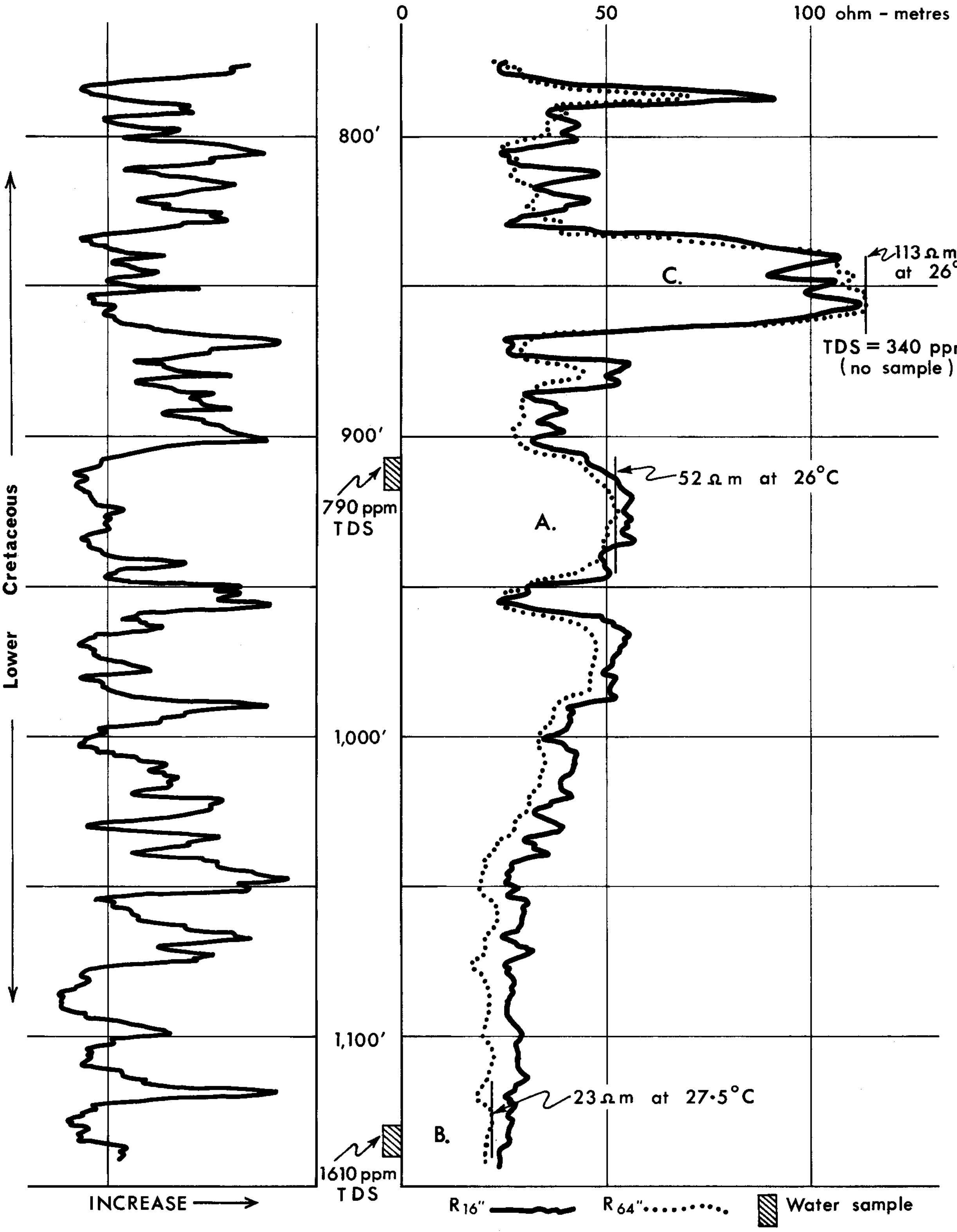
PERTH BASIN EXPLORATORY WATER BORE LOCATIONS

To accompany report by D.L. Rowston, 1967

7165

PINJAR No. 1 - EXPLORATORY WATER BORE

R_m = 1·97 Ω m at 20°C



A.
$R_{64''}$ = 52 Ω m at 26°C
F = 6·4 (empirical)
$R_{64''} = F R_w$
R_w = 8·1 Ω m at 26°C
TDS = 750 ppm

B.
$R_{64''}$ = 23 Ω m at 27·5°C
F = 6·4
R_w = 3·6 Ω m at 27·5°C
TDS = 1600 ppm

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

EXAMPLE OF CALCULATION OF WATER SALINITIES FROM RESISTIVITY WELL LOGS

To accompany report by D. L. Rowston, 1967

7168

The objections to assuming $R_{64}'' = Ro$ are related primarily to the unknown influence of the mud filtrate in the flushed and invaded zones on the R_{64}'' curve. Long normal dogging runs made under different hole conditions indicate that variations such as mud resistivity (Rw) and borehole diameter have negligible effect; the R_{64}'' long generally repeats within 1 to 2 per cent. even in permeable sands. On the other hand the short normal (R_{16}'') curve can be strongly affected by changes in these parameters. The relative magnitudes of the two curves can be used qualitatively to gauge the permeability of a bed. Rm, and thus the filtrate resistivity Rmf, are usually lower than Rw with the result that, in permeable beds, the R_{64}'' is appreciably greater than R_{16}''. Where the R_{16}'' and R_{64}'' logs have similar magnitudes, penetration of the mud filtrate into the formation is inhibited by either a tight formation or high formation pressure. These are broad generalisations of a complex relationship which do not always apply and each case must be assessed individually.

Experience has shown that the R_{64}'' log indicates Ro reliably in most cases and besides, as the method is empirical, small discrepancies are compensated for when F is determined. In permeable strata where invasion is deep, salinities estimated from R_{64}'' are liable to be maximum values.

The determination of F and the validity of applying it elsewhere to estimate unknown salinities are the more serious problems.

The main prerequisite for finding F is a reliable water sample. The Geological Survey obtains samples by using Johnson and Halliburton formattion testers, or by plugging, casing and bailing the hole; salinities are found by conductivities and chemical analyses. The latter indicate that about 30 per cent. of the samples obtained have been contaminated by the drilling mud or the cement used in plugging the hole. Another 20 per cent. cannot be used because the interval sampled is silty and the corresponding R_{64}'' value is therefore unrealistic, or for other reasons.

An appraisal of the remaining reliable data shows that F ranges from 5.5 to 42 and can be related to the ages of the strata. The observed increase in F with increase in age agrees with the theoretical inverse aependence of F on porosity; the older and more compacted sediments are less porous and thus have higher factors. An investigation of the possible variation in F with depth, irrespective of age, failed to reveal any relationship.

Although the values of F tend to be gradational there are three distinct stratigraphic groups in the range. In the Cretaceous and younger sediments F ranges from 5.5 to 7.4 and has an average value of 6.4. The even frequency distribution precludes further subdivision even though finer stratigraphic distinctions can be made readily. Only eight reliable water samples have been obtained from rocks identified positively as Jurassic; F varies between 7.9 and 11.5 and has been given a tentative weighted value of 10.4. Five values of F, from 22 to 42 have been determined for the Permian and obviously the accuracy of the method under these circumstances is very low. As water from the Permian is saline and the yields generally small, this inaccuracy does not detract from the usefulness of the method.

Thus, F cannot be applied unconditionally and, for accurate results, the stratigraphy should be known. Palynological examination of core is used extensively by the Geological Survey for this purpose.

EXAMPLE

A section of the gamma ray and normal resistivity logs from the Pinjar 1 bore (Plate 54) have been selected as typical and because two uncontaminated water samples are available for comparison with the estimated salinities.

The gamma ray log indicates an interval of interbedded sandstone and siltstone which has been identified by palynology as the Leederville Sandstone of lower Cretaceous age. Thus the average formation resistivity factor, F = 6.4, has been used to determine Rw at the appropriate temperature from the R_{64}'' log. The gamma ray log also shows that the sands A and B from which the samples were taken are relatively clean and of sufficient thickness to assume $R_{64}'' = Ro$. On the other hand sand C is somewhat silty and R_{64}'' is probably lower than the actual formation resistivity.

The estimated salinities for A and B compare very favourably with the water sample salinities found by chemical analyses. Although the salinity of water from C has not been verified this estimate is considered realistic because water of this quality is common elsewhere in the Leederville Sandstone. The estimated salinity here is a maximum value and the true salinity could be as low as 300 ppm.

Reliable salinities cannot be calculated from R_{64}'' in silty or shaly sections such as 1,010 to 1,053 feet where a transition zone occurs, or in thin sands similar to the one at 787 feet. Experience has shown that for the thinner, silty sands (B and C) the peak R_{64}'' values give better results, whereas in the thick aquifers (A) minor peaks can be ignored.

CONCLUSIONS

The long normal resistivity log has been used successfully in rotary drilled water bores in the Mesozoic and younger sediments of the Perth Basin to determine water salinities within an accuracy of $\pm$ 15 per cent. In common with most other well logging interpretive procedures, the method is empirical and depends on the amount of control data available. It is unlikely that the accuracy can be improved to better than $\pm$ 10 per cent. but this is acceptable for most regional hydrological investigations and particularly where water sampling is unsatisfactory or incomplete.

The main requirements for effective application in similar environments are:

(a) a reliably calibrated long normal resistivity log;

(b) uncontaminated water samples, initially for finding F and for verification of results when the method has been established;

(c) stratigraphic control;

(d) formation temperature measurements;

(e) a gamma ray or other log to indicate the quality of the sands. The method is advocated only for clean sands which are preferably more than 20 feet thick.

Proving the efficacy and reliability of this or related methods for a particular area is generally a long term project. For this reason it is suggested that records of hole conditions, (mud weight, mud resistivity, mud cake) lithology and stratigraphy, porosity and permeability of cores etc. be kept from the inception of logging to study the theoretical aspects more fully.

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Patten, E. P., and Bennett. G. D., 1963, Application of electrical and radioactive well logging to ground water hydrology: U.S. Geol. Survey Water - Supply Paper 1544D.

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DIVISION V

School of Mines, Western Australia Annual Report — 1967

The Under Secretary for Mines:

I submit for the information of the Honourable, the Minister for Mines my report for 1967. The report refers to Kalgoorlie and to Norseman.

KALGOORLIE

Enrolments

The number of enrolments was 278, an increase of 38 on the previous year. Class enrolments increased by 26 to 801. Details of enrolments are supplied in Tables I and II. Enrolment distributions and trends over the last five years are shown in Table III.

Revenue

The revenue for the year totalled $14,756, an increase of $2,335 on the previous year. The moneys received included $2,000 paid into the Apparatus and Equipment Trust Fund by the Chamber of Mines. A detailed statement is given in Table IV.

Staff

There were no changes in the lecturing staff during the year.

Courses of Study

The first years of the new Associateship Courses were introduced. The previously existing courses were retained for second, third and fourth year students. In 1968 the first two years of the new courses will be taught: the old Courses will be phased out by 1970.

The new Three-Year Certificate Course was introduced and the new Senior Certificate Course will be effective in 1968.

The Chamber of Mines has been requested to grant Day Release to School of Mines students in 1968 and this should materially assist the development of the new Certificate Courses.

Examinations

The results of the Annual Examinations are summarized in Tables VI and VII and disclose no significant variation from those of previous years.

Scholarships and Prizes

Of the fourteen Chamber of Mines Scholarship holders eleven completed a satisfactory year of study. Of the four Mines Department Scholars only two completed a satisfactory year.

The usual awards were made at the end of the year and are listed in Appendix 2.

Diplomas and Certificates

Nine students completed Associateships, eight completed Certificate Courses and no Technician Courses were completed.

In 1968 the Three-Year Certificate will be in operation for the second year and the Senior Certificate Course will be commenced. This, together with Day Release, should result in a considerable expansion of Certificate Courses.

The Technician Courses will be phased out but the Mine Manager's Certificate (2nd class) will be retained.

Library

The number of items catalogued at December, 1967 was 11106, the new titles for the year being 919. Inter-library loans show an increase of more than 100%.

Bibliographies of nickel ores and other items of interest were compiled to meet requests resulting from the current mining expansion.

In addition, the library has this year handled text-books for students.

Services to the Public

The School provided the usual services to industry and to the public in addition to its teaching activities. The number of samples submitted for free assay and determination totalled 821. The handling of these samples involved 207 mineral determinations and 162 gold assays and 560 assays for metals other than gold.

Advisory Committee

The Advisory Committee met 10 times. During the year the Committee has authorized the purchase of a Geodemeter—$6206, for the Mining and Mine Surveying Department and a Ratemeter and X-Y Plotter—$2100 for the Department of Mathematics and Physics. The McPhar Rope Testing Machine authorized in 1966 has been obtained, the cost of $7675 being met out of the Apparatus and Equipment Trust Fund.

Kalgoorlie Metallurgical Laboratory

During the year 5 requests for investigations were received and 7 investigations were completed. The Senior Research Metallurgist continued as a member of the Chamber of Mines Metallurgist Committee and continued to help mine owners and prospectors with metallurgical advice. Additional information is furnished in Appendix 3 including a summary of the year's work.

Students' Association

The President of the Students' Association was Mr. R. A. Tastula. The usual activities of the Association were carried out and once again the profits from the Annual Ball were donated to the Slow Learners Group in Boulder. Congratulations are extended to those students who were successful in the Annual Examinations and particularly to those who completed courses.

NORSEMAN

Enrolments

The number of students enrolled was 50 and class enrolments 124. Further details are furnished in Tables I, II and III. There has been very little variation over the last three years.

Revenue

The revenue—$321 was entirely from student fees.

Staff

There were no changes in full-time staff. There were 15 subjects taught involving considerable use of part-time staff.

ACKNOWLEDGEMENTS

The assistance and co-operation of all members of the Staff, both full-time and part-time, is gratefully acknowledged. The statistical information contained in this Report has been compiled by the Registrar and the office staff in Kalgoorlie and by the Registrar in Norseman. Assistance and co-operation throughout the year received from Advisory Committees, Kalgoorlie and Norseman, staffs of Mining Companies, Mines Department staff and others is also gratefully acknowledged.

J. DOUGLAS COLLISTER,
Acting Director, School of Mines.

May 3, 1968.

Table I

ENROLMENTS, 1963–1967

Year	Kalgoorlie		Norseman	
	Individual	Class	Individual	Class
1963	365	926	68	140
1964	329	830	59	128
1965	275	858	50	122
1966	240	775	51	122
1967	278	801	50	124

Table II

CLASS ENROLMENTS, 1967

Subject	Kalgoorlie	Norseman
Chemistry P	31	....
Chemistry Q	22	....
Chemistry 10	14	....
Chemistry 2	2	....
Analytical Chemistry 1	3	....
Analytical Chemistry 2	3	....
Chemical Metallurgy 1	1	....
Chemical Metallurgy 2	5	....
Metallurgy 10	9	....
Mineral Dressing 2	2	....
Mineral Dressing 3	2	....
Physical Metallurgy 1	5	....
Assaying	7	....
Metallurgy A	4	....
Mathematics PA	39	....

Table II—*continued*

CLASS ENROLMENTS 1967,—*continued*

Subject	Kalgoorlie	Norseman
Mathematics PB	34	....
Mathematics Q	51	....
Mathematics QS	18	8
Mathematics 1.1	38	10
Mathematics 1.2	25	....
Mathematics 2	5	....
Physics Q	39	....
Physics 1.1	28	....
Physics 1.2	26	....
Electronics 10	1	....
Electronics 11	5	....
Engineering Drawing P	30	7
Engineering Drawing Q	34	4
Engineering Drawing 11	7	1
Engineering Drawing W	....	10
Engineering Design	2	....
Mechanical Engineering 1	10	....
Mechanical Engineering 2	2	....
Electrical Engineering 1	13	....
Electrical Engineering 21	2	....
Electrical Engineering 22	3	....
Structural Engineering 1	12	....
Structural Engineering 21	6	....
Structural Engineering 22	6	....
Machine Design 1.1	8	....
Machine Design 1.2	3	....
Hydraulics	11	....
Materials Science 13	7	....
Electrical Technology 12	4	....
Strength of Materials 14	5	....
Applied Thermodynamics 15	4	....
Workshop Practice	....	12
Welding A	....	13
Welding B	....	9
Internal Combustion Engines	4	6
Geology 13	32	11
Geology 1.1	10	9
Geology 12	15	....
Geology 2.2	5	....
Geology 2.3	5	....
Geology 3.1	2	....
Geology 3.4	6	....
Mining A	3	....
Mining 10	9	....
Mining 2.1	3	....
Mining 2.2	4	....
Mining 3	....	....
Mine Ventilation 10	7	....
Surveying 10	11	10
Surveying 2.1	8	....
Surveying 2.2	9	1
Cartography 10	10	....
English P	22	....
English 10	14	....
English Q	10	....
English 1	14	....
Mathematics A	....	....
Mathematics B	....	....
Physics P	....	13
Electrical Theory A	....	....
Electrical Theory B	....	....
Electrical Theory C	....	....
Electrical Drawing A	....	....
Totals	801	124

Table III

NUMBER OF STUDENTS ENROLLED FOR VARIOUS COURSES

Courses	Kalgoorlie					Norseman				
	1963	1964	1965	1966	1967	1963	1964	1965	1966	1967
ASSOCIATESHIP COURSES										
Mining	34	31	19	21	20	4	3	1	....	....
Metallurgy	18	20	19	19	19	....	....	....	....	....
Engineering	37	43	31	25	27	....	....	....	....	....
Mining Geology	9	7	7	8	10	....	....	....	....	....
Total	98	101	76	73	76	4	3	1	....	....
CERTIFICATE COURSES										
Chemical Technician	....	....	....	....	3	....	....	....	....	....
Mining Surveyor's	37	27	30	25	28	9	9	10	11	12
Engineering Draughtsman's	33	29	24	18	18	8	....	3	....	1
Assayer's	10	8	4	3	....	....	....	....	....	....
Total	80	64	58	46	49	17	9	13	11	13
TECHNICIAN COURSES										
Engine Operation and Maintenance	....	....	....	....	....	2	....	....	....	....
Welding	17	19	11	14	4	7	6	4	6	6
Workshop (Mechanical)	....	1	....	1	....	12	1	20	12	15
Workshop (Electrical)	2	....	....	....	....	5	....	5	6	5
Mine Manager's (2nd class)	5	8	7	5	6	....	1	2	2	....
Total	24	28	18	20	10	26	8	31	26	26
NO SET COURSE										
Preparatory subjects	27	17	26	29	53	11	....	3	7	3
Qualifying subjects	17	17	16	7	18	....	....	....	3	....
External students	....	2	....	....	....	....	....	....	....	....
Junior and Leaving	32	18	7	1	9	....	....	....	....	....
University	1	1	2	....	1	....	....	....	....	....
Others	86	81	72	64	62	10	39	2	4	8
Total	163	136	123	101	143	21	39	5	14	11
TOTAL FOR YEAR	365	329	275	240	278	68	59	50	51	50

Table IV

REVENUE, 1965-1967

	Kalgoorlie			Norseman		
	1965	1966	1967	1965	1966	1967
	$	$	$	$	$	$
Class Fees	3,003.25	2,532.05	2,705.20	371.20	447.20	306.50
Lecture Notes	103.00	85.50	101.75	16.00	16.75	14.50
Laboratory Deposits	188.00	182.00	236.00	....	20.00	....
Supplementary Examinations	72.00	46.00	34.00	....	2.00	....
Apparatus and Equipment Trust Fund	4,000.00	4,000.00	2,000.00	....	....	....
Metallurgical Laboratory Trust Fund	1,005.55	1,835.55	1,759.55	....	....	....
Commonwealth Grants—Research Laboratory—Trust Fund	6,060.00	3,060.00	6,200.00	....	....	....
Students' Association	373.50	320.50	366.50	....	....	....
Mine Managers and Underground Supervisors	105.05	86.10	62.90	....	....	....
Sundries	185.48	273.10	1,290.40	....	....	....
Total	$15,095.83	$12,420.80	$14,756.30	$387.20	$485.95	$321.00

Table V

NUMBER OF STUDENTS PAYING FEES 1965-1967

Group No.	Description	Kalgoorlie						Norseman					
		1965	1966	1967				1965	1966	1967			
		Total	Total	Full Time	Part Time	External	Total	Total	Total	Full Time	Part Time	External	Total
1	Students under 18. Class fees, deposits, lecture notes fee, Students' Association	77	63	13	55	....	68	16	17	....	24	....	24
2	Students 18–20. Class fees and other fees as for Group 1	58	65	14	57	....	70	18	15	....	12	....	12
3	Students 21 and over. Class fees and other fees as for Group 1	107	95	5	118	....	123	15	19	....	14	....	14
4	Returned Servicemen. Exempt Class fees	9	2	....	2	....	2	....	....	....	....	....	....
5	Staff. Exempt class fees	22	13	....	12	....	12	1	....	....	....	....	....
6	Scholarship Holders. Exempt class fees	2	2	3	....	....	3	....	....	....	....	....	....
		275	240	....	....	....	278	50	51	....	....	....	50

Table VI

RESULTS OF ANNUAL AND OF SUPPLEMENTARY EXAMINATIONS BASED ON CLASS ENROLMENTS, 1963-1967

	Kalgoorlie					Norseman				
	1963	1964	1965	1966	1967	1963	1964	1965	1966	1967
Class Enrolments = A	931	827	858	775	801	140	115	122	122	124
Number of entries for Annual Examinations = B	633	581	558	426	534	96	97	82	92	72
B/A per cent.	68	70	65	55	67	69	84	67	75	58
Number of passes at Annual Examinations as a per cent. of A	49	53	53	51	49	54	75	55	60	40
Number of passes at Annual Examinations as a per cent. of B	71	75	81	93	73	79	89	82	79	69
Number of passes at Annual Examinations and Supplementary Examinations as a per cent. of A	52	57	54	53	51	56	75	56	61	41
Number of passes at Annual Examinations and Supplementary Examinations as a per cent. of B	76	81	82	95	76	81	89	83	80	71

Table VII

STUDENTS SITTING FOR ANNUAL EXAMINATIONS, 1965-1967

Course	Kalgoorlie						Norseman					
	1965		1966		1967		1965		1966		1967	
	Number Enrolled	Percent. Sitting	Number Enrolled	Percent. Sitting	Number Enrolled	Percent. Sitting	Number Enrolled	Percent. Sitting	Number Enrolled	Percent. Sitting	Number Enrolled	Percent. Sitting
Associateship	76	95	73	96	76	87	1	100	....	....	....	....
Certificate	58	66	46	61	49	76	13	85	11	82	13	85
Technician	18	67	20	60	10	50	31	68	26	85	26	77
No Set Course	123	53	101	54	143	46	5	80	14	57	11	9
	275	68	240	69	278	62	50	74	51	76	50	64

Table VIII

COURSES COMPLETED 1963-1967 KALGOORLIE AND NORSEMAN

	1963	1964	1965	1966	1967
Associateship Courses—					
Mining	3	10	4	4	4
Metallurgy	1	2	2	5	2
Engineering	2	8	6	5	3
Mining Geology	1	....	3	2	....
	7	20	15	16	9
Certificate Courses—					
Assayers	1	6	4	4	3
Mine Managers	2	4	1	....	....
Mine Surveyors	5	3	10	1	4
Engineering Draughting	4	8	6	7	1
Electrical Engineering	....	1	....	....	....
Mechanical Engineering	....	1	....	....	....
Chenical Technician	....	....	....	....	....
	12	23	21	12	8
Technician Courses—					
Engine Operation and Maintenance	1	....	....	....	....
Workshop Foremans	....	1	....	....	....
Welding	1	3	1	1	....
Workshop Practice (Mechanical)	....	....	1	3	....
Workshop Practice (Electrical)	....	....	....	....	....
Mine Managers (2nd Class)	....	1	2	2	....
	2	5	4	6	....

APPENDIX 1

ASSOCIATESHIPS COMPLETED, 1967

Metallurgy

Dombrose, E. J.
Brinsden, W. K.

Mining Engineering

Powell, P.
Lea, R. J.
Loxton, I. W.

Engineering

Pearson, C. A. L.
May, A. J.
King, R. M.
Carroll, G. R.

Geology

—

APPENDIX 2

SCHOLARSHIPS AND PRIZES AWARDED, 1967

Chamber of Mines Prizes

Mining: Sheppard, I.
Metallurgy: Zamorski, G.
Engineering: Brooks, T. E.
Mining Geology: Kerspein, H.

School of Mines Students' Association Scholarships

Mining: Lockyer, P. C.
Metallurgy: Tillotson, L. D.
Engineering: Hobson, J. C.
Mining Geology: None eligible.

Institute of Mining Surveyor's Prizes

$30-00 Prize: Jardine, T. L.
$15-00 Prize: Chamberlain, E. H. N.
$10-00 Prize (Cartography): Wearne, J. M. (Miss)

Society of the W.A. School of Mines Associates' Prize

Hosking, D. J. (no award until March)

Reg Dowson Scholarships

Group A—

Underwood, G. A.

Group B—

1. James, E. P.
2. Van Gelderen, I. M. F.
3. Sloan, G. K.

Robert Falconer Prizes

$10-00 Prize: Rintoul, D. S.
$5-00 Prize: Giles, C.

C. A. Hendry Prize

Underwood, G. A.

Wesley Ladies Guild

Radosevich, W. P.

APPENDIX 3

KALGOORLIE METALLURGICAL LABORATORY

by

E. Tasker, A.W.A.S.M. (Met.), A.M.Aus.I.M.M.
Senior Research Metallurgist

INTRODUCTION

Seven reports of investigations and two hundred and thirty eight certificates of testing or analysis were issued during the year. Brief descriptions of the investigations are included in the report.

For further information regarding these reports apply to:

The Secretary,
Commonwealth Scientific and Industrial Research Organisation,
314 Albert Street,
East Melbourne,
Victoria, 3002.

from whom copies of the reports can be obtained usually six months after date of issue.

In addition to the reports issued, two other investigations were approved and test-work was in progress.

COMPLETED INVESTIGATIONS

Report No. 728

This work was carried out to determine a flotation method suitable for upgrading a low-grade lime-stone from Perth, W.A. to cement lime-rock requirements. A method using a cateonic type collector appeared to be suitable.

Report No. 736

This investigation was carried out on a lead ore from Mary Springs Lead Mine, near Geraldton, W.A. The ore was simple in nature and high recovery of galena was possible by gravity concentration.

Report No. 739

Test-work was carried out on a pyrite-pyrrhotite ore from Norseman, W.A. Test results showed that sulphide sulphur recovery could be improved by using an acid flotation pulp.

Report No. 740

Test-work was carried out on a sample of wind-blown sand from Kambalda, W.A., the sand was to be used as underground backfill. The stabilising effect of various cementing additives was studied.

Report No. 741

Gold recovery tests were made on diamond drill core samples from Mt. Magnet, W.A.

Report No. 742

Test-work was carried out on a tungsten ore from Cue, W.A.

Report No. 744

Flotation tests were carried out on an oxide copper ore from Kumarina, W.A.

INCOMPLETE INVESTIGATIONS

Report No. 743

Test-work was in progress on drill core samples of pegmatite from Londonderry, W.A.

Report No. 745

Test-work was in progress on a sample of beach sands from near Onslow, W.A.

Kalgoorlie Metallurgical Laboratory

SUMMARY OF YEAR'S WORK, 1967

Report Number	Owner	State	Locality	Ore Type	Type of Investigations	Confidential Until	Number of Metallurgical Tests	Number of Assays Gold	Number of Assays Other
728	Swan Portland Cement, Perth	W.A.	Fremantle	Cement-lime rock	Benefication	17/1/68	12	....	76
736	T. A. Bridson, Geraldton	W.A.	Mary Springs Lead Mine	Galena	Concentration tests	26/12/67	6	....	30
739	Norseman Gold Mines N. L., Norseman	W.A.	Norseman	Pyrite-pyrrhotite	Flotation tests	28/1/68	45	....	140
740	Western Mining Corporation, Kalgoorlie	W.A.	Kambalda	Wind-blown sands	Stabilised backfill	18/6/68	70	....	200
741	Hill 50 Gold Mine, N. L. Mt. Magnet	W.A.	Mt. Magnet	Gold	Treatment tests	16/2/68	10	50	10
742	Geotechnics (Aust) Pty. Ltd., Perth	W.A.	Cue	Tungsten	Concentration tests	27/6/68	20	....	80
744	E. A. Parkinson, Kumarina via Meekatharra	W.A.	Kumarina	Oxide Copper	Contentration tests	21/6/68	8	....	40
....	Certificate Nos. 3516 to 3545, 3547 to 3567, 3569 to 3622, 3624 to 3756	....	....	....	....	....	....	399	936
....	Free Assays	....	....	....	....	....	....	162	560
						Totals	171	611	2,072

The following investigations were incomplete or pending at December 31, 1967 :—

743	Western Mining Corporation, Kalgoorlie	W.A.	Londonderry	Lithium pernatite	Concentration	....	20	....	60
745	Halpern, Glick and Lewis Perth	W.A.	Onslow	Ferruginous Beach Sand	Concentration	....	30	....	180
						Totals :	221	611	2,312

DIVISION VI

Annual Report of the Inspection of Machinery Branch of the Mines Department for the Year 1967

The Under Secretary for Mines:

For the information of the Hon. Minister for Mines I submit the report of the Deputy Chief Inspector of Machinery in the administration of the Inspection of Machinery Act, 1921-1958, for the year ending 31st December, 1967.

A. Y. WILSON,
Chief Inspector of Machinery.

Section 1

INSPECTION OF BOILERS, MAINTENANCE, ETC.

(See Returns Nos. 1, 2 and 3)

Under the Act "Boilers" means and includes—

(a) any boiler or vessel in which steam is generated above atmospheric pressure for working any kind of machinery, or for any manufacturing or other like purpose;

(b) any vessel used as a receiver for compressed air or gas, the pressure of which exceeds 30 lb. to the square inch, and having a capacity exceeding five cubic feet; but does not include containers used for transport;

(c) any vessel used under steam pressure as a digester; and

(d) any steam jacketed vessel used under steam for boiling, heating, or disinfection purposes.

It also includes the setting, smoke stack, and all fittings and mountings, steam or other pipes; feed pumps and injectors and other equipment necessary to maintain the safety of the boiler.

Return No. 1

In this return is recorded the number of boilers of the various types added to our registrations during the year; those of Western Australian origin exceed by 206 the number of pressure vessels imported.

Return No. 2

This return shows the number of each type and overall total in the register of useful boilers. Of the total 3,105 were not in service.

Return No. 3

This contains a summary of operations for the year.

Manufacture of boilers in this State for export to other Australian States shows an increase of approximately 45 per cent. compared with 1966. One hundred and thirty four were sent to other Australian States and, in addition, seven were exported outside Australia.

Imports into Western Australia from other States showed a slight increase but there was a marked decrease of over 50 per cent. in imports from outside Australia.

In the field of boiler exports the numbers shown are again made up almost entirely of package boilers from one firm. Imports range over a variety of vessels including portable air receiver units, engine starting air receivers and some large L.P. Gas and anhydrous ammonia vessels. Several more large water tube boilers have been commissioned and more are being erected.

Construction of another big iron ore project has commenced and nickel production is under way with considerable expansion planned together with a refinery at Kwinana. Other industries, both large and small, in Perth, Fremantle and Kwinana are also expanding or being established.

MAINTENANCE AND MISCELLANEOUS

I am pleased to report that maintenance and operation of boilers and pressure vessels was again of quite a high standard during the year. As usual large plants were well up to the mark and a pleasing feature with smaller installations is the increasing use of maintenance firms specialising in this type of work.

It is still felt that we are not doing enough in the working inspection field, again due to shortage of staff. However in the examination of Boiler Attendants emphasis is laid on checking the knowledge of the candidate concerning requirements to ascertain and maintain the water level in a boiler.

One field where correct operating procedure is lacking is air receivers, particularly in service stations. It is not uncommon for an Inspector to arrive on site before the vessel is blown down and prepared. On many occasions it is found that the vessel has a large amount of water in it. This of course leads to premature corrosion. It appears that as most service station proprietors do not own the equipment many of them do not care.

Manufacture of boilers and pressure vessels in Western Australia has maintained a good standard. The usual teething troubles are still experienced when a new fabricator tries his hand in this field.

The number of boilers and pressure vessels in Western Australia increased by 403 during the year.

Return No. 1

SHOWING THE NUMBER OF BOILERS OF EACH TYPE AND COUNTRY OF ORIGIN OF NEW REGISTRATION FOR THE YEAR ENDED 31/12/67

Types of Boilers	W.A.	Eastern States			U.S.A.	United Kingdom	Belgium	Sweden	Germany	Un-known Resources	Total
		Vic.	N.S.W.	QLD.							
Water Tube	7	2	1	....	....	....	....	....	....	....	10
Air Receiver	125	31	23	....	15	18	2	1	1	6	222
Gas Receiver	44	9	20	10	2	4	....	....	....	....	89
Steriliser	29	44	....	....	....	....	....	....	....	....	73
Autoclave	1	7	....	....	....	....	....	....	....	1	9
Steam Jacketed Vessel	20	....	8	....	....	....	....	....	....	....	28
Vulcaniser	2	6	....	....	....	....	....	....	....	....	8
Digester	13	1	....	....	....	1	....	....	....	....	15
Return Multi. Stat. Intern. Fired	177	....	....	....	....	....	....	....	....	....	177
Return Multi. Stat. U/Fired	2	....	....	....	....	....	....	....	....	....	2
Horizontal Electric	....	....	....	....	....	....	....	....	....	1	1
	....	100	52	10	....	....	....	....	....	....	....
Total	420	162			17	23	2	1	1	8	634

Return No. 2

SHOWING CLASSIFICATION OF VARIOUS TYPES OF USEFUL BOILERS IN PROCLAIMED DISTRICTS ON 31/12/67

Type of Boiler	Districts Worked from Perth	Districts Worked from Kal-goorlie	Total
Lancashire	31	27	58
Cornish	211	66	277
Semi Cornish	14	1	15
Vert. Stationary	390	45	435
Vert. Port.	30	12	42
Vert. Multi. Stat.	38	4	42
Vert. Multi. Port.	4	1	5
Vert. Pat. Tubular	49	....	49
Loco. Rect. F/box Stat.	72	17	89
Loco. Rect. F/box Port.	143	20	163
Loco. Circ. F/box Port.	84	3	87
Locomotive	75	12	87
Water Tube	541	59	600
Ret. Multi. U/fired Stat.	252	7	259
Ret. Multi. U/fired Port.	....	5	5
Ret. Multi. Int. fired Stat.	379	15	394
Sterilisers	906	75	981
Autoclaves	119	2	121
Digesters	332	6	338
Gas Receivers	897	4	901
Air Receivers	2,812	814	3,626
Vulcanisers	449	12	461
Steam Jacketed Vessels	751	15	766
Not specified elsewhere	293	5	298
Total Registrations Useful Boilers	8,872	1,227	10,099
Total Boilers out of use, 31/12/67	2,258	847	3,105

Return No. 3

SHOWING OPERATIONS IN PROCLAIMED DISTRICTS DURING YEAR ENDED 31/12/67

Boilers	Districts Worked from Perth	Districts Worked from Kal-goorlie	Totals	
			1967	1966
Total number of useful boilers registered	8,872	1,227	10,099	9,696
New Boilers registered during year	634	12	646	623
Boilers inspected thorough	5,157	318	5,475	5,603
Vessels exempt under Act constructed for export thorough	....	....	....	....
Boilers inspected working	1,457	58	1,515	1,053
Boilers condemned during year temporarily	1	....	1	2
Boilers condemned during year permanently	106	3	109	53
Boilers sent to other states during year	134	....	134	92
Boilers sent from other states during year	162	....	162	151
Boilers sent from other countries during year	44	....	44	98
Boilers sent to other countries during year	7	....	7	1
Transferred to other Departments	....	....	....	3
Transferred from other Departments	....	....	....	1
Re-instated	2	....	2	1
Converted	....	....	....	....
Number of Notices of Repairs issued during year	615	103	718	686
Number of certificates issued including those issued under Sec. 30 during year	5,485	336	5,821	5,671

Section 2

EXPLOSIONS AND INTERESTING DEFECTS

I regret to report that during the year there were three explosions. The first (case "A") concerns a water tube boiler and resulted in the death of the Boiler Attendant; the second (case "B") also involved a water tube boiler but was a furnace explosion and fortunately only slight injury to the operator resulted. The third instance (case "C") concerns a petroleum products storage tank which was being air tested when the end blew out fatally injuring a welder.

Case "A".

The water tube boiler involved in this mishap was the type with the mud drum attached by expanded nipples to the bottoms of the rear headers. Prior to the accident the mud drum had been replaced with a new one. This had necessitated the renewal of all the nipples. This work had been carried out without the supervision of this Branch.

Events leading to the mishap were as follows. After the renewal had been completed a slow fire was lit in the fire box which was kept going for a day without raising pressure. On the second day pressure was gradually raised to 175 p.s.i. when the engineer went into the back end and checked the mud drum and nipples for any leakage. None was found.

It was not intended to put this boiler into service immediately so pressure was reduced and the fires banked. However one of the other boilers developed a header cap leak and the repaired boiler was brought up to pressure and used for approximately 20 hours when it was again taken off line and the fires banked. Approximately three hours later an explosion occurred in the boiler room which was filled with steam, smoke and dust. When the engineer managed to find his way into the boiler room he found the fireman struggling towards the door. He was very severely burnt and died in hospital later the same day. It was not possible to get a statement from him.

When the boiler was inspected after the accident it was found that the blow down drum had become detached from the boiler and come to rest approximately 3 feet to the rear. The contents of the boiler escaped and the victim, who was thought to be standing in front of the open fire box door, was caught in the path of the escaping steam.

The displacement of the mud drum was found to be due to the mud drum nipples drawing out of the expansions, eight from the mud drum header and one from a rear header.

It is considered that the nipples were insufficiently expanded onto their landings at the time of the repairs and were not bell mouthed. Additionally it is believed only a token hydrostatic test to much less than working pressure was applied. This was done without official sanction. Furthermore the header was packed up on bricks during the hydrostatic test and subsequent steaming which would restrict the expansion and floating characteristics and could be contributory to the failure.

This accident points out the need for skill and experience in all boiler work and the necessity to comply with statutory requirements at all times.

Case "B".

This explosion, as previously stated, was in the furnace of a water tube boiler but of much more modern design and considerably greater output. It was oil fired and fitted with quite sophisticated controls and indicating panels. Fortunately no loss of life occurred but the damage to the boiler was extensive.

Prior to the explosion there had been trouble with the fuel oil pressure thought to be due to air having entered the fuel lines. The pressure dropped so much that it was necessary to shut the boiler down. The shift supervisor then spent a considerable time attempting to regain the oil pressure and during this period the boiler attendant stated he went through the furnace purging sequence three times. Eventually, approximately two hours after the shut down, oil pressure had recovered sufficiently for the supervisor to attempt to flash the boiler. The purge procedure was again performed and when the annunciating panel lights indicated that this had been completed flashing up was attempted and the explosion resulted.

It appears from investigation that with low oil pressure and other abnormal conditions existing at the time flash up was attempted either the instrumentation indicators had become unreliable or the operator's interpretation of them was not correct. Study of charts from recorders on air flow indicates that the final purge was not effectively accomplished as a damper remained closed or nearly so at this time. In addition it is believed fuel was being sprayed into the furnace for some time before the flash up so that the combustion chamber contained a large quantity of oil and gas trapped in it.

It is felt that this mishap emphasises the need for reservations in relying completely on instrumentation and also instruction in interpreting the instruments so that variations are viewed with suspicion and physical checking is immediately carried out to verify the conditions. The foregoing presupposes efficient maintenance at all times on the instruments.

Case "C".

The vessel which failed in this instance was not a pressure vessel but an oil storage tank. However as it was being tested, at the manufacturer's, by means of compressed air supplied from a registered air receiver it was the subject of investigation by this Department.

The usual procedure in this plant is to test every tank after welding by filling it with compressed air to a maximum of 5 p.s.i. and then brushing soap and water solution on all the welds to detect any leakage.

The Inspector who investigated this accident found that compressed air mains were fitted along both sides of the shop. Each side had one at receiver pressure (90-100 p.s.i) and on one side a reduced line at 4 p.s.i. specifically for the test purpose outlined above. In addition a portable reducing unit fitted with reducing valve on inlet to a small air receiver from which the outlet was approximately 5 p.s.i. was supplied.

It appears that the victim had finished welding the tank and connected up for air testing which he was doing when one end blew out hitting him and inflicting fatal injuries. Checking after the accident showed the tank to be coupled directly to the 90-100 p.s.i. line, and it is thought that this excessive pressure caused the rupture of the end to shell weld.

It is difficult to understand why the welder coupled the vessel direct to the higher pressure line as he had been working at the same job for several weeks and had carried out the testing operation on many occasions.

This accident does point out the need to clearly identify various air lines which have different operating pressures and to make sure all personnel are aware of the differences. A further safeguard is to have a special type of coupling reserved for low pressure air so that low pressure equipment can only be connected to the low pressure line or portable reducing unit.

INTERESTING DEFECTS

In this section I will list some of the more interesting defects which have occurred and attempt to give reasons and/or causes.

1. A low water condition occurred with an internally fired multi-tubular boiler which resulted in severe damage, fortunately without violence. The furnace crown was brought down over almost the full length and almost touching the bottom. It also tore away from the tube plate at the back end. Most of the plain tubes were started in their expansions. We were unable to pinpoint the cause but the boiler was unattended at the time and had been for a number of hours.

2. This concerns a 16 in. diameter jacketed autoclave with 3/16 in. t. stainless steel inner, 10 gauge stainless steel outer. Cracks were found in the inner, two circumferential at approximately 5 and 7 o'clock with a short longitudinal crack at 6 o'clock. The cracks were towards the back end of the shell and when the outer was stripped off were found to be in line with the circumferential fillet weld attaching the rear foundation ring to the inner shell. It is thought the circumferential cracks could have started at the toe of the fillet weld. Some undercut was present at the start of the longitudinal crack. The inner was condemned.

3. This also concerns sterilizing vessels but of the square design in this instance. In this particular design the doors are of mild steel. The inside face is protected by a 20 gauge stainless steel false plate. This plate also carries the square jointing material which is held in a groove formed by bending up the edges of the stainless material to an angle of 105 degrees to form the outside of the groove. The inside of the groove is formed by angled pieces bent at 85 degrees and spot welded to the main sheet. In the case of the vessel in question it was reported to this Department that the door joint had blown out under pressure.

Investigation showed that the top section of jointing had blown out because the metal forming the inside and outside edges of the jointing groove had cracked off almost flush with the main plate. Fortunately nobody was injured.

Inspection of the false plate showed cracking in the same positions on all the other sides but worst towards the top. It is thought that the bends to form the sides of the groove, being very sharp, little or no radius being evident, set up high stresses in the metal at that point leading to stress corrosion cracking. In an attempt to overcome this fault the material thickness has been increased to 18 gauge and the radius of the bends has been appreciably increased.

4. This case history concerns a portable air compressor unit on which the air receiver was made from high tensile carbon manganese steel plate. The type of defect is not uncommon and will not be remarkable to inspecting bodies or other people versed in the use of high tensile material. It is included in the hope that some users of this type of equipment may be alerted to difficulties which arise from its use.

The vessel in question was being used on a construction project approximately 400 miles from Perth. It was reported to the Inspector in the district that it had developed a crack in the shell in way of a tangential oil stand pipe. When an inspection was made it was found that an unsuccessful attempt had already been made to weld the crack without reference to this Department and without knowledge of the material. In order to carry out a sound repair it was necessary to bring the vessel to Perth, cut out the stand pipe and approximately a 9 in. diameter section of shell plate round it to eliminate the crack. Plate of a similar composition is not readily avaliable in Perth. However some was found and after rolling to the shell radius the stand pipe was welded into the patch and the patch in turn was welded into the shell using backing strips. All welding was carefully controlled, after procedure qualification, using low hydrogen rods.

It is felt that the use of higher tensile steel in this type of vessel could be of doubtful value. When made in big quantities there is material saving but I feel that the reduced thickness of material in a vessel for use in portable plants on construction reduces the capacity to absorb mechanical shock, rough treatment and the vibration usually associated with such plants. Additionally, if cracks develop or any other repair is required it is difficult in out of the way places to find qualified welders, electrodes, etc. to carry out repairs. This necessitates sending the vessel many miles for repair, that is if it is realised that such care is necessary. If not a bodged repair will be made on site which could lead to complete failure of the vessel with consequent danger to persons.

Section 3

INSPECTION OF MACHINERY

(See Returns Nos. 4, 5 & 6)

At the end of the year 56,569 groups of machinery were registered, an increase of 2,407 groups compared with 1966. Of this total number of groups almost 40% were NOT inspected during the year owing to shortage of staff. Lift and escalator figures were increased by 55 new installations, 10 installations were removed from service, making a nett gain of 45. In this field the checking of new submissions and inspection and testing of same has been almost a full time job for one Inspector. Owing to pressure of work and again staff shortage regular inspections of installed lifts are few and far between.

ACCIDENTS TO MACHINERY

Again this year I regret that most accidents involving machinery led to injury to persons. Mobile cranes figured in several mishaps. Two of the latter are considered worth reporting because investigations revealed in one case substandard construction and the other use of a crane outside the maker's recommended loadings.

The first case concerns a locally designed and built machine. When submitted the design was checked and reluctantly approved for very restricted conditions of working. The construction was carried out by a firm with no experience of this class of work but a certain amount of antagonism to the requirements laid down by the Department. Supervision of construction was considered adequate but unfortunately was not continuous. The machine was tested on completion and appeared satisfactory for the stipulated loads. Approximately two years later the crane was working when the driver noticed movement in the jib and thought the crane was slewing. This was not the case and he then realised that the 60 ft. jib was collapsing sideways which continued till it fell across a conveyor. Fortunately nobody was injured.

Examination after the accident showed that the welding of the jib hinge pin bracket had failed. Further examination of the failed brackets revealed that instead of being made from 2"t. solid material as they appeared, they were in fact fabricated from several pieces of 3/8"t. and 3/4"t. plate forming the sides with edges covered by a strip of flat 1/8" plate. This gave the appearance of solid plate. The welding was extremely poor and appeared to have been done by an inexperienced welder.

This type of mishap shows the difficulties experienced by Inspecting Authorities when this type of design and construction is carried out by people, new in the field, with very little appreciation of the loadings involved, and with equipment and techniques below required standard. It is almost impossible to have an Inspector on site all the time during manufacture but in this case it appears it would have been warranted. Fortunately incidents such as the foregoing are the exception rather than the rule.

This second incident involves a 37-ton mobile crane, of reputable manufacture, being used to erect some heavy main building columns. These columns were not straight but had an offset section at the top. During this operation the crane lost stability and turned upside down, completely wrecking the jib in the process. Fortunately nobody was injured.

Enquiries revealed that there were two main contributing factors in this mishap. Firstly, the rigging of the crane to lift this load was not included in the regular load chart. Secondly, the load was moved outside the radius which had been deduced under the conditions above.

The basis on which the condition mentioned above was founded was reasonably sound as follows. The site engineer noted that there was a reduction in allowable load of approximately 2000 lbs. for each 10 feet increase of jib length, up to 70 feet, at the same radius. There was then a decrease of 11,000 lbs. at the next jib length increment, i.e., 80 feet. This seemed an excessive reduction until he realised that at this point the hoist rope was reduced to 3 parts against 4 parts used at the shorter jib lengths. He therefore assumed that by getting a longer hoist rope and reeving it in four parts he could lift the weight of the columns with safety at a 21 feet radius. The thinking in this exercise was logical but it was then put into practice without reference to this Department or the manufacturer.

It is most likely that the job would have been successfully accomplished but the second factor, previously mentioned, intervened.

Owing to the length of the columns the crane jib had insufficient length to enable the column to be picked up near enough to the top so that it would hang vertically. This, together with the offset top section, caused the load to hang at an appreciable angle. This condition had not been foreseen in setting up the crane which was placed so that at the estimated maximum radius the hook was over the column footing. However when it came to placing the base of the column on the footing the base was well inside the vertical hook line. This was not realised and in luffing out to line the base up with the footing the maximum radius was exceeded by approximatly 5-6 feet. This was sufficient to destroy the stability and overturn the machine.

This incident emphasises that cranes should not be used for conditions outside the maker's load chart, and more importantly, the necessity to watch the working radius very carefully when working at maximum loads and radii. In effect the machine was really too small for the job asked of it.

Return No. 4

SHOWING CLASSIFICATION ACCORDING TO MOTIVE POWER OF GROUPS OF MACHINERY IN USE OR LIKELY TO BE USED BY PROCLAIMED DISTRICTS AND WHICH WERE ON THE REGISTER DURING THE YEAR ENDED 31st DECEMBER, 1967

	Disrticts Worked from Perth	Districts Worked from Kalgoorlie	Totals 1967	Totals 1966
Number of groups driven by Steam Engines	118	367	485	484
Number of Groups driven by Oil Engines	4,095	913	5,008	4,799
Number of Groups driven by Other Power	145	199	344	330
Number of Groups driven by Electic Motor	46,882	3,850	50,732	45,548
Total	51,240	5,329	56,569	54,161

Return No. 5

SHOWING OPERATIONS IN PROCLAIMED DISTRICTS DURING YEAR ENDED 31st DECEMBER, 1967

(MACHINERY ONLY)

	Districts Worked from Perth	Districts Worked from Kalgoorlie	Totals	
			1967	1966
Total Registrations Useful Machinery	51,240	5,329	56,569	54,162
Total Inspections made	31,547	3,094	34,641	34,824
Certificates (Bearing Fees)	6,072	446	6,518	6,293
Notices issued (Machinery Dangerous)	616	43	659	709

Return No. 6

SHOWING CLASSIFICATION OF LIFTS ON 31st DECEMBER, 1967

Types	How Driven	Totals	
		1966	1967
Passenger	Electrically Driven	466	366
Passenger	Electric Hydraulic Driven	22	22
Goods	Electrically Driven	128	127
Goods	Electric Hydraulic Driven	11	10
Service	Electrically Driven	187	150
Service	Electric Hydraulic Driven	4	4
Escalators	Electrically Driven	49	46
		867	725

Section 4

PROSECUTIONS FOR BREACHES OF THE ACT

The prosecution, mentioned in last year's report as having been initiated, was successfully concluded with the conviction of the owner of a crane used without being certificated by this Department.

Section 5

ACCIDENTS TO PERSONS

Returns 7 and 7a record accidents to persons in which machinery subject to the Act was involved. The former relates to those of a serious nature, the latter to accidents classified as being minor.

Return 7b shows accidents caused by machinery not subject to registration by this Department but investigated under the provisions of Section 50 of the Act.

During the year four (4) fatalities occurred involving a boiler, an oil rig, a fuel tank and a mobile crane. The majority of the serious accidents occurred on metal stamping presses and buzzer planing machines. These machines are in common use but operators will persist in using them without the guards fitted.

CASE "A"

This fatality occurred on an oil drilling rig and the particular part concerned was a "pick up elevator". This component is made up of a loose fitting pipe clamp, hinged at one side so that it can be placed round sections of bore casing, closure is effected by a snap catch and locked in position by passing a pin through holes in the mating lugs of the two halves. This clamp is connected by two wire rope slings to the rig "travelling block" which is the main hoisting mechanism on the rig and is centred over the hole being drilled. The casing is picked up in two movements. One end is lifted from the "cat walk", where the lengths of casing are kept (the casing is 9.5/8" O.D. x .395" wall thickness in 30 ft. lengths), by the "cat line". This moves the length of casing up over the edge of the rig platform so that the "Pick up Elevator" can be attached for the lift up and over the hole. Speed is the essence hence the quick attachment and release clamp ("Pick up Elevator").

In the case in point the "Pick up Elevator" had been attached to a length of casing and one end of the casing had been hoisted up approximately 20 feet when the "Pick up Elevator" opened, dropping the load which struck the victim inflicting fatal injuries.

Examination of the clamp showed that it was possible to "snap" the elevator closed with the safety pin in position, however the pin is not then on the correct side of the main catch arm, nor is the catch fully engaged. In this condition a slight bump is all that is necessary to open the elevator.

The investigating Inspector reported:

> I consider the above situation could arise if the "Pick up Elevator" is not quite parallel with the casing when it is "snapped shut".
>
> In my opinion this is most likely what happened and as the travelling block was hoisted with the free end being dragged across the floor a jolt or bump caused the "Pick up Elevator" to open.

CASE "B"

This mishap which resulted fatally was rather unusual in that the machine involved, a tractor powered hydraulically operated jib crane, was still under construction and had not reached the stage of testing, registration and certification by this Department.

At the time of the accident the machine was in the painting section. Painting was complete with the exception of the hook, steps and wheel centres which are black in contrast to the predominant yellow of all other components. Deceased had completed the painting of the wheel centres and it is assumed he intended to do the hook next. In order to do this it was necessary for him to lower the hook which required the starting of the machine to drive the hoisting winch. It appears he moved to a position where he could reach the ignition key which also incorporated the starting mechanism. In this position he was against the machine just in front of one of the rear wheels. Reconstruction of events after the mishap, there were no witnesses, indicates that as soon as the key was turned the machine moved forward running the victim down. It was found that the machine had been in low gear and the throttle was in notch 5 on a 16 notch quadrant. The crane finished up 70 feet from starting point and stopped itself by running into a wire fence.

This unfortunate accident shows the need for great care in this painting operation as the gear, lever, throttle and other parts have to be moved from time to time so that all parts are fully painted. It also indicates the wisdom of the Company rule that machines shall only be started from the driving position which the victim ignored.

CASE "C"

This mishap concerns a tower crane and caused injuries to two persons. Such was the nature of the accident that I feel it was very fortunate nobody was killed.

At the time of the accident the tower section of the crane had been lengthened and the jib and counterweight section was being hoisted to its new position, approximately 26 feet above the previous working position. Five men were engaged in the operation, three on the crane and two on the adjacent partly completed building holding tail ropes. The three men on the crane were disposed as follows, one at the pendant control on a platform inside the tower structure on the same level as the driver's cab, one on top of the tower watching the hoist rope passing over the sheaves, and the other moving up inside the tower watching the progress of the jib and counterweight assembly. The hoisting had been in progress for some time and according to all witnesses had proceeded smoothly. The assembly was within 2' 6" of the new position when the hoist rope parted dropping it back to its previous position, approximately 20 feet lower. When it hit the stops at the previous position the four vertical slewing ring struts failed, the jib bent down and struck the ground and the counterweight bent down hitting the tower about mid height.

The two men inside the tower were jolted loose and both fell approximately 20 feet inside the tower till their falls were arrested by platforms below.

In spite of a thorough investigation the source of the overload which undoubtedly caused the rope, which was in good condition, to break, could not be definitely pinpointed. However several recommendations to avoid repetition of this failure have been made. The crane in question was written off.

CASE "D"

In this accident a crane was also involved and again it was fortunate that a fatality did not result. The incident is noteworthy not so much for the accident as the rigging conditions of the crane revealed by investigations.

The crane in question was a large mobile being used with 130 feet of main jib and 30 feet of fly. The job in hand was the erection of a flood light tower to a final height of approximately 150 feet. The method employed was to lift prefabricated sections approximately 35 feet long into position with the crane where they were secured by riggers. During one of these operations the hoist brake slipped and allowed the suspended tower section to fall onto the already erected section. This resulted in a rigger being injured.

The crane brake was stripped down and it was found that some foreign material had been introduced into the brake drum and brake linings. It is thought this caused the slippage. During investigations the Inspector checked the main jib and fly lengths against the maker's load chart. It was found that 130 feet main jib and 30 feet fly jib was outside the permissible, which was either 130 feet main jib and no fly or 110 feet main jib plus 40 feet fly. Although this did not contribute to the accident it shows an irresponsible outlook on the part of the crane owner in ignoring the approved load chart. Such an attitude is deplored by both the manufacturer and this Department.

Section 6.

EXAMINATION OF ENGINE DRIVERS, CRANE DRIVERS AND BOILER ATTENDANTS.

During the year the Board of Examiners granted 137 Engine Drivers', 357 Crane Drivers' and 114 Boiler Attendants' Certificates of Competency.

Compared with 1966 these figures show an increase of 1, a decrease of 117 and an increase of 7, respectively.

These figures show a slackening, compared with last year, in the number of crane drivers examined, to slightly above the numbers for 1965. There was a slight increase in other certificates. This has not meant a respite for the Board members, whose Board activities are only a part of their duties.

During the year a number of amendments to the Act and Regulations relating to Engine Drivers were drafted but were not presented to Parliament.

Section 7.

STAFF AND GENERAL.

I regret that once again I have to report that this year has proved frustrating to all concerned in attempting to administer the Inspection of Machinery Act. The staff has been increased by the addition, on a temporary basis, of two Supervising Inspectors which has lifted the load on myself and the Senior Inspector to a degree. Two temporary Inspectors have been granted to make up the numbers decreased by the creation of the two Supervising Inspector items. It is becoming increasingly clear that it is necessary to station an Inspector in the area of the iron ore mining activity, probably at Port Hedland.

This year saw the retirement of Mr. H. Q. Kennedy who had served the Department most efficiently and conscientiously for many years. Mr. A. Brown was transferred from this Department to Harbour and Lights Department. The losses of experienced staff for one reason or another increases the difficulty in efficient operation of the Branch.

Further difficulties due to the proposed transfer of this Branch to another Department have arisen. Discussion has been in progress for many months and this seems to create a reluctance to grant additional staff commensurate with the spectacular increase in industrial expansion in this State.

In the clerical section of the Branch an additional position of Assistant has been created. During the year Mr. Mell was finally appointed Senior Clerk after a considerable period in an acting capacity and the position Secretary to Board of Examiners was filled by Mr. Ward. Apart from the interruption to normal working created by the above change and delays there were approximately ten relief personnel of various types in other positions during the year. This means many changes of staff in almost every item leading to some inefficiency and mistakes which are not immediately apparent and sometimes are only discovered weeks later when the culprit has left the Branch.

Staff generally during the year have been working to capacity responding willingly to demands imposed on them. I am most appreciative of their loyalty and co-operation.

Thanks are due to the Police Department for the reporting of accidents and co-operation where joint investigations have been carried out.

In conclusion on behalf of all members of the Branch I wish to note our appreciation of the assistance given by yourself and all Mines Department officers when requested.

E. J. McMANIS,
Deputy Chief Inspector of Machinery.

Return No. 7

FATAL AND SERIOUS ACCIDENTS FOR 1967

Industry	Circular Saws	Spindle Moulder (Shaper)	Buzzer	Band Saw	Belts and Shafting	Conveyor Belts	Hoist	Dough Mixer	Abrasive Wheels and Belts	Lathe	Guillotine (Metal)	Guillotine (Others)	Boring Machine	Drilling Machine	Punch and Shears	Press	Printing Machine	Pad Cutter	Wool Opening Machine	Asbestos Sheet Making Machine	Steam Jacketed Vessel	Explosions	Boiler and Furnace Explosion	Rolls	Oil Drilling Rig	Tennoner	Bottling Machine	Pug Mill	Drop Hammer	Socket Parting Machine	Pipe Spinning Machine	Lifts	Tappering Machine	Splitting Machine	Feed Mill	Wrapping Machine	Wharf Crane	Mobile Crane	Winding Engine	Tower Crane	Chain Saws	Totals of Industry
Woodworking and Furniture	5	1	14	2	....	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	2	....	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	2	28
Metal Working and Engineering	1	....	....	1	....	....	....	....	4	4	3	....	1	2	1	11	....	....	....	....	....	1 and 1 (F)	1	....	....	....	....	1	1	....	....	....	....	....	....	....	....	....	....	....	....	1 (F) and 32
Printing and Allied Industries	1	....	....	....	....	....	....	....	....	....	....	1	....	....	....	....	1	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	4
Food and Drink Processing	....	....	....	....	....	2	....	1	....	....	....	....	....	....	....	....	....	....	....	....	1	....	....	....	....	....	1	....	....	....	....	....	....	....	....	1	....	....	....	....	....	6
Oil Exploration	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	1 (F)	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	1 (F)
Mining																																							1	....	....	1
Building and Building Materials																																						2	....	2	....	4
Wool Processing	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	1
Chemical Industries	....	....	....	....	....	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	1
Fertiliser Manufacture																																										....
Card Board Box Manufacture	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	1	....	....	....	....	....	....	....	....	1	....	....	....	....	....	....	....	....	2
Others	....	....	....	....	1	1	1	....	1	....	....	....	....	....	....	....	....	....	....	1	....	1	1 (F) 1	2	....	....	....	....	....	1	1	1	....	1	1	....	1	1 (F)	....	....	....	2 (F) 15
Totals, Type of Machine	7	1	14	3	1	5	1	1	5	4	3	1	1	2	1	11	1	1	1	1	1	1 (F) 2	1 (F) 2	5	1 (F)	1	1	1	1	1	1	1	1	1	1	1	1	1 (F) 2	1	2	2	4 (F) 94

Return No. 7a

MINOR ACCIDENTS FOR 1967

Industry	Circular Saw	Spindle Moulder	Buzzer	Band Saw	Belts and Shafting	Hoist	Abrasive Wheels and Belts	Lathe	Guillotine	Boring Machine	Drilling Machine	Punch and Shears	Press	Printing Machine	Staying Machine	Paper Ruling Machine	Rewind Machine	Lino Type Machine	Labelling Machine	Plate Freezer	Cutting Off Wheel	Batch Mixer	Duplex Slotter	Tube Winding Machine	Chair-O-Plane	Soaking Machine	Scotch Derrick	Mobile Crane	Totals of Industry
Woodworking and Furniture	3	2	1	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	7
Metal Working and Engineering	....	....	....	....	....	....	4	5	2	1	1	1	5	....	....	....	....	....	....	....	1	....	....	1	....	....	1	1	23
Printing and Allied Industries	....	....	....	....	....	....	....	1	....	....	....	....	....	2	1	1	1	1	....	....	....	....	....	....	....	....	....	....	7
Food and Drink Processing	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	1	1	....	....	....	....	....	1	....	....	3
Cardboard Box Manufacture	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	1	....	....	....	....	....	1
Others	....	....	....	1	1	1	....	....	....	....	1	....	....	....	....	....	....	....	....	....	....	1	....	....	2	....	....	2	9
Totals, Type of Machine	3	2	1	2	1	1	4	6	2	1	2	1	5	2	1	1	1	1	1	1	1	1	1	1	2	1	1	3	50

Return No. 7b

ACCIDENTS CAUSED BY MACHINERY NOT COVERED BY MACHINERY ACT

Industry	Circular Saws	Tapering Machine	Abrasive Wheels	Lathe	Drill	Press	Boring Machine	Hydraulic Ram	Stapling Machine	Feeding Machine	Drying Fan	Batch Mixer	Trimming Machine	Totals of Industry
Woodworking and Furniture	3	1	2	....	....	....	....	....	....	....	....	....	....	6
Metal Working and Engineering	1	....	....	1	1	3	1	1	....	....	....	....	....	8
Printing and Allied Industries	....	....	....	....	....	....	....	....	1	1	....	....	....	2
Cardboard Box Manufacture	....	....	....	....	....	....	....	....	1	....	....	....	....	1
Food and Drink Processing	....	....	....	....	....	....	....	....	....	....	1	....	....	1
Glass Manufacture	....	....	....	....	....	....	....	....	....	....	....	1	....	1
Others	....	....	1	....	....	....	....	....	....	....	....	....	1	2
Totals, Type of Machine	4	1	3	1	1	3	1	1	2	1	1	1	1	21

Return No. 8

SHOWING TOTAL OF ENGINE DRIVERS' AND BOILER ATTENDANTS' CERTIFICATES (ALL CLASSES) GRANTED IN 1967 COMPARED WITH 1966

——		Numbers 1967	Granted 1966
Winding	Competency including Certificates issued under Reg. 40 and Section 60 of the Act	8	6
First Class	" " " " " Reg. 40 and 45 and Sections 60 and 63 of the Act	29	28
Second Class	" " " " " Reg. 40 and Section 60 of the Act	16	10
Third Class	" " " " " Reg. 40 and 45 and Sections 60 and 63 of the Act	11	14
Locomotive and Traction	" " " " " Reg. 40 and Section 60 of the Act	4	8
Traction	" " " " " Reg. 40 and Section 60 of the Act	....	1
Internal Combustion	" " " " " Reg. 40 and Section 60 of the Act	44	45
Crane and Hoist	" " " " " Reg. 40 and Section 60 of the Act	357	474
Boiler Attendant	" " " " " Reg. 50 and Section 60 of the Act	114	107
Diesel Loco.—			
Class A	" " " " " Reg. 40 and Sections 53 and 56 of the Act	24	24
Class B	" " " " " Reg. 40 and Sections 53 and 56 of the Act	1	....
Interim Certificates	Section 61	2	4
Copies		16	18
		626	739
	Decrease compared with 1966	113	

Return No. 9

REVENUE AND EXPENDITURE FOR THE YEAR ENDED 31st DECEMBER, 1967, AND COMPARISON WITH PRECEDING YEAR

——	Revenue	
	1967	1966
	$	$
Fees for Boiler Inspections	13,282.07	13,641.89
Fees for Machinery Inspections	20,111.68	20,486.32
Fees from Engine Drivers	2,414.20	2,724.67
Incidentals	499.35	706.06
Total	36,307.30	37,558.94

Decrease in Revenue compared with 1966—$1,251·64

——	Expenditure	
	1967	1966
	$	$
Salaries	113,796.12	106,399.63
Incidentals	21,789.60	19,728.89
Engine Drivers' Examinations	841.71	1,050.60
Totals	136,427.43	127,179.12

Increase in Expenditure compared with 1966—$9,248·31

Return No. 10

SHOWING DISTANCES TRAVELLED, NUMBER OF INSPECTIONS MADE AND AVERAGE MILES TRAVELLED FOR INSPECTIONS FOR THE YEAR ENDED 31/12/67

——	Road Miles	Air Miles	Rail Miles	Water Miles	Collective Mileage all Transport Services	Number of Inspections	Average Miles per Inspection
Districts operated from Perth	138,844	8,100	*Nil*	*Nil*	146,944	38,161	3.85
Comparison with 1966	Inc. 7,320	Inc. 6,010	*Nil*	*Nil*	Inc. 13,330	Inc. 914	Inc. .27
Districts operated from Boulder	16,574	*Nil*	*Nil*	*Nil*	16,574	3,570	3.801
Comparison with 1966	Inc. 1,938	*Nil*	*Nil*	*Nil*	Inc. 1,938	Dec. 662	Inc. .343
Totals	155,418	8,100	*Nil*	*Nil*	163,518	41,731	3.85
Comparison with 1966	Inc. 9,258	Inc. 6,010	*Nil*	*Nil*	Inc. 15,268	Inc. 251	Inc. .28

Note Abbreviations :—Inc. = Increase ; Dec. = Decrease.

Average Miles per inspection all districts, 1967 .... 3·85
Average Miles per inspection all districts, 1966 .... 3·57
Increase per inspection compared with 1966 .... Inc. 0·28

DIVISION VII

Government Chemical Laboratories Annual Report—1967

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, 1967.

Administration:

The Laboratories consist of six Divisions, a Physicist and Pyrometry Section, 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 and Water Supply Division—H. C. Hughes, B.Sc., A.R.A.C.I., Divisional Chief.

Engineering Chemistry Division—S. Uusna, Dr. Ing., M.Aust.I.M.M., A.M.I.E. (Aust.), M.Inst.F., Divisional Chief.

Foods, Drugs, Toxicology and Industrial Hygiene Division—N. R. Houghton, B.Sc., A.R.A.C.I., Divisional Chief.

Fuel Technology Division—R. P. Donnelly, M.A., B.Sc., C.Eng., M.I. Gas Eng., A.M.I. Chem. Eng., M.Inst.F., Divisional Chief.

Industrial Chemistry Division—A. Reid, M.A., B.Sc., A.R.I.C., A.P.I.A., M.S.P.I., Divisional Chief.

Mineralogy, Mineral Technology and Geo-Chemistry Division—G. H. Payne, M.Sc., A.W.A.S.M., A.R.A.C.I., Divisional Chief.

Physics and Pyrometry Section—N. L. Marsh, B.Sc.

Librarian—Miss J. E. Maughan, B.A.

Office—Miss D. E. Henderson, Senior Clerk.

At 31st December, 1967, the staff of the Laboratories numbered 115, being

Professional	62
Cadets	5
General	32
Clerical	10
Wages	6

Because we are still unable to cope expeditiously with all the work required by Government Departments and the public, provision was made in the 1967-68 Staff Budget for a further four Chemist and Research Officers and four Laboratory Technicians.

The close association of these Laboratories with other Government Departments, and with kindred associations was maintained during 1967 and various members of the staff are members of the following committees:—

Air Pollution Control Council.

Applied Science Advisory Committee.

Australian Coal Industry Research Laboratories Limited—Board of Management.

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.

National Coal Research Advisory Committee.

Oils Committee of the Government Tender Board.

Paints Advisory Committee of the Government Tender Board.

Pesticides Registration Committee.

Pesticides Residues Advisory Committee.

Phytochemical and Toxic Plants 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.

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 Air Pollution Control Council and the Scientific Advisory Committee under the Clean Air Act had meetings during the year to formulate regulations under the Act and these have now been promulgated.

The Fluoridation of Public Water Supplies Advisory Committee was active in preparing for the introduction of fluoride into public water supplies early in 1968. A large number of samples of water for analysis for fluoride is expected early in 1968, but even after the initial "teething troubles" it is anticipated that the regular control analyses of water samples will result in an increase of approximately 1,000 samples a year.

Dr. Uusna and Mr. Donnelly have continued regular attendance at meetings of the National Coal Research Advisory Committee and the Board of Management of the Australian Coal Industry Research Laboratories Ltd. respectively.

The Pesticides Registration Committee dealt with only 33 applications for registration of new pesticide formulations. The total number of applications considered by this Committee to 31st December, 1967, is 2,030. 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 145 samples of river water and 9 samples of effluents. The Veterinary Medicines Advisory Committee dealt with 935 applications, being 823 renewals, 77 new registrations, 9 changes of formula or claim, 7 deferred, 13 not required to be registered and 6 rejected.

In addition to the above Committees the Director was very much occupied during the year with the Amendment, Sections 32A, 32B, 32C and 32D, to the Traffic Act providing for the use of the Breathalyzer as well as blood samples for determining the concentration of alcohol in the blood of drivers. The Director is responsible not only for accrediting analysts for the blood samples but also the operators of the Breathalyzer for breath tests and is the expert witness on the Breathalyzer for Court purposes.

This amendment provides for the taking of a blood sample from the driver of a motor vehicle involved in an accident causing bodily injury requiring immediate medical attention. Since there are several thousand such accidents each year it was expected that some thousands of such samples would be received yearly after the amendment came into operation in October, 1966. However, this has not eventuated, very few such samples have been received in 1967.

The wide-spread 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 State Government Departments as shown in the Public Service List, 1967, 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 such as the University and the Museum, and Commonwealth Government Departments.

Table 1 shows not only that we were of assistance to 18 of the 28 Government Departments, but also shows the advantage of one centralised organisation for chemistry—an organisation containing the very wide range of specialised chemical knowledge required for today's problems. Each of a number of Government Departments required work done in a number of Divisions—indeed for only four of the 18 Departments was the special knowledge, ability and experience of only one Division sufficient. At the other end of the scale one Department required all six of our Divisions and our Physicist, another required all six Divisions, two others required five Divisions and two others required four Divisions.

Equipment.

Major items of equipment obtained in 1967 were an Auto-analyser and a Leitz Ortholux mineralogical microscope and accessories.

Accommodation.

The extensions to the Office and Laboratory at our Engineering Chemistry Division, Bentley, were completed and occupied during the year.

The great increase in the work of these Laboratories over the past five years, an increase which shows no signs of slackening, but rather of accelerating, makes it imperative to plan now for future building. A long term programme involving the re-planning of the site of the Laboratories has been submitted.

General.

The total number of registrations for 1967 was 4,419, an increase of nearly 10 per cent. over the 4,045 registrations for 1966. The number of samples received in 1967 was 20,570, an increase of 33 per cent. over the 15,522 received in 1966.

The increase in sample numbers, as indicating the increase in work undertaken in these Laboratories, during the past six years, is shown in the following Table. The increase is some 93 per cent. in five years. Indeed, in 1967, the number of samples received into one Division, that of Agriculture and Water Supply (11,543) was more than the number of samples received into the Laboratories in 1962 (10,658).

Year	Samples received
1962	10,658
1963	11,421
1964	12,962
1965	14,816
1966	15,522
1967	20,570

Table 1.

Department	Division							Laboratories
	Agriculture and Water Supply	Engineering Chemistry	Food and Drugs	Fuel Technology	Industrial Chemistry	Mineral	Physicist	
Agriculture	x	x	x		x	x	x	x
Audit								
Chief Secretary's			x					x
Child Welfare								
Crown Law								
Education	x							x
Electoral								
Fisheries and Fauna	x		x					x
Forests		x						x
Industrial Development	x		x		x	x		x
Labour			x			x		x
Lands and Surveys	x				x	x		x
Local Government								
Medical	x		x		x	x		x
Mental Health Services			x					x
Metropolitan Water Supply, Sewerage and Drainage	x					x		x
Mines	x	x	x	x	x	x	x	x
Native Welfare	x					x		x
Police			x			x		x
Premier's								
Public Health	x		x	x	x	x		x
Public Service Commissioner								
Public Works and Country Water Supplies, Sewerage and Drainage	x		x	x	x	x		x
State Government Insurance Office								
State Housing Commission	x					x		x
Town Planning								
Treasury	x		x					x
Workers' Compensation Board								
Total 28	13	3	12	3	7	12	2	18

Table 2

SOURCE AND ALLOCATION OF SAMPLES RECEIVED DURING 1967

Source	Division							Total
	Agriculture and Water Supply	Engineering Chemistry	Food and Drug	Fuel Technology	Industrial Chemistry	Mineralogy	Physicist and Pyrometry Officer	
State—								
Agriculture Department	7,772	1	1,038	....	2	5	20	8,838
Chief Secretary's Department	....	....	5	....	....	....	....	5
Departmental	35	1	5	70	27	258	3	399
Education Department	2	....	....	....	....	....	....	2
Fire Brigades Board	....	....	1	....	2	....	....	3
Fisheries & Fauna Department	135	....	15	....	....	....	....	150
Forests Department	....	1	....	....	....	....	....	1
Hospitals	1	....	79	1	....	....	....	81
Industrial Development Department	2	....	2	....	39	2	....	45
Institute of Agriculture	211	....	....	....	....	....	....	211
Labour Department	....	....	51	....	....	8	....	59
Lands & Surveys Department	4	....	....	....	1	1	....	6
Main Roads Department	....	....	....	....	....	8	....	8
Medical Department	25	....	2	....	1	1	....	29
Mental Health Department	....	....	145	....	....	...	....	145
Metropolitan Water Board	977	....	....	....	....	4	....	981
Milk Board	....	....	397	....	....	....	....	397
Mines Department	509	....	75	4	....	422	10	1,020
Museum	....	....	2	....	....	....	....	2
Native Welfare Department	1	....	....	....	....	6	....	7
Police Department	....	....	1,771	....	....	8	....	1,779
Public Health Department	31	....	388	1	7	38	....	465
Public Works Department	665	....	122	4	44	47	....	882
State Housing Commission	2	....	....	....	....	1	....	3
State X-Ray Laboratories	2	....	....	....	....	....	....	2
Swan River Conservation Board	28	....	162	....	....	....	....	190
Treasury Department	3	....	5	....	....	....	....	8
University	6	....	4	....	....	....	....	10
Western Australian Government Railways	....	....	1	....	....	....	....	1
Commonwealth—								
Air Department	5	....	2	....	....	....	....	7
Navy Department	....	....	2	....	....	....	....	2
Postmaster Generals Department	5	....	....	....	....	....	....	5
Public—								
Free	5	....	....	....	....	2,054	....	2,059
Pay	1,103	3	211	39	13	1,491	54	2,914
United States Medical Department	9	....	....	....	....	....	....	9
United States Navy	5	....	....	....	....	....	....	5
	11,543	6	4,485	119	136	4,354	87	20,730

The increase in our accommodation and staff which occurred late in 1966 has not enabled us to cope with the increase of 33 per cent. in samples from 1966 to 1967, and further provision must be made to handle the backlog of work and expected increase. At the end of 1967 the number of samples received but not reported was 4,057, compared with 3,234 at the end of 1966.

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.

The samples received during 1967 were allocated to the various Divisions of these Laboratories according to the specialised work undertaken by each Division, 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 and not six 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. To assist in this, we introduced in 1965 talks by senior chemists to groups of staff from other Divisions, talks on the work done, the facilities available and the capacity of those facilities.

Fees were charged for work undertaken for some State Government Departments, Government Instrumentalities, for 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, together with an appreciable amount of free mineral identification and assay to assist prospectors.

The summarised reports of the individual Divisions which follow show the very wide range of subjects dealt with by these Laboratories. Comparing 1967 with 1966 there were some marked alterations in the numbers of various types of samples received. These were:—

	1966	1967
Marked increase	1966	1967
Clover	535	1,074
Fertilisers	68	155
Gold samples	521	885
Industrial hygiene	183	297
Linseed	17	569
Lupins	—	208
Nickel ores	179	311
Oats	20	146
Pasture	854	1,431
Silver ores	32	105
Soils	784	2,057
Tantalite	28	93
Toxicology—human	718	1,116
Water	2,305	3,265
Wheat	1,756	2,031
Marked decrease	1966	1967
Butter	64	—
Cottonseed	84	—
Lithium ores	45	24
Manganese ores	41	—
Orange leaves	106	8
Toxic plants	162	—
Tin ores	266	170

A talk on "Corrosion and the Hospital Engineer" was given by the Deputy Director to the Annual Conference of the Institute of Hospital Engineers.

Organisation.

Of the marked increase in the activities of these Laboratories, an almost doubling since 1962, the greater portion has been in the Agriculture and

Water Supply Division and this is particularly applicable to numbers of samples, an increase of 6,786. This has resulted in a considerable increase in staff and consideration has been given to a re-organisation of this Division, which has a natural grouping of Agriculture on the one hand and Water Supply with its attendant problems on the other.

L. W. SAMUEL,
Director.

AGRICULTURE AND WATER SUPPLY DIVISION

The output of samples from the Division during 1967 was 11,121, compared with 7,942 in the previous year, thanks to the improved staff position, from 19 to 23, but also to a greater output from each staff member. Inspections and reports showed a commensurate increase.

Mr. E. Laidlaw, who had joined the technical staff of the Laboratories 12 years previously, was forced by ill health to retire during the year. We miss his ingenuity and willingness to help, if not indeed, "takeover", with any task where his assistance was required. New officers appointed at the end of 1966 adapted themselves well and we welcomed the further help of a lady laboratory attendant.

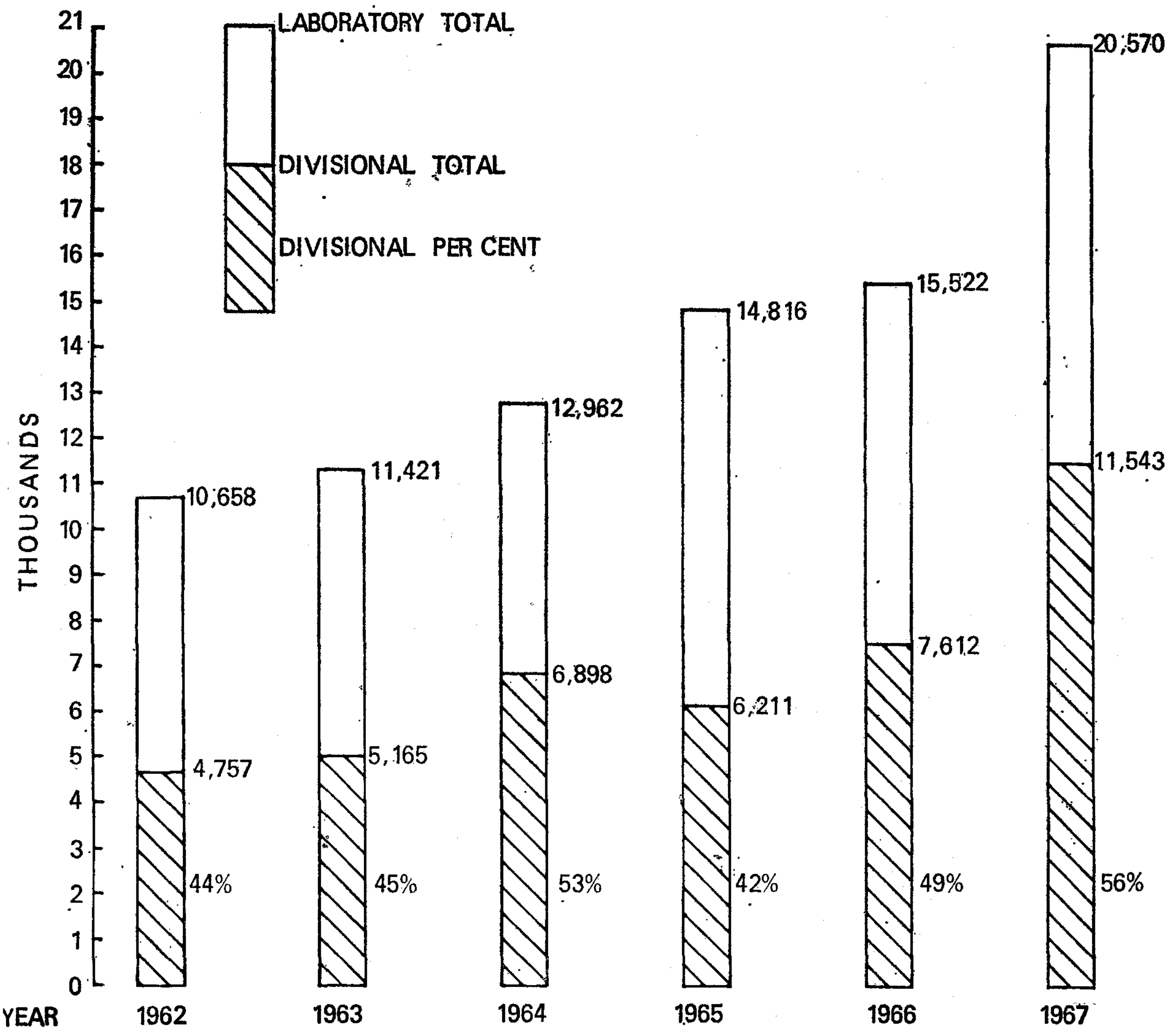
As shown in the numerical and graphical Table 3 and Figure 1 of samples received, while the receivals of the whole Laboratories have increased by 93 per cent. since 1962, the increase in the Agriculture and Water Supply Division has been 142 per cent. This increase accounts for 69 per cent. of the total Laboratories increase. The situation is reached where this Division received in 1967 more than the Laboratories as a whole in 1962.

In 1962 the effective staff of the Division numbered 16, by 1967 this had grown to 23. With already approved additions the positions in the Division will increase during the ensuing year to a nominal 29.

The administrative and supervisional problems presented both by the greater throughput of work, and the growth of staff to the stage where Agriculture and Water Supply will equal two of the major Divisions just six years previously, require a re-organisation of this Division and this has been given consideration.

TABLE 3

	1962	1963	1964	1965	1966	1967
Animal	262	546	64	154	160	23
Cereal	386	89	689	1,253	1,783	2,182
Fertiliser	110	61	151	205	68	155
Horticulture :						
Tobacco	162	581	....	....		....
Other	184	144	292	317	573	420
Miscellaneous :						
Oilseeds	466	329	360	452	....	....
Other	90	102	148	155	176	177
Feeding Stuffs	1,045	1,369	2,576	1,470	1,764	3,307
Soil	254	243	864	503	784	2,057
Water	1,798	1,701	1,754	1,702	2,304	3,222
Total	4,757	5,165	6,898	6,211	7,612	11,543



AGRICULTURE AND WATER SUPPLY DIVISION

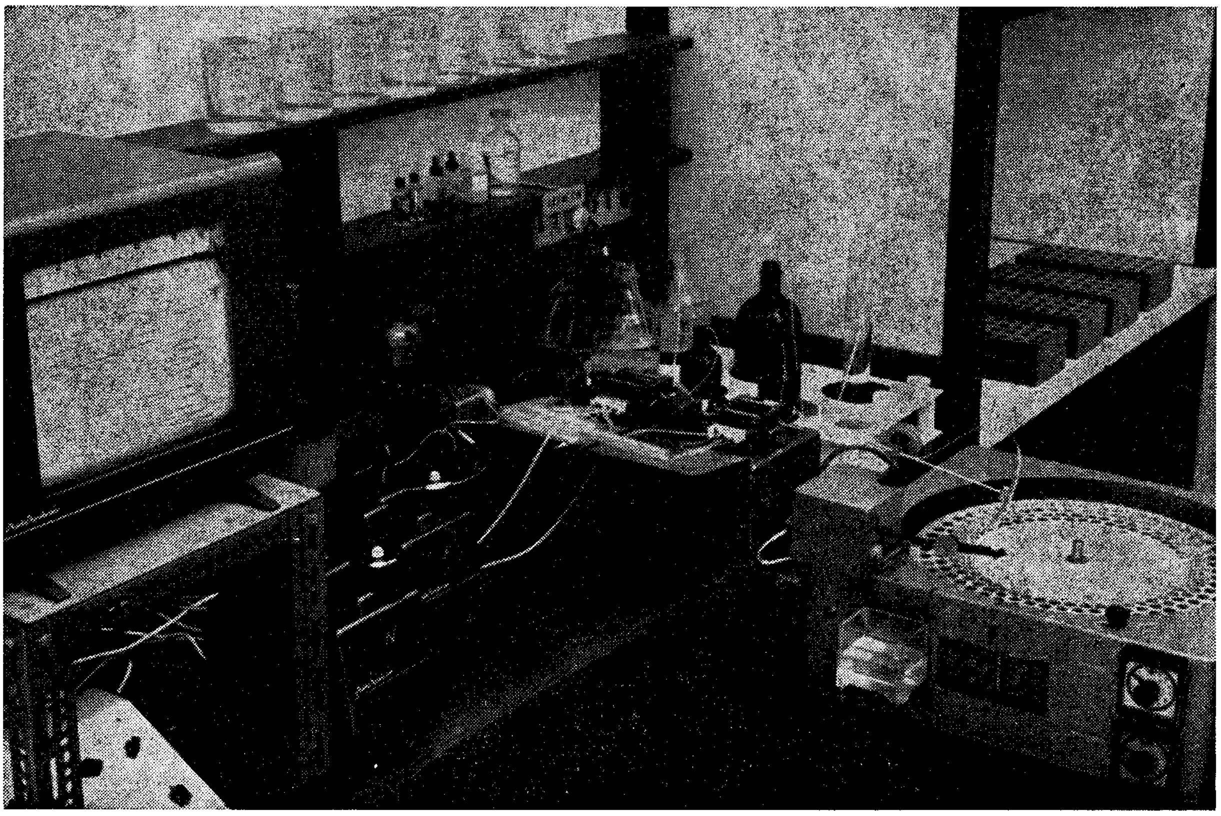
SAMPLES RECEIVED

FIG. 1

Table 4

AGRICULTURE AND WATER SUPPLY DIVISION

	Agriculture Department	Fisheries Department	Medical Department	Metropolitan Water Board	Mines Department	Public Free	Public Health Department	Public Pay	Public Works Department	Swan River Conservation Board	Other Govt. Departments	Other	Total
Animal—													
Bovine Blood	4	....	....	....	....	....	....	....	....	....	....	....	4
Liver and Kidney	19	....	....	....	....	....	....	....	....	....	....	....	19
Cereals—													
Oat :													
Hay	2	....	....	....	....	....	....	....	....	....	....	....	2
Plants	81	....	....	....	....	....	....	....	....	....	....	....	81
Tops	63	....	....	....	....	....	....	....	....	....	....	....	63
Wheat :													
Grain	563	....	....	....	....	....	....	....	....	....	....	....	563
Grain and flour	9	....	....	....	....	....	....	....	....	....	....	....	9
Plant	379	....	....	....	....	....	....	....	....	....	....	....	379
Straw	59	....	....	....	....	....	....	....	....	....	....	....	59
Tops	1,021	....	....	....	....	....	....	....	....	....	....	....	1,021
Various	3	....	....	....	....	....	....	2	....	....	....	....	5
Fertiliser—													
Fertilisers Act	78	....	....	....	....	....	....	....	....	....	....	....	78
Fertiliser	38	....	....	....	....	....	....	5	....	....	....	....	43
Gypsum	....	....	....	....	....	....	....	4	....	....	....	....	4
Lime	2	....	....	....	....	....	....	28	....	....	....	....	30
Horticulture—													
Apple :													
Leaves	353	....	....	....	....	....	....	....	....	....	....	....	353
Twigs	3	....	....	....	....	....	....	....	....	....	....	....	3
Banana leaves	14	....	....	....	....	....	....	....	....	....	....	....	14
Bean leaves	10	....	....	....	....	....	....	....	....	....	....	....	10
Citrus leaves	11	....	....	....	....	....	....	....	....	....	....	....	11
Various	29	....	....	....	....	....	....	....	....	....	....	....	29
Miscellaneous—													
Clay	....	....	....	....	....	....	....	13	....	....	....	....	13
Corrosion	....	....	6	1	....	1	....	23	8	17	1	12	69
Effluent	....	....	....	1	1	....	....	....	....	9	....	....	11
Sodium silicofluoride	....	....	....	6	....	....	....	....	....	....	....	....	6
Various	4	34	....	3	3	....	10	11	8	....	3	2	78
Pasture and Fodders													
Cape weed	40	....	....	....	....	....	....	....	....	....	....	....	40
Clover	1,074	....	....	....	....	....	....	....	....	....	....	....	1,074
Clover and grass	100	....	....	....	....	....	....	....	....	....	....	....	100
Clover and pasture	55	....	....	....	....	....	....	....	....	....	....	....	55
Feeding Stuffs Act	4	....	....	....	....	....	....	....	....	....	....	....	4
Grass	192	....	....	....	....	....	....	....	....	....	....	....	192
Grass and weeds	40	....	....	....	....	....	....	....	....	....	....	....	40
Lucerne	40	....	....	....	....	....	....	1	....	....	....	....	41
Lupin	....	....	....	....	....	....	....	....	....	....	....	208	208
Pasture	1,431	....	....	....	....	....	....	....	....	....	....	....	1,431
Poultry feeds	32	....	....	....	....	....	....	3	....	....	....	....	35
Stock foods	39	....	....	....	....	....	....	4	....	....	....	3	46
Various	11	....	....	....	....	....	....	29	1	....	....	....	41
Soil	1,946	....	....	....	....	....	....	109	2	....	....	....	2,057
Water	23	101	19	966	540	4	21	871	646	2	12	17	3,222
	7,772	135	25	977	544	5	31	1,103	665	28	16	242	11,543



AUTO-ANALYSER

The picture shows from right to left, 200 tube sampler, reagent rack, proportioning pumps with manifolds, heating bath, colorimeters and recorder with scale expander.

A two channel Auto Analyser capable of determining nitrogen and phosphorus simultaneously on plant digests or soil extracts was commissioned.

Kjeldahl digests of plant samples are processed at the rate of 40 per hour. Trouble was experienced initially with excessive base line drift in the phosphorus channel due to selenium used as a catalyst in the Kjeldahl digest. High values of nitrogen when compared with results obtained by distillation were found to be due to catalysis of the colorimetric method (indo-phenol blue reaction) used for the automatic procedure. Both these troubles were overcome by dilution of the sample before addition of reagents.

The number, type and source of the samples received in 1967 are shown in Table 4.

Soils.

1. Nitrogen.—There is a much greater present interest in the use of nitrogen fertilisers, the most economical being urea at present, but also of great interest is anhydrous ammonia. Urea has the virtue of being able to be topdressed before or after sowing, whereas anhydrous ammonia requires the use of a special applicator and is applied under contract by the vendor. Because of the need to apply through tubes carried by tines below the surface, application can only be before or at seeding.

However, what may prove a virtue is the ammonia's immobility in the soil; it is very resistent to leaching and a feature has been the lack of movement from the tine lines either vertically or laterally.

(a) Experiments were commenced at Wongan Hills in 1966 with a wheat crop to investigate the fate of applied urea and ammonia fertilisers. Analytical methods were developed to estimate ammonium, nitrate, nitrite and hydrolysable ammonium nitrogen fractions in both soil extracts and plants. Soil and plant samples were taken at fortnightly intervals throughout the growing season, levels before fertilising being of the order of 6 parts per million of ammonium nitrogen in the soil. The soil of the experimental area was of the following approximate composition: coarse sand 66 per cent., fine sand 19 per cent., silt 5 per cent., clay 10 per cent.

There was a rapid hydrolysis of urea to ammonia, it having been applied at a rate equivalent to approximately 14 ppm of nitrogen in 1 ft. of soil and all being converted within the first fortnight's sample period. A more rapid conversion of ammonia to nitrate occurred in the urea treatments than for the anhydrous ammonia. The peak of conversion to nitrate at about 5 ppm as nitrogen, was some seven weeks after application for urea treatments and 10 weeks for ammonia treatments.

Evidence was obtained of the leaching of nitrate-nitrogen but not of the ammonium-nitrogen fraction. By about 12 weeks after the application of the fertilisers, the mineral nitrogen contents of the soils for both treatments had dropped to the same levels as the nil controls.

Both nitrogen treatments gave increased contents in the plants of all the forms of nitrogen by comparison with the controls. This effect decreased with time until after about 15 weeks' growth when all the forms of nitrogen had decreased to the same levels irrespective of treatment. The plants had reached maximum uptake of nitrogen after about 20 weeks' growth and uptake with nitrogen treatment was about double that of the controls. Final grain yields showed that the uptake of nitrogen was slightly more for the urea treatment than the equivalent of anhydrous ammonia.

(b) A continuation of the 1966 fate of nitrogen fertiliser experiment at Wongan Hills was again with a wheat crop to compare times of application of anhydrous ammonia and the fate of the nitrogen applied at the various times. Only two times of application, namely four weeks before seeding and at seeding and one rate of application at 67 lb. per acre of ammonia were selected from a larger trial for laboratory control.

Ammonium nitrogen in the soil before treatment was 5 ppm as nitrogen and treatment was equivalent to 19 ppm in the first foot.

The conversion of the ammonium to nitrate nitrogen and its subsequent leaching followed a similar rate pattern for both treatments but out of phase by four weeks, the earlier application being ahead. Eventually, about 17 weeks after the first treatment the mineral nitrogen contents of the soils for both treatments had dropped to the same levels as the controls, 1 or 2 parts per million. More nitrate-nitrogen was in consequence available in the earlier stages of growth in the "at seeding" plots. Nitrite-nitrogen was found only in the treated plots and then only when there was a large conversion of the ammonium to nitrate form, but none was found in any of the plant samples.

In general, the uptake of nitrogen and the contents of the various forms within the plants followed the same pattern as the 1966 experiment. The final sampling of the plants before harvest after 24 weeks' of growth showed the uptake to be the same for both times of application. Comparison of growth rates however, showed that the "at seeding" treatment was faster in the earlier part of the season, but that the growth rate fell off sooner than the "before seeding" rate. Although yields are not yet to hand, it seemed apparent at harvest that there was little or no difference between the yields from the two ammonia treatments.

This is a fortunate result considering the heavy demand placed on the use of the necessary equipment if all properties wished to be treated at once at the break of season.

(c) In the 1967 season an experiment was carried out on a property at Lancelin to investigate the fate of urea applied at various times after the seeding of a wheat crop. The soil here was poorer than at Wongan Hills, being 80 per cent. coarse sand, 14 per cent. fine sand, 2 per cent. silt and 4 per cent. clay and commencing levels of ammonium nitrogen were 1-2 ppm. Treatments were from seeding until eight weeks after, at intervals of two weeks and with one split dressing half at seeding and half at eight weeks. Samples of soil and plants were taken initially each week, and finally involved some two thousand analytical determinations.

There was a rapid hydrolysis of urea to ammonia, all of the urea having been converted inside the one week sampling period. A rapid conversion of ammonium to nitrate-nitrogen followed in about three to four weeks and evidence was obtained that the nitrate was being continually leached. The weekly average rainfall was about 0.8 inches for the first 12 weeks after which there was practically a complete washout with 3 inches in one week. This reduced the mineral nitrogen in all treatments to that of the controls with the one exception, the eight weeks after seeding treatment, which was left with mineral nitrogen content of three times the controls.

Again nitrite nitrogen was found only when there was a large conversion of ammonium to nitrate form, and none was found in any of the plants.

The plant contents of the various nitrogen forms followed the pattern of increase with nitrogen application and decrease with time of growth, the increases taking place in the first four or five weeks after application. The final sampling of plants before harvest and after 20 weeks of growth showed that the four weeks after seeding treatment gave the highest yield of dry matter and largest uptake of nitrogen, followed closely by the six, eight and split treatments. Although the grains are not yet to hand for analyses, the yield weights showed that the eight weeks after seeding treatment gave the highest yield followed by the four weeks after. It may be significant to this experiment as noted above, that the eight weeks treatment was the one not completely washed out 12 weeks from the commencement.

(d) Samples from the Long-term Ley Rotation Experiment at Wongan Hills, which was written up in the 1966 Annual Report at its half way stage, were received again with the addition in this year of wheat crops following 2, 3, 5 and 7 years of clover. One year's result is hardly meaningful, but in a year when the replicates of previous histories were all high compared with averages in the past, nitrogen in the soils carrying the cereal was down by comparison with that once again under clover.

(e) Other pasture legumes are to be similarly tested for their ability to build soil fertility and at Nangeenan the soils from the experimental plots were tested for both organic carbon and nitrogen before planting. A similar experiment at Lake Grace had been in progress for one year comparing four legumes and a mixture thereof with volunteer pastures and carrying two stocking rates. No difference was apparent between any of the soils either for pastures or stock rate.

2. Potassium.—Lysimeter tests on leaching of potash fertiliser through Karrakatta sand at South Perth has shown that some 30 per cent. of applied fertiliser had leached beyond 18 inches in the period July-November, 1966. The distribution of the remaining fertiliser potassium in the profile was studied but since the maximum rate of application of 120 lb. per acre of potash-potassium chloride KCl—was only equivalent to 11 ppm of potassium in 18 inches depth of soil, the absence of any significant differences—all samples of three successive 6 in. depths containing approximately 30 ppm potassium—was not unexpected.

3. Organic Carbon.—Samples were taken in August, 1966, from an experiment at Wongan Hills which studied the build up in organic matter in the top 4 in. under clover and subsequent cropping. Virgin bush soil contained 0.40 per cent. organic carbon, the same soil after two years of clover and then carrying a wheat crop had 0.45 per cent. and with a third year of clover 0.55 per cent. organic carbon.

4. Trace Elements.—Work with copper fertiliser from many sites relating copper sulphate use to wheat yields and pasture growth involved the determination of both the total copper content and that extractable by 0.5M E.D.T.A.

Many of these required the determination of bulk density and pH, and additionally to the copper similar results were obtained for zinc.

Work with molybdenum and its effect on nitrogen metabolism in cereals required the determination of this element on both the greater and less than 2 mm fractions of the soils of the experiments.

Virgin soils from an area at Newdegate for an experiment to study comprehensively the relation of wheat yield, pasture composition and production, wool production and black pigmentation, and body weights of sheep to copper treatments were analysed for their copper contents. Total copper contents ranged from 1.5 to 3.5 ppm, averaging 1.8; E.D.T.A. extractable copper ranged 0.12-0.38 averaging 0.18; and exchangeable copper ranged 0.10-0.43 ppm at an average of 0.23.

5. Farm Dams.—The failure of many farm dams to hold water because of leakage problems is a frequent cause of economic loss to the farmer both due to the expense of having the dam constructed and the subsequent need to find alternative sources when the dam dries up. As part of a project to investigate the causes, the cation exchange capacity and the composition of the exchangeable cations were determined on a series of soils from farm dam excavations from scattered properties. No overall consistency was apparent, but of three dams on one property with soils which were dolomitic, that with the soil which was lowest in exchange capacity was the one to fail.

6. Sulphur.—Because of the use of superphosphate as the basic fertiliser in all farming in W.A. the possibility of deficiency of sulphur was long unsuspected and its potential importance unrecognised until the imminence of the use of locally made phosphatic fertiliser without a sulphate content, almost coincident with the declining need for phosphate on some long established properties where the fertiliser history may have reached a level of a ton per acre of superphosphate.

One experiment resulting from the awakened interest involves the investigation of the leaching and mineralisation of sulphur in soils at Chapman. This commenced in March, 1967, where the clover established on the site has exhibited symptoms that sulphur deficiencies have occurred particularly in winter. The symptoms have been a yellowing of the leaves and petioles with reduced growth. Often these symptoms have disappeared by early mid-spring, although pasture yield differences have been apparent.

Various rates of sulphur, as gypsum $CaSO_4.2H_2O$ were applied at the beginning of June both with and without phosphate fertiliser. The programme included analyses of the soil before treatment for total and sulphate sulphur and thereafter monthly for sulphate sulphur together with samples of the pasture at each sampling during the growing season.

A summary of the soil analyses for sulphate sulphur is given in Table 5 for all plots receiving gypsum—averaging about 20 lb. per acre of sulphur, the presence or absence of phosphate fertiliser making no difference to sulphur content and there being little variation in the range approximately 10-30 lb. per acre sulphur as gypsum.

TABLE 5
Sulphate Sulphur S
ppm dry basis

Level Inches	May	June	July	August	September	October	November	December
0–6	4	12	7	5	5	5	5	4
6–12	2	4	8	6	5	5	5	5
12–24	2	3	4	5	7	5	5	4

The sharp increase in sulphate sulphur in the surface level for June follows the application of the gypsum and also the mineralisation of residual organic sulphur compounds with the first rain. The next two or three months give some evidence of leaching, with stable and evenly spread sulphate in the late spring and early summer. Further assessment of the experiment must await pasture analysis results.

Fertilisers.

1. Fertilisers Act.—Because of changes in technology, manufacture and farm practice the Fertilisers Act is in need of review. A Committee on which the Laboratories are represented by the Deputy Director has been considering the desirable changes which from the point of view of the analyst will include the use of more modern instrumental methods of analysis.

Seventy-eight samples were analysed under the Act this year, emphasis being placed on fertilisers containing trace elements. Deficiencies were found in molybdenum in 12 instances, copper in nine, zinc in six. With the macro-nutrients there were three cases of nitrogen deficiencies, one each of water soluble and of citrate soluble phosphoric anhydride and in one case a pelleting lime had insufficient fine material.

2. Gypsum.—The current interest in gypsum as a sulphur fertiliser resulted in 14 samples either recognised as gypsum, or lake deposits which it was hoped would prove to be so. In not many instances did these reach the required standard of purity for registration for sale as a fertiliser, but another shortcoming in the Act was revealed.

Gypsum in the past has been looked on primarily as a soil amendment, the useful part of it being considered to be the calcium to render clay soils more workable. As a result the Act calls for the calculation of the purity of gypsum from its calcium content. However, as a sulphur fertiliser, it is of greater importance to use a sulphur or sulphate determination as the basis of calculation.

3. Copper.—Copper ore being mined in W.A. is finding use as a replacement for copper sulphate. The ore requires fine grinding to make the copper from it more readily available to plants. Tests of screen size and "availability", taken as the acetic acid soluble copper content, were determined on a number of samples represented below in Table 6. For comparison, copper sulphate contains approximately 25 per cent. copper.

TABLE 6

Copper Ores
Copper Cu
per cent.

Sample	1	2	3
Total	10.4	11.8	9.5
Available	7.2	8.8	6.3

4. A sample of potassium metaphosphate to be tried as a source of potassium on country from which the usual potassium sulphate or chloride is rapidly leached was found to contain 53.6 per cent. total phosphorus as phosphoric anhydride P_2O_5 and 39.4 per cent. potassium as potash K_2O. The material was confirmed as only very slightly soluble in water.

5. Granules, prepared by the Engineering Chemistry Division for experiments on the slow release of phosphate when ground rock phosphate is mixed with native sulphur, had the compositions shown in Table 7.

TABLE 7

Fertiliser Granules

Granule	Rock Phosphate	Rock Phosphate Sulphur	Rock Phosphate Sulphur-Super
		per cent	
Phosphorus P			
Water soluble	0·05	0·05	0·47
Citrate soluble....	0·95	0·75	0·73
Acid soluble	15·3	12·4	11·8
Total	16·3	13·2	13·0
Sulphur S			
Sulphate	0·08	0·11	0·90
Total	0·79	19·0	19·0

The rock phosphate-sulphur granules complied closely with the intended 80:20 proportions. The rock phosphate-sulphur-superphosphate granules intended to be a 80:20:10 mixture were somewhat lower in super at 6 to 8 per cent. compared with 9 per cent. in the theoretical mixture.

Pastures, Fodders and Stock Foods.

1. Feeding Stuffs Act.—Four samples only were analysed under the Act, of which one contained less than the registered minimum of crude fat and calcium, two were deficient in crude protein and crude fat and one was deficient in protein, but contained an excess of phosphoric anhydride.

2. Clovers and clover pastures.

(a) Trace Elements: (i) The residual values of copper and cobalt sulphates on red brown earths believed to be deficient at Forest Hill and Darkan were compared. Copper deficiency in stock occurs and cobalt deficiency is suspected.

At Forest Hill in the first year the untreated clover contained 5.4 ppm copper and 0.18 ppm cobalt. Rates of copper sulphate up to 8 lb. per acre and of cobalt sulphate up to 16 oz. per acre did not show any interaction, but 8 oz. of the latter were necessary to cause an appreciable increase in concentration in the pasture whereas the pasture copper reached a maximum concentration with 4 lb. per acre and did not increase by further addition.

At Darkan the clover without treatment also contained 5.4 ppm copper, but the cobalt was less at 0.06 ppm. Here again no interaction was evident, but as little as 2 oz. per acre of cobalt sulphate more than doubled the cobalt concentration which continued to increase with further addition. The copper repeated the Forest Hill pattern of reaching maximum concentration with 4 lb. per acre and not significantly increasing further.

(ii) The seasonable fluctuations of cobalt concentration from treatment of clover pasture with cobalt sulphate are illustrated by the following analyses. Cobalt was applied in autumn, 1965.

TABLE 8

Cobalt Co
ppm dry basis

Cobalt Sulphate lb. per acre	Spring 1965		Winter 1966		Spring 1966	
	clover	grass	clover	grass	clover	grass
Nil	0·13	0·07	0·30	0·15	0·23	0·13
0·5....	0·33	0·15	0·29	0·16	0·26	0·14
1	0·68	0·40	0·21	0·13	0·28	0·15
1·5....	1·1	0·66	1·1	0·28	0·49	0·27
2·0....	1·8	1·6	0·28	0·17	0·53	0·48

(iii) Various aspects of copper were examined in experiments at Bramley and Woogenellup. Where the clovers Yarloop, Mt. Barker, and Dinninup comprised the sown pasture, capeweed had become dominant in some sections of some paddocks, only young capeweed being eaten in the growing period.

Yarloop proved to contain the highest copper concentration of the clovers, at about 4.2 ppm, the same as the capeweed and the little available grass. There was some evidence that the copper was "mobile" in grazed paddocks where stock tended to camp along fence lines, previous work having shown that up to 50 per cent. of excreted copper may be available to plants.

(iv) Table 9 shows the copper levels in a mixed pasture at Bramley with the various components of cuts made in June and September. Figures are the means of four replications and two rates of copper sulphate treatment.

TABLE 9

Mixed Pasture
Copper Cu
ppm dry basis

Treatment $CuSO_4.5H_2O$ lb. per acre	Native Legumes		Grass		Weeds		Clover	
	June	Sept.	June	Sept.	June	Sept.	June	Sept.
0	3·8	3	7·1	3·5	7	3·3	4·7	3·5
2·5	13	9	14	8·2	13	6·6	11	7·4
7·5	13	11	16	9·3	15	12	15	9·7

The dilution by the flush of spring growth is shown as are the residual effects of the application four years previously of 2.5 lb. per acre of copper sulphate. Without further copper the spring level of copper is deficient to sub-normal.

(v) One hundred and twenty samples of subterranean clovers, medics, lucerne and serradella were grown at Lancelin to investigate the response to inoculation and the need for molybdenum.

Without fertilisation with molybdenum trioxide, levels of molybdenum were of the order 0.4 ppm increasing with 2, 4 and 8 oz. per acre to 1, 2 and 2-5 ppm approximately, but this did not produce detectable changes in either protein nitrogen or fibre, although both Geraldton sub-clover and W.A. serradella have shown increases in yield by the application of molybdenum trioxide.

Other work at Lancelin investigated the need for inoculation and lime pelleting of a range of legumes where these treatments greatly improved germination and thus yields. However, the protein contents were not dissimilar in plants from inoculated, pelleted or untreated seed.

(b) Other. (i) Further work on the best time and rate of application of potash fertilisers to compare spring, autumn and split applications were evaluated from Boyanup, Albany, Torbay and Upper Kalgan.

(ii) From several areas sub-clover varieties, the most widely grown legumes, were compared with rose-clover, serradella, medics, cherleri and lucerne, either alone or in combination, for their protein production, this being the best single indicator of feed value, and also for fibre—"roughage". These were also assessed by the Department of Agriculture officer concerned for their production of dry matter both quality and quantity being essential factors for a successful pasture.

Miscellaneous Pastures and Feeding Stuffs.

(a) Continuation of stocking rate-superphosphate experiments confirmed at Avondale that the higher stocking rate, up to four sheep per acre, increased the nutrient content of the available pasture in any one year. However seasonal factors showed that material available in the end of the summer season of 1965 was of only half the protein content of similar material collected at the end of the 1966 summer. At Mt. Barker, with higher stocking rates up to six sheep per acre, the same effect of stocking rate was confirmed.

(b) Early results from a trial at Woogenellup comparing perennial pastures with annual for weaner production, favoured the latter with better than 14 per cent. protein whereas the perennials averaged only about 10 per cent. protein in the dry matter from the previous season, but as the season advanced the respective figures were 21 and 18 in June and finally in November there was no significant difference, each being 15-16 per cent. protein.

(c) Samples of native grasses and volunteer pastures from the North-West in connection with the development of a grass sorghum and intense pasture project by an overseas syndicate were analysed for their feeding stuffs values and also for a number of trace elements. Subsequently trouble was experienced when the sorghum, irrigated with water containing 140 grains per gallon of salts, showed patchy affected growth and leaf tipping.

To see whether problems other than salinity might be involved other nutrient and toxic elements were determined in plant tissue samples covering the range of symptoms. None of the potentially toxic elements were at hazardous levels, but chloride was 1.34 per cent. in healthy tissue, 1.59 per cent. in tissue burned on the day of irrigation and 1.88 per cent. from an area of retarded growth, suggesting that the technique of irrigation with the water needs to be good if any success is to be achieved.

(d) At Badgingarra it had been found that both copper sulphate and zinc oxide were required for maximum dry matter production from lucerne, the optimum combination being 2 lb. per acre copper sulphate and 1.5 oz. per acre zinc oxide. This combination gave 50 per cent. more dry matter than the control, 60 per cent. more than nil copper 1.5 lb. zinc oxide and 40 per cent. more than 2 lb. per acre copper sulphate nil zinc treatment.

Two lb. per acre copper sulphate was sufficient to raise the concentration to 2.5 ppm copper from the untreated level of 1.6 and 1.5 oz. per acre of zinc oxide raised the zinc from the order of 10 to the order of 20 parts per million.

(e) A dairying property was in trouble because of the quality of its milk output, cancellation of its quota being the penalty for failure to achieve improved results. Throughout the year many samples of the feeding stuffs available to the stock were analysed, showing the benefit of constant efforts in co-operation with officers of the Department of Agriculture to improve the nutrition of the cattle.

(f) Bark.—The phenomenon of cattle chewing bark to the point where shelter timber is killed by ringbarking occurs from time to time. An instance at Kojonup led to the anlysis of bark from the Wandoo *(E. redunca)*.

TABLE 10

Wandoo Bark

	per cent.
Moisture	14.0
Ash	2.8
Crude protein (N x 6.25)	0.7
Crude fat (petroleum ether extract)	0.6
Crude fibre	29.5
Nitrogen free extractive	52.4
Calcium, Ca	1.28
Magnesium, Mg	0.07
Phosphorus, P	0.01
	parts per million
Copper, Cu	3.4
Cobalt, Co	0.05

Clearly it was not for the nutrients in the bark that the cattle sought it out, but the high content of carbohydrates, appearing here as nitrogen free extractives and in the bark as gums and other polysaccharides would make it seem likely that the pure pleasure of chewing accounts for the habit.

(g) By-products of industry find some use as supplementary feeding stuffs. Among those in use or proposed for use were—

(i) dried and ground brewers grain containing 0.25 per cent. cystine or 1.4 g per 16 g nitrogen, and 0.19 per cent. methionine or 1.0 g per 16 g nitrogen, levels consistent with barley grain;

(ii) spent brewers yeast which contained only 6.3 per cent. crude protein in its wet condition but in any event is more valuable as a source of vitamin B;

(iii) pig hair containing 65 per cent. crude protein which it was proposed to incorporate in meat meal;

(iv) linseed meal, the residue after extraction of the oil, which is a useful stock food with the analysis in Table 11.

TABLE 11

Linseed Meal

	per cent		parts per million
Moisture	7·2	Cobalt, Co	0·58
Ash	5·4	Copper, Cu	20
Crude protein	34·1	Manganese, Mn	44
Crude fat	14·6	Molybdenum, Mo	0·49
Crude fibre....	5·8	Selenium, Se	0·02
Nitrogen free extractive	32·9	Zinc, Zn	94
Calcium, Ca	0·02		
Phosphorus, P	1·14		
Magnesium, Mg	0·65		
Sulphur, S	0·21		

Cereals.

1. Oats. (a) There was a large visual residual effect on oats growing on the site of an experiment at Wongan Hills which in 1966 had been used to test the response of wheat varieties to urea. There had been three replications of six wheat varieties and in oats grown in 1967 on those plots which received no urea, the nitrogen content when sampled in August, 1967, was 1.64 per cent. dry basis, compared with oats from plots which had received 400 lb. per acre of urea a year before and contained 2.01 per cent. nitrogen.

(b) Oat husks crushed for use as a stock food for export to Japan had little crude protein at 3.6 per cent. but consisted mostly of carbohydrate 48.7 per cent. and fibre 34.4 per cent.

2. Wheat. (a) At selected sites throughout the wheatbelt trials of up to half a dozen varieties, varying between sites, are carried out to test their yields and also their ability to take up nitrogen applied as urea together with a basal dressing of super containing copper, zinc and/or molybdenum depending on the area. Although the pattern varied somewhat between sites in 1966 the variety Bencubbin was the most consistent in both its ability to produce protein without nitrogen fertiliser and to make good use of it when supplied.

The use of Festiguay as a replacement for Gabo in 1967 altered the story. This was a season with good opening but poor finishing rains, and Festiguay performed best of all varieties. In both seasons Noongar was a consistently poor performer.

(b) Seven varieties of wheat received 20 to 50 lb. per acre of urea on an experimental area at Forrestania, but this failed to produce any real improvement in nitrogen content, the best being Bencubbin, which reached 1 per cent. nitrogen compared with levels of 2-4 per cent. in the established cereal areas.

(c) To examine the effect of the level of application of both nitrogen and phosphate on the uptake of the other nutrients, 80 samples of wheat tops cut in October, 1966, at Wannamal, were analysed.

In this instance increasing dressings of superphosphate at 150, 300 and 450 lb. per acre did suppress the concentration of nitrogen at all rates of application of urea up to 300 lb. per acre and there was some suppression of phosphorus concentration by increasing amounts of urea when the concentration of phosphorus had been raised to the 0.1 per cent. level by the highest superphosphate addition.

In a similar experiment at Toodyay there was not a significant decrease in nitrogen with superphosphate rate, but urea treatment did lower the phosphorus content.

(d) The samples of flour from wheat representative of each of the zones related to the ports of export, and of the F.A.Q. bulk wheat sample were tested for protein and ash and the flours for maltose. Protein in the F.A.Q. wheat was 9.3 per cent. on a 13.5 per cent. moisture basis and ranged from 8.2 at Geraldton up to 8.8 per cent. at Bunbury for the flours. The maltose figures at Geraldton were highest at 280 mgm per 10 g and least at Bunbury at 256.

(e) Analyses of wheat tops and grain samples from experiments designed to study the effects of molybdenum application on wheat yields gave some expanation of the responses to molybdenum.

The fact that molybdenum promoted plant growth but produced a decrease and not an increase in protein nitrogen concentration in tops would seem at first to preclude the existence of the classical situation where a deficiency of molybdenum results in a restriction of nitrate reductase activity and a consequent block in nitrogen metabolism.

However there was a marked decrease in nitrate nitrogen, a corresponding increase in hydrolysable nitrogen (largely amide nitrogen), and an increase in the protein nitrogen: total nitrogen ratio, in sample tops which had received molybdenum applications, supporting the classical explanation.

Nitrate nitrogen levels were also affected by applications of copper-zinc fertiliser. A marked increase in nitrate content occurred in the presence of increased rates of copper-zinc treatment, but only in the absence of molybdenum. It would appear that molybdenum can have some other role in the plant, or that copper and zinc aggravate molybdenum deficiency.

Molybdenum levels in the grain harvested from untreated plots of experiments where yield responses to molybdenum were obtained were 0.03 to 0.04 ppm, where no response was obtained corresponding levels were 0.1 ppm or more and it seems that where molybdenum in the grain is below this concentration a deficiency of molybdenum for wheat is likely to exist.

Plant Nutrition.

1. Apples. (a) Dual experiments at Manjimup and Bridgetown in cultural practice on orchards suffering from dieback involved six differing treatments. All variations from normal orchard practice favourably affected nutrient concentration whether by spray thinning, cultivation, fertilisation or sawdust mulching with added nitrogen, or a combination of these.

The trace elements rose to their maximum concentration by the use of high application rates with either clean cultivation or sod culture. Nitrogen levels were little affected at Manjimup, but at Bridgetown, where the initial nitrogen status was lower, response was given to nitrogen fertilisers.

Calcium tended to be suppressed at both sites by the sawdust mulch and enhanced by sod culture with high fertiliser application. Phosphorus was unaffected and potassium which was below the critical level improved by either fertiliser application or sawdust mulch at both sites and additionally by sod culture alone at Bridgetown.

(b) Leaf samples from Granny Smith apple trees at Manjimup showed response in nitrogen concentration with rates of nitrogen as urea of 1 lb. per tree in spring, 2 lb. in spring and 2 lb. in spring with a further 2 lb. in summer. The further addition of 4 lb. of potassium sulphate in spring tended to decrease nitrogen concentration slightly by comparison with trees receiving similar nitrogen treatment but without potash.

The addition of 10 lb. of superphosphate in spring only increased phosphorus concentration from 0.16 per cent. to 0.18, independently of the other nutrients. Calcium was marginally greater in the superphosphate treated trees, but more marked was the suppression of calcium concentration by potassium fertiliser, decreasing by 0.14 per cent. to a level of 0.90 per cent. which could be considered deficient.

Potassium, unaffected by either superphosphate or nitrogen fertiliser, was increased from 1.36 per cent. to 1.78 per cent. by the use of 4 lb. of potassium sulphate per tree in spring.

(c) The nutrient status of young trees to be used in a study of bitter pit development in Golden Delicious, believed to be a calcium deficiency, was established.

Of 50 samples all but three marginal exceptions contained under 1 per cent. calcium and generally were well under, and with nitrogen levels high, the trees proved suitable for the study of this storage disorder in future years.

(d) Bornholm, near the south coast in the Albany district, was the site of a new orchard where leaf scorch was attributed to either salt laden winds or copper deficiency. Leaves from two-year-old trees of three varieties had copper contents in excess of 30 parts per million certainly ruling out all suggestion of deficiency, but the chloride at 1 per cent. was clearly implicated.

(e) There were many other samples connected with rootstock trials, soil management, urea spraying, weedicide damage and general diagnostic purposes.

2. Citrus. (a) The use of nitrogen, phosphorus and potassium fertilisers on orange trees at Capel as usual did not increase phosphorus concentration, but nitrogen at the higher rate was more when phosphate was used than without it. Potassium was taken up progressively but reached the highest concentration with the least nitrogen fertiliser. but nitrogen was unaffected by potash. The rates involved were 0.5, 1 and 2 lb. of nitrogen, 4 lb. superphosphate and 2 and 4 lb. of potassium sulphate per tree.

(b) Three samples of leaves with interveinal chlorosis from problem citrus trees at the Carnarvon irrigation area were found to contain excessive amounts of boron at 400-500 parts per million and this was compounded by excessive sodium in two of them at 0.26 and 0.34 per cent.

(c) Citrus management problems also resulted in a variety of other analyses in endeavours to relate to symptoms such as decline in vigor due to rootstock and nematode troubles, deficiencies of trace elements and macro-nutrients.

3. Beans. (a) For some years there has been a problem at Carnarvon appearing as poor growth and yield of beans, possibly related to a similar problem with bananas. Various factors have been investigated including high exchangeable potassium, chlorides, excess manganese or boron or the use of brominated fumigants (see Annual Report 1966).

Bean plants were sampled in September from properties representing varying degrees of the problem symptoms. The results given below in Table 12 did little to explain the problem as one of nutrition.

TABLE 12

Beans

Growth	Good	Medium	Poor
		dry basis per cent	
Calcium, Ca	3·0	2·0	3·2
Magnesium, Mg	0·72	0·70	0·76
Potassium, K	3·0	2·1	2·6
Sodium, Na	0·04	0·04	0·06
		parts per million	
Boron, B	90	85	90
Bromine, Br	140	160	140
Copper, Cu	11	16	12
Iron, Fe	440	420	300
Manganese, Mn	80	130	100
Zinc, Zn	28	47	30

(b) Further to the work reported in 1966 a second crop of runner beans was planted on the same site at Medina Research Station which illustrated the toxic effects of the use of sewage sludge for this crop. An adverse residual effect was obtained and the levels of zinc at 500 ppm were comparable with those in the leaves of the previous year although copper had decreased a little and manganese levels were a more normal 40-60 ppm.

4. Tomatoes and Parsnips.—Tomatoes suffering from "curly top" and growing at Wanneroo were believed to have a nutritional deficiency. Parsnips also exhibited similar symptoms on a Balcatta property. Analysis did not reveal any marked dissimilarity between unhealthy and healthy tomato foliage, but the affected parsnip leaves contained only 16 ppm manganese compared with 60 ppm in healthy plants and they also contained exceptionally high molybdenum at 160 ppm compared with normal plants at only 0.8 ppm.

Miscellaneous.

1. Blood Alcohol.—Seventy-one samples of blood were analysed for alcohol as an internal check on results by another method used for official samples by the Food, Drug, Toxicology and Industrial Hygiene Division.

2. Salt used in regeneration of water softening plant for the town supply of Albany was up to specification, but was bought by volume measurement. Because of the variable bulk density it was suggested that future contracts be in terms of weight and purity.

3. Other salts, sodium, calcium and magnesium chlorides were tested for purity and a method of preparing them in solutions to be fed to stock at two concentrations and two different ratios of cations was advised to assist an experiment on the effects of drinking water salinity and composition for cattle in summer months.

4. Samples of cottonseed—potentially of use for producing oil and seedcake as by-products of cotton production from the Ord River Irrigation Project—were analysed for oil content, ranging between 18.2 and 28.8 per cent. oil and having a nitrogen content of 3.01 to 4.62 per cent. The seedcake would be a good protein supplement.

5. Copper sulphate produced at the W.A. Mint from metal of old coins was tested and found suitable for use in treatment of drinking water, the concern being the nickel content which was shown not to be at a harmful level at rates of use of copper sulphate normally added to water supplies.

6. Lactose used in the preparation of baby foods was proven free of contamination by borates, containing approximately 5 ppm boron to be expected in a natural product.

Water Treatment and Supply.

1. Corrosion, Scales and Deposits. (a) In the absence of facilities provided by any other laboratory in this field of chemistry we are frequently consulted by private industries with problems relating to the cooling water systems of their machinery or air conditioning plants, heating waters perhaps in bottle washing operations, chlorination in food handling plant, on scaling, staining or any other way in which the presence in water of dissolved or suspended matter manifests itself to the detriment of operations.

(b) Many boiler problems were examined. An essentially magnesium phosphate scale could indicate correct chemical treatment to prevent carbonate scale, but in another instance although largely phosphate the presence of some carbonate suggested treatment had been inadequate at some time. Boiler water condensate and feed waters at a chemical extracts factory suggested carryover.

A Western Australian exporter of boilers was puzzled by the localised deposition of scale in a boiler sold to Malaysia leading to a hot spot and collapse of the boiler wall. Analysis of the scale suggested, among other things, that insufficient phosphate had been used, but whether the deposit caused the hot spot or *vice versa* was uncertain. The physical nature of the deposit suggested a vortex at the point.

Examination of the boiler chemistry log revealed a number of apparent anomalies and analyses of the water supply to the boiler showed a very different composition of soluble salts to that commonly found in W.A. The raw water, to be softened before use in the boiler had a pH of 9.8, total dissolved solids of 70 ppm of which 10 ppm only was sodium chloride, the hardness being 31 ppm and alkalinity 25 ppm with comparatively high sulphate of 11 ppm.

Several alternative methods of treating this water with polyphosphate were indicated but none of these had been carried out in accord with the recommendations of the manufacturers of the chemical in use. The use of this chemical in slug doses could indeed have led to the removal and redeposition of already formed scale as had happened in this instance.

(c) White deposits on headstones of some graves at Karrakatta Cemetery were the result of calcium carbonate depositing from the bore water used in garden irrigation. While this could readily be removed by dilute acid from stones such as granite, the use of white marble, essentially the same chemically as the deposit, made this ill-advised. A detergent and mild abrasive unlikely to scratch the polished stone surfaces was recommended, since softening the water for gardening purposes is uneconomic.

(d) The reported rapid attack on copper piping of a hot water service beneath a concrete floor was suspected to be caused by stray electric current, because piping above the floor in the same system showed only a normal oxidised surface with a deposit of fine rust from the water on its internal surface.

(e) Chlorination of water at a meatworks was exonerated from blame for the corrosion of copper piping when the bore water used was shown to be acidic. pH correction of the water was advised.

2. Institutional Water Supplies and Treatment. (a) At Swan Districts Hospital the boiler being used to heat the primary water of the hot water and air conditioning services was subject to corrosion of the tubes. Inspection of the opened boiler

and analysis of waters and deposits showed that the steel of the boiler was being electrolytically corroded by copper in solution in the recirculating water.

The condensate return from other boilers being used in make up had over 2 ppm copper in solution and improved amine treatment was suggested for this. For the hot water boiler the use of pH control and either nitrite or chromate at 1,000 ppm was recommended, the former being preferred because of the possibility of leaks to the hot water being used.

Chromate inhibitor was introduced and test pieces of steel placed in the boiler. A laboratory test had shown that 1,000 ppm of sodium chromate was capable of protecting mild steel against the attack of an approximately 20 ppm copper solution —shown to be present in the system—for longer than 16 hours at incipient boiling.

(b) At Albany District Hospital corrosion of calorifiers made of Cusilman bronze was previously inspected in 1965 and suggestions were then made of fitting air eliminators. As anticipated patching and plugging carried out then only provided additional sites for corrosion so that two of the units had now to be replaced.

In order to avoid the same unhappy history repeating itself it was emphasised that units of Cusilman bronze, the most suitable material for the units, should be stress relieved after fabrication so as to reduce the potential for corrosion and allow the other corrosion inhibitive factors a chance to work.

(c) A deposit in the steam header of the calorifier at the Home of Peace was a mixture of corrosion products with organic degradation products from the filming amines which had been used to try to prevent corrosion in steam lines.

(d) Corrosion problems at Geraldton District Hospital in heat exchangers, and trouble with the functioning of the demineralising unit were examined and recommendations made to correct these by appropriate changes in chemical control.

(e) Because the salinity of the raw water supplied to the Bunbury Regional Hospital, being derived from several bores, was much greater than that of the single bore water on which its design was based, the demineralising unit was proving incapable of giving a satisfactory product or functioning at all economically. Since it was possible to operate all plant including boilers economically by softening only, conversion of the plant for this purpose was suggested as the first among alternatives, including obtaining an improved quality raw water, or the direct purchase of treated water from the Bunbury Power Station for make up.

(f) A deposit in the condenser water system of the new Government Offices proved to be rust. This was in spite of a good system of anti-corrosion treatment which was in use but emphasised the need for the introduction of anti-corrosion practices at installation and during testing and running in, rather than, as most frequently occurs, these treatments having to wait until the system is handed over to the operator.

3. Metropolitan Water Supply. (a) In preparation for the introduction of fluoridation of public water supplies in the first days of 1968, advice was given to the water supply authorities on the standards to be used in purchasing sodium silico fluoride, the salt to be added to the supplies. The requirements covered not only purity but feedability which relates to the way the dry powder will flow in a hopper.

Subsequent tendered samples were tested for compliance with the resultant specification, and after the acceptance of a tender and the delivery of the first shipment of sodium silico fluoride this was again tested.

(b) Canning and Serpentine Dams, the main hills catchments for Perth water supply, were depth sampled prior to isothermal conditions in autumn and showed the usual stratification and the further improvement in the deep water quality at Serpentine with ageing of the catchment until it approaches that of Canning.

At Canning Dam the results showed that water was being drawn from the dam into the reticulation via the bottom of the wet well and not through the scour at the 25 ft. level as had been supposed. This was not a cause for concern because of the good degree of oxygen saturation and the low iron and manganese contents at this long established dam.

(c) Potential sources for augmenting the city's supply are constantly under examination.

Bores in the Gnangara area north of Perth are of low salinity compared with bores at present in use around the metropolitan area, but regrettably involve problems of their own in that chemical clarification will be necessary to remove colour, turbidity and iron to make them suitable for human consumption.

Potential catchment waters being tested are from Wungong, Seldom Seen and More Seldom Seen Brooks, Waterfall Gully, North, South and Little Dandalup Rivers and Munday and Bickley Brooks.

(d) With regard to the reticulation, no trouble has been reported to us this summer from algae or other causes in holding reservoirs, the one rather dramatic report proving to be caused by the floating body of bright yellow pollen blowing into the Mt. Eliza Reservoir from the pine trees which surround it. Copper treatment and chlorination programmes have operated satisfactorily.

An aspect of the reticulation which the routine samples point up is the increase in pH and alkalinity due to the uptake of lime by contact with cement lined pipes. While of little significance to the domestic consumer, these properties of the water can be of importance to industrial users with water treatments in operation.

4. Country Water Supply. (a) Carnarvon. Several possible means of removing fluoride were examined and tests of potential materials for the purpose were made during the year. A proposal to remove fluoride by means of an ion exchange resin since it was not specific for fluoride ion was shown to be uneconomic for water even moderately high in exchangeable anions and certainly for Carnarvon with 7-800 ppm of total salts.

The most promising materials were activated alumina and bone char. The latter was shown to be potentially the more economic, but further work of a pilot plant nature is suspended pending a decision on the future of Carnarvon Town Water Supply.

Exploratory drilling and the possible construction of dams on the Gascoyne River may provide alternatives and thus avoid the decision as to whether it is really necessary to reduce the fluoride level from the present 1.3-1.9 ppm found during 1967.

(b) Marble Bar. The water sources used for the town supply were tested for possible contamination by ore bodies or processing works and shown to be satisfactory. The water indeed contains fluoride at a level suitable for the control of dental caries. A white deposit forming in the water was due to the bore water being supersaturated with calcium carbonate and this precipitating out on aeration.

(c) Geraldton. Because of the acidic pH, free carbon dioxide, negative saturation index in both cold and hot water and the relative high total dissolved solids of approximately 900 ppm, Geraldton water supply can be expected to be corrosive. This supported hearsay reports of corrosion of hot water services and the finding that this was less likely to occur where cisterns were fitted because these provide additional aeration.

Dramatic pitting corrosion of stainless steel was seen in rods in the wash bath of an automatic X-ray film processing machine at Geraldton Hospital. The pits formed where the rods rested on plastic brackets, points where the combined effects of lack of aeration, penetration of chemicals used in processing and the relatively high salinity caused the ¼ in. rod to corrode through half its diameter within three months. The use of plastic coated rods and washing down and drying each night were advised as well as a check to ensure the absence of stray electric currents.

(d) Mt. Barker. Depth sampling of Bolganup Dam was carried out in February, 1967, to investigate whether stratification was contributing to odours and tastes reported in the town supply during autumn in previous years. Thermal stratification was present and all water below 10 ft. was completely devoid of dissolved oxygen and had a swampy, hydrogen sulphide odour and a high iron content.

To minimise the effects of the anaerobic bottom water the fitting of a floating take-off was planned because when the bottom water rises during autumn with isothermal conditions it will soon be improved at the surface by aeration.

It was further suggested that the dam be experimentally stirred by means of compressed air to improve the conditions of the whole of the water and test a technique which could be useful with other dams with similar problems.

(e) Exmouth. The water supply is supersaturated with calcium carbonate and a sample of 1½ in. diameter copper pipe had a scale of this material uniformly deposited. This can be an effective method of reducing corrosion in reticulation systems, but from the point of view of use in hot water systems or cooling water circuits the more rapid scale formation on heating can cause or contribute to other problems.

For instance, the breakdown at the circumferential weld at the dome edges of a cylindrical form copper chilled water unit from Exmouth was related to this being the stressed area, the welding material being more resistant than copper, metallurgical changes due to the heat of welding, and the formation of a scale by the water passing through the unit.

Suggestions to modify the design by giving greater curvature and removing the stress adjacent to the weld were carried out by the manufacturer and a unit of the new design was installed.

A study of the feasibility of at least partly softening the Exmouth supply was suggested in view of the number of problems which have arisen with its use.

(f) Clarification chemicals and rates were advised for Newdegate, Jerramungup, Mt. Magnet, Lake Grace, Karlgarin, Borden and Ongerup. Waters from iron ore development centres at Dampier, Tom Price and Mt. Newman and construction camps along their rail-roads were tested for their suitability for human consumption and industrial purposes.

ENGINEERING CHEMISTRY DIVISION

During the absence of Mr. B. A. Goodheart, Chemist and Research Officer, Grade 2, in the second half of the year, the numerical strength of the professional staff of the Division was maintained by the temporary secondment to this Division of Mr. A. Rouillard, Chemist and Research Officer, Grade 3, from the Fuel Technology Division. Mr. Goodheart, proceeding on long service and study leaves, left in August for England, where he was last working with the Warren Spring Laboratories of the British Ministry of Technology.

After the transfer of the Drafting Assistant, Mr. R. F. Dees, to the Drawing Office of the Mines Department, the position was re-classified to that of a Laboratory Technician, Grade 3, and applications for this position were called.

A position of General Assistant was created in the Division and filled in April. Mr. F. Q. Laslett, occupying this position on a temporary basis, was appointed to the permanent staff in October.

At the beginning of the year Cadet N. T. Campbell, was seconded to a firm to assist in investigations concerning the production of iron ore pellets at Dampier.

During the year, the Divisional Chief, Dr. S. Uusna, attended four meetings of the Board of Management of the Australian Coal Industries Research Laboratories Ltd., North Ryde, N.S.W., of which he is the member representing Western Australia.

Work on the extension of the Divisional chemical laboratory and office building was completed by the end of July and occupied in August.

The installation of an underground oil tank, the construction of an oil ring-main connecting all oil-fired furnaces in the Division with the new oil delivery system, and the conversion of the steam boiler installation from wood firing to oil firing, was completed and released for use in September.

A 20 in. diameter, 5 ft. long drum pelletising machine was designed by the staff of the Division, built in the Divisional mechanical workshop, and was commissioned during the year.

From the projects tackled by the Division during the year, six, i.e., 60 per cent. of the total, were carried out in response to requests from outside interests (5) and from other Government Departments (1).

Three of the Division's own research and development projects into utilisation of natural resources of this State for industrial purposes, viz. (a) the utilisation of titaniferous vanadium bearing magnetite ore (gabbro) at Coates, (b) the effect of the method of preheating limesand on its electrostatic beneficiation, and (c) production from local raw materials of a lightweight aggregate for use in concrete, were carried over from the previous year, the last mentioned project being finalised during the year.

In response to the upsurge of interest in local industrial circles towards the manufacture of high grade lime from calcareous beach sands, investigation into calcination of beneficiated sand was resumed this year with the view of developing a suitable economic process based on raining bed technique.

Lightweight Aggregate for Concrete.

The work on production of lightweight aggregate from bloating clays and shales found in the vicinity of Perth, for use in concrete, started on a pilot plant scale in 1964 and continued intermittently since then, was finalised in 1967.

The work during this year consisted mainly of the preparation of a cost estimate for the production of such an aggregate in a small commercial plant capable of providing Perth's present and not so distant future needs.

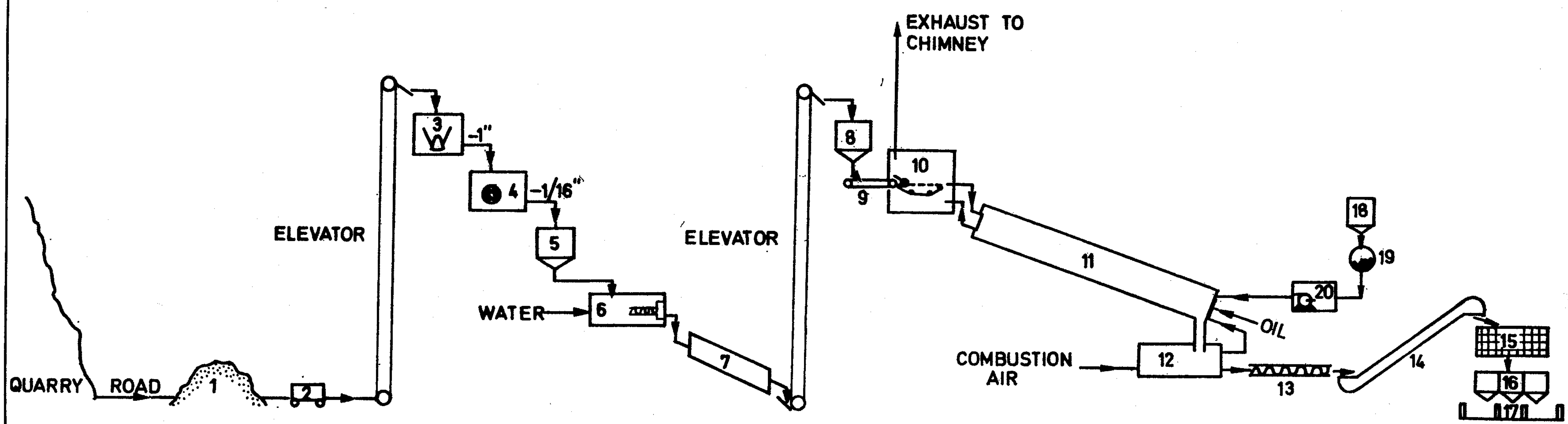
The immediate Western Australian market was assessed to be only of the order of 5,000 cubic yards of bloated aggregate per annum. However, once availability was established, local demand was expected to increase rapidly to the vicinity of 30,000 cubic yards per annum and probably rise to 50,000 cubic yards per annum within five years.

The estimate was prepared for the production of 30,000 cubic yards of aggregate per annum.

Data obtained from the kiln trials carried out by the Division in the previous year were used as a part basis for calculation of the costs. The material and energy balances obtained as a result of these trials provided a starting point for the assessment of operating costs and enabled determination of the flow sheet for a commercial plant, shown in Fig. 2.

The estimates were prepared for a rotary kiln plant with the required ancillary equipment such as crushers, balling and product handling equipment, etc.

With an average bulk density of the aggregate of 40 lb. per cubic foot, the annual production of 30,000 cubic yards is equivalent to approximately 14,500 tons. Allowing for losses, the annual quantity of raw material to be processed is of the order



1 WORKS DUMP
2 MECHANICAL LOADER
3 CRUSHER-BREAKER
4 SWINGING ARM HAMMER MILL
5 CRUSHED CLAY STORAGE
6 MIXER-EXTRUDER
7 BALLING DRUM
8 PELLET STORAGE
9 VIBRATOR FEEDER
10 GRATE DRIER-PREHEATER
11 ROTARY KILN
12 COOLER-PREHEATER
13 SCREW EXTRACTOR
14 ELEVATOR
15 THREE-DECK SCREEN
16 PRODUCT HOPPERS
17 STORAGE BAYS
18 SILICA STORAGE
19 BALL MILL
20 SILICA INJECTOR

FIGURE 2: FLOW SHEET FOR PRODUCTION OF LIGHT WEIGHT AGGREGATE

of 16,000 tons. On a basis of 320 working days per year, this would correspond to a production rate of 50 tons per day.

The estimate of capital cost was prepared by using a combination of the equipment ratio and unit cost methods. Individual unit costs were obtained from quotations made by equipment manufacturers or by comparison.

The summary of the plant capital costs arrived at is as follows:—

	$ Aust.	$ Aust.
Equipment	126,000	
Installation and civil works	45,000	
Fixed capital		171,000
Working capital	49,000	49,000
Total plant capital cost		220,000

The operating costs were defined to include all items contributing to manufacturing or production costs and any applicable non-manufacturing cost, such as selling expenses and capital charges.

The operating costs were assessed to be $ Aust. 6.62 per cubic yard of product, as follows:—

	$ Aust. Per cu. yd.	$ Aust. per cu. yd.
Raw materials	1.23	
Utilities	1.04	
Direct labour	2.19	
Repairs and maintenance	0.42	
Total direct cost ..		4.88
Indirect costs	1.26	1.26
Total manufacturing costs		6.14
Additional costs (selling expenses and capital charges)		0.48
Total operating costs		6.62

The addition of a margin for profit of, say, 58 cents per cubic yard, would result in a selling price at works of $7.20 per cubic yard.

Opportunities for cost reduction would arise when the above independent small aggregate-production plant was integrated with a similar industrial undertaking. Ready examples would be: the manufacture of cement or lime, gypsum and plaster, stone quarry and producers of concrete, etc.

Substantial reduction in costs per produced unit would, of course, result from an increase in plant size. An approximate indication of the gain potential can be gauged by calculating for an output of 60,000 cubic yards per annum, where the total operating costs would be of the order of $301,000 per annum, resulting in the cost per cubic yard of $5.00.

Utilisation of Titaniferous Vanadium Bearing Magnetite Deposits at Coates.

This project was initiated in 1964 with the view of finding ways and means for industrial utilisation of deposits at Coates, about 43 miles east of Perth.

The description of the deposits, containing an estimated 8.2 million tons of weathered ore and possibly over 32 million tons of original gabbroic rock (ore) together with the results of bench scale investigations, carried out since 1964, were given in the Annual Reports for 1964, 1965 and 1966. In 1966 a theoretical appraisal was made of some processes which could possibly be applied for treatment of this rather difficult ore.

From this comparison it was concluded that at the ruling Western Australian price of bulk chlorine, which has to be imported into the State at present, there was little likelihood of a chlorination process being economic for treatment of Coates ore. These conclusions were based on the treatment of all the ore as mined, the objective being maximum possible recovery of iron and vanadium. It was shown that under these conditions excessive consumption of chlorine by gangue components, particularly calcium and sodium, would prevent such a process from becoming economically feasible.

In view of this, during the year under review, revised calculations were made on the basis of chlorinating only the magnetic concentrates, thus eliminating most of the chlorine consuming gangue components at the expense of the recovery of iron and vanadium.

A probable consumption of chlorine by the magnetic concentrates from the original gabbro and from the weathered ore, was calculated. In Table 13 total chlorine consumption is compared for ores as mined and for magnetic concentrates, separately and combined, and also for a combination of weathered ore, as mined, with magnetic concentrate from gabbro. Component distributions for each case are shown as a proportion of the contents of the total ore mined.

A preliminary appraisal of the economics of chlorination was made in order to get an indication of possible costs and product values, to be used as a guide in deciding whether or not experimental investigations of chlorination are justified.

For the purpose of calculation, it was assumed that the ore would be treated at or near the mine site and that iron oxide product would be utilised as blast furnace feed at Wundowie, replacing Koolyanobbing ore. A value of $8 per ton of iron oxide product was assumed. Supply of bulk chlorine was assumed to be available at Kwinana at half the current quoted price for chlorine in cylinders. Transport of chlorine by road was estimated at 20 cents per ton-mile.

The calculations indicated that likely production costs were of the same order as the value of products, provided that bulk chlorine was available as indicated above. The experimental investigations of chlorination was thus justified.

Table 13

COMPARISON OF CHLORINATION OF ORES AND CONCENTRATES

	Ores as Mined (1)		Magnetic concentrates		Possible combinations for treatment	
	gabbro	weathered ore	from gabbro	from weathered ore	both concentrates	gabbro concentrate plus weathered ore as mined
Quantity (2)						
per cent of total ore mined	75	25	23	8	31	48
Chlorine Required						
tons chlorine per 100 tons treated	12·05	2·46	4·26	2·72	3·87	3·33
tons chlorine per 100 tons ore mined	....	....	....	....	1·20	1·60
tons chloride per 100 tons of Fe contained in material treated	....	....	....	....	7·22	7·93
Chlorine Cost (3)						
Dollar per ton of Fe contained in the material treated	....	....	....	....	12·3	13·5
Distribution of Components						
per cent of contents of total ore mined Fe	76	24	50	12	62	74
V	75	25	61	12	73	86

(1) See Annual Report for 1966.
(2) Based on assumed mining ratio—3 gabbro : 1 weathered ore.
(3) Based on current price of chlorine in cylinders = $170 per ton.

Proposed expansion of the alumina plant at Kwinana would raise the level of caustic soda requirements to about 50,000 tons per annum. This level of consumption would justify consideration of the establishment of an electrolytic chlorine/ caustic soda plant at Kwinana.

The cost and profitability estimates, made by the Division, show that it should be economically feasible to establish such an electrolytic chlorine/ caustic soda plant at Kwinana, provided markets for hydrogen and chlorine can be found to match the demand for caustic soda. The use of a portion of the chlorine production for treatment of Coates ores would possibly play a prominent part in matching the consumption of chlorine with that of caustic soda.

The preliminary bench scale trials of the proposed chlorination procedure, initiated during the year, have so far given very promising results. The oxidation chlorination of the ores showed that iron and vanadium in the ore can be almost completely volatilised as chlorides at temperatures of 750°-800° C. No titanium was detected in the volatile products, showing that a clean separation of iron and vanadium from titanium was possible by this type of chlorination.

Judged by the weight of residue, very little volatilisation of ore components other than iron and vanadium occurred and in tests on magnetic concentrate the non-volatile residue contained more than 60 per cent. TiO_2. Being free from iron and vanadium, these residues could be considered to have a value as a titanium raw material.

Fractional condensation of vanadium oxytrichloride from ferric chloride was good, despite the large ratio of ferric chloride to vanadium oxytrichloride, approximately 70 to 1 by weight. No vanadium was detected in the chlorination residue.

The work on chlorination is being continued.

The Effect of the Method of Preheating Limesand on its Electrostatic Benefication.

When assisting a local company with the commissioning of an electrostatic limesand beneficiation plant some years ago, difficulties were encountered which were associated with the method of preheating the sand prior to its benefication. Although a procedure enabling good separation was arrived at experimentally and the beneficiation process was made to work successfully, a satisfactory explanation of the fundamentals of the anomalies encountered was not readily apparent.

Investigation into this problem was carried over from the previous year, being continued this time using the Division's large four-stage electrostatic separator. The separator was equipped with the device for heating the sand while being pneumatically transported to the feeding bin of the separator. This device was modified to include a town gas pressure booster.

Apart from the above investigation, the trials were conducted to produce a stockpile of beneficiated sand for subsequent calcination tests.

About two tons of beneficiated sand, uniformally less than 1 per cent. acid insolubles, were produced.

Owing to the departure of the investigating officer, Mr. B. A. Goodhart, the work was temporarily suspended without reaching any conclusions.

Upgrading of Ilmenitic Sand.

The Division is pleased to record that its work on the development of a process for upgrading of Western Australian ilmenitic sand by removing iron oxides from it, work which was commenced in 1958 and was last reported in the Annual Report for 1966, has culminated in the decision to erect a semi-commercial plant at a Western Australian ilmenite field.

After exhaustive investigations of the economics of the process and trials abroad, Western Titanium N.L. announced (*West Australian*, May 27, 1967) the building at their Capel works of a semi-commercial plant for upgrading ilmenite based on the process developed and patented by members of the Engineering Chemistry Division. The plant, the first of its kind in the world, would have an initial capacity of 10,000 tons of upgraded ilmenite per annum, and there are prospects of a larger scale commercial plant being erected later.

Apart from widening the market for West Australian ilmenite, the plant would create an additional outlet for Collie coal used in the process as reducing and heating medium.

Calcination of Beneficiated Calcareous Limesand.

There are huge calcareous sand deposits along the west and the south-west coasts of the State, containing 8 to 30 per cent. and more of silica. These sand deposits are a potential source of high-grade lime, an important industrial raw material, especially for chemical industry.

Investigations carried out by the Division, into beneficiation of these sands had resulted in the development of a relatively simple electrostatic process whereby the silica content of the sand can be reduced to less than 1 per cent.

Though attempts with qualified success have been made to calcine beneficiated limesand in a rotary kiln, owing to its fineness its economic calcination or "burning", still poses certain problems.

Some years ago, a process was evolved by the Division for calcination of beneficiated limesand in entrained bed. Although experiments of short duration carried out in a small entrained bed pilot kiln confirmed the soundness of the basic principles of the process, difficulties were experienced with blockages in the lime recovery system of the pilot plant during prolonged operations. No practical solutions were found for the elimination of these difficulties.

The possibility of using falling bed technique for sand calcination was first considered by the Division in 1963, the exploratory investigations yielding an inconclusive result.

During the past few years new techniques for contacting granular solids with gases in falling beds have been evolved, permitting counter current heat exchange at gas velocities in excess of the terminal velocity of the solid particles.

It was felt that this technique offers certain advantages when applied to limesand calcination, viz.:—

(i) the solids-gas separation takes place at a relatively low temperature;

(ii) as there are no severely restricted gas passages in the system and as the shaft surface is continually "scrubbed" by sand, deposits are unlikely to form on the walls of apparatus;

(iii) the process being counter current, the hot lime is not in contact with carbon dioxide after calcination. This would tend to lessen the danger of lime recarbonation.

Investigations into the possibility of applying this technique to the calcining of limesand were commenced in the second half of the year.

The preliminary studies were made using "cold" heat exchanger models constructed of steel and perspex. In particular, the dependence of solids entrainment on superficial gas velocities in the shaft, pressure drops, times of solids retention in the unit, the effect of the ratio at restricted shaft cross-sectional area to that of the unrestricted area, etc., were studied at a predetermined solids: gas ratio, calculated from the conditions of sand calcination at 1,000° C.

Two models, one of round cross-section, 5½ in. diameter, and another of nearly square cross-section, 4 7/8 in. x 5 3/8 in. were used in this work.

In order to simulate actual conditions in the heat exchanger during the calcination, fine lime was introduced with air at the base of the shaft in a number of experiments.

The results of the work done so far indicate that such a technique could possibly be applied successfully to the calcination of limesand, and that the expected specific throughput of the unit, measured in weight of product per unit of cross-sectional shaft area on a time unit, would not be less than that of the entrained bed unit.

The work is being continued with the view of gathering data for designing of a small "hot" experimental plant.

Production of Rock Phosphate—Sulphurs Pellets.

Batches of rock phosphate—sulphur pellets in 4:1 and 5:1 mixture were prepared for experimental purposes for the Department of Agriculture and for the Forests Department. The size of the pellets requested was approximately minus 1/8 in., plus 1/16 in. and minus ¼ in. plus 1/16 in. respectively.

Also a batch of pellets from rock phosphate alone and a batch of pellets from the mixture of rock phosphate, sulphur and superphosphate in a 8:2:1 mix was prepared for the Department of Agriculture.

The pellets were prepared in a 14 in. diameter rotary drum pelletiser. A rotary brush feeder was used to force the premixed wet feed through a 1/8 in. mesh screen into the pelletiser. This was designed to provide suitable starting nuclei for the formation of pellets. The under- and over-sized pellets were screened out by a trommel type screen, attached to the discharge end of the pelletiser, and were fed back for re-pelletising.

Separation of Nickel and Zinc Sulphates.

Assistance in the work on separation of nickel and zinc sulphates, which was to be carried out in this laboratory, was requested by an establishment in Perth in the last quarter of the previous year.

A senior member of the professional staff of the Division was assigned for this work.

Investigations, whicn involved organic solvent extraction, were successfully completed in the first quarter of 1967 and calculations and flowsheet for a production plant were prepared.

Hydrometallurgical Treatment of Tin-Bearing Pyrrhotite.

Investigations into the feasibility of hydrometallurgical treatment of a tin-bearing pyrrhotite, requested by a firm outside Western Australia were finalised during the first half of the year.

Hydrometallurgical Treatment of Nickel-Sulphide Ore.

Investigations into the possibility of the recovery of elemental sulphur and nickel from a nickeliferous pyrrhotite by using hydrometallurgical treatment, commenced in the previous year on the request of a mining company, was continued during the year.

Carbonisation of Collie Coal for Testing the Product.

At the request of a company, batches of char from a bulk sample of Collie coal were prepared by the Division for testing the char.

The description of a specially designed carboniser, used in this work was given in the Annual Report for 1966.

Crushing and Concentrating of Tantalite Ore.

At the request of private interests, a parcel of tantalite ore was crushed and concentrated using the equipment available in the Division.

Consultative Service.

During the year advice was given and discussions were held on a wide variety of subjects including: the possibility of the recovery of vanadium from W.A. titaniferous magnetites by an electric furnace process similar to the Sorel plant in Canada (titaniferous slag recovery); processing, particularly leaching, of low grade copper canbonate ores for use of copper in fertilisers; separation of silica from barytes; methods of char production from Collie coal, and its possible use for certain industrial processes; nickel salts and their production.

FOODS, DRUGS, TOXICOLOGY AND INDUSTRIAL HYGIENE DIVISION

The work of this Division in 1967 consisted of the chemical examination of samples submitted chiefly by the Departments of Agriculture, Police, Public Health and the Milk Board of Western Australia. Lesser numbers were received from the Swan River Conservation Board, Mental Health Services and the Public Works Department, while the normal variety of miscellaneous work was performed for other Departments and the general public.

Although there were 20 officers in the Division for a period, during most of the year the staff numbered 19 officers, comprising 14 qualified chemists, three technicians, one laboratory assistant, and one laboratory attendant. Vacant positions for two chemists had not been filled by the end of the year due to lack of qualified applicants.

Mr. H. Sedgman, B.Sc., who had joined the Division in July, 1935, retired in February after more than 31 years' service. Over this period he had been associated with most fields of the Division's activities, but during the last 10 years or so of his career he was engaged almost exclusively with toxicological investigations.

Four thousand four hundred and eighty-five samples were received during 1967, being an increase of 12 per cent. on the number received in 1966, and an 84 per cent. increase over the past seven years.

A broad outline of the variations in numbers during the period 1962-67 is indicated in Table 14 (selected sample groups):—

TABLE 14

Class	1962	1963	1964	1965	1966	1967
Foods—						
Total	815	656	773	720	1,084	796
Milks	574	382	604	588	865	699
Exhibits—alcohol	331	378	433	458	484	573
Human toxicology	611	649	604	711	718	1,116
Industrial hygiene	446	233	349	262	183	297
Miscellaneous	608	1,010	883	1,053	1,163	1,260
Pesticides	231	210	175	153	132	145
Oil seeds	....	342	143	265	16	566
Toxic plants	....	....	....	53	162	68
Specimens from patients	92	97	166	133	147	208
Pollution surveys						
Swan River	128	128	145	109	110	145
Bunbury	50	48	48	48	48	48
Total samples received	3,177	3,279	3,511	3,611	4,000	4,485

Table 15 shows the source and condensed description of samples received during 1967.

Foods.

Seven hundred and ninety-six samples of food of various kinds were received for examination during the year. Three hundred and ninety-seven of these were samples of cows' milk submitted by the Milk Board of Western Australia.

Of this number, 278 were samples taken by inspectors for checking against the chemical standards for quality prescribed by Milk Act Regulations. 3.6 per cent. of these samples contained less than the legal minimum of milk fat (3.2 per cent.), and 52.5 per cent. contained less than the legal minimum of solids not fat (8.5 per cent.), while 39.9 per cent. of the samples failed to comply with the legal standard for freezing point of milk (0.540 degrees Centigrade below zero). The proportion of samples which failed to comply with the standard for fat is much the same as in 1966, but shows—

(a) a marked improvement in respect of solids not fat figures;

(b) a deterioration in respect of freezing point figures.

Table 15

FOODS, DRUGS, TOXICOLOGY AND INDUSTRIAL HYGIENE DIVISION

	Agriculture Department	Hospitals	Labour Department	Mental Health Department	Milk Board	Mines Department	Police Department	Public Health Department	Public Pay	Public Works Department	Swan River Conservation Board	Other Government Departments	Other	Total
Food—														
Apples	38	....	....	....	....	....	....	....	....	....	....	....	....	38
Milk	197	....	....	....	397	....	....	104	....	....	....	....	1	699
Various	10	3	1	....	....	2	4	33	....	....	....	6	....	59
Industrial Hygiene—														
Diesel exhaust gas	....	....	....	....	....	48	....	....	....	....	....	....	....	48
Dust	13	....	4	....	....	....	....	13	....	....	....	....	....	30
Urine	....	3	46	....	....	....	....	31	114	....	....	....	1	195
Various	....	1	....	....	....	6	....	17	....	....	....	....	....	24
Miscellaneous—														
Blood-rat	....	....	....	143	....	....	....	....	....	....	....	....	....	143
Criminal Cases	....	....	....	....	....	....	83	....	....	....	....	....	....	83
Explosives	....	....	....	....	....	13	....	....	....	....	....	....	....	13
Linseed and oil	565	....	....	....	....	....	....	....	3	....	....	....	....	568
Pesticides	100	....	....	....	....	....	....	10	5	52	....	....	....	167
Plants	68	....	....	....	....	....	....	....	....	....	....	....	....	68
Soil	9	....	....	....	....	....	....	....	....	13	....	....	....	22
Tallow	....	....	....	....	....	....	....	....	18	....	....	....	....	18
Water	....	....	....	....	....	....	....	3	....	....	4	1	....	8
Various	24	1	....	2	....	6	15	34	43	9	2	27	9	172
Pollution—														
Effluent	....	....	....	....	....	....	....	....	3	....	9	....	....	12
Maritime	....	....	....	....	....	....	5	....	....	....	....	....	....	5
Surveys—														
Bunbury	....	....	....	....	....	....	....	....	....	48	....	....	....	48
Swan River	....	....	....	....	....	....	....	....	....	....	145	....	....	145
Various	....	....	....	....	....	....	....	....	....	....	2	....	....	2
Toxicology—														
Animal	14	....	....	....	....	....	....	2	5	....	....	....	....	21
Human—														
Specimens from patients	....	70	....	....	....	....	....	130	7	....	....	....	1	208
Sobriety	....	....	....	....	....	....	254	....	13	....	....	....	....	267
Toxicology	....	1	....	....	....	....	1,108	7	....	....	....	....	....	1,116
Traffic death	....	....	....	....	....	....	302	4	....	....	....	....	....	306
Total	1,038	79	51	145	397	75	1,771	388	211	122	162	34	12	4,485

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	1.1
3.00-3.19	2.5
3.20-3.49	18.0
3.50-3.74	15.8
3.75-3.99	8.6
4.00-4.99	46.1
More than 4.99	7.9
	100.0

Milk Solids not Fat

Per cent. in sample	Per cent. of total samples
Less than 8.00	1.1
8.00-8.24	17.2
8.25-8.49	34.2
8.50-8.74	34.2
8.75-8.99	11.9
More than 8.99	1.4
	100.0

Freezing Point

Degrees C below zero	Per cent. of total samples
Less than 0.510	0.4
0.510-0.519	1.1
0.520-0.529	4.0
0.530-0.539	34.4
0.540-0.550	51.1
More than 0.550	9.0
	100.0

In presenting the above figures it is emphasised that these were inspectors' samples for which there was *prima facie* evidence of their non-compliance with the legal standards.

An additional 119 samples of bottled milk were taken by inspectors from metropolitan and country treatment plants for the determination of freezing point only. The distribtuion of figures is shown in the following Table:—

Freezing Point

Degrees C below zero	Per cent. of total samples
0.520-0.529	0.8
0.530-0.539	77.3
0.540-0.550	21.9
	100.0

One hundred and ninety-seven samples of milk received from the Department of Agriculture were analysed for lactose (117 samples) and protein (80 samples) to assist the Dairying Division in the calibration of an infra-red milk analyster.

One hundred and four samples of bottled milk were received from the Public Health Department and examined for residues of chlorinated hydrocarbon pesticides. Dieldrin was detected in all samples, "D.D.T. and its derivatives" in 103 samples and B.H.C. in six samples.

In the early part of the year it was not possible to report some figures more accurately than "less than 0.01 part permillion" or "less than 0.005 part per million", but with improvements in technique greater accuracy was obtainable, particularly in respect of the dieldrin analyses.

The distribution of analytical figures is shown in Table 16.

TABLE 16

Pesticide Residues in Milk

Concentration parts per million	No. of samples Diel-drin	D.D.T. etc.	B.H.C.
Less than 0.01	16	16	
Less than 0.005	17	71	
0.08	1		
0.02	2	2	
0.01	2	3	
0.008	2		
0.006	11		
0.005	2	11	
0.004	18		
0.003	14		
0.002	11		
0.001	7		
Less than 0.001	1		6
Not detected		1	98

Work was continued by the Horticulture Division of the Department of Agriculture on the control of "scald" in apples held in cold storage and samples of apples which had received experimental treatments with diphenylamine and ethoxyquin were analysed to determine the concentration of each chemical on the skin and in the flesh of the treated fruit.

Samples of cool drink were examined for sugar content in connection with a community health survey. Other samples thought to have been responsible for sickness were found to be free from chemical poisons, although typical mould material was present in one sample.

Of interest was a sample of imported fish paste which could justifiably be described as having an odour suggesting protein decomposition. This opinion was supported by the ratio of volatile bases to total nitrogen. Bearing in mind, however, the origin of the sample and the manner of its use, it was concluded that this was a case where the normal criterion of quality was not applicable.

Of four samples of fruit juice cordial analysed specifically for ascorbic acid, one did not contain any, and two were markedly deficient. The fourth was satisfactory, but a repeat analysis after standing one month at room temperature (winter) showed that there had been a decrease of 60 per cent. in ascorbic acid content.

In another sample of fruit juice cordial some "inaccuracy" in description of the product was apparent, while yet another contained an artificial dye believed to have been formed by chemical action of the preservative and permitted colouring in the sample.

Of mince meat samples received for examination, one was notable for its poor quality; it was estimated that more than 50 per cent. of "meat" was sinew and fatty tissue.

A jar of coffee was found to contain numerous fragments of common soda glass, but despite further detailed investigation, no indication of their origin could be determined.

Six samples of margarine were submitted by the Dairying Division, Department of Agriculture and examined for compliance with the Margarine Act and Regulations. None complied with these requirements, although in two cases the deviation was only slight.

Of five samples of ice cream only one complied in full with the requirements of the Food and Drug Regulations, and an imitation ice cream, while satisfactory in chemical quality, gave rise to some concern as to its labelling.

Human Toxicology.

Exhibits were received from approximately 400 cases of sudden death which were the subject of police investigation. One hundred and sixty-three cases were as a result of traffic accidents, while 154 cases, comprising 1,005 exhibits, were submitted for examination for poisons or other physiologically active drugs.

In 53 cases no poison or drug was detected, whilst in 101 cases a poisonous substance or drug was identified on analysis. Details are listed in Table 17.

TABLE 17

Poison or Drug	No. of cases
Carbon monoxide	15
Pentobarbitone	35
Amylobarbitone	19
Quinalbarbitone	10
Phenobarbitane	6
Barbiturate (not further identified)	2
Carbromal	4
Bromvaletone	2
Methaqualone	3
Methyprylone	2
Amitriptylene	3
Nortriptylene	4
Thioridazine	6
Arsenic	2
Chlorpromazine	2
Phenacetin	3
Promethazine	2
Mercury	2
*Various (one of each)	14
Negative	53

* Aspirin, butabarbitone, chloral, glutethimide, lysol, paraldehyde, parathion, prochlorperazene, quinine, salicyclic acid, strychnine, thimet, thiopentone, trifluoperazene.

In 38 of the 124 cases where a sample of blood was available, alcohol was found to be present. The distribution of the analytical figures is shown in Table 18.

TABLE 18

Alcohol, per cent.	No. of cases
Negative	86
0.05 and less	7
0.06-0.08	7
0.09-0.14	9
0.15-0.20	10
0.21-0.25	2
0.26-0.30	1
More than 0.30	2

Blood Alcohol (Traffic Deaths).

Three hundred and six samples of blood and/or urine were received in connection with investigation into fatal traffic accidents. One hundred and sixty-three 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 19.

TABLE 19

Traffic Accident Deaths

Alcohol, per cent.	Number involved Drivers	Passengers	Pedestrians
Negative	37	22	17
0.05 and less	5	9	2
0.06-0.08	2	4	2
0.09-0.14	11	5	2
0.15-0.20	12	1	7
0.21-0.25	9	1	2
0.26-0.30	4	1	3
More than 0.30	3	—	2
	83	43	37

Table 19 shows that 34 per cent. of fatally injured drivers had a blood alcohol figure of 0.15 per cent, or greater, while the corresponding proportion for passengers and pedestrians was 7 per cent. and 38 per cent. respectively.

If the "upper limit" were 0.08 per cent., as laid down in some legislations, then Table 19 shows that 47 per cent. of the drivers had a blood alcohol figure exceeding this limit.

Blood Alcohol (Traffic Act).

Two hundred and fifty-four samples of blood were submitted by the Police Department and 13 by Local Government 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 such 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 causing injury which required immediate medical attention, and of whom it was suspected that driving ability may have been impaired by alcohol. In some cases in which samples were taken "breath analysis" equipment was not readily available, e.g., in country areas, in other cases the sample was requested by the subject, exercising his rights following a "breath analysis" test (Section 32B (4) and (5) of the Traffic Act).

The Traffic Act states (Section 32C (4)), that if the alcohol content of the blood at the time (of an alleged offence, or accident) is 0.15 per cent. or greater it shall be *prima facie* evidence that the subject was under the influence of alcohol at that time.

The results of these analyses are set out in Table 20, 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 20

Alcohol, per cent.	No. of cases
0.05 and less	9
0.06-0.08	7
0.09-0.14	36
0.15-0.20	90
0.21-0.25	71
0.26-0.30	45
More than 0.30	9
	267

In accordance with established practice, the analysis was repeated independently by another chemist when sufficient sample was available and no prior plea of guilty had been entered. One hundred and sixty-one samples were repeated in this way, making a total of 428 analyses in connection with this work.

Table 20 shows that 215 persons, or 80 per cent. of the total, had a blood alcohol figure of 0.15 per cent. or greater and that 251 persons, or 94 per cent. of the total, had a blood alcohol figure in excess of 0.08 per cent.

An examination of the times at which the accident or "offence" occurred showed that the greatest number occurred between 10 p.m. and 11 p.m., followed by a lesser but fairly uniform number through the hourly periods 5 p.m. to 8 p.m., 9 p.m. to 10 p.m. and 11 p.m. to midnight. The distribution of these "times of occurrence" is given in Table 21.

TABLE 21

Time of occurrence	No. of cases
p.m.	
4-5	13
5-6	26
6-7	24
7-8	27
8-9	19
9-10	28
10-11	45
11-mn	27
a.m.	
mn-1	17
1-2	11
2-3	11
3 a.m.-4 p.m.	19
	267

Specimens from Patients.

Two hundred and eight samples were received under this classification. Approximately 100 samples of blood and 90 of urine together with a small number of gastric contents, hair and nails were analysed in connection with the medical examination of patients for clinical purposes as distinct from industrial hygiene and toxicology. The various analyses performed under this classification are detailed in Table 22.

TABLE 22

Analysis	Number
Alcohol	2
Amphetamines	20
Arsenic	15
Barbiturates	88
Chlorophenols	1
Copper	20
D.D.D.	1
Dieldrin	8
Drugs (general)	5
Hydrocarbon solvents	1
Iron	10
Lead	24
Malathion	1
Mercury	6
Paraquat	2
Phenothiazine derivatives	3
Strychnine	2
Thallium	5
Zinc	5

Animal Toxicology.

Twenty-four exhibits were received from 12 animal post mortem examinations. In four cases strychnine was detected, six cases were negative and in two cases trace levels of chlorinated pesticides and arsenic respectively were detected.

From 10 suspected poison baits, strychnine was detected in one; the remainder were negative.

Work was continued for the Vermin Branch of the Department of Agriculture on the distribution of poison in prepared baits during the mixing process and 18 samples of dingo baits were analysed for strychnine.

Samples of rabbits poisoned with sodium fluoroacetate were also received from the Vermin Branch and examined to determine the fluorine levels in various organs.

Industrial Hygiene.

Nearly 300 samples were examined during the year in connection with industrial hygiene investigations.

One hundred and sixty-five of these were specimens of urine from workers exposed to suspected lead hazard and were analysed to assist clinical diagnosis or as a "screening" to exclude the possibility of undue exposure.

Of these specimens, 129, or 78 per cent., contained not more than 0.08 part per million (milligram per litre) of lead (Pb), 14 per cent. contained 0.09-0.15 part per million, 4.8 per cent. contained 0.16-0.20 part per million and 3.2 per cent. contained more than 0.20 part per million.

Other speciments of urine examined in connection with possible exposure to hazardous materials included analyses for—

(1) arsenic, from pest control operators, etc.;

(2) mercury, from workers exposed to the vapour or to mercurial compounds;

(3) dieldrin, from pest control operators;

(4) "sulphate ratio", from workers exposed to potential benzene hazard;

(5) trichloroacetic acid, from an operator suspected of undue exposure to trichloroethylene.

Inspections were made of working conditions in various factories, and samples of air and/or dust were analysed for—

(1) lead, in a "plastics" factory and on a scrap-metal premises;

(2) sodium fluoroacetate, in a pilot plant being designed for the manufacture of poisoned oats;

(3) phosphine, from lathes used for "turning" cast iron rollers (a substantial decrease in phosphine concentration was observed when water was not used for cooling);

(4) M.D.I., in premises where pouring of polyurethane foam was being carried out.

Four inspections were carried out as a result of complaint of hazardous working conditions in the holds of cargo ships.

These were the result of leakage or spillage due to broken containers of cyanide, sodium fluosilicate, T.D.I. and ethyl acrylate. "On the spot" assessments were made of the potential hazard and advice given as required on ventilation and other protective measures thought necessary to ensure safe working conditions.

Pollution Surveys.

Swan River.—The regular surveys of the Swan River were again carried out in 1967 when 145 samples of river water were collected and analysed for the Swan River Conservation Board. Three "non-survey" samples were also examined to investigate specific instances of suspected pollution, while samples of oily water and other material were submitted in an endeavour to trace the source of oil pollution of the river.

Nine samples of trade effluents from specific factories were examined as a check on their suitability for discharge into the river.

Leschenault Inlet, Bunbury.—Examinations for the Public Works Department were continued with the regular summer and winter pollution surveys of the water in the Leschenault Inlet at Bunbury, and 48 samples of water were collected and analysed in the surveys of February and July, 1967.

Maritime.—Five samples of suspected oil were received and examined. These were fluids alleged to have been discharged from ships into waters under the jurisdiction of the Fremantle Port Authority, and were submitted for analysis in order to establish that they were in fact oil or similar substance.

Miscellaneous.

Pesticides.—One hundred and forty-five samples classified as pesticides were received for examination during the year. The types and numbers of these samples are listed in Table 23.

TABLE 23

Type of Pesticide	No. of Samples
Aldrin (concentrate)	20
Aldrin (diluted emulsion)	30
Dieldrin (solid)	6
Dieldrin (concentrate)	11
Malathion (concentrate)	7
Mixed formulations	10
Weedicide concentrates—	
2,4-D amine	8
2,4-D ester	34
2,4,5-T ester	3
Various	16

The samples of aldrin concentrate and diluted emulsion were examined for the Architectural Division, Public Works Department in connection with "white ant" preventive treatments being applied to building projects, where sampling was carried out as a check on the materials being used for treatment purposes.

Although not classified as pesticides, 22 samples of soil were also examined to determine the efficiency of application in specific cases.

Samples of technical dieldrin and dieldrin concentrates were analysed for conformity to the specifications required by the Biological Services Division of the Department of Agriculture.

The increase in the number of 2,4-D type weedicides which commenced in 1965 was observed again in 1967. Forty-five samples were received from the Weed Control Branch at regular intervals during the spraying season and checked for quality of concentrates.

Similar checks for quality were carried out on malathion concentrates used in fruit fly control, while a more extensive examination was made of malathion concentrates for use in controlling vermin infestation of stored grain.

Miscellaneous pesticides received for examination included arsenic solutions, for spraying hides, mixed formulations for check with their declared composition, and a varied assortment of insecticides suspected of being contaminated with a weedicide.

Criminal Cases.—Eighty-three exhibits were submitted by the Police Department in connection with general criminal investigations.

Thirty exhibits were examined for an essential item of their composition as a result of alleged misrepresentation as to the nature of an exterior surface coating for houses.

A collection of 20 medicinals said to be responsible for "drugging" were found to be true to label and contained no injurious substances.

Metallic scrapings from the railings of a balcony were examined in connection with a shooting offence, while articles of clothing were the subject of further examination for evidence of ballast from safe breakings.

Charred remains of clothing, fibres and other materials, were submitted in connection with cases of suspected arson or accidental fires. In one instance, it was possible to determine the presence of kerosine, and in another, mineral turpentine.

Miscellaneous exhibits included a cigarette examined for heroin, with negative result, tablets for identification of drugs of addiction, waters for poisons, clothing for presence of automotive oil or grease, and exhibits from cases of alleged "doping" of horses.

General.—Five hundred and sixty-five samples of linseed from the Department of Agriculture were analysed for oil and moisture contents in connection with the Department's variety selection trials.

Interest in the toxicity to stock of natural plants was maintained in 1967 and 66 samples of plant material were received from the Botanist's Branch of the Department of Agriculture and analysed for fluoroacetic acid and derivatives.

Fourteen samples of sheep's milk were examined for the Department of Fauna and Fisheries in an investigation into the poor condition of these animals in an area where other species were thriving.

Eighteen samples of tallow were analysed to check their quality against trade requirements and 11 sets of blood alcohol collection kits, as distributed to Police Stations, were tested to ensure the absence of alcohol in the sampling equipment.

An experiment, commenced in 1966, was continued until mid 1967 to determine the stability of dioxathion (Delnav) in beef fat during prolonged storage in "deep-freeze", $-10°$ C. It was found that the concentration was stable for four months, a decrease of one third to one half was observed after six months' storage, while after nine months' storage the dioxathion had almost completely disappeared.

Forty-eight samples of mine air were analysed variously for carbon monoxide, carbon dioxide and oxides of nitrogen, in connection with investigations into pollution of underground air by—

(a) exhaust gases from diesel-powered equipment;

(b) fumes generated by different types of explosives used for blasting underground.

Eleven samples classified as explosives were submitted for various examinations. These included complete analyses, identification of specific constituents and testing for compliance with accepted standards.

Interest in the possible potentiation of the action of alcohol and antidepressant drugs was reflected in experimental work conducted by the Mental Health Services, and 143 samples of blood from rats were received and analysed for alcohol content.

Miscellaneous samples received and examined during the year included eucalyptus oils tested for compliance with British Pharmacopoeia requirements, leathers for examination to Commonwealth specifications, a Breathalyzer for examination and overhaul, plant materials and soils for traces of various pesticide residues, building materials for fire-testing and "overall" material for flame proofness testing.

The normal range of enquiries for technical information and advice were received during the year, and expert evidence was tendered as required by officers of the Division in connection with their official duties.

The Divisional Chief, Mr. N. R. Houghton, attended the meeting of the Food Analysts Subcommittee of the National Health and Medical Research Council held at Adelaide in July.

Mr. F. E. Uren attended the Annual Conference of Scientific Officers engaged in Industrial Hygiene, held in Melbourne in August, and following that, a Conference of Chemists engaged in the analysis for Pesticide Residues.

Mr. V. J. McLinden delivered a paper "Thin Layer Cromatography of Barbiturates and Related Drugs" at a one day Symposium on Analytical Applications of Chromatography, organised by the Western Australian Branch of the Royal Australian Chemical Institute.

FUEL TECHNOLOGY DIVISION

The Division had 119 registrations of investigations or samples assigned to it in the year. The National Coal Research Advisory Committee project, viz., "Investigation of the mechanism of the reaction of solid carbon with metallic oxides in connection with the direct reduction of ores with coal", Lab. No. 11926/65 has been continued. Our reports of progress with the investigation have been received sufficiently favourably by the Committee for it to continue the enabling grant of $10,000 for a further year. The work has developed a standard experimental method which gives concordant results and has defined a wide area of research from an investigation which commenced with examination of the reactivities of Collie coal chars in the reduction of ilmenite.

Analyses of a number of coal samples have been made and reported. Survey of dust deposits in the metropolitan area has been continued. Commercial work has been done on sub-sieve size analyses and on thermal conductivity of insulating materials. Technical advice has been given on dust collection and arrestment on a sawmill and on combustion of palm nut fibre in Malaya.

The Fuel Technologist continues to serve as State Representative on the National Coal Research Advisory Committee of which there have been three meetings during the year. He also served as Mines Representative on the Air Pollution Control Council which met three times during the year. The Clean Air Act was amended during the year to include the State Mining Engineer in the Air Pollution Control Council so that both the mining and scientific functions of the Mines Department are now represented on the Council.

Table 24

FUEL TECHNOLOGY DIVISION

	Hospitals	Mines Department	Public Health Department	Public Pay	Public Works Department	Total
Atmospheric pollution	....	66	....	2	....	68
Coal and coal products	....	4	....	9	....	13
Corrosion	....	....	....	....	4	4
Fuel	....	4	....	5	....	9
Sizing	....	....	1	10	....	11
Miscellaneous	1	....	....	13	....	14
Total	1	74	1	39	4	119

Table 25

COAL ANALYSES

Source	Collie (a)	Collie (b) Western 2	Collie (c)	Myroodah (c)	South-West (c)	South-West (c)	unknown (c)	unknown (c)	unknown (c)
Lab. No.	18612	18981–18983	18984	19638	14574–14575	1206	9414–9415	8330–8333	3450
	Per cent								
Analysis—									
Moisture	21·0	24·0	20·0	20·0	20·0	20·0	20·0	20·0	20·0
Ash	2·8	3·8	30·9	31·6	12·8	5·2	46·6	13·9	65·3
Volatile matter	31·6	32·2	25·8	20·8	28·5	42·6	21·0	25·8	....
Fixed carbon	44·6	40·0	23·3	27·6	38·7	32·2	12·4	40·3	....
	100·0	100·0	100·0	100·0	100·0	100·0	100·0	100·0	....
Sulphur	1·0	0·7	0·2	0·6	0·3	....	....	....	....
				Btu per lb.					
Calorific value—									
As analysed basis	9,700	9,280	5,650	6,400	9,760	8,870	....	....	....
Dry, ash-free basis	12,730	12,850	11,510	13,220	14,530	11,860	....	....	....

(a) Sampled at point of use during investigation of combustion conditions in a furnace.
(b) An average of three samples from the working faces of a mine.
(c) Samples obtained by drilling and therefore usually contaminated to some degree with extraneous matter from strata adjacent to the coal seam. The analyses are reported on the basis of 20 per cent moisture content for purpose of comparison.

Similarly the Division's Grade 1 Chemist and Research Officer will now be joined by an Inspector of Mines on the Scientific Advisory Committee provided for by the Clean Air Act. This Committee has met 11 times during the year and has done much detailed work in granting of licences and determining chimney heights, especially in relation to new major undertakings at Kwinana. This has required close attention and had taken up a major portion of the Grade 1 chemist's time.

The effective staff of the Division has comprised the Chief of the Division, one Grade 1 Chemist, one Grade 3 Chemist, one Laboratory Technician, one Laboratory Assistant. Attempts to recruit and hold a second Grade 3 chemist have not succeeded. At the moment of writing there are nominally two Grade 3 officers in the Division, but one of these has been on loan and exchange to the larger establishment of the Engineering Chemistry Division for six months not yet expired. The second Grade 3 position has had three incumbents in 18 months. It is difficult to maintain continuity of work in such circumstances and a position arises that experience in the many skills of the Division resides with only three officers, of whom two are close to retirement.

Coal Analyses.

Coal analyses made during the year are set out in the accompanying Table 25. None shows any variation from the sub-bituminous coal found at Collie.

Air Pollution.

Measurements of dust deposition have been made at five places over monthly collection periods. The results show little variation from those of previous years. The average loss on ignition is 50 per cent., indicating considerable organic matter. Collection figures are low at suburban residential sites and much higher close to main road traffic or industry. None of the figures is as high as those experienced under industrial conditions overseas.

TABLE 26

Dust Deposition, 1967

Test Position	Rate of Deposition Tons per Square Mile per Year					
	Summer			Winter		
	Max.	Av.	Min.	Av.	Max.	Min.
Industrial—						
East Perth	410	330	240	460	290	160
Rivervale	540	280	150	1,090	460	160
Main thoroughfare—						
Laboratories	270	200	80	130	110	80
Residential—						
Redcliffe	150	100	50	80	50	30
Wembley	60	50	40	60	50	30

Sulphur dioxide has not been determined nor have any figures for coefficient of haze been taken although the laboratory is equipped to make these determinations as a routine matter. The Air Pollution Control Council so far has not discussed the establishment of such routine tests to provide information on any increase in pollution consequent on the increase of industry. The origin of the above dust deposition figures dates back to their authorisation by the Air Pollution Investigation Committee of 1963.

Considerable theoretical and practical attention has been given to the calculation of chimney heights and their relation to probable ground level pollution in connection with work on the Air Pollution Control Council and on its Scientific Advisory Committee and in the course of preparation of a paper, by the Fuel Technologist, to the Institution of Engineers, on "Air Pollution" and an invited contribution to the Tasmanian Branch of the same Institution on "The Engineer and Air Pollution".

From the foregoing work it appears that there is some inconsistency about the permissible ground level concentrations of sulphur dioxide between different States. A higher figure is in effect acceptable in New South Wales than in Western Australia and, in consequence, for a given emission of sulphur dioxide chimneys may be lower and therefore less costly in New South Wales.

The view has also been advanced that the whole matter calls for review in Australia where conditions are often so calm that chimney plumes do not return to ground level. Under windy conditions, ground turbulence brings about rapid dilution of any pollution which does reach ground level.

In illustration, for a 40-MW boiler with a 200 ft. high chimney the combination of plume rise and turbulence coefficients gives the following values of point of maximum ground level concentration:—

Wind speed knots	5	15	20
Coefficient of turbulence	0.05	0.115	0.2
Plume height, feet	850	470	430
Point of maximum ground level concentration, miles	12.7	2.5	1.2

The Table shows that in calm conditions, 5 knot wind, the chimney plume rises high and travels so far that return to ground level is a purely theoretical concept since there is so little turbulence to bring about return. Above 10 knots turbulence develops as shown by the characterisation of the 10-15 knot condition as No. 4 on the Beaufort scale when "dust and loose paper blow about and tree branches wave"; thus pollution reaching ground level in such circumstances must be rapidly dissipated.

It would appear from this discussion that measurements at ground level of sulphur dioxide from existing chimneys are needed to verify present calculations of chimney heights.

Metal Oxide Reduction Investigation.

Work on this project is being done with the assistance of $10,000 per annum grant from the National Coal Research Advisory Committee. Progress to date has been itemised and reported as follows:—

Two hundred and one runs have been made to date in the examination of the reduction of the iron oxide in ilmenite. Twenty-nine polished mount microscopical examinations and X-ray mineral identifications have been made of reduction products, by Mineral Division. Sixty-eigth of the runs have been made using char as reductant, and 113 using hydrogen, carbon monoxide or mixtures of these gases and nine using these gases in conjunction with char.

A second line of investigation has been commenced into the reactivity of chars towards carbon dioxide in which the rate of reaction is followed thermogravimetrically using the indicating decigram balance, suspended reaction tube technique evolved for the investigation of ilmenite reduction. The method measures reactivity directly as rate of loss of carbon and shows that the reactivities of Collie coal chars are, on this basis, four times that of a New South Wales foundry coke at 1,000° C. There is no marked difference in the reactivities of Collie coal char prepared at 700° C and the same char which is residual from its reaction at 1,100° C with ilmenite; if anything, the latter char is slightly more reactive.

An outcome of the work with chars on ilmenite reduction is confirmation of industrial observations that 1,100° C ilmenite reacted char is less satisfactory as a reductant than Collie coal char prepared at 700° C despite the similarity in reactivity as noted above.

The effect is twofold. There is less reduction accomplished below 1,000° C and at 1,100° C the final reduction is less complete. The figures given below (Table 27) for the reduction of oxidised ilmenite at 1,100° C emphasise the difference in degree of final reduction. They are for varying

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ratios of char to ilmenite ranging from char to ilmenite ratio of 1:10 to one of 1:1 which provides approximately 10 times the theoretical amount of char required for reduction. This amount is 10.6 grams of char per 100 grams of oxidised ilmenite. The results show that 10 per cent. of char is inadequate but that 20 per cent. gives 99.1 per cent. oxygen removal which corresponds to 98.6 per cent. of the iron oxide present reduced to the metallic state. The standard amount of char taken in most reduction experiments is usually 30 per cent. of the ilmenite by weight. The Table of results confirms that this is an adequate excess.

TABLE 27

Char Reduction of Oxidised Ilmenite at 1,100° C.

Char as percentage of oxidised ilmenite	Per cent metallisation of iron oxide		Per cent reduction of iron oxide	
	700°C char	1100°C char	700°C char	1100°C char
10	68	47·9	78·6	65·1
20	98·8	90	99·3	93·4
30	98·6	89	99·1	92·7
50	100+	88·2	100·9	92·1
100	100+	82·2	105·3	88·2

Table 27 shows that 700° C char is sufficiently active in reduction to remove oxygen from the TiO_2 molecules in ilmenite if the char is sufficiently in excess. On the other hand 1,100° C char actually shows less reducing capacity when used in excessive amounts.

Table 28 shows that 700° C char is still effective as a reductant at 1,000°C although the amount of reduction effected is noticeably less than at 1,100° C and TiO_2 reduction does not occur.

TABLE 28

700° C and 1,100° C Char Reduction of Oxidised Ilmenite at 1,000° C

Char as percentage of oxidised ilmenite	Per cent metallisation of iron oxide		Per cent reduction of iron oxide	
	700°C char	1100°C char	700°C char	1100°C char
10	40·8	9·8	60·4	93·7
20	76·8	23·0	84·5	48·5
30	93·3	25·3	95·4	50·0
50	99·6	30·9	99·8	53·9
100	....	54·0	....	69·2
150	98·1	....	98·6	....

It has been shown that hydrogen reduces both oxidised and unoxidised ilmenite readily at 800-900° C and that there is very little difference in the final degree of reduction which is in excess of 95 per cent. On the other hand carbon monoxide is a poor reducer and below 1,000° C the producer gas reaction $2CO \rightleftharpoons C + CO_2$ probably prevents the reduction reaction $2CO + O_2 \rightleftharpoons 2CO_2$ from taking place.

It has also been shown that 700° C char contains more hydrogen and yields more gas with a higher hydrogen to carbon monoxide ratio than 1,100° C char.

From this a reasonable hypothesis emerges that while all Collie coal chars are reactive those prepared at a lower temperature and/or not subjected to a higher temperature in use have a reactivity approaching that of hydrogen in reduction. It has already been shown that hydrogen is an excellent reducer of the iron oxide in ilmenite.

The work has been extended to evaluate graphite, coke, vertical retort scurf and jarrah wood charcoal as reducers of iron oxide in ilmenite and so to broaden the scope of the investigation which might otherwise become confined to an investigation of slight variations in the reactivities of subbituminous coal chars. The results are interesting and conform to expectations apart from the linear form of the graphite reduction line. The graphite used was an impure commercial one containing 16 per cent. of ash. A run with pure graphite has yet to be made.

A difficulty apparent in the work done is that the reduction of ilmenite is complex. The hydrogen reduction curves show for both oxidised and as received ilmenite an initial rapid rise which in slope and extent corresponds closely to the reduction of ferric to ferrous oxide in each sample. After the completion of this stage both ilmenites reduce at slower, parallel rates which at the space velocity used are only half the rates associated with reaction to equilibrium.

Results with 700° C char reduction at 1,100° C show that TiO_2 in ilmenite can also be reduced.

The mineralogy of ilmenite also suggests that they are a mixture of true ilmenite $FeO.TiO_2$, with haematite, rutile and pseudobrookite ($Fe_2O_3.TiO_2$). Oxidation at 900° C of such a mineral is said to break it up into haematite (not magnetite) pseudobrookite and rutile and the haematite can then be reduced so that masses of iron occur in the reductate.

According to such views there should be marked differences between the reductions of the oxidised and as received mineral. Our findings show otherwise, reductions seem similar.

Both reductates also show micron sized accumulations of iron in veins and pores (as photomicrographs). This massing of supposedly molecular iron in micron sized accumulations is an accepted but unexplained feature of ilmenite reduction.

As a reduction it is a useful and interesting one to investigate, but as a yardstick against which to assess the reducing properties and mechanism of chars it is unsatisfactory. It thus seems that it is not a suitable oxide to use in comparing the effectiveness of different forms of carbon in metal oxide reduction.

Iron ores, on the other hand, provide such oxides of well investigated reductibility. Samples of Western Australian iron ores have therefore been accumulated which can first be compared with hydrogen as a standard reductant and then with Collie coal char and other reductants.

The eventual outcome of this work should be the elucidation of the role of gases absorbed on the surface of carbon, in its various forms, in effecting reduction. Such an elucidation necessarily requires work on gaseous as well as char reduction if, as is generally accepted, carbon reduces iron oxide through gaseous reactions.

A practical outcome of the investigations has been the finding that hydrogen, contrary to frequently expressed opinions, is an excellent reducing agent for the iron oxide in ilmenite. This finding brings in question the value of preoxidation of ilmenite. Preoxidation undoubtedly gives an attractive high initial rate of reaction associated with the normal rapid and easy reduction of ferric oxide by hydrogen but the time to complete the reduction to metallic iron seems no better than when the unoxidised mineral is reduced.

There may therefore be no point in an increase of requirement of reductant if there is no ultimate gain as shown by the following figures for hydrogen reduction related to its production of steam-iron process from Collie coal based on a hydrogen production of 37,000 cft. per ton of coal.

Mineral	Hydrogen cft per ton of mineral	Coal for hydrogen lbs per ton of mineral
Unoxidised ilmenite	5,500	330
Oxidised ilmenite	7,000	420
Leucoxene	3,200	192

Leucoxene is a mixed ilmenite rutile fraction with an iron oxide content of about 12 per cent. and, at present, does not have a ready market as it is neither acceptable as rutile for titanium metal nor as ilmenite for titanium pigment. Its beneficiation using hydrogen is therefore attractive.

A study of steam-iron hydrogen reduction of leucoxene and ilmenite is merited comparatively with rotary kiln reduction. The hydrogen reduction reaction operates at 800-900° C against 1,100° required in coal rotary kiln reduction. The power requirements of rotary kilns are considerable. No power consuming compression of hydrogen is required other than of low pressure blowers for circulation. The lowest figure for coal consumption reported for coal used in a rotary kiln is 0.75 tons per ton of ilmenite. A comparative study would thus be enlightening.

Dust Arrestment.

Work on the dust arrestment train set up at Engineering Chemistry Division continues as staff availability and opportunity permit. A standard short cone Buffalo Forge design of cyclone has been tested since this is a type much used industrially in dust arrestment. At the standard inlet velocity of 50 fps. this type throws only 2.3 ins. w.g. pressure and its cut size on standard silica sand appears to correspond closely with the calculated value from the standard cut formulae set out below.

A cyclone corresponding to a commercial Van Tongern design has been made and is in the course of testing. This proves to be a cyclone which throws the rather high differential of 5.7 ins. w.g. at an inlet velocity of 50 fps.

Results on the dust train are still being assembled for final presentation. The work has however led to condensation of formulae for cyclone size and cut, and it has been possible to supply commercial interests requiring cyclone designs with standard drawings and these formulae.

Where D is the diameter of a cyclone in feet, V is the inlet velocity, fps., Q is the flow rate, cfm. and S is the specific gravity of the material.

The cut measured as the diameter of the smallest particle retained expressed in microns is

$$11\sqrt{\frac{D}{S.V}}$$

For short cone low resistance cyclones .... $Q = 130\ D^2$ up to $150\ D^2$

For Stairmand long cone cyclones .... $Q = 300\ D^2$

For Stairmand high capacity cycloidal entry cyclones .... $Q = 900\ D^2$

Thermal Conductivity.

An orchardist concerned with construction of a fruit cold store submitted samples of the expanded polystyrene insulation for information on its specific gravity—thermal conductivity relationship. The thermal conductivity was determined on annular cylinders by the log mean diameter method.

The figures show a minimum thermal conductivity at a density of 20.1 oz. per cft. and it appears that this is a specified density of expanded polystyrene. At greater densities there is greater conduction by cell walls and at lower densities convection in larger air pockets becomes of greater moment. Our results have been confirmed by figures which have lately appeared in the literature.

TABLE 29

Thermal Conductivity of Expanded Polystyrene

Lab. No.	Density oz per cu ft.	Thermal conductivity Btu per ft. hour deg. F
2063	14·8	$2{\cdot}79 \times 10^{-2}$
2064	21·3	$2{\cdot}40 \times 10^{-2}$
3781	17·8	$2{\cdot}14 \times 10^{-2}$
3782	18·5	$2{\cdot}06 \times 10^{-2}$
3783	21·1	$2{\cdot}05 \times 10^{-2}$

Miscellaneous.

Some anlyses have been made of mine air to verify the absence of methane. Liquified ammonia was checked for absence of water. Advice was given on hot water boiler at a hospital relative to alternative fuels. An oil fired hot water boiler was examined for fire tube corrosion in relation to the now perennial problem that these fire tube boilers accumulate much ferrous sulphate on the tubes without showing corrosion attack on the steel of the tubes but without finding as yet any accountable relation between ferrous sulphate deposited and iron oxide entering in either oil fuel or in combustion air.

INDUSTRIAL CHEMISTRY DIVISION

Introduction.

One hundred and thirty-six samples were examined during the year as against 122 in the previous year and as usual these formed the basis of investigations on the suitability of materials for specific purposes and on the reasons for failures in use. Consultative work continued to grow and the questions were as usual varied, although an increasing percentage related to plastics. Government Departments made an increasing use of consultative facilities and there were numerous private enquiries.

Staff.

1. Mr. H. Douglas was promoted to Inspector, Explosives Branch, from 24th November, 1967.
2. Mr. H. Schuller, temporary Laboratory Assistant, resigned on 16th June, 1967.
3. Mr. M. Pinter, Laboratory Assistant, started duties on 12th June, 1967.
4. Mr. R. I. McKinnon was admitted as a graduate member of the Institution of Chemical Engineers (Great Britain).

TABLE 30

Industrial Chemistry Division

	Agriculture Department	Fire Brigades Board	Industrial Development	Lands & Surveys	Medical Department	Mines Department	Public Health Department	Public Pay	Public Works Department	South Perth City Council	Total
Building Materials	....	....	39	....	....	....	....	1	4	....	44
Paint	....	....	....	....	....	25	....	....	24	....	49
Plastics	2	....	....	1	....	....	7	....	14	5	29
Miscellaneous	....	2	....	....	1	2	....	7	2	....	14
Total	2	2	39	1	1	27	7	8	44	5	136

Classification of Work.

(1) Routine:

(a) Building Materials.

(b) Plastics.

(c) Miscellaneous.

(2) Assistance to Industry.

(3) Investigational.

(4) Consultative.

(1) *Routine.*

(a) Building Materials.—Ninety-three samples of building materials were examined, including paints and thirty-nine samples of locally-manufactured material, tested on behalf of the Department of Industrial Development. There were seven "pay-public" samples for local contractors.

Two cases of staining of plaster were investigated and recommendations made for their removal and for a prevention of their recurrence.

A sample of butyl rubber weather strip was examined for oil and solvent resistance. It was found to be inferior to the fluorinated rubber types.

Five samples of aluminium insulating foil were examined for general quality and comparison with samples received in previous years. One brand was reinforced with a mixture of fibre glass and organic fibres; the other brand was reinforced with glass fibres only. There was no significant variation in total weight per unit area, weight of aluminium per unit area, quantity and type of adhesive.

Buckling of a wood mosaic floor laid over concrete was traced to enhancement of the moisture content of the concrete by absorption of ground water. Moisture was transferred to the mosaic which swelled and buckled. Recommendations relating to the dryness of concrete floors before laying tiles or mosaic are often neglected in the interests of quick completion of a project.

In order to determine the relative impact resistance of wire-reinforced and rendered polystyrene foam vs. cork-board, 39 samples of several types of reinforced and unreinforced foam and cork-board were submitted to a rigorous falling weight test. Results for wire reinforced and rendered polystyrene foam proved as good as for cork, and as the latter is an import, the locally made foam was preferred for the lining of cool rooms at a large abattoir.

Nineteen samples of coal tar epoxy anti-corrosive paints were examined for ultra-violet light resistance. The samples were irradiated for 1,200 hours in a "dust bin" weatherometer. No preparation was proof against the ultra-violet but the wide variation in the effects observed was a little surprising.

Three samples of cement additives were examined during the year. Two were of the lignosulphonate retarder-plasticiser type, and one was a chlorinated rubber based membrane curing compound. The chlorinated rubber based membrane curing compound was found to be more effective than either the wax emulsion or P.V.A. types tested in previous years.

(b) Plastics.—Twenty-nine samples of plastics were examined during the year.

Leakages in the reticulation system on a South Perth oval were found to be due to the erosion of P.V.C. lines in the neighbourhood of leaking joints. The eroded areas had all the hallmarks of termite attack, but no infestation of these or other creatures attacking P.V.C. could be found in the vicinity. Following laboratory experiments it was found that the trouble initiated at the joints, some of which seems to have been incorrectly aligned when first installed. Water issuing from leaks at the joints in certain areas picked up sand which was subsequently "jetted" on to the pipe causing rapid erosion. It was observed that a water jet with no sand even at high velocity had no visible tendency to erode the pipe.

Lands and Surveys Department requested help in making a mould for a relief map of Western Australia from which polyester resin maps could be cast. The mould was successfully made and a relief map of Western Australia in resin prepared. This was backed by an ordinary map of Western Australia behind which was installed a complex system of wiring. Set in a wooden frame the map can be illuminated at the touch of a button to show main ports, beef roads, railways, mineral deposits, etc.

Seven samples of plastic motor car body filling compound were analysed for pigment content and the extracted pigment passed to Mineral Division for investigation. Two years ago manufacture of these patching compounds was virtually an Eastern States monopoly, but today local manufacture is steadily taking over a market increasing with the rising tide of traffic accidents.

A comparison between acrylic modified polyester corrugated panels and some methyl methacrylate sheeting in their resistance to ultra-violet light was afforded when samples of both were exposed in a dustbin weatherometer. The acrylic-modified polyesters showed remarkably good ultra-violet resistance but, curiously the methyl-methacrylate seemed less resistant.

A sample of polyethylene film for the packaging of hygroscopic materials was examined for water vapour permeability. The results were so irregular that an investigation of the method used had to be undertaken. Shortly after a number of articles were found suggesting alternative methods of determination of film permeability and it is learnt that standard methods are now under revision.

Two samples of an epoxy resin based compound for the repair of a glass-reinforced plastic pipe line were examined for compliance with specifications.

Harbour and Light Department's requirements for boats built in reinforced plastics (so-called "fibreglass"), and intended for commercial or hire purposes include compliance with the Australian Standard. Since this involves tensile strength tests (the value of which is to say the least dubious), and there is no local plastics-testing laboratory, the reinforced plastics boat industry has been severely handicapped. Until such time as testing can be arranged it has been agreed that a Surveyor for Harbour and Light Department would inspect facilities at any boat-building factory intending to make commercial vehicles in "fibreglass" and, if satisfactory, allow the boat(s) to be built under supervision. Mr. Reid has accompanied the Harbour and Light officer on three visits. In two cases permission to build was recommended, subject to minor alterations in technique and services; in the other, permission was refused. It is pleasing to record that the standard of reinforced plastics boat building in Western Australia is high and probably equal to the average standard in other States.

(c) Miscellaneous.—Two samples of fire hose which had inexplicably burst at a below-rating pressure were examined. The fault appeared to lie in the manufacturing process.

Samples of karri sawdust and of a cereal waste were processed as raw materials for the manufacture of furfural. Results were very encouraging. (See also under "Assistance to Industry".)

(2) *Assistance to Industry.*

Poisoned Oats Production.—Design for a plant to manufacture plastic-coated poisoned oats by the Agriculture Protection Board proposed a neoprene conveyor to carry sticky coated oats. By itself the neoprene was not at all successful as oat grains readily adhered to it. Dusting the belt with zinc stearate greatly reduced grain adhesion. As a coating material adhesive grade P.V.A. had been used; tests indicated that acrylic P.V.A. copolymers considerably reduced tackiness of the coated oats and gave a superior film on the oats.

Process for Production of High Protein Material from Wastes.—The Industrial Chemistry Division was again able to help in the development of a solvent process for recovery of high protein products from offal and abattoir wastes. A large sample of mixed solvent was fractionally distilled for use in solvent extraction trials.

Two large samples of fish were partially dehydrated at relatively low temperatures under vacuum in an evaporator made by altering a five gallon glass lined reaction kettle. This work was done as a preliminary to solvent extraction, and to remove a large proportion of the water, thus enhancing the activity of the solvent. After one trial, modifications were made to the evaporator which resulted in a 60 per cent. increase in the evaporative capacity.

(3) *Investigational.*

Painting of Karri Timber.—Work on this project continued throughout the year. Preparation of test panels was completed, and samples on exposure were examined regularly. Considerable changes have become apparent in some of the test panels. Blistering of the paint films has occurred in most of the test panels which had a high moisture content when painted. As these panels dried out, in many cases the blisters collapsed, leaving no adverse changes in the paint film. Changes in atmospheric humidity have in many cases been accompanied by peeling paint and cracking timber. It is these features which are characteristic of paint failure on karri timber. One note-worthy feature is that two painting systems have shown no deterioration during an exposure period of 18 months. Eighteen samples with varying timber moisture and differing types of sawing were used for each painting system.

Furfural from Forest Wastes.—Research on this subject and the compilation of an extensive literature survey was in hand when a large local chemical firm offered to sponsor further work. A number of tests have been run on marri bark chips using the more or less conventional pressure hydrolysis process. Results have been very encouraging.

Meanwhile work is projected on a new continuous fluid bed process which, if successful, would greatly reduce costs.

The market for furfural in Western Australia is a promising one and with the use of furfural in the manufacture of polyurethanes it seems that Australia might consume all that can be made.

Plastic Chimney Stacks.—Industry in the U.S.A., Britain and Europe is making more and more use of reinforced plastics chimney stacks. They are much lighter than conventional stacks and thus require much less foundation work. They are easier to erect and much more chemically resistant. Their weakness lies in the action of heat on the plastics system.

Since the Public Works Department was interested in stacks, various resin suppliers were queried as to the best resins they could provide. Only one firm suggested a product which they could provide. Only one firm suggested a product which they said would do and others said there were no such products available. One so remarking is reportedly said to have supplied the resin for an English chimney stack.

There seemed no other way than to test some resins ourselves for heat distortion and for the effect of reinforcements thereon. The work is almost complete and results as a whole do not altogether support suppliers' statements.

(4) *Consultative.*

It might be expected that the State's rapid industrial progress would affect both the quantity and direction of queries received. This on the whole is what happened, but one interesting feature was the varying nationality of enquirers. Apart from local people we had calls from people from every other State, as well as from France, Malta, the United Kingdom, Netherlands and the U.S.A. Answering these enquiries by telephone or personal call occupies one officer on the average at least half the working day.

We should like to record our appreciation of the co-operation received from so many sources, from Consulates to small firms. A loosely-knit body has emerged, each member of which consults his fellows to the mutual benefit.

As in past years the main questions asked have been (a) Who are the local agents for X? (b) What are the specifications for Y? (c) What would you suggest for . . . ? (d) Can you tell me why so and so failed? (e) How would you formulate for . . . and where can I get the chemicals? (f) Can you tell me the best sort of machine for . . . ? Many of the queries related to building materials. With the increasing use of plastics and especially foams in building there have been numerous queries on their properties and applications. Some of these have come from the Building Advisory Board, Government architects, private architects, builders and householders. Polyurethane foam may soon prove to be a highly important building material especially in the North-West. It is most desirable that this material be subject to quality control in order that it may be used effectively, safely and efficiently.

Some of the various formulations we are asked to vet or comment on must have originated in great-grandmother's day, yet they still retain their popularity. In the specifications for a contract awarded to a Western Australian firm, was a reference to the use of "Dr. Angus Smith's solution". Dr. Angus Smith was an engineer with the Glasgow Corporation in Scotland and his solution, a phosphate, dates from the 1870's. Enquirers included architects, engineers, builders, medical men (particularly on epoxies and polyesters), lawyers and householders.

The consultative service of the Division, starting uncertainly in 1950, may yet become the major item in the Division's work. No other State, we are told, has a similar service.

MINERAL, MINERAL TECHNOLOGY AND GEOCHEMISTRY DIVISION

General.

A total of 4,354 samples was received during the year, from the following sources:

General Public (free)	2,054
General Public (pay)	1,491
Mines Department	680
Other Government Departments	129

The source and type of sample are shown in Table 32.

The number of samples received into the Division in the past six years is shown in Table 31.

TABLE 31

	1962	1963	1964	1965	1966	1967
Public pay	717	744	796	741	1,154	1,491
Public free	1,009	837	879	3,210	1,757	2,054
Government Department	737	1,097	720	887	928	809
Total	2,463	2,678	2,395	4,838	3,839	4,354

Comparing 1967 and 1962 there is an increase of 108 per cent. in the Public Pay samples, of 104 per cent. in the Public Free samples, of 10 per cent. in the samples from Government Departments and an overall increase of 77 per cent.

Staff.

The vacancy existing at the end of 1966 for a Mineralogist and Research Officer was filled by Mr. E. Tovey, who was promoted from Laboratory Technician upon completing professional qualifications.

Mr. R. C. Morris, Mineralogist and Research Officer was promoted from Grade 3 to Grade 2 as from 5th October, 1967.

Mr. M. B. Costello read a paper entitled "Chromatography in Mineral Analysis" to a symposium on analytical applications of chromatography arranged by the Royal Australian Chemical Institute, and Mr. R. W. Lindsey gave two talks to the W.A. Lapidary Club.

TABLE 32

Mineral Division

	Mines Department	Public Free	Public Pay	Public Health Department	Public Works Department	Other Government Departments	Total
Burnt Lime	5	....	6	....	....	....	11
Clay	9	21	9	....	....	....	39
Concrete	6	....	15	....	10	7	38
Dust	66	....	2	21	31	8	128
Metals and Alloys	....	....	15	....	....	6	21
Mineral Identification	115	688	106	2	....	9	920
Minerals and Ores—							
Arsenic	....	572	....	....	....	....	572
Copper	34	75	38	....	....	1	148
Gold ores	4	148	658	....	....	....	810
Tails	62	....	....	....	....	....	62
Umpire	13	....	....	....	....	....	13
Heavy Sands	2	29	13	....	....	....	44
Iron	12	75	35	....	....	....	122
Lead	5	23	6	....	....	....	34
Limestone	....	24	8	....	....	....	32
Lithium	....	4	20	....	....	....	24
Nickel	19	246	42	4	....	....	311
Phosphate	31	14	....	....	....	....	45
Rare earths	....	5	26	....	....	....	31
Sands	109	....	12	....	....	....	121
Silver	3	....	102	....	....	....	105
Tantalite	8	31	54	....	....	....	93
Tin	9	14	143	....	....	4	170
Titanium	32	14	3	....	....	....	49
Tungsten	5	9	2	....	....	....	16
Vanadium	9	15	1	2	....	....	27
Others	9	47	106	....	....	....	162
Miscellaneous Investigations	30	....	29	9	6	9	83
Geochemical Analyses	50	....	39	....	....	....	89
Complete Analyses	33	....	1	....	....	....	34
Total	680	2,054	1,491	38	47	44	4,354

Mr. L. C. Hodge visited the Mogumber and Moora areas with Professor A. Wilson of the Queensland University to study the occurrence of the mineral hogbomite in relation to the general geology of the area and Mr. R. C. Morris travelled to Marvel Loch to take samples and examine the occurrence of a rare silver mineral.

By arrangement with the State Mining Engineer, Mr. G. H. Payne visited Dampier, Mt. Tom Price, Wittenoom, Mt. Newman, Mt. Goldsworthy and Port Hedland.

At the request of the National Association of Testing Authorities, Mr. Payne acted as an assessor in the routine periodic reassessment of the W.A. Government Railways Laboratory.

Equipment.

The only major item of equipment received during the year was a Leitz Focomat IIC photographic enlarger with colour filters, automatic timer and masking board accessories. The enlarger can handle both ¼ plate and 35 mm negatives.

The reflectivity hardness equipment developed in the Division proved a very useful tool and considerably expedited identification of opaque minerals. A description of this is available as a separate publication on request.

Mineral Collections.

Two hundred and twenty-eight specimens were added to the Mineral Division reference collection, 193 of them from within the State. Seven originated interstate, 21 came from U.S.A., six from South Africa and one from Brazil. All the specimens from U.S.A. came from California and in most cases represented the only member of their species in the collection. Among these were the seven recently discovered barium-bearing silicate minerals from Fresno County, California, namely, fresnoite, kranskopfite, macdonaldite, muirite, traskite, verplanckite and walstromite. Others included deerite, howieite, mussmanite, miargyrite, taramallite, coalingite, hanksite and the mercury oxide montroydite associated with native mercury.

All the South African specimens were crocidolite.

A selection from the minerals added from localities within Western Australia includes baryte (from Murramunda Station, Mt. Trew, Muggon Station, Chesterfield, Range Station, Kooline, Nicholson Station), galena (Murramunda Station, Kooline, Nullagine, Kununurra, Mangaroon Station), fluorite (Poona, Yunderamindera, Mt. Elvire, Koolyanobbing), tourmaline (Spargoville, Kennedy Range, Erlistoun Station, Nukarni), lepidolite (Spargoville, Lepidolite Hill), zinnwaldite (Spargoville), muscovite (Yinnietharra, Glenflorrie), beryl (Spargoville, Mt. Francisco, Byro, Koolyanobbing, Lepidolite Hill), cassiterite (Mt. Francisco), ilmenite (Mt. Francisco, Peak Hill, Augusta, Payne's Find), rutile (Kennedy Range, Trillbar Station, Calingiri), columbite-tantalite (Kathleen Valley, Mid Mt. Barren, Yalgoo, Woodstock, Wodgina, Mt. Francisco), pyrolusite (Wyndham, Parker Range), cryptomelane (Kalgoorlie, Bremer Range, St. Ives), tapiolite (Mt. Francisco), bismutite (Peak Hill, Marble Bar), scheelite (Hawkesstone Peak), tungstite (Ora Banda, Wombola), wulfenite (Whim Creek), descloizite (Yinnietharra), prehnite (Yinnietharra, Mt. Ida, Day Dawn) alunite (Yerilla, Mt. Vernon), natrojarosite (Lake Rebecca), kyanite (Limestone Springs, Kimberley) and wavellite (Ullawarra).

Sixteen sets of W.A. mineral specimens were made available to applicants for educational and prospecting purposes. Sets were sent to the Education Department's Technical Extension Service, to the Department of Industrial Development for display purposes at the Derby Boab Festival and to the W.A. Institute of Technology for production of typical emission spectra. Twenty-four specimens of niobium and tantalum-bearing minerals were made available to C.S.I.R.O., Floreat Park, for examination by X-ray diffractometry (see later under tantalum-niobium minerals).

A set of specimens, of the size and species likely to be encountered in the treatment of material at the new magnetic concentration plant at the Marble Bar State Battery, was prepared for the battery staff as an aid to identifying and grading their various products.

Twenty specimens were donated by Ford Rhodes Foulkes & Co., of Kalgoorlie, consisting of specimens from various depths of the east and middle lodes of the Ivanhoe G.M. They were particularly fine specimens, the minerals present including coloradoite, calaverite, tetrahedrite, sphalerite, chalcocite, nagyagite, arsenopyrite, pyrite, ilmenite, magnetite and gold.

Building Materials.

(1) Aggregates.—Materials for both fine and coarse aggregate were submitted by private and Government bodies for testing their potential use as concrete ingredients.

Coarse aggregate examined included granites, greenstones and basalts. As would be expected, the granites contained no deleterious minerals. The greenstones, made up essentially of sericite, ankerite, chlorite and amphibole, contained no minerals potentially reactive towards the alkali of cement, but carried up to 2 per cent. of pyrite. However, mortar bar tests did not show any reaction due to pyrite over a period of 54 weeks.

To obtain more data concerning the effect of different sulphides on concrete, mortar bar tests were carried out using aggregates containing pyrite, pyrrhotite and marcasite. The results of this investigation are available as a separate report on request.

The basalt aggregate from the Collie area, was composed essentially of plagioclase feldspar and ferromagnesian minerals, but in a groundmass containing areas of devitrified glass. The presence of this non-crystalline glass accounted for the aggregate being reactive towards cement and therefore unsuitable for use in concrete.

Further work was carried out on the reaction of opal with cement having an alkalinity typical of Western Australian products. These results are also detailed in the separate publication referred to above.

(2) Mortar.—A mortar that was fretting badly after five years in the external leaf brickwork of a house was examined and found to have an original mix approximating 1 cement : 2 hydrated lime : 14 sand by volume. The specified material was 1:2:9.

(3) Bricks and Tiles.—White stain on cream burnt bricks became evident only after the bricks had been in use in a wall for some time. The stain was resistant to acid and was found on examination to be essentially amorphous silica. The stain had apparently originated from the action of hydrochloric acid (used for routine cleaning of the wall) on calcium silicates derived from the cement or lime in the mortar. The gelatinous silica so formed could be readily removed by copious hosing down immediately after treatment, but if allowed to dehydrate first became very tenacious.

Green and reddish-brown stains on cement tiles taken near the stack of an oil-fired boiler of a motel were shown to have high concentrations of calcium, iron and sulphate. The stain had probably originated from the formation within the boiler stack of ferrous sulphate produced by sulphur in the fuel oil. This ferrous sulphate, being deposited on the cement tiles, reacts in part with the lime of the tile in presence of air, to form a layer of brown ferric hydroxide and calcium sulphate; the upper surface, not subjected to reaction with lime is stabilised as a green basic sulphate by reaction with moist air.

Dusts.

Twenty-two dust samples from Port Hedland were examined for the Public Works Department to determine their relationship to iron and manganese ores being shipped through that port. Taken from selected localities around the port most were found to contain less than 5 per cent. of iron or manganese ore minerals, by far the greater proportion of the samples being made up of quartz, calcite and clay.

Other samples taken from the one gauge at monthly intervals over a period of six months, were examined and analysed to show the variation in the dust composition under changing seasonal conditions.

Samples from the Public Health Department were examined in connection with cases of dust pollution, suspected sources including phosphate rock stockpiles, and plants producing zinc oxide and plaster of paris.

Five Departmental samples, taken from gauges in five metropolitan areas, were examined each month to determine the nature and size of the dust particles.

A range of samples was submitted by the Public Health Department of dusts or materials suspected or known as potential health hazards.

Of two fine soap fillers, one was found to be quartz with 4 per cent. smaller than 5 microns in diameter, the other was feldspar with 7 per cent. of the grains less than 5 microns in size.

The inorganic fraction of materials used in seven different types of panel beating plastic fillers were examined. Talc (magnesium silicate) was the most widely used, either alone or mixed with other powders such as baryte (barium sulphate) and calcite (calcium carbonate).

An asbestos mixture used for fire proofing contained anthophyllite but no crocidolite. Dusts taken in premises specialising in fitting brake linings were all found to contain fibrous asbestos particles in concentrations ranging from 10 to 75 per cent. of the total airborne dust.

Other samples, taken while cement floors of buildings under construction were being mechanically smoothed prior to tile laying, were found to represent free silica concentrations as high as 1,000 particles per millilitre of air.

Other dusts examined included samples from iron foundry and manganese mining centres, while nickel concentrates and vanadiferous boiler soots were analysed for Public Health Department to assess them as potential health hazards.

Minerals and Ores.

1. Arsenic.—Most of the arsenic determinations carried out were geochemical in nature. Several hundred samples were received in continuation of the work initiated in 1965 whereby the Division is assisting a research programme carried out by a mining company into the nature and structure of the Kalgoorlie ore bodies. The main purpose of the analyses is to study the correlation between gold and arsenic concentrations.

2. Baryte.—An unusually large number of baryte samples were received from localities ranging from the Borden-Jerramungup area in the South-West to Muggon Station in the Murchison, and from Kooline, Range Station and Marble Bar in the North-West to Nicholson Station and Kununurra in the Kimberleys.

Most were iron-stained, but many crushed to only slightly off-white powder.

A sample from Jigalong Mission was associated with a little quartz and contained small spots of covellite, chalcopyrite, pyrite, sphalerite and galena as well as some oxidised minerals as chrysocolla and cerussite.

3. Cadmium.—Eight samples were submitted for the determination of zinc, cadmium, gallium and indium. Gallium and indium hollow cathode tubes were obtained so that atomic absorption technique could be used to estimate these trace elements.

A review was made of the cadmium, gallium and indium contents of Western Australian sphalerites the results of which are available as a separate report on request.

4. Clay.—Localities from which clay samples were received included Albany, Capel, Collie, Field's Find, Forrestonia, Kojonup, Lake McLeod, Mukinbudin, Mulgabbie and Narembeen. In many cases insufficient information was available regarding tonnages to justify detailed firing tests.

A sample from Cleary, consisting of quartz and clay minerals with weathered mica and minor feldspar, was particularly refractory, giving briquettes still rather friable after burning at 1,250° C and showing a linear shrinkage of only 2.7 per cent.

A New South Wales clay, currently being used for the manufacture of earthenware pipes of high quality, was submitted for comparison with local clays. The company concerned was prepared to consider the establishment of a plant in Western Australia if deposits of similar clays were available reasonably near to potential markets.

Burning tests were carried out on this New South Wales clay to obtain briquettes for use as standards for comparison with those from Western Australian clays burnt under similar conditions. The New South Wales clay gave porosity and linear shrinkage figures (at temperatures between 1,150° C and 1,250° C) each of the order of 5 per cent. Unfortunately no local material gave equally low figures together for both these characteristics.

5. Cobalt.—Rather more interest than usual was shown in cobalt due to its association with nickel.

Samples were received from the well known localities of Glenroebourne and Ravensthorpe. Specific cobalt minerals identified in these samples were cobalt-bearing calcite and the calcium cobalt arsenate, beta-roselite from Glenroebourne and cobaltite from Ravensthorpe.

A sample was received from Gindalbie Station assaying 0.8 per cent. cobalt and 1.2 per cent. nickel, while others from the vicinity of Holleton showed up to 0.3 per cent. cobalt but only about 0.01 per cent. of nickel. Cobalt bearing manganese ore from St. Ives assayed 1.1 per cent. Co.

As a pyrite-marcasite specimen from the Gurkha Mine received in 1954 had shown a nickel content of 0.54 per cent. and a cobalt figure of 0.16 per cent., it was decided to assay 16 other specimens of mainly sulphide minerals from the Northampton area for these two elements. With the exception of galena from Baddera (which showed 0.04 per cent. Ni and 0.11 per cent. Co) all the other samples, which included galena, sphalerite, chalcopyrite, anglesite and malachite, assayed only trace amounts.

6. Copper.—Copper samples received covered the usual wide range as regards grade and mineral composition.

A batch of seven samples from Glenroebourne showed a consistent copper : cobalt : nickel ratio of the order of 10:1:1 though in a second consignment from the same area the cobalt and nickel figures were considerably lower.

A sample from an undisclosed locality contained the sulphide copper minerals digenite, chalcocite, chalcopyrite and covellite as well as pyrite and pentlandite with traces of electrum. It assayed 25 per cent. copper, 0.4 per cent. nickel and between 3 and 4 oz. per ton of both gold and silver.

A specimen from Rothsay represented probably the most complex ore received during the year. In addition to the copper minerals chalcopyrite, chalcocite, malachite and azurite, it also contained pyrite, pyrrhotite, galena, sphalerite, ilmenite, magnetite, geothite and chlorite together with trace amounts of the bismuth and tellurium-bearing minerals tetradymite and tellurbismuth.

Copper hydroxy-chloride mineral was received in both its forms, as orthorhombic atacamite from Rothsay and as paratacamite from Doolgunna Station in the Peak Hill area.

A particularly striking specimen was received from Nicholson Station in the East Kimberley region. It was composed of native copper surrounded by cuprite which in turn was surrounded by chrysocolla. The country rock was an altered basalt and the mineral relationships suggest that the copper minerals had developed as a replacement of the basalt by infiltration of copper-bearing solutions.

A number of determinations for total and acetic acid-soluble copper were carried out in connection with the State Mining Engineer's survey of ore reserves in the Warriedar area.

Tests carried out on the acid-leaching of a mixed oxidised sulphide ore gave recoveries of better than 90 per cent. of the oxidised copper, representing a recovery of about 70 per cent. of the total copper content. Acid consumption was little over the theoretical requirements of the oxidised copper. As would be expected, residual copper was mainly in the form of sulphide minerals, chalcopyrite predominating, with lesser amounts of chalcocite and covellite.

7. Gold.—There was a big increase in the number of gold assays carried out on a pay basis. Many of these were from large exploration companies, suggesting that in the current base metal boom gold is not being overlooked. On the other hand, gold tailings originating from prospector parcels passing through State Batteries decreased considerably in number compared with the previous year.

8. Heavy Sands.—Samples of heavy sands were received from a number of localities, ranging from Bremer Bay, Walpole, Cape Leeuwin, Augusta on the coast up to Moore River, Berni Island and Point Charles, and from inland sources including the vicinity of Lake Dumbleyung, between Youanmi and Curran's Find, and Turkey Creek in the Kimberleys.

Many showed high concentrations of ilmenite and other commercial minerals, but it was not often possible to assess the validity of the sampling or the tonnages available.

A coastal sand, about half of which was made up of heavy (specific gravity greater than 2.85) minerals, was separated into heavy and light fractions. The heavy fraction was further divided into magnetics and non-magnetics, showing a large preponderance of magnetics. The magnetics, being mostly magnetite were looked on as potential raw material for production of pelletised blast furnace feed. With this purpose in view, a complete analysis was carried out to determine the extent of deleterious impurities.

9. Kyanite.—A sample of kyanite from a newly discovered deposit near Limestone Springs in the West Kimberley area was submitted for examination by the Geological Survey Branch. It consisted of alternating blue and white bands of kyanite, with a bulk specific gravity of 3.62. Chemical analysis gave the following figures:

	per cent. on dry basis
SiO_2	37.0
Al_2O_3	59.4
CaO	0.06
MgO	0.18
Na_2O	0.96
K_2O	0.30
Fe_2O_3	0.76
TiO_2	0.30
Ignition loss	1.34

These figures showed that the material met the stringent requirements of U.S. National Stock Pile Specification for refractory grade kyanite in all respects but one: the combined alkali, at 1.26 per cent., was considerably in excess of the specified maximum of 0.20 per cent. However, it is generally accepted that specifications for kyanite have been based primarily on the availability of materials rather than upon scientific data or operating experience and it is considered that practical trials of material similar to the above may well show it to have commercial application.

10. Lithium.—Analyses were carried out on shipment parcels of petalite to determine lithium and iron contents.

A number of micas were examined, including lepidolite, zinnwaldite and lithium-bearing muscovites. Very few samples were clean enough to be regarded as commercial grade.

Of the lepidolites, lithia percentages ranged from 1.63 on a Marble Bar specimen to 2.28 (Wodgina), 2.68 (Payne's Find), 3.22 (Poona) up to 3.4 on a sample from an undisclosed locality.

Zinnwaldite specimens contained between 2.11 and 3.02 per cent. Li_2O, while a lithium-bearing muscovite from Wodgina assayed 0.54 per cent.

No specimens containing spodumene, lithiophilite or purpurite were received during the year.

11. Nickel.—The current nickel boom led to a large increase in the number of samples submitted to the Division for nickel determinations.

Fortunately nickel responds well to atomic absorption techniques and so analyses of specimens carrying nickel in the normal concentration range can be carried out expeditiously. Digestion with *aqua regia* does not always give full recovery of nickel and so many geochemical procedures use an alkaline fusion. However, a less time-consuming attack with a mixture of hydrofluoric and perchloric acids has proved satisfactory and is the method regularly used in the Division.

The nickel content of various types of rocks has been recorded in geochemical literature and though agreement between different authors is not always good the following represent average ranges expressed as per cent. nickel:

Ultrabasic rocks (dunites, peridotites, serpentine........)	0.1-0.3
Basic rocks (basalts, gabbros........)	0.01-0.02
Intermediate rocks (diorites, andesites ......)	0.004-0.006
Acid rocks (granites, rhyolites........)	0.0002-0.0008
Sedimentary rocks (clays and shales........)	0.01

To represent potentially commercial ore a sample should assay at least 1.5 per cent.

Owing to the virtual impossibility of recognising material of such low concentration by simple visual inspection a great number of the samples hopefully submitted by prospectors and others proved to contain only background concentrations. On the other hand, samples representing payable ore are often so indistinguishable from nondescript material that only few samples can be safely rejected without a chemical examination.

Samples assaying between 0.2 and 0.3 per cent. nickel included a rock composed mainly of goethite with clay minerals and magnetite from the Southern Cross area; goethite and clay from Gindalbie Station; serpentine containing chlorite with some iron minerals from Mt. Dick; and a sample composed of clay, quartz, calcite and goethite from Kondinin.

An unusual specimen of opaline material containing discrete crystalline areas of alphacristobalite with opal, chalcedony and nontronite assayed 0.42 per cent. nickel, while an ironstone, composed of goethite, opal and weathered muscovite assayed 0.47 per cent. A serpentine from the Gabanintha area contained 0.40 per cent. No specific nickel mineral could be isolated from any of the above samples.

Pyrite separated from a quartz goethite rock showed an unusual range of magnetic susceptibilities. Two magnetic and one non-magnetic fraction were each identified by X-ray diffraction as pyrite. The most magnetic assayed 1.37 per cent., the more weakly magnetic 1.20 per cent. and the non-magnetic 1.20 per cent. nickel.

A sulphide ore from an undisclosed Western Australian locality was found to be mainly pentlandite with magnetite and subordinate amounts of pyrrhotite, pyrite and chalcopyrite. Traces were also present of nickel arsenide (niccolite) and, possibly, gersdorffite (a sulphide of nickel, iron and arsenic).

An interesting carbonate mineral from the Coolgardie district was essentially a copper nickel carbonate which in its reasonably pure form contained 32 per cent. copper and 20 per cent. nickel. Though unlikely to be of commercial significance this mineral is of considerable academic interest.

Minerals which could be members of a continuous series of nickel magnesium carbonates were obtained from several localities between Norseman and Laverton. These have been the subject of considerable research on which a progress summary report is available separately on request.

12. Phosphates.—A clay-like material from a bore at the Kennedy Range damsite was submitted for examination by the Geological Survey. About one third of the sample was the hydrated ferrous phosphate, vivianite, giving an overall phosphorus pentoxide figure of 10 per cent.

Vivianite alters rapidly on exposure, from a colourless mineral to a deep blue pleochroic mineral and finally to an isotropic semi-amorphous brown material. All stages were present in the sample received.

A number of samples of deep green variscite (hydrated aluminium phosphate) were received during the year, some being of particularly good lapidary quality. The variscite occurred as vein material in a cream-coloured fine-grained rock composed mainly of clay minerals, with fine mica and minor amounts of quartz and opal. This country rock contained virtually no phosphate.

An interstate opinion that this green mineral was turquoise was attributed to loose usage of the term. True turquoise, a copper aluminium phosphate, contains a theoretical copper content of 7.6 per cent.; the local material contained only 0.04 per cent.

Many samples were submitted as potential phosphate rock but none contained more than trace amounts of phosphorus. Most were coastal limestones.

13. Salt.—Analyses of salt were made on high quality material from Bendering and on three potential export samples from Lake Lefroy. A sample from a salt pan south-west of Comet Vale showed a sodium sulphate content of 1.04 per cent. with sodium chloride of 98.3 per cent.

Analyses of a stalactitic formation from the "Thylacine Hole" cave on Mundrabilla Station, Nullabor Plain, gave the following figures:

	per cent.
Calcium, Ca	0.21
Magnesium, Mg	0.19
Potassium, K	0.01
Sulphate, SO_4	0.14
Carbon dioxide, CO_2	0.05
Chloride, Cl	58.7
Moisture at 105° C, H_2O	2.79
Sodium, Na (by difference)	37.9

This sample was one of a considerable number obtained as a result of the geological study of the Eucla Basin by the Geological Survey and a study of cave minerals from the area by this Division.

14. Sand.—Sands received (other than heavy mineral sands) included a considerable number resulting from the water drilling activities of the Geological Survey in the Gnangara area. These were sent in for sieve analyses to determine screen size requirements for the various bores.

Glass sand samples represented commercial shipment parcels and test samples taken by the Geological Survey. Requirements were figures for iron, titanium and aluminium as well as silica. The iron content is of particular significance. A batch of three samples was submitted to three independent laboratories (including the Mineral Division) for determination of iron by atomic absorption and by two different colorimetric methods. Results (in a range of iron contents from 0.06 to 0.08 per cent.) were virtually identical, regardless of which laboratory or which method was used.

Three samples of potential glass sand from Jandakot, were submitted by the Geological Survey. A typical partial analyses showed:

	per cent. on dry basis
Silica, SiO_2	98.3
Alumina, Al_2O_3	0.29
Ferric oxide, Fe_2O_3	0.075
Titanium dioxide, TiO_2	0.061
Chromium oxide, Cr_2O_3	0.0004
Ignition loss	0.21

Much of the iron and titanium occurred as discrete grains of ilmenite and leucoxene. These grains are markedly smaller than the quartz grains and iron and titanium figures could be considerably reduced simply by wet screening through 100 mesh.

15. Tantalum-niobium.—Tantalite and columbite were the most common minerals examined under this heading though specimens were received also of microlite, simpsonite, tapiolite and others.

The highest grade tantalite contained 70 per cent. tantalic oxide, the highest columbite graded 69 per cent. niobic oxide. The latter came from Cocanarup, the tantalite from an unrevealed locality. A tantalite specimen from Youanmi contained 67 per cent. Ta_2O_5 and 18 per cent. Nb_2O_5.

Samples containing rare earth tantalates and columbates, as well as tantalite and columbite, came from Yinnietharra and Cooglegong.

A fine selection of specimens was received from the Mt. Francisco area. These included well developed crystalline forms of columbite (grading up to 63 per cent. Nb_2O_5) and tantalite, a distinctly tack-shaped specimen of microlite, cassiterite composed of numerous small interlocking grains carrying fine intergrowths of columbite, and a particularly interesting tantalite. This latter was a brown translucent fragment having a specific gravity of 6.7 which was shown by X-ray diffraction to be the ordered form of tantalite known previously in Western Australia only from Nullagine and Ravensthorpe.

A sample from Mt. Hawkestone contained, in addition to columbo-tantalite, scheelite, scorodite (as green crystals developed probably as a replacement of arsenopyrite) and jarosite. A concentrate from Cooglegong contained wodginite, simpsonite and tanteuxenite together with monazite and a little cassiterite.

A sample of metamict columbite, partially altered to microlite, was received from Yalgoo. It showed a radioactivity about 70 times background, due to the presence of about 0.2 per cent. thorium oxide.

The alteration product from another metamict columbite (from Woodstock Station) was shown by X-ray diffraction patterns to be pyrochlore.

A sample of tapiolite, with a specific gravity of 7.16, was assayed chemically and found to contain 68.7 per cent. Ta_2O_5. Converting the specific gravity of 7.16 to grade by the formula used to grade columbites and tantalites gives a Ta_2O_5 figure of 68.9 per cent., suggesting that this formula applies equally well to the tetragonal phase as to the more common orthorhombic phases of the iron columbo-tantalites.

Shipment parcels of mineral concentrates were analysed for tantalum, niobium, tin and titanium. Four tantalite samples were analysed chemically for use as standards by an interstate laboratory using X-ray fluorescence techniques for tantalum and niobium determinations.

Twenty-five specimens from the Divisional reference collections were loaned to C.S.I.R.O. for use in that organisation's examination of Western Australian tantalum and niobium minerals by X-ray diffractometry. The specimens, all from recorded localities, included tantalite, columbite (completely and partly disordered), wodginite, microlite and ixiolite.

16. Tin.—Though the majority of tin assays were on commercial parcels of cassiterite concentrates from the Pilbara area, a considerable amount of analytical work was done in other fields.

A study was made of the recovery of tin by gravity concentration as compared with the total tin present. Direct determination of very low concentrations of tin are not always satisfactory and it is common practice to concentrate the mineral first and then determine tin in the concentrates by conventional volumetric methods. Considerable and variable losses can follow ordinary wet panning, but these are more easily controlled if concentration is by heavy liquid separation.

On several tin-bearing pegmatite samples, containing from 0.4 per cent. tin up to about 6.0 per cent. the ratio of true chemical figures to those obtained on a heavy liquid concentrate was fairly constant at 1.25 to 1, indicating a loss of about 20 per cent. of the tin during concentration.

Ten tin ores of varying concentrations were analysed for use as standards by a commercial laboratory, and a considerable number of low grade samples were handled for clients engaged in mineral exploration.

A concentrate from the Norseman State Battery was received for up-grading tests. As received, the sample assayed 67.5 per cent. tin and contained, in addition to cassiterite, iron oxides, quartz, ilmenite, columbite and traces of monazite and silicate gangue minerals. Treatment with heavy liquid gave a concentrate assaying 69 per cent. which in turn was further up-graded by electromagnetic means to give a final concentrate assaying 73 per cent. tin.

Examination of another tin concentrate showed that the fractions finer than 60 mesh contained virtually no cassiterite but were composed mainly of quartz, ilmenite and iron oxides with minor gangue silicates and leucoxene. Simply screening through 60 mesh up-graded the concentrate from 55 to 62 per cent. tin.

A columbite concentrate from the Mt. Francisco area contained also appreciable amounts of garnet, ilmenite and cassiterite. It represented the magnetic fraction from a cassiterite ore and had been rejected by buyers of columbite-tantalite concentrates because of its excessive tin content. The percentage of cassiterite present was only 4 per cent., but the tin content, by chemical analysis, was 6.1 per cent. The sample was therefore unusual on two counts: the cassiterite was magnetic (showing a magnetic susceptibility equal to that of columbite) and the columbite-tantalite also contained tin. Examination by X-ray diffraction showed the tantalum-niobium mineral to be a disordered columbite and not either of the true tin-bearing tantalites ixiolite or wodginite.

Other specimens from the Mt. Francisco area included a white slightly translucent form of cassiterite.

Eleven samples, representing products obtained by sizing and magnetic treatment of accumulated jig tailings from a tin mining venture on the Pilbara, were submitted for examination. Minerals present included cassiterite, columbite, tantalite, iron oxides, garnet, monazite and other rare earth minerals, and quartz. Analyses for tin, tantalum and rare earths were carried out to obtain the concentration and distribution of these valuable metals through the various sizing and magnetic fractions, and to provide data to determine optimum plant operating conditions.

17. Vanadium.—Fifteen soil samples taken from within the boundaries of geological anomalies in the North-West were analysed for vanadium, together with four samples representing the basaltic source rock from which high vanadium laterites had evolved in the same area.

A single specimen of magnetite from Taincrow Station was found to contain 1.8 per cent. of vanadium pentoxide, but follow up samples showed less than one-tenth of this concentration.

A number of determinations for vanadium, iron and titanium were made on various treatment fractions derived from the vanadiferous gabbro at Coates Siding.

Work by the Geological Survey led to the receipt of a number of samples of titaniferous magnetic iron ores taken from a magnetic differentiate of a gabbroic intrusion in the Jameson Range near the South Australian border. Virtually complete analysis carried out on these samples showed V_2O_5 contents varying from 0.5 to 1.4 per cent., with TiO_2 in the range 15 to 25 per cent.

Analytical problems associated with this type of ore led to an investigation of methods for determining vanadium.

Miscellaneous Investigations.

1. Alloys and Metals.—Analyses of six high tensile steel wires were carried out for the Main Roads Department for compliance to specification. Determinations of carbon, silicon, manganese, sulphur and phosphorus showed these elements to be within specified limits.

A metallurgical product remaining from blast-furnace operations at Wiluna 20 to 30 years ago was found to be rich in arsenic and to carry an appreciable gold content.

Other materials analysed under this head include white metals, brasses and a dross carrying a significant percentage of metallics.

2. Artificial Minerals.—Artificial minerals received were usually submitted by the sender in the belief that they were natural species.

Materials received included ferromanganese and ferrochrome, a piece of coarsely crystalline zinc coated with basic zinc carbonate which had been found on the Nullabor, bronze and glassy slags.

Two samples from the Melville area were metallurgical products rich in copper. One was copper sulphides with small droplets of metallic silver and silver-gold alloys and a trace of zinc sulphide. The other was an intergrowth of copper sulphides and copper iron sulphides with droplets of metallic copper, metallic silver and gold-silver alloy. It contained approximately 4 per cent. of silver and 4 oz. of gold per ton.

Panned concentrate from a mineral sample from Cullculli was found to contain carborundum and metallic flakes of a copper based alloy.

Five samples of known artificial ferrites were submitted for analysis by the University Physics Department. These were compounds of ferric oxide with ferrous oxide, cobalt oxide and manganese oxide.

3. Corrosion.—A corroded metal plate, part of the framework which supports switching equipment in closed country automatic exchanges, was submitted by the Postmaster General's Department for examination of the white corrosion product. This product proved to be hydrated zinc formate. The plate was of zinc coated steel. The deposit appeared in general to be associated with finger prints on the metal. As formalin was demonstrated to produce a white corrosion product on the metal surface the use of this fluid for cleaning purposes suggested a possible explanation. However, another sample submitted later, also by Postmaster General, of a cable box from an exposed position near Pingelly was similarly coated with a formate corrosion product. This box, when dismantled, had been found full of dead black ants which effectively explained corrosion products derived from formic acid.

Black deposits from air scavenge space in a diesel engine were examined to determine their nature, particularly whether coal or not. The coarse black particles showed no optical properties of a diagnostic nature when examined microscopically; they burned when heated, leaving considerable fine white ash. Palynological examination by the Geological Survey revealed no characteristic spores or plant tissue. It was concluded the deposit was not coal.

An examination was made of an internally corroded fire extinguisher at the request of W.A. Fire Brigades Board. The internal coating had been a lead-tin alloy. Uniform pitting had occurred both above and below the level of the alkaline liquid charge, being most intense above this liquid level. Polished mounts of sections cut from various parts of the extinguisher showed remnant protective coatings varying from nil to 0.0003 inch thick, while chemical analysis showed a selective leaching of tin from the lead-tin alloy. It was concluded that the thickness of the original anti-corrosion coating had been below the minimum specified.

4. Explosives.—Five samples of prilled ammonium nitrate for use in mixing blasting agents were submitted by the Inspector of Explosives. These had shown varying porosities as measured by their oil absorption capacities and different detonator sensitivities. Tests were requested to supply data of possible assistance in explaining these differences.

The prills consisted essentially of ammonium nitrate with a water insoluble coating varying from a trace up to 0.7 per cent. of the total weight of the prill. The coating consisted of diatomite and/or kaolin.

X-ray powder patterns showed the ammonium nitrate in all cases to be the orthorhombic form which is stable between $-18°$ C and $+32°$ C. Stationary and rotation X-ray patterns of selected prills from each brand showed that in one brand each prill was composed of several large crystals of the order of 1 mm mean diameter whereas in others the crystals were finer grained with an orientation varying from marked to random. By comparison with field results it appeared that fine-grained prills with semi-random grain orientation gave the most satisfactory results.

5. Other.—The Public Health Department submitted a sample of material that had been dumped by the truckload in an open limestone quarry. It was producing considerable effervescence and concern was expressed that it could constitute a hazard to children playing in the vicinity. The material was identified as crystalline sodium acid sulphate, the residue from a commercial acid plant.

A fraction isolated from a complex commercial preparation was believed to be essentially an iron-phosphorus compound. The X-ray pattern was found to be composed of a few weak diffuse lines, the strongest of which gave an approximate match with those published for Fe_2P. Chemical analysis gave figures of 68.2 per cent. iron and 22.5 per cent. phosphorus equivalent to a molecular ratio approximating 5 iron and 3 phosphorus. The three iron-phosphorus compounds generally recognised are FeP, Fe_2P and Fe_3P. The chemical figures obtained above would be satisfied by a mixture of one third FeP and two thirds Fe_2P.

Eight samples of coastal sands from the Onslow area were examined at the request of Public Works Department. It was hoped that a mineralogical examination would assist in establishing the origins of the sand relative to a creek mouth and the proposed groyne to provide a small craft harbour in the creek.

The limited number of samples, together with the similarity in nature of the heavy minerals present in all samples made it difficult to base any definite conclusions on petrographic findings alone, but with the additional aid of aerial photographs taken at different seasons of the year some useful observations could be made.

Complete Analyses.

Thirty-four complete analyses of rocks or minerals were reported during the year.

The majority were for the Geological Survey, the largest batch comprising 14 specimens of the titaniferous vanadium-bearing iron ores from the Jameson Range region. Chemical problems associated with analyses of such complex ores led to a review of methods for the determination of vanadium.

Complete analyses were carried out on 10 igneous rocks from the Giles Complex in the Blackstone Range to assist the Geological Survey in its regional geological study of this formation. Nineteen determinations were made on each sample. By courtesy of the University of Western Australia, these figures were fed to an IBM 1620 computer and the following petrological functions recorded: CIPW Norms, Niggli values, alkalis triangle, granite triangle, residua triangle, Brammal triangle, feldspar triangle, ACF and AKF triangles, Larsen function and Rittman series index.

Other analyses were of silicate rocks from the Hamersley area, kyanite from the Kimberleys and bore cores from oil exploration wells in the Warburton Ranges area.

A complete analysis of a glass was carried out in connection with a University research project, together with accurate measurements of its specific gravity and refractive index.

Mineral Identifications.

A selection only can be given of the wide range of minerals submitted for identification. Here again the emphasis was on nickel, though with the exception of the sulphides, identification of specific nickel minerals was unlikely at the low concentrations which are commercially significant.

Topaz, partially altered to fine-grained mica, was received from Payne's Find, while a rock containing corundum, spinel and micaceous alteration products came from the Paynesville area. Some of the corundum grains in this rock were strongly coloured sapphire but too small to be of gem quality.

Many rocks containing fuchsite were submitted because of their green colour and the popular association of nickel ores with this colour. Though many showed up to 0.5 per cent. chromium none registered more than 0.01 per cent. nickel. A suite of specimens collected by the Geological Survey in the Widgiemooltha and Boorabbin areas all contained fuchsite as a major constituent associated with quartz, andalusite and kyanite and traces of rutile and magnetite. A specimen from Payne's Find consisted of well formed crystals of andalusite in a matrix of fuchsite.

A sample showing crystals of garnet and staurolite with phlogopite mica came from Meekatharra; a hypersthene rock from Dangin was submitted as a potential abrasive, but with a hardness less than quartz it had no potential in that field.

A large crystal of yellow-brown tourmaline came from the Kennedy Ranges. Other specimens of this mineral included acicular tourmaline as radiating rosettes, blue tourmaline as a fine intergrowth with quartz and tourmaline crystals showing unusual flattened rolls developed under shearing stresses during crystal growth.

Clinozoisite was recorded from a number of localities, including Nukarni, Denmark, Roebourne and Bardoc. The latter was a metamorphic rock composed of crystals of actinolite in a ground mass of clinozoite. The sample from Roebourne was a relatively soft grey and green rock composed essentially of clinozoisite, muscovite and their alteration products. The grey clinozoisite was partially altered to a green compact mica which gave an X-ray diffraction pattern of a mica of indefinite species. Chemical analysis showed a preponderance of potash over soda, with traces of lithia, suggesting a muscovite in preference to the sodium-bearing paragonite.

Of the asbestos minerals, anthophyllite was the most frequently received. The most striking specimen came from Payne's Find, consisting chiefly of asbestiform anthophyllite with a little talc and chlorite but coloured blue, green and yellow by azurite, malachite and chlorite weathering products. Anthophyllite from Young River was received both in the form of brittle fibres and, in association with green actinolite, in the less common prismatic habit.

A particularly well formed twinned crystal of microcline from Kondinin was donated to the Divisional collection.

Less commonly recorded silicates received included celadonite and grunerite. Celadonite, a silicate of iron, magnesium and potassium, was identified in a specimen from Mt. Gibson which was essentially quartz containing pale greenish blue spots of celadonite and green spots made up of minute crystals of actinolite. A celadonite from Narrikup made up the matrix of a rock containing grains of quartz and feldspar.

Grunerite occurred as the major constituent of a rock from an undisclosed locality, in association with magnetite, actinolite, quartz, chlorite and plagioclase feldspar.

Quartz was received in the expected wide range of forms and colours. Black crystalline material came from Mukinbudin, Augusta and Borden while a sample from the mouth of the Scott River was part of a boulder which could best be described as black chert or flint.

A pink specimen from Barblin, suspected of being the pink cesium-bearing beryl, proved to be quartz. A sample of rose quartz came from Bowes River. while a green quartz from Ned's Creek owed its colour to the inclusion of extremely fine crystals of malachite.

Some of the common opal submitted would have produced attractive trinkets if cut and polished. Separate green and brown specimens from Goomalling were of quite good quality for this purpose, as were material from Ora Banda showing manganese dendrites and from Byro Station having a deep green colour. Other green specimens of good quality came from Yinnietharra Station; a pale green variety from Mt. Gould assayed 0.11 per cent. nickel.

Opaline silica, in the form of sponge spicules, was the main constituent of spongolite samples from Munglinup and Fitzgerald River.

Less common sulphate minerals received included alunite, jarosite, natroalunite, brochantite and beudantite. Partial analysis of a sample from Yerilla gave the following figures:

	per cent.
Potassium oxide, K_2O	5.85
Sodium oxide, Na_2O	5.19
Sulphur trioxide, SO_3	36.2
Alumina, Al_2O_3	26.2

which indicates that the mineral is a basic potassium sodium aluminium sulphate about midway along the continuous alunite-natro-alunite series.

Brochantite was the main copper mineral in a sheared quartz rock from Woodie Woodie which assayed 8.4 per cent. copper. It also occurred with quartz, feldspar and clay minerals in a rock from Canna. Beudantite, a complex lead iron arseno-sulphate, was also identified in a sample from this area.

The rare iron antimonate, tripuhyite, occurred associated with quartz and a little malachite in a specimen from 15 miles west of Kununurra. The tripuhyite formed a complex intergrowth with unidentified copper and silicate minerals and possibly other antimony compounds, but the material was so fine-grained that only the tripuhyite could be identified from X-ray diffraction patterns.

Scheelite comprised about 1 per cent. of a rock from Mangaroon composed largely of garnet cut by numerous veinlets of epidote and clinozoisite with smaller amounts of hornblende, pyroxene and quartz.

A ferroan dolomite from Warriedar was associated with magnetite and minor amounts of arsenopyrite, pyrite and chalcopyrite.

A banded stalactitic calcite with minor clay minerals and surface coatings of travertine was received from Belele Station.

A suite of minerals was collected by a Divisional Staff member from various caves on the Nullabor Plain. Detailed mineralogical work is in hand on the less common mineral species of this suite. Minerals present include gypsum, aragonite, halite, mirabilite, thenardite and as yet unidentified phosphate minerals.

The following minerals were identified in a set of specimens from the North Kalgurli G.M.: galena, pyrite, chalcopyrite, arsenopyrite, tetrahedrite, calaverite, altaite, coloradoite, dolomite, celestite, anhydrite, gypsum, muscovite and gold.

Tetrahedrite also occurred in a rock from Mt. Ida.

A sample of limestone from Bunbury had a yellow surface deposit of sulphur. Similar deposits of sulphur have been recorded from the soft sandstones of Dongara and Geraldton and are believed to have resulted from the reducing action of organic material (such as sea weed) on sulphate minerals (such as gypsum).

The hydrous manganese zinc oxide, chalcophanite, was identified in gossanous material consisting mainly of goethite, quartz and chalcedony.

A complex specimen from Wombola Gold Mine in the Kurnalpi district contained pyrite, scheelite, gypsum, ferritungstite, tungstite with traces of covellite and pyrrhotite. The ferritungstite and tungstite occurred as yellow alteration products of scheelite.

A gossan from Kondinin was examined to determine if possible the nature of the original sulphides. Chemical analysis indicated traces only of copper and zinc, but no lead. A polished mount showed a relict texture similar to typical limonitised chalcopyrite-pyrrhotite (or pyrite) ore: no relict sulphides were present.

A green mineral occurring as narrow veins in a pegmatite dyke at Marvel Loch presented a number of problems. Optical examination showed the presence of isotropic material resembling opaline silica. X-ray diffraction gave a weak pattern of talc with a few extra lines consistent with alpha-cristobalite. As much opal gives weak X-ray patterns of cristobalite and probably consists of minute cristobalite crystals in an amorphous matrix it was concluded that the material consisted of weathered talc in association with impure opaline material. Partial chemical analysis showed:

	per cent.
SiO_2	73.4
Fe_2O_3	4.15
Al_2O_3	3.59
MgO	11.3
CaO	not detected
K_2O	0.06
Na_2O	0.20
H_2O+	5.42

During the year further work was done on a new mineral from Greenbushes. A Guinier pattern done on the mineral was measured and indexed for publication. Two further samples of different specific gravities were prepared for analysis in an attempt to solve the problem of the true formula of the mineral.

Single crystal X-ray patterns were also obtained of a rare mineral found in a Nullabor cave. This represented preliminary work towards eventual publication of a full description of the mineral and its occurrence.

No tectites (australites) were received but a sample from four miles west of Wiluna proved to be a stony meteorite. It was composed largely of olivine and pyroxene with some feldspar and the metallic minerals nickel-iron, troilite (a variety of magnetic iron sulphide) and minor chromite. It was a chondrite virtually identical to the Woolgorong stony meteorite found in 1961.

New Localities.

Minerals for which new Western Australian localities were recorded in 1967 are listed below.

Mineral.	Locality.
(a) Kimberley Division.	
Antlerite	13m. N. of Kununurra.
Anglesite	13m. N. of Kununurra.
Baryte	Nicholson Station.
Baryte	66m. peg on Wyndham-Kununurra road.
Braunite	13 Mile Camp, Wyndham.
Cerussite	13m. N. of Kununurra.
Columbite-tantalite	Mt. Hawkestone.
Galena	13m. N. of Kununurra.
Glauconite	Napier Downs.
Ilmenite	4m. W. of Turkey Creek.
Kyanite	Limestone Springs.
Pyrolusite	13 Mile Camp, Wyndham.
(b) North-West Division.	
Alunite	Mt. Vernon.
Anglesite	20m. S.W. of Nullagine.
Baryte	Mt. Trew.
Baryte	8m. S. of Range Station.
Beudantite	3m. S.E. of Mangaroon.
Cerussite	20m. S.W. of Nullagine.
Chrysocolla	Mt. Brockman Station.
Conichalcite	15m. N.E. of Abydos.
Corundum	Morrissey Hill, Yinnietharra.
Fluorite	7m. N. of Mt. Phillip's Homestead.
Galena	20m. S.W. of Nullagine.
Malachite	Mt. Brockman Station.
Prehnite	2m. N. of Morrissey Creek.
(c) Murchison Division.	
Beaverite	2m. N.W. of Northampton.
Rutile	10m. N. of Trillbar Homestead.
Spessartite	Mt. Padbury.
(d) South-West Division.	
Andalusite	2m. S.E. of Payne's Find.
Atacamite	Warriedar.
Cassiterite	2m. N. of Bow River Bridge.
Cassiterite	2m. N.N.E. of Ravensthorpe.
Cassiterite	Mid Mt. Barren.
Clinozoisite	Denmark.
Columbite-tantalite	Donnelly Mill.
Epsomite	Mt. Dick.
Gold	2m. N. of Bow River Bridge.
Scheelite	Jerramungup.
Tantalite	Mid Mt. Barren.
(e) Central Division.	
Cassiterite	Amy Trew Lake.
Corundum	3m. N. of Kathleen Valley.
Fluorite	Koolyanobbing.
Huntite	Burtville.
Tantalite	Kathleen Valley.
Tetrahedrite	Mt. Ida.
(f) Eastern Division.	
Chalcocite	Warburton Ranges.
Chrysocolla	Mt. Elvire.
Covellite	Warburton Ranges.
Fluorite	Mt. Elvire.

PHYSICS AND PYROMETRY SECTION

Pyrometry.

A total of 20 mercury in glass thermometers was calibrated by comparison with laboratory standards in the range -35 to $+320°$ C to accuracies ranging from $\pm 0.05°$ C to $\pm 3°$ C.

The temperature of operation of a commercial fire alarm heater sensor was also determined for an electrical firm.

Thermal and X-ray Methods.

1. The total number of samples processed by these methods was 66, of which most (42) were soils and clays for semi-quantitative analysis. The remainder comprised natural minerals and corrosion products.

2. Progress in the investigation of unusual phosphate minerals (Mines Department Annual Report 1966, p. 191) has diverged in two directions:

(a) the study of cave guano phosphates from Sabah and Sarawak;

(b) selection and study of single crystals of ardealite from the Jurien Bay collection.

(a) A study of the geology of the Sabah and Sarawak caves by Dr. G. E. Wilford of the Malaysia Geological Survey, Borneo Region, reported many bat guano deposits for which no X-ray or thermal work had then been done. Dr. Wilford kindly supplied samples of these for X-ray, thermal and further optical examination and a detailed report to him is in the process of being prepared. Preliminary results indicate that approximately 32 per cent. of the minerals to be observed are brushite or gypsum, 22 per cent. are ardealite or gypsum variants resembling ardealite, 10 per cent. are presently unidentified, and the remainder include infrequently found types such as hannamite, leucophosphite, taranakite, strengite, etc.

(b) The ardealites recognised to date occur as fine powders, but ardealite I is sufficiently coarse for single crystal X-ray work. Unit cell parameters determined on two such crystals indicate some departure from gypsum and brushite.

Indexing of the powder and oscillation patterns on these parameters is proceeding. Such studies as this are hindered by the present need to use makeshift or borrowed equipment, and will be facilitated by the projected acquisition of new X-ray diffraction equipment in 1968.

CONTENTS

DIVISION VIII

Annual Report of the Chief Inspector of Explosives for the Year 1967

Under Secretary for Mines:

For information of the Hon. Minister for Mines I am pleased to report on the Explosives Branch's operations during 1967.

Staff

Mr. H. Douglas A.P.T.C., A.R.A.C.I. was appointed as Inspector of Explosives in the professional division and will commence duty on 3rd January, 1968. Since the present Chief Inspector will retire early in 1968 the number of professionally qualified officers will then remain at two. Approval has been obtained for the appointment of an Inspector in the general division who will specialise in shipping, transport and storage of explosives and prepare for the inspection of flammable liquid depots.

Mr. L. M Calneggia was transferred to the Health Department in July, 1966, and clerical work of the Explosives branch was carried on by part-time relief until the appointment of Mr. R. K. Douglas who commenced duty on 27th February, 1967.

Distribution of Explosives

For purposes of this discussion, the term explosives is taken to include all blasting materials, accessories and components of ANFO and slurries.

Diversion of shipments to northerly ports instead of channelling supplies through Woodman's Point made considerable headway. Whether of Australian or oversea manufacture, explosives were landed as required at Port Hedland, Dampier, Barrow Island, Geraldton and occasionally elsewhere, with or without a call at Woodman's Point according to demand. Although not every ship was thus routed, advantages of doing away with long costly road haulage from the south and the assurance of fresher supplies need no emphasis. Further gains may be expected when preparation of the blasting agent "Molanal" assumes full-scale operation in a plant under construction at Port Hedland.

The long-establiished practice of conveying explosives from the Eastern States by Commonwealth Rail to Kalgoorlie continued unchanged. The scheme covered local and district demands including Kambalda, and served also to supplement stocks on the coast and at intermediate points when necessary.

Explosives Reserves

If adequate security and isolation are attainable elsewhere, explosives storage is not compulsorily restricted to Government Reserves. Instances abound of magazines on private land, often more conveniently situated than otherwise afforded and sometimes of necessity thus located because a declared area under rapid development may prove inadequate to accommodate applicants for leasehold sites. However, with most importers showing preference for government-owned land, the Branch has recommended gazettal of explosives reserves as required or anticipated. Inspection and inquiry as to local conditions entailed much time and travel, but efforts have paid off well. At Port Hedland, for example, two reserves totalling about 1,200 acres were found essential for immediate and near future requirements.

Woodman's Point

Direct deliveries to the Goldfields and several outports have not degraded the status of this Reserve as the principal centre for explosives reception, inspection, trials and investigations, storage and despatch. To maintain its efficiency, a plan formulated last year for ensuring more equitable allocation of magazine space and to permit higher loadings up to limits imposed by safety distance tables achieved promising results even on gradual application.

Progress in other directions was impressive during 1967. Some 30 chains of worn rails and crossover points, the scene of earlier derailments and minor accidents, were replaced by heavier materials appropriate to present-day traffic. Extra lighting was provided along the jetty and at the transit shed, the whole circuit was rewired and master-switched from within the main compound. Electrical fires, often defying early detection unless somebody was in attendance nearby, may henceforth be regarded as unlikely. Further general fire prevention measures were instituted by purchase of extinguishers, and water reticulation extensions to serve several hydrants. The tractor-driven scrub cutter proved a valuable aid in maintaining fire-breaks. Perhaps the year's major work was connection of a branch road near the main entrance with one already constructed to serve the DuPont magazines near the western boundary. Thus the northern half of the Reserve was ringed by road, affording among other advantages direct vehicular access to the railway gates on the Coogee fence. Smaller jobs comprised turning bays for several magazines, replacement of the old sandy track to the Government magazines by a paved road and provision of a spacious standing area for trucks awaiting supplies.

Future of Woodman's Point Explosives Reserve

The above improvements, following on changes stimulated in former years to meet increased use and explosives throughput, have brought this Reserve to a high standard of serviceability. Periodic pressure to relinquish it for industrial or recreational purposes is therefore disconcerting, particularly when no acceptable alternative is offered. One scheme suggested an inland block connected with the existing jetty by road and rail presumably bisecting the area. Even with minimum safety zones abutting the explosives traffic route, radial distances to be maintained from the usual 250-400 ton explosives shipment at berth would leave little room for industrial establishments or public congregation. Also, recreational use could attract pleasure craft which, under Fremantle Port Authority regulation are prohibited within a quarter mile of the Reserve's Western skirting beach. Inspection of land near Jandakot, suitable in many respects though naturally lacking contiguous shipping facilities, left impression that its effective area might be curtailed through encroachment of industry and settlement. The best proposition so far proved to be in Becher Point area, with deep water near shore—but apparently earmarked for purposes other than an explosives reserve.

The time may come when the Reserve's expanding function forces its replacement or supplementation. In the writer's view, no such immediate change is warranted. Any move would involve colossal expenditure and certain complicating factors inasmuch that the F.P.A.; as owners of the jetty, could hardly be expected to abandon it and establish similar facilities elsewhere.

Other Explosives Reserves

Geraldton.—Whilst accomplishing its original purpose, this small reserve proved unequal to recent demand, leaving no option other than asking a large importer to acquire private sites for his explosives storage. Investigation of additional land for departmental use, possibly at Narngulu, is proceeding.

Carnarvon may yet assume importance. After cancellation of the old Reserve 14342 a 50-acre tract north of the town and west of the road to Onslow, with access from N.W. Coastal Highway, was deemed suitable, subsequently surveyed and declared an Explosives Reserve.

Port Hedland.—The Pippingarra Reserve has been retained, but quite understandably in so busy a district, it failed to cope with several importers' storage requirements, and much less to afford room for explosives manufacture. The situation was met by grant of 1,060 acres, under control of the Lands Department, with indications of a further 200 acres being available. In its few months' existence to date, this reserve has undergone remarkable occupancy and development.

Onslow.—An old small reserve on rough hilly ground unsuited for additional storage will be replaced by an alternative site which, after inspection, was recommended for survey and gazettal.

Explosives—Consumption in W.A. for year 1967

	Short Tons	Short Tons
Ammonium nitrate—		
Shipped	5,417.46	
Railed	4,086.89	
		9,504.35
Nitro-compounds—		
Shipped	1,221.80	
Railed	291.57	
		1,513.37
T.N.T.		Nil
Class 2 Explosives: (M-Pak, Molanal)		708.44
Slurry explosives manufactured on site		3,690.96
Marine seismic explosive (N.C.N.)		535.00
Sodium nitrate		450.00
Primers and Boosters		51.49

Detonating Fuse—3,303 cases.
Detonators, plain—359 cases.
Detonators electric—1,815 cases.
Blasting Powder—2,000 lb.
Rifle Powder—1,450 lb.
Whaling explosives—25 cases.

Bearing in mind that during an era preceding the wide acceptance of blasting agents, total explosives consumption was typically about 3,500 tons annually, the above figures significantly reflect the State's industrial progress and the trend toward the newer agents including slurries and N.C.N. In round figures, of the 9,500 short tons of ammonium nitrate listed above, 8,020 were calculated as having been used for preparation of ANFO.

Inspection

Inspection of explosives on arrival, attention to the soundness of packaging and application of the heat-test for stability in the instance of the so-called conventional nitroglycerin-activated types of Class 3 Division 1 continued as usual. Except where deterioration might be suspected from prolonged storage, heat or humidity, follow-up inspections could not be routinely conducted because of limited staff resources. Australian explosives were admitted to the North West on certificates of condition and stability issued by the Chief Inspector in the consignor State. As no such arrangement could be made in respect to American explosives, Mr. Greaves personally attended several such operations, but when he was unavoidably absent, the only solution was to send samples south. One lot arrived at our Woodman's Point laboratory five weeks after collection, by which time the bulk had probably gone into consumption. This principle of use prior to inspectional formalities is a bad one, despite mitigating factors such as direct delivery to the purchaser from the importer's magazines or even shipside. with relative freedom from protected works en route.

Except for finding oddments of old unwanted explosives, on a few store licensees' premises and in small magazines, nothing untoward was disclosed in this avenue of inspectional work, orders for reconditioning or more secure locking of the receptacle, and its relocation when necessary, were served as warranted.

About five tons of safety fuse, gelignite and Quarry Monobel surplus to needs at Wittenoom after cessation of asbestos mining were examined by the District Inspector of Mines, who duly sent on three cases for chemical testing. Though somewhat indurated, these explosives were pronounced serviceable except for some ⅞ in. x 4 in. gelignite, exuding and of low heat-test. Unconnected with this was another instance of exudation in Australian explosives detected among reference samples and brought to local notice by the Victorian authorities. However, more serious and widespread decomposition was found on inspection to affect both bulk at Woodman's Point and consumers' stocks in the north, necessitating destruction of 200 cases of American explosives.

Blasting agent grade ammonium nitrate, though not classified as explosive, was subjected to inspection and test for free-running qualities, oil absorption and organic matter content (which is limited to 0.05%). None had to be rejected, and improved packaging helped to reduce the spillage referred to in a previous report.

Minor inspectional duties called for attendance at ordnance movements within the inner harbour at Fremantle and the inspection of an explosives-carrying lighter and launch prior to licensing by the Harbour and Light Department.

New Compositions

Variation from prototype composition within limits defined by authorisation brought into being new designations such as Anzite Yellow, Anzite Blue, Semigel No. 2 etc. These changes, though not in conflict with regulations, tend to confuse both the explosives inspector and user. All importers originally furnish full information respecting their products but have not invariably kept the State authority abreast with alterations which, however small, should be notified.

Authorisation

Class 3—Nitro Compound,
Division 2,
Procore Boosters, ZZ.

Blasting Agents

Little may be added to last year's account of the simple 94:6 ammonium nitrate-oil mixtures. They still spell economical and effective blasting under most conditions. Their inexplosive components are freighted at lower rates than applicable to dynamites and N.C.N. types, and lesser standards of storage and isolation are imposed. Nevertheless, for heavy mining and quarrying, more sophisticated compositions have virtually won the day. As examples, the Molanal plant under construction at Port Hedland will have an annual production capacity of 2,500 tons. Another carefully designed slurry is made on the mining lease at Mt. Tom Price, and trials are in progress with a dry-mix type which, if successful, will be manufactured at a second plant in Port Hedland. This activity involves three separate explosives companies in meeting what seems an almost insatiable demand for blasting materials in the North West. Other concerns, too, are considering entry to the field, whence it appears that the next few years will see an even greater variety of blasting products introduced to the State.

Explosives Accessories

Detonators.—Although detonators as such underwent no change during the year, the recognised hazard from radio transmission on electrical detonators whether packed or laid out in circuit received attention. The outstanding instance was at N.W. Cape in operation of one V.L.F. transmitter of a million watts, another of 40,000 and several lower powered units. Safety distances therefrom, as defined by American and Australian codes, were imposed in respect to all electric detonators under conveyance, storage or use.

Explosives Magazines

Large magazines and nitrate stores have been successfully constructed from pre-cut Armco steel and mounted by an earth cover. These buildings appear to be especially suitable for the north-west climate and it is probable that more of them will be used in the future.

Fire

Where dangerous goods are involved or suspected of initiating fire, Branch officers, when so called upon, collaborate in police investigations. In January, a fruit packing and storage shed at Kalamunda gutted by fire was found under inquiry to have contained 10 tons of fine wood shavings, waxed paper, fertilisers calcium nitrate and nitrophoska, together with flammable packaging materials. Shade temperatures of 91° to 95°F had prevailed for three days preceding the fire and sometime previously the shavings were wetted by rain. Thence would probably follow bacterial action accompanied by heating to the point of spontaneous ingition, aggravated by the adjacent nitrate—a strong oxidiser.

On January 27th, fire unaccompanied by explosion destroyed an I.C.I.A.N.Z. Ltd. magazine at Port Hedland. Its exact content was unknown, but when last inspected the interior was orderly and clean except for staining of the masonite floor by molasses seepage from a type of blasting agent then used. Saturation with ammonium nitrate, another component of the preparation, would be expected. Such a mixture filmed out, dry and subject to summer heat must constitute a hazard, whether or not the fire started there. A feature of the disaster defying explanation was the finding alongside the magazine of two tarpaulins, one of which smoldered for hours after the main fire had burnt out.

Fortunately without serious consequences, and at no time endangering the cargo, fire occured aboard the explosives ship "Rosita" at Port Hedland on 29th October. Originating in the crew's quarters and due probably to electrical ignition of spilt paint thinner, the blaze was rapidly subdued with extinguishers. The occurrence served to emphasize the necessity for fire protection measures and trained operatives aboard ships and on wharves handling explosives in N.W. ports. The Explosives Branch has repeatedly recommended the employment of permanent fire officers at these places.

Outrages with Explosives

Two explosions 20 minutes apart wrecked a public telephone box in Brentwood and a beach snack bar caravan at Cottesloe during early hours of Sunday 21st May. Another two boxes at South Fremantle and Cottesloe suffered destruction in December. All four acts presented certain common features such as effective placing and timing of the charges, and the apparent lack of intention to injure anyone or to rob the caravan till and phone coin receptacles. The May outrages were preceded by several small explosions in sandhills at Swanbourne not far from the snack bar. Thorough search and investigations failed to yield any useful evidence as to the type of explosive or the size of the charges.

On May 23rd money was stolen from a Chubb safe at the Applecross branch of the Bank of N.S.W. Explosives inserted through a hole cut with oxy-acetylene equipment blew open the door without unhinging it, damaged furnishings and smashed a plate-glass window 30 feet away. A remnant of burnt-out fuse and the characteristic smell following explosion left no doubt as to the thief's method of working, but afforded insufficient evidence to identify the explosive.

Neither personal injury nor damage to property other than a small drum resulted from detonation of a time-bomb in a public reserve at Mandurah on May 27th. The drum had contained two 1.5 volt batteries wired in series through an alarm clock which, on ringing at a pre-set time, closed the circuit as the key rotated and so fired the charge electrically. Examination of spattered material from the blast suggested that a home-made composition had been used.

Accidents with Explosives

Deepening of an entrance channel and turning basin to serve the new B.H.P. jetty in Cockburn Sound neared completion on May 13th when a premature explosion on the shooting barge caused one man's death and injured four others, two seriously. A sixth victim, the skipper of the towing launch standing some distance off at the time, sustained ruptured eardrums. The barge's hull and decking received little damage, but one sideplate of its winch was holed, the firing cable pay-out gear twisted and a trough containing seven polythene-bagged charges of ANFO for the next intended round dislodged from its trunnions. When recovered in pieces a couple of days later it gave evidence that only a portion of the charge, probably the centrally-situated bag, had exploded, and indeed the tattered remains of the others were duly found. Though knocked about in varying degree by the blast, a hundred or so bags stacked near the trough for future use fortunately did not explode. Examination of this composition and bulk supplies ashore, together with accessory detonating fuse, primers and detonators established that all were up to standard. Similarly the exploder, tested by an S.E.C. expert, proved to be in good order and capable of momentary 250 volt output. The firing cable, however, was merely bell wire of small gauge and too thinly plastic-insulated for its purpose. Several witnesses reported electric shocks from the activated cable which, instead of diversion round the laden trough, ordinarily crossed it to connect with charges already on the seabed. Just before tipping the explosive overboard a pre-fabricated unit consisting of two electric detonators taped in parallel onto a loop of Primacord or Cordtex (detonating fuse) was tied to the primed fuse in the bagged ANFO. As soon as the charge reached the bottom, the barge retreated 180 to 200 feet before the shot-firer connected up his exploder.

This procedure proved safe and reliable over a long period during which a total 1,280 tons of ANFO were used. What then caused the disaster? Without anticipating the Coroner's finding, there seems no explanation but to assume that an electric detonator, or one of the units described above, had found its way onto or under the central charge and either electrically contacted the defective cable or fired by leakage therefrom. Although the company's rules insisted that detonators be handled singly, the possibility of error could not be denied. All other potential causes such as radio transmission, electrolytic effects and direct application of electricity to the explosive were ruled out on results of continued investigations.

Tragedy struck again on 4th November in different circumstances inasmuch that explosion occuring underneath the barge destroyed the trough, blew off a pontoon, killed one man and injured others. Just why a charge should have found its way under the vessel's hull could not be explained. The bags were always weighted with sand to ensure sinking, and apparently there was no change in tension on the firing cable to indicate misplacement or movement of the bagged blasting agent.

Under circumstances suggesting suicide rather than accident, a man died near Agnew in February. Not until four months later was his skeleton found alongside a wrecked camp and utility. Cratering of the ground and destruction generally indicated to police investigators that a substantial charge had detonated. Departmental records determined possible supply sources, but nothing remained as a basis for identifying the explosive.

A blast followed by fire in a Floreat Park home on May 8th caused one fatality, but investigation failed to link the disaster with explosives as ordinarily understood. Evidence suggested attempted arson: what actually exploded was vapor from a flammable petroleum solvent, splashed about deliberately.

Legislation

Fireworks.—Because of anomalies in the draft, the 1966 Amendment Bill was not proclaimed. Actually the sale and use of fireworks could have continued as provided by the Explosives and Dangerous Goods Act (1961) and Regulations, but fear of a complete ban so depressed the trade that only one consignment of shopgoods-class fireworks entered the State, compared with 15 to 20 normally received. Few if any chain stores and other large retailers offered fireworks for sale. Several small licensed suburban shops functioned as formerly, probably in anxiety to quit carry-over stock. These sales, quite within the law at the time, evoked complaint from parents and a generally confused public obsessed with the idea that fireworks were forbidden. As expected, professionally staged displays gained in popularity and frequency notwithstanding more rigid departmental safety requirements and measures imposed to minimize nuisance. In passing it is pleasing to record that the products of two local manufacturing pyrotechnicians were used in several displays.

Early November, 1967, a second Amendment Bill was drafted and proclaimed but not enforced until a week after the traditional "bonfire night" celebrations. In full impact, it will prohibit sale, purchase and use of Class 7 Division 3 explosives (shopgoods Fireworks). The situation respecting specially-defined novelty lines like sparklers, streamer bombs etc. awaits clarification. Div 2 display fireworks, marine flares and fuse lighters were not banned.

The amendment Act now requires consolidation and reprinting, followed by a revision of the Regulations relating to fireworks control and expungement of those sections no longer applicable.

Conferences, etc.

The writer attended meetings of the Australian Port Authorities' Dangerous Goods Sub-Committee in Sydney on 8-9 February and the Australian Dangerous Goods Transport Committee at Melbourne six weeks later. The agendas embraced topics of vital concern to W.A.'s rapidly developing industries. Inspection of new wharves at Circular Quay and a day spent at Point Wilson Explosives Reserve, Corio Bay, Victoria, and its 2 mile long jetty, were rewarding experiences in furnishing information of potential local application.

Mr. Greaves attended an in-service Organisation and Methods course conducted by the Public Service Commissioner's Staff. He prepared a report on reorganisation of the Branch necessary for the future functioning generally and particularly to cope with full operation of the Dangerous Goods Regulations.

Acknowledgments

High appreciation is expressed to my colleague Mr. G. A. Greaves for diligent pursuit of all duties and his resourcefulness in keeping the Branch's activities abreast with the times. As before, the assistance and co-operative attitude of other Government Departments, Local Authorities, Mines Inspectors, the Chamber of Mines and the host of people concerned with explosives and dangerous goods must be recorded with gratitude. On both the clerical side and at the explosives reserve, the staff carried out its functions creditably.

F. F. ALLSOP,
Chief Inspector of Explosives.

DIVISION IX

Report of Superintendent, Mine Workers' Relief Act, and Chairman, Miners' Phthisis Board—1967

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, 1967.

2. *General*

The State Public Health Department, under arrangements made with this Department, continued the periodical examination of mine workers, the work being carried out through the year at the State X-Ray Laboratory Kalgoorlie, the Perth Chest Clinic, and in conjunction with the mobile X-ray unit which visited the West Pilbara, Pilbara, Peak Hill, Murchison, Yilgarn and Coolgardie Goldfields, the South West Mineral Field and the Greenbushes Mineral Field.

3. *Mine Workers' Relief Act*

3.1. *Total Examinations*

The examinations under the Mine Workers' Relief Act during the year totalled 2029 as compared with 3,941 the previous year, a decrease of 1,912. The results of examinations are as follows:—

Normal	1,644
Silicosis early, previously normal	19
Silicosis early, previously silicosis early	329
Silicosis advanced, previously normal	nil
Silicosis advanced, previously silicosis early	7
Silicosis advanced, previously silicosis advanced	1
Silico-tuberculosis, previously normal	nil
Silico-tuberculosis, previously silicosis early	2
Silico-tuberculosis, previously silicosis advanced	nil
Silico-tuberculosis, previously tuberculosis	3
Tuberculosis, previously normal	2
Asbestosis early, previously normal	4
Asbestosis early, previously asbestosis early	2
Asbestosis advanced, previously normal	nil
Asbestosis advanced, previously asbestosis early	3
Silico-asbestosis early, previously normal	4
Silico-asbestosis early, previously asbestosis early	nil
Silico-asbestosis early, previously silicosis early	3
Silico-asbestosis early, previously silico-asbestosis early	4
Silico-asbestosis advanced, previously silico-asbestosis early	2
Silico-asbestosis advanced, previously silicosis early	nil
Silico-asbestosis plus tuberculosis, previously normal	nil
Silico-asbestosis advanced plus tuberculosis, previously silico-asbestosis early	nil
Total	2,029

These 1967 figures, together with the figures for the previous years, are shown in 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 1644 or 81.02% of the men examined and include men having first class lives or suffering from fibrosis only. The figures for the previous year being 3,411 or 86.56%.

3.2.2. *Early Silicosis*

These numbered 351 of which 19 were new cases and 332 have previously been reported, the figures for 1966 being 26 and 469 respectively. Early silicotics represent 17.15% of the men examined, the percentage for the previous year was 12.56%.

3.2.3. *Advanced Silicosis*

There were 8 cases reported seven of which advanced from early silicosis and 1 was previously diagnosed advanced. Advanced silicotics represent 0.39% of the men examined, the percentage for the previous year being 0.36%.

3.2.4. *Silicosis Plus Tuberculosis*

Five cases were reported which was one more than reported in 1966.

3.2.5. *Tuberculosis Only*

Two cases were reported compared with one in 1966.

3.2.6. *Asbestosis*

Six cases of early asbestosis were reported, four being new cases and two had previously been reported.

In addition, there were three cases of asbestosis advanced.

3.2.7. *Silico-Asbestosis*

Thirteen cases were reported of which four were new cases.

4. *Mines Regulation Act*

4.1. *Total Examinations*

Examinations under the Mines Regulation Act totalled 3,262. These were in addition to 2,029 under the Mine Workers' Relief Act. There was an increase of 354 examinations under this Act in 1967 as compared with 1966. Of the total of 3,262 examined, 2,873 were new applicants and 389 re-examinees. In addition 774 examinations for the Provisional Certificate were carried out in isolated areas.

4.2 *Analyses of Examinations*

Particulars of examinations are as follows:—

4.2.1. *New Applicants*

Normal	2,850
Silicosis early	nil
Silicosis early with tuberculosis	nil
Tuberculosis	nil
Other conditions	23
TOTAL	2,873

4.2.2. *Re-examinees*

Normal	388
Silicos early	nil
Tuberculosis	nil
Other conditions	1
TOTAL	389

These men had been previously 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)	3,234
Temporary Rejection Certificates (Form 3)	6
Rejection Certificates (Form 4)	18
Re-admission Certificates (Form 5)	3
Special Certificate (Form 9)	1
TOTAL	3,262

5. *Miner's Phthisis Act*

The amount of compensation paid during the year was $13,571.00 compared with $14,653.67 for the previous year.

The number of beneficiaries under the Act as on 31st December, 1967 was 60 being 6 ex-miners and 54 widows.

6. *Administrative*

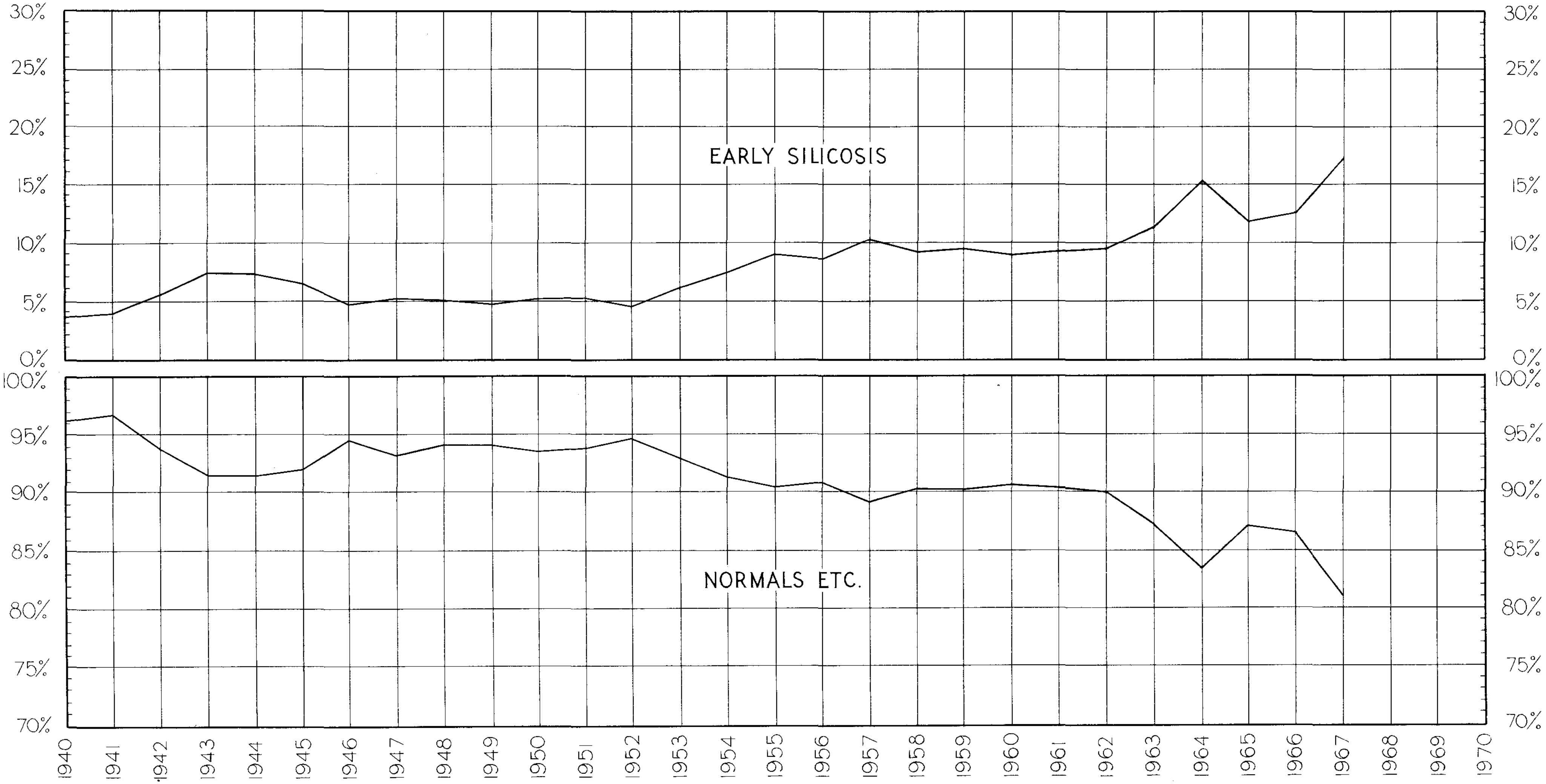
During the year the duties of Superintendent of the Mine Workers Relief Act was taken over by Mr. A. L. Day from Mr. A. R. Jackson who was transferred in January, 1967.

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



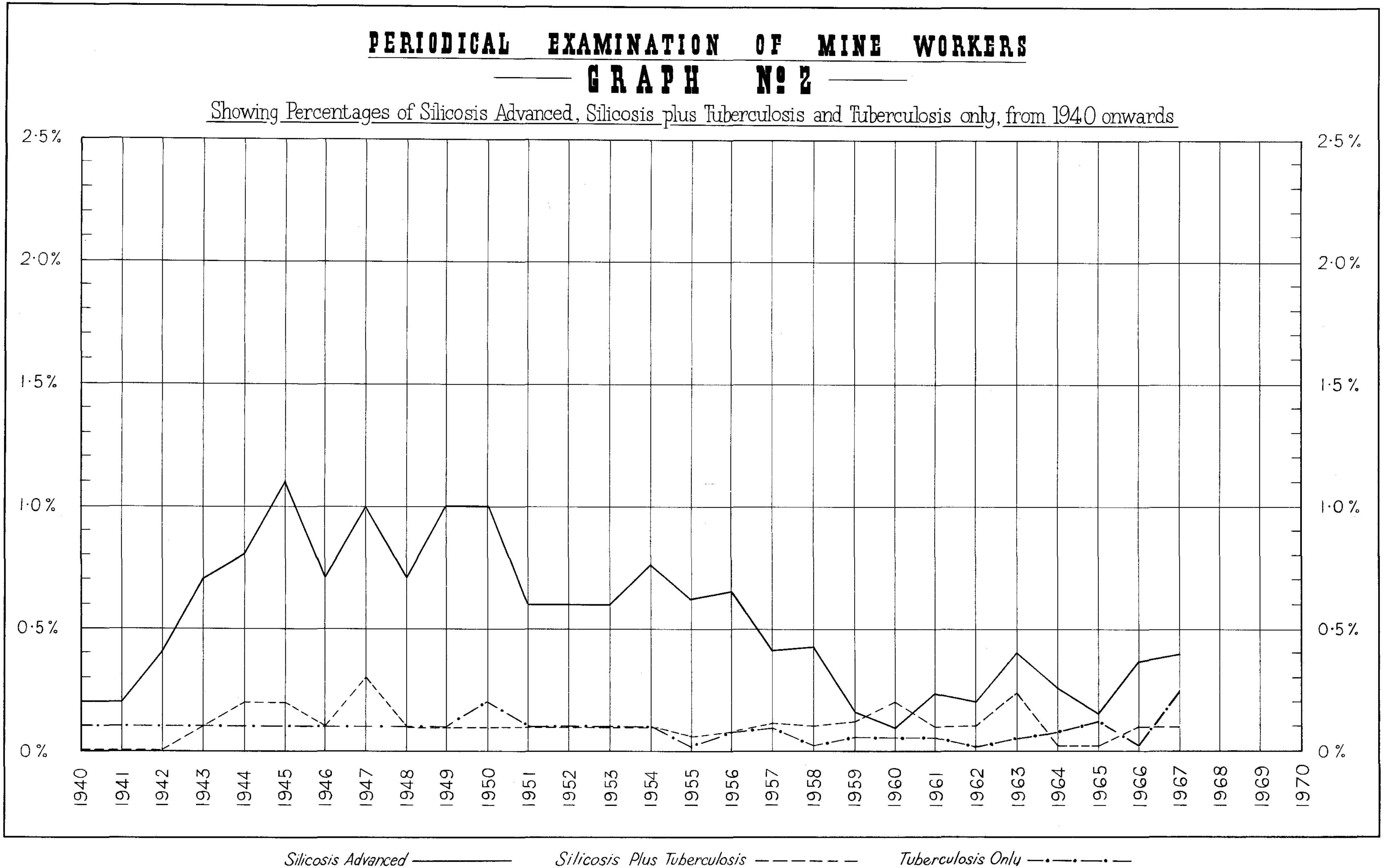
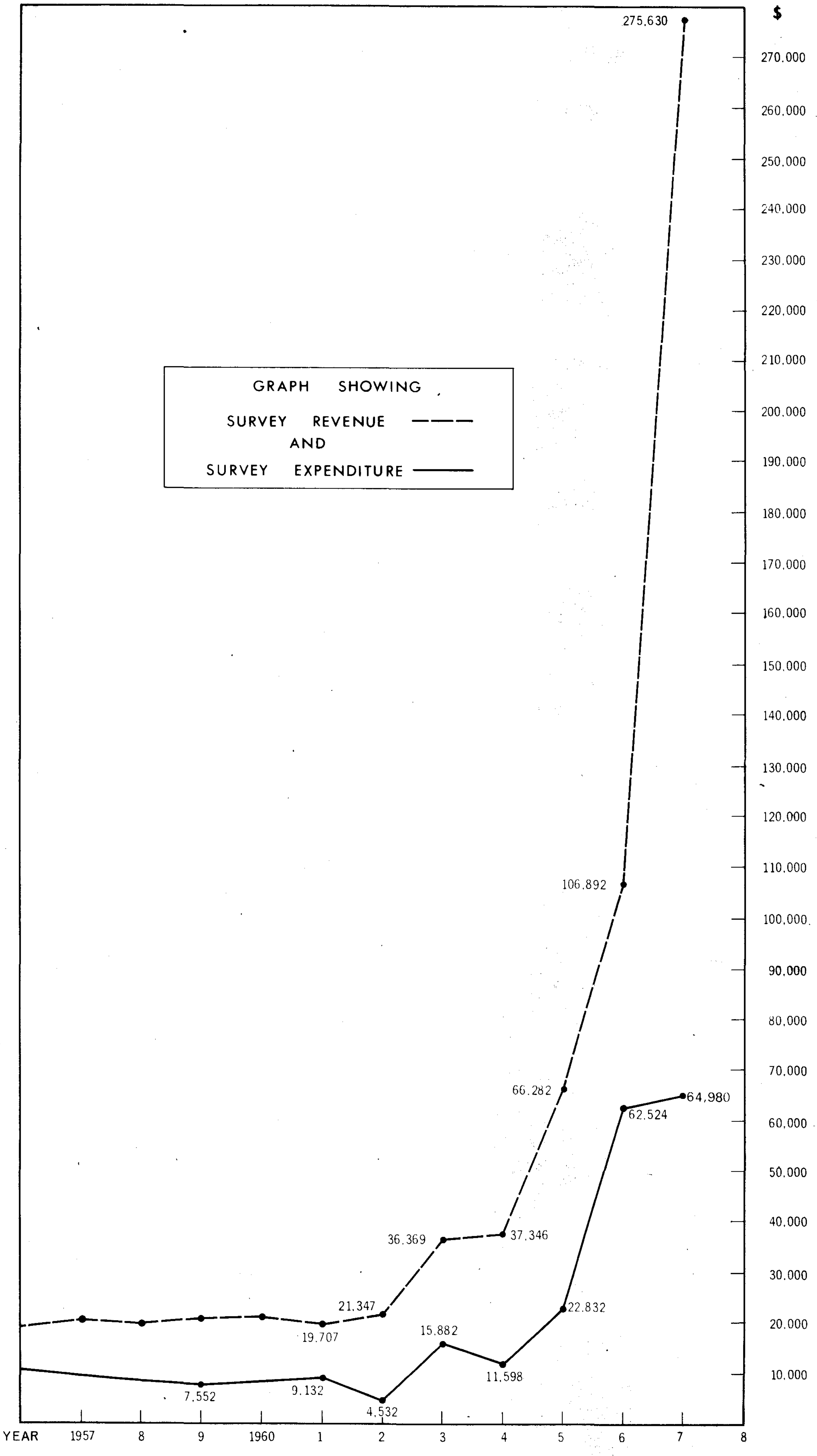

PERIODICAL EXAMINATION OF MINE WORKERS
GRAPH No 2
Showing Percentages of Silicosis Advanced, Silicosis plus Tuberculosis and Tuberculosis only, from 1940 onwards
2·5%
2·0%
1·5%
1·0%
0·5%
0%
1940 1941 1942 1943 1944 1945 1946 1947 1948 1949 1950 1951 1952 1953 1954 1955 1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970
Silicosis Advanced
Silicosis Plus Tuberculosis
Tuberculosis Only

TABLE SHOWING RESULTS OF PERIODICAL EXAMINATION OF MINE WORKERS FROM INCEPTION OF EXAMINATIONS (1925).

Year	Normal		Silicosis Early				Silicosis Advanced					Silicosis plus Tuberculosis					Tuberculosis Only		Asbestosis									
	Total	Per Cent.	Previously reported as Normal etc.	Previously reported as Silicosis Early	Total	Per Cent.	Previously reported as Normal etc.	Previously reported as Silicosis Early	Previously reported as Silicosis Advanced	Total	Per Cent.	Previously reported as Normal etc.	Previously reported as Silicosis Early	Previously reported as Silicosis Advanced	Total	Per Cent.	Total	Per Cent.	Asbestosis early previously normal	Asbestosis early previously asbestosis early	Asbestosis advanced previously normal	Asbestosis advanced previously asbestosis early	Asbestosis advanced previously asbestosis advanced	Asbestosis plus tuberculosis previously normal	Asbestosis plus tuberculosis previously asbestosis	Total	Per Cent.	Total
1925 } 1926 }	3,239	80·5	....	....	459	11·4	....	....	....	183	4·5	....	....	....	131	3·3	11	0·3	....	....	....	....	....	....	....	....	....	4,023
1927	3,116	83·6	33	348	381	10·2	8	....	85	93	2·5	39	27	62	128	3·4	10	0·3	....	....	....	....	....	....	....	....	....	3,728
1928	2,977	85·5	59	303	362	10·4	3	16	79	98	2·8	18	14	10	42	1·2	4	0·1	....	....	....	....	....	....	....	....	....	3,483
1929	2,120	81·9	102	224	326	12·6	....	34	60	94	3·6	8	14	19	41	1·6	7	0·3	....	....	....	....	....	....	....	....	....	2,588
1930	2,785	81·9	136	247	383	11·3	2	22	43	67	2·0	8	60	46	114	3·3	50	1·5	....	....	....	....	....	....	....	....	....	3,399
1931	2,530	84·0	94	252	346	11·5	....	18	35	53	1·8	4	35	19	58	1·9	25	·8	....	....	....	....	....	....	....	....	....	3,012
1932	3,835	89·5	35	338	373	8·7	....	6	47	53	1·2	3	9	4	16	·4	8	·2	....	....	....	....	....	....	....	....	....	4,285
1933	2,920	86·5	57	322	379	11·2	1	15	44	60	1·8	2	9	4	15	·4	3	·1	....	....	....	....	....	....	....	....	....	3,377
1934	5,140	92·4	54	315	369	6·6	1	24	12	37	·7	6	6	....	12	·2	5	·1	....	....	....	....	....	....	....	....	....	5,563
1935	4,437	92·3	35	303	338	7·0	....	24	2	26	·6	....	5	....	5	·1	2	·0	....	....	....	....	....	....	....	....	....	4,808
1936	6,972	94·7	29	323	352	4·8	1	15	4	20	·3	3	8	....	11	·1	8	·1	....	....	....	....	....	....	....	....	....	7,363
1937	7,487	95·4	15	319	334	4·3	....	14	4	18	·2	1	10	....	11	·1	2	·0	....	....	....	....	....	....	....	....	....	7,852
1938	6,833	95·7	13	266	279	8·9	....	15	2	17	·2	1	8	....	9	·1	3	·0	....	....	....	....	....	....	....	....	....	7,141
1939	6,670	95·6	18	264	282	4·0	....	7	3	10	·1	1	9	1	11	·2	2	·0	....	....	....	....	....	....	....	....	....	6,975
1940	7,023	96·2	12	245	257	3·5	....	10	1	11	·2	....	4	....	4	·0	4	·0	....	....	....	....	....	....	....	....	....	7,299
1941	6,840	95·8	32	248	280	3·9	....	11	3	14	·2	....	....	....	....	....	7	·1	....	....	....	....	....	....	....	....	....	7,141
1942	5,469	93·9	61	264	325	5·6	....	20	5	25	·4	....	2	....	2	·0	3	·1	....	....	....	....	....	....	....	....	....	5,824
1943	3,932	91·5	63	262	325	7·6	....	25	7	32	·7	....	5	....	5	·1	4	·1	....	....	....	....	....	....	....	....	....	4,298
1944	4,079	91·5	70	270	340	7·5	....	21	14	35	·8	1	7	....	8	·2	6	·1	....	....	....	....	....	....	....	....	....	4,468
1945	3,071	92·1	54	166	220	6·6	....	26	10	36	1·1	3	2	....	5	·2	2	·1	....	....	....	....	....	....	....	....	....	3,334
1946	5,294	94·4	89	172	261	4·7	1	36	2	39	·7	3	1	2	6	·1	6	·1	....	....	....	....	....	....	....	....	....	5,606
1947	6,021	93·3	101	237	338	5·2	....	49	9	58	1·0	13	11	1	25	·3	8	·1	....	....	....	....	....	....	....	....	....	6,450
1948	4,827	94·0	24	239	263	5·1	....	18	17	35	·7	1	3	....	4	·1	5	·1	....	....	....	....	....	....	....	....	....	5,134
1949	5,162	94·0	24	239	263	4·8	....	20	31	51	1·0	3	2	1	6	·1	7	·1	....	....	....	....	....	....	....	....	....	5,489
1950	5,077	93·6	14	269	283	5·2	....	14	41	55	1·0	....	1	2	3	·1	8	·2	....	....	....	....	....	....	....	....	....	5,426
1951	4,642	93·9	13	248	261	5·3	....	9	20	29	·6	....	4	2	6	·1	4	·1	....	....	....	....	....	....	....	....	....	4,942
1952	5,073	94·6	8	234	242	4·5	....	4	31	35	·6	....	2	....	2	·1	7	·1	....	....	....	....	....	....	....	....	....	5,359
1953	4,474	93·03	74	225	299	6·22	....	8	24	32	·6	....	2	....	2	·1	2	·1	....	....	....	....	....	....	....	....	....	4,809
1954	5,142	91·33	154	275	429	7·62	....	22	21	43	·76	1	6	2	9	·1	7	·1	....	....	....	....	....	....	....	....	....	5,630
1955	4,559	90·40	63	386	449	8·90	....	9	22	31	·62	1	1	1	3	·06	1	·02	Segregation of asbestosis diagnoses commenced in 1959									5,043
1956	4,600	90·78	25	401	426	8·41	....	8	25	33	·65	1	3	....	4	·08	4	·08	....	....	....	....	....	....	....	....	....	5,067
1957	3,925	89·08	30	424	454	10·30	....	8	10	18	·41	1	4	....	5	·12	4	·09	....	....	....	....	....	....	....	....	....	4,406
1958	5,154	90·20	46	483	529	9·26	....	15	9	24	·42	....	6	....	6	·10	1	·02	....	....	....	....	....	....	....	....	....	5,714
1959	5,242	90·10	66	485	551	9·47	....	9	....	9	·15	1	5	1	7	·12	3	·05	6	....	....	....	....	....	....	6	....	5,818
1960	5,214	90·54	50	473	523	9·08	....	5	....	5	·09	2	9	....	11	·19	3	·05	2	....	....	....	....	1	....	3	....	5,759
1961	5,188	90·18	54	479	533	9·26	....	13	....	13	·23	2	3	....	5	·09	3	·05	5	5	....	1	....	....	....	11	·19	5,753
1962	5,183	89·98	50	499	549	9·53	1	10	....	11	·19	1	5	....	6	·10	1	·02	2	7	....	1	....	....	....	10	·18	5,760
1963	4,795	87·21	188	451	639	11·62	....	22	....	22	·40	7	6	....	13	·24	3	·05	10	11	....	4	....	1	....	26	·47	5,498
1964	3,484	83·85	64	561	625	15·04	....	9	1	10	·24	....	1	....	1	·02	2	·05	13	17	....	2	....	....	1	33	·80	4,155
1965	3,770	87·39	53	459	512	11·87	....	6	....	6	·14	....	1	....	1	·02	5	·12	5	15	....	....	....	....	....	20	.46	4,314
1966	3,411	86·56	26	469	495	12·56	....	14	....	14	·36	3	1	....	4	·10	1	·02	4	12	....	....	....	....	....	16	·40	3,941
1967	1,644	81·03	19	332	351	17·30	....	7	1	8	·39	....	2	....	2	·10	5	·24	8	6	....	5	....	....	....	19	·94	2,029



GRAPH SHOWING
SURVEY REVENUE
AND
SURVEY EXPENDITURE
$
270,000
260,000
250,000
240,000
230,000
220,000
210,000
200,000
190,000
180,000
170,000
160,000
150,000
140,000
130,000
120,000
110,000
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
275,630
106,892
66,282
64,980
62,524
36,369
37,346
21,347
19,707
22,832
15,882
11,598
7,552
9,132
4,532
YEAR
1957
8
9
1960
1
2
3
4
5
6
7
8

DIVISION X

Report of the Chief Draftsman for the Year 1967 (31st Dec. 1967)

Under Secretary for Mines:

For the information of the Hon. Minister, I herewith submit my report on the operation of the Survey and Mapping Branch for the year ended 31st December, 1967.

The continued resurgence of mining maintained an almost overwhelming pressure on the branch throughout the year, but despite inadequate staff, and space restrictions, service requirements were maintained fairly satisfactorily.

Cadastral survey demands have increased throughout with continued emphasis in the Pilbara region in the North West, and Kambalda in the Eastern Goldfields portions of the State.

The proposed re-organisation of the Branch, when effected, should improve the efficiency, but the accommodation problem is still a serious one, with some officers still working under sub-standard conditions.

STAFF

The membership of the staff now totals 51 officers comprising 47 males and 4 females.

There were 3 resignations (2 males and 1 female) during the past twelve months but replacements have been appointed.

Cadet Cartographer R. McFarlane became eligible for permanent appointment while the remainder were successful in their respective examinations.

Itemised reports of the activities of the various sections of the Branch are appended hereto.

A. A. HALL,
Chief Draftsman.

SURVEYS

During the year an amount of $64,980 was paid to the Departments contract Surveyors, as against $62,524 for the previous year.

Surveys during the year were carried out at the following centres:—

South West Mineral Field

Jandakot.	Byford.
Capel.	Marchagee.
Toodyay.	Wanneroo.

Pilbara Goldfield

Talga Talga.	Bamboo.
Moolyella.	Cooglegong.
Hartigans.	Shaw River.
Chocolate Hill.	North Shaw.
Coolyia Creek.	Tambina Creek.
Hillside.	Split Rock.
Mt. Rove.	Pilgangoora.
Wodgina.	Woodie Woodie.
Mt. Sydney.	Ragged Hills.
Mt. Brockman.	Mt. Nicholas.
Mt. Newman.	

Coolgardie Goldfield

Spargoville.	Widgiemooltha.
Hilditches.	Holmans.
Kambalda.	Mandilla.

Yilgarn Goldfield

Marvel Loch.	Nevoria.
Holleton.	

Dundas Goldfield

Norseman.	Esperance.

Phillips River Goldfield

Ravensthorpe.	Munglinup.

West Pilbara Goldfield

Roebourne.	Glenroebourne.
Whim Creek.	

Ashburton Goldfield

Cardabia.	Uaroo.
Range Station.	Wyloo.
Ashburton Downs Station.	

Gascoyne Goldfield

Useless Loop.	Mooloo Station.
Mooka.	Arthur River Station.
Dalgety Downs Station.	Mangaroon.
Gifford Creek Station.	Byro Station.

Mt. Margaret Goldfield

Laverton.	Leonora.
Pykes Hill.	Eulaminna.
Dodgers.	Murrin Murrin.
Randwick.	Yundamindera.
Pykes Hollow.	Linden.

Northampton Mineral Field

Northampton.

Greenbushes Mineral Field

Greenbushes.

Collie River Mineral Field

Muja.

Peak Hill Goldfield

Thaduna.

North East Coolgardie Goldfield

Gessners.	Kanowna.
Golden Valley.	

North Coolgardie Goldfield

Goongarie.	Yerilla.
Comet Vale.	Lake Rebecca.
Menzies.	Welches Find.
Kookynie.	Yilgangi.
Heppingstones.	Gindalbi.

The total number of surveys, under the Mining Act, completed during the year was 465 representing a Surveyors Account total of $63,581.57 from which an amount of $1655.61 was deducted for drafting fees.

The surveys were performed by the following surveyors:—

	Surveys
K. J. Croghan	142
J. A. Jamieson	67
P. J. Hille	54
K. H. Piper	53
R. Bishop	51
W. Lenz	39
M. J. McKimmie	20
M. M. Fisher (F Rodda)	16
E. Brook	13
G. Pascott	6
"Compiled"	4

Two special surveys were called for during the year as follows:—

I Mt. Newman.—The location of the datum peg in association with the common boundaries of Temporary Reserve 3225H under the Mt. Newman Iron Ore Agreement and Temporary Reserve No. 4194H.

II Mandilla Station.—The datum peg of Temporary Reserve 3700H near Mandilla Station was located and its position established with relation to its plan description which was set out on the ground and on North-South line cleared out therefrom.

In spite of another record year in performance of surveys there were 2,776 applications received which were not surveyed and this number when added to the previous arrears of 4,733 makes a total of 7,509 leases awaiting survey.

SURVEY EXAMINATION

Diagrams of surveys were drawn and examined. Original and duplicate plans were prepared on lease instruments and diagrams of surrender and resumption were prepared as required.

Survey instructions and necessary information relating to survey details were supplied to surveyors in the field.

GEODETIC

No calculations were made for standard plans during the year. Many new standard plans are needed but the work of the staff was concentrated on survey and diagram work with the result that the geodetic work has accumulated.

Mathematical tables for the Universal Transverse Mercator Projection on the Australian National Spheroid have now been received and all future geodetic calculations must be made on this spheroid upon resumption of this work.

MAPPING SECTION

Standard Compilations

Calculations and drawing were completed on Transverse Mercator Projection of the Standard Compilations, for the following sheets:—

F50-8-119 Split Rock 20-9
F50-8-119 Split Rock 20-13
F50-8-118 Hillside 20-11
F50-8-118 Hillside 20-15
F51-5-100 Gnumbina 20-1
F51-5-100 Gnumbina 20-2
F51-1-90 Bamboo 20-13
F50-4-89 Eginbah 20-16
F50-8-99 Marble Bar 20-4
F50-8-128 Tambourah 20-3
F50-8-128 Tambourah 20-6
F50-8-128 Tambourah 20-8
F50-8-128 Tambourah 20-12
F51-9-3053-IV Mt. Cooke 1:50,000
F51-9-3053-I Bee Hill 1:50,000
F50-8-108 North Shaw 20-12
F50-8-108 North Shaw 20-11
H51-9-2936-IV Breakaway 1:50,000
F50-9-1952-IV Globe Hill 1:50,000
F50-10-2152-IV Wyloo 1:50,000
F50-14-113 Mangaroon 80
H51-9-2936-III Mt. Walter 1:50,000
Old Series 9/390 13/331 5/318

Surveys

A total of 207 surveys were plotted on to standard compilation system in 1967. A further 258 surveys are required to be plotted when the standard compilations in these areas have been drawn.

Standard Mapping (Planimetric) 1:50,000

A total of 39, 1:50,000 standard mapping sheets were completed during 1967.

Kalpini.	Wanaway.
Gindalbie.	Kambalda.
Binti Binti.	Mt. Monger.
Mulgabbie.	Bare Hill.
Pinnacles.	Samphire.
Arcoona	Widgiemooltha.
Kanowna.	Parker Hill.
Lillis.	Parker Hill East.
Mt. Magnetic.	Mt. Eaton.
Golden Ridge.	Cowan Hill
Kurnalpie.	Binneringie.
Jurangie.	Pioneer.
Cowarna Rocks.	Eundynie.
Gundockerta.	Tanta Biddi
Woolgangie.	North West Cape.
Gibraltar.	Mandu.
Burbanks.	Learmonth.
Marion.	Bundera.
Larkinville.	Rough Range.
Burra Rock.	

Geological (Cartographic Section)

1:250,000 Maps

During the year, Widgiemooltha and Busselton-Augusta sheets were printed by the Bureau of Mineral Resources. Yarraloola and Turee Creek were despatched to the Bureau of Mineral Resources for printing and drawing of Robertson and Edmund was completed.

Kalgoorlie, proceeded and Wyloo, Culver, Loongana, Naretha, Plumridge, Forrest, Jubilee, Balladonia and Zanthus were commenced.

Bulletins

Bulletin 118—"The Devonian Reef Complex of the Canning Basin" consisting of 7 plates was printed at the Government Printing Office, Perth.

State Map

The new State Map proceeded, all scribing being completed and ready for laying out of type details.

Regional Mapping Completed (1:250,000.)

Menzies.	Lake Johnston.
Edjudina.	Norseman.
Southern Cross.	Robertson.

Technical Plans

442 Technical Plans were prepared and drawn for the Geological Surveys together with 8,306 prints and duplicates from various originals.

Plan Printing and Photo Section

Dyeline Prints and Duplicates of all types produced during the year amounted to 41,515 copies.

Public Plan Section

During the year the following applications were received and charted on public plans:—

Mining Tenements (P.A's. M.C's. M.L's. etc.)	3393
Temporary Reserves	546
Licenses to Prospect (Oil)	13
Permits to Explore (Oil)	5

A total of 4575 plans were produced during the year for Head Office and Outstations, for sale and working plans purposes.

Of this total 3535 plans represent Head Office sales to value $3970.00.

In addition numerous special purpose plans were prepared for Departmental and inter-departmental use.

A total of 842 searches to determine land tenure and mineral ownership have been carried out, an increase of 25% on 1966 and still rapidly expanding.

1:50,000 Series

In line with modern exploration techniques, and because of such exploration in the State, it has been possible for the first time to programme in advance with relative accuracy the standard mapping requirement.

This programme based on factual and estimated trends has proved most satisfactory, more particularly in the Kambalda area where successful Nickel exploration is culminating in hundreds of applications for Mineral Claims.

A total of 45, 1:50,000 Series plans, the bulk of which are based on the above programme, have been introduced into the public plan system, 16 of these plans being compiled and prepared by this section.

3237-IV Whitehead, 3237-I Binti Binti, 3337-IV Binti Binti E. 3337-I Mulgabbie.

3237-III Gindalbie, 3237-II Kalpini, 3337-III Arcoona, 3337-II Pinnacles.

3236-IV Kanowna, 3236-I Lillis, 3336-IV Kurnalpi, 3336-I Jurangie Hill.

3236-III Golden Ridge, 3236-II Mt. Magnetic, 3336-III Gundockerta Hill, 3336-II Cowarna Rocks.

MINING STATISTICS
to 31st December, 1967

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TABLE I

PRODUCTION OF GOLD AND SILVER AS REPORTED TO THE MINES DEPARTMENT DURING 1967.

(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 1967					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.
Kimberley Goldfield.												
		Reported by Banks and Gold Dealers	6·58	....	....	....	....	8,927·48	1,994·63	·75	8·15	....
Pilbara Goldfield.												
MARBLE BAR DISTRICT.												
Bamboo Creek	G.M.L. 1118	Kitchener	....	....	229·50	232·47	....	....	....	599·25	809·17	3·53
	1203	Mt. Prophecy	....	....	958·05	526·59	13·36	....	....	2,296·30	1,520·45	88·14
	1216	Prince Charlie	....	....	101·25	91·89	....	....	....	101·25	91·89	....
	924	True Blue	....	....	57·50	·42	....	·62	....	4,728·75	115·06	·22
Marble Bar	....	Sundry Claims	....	....	13·75	2·55	....	67·08	255·30	21,750·29	12,899·34	10·96
Pilgangoora	....	Sundry Claims	....	....	32·00	30·69	....	161·08	47·76	630·10	348·96	·25
Yandicoogina	....	Sundry Claims	....	....	25·00	11·19	1·55	4·32	239·89	647·25	693·66	47·51
		State Battery, Marble Bar	....	....	....	*437·83	113·02	....	....	12·00	*13,476·36	276·38
		Reported by Banks and Gold Dealers	·75	....	....	....	....	14,629·01	457·21	....	15·41	2,224·95
NULLAGINE DISTRICT.												
Nullagine	....	Sundry Claims	....	....	29·75	12·96	·13	321·36	689·71	6,719·20	10,590·91	18·75
Twenty Mile Sandy	....	Sundry Claims	....	....	10·50	3·49	....	33·10	30·50	7,826·35	6,289·60	2·76
Gascoyne Goldfield.												
anga oon Station	G.M.L. 46	Star of Mangaroon	....	....	660·00	714·15	....	....	3·50	1,361·75	2,351·53	60·25

Peak Hill Goldfield.

Peak Hill	G.M.L. 584P	Dazzle Star	....	4·00	....	....	....	....	10·18	329·00	99·97	·67
		Sundry Claims	....	6·32	....	....	....	61·51	383·86	35,365·35	9,030·99	5·35

East Murchison Goldfield.

LAWLERS DISTRICT.

Wildara Station	G.M.L. 1389	Butcher Bird	....	....	622·00	263·14	....	....	....	622·00	263·14	....
	1385	Mangilla	....	....	289·00	243·72	....	....	....	1,623·00	1,644·56	36·18
	1382, 1383	Rowley's Find Leases	....	....	662·00	298·47	....	....	..	1,798·00	720·47	6·86
	1388	Tahmoo	....	....	535·00	212·21	....	....	....	1,271·00	362·00	....
		Sundry Claims	....	....	136·00	60·57	....	143·23	....	1,411·75	746·40	29·71
		P. R. Rumble (L.T.T. 1635H)	....	5·46	....	*30·86	....	....	5·46	....	*30·86	....

BLACK RANGE DISTRICT.

Sandstone	....	Sundry Claims	....	....	410·75	23·37	....	44·95	1,421·07	16,418·70	6,954·45	....

Murchison Goldfield.

CUE DISTRICT.

Big Bell	....	Sundry Claims	....	....	....	3·68	1·77	·39	6·32	612·00	498·25	15·25
Cue	....	Sundry Claims	....	....	16·00	4·22	....	252·92	899·44	47,478·99	20,567·21	5·72
Reedy's	....	Sundry Claims	....	....	205·00	14·25	·77	170·71	137·16	7,500·00	2,705·13	2·01
		State Battery, Cue	....	....	....	*627·50	27·73	....	....	76·25	*27,446·16	155·26
		J. & V. Hronsky (L.T.T. 1467H)	....	....	....	*26·09	5·21	....	....	....	*328·65	655·39
		M. J. Robertson (L.T.T. 1626H)	....	....	....	*10·21	·09	....	....	....	*10·21	·09
		Reported by Banks and Gold Dealers	2·77	....	....	....	·40	3,457·51	109·87	....	22·62	1·81

MEEKATHARRA DISTRICT.

Abbotts	....	Sundry Claims	....	....	....	2·17	....	....	5·29	3,951·57	2,359·71	....
Meekatharra	G.M.L. 2009N	Anna Bella	....	....	120·00	13·10	....	....	....	120·00	13·10	....
	2000N	Halcyon	....	....	2,103·00	95·67	1·02	....	....	8,647·50	437·02	15·38
	(1529N)	Prohibition	....	....	124·00	8·99	....	....	....	11,691·25	2,585·00	12·79
		Sundry Claims	....	137·00	160·00	72·23	·40	279·84	1,353·41	32,599·46	11,760·85	13·10

MOUNT MAGNET DISTRICT.

Mt. Magnet	G.M.L.1527M,etc.	Eclipse Gold Mine N.L.	....	....	....	172·42	20·02	....	12·20	36,408·00	42,171·51	4,660·44
	1282M,etc.	Hill 50 Gold Mine N.L.	....	....	158,895·00	40,441·34	3,242·57	....	....	2,685,738·40	1,227,672·39	59,458·12

Yalgoo Goldfield.

Goodingnow	G.M.L. 1063	Ark	....	....	40·00	27·25	....	....	12·49	2,310·50	1,954·54	....
	1242	Carnation	....	....	108·00	59·25	....	....	....	108·00	59·25	....
	1243	Threybit	....	....	334·00	15·90	....	....	....	334·00	15·90	....
	1244	Sweet William Extended	....	....	18·00	1·00	....	....	....	18·00	1·00	....
		Sundry Claims	....	....	257·00	31·73	....	152·96	169·70	10,690·05	5,167·81	·14

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 1967					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.
Mt. Margaret Goldfield.												
MOUNT MALCOLM DISTRICT.												
Diorite	....	Sundry Claims	....	....	85·00	209·83	....	11·21	332·13	4,786·85	4,786·46	....
Leonora	G.M.L. 1762C, etc.	Sons of Gwalia Ltd.	....	....	....	30·57	....	....	....	7,030,740·53	2,581,184·62	188,812·19
		Sundry Claims	....	....	970·00	135·72	....	37·73	377·26	23,554·45	12,990·20	26·77
Wilson's Patch	....	Sundry Claims	....	....	15·00	17·11	....	4·68	54·46	1,727·16	1,453·11	1·12
		State Battery, Lake Darlot	....	....	....	*686·93	....	....	....	18·00	*3,327·34	4·98
		State Battery, Leonora	....	....	....	*101·72	4·26	....	....	....	*101·72	4·26
		Reported by Banks and Gold Dealers	·38	....	....	....	....	3,653·54	252·83	47·00	59·57	·67
MOUNT MARGARET DISTRICT.												
		Reported by Banks and Gold Dealers	·57	....	....	....	....	2,585·31	108·08	....	29·18	....
North Coolgardie Goldfield.												
MENZIES DISTRICT.												
Comet Vale	....	Sundry Claims	....	....	156·00	8·70	....	....	40·19	2,486·96	1,192·42	....
Goongarrie	....	Sundry Claims	....	....	11·50	2·72	....	46·46	2,144·42	3,046·95	3,448·37	....
Menzies	G.M.L. 5794Z	Callie	....	....	82·25	16·46	....	....	....	397·75	101·78	....
	5799Z	First Hit	....	....	626·00	48·51	....	....	....	676·50	82·13	....
		Sundry Claims	....	....	189·00	34·99	....	56·87	624·33	42,668·69	26,556·71	813·76
Mt. Ida	G.M.L. 5701Z, etc.	Moonlight Wiluna Gold Mines Ltd.	....	....	6,334·00	2,670·33	525·18	....	40·77	455,406·86	232,068·43	7,614·32
		State Battery, Menzies	....	....	....	*10·73	....	....	....	20·00	*3,820·83	1,032·66
ULARRING DISTRICT.												
Morleys	G.M.L. 1094U	First Hit	....	....	134·00	20·53	....	....	82·48	5,605·00	7,444·59	11·89
Mulline	1173U	Riverina	....	....	401·50	31·91	....	....	....	1,403·00	185·68	....
		Sundry Claims	....	....	63·00	10·76	....	10·82	296·42	11,682·89	9,953·25	1·14
Mulwarrie	1113U	Oakley	....	....	184·00	246·92	....	....	....	5,412·00	8,631·10	333·95
NIAGARA DISTRICT.												
Kookynie	....	Sundry Claims	....	....	61·25	18·56	....	60·92	106·60	9,586·55	6,995·94	4·19

Broad Arrow Goldfield.

Bardoc	G.M.L. 2333W	Patience	....	....	73·50	6·17	....	....	....	186·50	25·60	....
		Sundry Claims	....	....	128·50	17·44	....	54·95	1,218·09	18,414·18	8,562·36	....
Black Flag	2229W	Bellevue	....	....	15·75	2·93	....	....	212·68	4,225·98	3,275·05	9·92
Broad Arrow	2336W	Duchess	....	....	6·25	2·77	....	....	....	6·25	2·77	....
	2328W	Hartom	....	....	168·75	16·44	....	....	....	168·75	16·44	....
		Sundry Claims	....	1·63	432·75	66·72	·36	1,008·56	3,056·21	39,035·15	17,583·42	1·42
Grant's Patch	2277W	Coronation	....	....	36·10	23·59	....	....	....	987·10	832·02	5·41
		Sundry Claims	....	....	129·75	38·16	....	....	356·66	7,820·62	3,393·56	4·28
Ora Banda	....	Sundry Claims	....	....	340·50	31·84	....	....	467·18	17,195·80	5,066·69	....
Paddington	2298W	Rona Lucille	....	....	146·00	156·06	....	....	....	786·75	673·61	17·97
		Sundry Claims	....	....	75·50	13·25	....	1,714·16	291·43	17,927·43	9,378·08	....
Siberia	....	Sundry Claims	....	....	59·00	5·27	....	289·06	1,261·72	21,433·59	12,900·86	....
		State Battery, Ora Banda	....	....	....	*517·82	31·19	....	....	128·05	*28,597·70	107·94
		Reported by Banks and Gold Dealers	2·70	....	....	....	....	10,034·16	166·91	61·68	95·83	·15

North-East Coolgardie Goldfield.

KANOWNA DISTRICT.

Kanowna	G.M.L. 1587X	Golden Feather	....	....	303·80	140·72	....	....	....	303·80	140·72	....
	1586X	Kanowna Red Hill	....	....	220·00	230·84	....	....	....	220·00	230·84	....
		Sundry Claims	....	....	11·00	·95	....	125·32	2,169·07	28,812·82	12,293·84	1·71
		Reported by Banks and Gold Dealers	3·24	....	....	....	....	106,043·87	40·42	·50	109·73	....

KURNALPI DISTRICT.

Karonie	....	Sundry Claims	....	....	284·50	66·40	....	....	....	467·50	144·37	....
Mulgabbie	G.M.L. 457K	Mulgabbie Lucknow	....	8·10	....	....	....	....	8·10	70·00	6·72	....

East Coolgardie Goldfield.

EAST COOLGARDIE DISTRICT.

Boorara	G.M.L. 6658E	Waterfall	....	....	103·00	55·83	....	....	....	103·00	55·83	....
Boulder	5345E, etc.	Gold Mines of Kalgoorlie (Aust.) Ltd.	....	....	464,297·00	100,988·49	38,255·98	....	....	5,502,333·00	1,395,130·22	376,540·90
		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.	....	....	295,894·00	64,409·82	44,259·30	....	1·53	16,496,360·97	6,991,469·89	1,844,622·64
	5708E, etc.	Lake View & Star Ltd.	....	....	638,813·00	147,133·09	17,815·25	....	....	20,470,115·30	5,796,897·86	648,527·35
		Prior to transfer to present holders	....	....	....	....	....	....	8·49	15,792,500·38	9,149,223·80	1,348,055·82
	5413E, etc.	North Kalgurli (1912) Ltd.	....	....	356,434·00	65,301·56	32,444·32	....	127·55	8,296,825·24	2,116,305·97	596,780·31
	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

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 1967					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.
		EAST COOLGARDIE GOLDFIELD—continued.										
		EAST COOLGARDIE DISTRICT—*continued.*										
Feysville	6661E	Parkers Reward	....	....	38·75	2·48	....	....	....	38·75	2·48	....
		Sundry Claims	....	....	52·50	3·64	....	....	199·00	1,480·25	674·01	....
Hampton Plains	P.P.L. 277, Loc. 50	Joyce & Africh	....	....	973·25	147·44	·58	....	....	13,136·75	1,195·21	2·06
	P.P.L. 488, Loc. 48	L. Lethlean	....	....	11·25	16·39	....	....	....	15·75	26·34	....
	P.P.L. 175A, Loc. 48	S. Shackleton	....	....	238·25	47·14	....	....	....	503·75	91·94	·27
	P.P.L. 280, Loc. 48	W. J. White	....	....	40·00	3·83	....	....	....	392·75	62·41	....
Kalgoorlie....	G.M.L. 6594E	Gledden South	....	....	60·00	48·86	....	....	....	60·00	48·86	....
	6537E	Golden Key	....	....	29·00	65·75	....	....	....	45·50	97·07	....
	6563E	Gold Mines of Kalgoorlie (Aust.) Ltd. (Mt. Charlotte Mine)	....	....	400,634·00	51,580·42	....	....	....	1,179,832·00	156,754·26	....
		Prior to transfer to present holders	....	....	....	....	....	....	5·72	85,723·60	18,167·21	171·56
	6227E	Hill End South	....	....	210·00	205·65	....	....	....	210·00	205·65	....
	6091E	Lesanben	....	29·19	54·00	94·93	....	....	223·15	1,368·10	968·42	3·88
	6615E	Middle Hannans	....	....	53·00	3·37	....	....	....	326·25	20·37	....
	6639E	Old Hinchcliffe	....	....	148·50	24·50	....	....	....	634·00	107·29	....
Wombola	5497E, 5500E	Daisy Leases	....	....	1,100·50	417·52	....	....	....	23,065·95	20,316·20	884·76
	5689E, etc.	Haoma Leases....	....	....	232·00	*47·82	....	....	....	7,142·50	7,851·75	1,011·58
		Prior to transfer to present holders	....	....	....	....	....	....	·25	60,201·00	57,932·14	827·18
	6635E	Hodad	....	....	267·00	54·20	....	....	....	3,232·50	467·25	51·81
	6650E	Inverness	....	....	240·50	31·72	....	....	....	240·50	31·72	....
	6533E	Rosemary	....	....	356·00	159·86	....	....	....	10,668·85	10,171·72	123·86
		Sundry Claims	....	....	135·50	17·89	....	....	711·10	26,276·93	14,613·07	·20
		State Battery, Kalgoorlie	....	....	....	*483·17	28·04	....	....	390·70	*39,545·27	526·54
		Linnett & Hawkins, T.A. 75E and 76E	....	....	....	*737·31	517·00	....	....	....	*802·06	558·26
		Reported by Banks and Gold Dealers	3·47	....	....	....	....	17,018·69	10,074·62	430·68	7,639·49	34,732·80
		BULONG DISTRICT.										
Balagundi	....	Sundry Claims	....	....	10·25	2·77	....	3·51	295·72	816·26	508·70	....
Bulong	G.M.L. 1342Y	Rocket	....	....	21·50	17·13	....	....	....	115·25	165·39	....
		Sundry Claims	....	....	11·00	9·78	....	1,655·86	1,611·58	18,457·23	18,131·14	·32

Coolgardie Goldfield.

COOLGARDIE DISTRICT

Bonnievale	G.M.L. 5986	Jenny Wren	....	....	40·00	14·17	....	....	....	441·00	250·22	·29
	5622	Lucky Hit	....	....	29·75	51·06	....	....	3·28	1,206·85	810·88	....
	5890	Rayjax	....	....	80·00	70·15	....	....	....	855·75	1,331·54	5·12
		Sundry Claims	....	....	351·50	40·08	....	....	238·91	9,749·63	5,653·88	1·11
Bulla Bulling	6035	Bernguard	....	....	624·75	141·26	....	....	....	860·25	189·30	....
	6003	Worked Out	....	....	23·75	29·11	....	....	....	169·00	189·20	....
		Sundry Claims	....	....	58·50	26·35	....	5·21	19·60	2,193·01	864·37	....
Burbanks	....	Sundry Claims	....	....	161·00	40·91	....	55·05	497·55	18,235·85	9,473·13	·93
Coolgardie	6051	Ada	40·91	....	5·69	16·20	....	40·91	....	50·94	34·98	....
	6049	Central Tindals	....	....	284·00	16·01	....	....	....	284·00	16·01	....
	6064	Mary Jea	....	....	40·50	3·89	....	....	....	40·50	3·89	....
		Sundry Claims	....	25·53	1,752·50	149·20	....	236·14	2,992·01	86,471·69	29,754·49	1·90
Gibraltar	....	Sundry Claims	....	....	20·00	7·84	....	1·39	50·76	3,589·60	1,439·96	....
Hampton Plains	P.P.L. 16A, Loc. 59	C. W. Avard	....	....	59·50	10·10	....	....	....	217·25	69·20	....
	P.P.L. 481, Loc. 59	T. R. Baker	....	....	286·00	50·39	....	....	....	388·00	90·54	....
	P.P.L. 316, Loc. 59; P.P.L. 330, Loc. 59	Gold Mines of Kalgoorlie (Aust.) Ltd.....	....	....	153·00	24·74	....	....	....	264,227·50	134,795·69	29,880·69
		Prior to transfer to present holders	....	....	....	....	....	....	....	9,346·75	5,081·22	....
	P.P.L. 490, Loc. 48	D. Rennie	....	....	55·50	28·24	....	....	....	55·50	28·24	....
Higginsville	G.M.L. 5647	Fair Play Gold Mine....	....	....	143·00	54·64	....	4·42	62·70	28,819·75	3,250·73	·02
	6061	Two Boys	....	....	655·75	170·27	....	....	....	655·75	170·27	....
Logan's	6044	Dorothy Gay	....	....	19·50	45·20	....	....	....	96·50	410·85	....
	6016	Great Lion	....	....	26·50	11·12	....	....	....	556·00	80·07	....
		Sundry Claims	....	....	25·00	18·74	....	6·88	551·62	3,531·03	3,653·70	45·29
		State Battery, Coolgardie	....	....	....	*610·29	4·34	....	....	771·01	*42,238·48	29·26
		Congdon, E. D. (L.T.T. 1625H)	*12·29	....	....	....	....	*12·29	....	....	....	....
		Reported by Banks and Gold Dealers	2·15	....	....	....	....	15,027·76	743·46	48·25	141·36	1·05
		KUNANALLING DISTRICT.										
Callion	....	Sundry Claims	....	....	15·50	1·19	....	....	....	15·50	1·19	....
Carbine	....	Sundry Claims	....	....	2·25	2·92	....	136·27	96·96	6,784·13	2,394·76	....
Chadwin	....	Sundry Claims	....	14·47	42·00	44·52	....	14·28	106·40	6,054·05	3,010·17	·25
Kintore	....	Sundry Claims	....	....	95·50	18·49	....	111·91	102·70	5,215·78	2,657·56	....
Kunanalling	G.M.L. 1052S....	Catherwood	....	....	106·00	7·99	....	....	....	340·50	18·43	....
		Sundry Claims	....	....	94·25	9·88	....	216·53	976·87	17,058·27	10,296·69	21·67
		Reported by Banks and Gold Dealers	·33	....	....	....	....	872·98	17·93	....	5·85	·49

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 1967					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.												
Forrestonia	....	Sundry Claims	....	....	10·75	3·11	....	....	·49	589·50	288·82	8·47
Golden Valley	G.M.L.s 3347, etc.	Radio Leases	....	....	....	32·73	1·13	....	2·70	46,599·80	66,907·70	2,003·95
		Sundry Claims	....	....	58·00	21·88	·28	4·58	241·60	6,737·07	4,972·41	2·62
Greenmount	....	Sundry Claims	....	....	187·00	27·99	12·76	·46	4·27	3,424·33	878·64	34·90
Hopes Hill	....	Sundry Claims	....	....	34·00	1·26	·02	21·12	96·11	4,883·62	1,475·53	1·61
Kennyville	....	Sundry Claims	....	....	84·25	12·67	....	....	5·06	8,813·25	2,364·95	·56
Marvel Loch	4434	Cornwall	....	....	7·75	1·46	·12	....	....	17,798·00	2,468·30	528·12
	3724	Frances Firness	....	....	559·00	280·03	14·66	....	512·87	22,948·25	10,224·69	283·24
		Sundry Claims	....	....	73·00	7·04	·17	11·35	809·31	38,885·34	13,922·96	86·02
Mt. Palmer	4250	Palmerston	....	....	177·25	52·08	·53	2·03	1·69	857·50	179·29	1·76
Mt. Rankin	....	Sundry Claims	....	....	43·75	31·77	1·07	....	1·85	814·75	988·34	1·07
Parker's Range	4508	Buffalo	....	....	37·50	6·14	·22	....	10·36	871·75	160·21	4·74
	4512	Constance Una	....	....	303·00	763·89	15·70	....	....	854·25	1,470·76	53·61
		Sundry Claims	....	....	142·00	12·16	·50	6·59	303·93	13,997·30	5,669·45	3·24
Southern Cross	....	Sundry Claims	....	1·04	52·00	2·82	....	95·90	650·03	8,732·66	2,751·11	7·93
		State Battery, Marvel Loch	....	....	....	*102·02	15·37	....	....	147·00	*3,551·78	279·87
Dundas Goldfield.												
Norseman	1936, etc.	Central Norseman Gold Corporation N.L.	....	....	185,224·00	86,478·03	81,057·62	....	....	4,334,609·20	2,038,462·42	1,357,056·96
	1315, etc.	Norseman Gold Mines N.L.	....	....	....	7·36	1·78	....	....	964,099·00	241,016·86	353,208·32
		State Battery, Norseman	....	....	....	*37·24	7·09	....	....	427·89	*25,881·59	1,087·19
		Reported by Banks and Gold Dealers	·69	....	....	....	....	1,187·05	49·59	47·50	21·37	1·04
Phillips River Goldfield.												
Ravensthorpe	M.C.'s 35, etc.	Ravensthorpe Copper Mines N.L.	....	....	....	§1,198·84	5,131·43	....	....	....	§17,934·02	54,659·94
		Prior to transfer to present holders	....	....	....	....	....	....	....	....	§1·99	....
South-West Mineral Field.												
Jerramungup	....	Sundry Claims	....	....	26·25	34·62	....	....	....	26·25	34·62	....
State Generally.												
		Reported by Banks and Gold Dealers	·12	....	....	38·59	....	1,195·07	1,111·85	....	1,059·21	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 1967.

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	....	....	....	....	....	....	....	6·58	....	....	....	6·58	....
West Kimberley	....	....	....	....	....	....	....	....	....	....	....	....	....
West Pilbara	....	....	....	....	....	....	....	....	....	....	....	....	....
Pilbara	Marble Bar	·75	....	1,417·05	1,333·63	1,334·38	127·93						
	Nullagine	....	....	40·25	16·45	16·45	·13	·75	....	1,457·30	1,350·08	1,350·83	128·06
Ashburton	....	....	....	....	....	....	....	....	....	....	....	....	....
Gascoyne	....	....	....	....	....	....	....	....	....	660·00	714·15	714·15	....
Peak Hill	....	....	....	....	....	....	....	....	10·32	....	....	10·32	....
East Murchison	Lawlers	....	5·46	2,244·00	1,108·97	1,114·43	....						
	Wiluna	....	....	....	....	....	....	....	5·46	2,654·75	1,132·34	1,137·80	....
	Black Range	....	....	410·75	23·37	23·37	....						
Murchison	Cue	2·77	....	221·00	685·95	688·72	35·97						
	Meekatharra	....	137·00	2,507·00	192·16	329·16	1·42	2·77	137·00	161,623·00	41,491·87	41,631·64	3,299·98
	Day Dawn	....	....	....	....	....	....						
	Mt. Magnet	....	....	158,895·00	40,613·76	40,613·76	3,262·59						
Yalgoo	....	....	....	....	....	....	....	....	....	757·00	135·13	135·13	....
Mt. Margaret	Mt. Morgans	....	....	....	....	....	....						
	Mt. Malcolm	·38	....	1,070·00	1,181·88	1,182·26	4·26	·95	....	1,070·00	1,181·88	1,182·83	4·26
	Mt. Margaret	·57	....	....	....	·57	....						
North Coolgardie	Menzies	....	....	7,398·75	2,792·44	2,792·44	525·18						
	Ularring	....	....	782·50	310·12	310·12	....	....	....	8,242·50	3,121·12	3,121·12	525·18
	Niagara	....	....	61·25	18·56	18·56	....						
	Yerilla	....	....	....	....	....	....						
Broad Arrow	....	....	....	....	....	....	....	2·70	1·63	1,612·35	898·46	902·79	31·55
North-East Coolgardie	Kanowna	3·24	....	534·80	372·51	375·75	....						
	Kurnalpi	....	8·10	284·50	66·40	74·50	....	3·24	8·10	819·30	438·91	450·25	....
East Coolgardie	East Coolgardie	3·47	29·19	2,160,415·00	432,082·68	432,115·34	133,320·47						
	Bulong	....	....	42·75	29·68	29·68	....	3·47	29·19	2,160,457·75	432,112·36	432,145·02	133,320·47
Coolgardie	Coolgardie	55·35	25·53	4,895·69	1,629·96	1,710·84	4·34						
	Kunanalling	·33	14·47	355·50	84·99	99·79	....	55·68	40·00	5,251·19	1,714·95	1,810·63	4·34
Yilgarn	....	....	....	....	....	....	....	....	1·04	1,769·25	1,359·05	1,360·09	62·53
Dundas	....	....	....	....	....	....	....	·69	....	185,224·00	86,522·63	86,523·32	81,066·49
Phillips River	....	....	....	....	....	....	....	....	....	....	1,198·84	1,198·84	5,131·43
South-West Mineral Field	....	....	....	....	....	....	....	....	....	26·25	34·62	34·62	....
Northampton Mineral Field	....	....	....	....	....	....	....	....	....	....	....	....	....
State Generally	....	....	....	....	....	....	....	·12	....	....	38·59	38·71	....
Outside Proclaimed Goldfield	....	....	....	....	....	....	....	....	....	....	....	....	....
Total	....	....	....	....	....	....	....	**76·95**	**282·74**	**2,531,624·64**	**573,444·98**	**573,754·67**	**223,574·29**

TABLE III.

Return showing total production reported to the Mines Department, and respective Districts and Goldfields from whence derived, to 31st December, 1967.

Goldfield	District	District						Goldfield					
		Alluvial	Dollied and Specimens	Ore Treated	Gold Therefrom	Total Gold	Silver	Alluvial	Dollied and Specimens	Ore Treated	Gold Therefrom	Total Gold	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	24,317·02	31,031·13	1,910·66
Pilbara	Marble Bar	15,511·22	4,569·14	346,285·77	334,015·87	354,096·23	33,195·98	26,020·75	7,478·83	496,368·44	469,489·53	502,989·11	34,276·90
	Nullagine	10,509·53	2,909·69	150,082·67	135,473·66	148,892·88	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	1,845·75	3,247·50	4,067·32	87·17
Peak Hill	....	....	....	....	....	....	....	3,387·79	5,388·29	783,070·73	322,738·34	331,514·42	3,794·07
East Murchison	Lawlers	7,103·51	2,348·65	2,021,367·67	827,478·69	836,930·85	27,268·77	9,010·95	22,212·73	12,627,122·83	3,655,212·55	3,686,436·23	60,324·41
	Wiluna	236·48	1,254·11	8,873,649·69	1,872,319·97	1,873,810·56	10,322·32						
	Black Range	1,670·96	18,609·97	1,732,105·47	955,413·89	975,694·82	22,733·32						
Murchison	Cue	5,137·89	9,109·73	6,815,612·31	1,403,376·81	1,417,624·43	274,835·65	25,776·47	59,635·41	15,024,899·13	5,939,917·86	6,025,329·74	515,883·60
	Meekatharra	14,704·53	18,716·13	2,324,397·57	1,311,428·53	1,344,849·19	5,278·85						
	Day Dawn	3,291·61	11,341·80	2,037,595·63	1,375,641·81	1,390,275·22	169,447·42						
	Mt. Magnet	2,642·44	20,467·75	3,847,293·62	1,849,470·71	1,872,580·90	66,321·68						
Yalgoo	....	....	....	....	....	....	....	1,815·77	3,224·00	444,106·58	264,171·52	269,211·29	1,523·06
Mt. Margaret	Mt. Morgans	3,574·87	9,401·98	1,218,139·31	718,011·55	730,988·40	5,831·33	11,790·33	35,425·32	11,500,948·52	4,963,570·63	5,010,786·28	262,816·30
	Mt. Malcolm	4,067·36	16,668·99	7,754,635·97	3,071,515·52	3,092,251·87	190,794·27						
	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	7,032·09	1,952,610·73	1,433,701·81	1,442,430·59	39,176·43	4,857·37	19,969·57	3,731,768·73	2,587,973·13	2,612,800·07	72,525·81
	Ularring	129·66	7,298·59	537,768·95	447,266·41	454,694·66	22,286·97						
	Niagara	1,718·48	1,821·77	944,509·27	528,600·83	532,141·08	5,716·17						
	Yerilla	1,312·54	3,817·12	296,879·78	178,404·08	183,533·74	5,346·24						
Broad Arrow	....	....	....	....	....	....	....	21,998·52	28,007·11	1,413,261·24	753,095·58	803,101·21	5,703·00
North-East Coolgardie	Kanowna	106,549·25	13,635·61	1,011,262·61	628,390·01	748,574·87	3,049·28	119,386·52	21,942·62	1,026,020·18	647,619·46	788,948·60	3,061·99
	Kurnalpi	12,837·27	8,307·01	14,757·57	19,229·45	40,373·73	12·71						
East Coolgardie	East Coolgardie	33,736·51	41,217·31	92,266,257·49	37,385,048·80	37,460,002·62	6,180,212·40	61,142·02	57,254·08	92,454,811·57	37,518,195·88	37,636,591·98	6,180,312·16
	Bulong	27,405·51	16,036·77	188,554·08	133,147·08	176,589·36	99·76						
Coolgardie	Coolgardie	17,208·91	21,825·87	3,004,882·47	1,545,966·51	1,585,001·29	54,478·97	18,730·80	27,649·43	3,371,685·92	1,799,749·27	1,846,129·50	55,252·03
	Kunanalling	1,521·89	5,823·56	366,803·45	253,782·76	261,128·21	773·06						
Yilgarn	....	....	....	....	....	....	....	2,198·76	6,333·43	8,285,987·37	2,439,709·71	2,448,241·90	213,894·80
Dundas	....	....	....	....	....	....	....	2,256·21	16,400·63	6,391,002·12	3,010,568·28	3,029,225·12	1,774,940·98
Phillips River	....	....	....	....	....	....	....	607·11	823·32	130,659·24	122,008·65	123,439·08	70,803·02
South-West Mineral Field	....	....	....	....	....	....	....	313·08	48·66	4,747·83	2,436·72	2,798·46	15·18
Northampton Mineral Field	....	....	....	....	....	....	....	....	....	....	....	....	5,185·58
State Generally	....	....	....	....	....	....	....	1,195·07	1,111·85	27·00	10,068·96	12,375·88	32,662·66
Outside Proclaimed Goldfield	....	....	....	....	....	....	....	....	....	....	....	....	1,259·58
Total	....	....	....	....	....	....	....	**335,881·46**	**316,943·92**	**157,732,974·14**	**64,554,298·52**	**65,207,123·90**	**9,375,650.65**

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	698,666·29	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	27,418,780
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
	11,601,442·37	55,142,333·80	66,743,776·17	$A1,047,524,121

	1966	1967
	$A	$A
Estimated Mint value of above production	1,021,396,797	1,039,398,152
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	2,876,196	2,946,765
Estimated Total	$A1,029,452,197	$A1,047,524,121
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	16,135,700	19,732,841
Gross estimated value of gold won	$A1,045,910,793	$A1,067,579,858

TABLE V.

Quantity and Value of Minerals, other than Gold, Reported during the year, 1967

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Long Tons	Metallic Content	Value $A
		ALUMINA (from Bauxite)			
			Alumina Recovered Tons		
M.L. I SA	South-West	Western Aluminium N.L.	405,225·00	....	(*f*)24,313,500.00
		ASBESTOS (Chrysotile)			
L.T.T. 1454H	Pilbara	Hancock, L. G.	76·30	....	(*b*) 3,214.60
		BARYTES			
P.A. 3626N	Murchison	Ward, C. A.	172·00	....	2,236.00
M.C. 20N	Murchison	Universal Milling Co. Pty. Ltd.	740·25	....	18,377.30
M.C. 64	Yalgoo	Fleming, A. K.	50·00	....	1,000.00
			962·25	....	(*c*) 21,613.30
		BERYL (*g*) (*h*)			
				BeO Units	
M.L. 80, etc.	Coolgardie	Australian Glass Manuf. Co.	9·85	112·25	3,259.00
P.A. 1148D	Murchison	Clarkson, E. E.	1·12	12·32	422.52
			10·97	124·57	(*b*) 3,681.52
		BUILDING STONE (Granite Facing Stone)			
M.C. 1228H	South-West	Markey, A. J.	6·00	....	(*c*) 48.00
		BUILDING STONE (Quartz, Dead White)			
M.C. 35	Coolgardie	Erceg, C. & Party	382·00	....	(*a*) 7,742·00
		BUILDING STONE (Quartz)			
P.A. 1786M	Coolgardie	Erceg, C. & Party	205·00	....	4,100.00
M.C. 3M	Murchison	McQuillen, H. J.	2·23	....	355.00
			207·23	....	(*a*) 4,455.00
		BUILDING STONE (Quartzite)			
M.C. 1158H, etc.	South-West	House, R. P.....	1,318·00	....	(*c*) 5,464.00
		BUILDING STONE (Sandstone)			
M.C. 990H	South-West	Caporn, C. A.	21·00	....	126·00
M.C. 1036H	South-West	Caporn, C. A.	21·00	....	126.00
			42·00	....	(*a*) 252.00
		BUILDING STONE (Spongolite)			
Q.A. 1, etc.	Phillips River	Frayne, W. L.	633·00	....	(*c*) 8,229.00
		CLAYS (Bentonite)			
M.C. 1042H, etc.	South-West	Noonan, E. J.	112·00	....	(*a*) 896.00
		CLAYS (Cement Clay)			
M.C. 1019H	South-West	Bell Bros. Pty. Ltd.	6,209·00	....	6,705.72
M.C. 788H	South-West	Bell Bros. Pty. Ltd.	10,605·00	....	29,694.00
			16,814·00	....	(*c*) 36,399.72
		CLAYS (Fireclay)			
M.C. 522H, etc.	South-West	Bridge, J. S. & T. D.	32,507·00	....	32,507.00
M.C. 304H, etc.	South-West	Clackline Refractories Ltd.	4,975·00	....	9,950.00
M.C. 685H	South-West	Kargotich, T. J. P. & S.	1,500·00	....	1,500.00
M.C. 732H	South-West	Midland Brick Co. Pty. Ltd.	41,113·00	....	41,113.00
Private Property	South-West	*Unspecified Producers	5,937·45	....	2,839.65
			86,032·45	....	(*c*) 87,909.65

* From Private Property not held under the Mining Act.

TABLE V.—*Quantity and Value of Minerals, other than Gold, Reported during the Year 1967—continued*

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Long Tons	Metallic Content	Value $A
		CLAYS (Kaolin)			
M.C. 247H, etc.	South-West	Linton, J. B. (Universal Milling Co. Pty. Ltd.)	332·45	....	(a) 2,164.07
		CLAYS (White Clay-Ball Clay)			
M.C. 109H	South-West	Brisbane & Wunderlich Ltd.	719·00	....	(c) 5,752·00
		CLAYS (White Clay)			
M.C. 19E	East Coolgardie....	Shearn, A. S.	20·00	....	(c) 60.00
		CLAYS (*Brick, Pipe & Tile Clay)			
Private Property	South-West	Stoneware Pipes & Tiles Pty. Ltd.	2,488·00	....	6,717.60
Private Property	South-West	Stoneware Pipes & Tiles Pty. Ltd.	16,733·00	....	33,466.00
Private Property	South-West	Stoneware Pipes & Tiles Pty. Ltd.	2,100·00	....	4,200.00
Private Property	South-West	Swaby, F. W.	20,000·00	....	50,000.00
Private Property	South-West	†Unspecified Producers	40,968·00	....	20,666.45
			82,289·00	....	(c) 115,050.05

* Incomplete. † From Private Property not held under the Mining Act.

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Long Tons	Metallic Content	Value $A
		COAL			
C.M.L. 448, etc.	Collie	Griffin Coal Mining Co. Ltd.	567,870·30	....	1,848,935.66
C.M.L. 437, etc.	Collie	Western Collieries Ltd.	494,280·50	....	2,915,566.88
			1,062,150·80	....	(a)4,764,502.54
		COPPER ORE AND CONCENTRATES (g) (h)			
				Copper Units	
M.C. 35, etc.	Phillips River	Ravensthorpe Copper Mines N.L.	3,093·00	66,204·00	552,031.53
		Gold and Silver content transferred to respective Items			
		CUPREOUS ORE AND CONCENTRATES (Fertilizer)			
				Assay Cu %	
M.L. 259	West Pilbara	Lee, T. (Yannery Hills Copper Mine)	68·67	13·98	4,556.15
M.C. 382L	Pilbara	McPherson, K. J.	22·41	20·07	2,977.00
Crown Land	Gascoyne	Sundry Persons—Crown Lands	2·00	10·00	99.00
M.C. 25–27	East Murchison....	Ricks, A.	17·91	7·68	442.21
M.C. 97P	Peak Hill	Alac, M.	191·68	18·71	22,013.63
M.C. 98P	Peak Hill	Ilgarari Copper Syndicate	26·30	13·86	1,886.31
P.A. 1688F	Mt. Margaret	Nelson, L.	9·09	14·40	637.23
P.A. 1684F	Mt. Margaret	Gray, F.	22·67	7·43	472.00
M.C. 39	Yalgoo	O'Callaghan & Howlett	6·65	9·49	287.62
M.C. 39	Yalgoo	Shearer, R. W.	402·00	10·14	18,008.00
Crown Land	Outside Proclaimed	Crown Lands—District Generally	6·75	18·00	729.00
			776·13	13·01	(a)(b)52,108.15
		DIATOMACEOUS EARTH (Calcined)			
M.C. 982H	South-West	Universal Milling Co. Pty. Ltd.	5·00	....	(c) 352.50
		FELSPAR			
M.L. 80, etc.	Coolgardie	Australian Glass Manuf. Co.	342·00	....	(a) 5,111.88
		FULLERS EARTH (See Clays)			
		GLASS SAND			
M.C. 417H	South-West	Australian Glass Manuf. Co.	14,047·10	....	18,967.00
M.C. 1071H	South-West	Ready Mix Concrete (W.A.) Pty. Ltd.	27,307·00	....	*
M.C. 1191H	South-West	Burlabup Downs Pty. Ltd.	100·00	....	*
M.C. 285H, etc.	South-West	Leach, R. J.	314·00	....	942.00
			41,768·10	....	(c) 19,909.00

* Value not available for publication.

TABLE V.—*Quantity and Value of Minerals, other than Gold, Reported during the Year* 1967—*continued*

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Long Tons	Metallic Content	Value $A
		GYPSUM			
M.C. 30, etc.	Yilgarn	Ajax Plaster Co. Pty. Ltd.	11,891·00	....	21,406.00
M.C. 51, etc.	Yilgarn	H. B. Brady Co. Pty. Ltd.	10,896·00	....	27,240.00
M.C. 9, etc.	Yilgarn	West Australian Plaster Mills	13,621·00	....	20,017.90
M.C. 12, etc.	Dundas	McDonald and Whitfield	120·00	....	120.00
M.C. 612H	South-West	*Hewitt, B.	2,074·00	....	5,822.00
M.C. 435H, etc.	South-West	Swan Portland Cement	1,370·00	....	2,671.55
M.C. 717H, 818H	South-West	†House, R. P. & Lyne, H.	100·00	....	200.00
M.C. 901H–904H	South-West	†House, R. P. & Lyne, H.	6·00	....	12.00
			40,078·00	....	(*a*) 77,489.45

* For Plaster Mills of Welshpool. † For Agricultural Purposes.

Plaster of Paris reported as manufactured during the year being 23,004 tons from 33,121 tons of Gypsum by five companies. Gypsum used in the manufacture of Cement = 9,642·00 tons.

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Pig Iron Recovered Tons	Metallic Content	Value $A
		IRON ORE (Pig Iron Recovered)			
T.R. 1258H	Yilgarn	Charcoal Iron & Steel Industry	54,328·00	....	3,069,933.00 (*c*) (*d*)

Ore treated = 86,401 tons—Average Assay = 62%.

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Long Tons	Av. Assay Fe%	Value $A
		IRON ORE (Ore Exported E. States)			
M.L. 10, etc.	West Kimberley	Dampier Mining Co. Ltd.	678,497·00	65·15	} 4,261,077.00
M.L. 50, etc.	West Kimberley	Dampier Mining Co. Ltd.	1,473,565·00	65·62	
			2,152,062·00	....	(*b*)4,261,077.00
		IRON ORE (Ore Exported Overseas)			
M.L. 50, etc.	West Kimberley	Dampier Mining Co. Ltd.	64,810·00	67·27	496,729.00
235 S.A.	Pilbara	Goldsworthy Mining Pty. Ltd.	3,111,776·20	65·02	26,428,889.29
4 S.A.	West Pilbara	Hamersley Iron Pty. Ltd.	3,641,626·45	65·30	31,249,467.39
M.C. 878H, etc.	South-West	Western Mining Corporation	521,412·22	60·11	4,120,578.00
			7,339,624·87	....	62,295,663.68 (*b*)
		IRON ORE (Ore Railed to Kwinana)			
M.L. 2 S.A.	Yilgarn	Dampier Mining Co. Ltd.	487,773·00	59·56	965,791.00

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Long Tons	Lead Tons	Value $A
		LEAD ORES AND CONCENTRATES (*g*) (*h*)			
M.C. 76	Northampton	Mitchell, G. H. & J. M.	(*i*) 91·23	57·95	7,446·28
M.L. 234	Northampton	Bridson, T. A.	(*i*) 419·46	333·74	49,582.72
M.C. 47	Northampton	Camp & Party	(*i*) 303·51	232·07	31,527.26
M.L. 284	Northampton	Nooka Lead Mine	(*i*) 95·48	64·13	8,336.84
			909·68	687·89	(*b*) 96,893.10

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Long Tons	Metallic Content	Value $A
		* LIMESTONE (For Building and Burning Purposes)			
M.C. 1241H	South-West	Bellombra, M. & L.	13,316·00	....	37,283.20
M.C. 874H	South-West	Brambles Holdings Ltd.	48,877·00	....	9,761.60
M.C. 989H	South-West	Casella, S., Casella, M. & Ioppolo, G.J.	7,175·00	....	17,927.00
M.C. 1071H	South-West	Koot, J. M.	15,150·00	....	15,150.00
M.C. 1105H	South-West	Moore, F. W. & E. M.	1,208·00	....	2,416.00
M.C. 1261H	South-West	Moore, F. W.	57·00	....	114.00
M.C. 1093H	South-West	Multari, N.	2,972·00	....	10,470.00
Lot M 1405	South-West	Parham Grazing Co.	9,637·50	....	24,093.25
Private Property	South-West	†Unspecified Producers	610,482·00	....	669,369.00
M.C. 1244H	South-West	Sullivan, K. J.	4,240·00	....	636.00
M.C. 727H	South-West	Thiess Bros. Pty. Ltd.	32,951·00	....	9,785.30
M.C. 1220H	South-West	Steer, E. J.	8·00	....	32·00
			746,073.50	....	(*c*)797,037.35

* Incomplete. † From Private Property not held under the Mining Act.

TABLE V.—*Quantity and Value of Minerals, other than Gold, Reported during the Year* 1967—*continued*

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Long Tons	Metallic Content	Value $A
		LIMESTONE (For Agricultural Purposes)			
M.C. 50	Dundas	Esperance Lime Supply	614·00	....	4,867.00
M.C. 723H	South-West	Plozza, C. W. & W. A.	90·00	....	180.00
			704·00	....	(*c*) 5,047.00
		LITHIUM ORES (Petalite) (*h*)			
				Li20 Units	
M.L. 80, etc.	Coolgardie	Australian Glass Manuf. Co.	667·00	2,905·60	(*a*) 10,476.90
		MAGNESITE			
M.C. 76, etc.	Phillips River	Magnesite (W.A.) Pty. Ltd.	1,165·48	....	10,755.96
M.C. 116–119	Coolgardie	Australian Glass Manuf. Co.	93·00	....	1,468.00
			1,258·48	....	(*a*)(*b*)12,223.96
		MANGANESE (Metallurgical Grade) (*g*)			
				Av. Assay Mn%	
M.C. 268, etc.	Pilbara	Mt. Sydney Manganese Pty. Ltd.	42,824·98	50·13	1,066,091.69
M.C. 244L, etc.....	Pilbara	Westralian Ores Pty. Ltd.	76,588·00	50·29	1,697,183.00
M.C. 30P, etc.	Peak Hill	Broken Hill Pty. Co. Ltd.....	8,823·00	46·00	220,570.00
M.C. 24P, etc.	Peak Hill	Westralian Ores Pty. Ltd.	60,860·00	36·24	943,214.00
			189,095·98	45·54	(*b*)3,927,058.69
		MINERAL BEACH SANDS (Ilmenite) (*g*)			
				Av. Assay Ti02%	
Sussex Loc. 7	South-West	Cable (1956) Ltd.	18,231·36	54·24	*
M.C. 746H	South-West	Ilmenite Minerals Pty. Ltd.	60,989·20	54·38	*
M.L. 398H, etc.	South-West	Western Mineral Sands Pty. Ltd.	107,990·00	53·73	*
M.C. 619H, etc.	South-West	Westralian Oil Ltd.	60,199·00	58·24	*
M.C. 516H, etc.	South-West	Western Titanium N.L.	182,210·68	54·57	*
			429,620·24	54·83	(*b*)4,185,150.13

* Current Values for separate Companies not available for publication.

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Long Tons	Metallic Content	Value $A
		MINERAL BEACH SANDS (Monazite) (*g*) (*h*)			
				Th02 Units	
M.C. 619H, etc.	South-West	Westralian Oil Ltd.	482·23	2,169·51	59,377.00
M.C. 516H, etc.	South-West	Western Titanium N.L.	864·92	5,718·97	109,153.65
M.C. 746H, etc.	South-West	Ilmenite Minerals Pty. Ltd.	70·05	469·34	9,807·00
			1,417·20	8,357·82	(*b*) 178,337.65
		MINERAL BEACH SANDS (Rutile) (*g*) (*h*)			
				Ti02 Tons	
M.C. 516H, etc.	South-West	Western Titanium N.L.	400·00	383·74	(*b*) 28,757.50
		MINERAL BEACH SANDS (Leucoxene) (*g*) (*h*)			
				Ti02 Tons	
M.C. 516H, etc.	South-West	Western Titanium N.L.	505·86	445·80	26,129.20
M.C. 746H, etc.	South-West	Ilmenite Minerals Pty. Ltd.	92·40	85·15	4,219·20
			598·26	530·95	(*b*) 30,348.40
		MINERAL BEACH SANDS (Zircon) (*g*) (*h*)			
				Zr02 Tons	
M.C. 619H, etc.	South-West	Westralian Oil Ltd.	16,444·00	10,756·26	685,885.00
M.C. 516H, etc.	South-West	Western Titanium N.L.	7,691·73	5,042·02	228,986.73
M.C. 746H, etc.	South-West	Ilmenite Minerals Pty. Ltd.	5,482·45	3,592·77	233,036.76
			29,618·18	19,391·05	(*b*)1,147,908.49

TABLE V.—*Quantity and Value of Minerals, other than Gold, Reported during the Year* 1967—*continued*

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Long Tons	Metallic Content	Value $A
		NICKEL (*i*)			
				Av. Assay Ni%	
M.C. 150, etc.	Coolgardie	Western Mining Corporation	2,252·92	12·94	(*b*) 381,628.00
		OCHRE (Red)			
M.C. 26 and 29	Murchison	Universal Milling Co. Pty. Ltd.	261·00	....	(*a*) 5,220.00
		PETALITE—see Lithium Ores			
		PETROLEUM (Crude Oil)			
			bbls.		
P.L. 1H	Barrow Island	West Australian Petroleum Pty. Ltd.	4,646,938	....	*14,853,605.00

* Based on the price assessed by the Tariff Board for Barrow Island crude oil at Kwinana, i.e. $US3.58 per bbl. ($A3.196428).

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Long Tons	Metallic Content	Value $A
		PYRITES ORE AND CONCENTRATES (For Sulphur)			
				Sulphur Content Tons	
G.M.L. 5715E, etc.	East Coolgardie....	Gold Mines of Kalgoorlie (Aust.) Ltd. (*i*) (*j*)	20,031·89	7,680·85	192,021.44
G.M.L. 1460, etc.	Dundas	Norseman Gold Mines N.L. (*i*)	58,653·00	26,677·96	875,665.00
			78,684·89	34,358·81	(*a*)1,067,686.44
		SEMI PRECIOUS STONES (Chalcedony)			
M.C. 60	Dundas	Rose, F. R.	15·50	....	1,550.00
P.A. 5652	Broad Arrow	W.A. Lapidary and Rock Hunting Club Inc.	·10	....	200.00
			15·60	....	1,750.00
		SEMI PRECIOUS STONES (Amethyst)			
M.C. 65	Ashburton	Soklich, F. F. D. & Z.	2·26	....	5,292.34
		SEMI PRECIOUS STONES (Chrysoprase)			
M.C. 5 O.P.	Outside Proclaimed	Gianni, J.	10·20	....	1,000.00
		SILVER			
			Fine Oz.		
		By-Product Gold Mining	304,120·71	....	414,398.15
		By-Product Copper Mining	5,355·41	....	6,267.89
			309,476·12	....	420,666.04
		TALC			
P.P.	South-West	Three Springs Talc Pty. Ltd.	7,901·24	....	(*b*)(*c*)227,037.44
		TANTO/COLUMBITE ORES AND CONCENTRATES (*g*) (*h*)			
				Ta205 Units	
M.L. 660, etc.	Greenbushes	Greenbushes Tin N.L.	(*k*) 17·27	849·98	111,988.46
M.C. 647, etc.	Greenbushes	Vultan Syndicate	(*k*) 4·22	141·15	9,538.26
M.C. 107, 355	Pilbara	Wilson, L. J.	·42	26·36	4,775.57
D.C. 201, etc.	Pilbara	Pilbara Tin Pty. Ltd.	(*k*) ·80	21·87	5,058.00
Crown Land	Pilbara	Crown Lands—District Generally....	·04	2·22	320.04
			22·75	1,041·58	(*b*) 131,680.33

TABLE V.—*Quantity and Value of Minerals, other than Gold, Reported during the Year 1967—continued*

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Long Tons	Metallic Content	Value $A
		TIN (*g*) (*h*)			
				Tons	
D.C. 53, etc.	Pilbara	Cooglegong Tin Pty. Ltd.	314·12	218·93	548,096.28
D.C. 201, etc.	Pilbara	Pilbara Tin Pty. Ltd.	428·08	302·76	886,896.00
D.C. 281, etc.	Pilbara	Johnston, J. A. & Sons Pty. Ltd.	5·94	4·24	12,612.05
D.C. 254, etc.	Pilbara	Johnston, J. A. & Sons Pty. Ltd.	254·80	180·59	467,835.09
M.C. 910....	Pilbara	Crow, Yegarla	5·67	3·03	7,874.00
D.C. 481, etc.	Pilbara	Stubbs, S. H.	19·00	12·99	35,739.75
D.C. 497	Pilbara	Henderson, J. M. & Sons	7·12	4·73	13,020.11
D.C. 276	Pilbara	D.D. Mining Co.	4·31	2·96	8,267·93
M.C. 815, D.C. 535 and 721	Pilbara	Brockman Tin	7·25	4·68	12,416.77
M.C. 691, etc.	Pilbara	Edwards, M. R.	42·81	28·30	77,496.21
D.C. 586, etc.	Pilbara	Edwards, R. W.	3·69	2·46	6,873.57
D.C. 546	Pilbara	Edwards, R. L. & F. J.	2·51	1·66	4,576.88
D.C. 276	Pilbara	Talga Gold Mining Syndicate—R. W. Edwards	3·05	1·92	5,159.87
D.C. 691, etc.	Pilbara	Canning Tin Pty. Ltd.	3·74	2·60	7,176.34
Crown Lands	Pilbara	Sundry Persons—Crown Lands	3·68	2·66	7,397.96
Crown Lands	Pilbara	Sundry Persons—Crown Lands	3·58	2·54	6,056.79
Crown Lands	Pilbara	Crown Lands—District Generally....	9·20	6·20	17,957.13
M.C. 109....	Pilbara	McLeod, D. W.	3·43	1·78	4,568.93
D.C. 15 W.P.	West Pilbara	McLeod, D. W.	1·54	·97	2,654.13
P.A. 2603, M.C. 93	Dundas	Weston, B. T.	3·14	2·03	5,499.47
P.A. 2609	Dundas	Jones, A. G. & K. E. J.	·05	·02	47.35
M.L. 707	Greenbushes	Guest, E. G.	1·54	1·03	2,794.97
M.L. 647, etc.	Greenbushes	Vultan Syndicate	55·98	38·68	106,164.24
M.L. 660, etc.	Greenbushes	Greenbushes Tin N.L.	54·48	36·79	111,588.73
			1,238·71	864·55	(*b*)2,358,770.55

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Long Tons	Metallic Content	Value $A
		TUNGSTEN ORE AND CONCENTRATES (Wolfram)			
				W03 Content Units	
M.C. 395....	Pilbara	McLeod, D. W.	·69	40·22	1,278.91
M.C. 46....	Murchison	Watkins, T. E. & T. J.	·24	14·74	410.49
			·93	54·96	(*b*) 1,689.40
		TUNGSTEN ORE AND CONCENTRATES (Scheelite)			
P.A. 7765	Coolgardie	Short, P. L.	1·30	89·31	(*b*) 2,858.00

(*a*) Value F.O.R. (*b*) Value F.O.B. (*c*) Value at Works. (*d*) Value of Mineral Recovered. (*e*) Value at Pit Head. (*f*) Estimated nominal value ex Works. (*g*) Only results of shipments realised during the period under review. (*h*) Metallic Content calculated on assay basis. (*i*) Concentrates. (*j*) By-Product Gold Mining. (*k*) By-Product Tin Mining. (*l*) Crude Ore only.

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, 1967, 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)	„	914,569·00	54,874,140.00
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	„	11,094·98	983,332.60
Chrocidolite	„	152,466·74	33,496,644.98
Tremolite	„	1·00	50.00
Barytes	„	6,561·41	93,397.70
Bauxite (Crude Ore)	„	36,741·00	187,069.50
Beryl	„	3,643·01	943,884.85
Bismuth	lb.	12,479·70	7,628.60
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)	„	742·00	13,582.00
Quartz	„	207·23	4,455.00
Quartzite	„	2,598·00	10,584.00
Sandstone	„	583·00	3,498.00
Sandstone (Donnybrook)	„	83·00	3,486.00
Slate	„	235·00	2,115.00
Spongolite	„	2,915·00	30,367.00
Calcite	„	5·00	50.00
Chromite	„	14,419·05	416,593.50
Clays—			
Bentonite	„	11,646·63	74,476.92
Brick, Pipe and Tile Clays (*g*)	„	436,922·00	726,139.95
Cement Clays	„	349,058·05	572,335.84
Fireclay	„	529,778·81	937,069.06
Fullers Earth	„	459·40	3,821.00
White Clay—			
Ball Clay	„	24,942·60	154,880.60
Kaolin	„	5,963·07	22,122.61
Coal	„	36,968,295·14	116,418,479.44
Copper Ore and Concentrates	„	295,525·75	8,098,367.53
Copper (Metallic By-Product) (*a*)	„	(*i*) 191·50	65,375.10
Corundum	„	63·15	1,310.00
Cupreous Ore and Concentrates (Fertiliser)	„	84,270·29	2,998,332.25
Diamonds (*e*)	Carats	(*e*)	48.00
Diatomaceous Earth (Calcined)	tons	476·50	14,629.00
Dolomite	„	3,046·82	26,118.20
Emeralds (cut and rough)	carats	18,381·68	3,844.00
Emery	tons	21·15	750.00
Felspar	„	69,398·61	506,180.06
Fergusonite	„	0·30	782.80
Gadolinite	„	1·00	224.00
Glass Sand	„	196,005·61	(*g*) 216,712.12
Glauconite	„	(*h*) 6,467·00	(*f*) 300,769.00
Gold (Mint and Export)	fine ozs.	66,743,776·17	1,047,524,121.00
Graphite	tons	153·20	2,608.40
Gypsum	„	994,232·33	2,106,859.13
Iron Ore—			
Pig Iron Recovered	„	547,562·08	24,696,734.12
Ore Exported	„	25,860,775·79	109,026,227.06
For Flux	„	58,064·35	74,096.00
Locally used Ore	„	487,773·00	965,791.00
Jarosite	„	9·54	75.00
Kyanite	„	4,215·69	43,562.00
Lead Ores and Concentrates	„	479,822·49	10,351,928.99
Limestone (*g*)	„	2,105,291·71	2,387,018.19
Lithium Ores—			
Petalite	„	2,775·98	42,394.10
Spodumene	„	106·58	3,627.20
Magnesite	„	28,419·28	300,061.36
Manganese—			
Metallurgical Grade	„	1,096,126·84	26,371,664.06
Battery Grade	„	2,218·25	90,860.20
Low Grade	„	5,054·36	81,538.20
Mica	lb.	32,930·00	7,968.48
Mineral Beach Sands—			
Ilmenite Concentrates	tons	2,405,904·68	23,109,143.49
Monazite Concentrates	„	9,052·68	841,086.32
Rutile Concentrates	„	4,978·86	284,809.72
Leucoxene Concentrates	„	4,358·34	159,481.54
Zircon Concentrates	„	127,561·11	3,624,576.77
Crude Concentrates (Mixed)	„	155·95	1,553.00

TABLE VI.—Total Mineral Output of Western Australia—*continued*

Mineral		Quantity	Value
			$A
Molybdenite	tons	51·00	1,010.00
Nickel	,,	2,252·92	381,628.00
Ochre—			
Red	,,	9,848·94	210,170.40
Yellow	,,	447·60	5,955.50
Petroleum (Crude Oil)	bbls.	4,646,938·00	(*k*)14,853,605.00
Phosphatic Guano	tons	11,857·06	145,420.90
Pyrites Ore and Concentrates (For Sulphur) (*b*)	,,	1,300,752·51	15,666,983.53
Quartz Grit	,,	829·50	1,400.70
Semi-Precious Stones—			
Amethyst	lb.	5,062·40	5,292.34
Beryl (Coloured)	,,	200·00	100·00
Chalcedony	,,	35,840·00	2,550.00
Chrysoprase	,,	22,853·00	1,010.00
Opaline	,,	25·00	7.50
Prase	,,	2,240·00	80.00
Tiger Eye Opal	,,	120·00	194.00
Topaz (Blue)	,,	7·00	3.50
Sillimanite	tons	2·00	26.00
Silver (*c*)	fine ozs.	11,736,765·79	5,938,901.55
Soapstone	tons	565·40	3,855.70
Talc	,,	75,335·06	2,053,462.04
Tanto/Columbite Ores and Concentrates	,,	583·82	1,312,411.33
Tin	,,	23,868·81	13,770,847.02
Tungsten Ores and Concentrates—			
Scheelite	,,	169·18	143,424.24
Wolfram	,,	304·35	125,206.70
Vermiculite	,,	1,832·96	23,661.20
Zinc (Metallic By-Product) (*d*)	,,	2,887·75	(*j*)
Zinc Ore (Fertiliser)	,,	20·00	200.00
Total Value to 31st December, 1967		....	1,531,398,542.55

(*a*) By-Product from Gold Mining.
(*b*) Part By-Product from Gold Mining.
(*c*) By-Product from Gold, Copper and Lead Mining.
(*d*) By-Product from Lead Mining.
(*e*) Quantity not recorded.
(*f*) Value of mineral or concentrate recovered.
(*g*) Incomplete.
(*h*) Mineral Recovered.
(*i*) Assayed Metallic Content.
(*j*) Value included in Lead Value.
(*k*) Based on the price assessed by the Tariff Board for Barrow Island crude oil at Kwinana, i.e. $US3·58 per bbl. ($A3·196428).

Footnote.—Comprehensive mineral production records maintained in the Statistical Branch of the Department of Mines show locality, producers, period, quantity, assayed or metallic content, and value of the various minerals listed above.

TABLE VII

Showing average number of men employed above and below ground in the larger mining companies operating in Western Australia during 1966 and 1967.†

Company	1966			1967		
	Above	Under	Total	Above	Under	Total
Gold*—						
Central Norseman Gold Corporation N.L.	144	152	296	137	147	284
Gold Mines of Kalgoorlie (Aust.) Ltd. (Boulder)	365	343	708	369	315	684
Great Boulder G.M.s Ltd.	262	351	613	249	293	542
Hill 50 Gold Mine N.L.	88	102	190	94	108	202
Lake View & Star Ltd.	353	477	830	348	484	832
Moonlight Wiluna Gold Mines Ltd. (Timoni)	31	31	62	....	....	....
Gold Mines of Kalgoorlie (Aust.) Ltd. (Mt. Charlotte)	7	95	102	8	113	121
North Kalgurli (1912) Ltd.	203	259	462	201	256	457
Radio Gold Mines	3	1	4	1	3	4
All other operators	522	264	786	632	269	901
State Average	1,978	2,075	4,053	2,039	1,988	4,027
Alumina (from Bauxite)—						
Western Aluminium N.L.	389	....	389	526	....	526
Coal—						
Griffin Coal Mining Co. Ltd.	209	....	209	185	....	185
Western Collieries Ltd.	98	419	517	99	410	509
Copper—						
Ravensthorpe Copper Mines N.L.	36	32	68	48	45	93
Iron Ore—						
Charcoal Iron & Steel	7	....	7	7	....	7
Dampier Mining Co. Ltd.	335	....	335	437	....	437
Goldsworthy Mining Ltd.	67	....	67	145	....	145
Hamersley Iron Pty. Ltd.	63	....	63	506	....	506
Western Mining Corporation	90	....	90	90	....	90
Mineral Beach Sands—						
Cable (1956) Ltd.	53	....	53	26	....	26
Ilmenite Pty. Ltd.	4	....	4	....	....	....
Ilmenite Minerals Pty. Ltd.	57	....	57	87	....	87
Western Mineral Sands Pty. Ltd.	42	....	42	39	....	39
Westralian Oil Ltd.	54	....	54	64	....	64
Western Titanium N.L.	112	....	112	115	....	115
Nickel—						
Western Mining Corporation	60	....	60	189	....	189
Petroleum—Crude Oil—						
West Australian Petroleum Pty. Ltd.	....	....	....	229	....	229
Pyrites—						
Norseman Gold Mines N.L.	71	31	102	75	36	111
	1,747	482	2,229	2,867	491	3,358
All other minerals	692	63	755	437	28	465
State Total (Other than Gold)	2,439	545	2,984	3,304	519	3,823

* 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.

By Authority: ALEX. B. DAVIES, Government Printer