Department of Mines
ANNUAL REPORT
1976

Department of Mines ANNUAL REPORT 1976

REPORT OF THE
DEPARTMENT *of* MINES
WESTERN AUSTRALIA
FOR THE YEAR 1976

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

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To the Honourable the Minister for Mines.

Sir,

I have the honour to submit the Annual Report of the Department of Mines of the State of Western Australia for the year 1976, *together with the reports from the officers controlling Sub-Departments, and Comparative Tables furnishing statistics relative to the Mining Industry.*

B. M. ROGERS,
Under Secretary for Mines.

Perth, 1977.

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Report of the Department of Mines for the Year 1976

DIVISION I

PART 1—GENERAL REMARKS

The Honourable the Minister for Mines

I have the honour to submit for your information a report on the Mining Industry for 1976.

The estimated value of the mineral output of Western Australia (including gold, coal and petroleum) for the year was $1 490.5 million, an increase of 20 percent over the previous year and an all-time record. Once again the increase was due mainly to higher prices for iron ore and nickel and increased production of alumina, ilmenite and rutile.

To the end of 1976 the progressive value of the mineral production of the State from 1886 amounted to $8 424 million. The importance of the iron ore industry can be seen from the following figures: the value of iron ore exports which commenced in 1966 is now $4 146 million, close to half the progressive total.

ROYALTIES

Royalty revenue during the year amounted to $46.6 million, an increase of $3.8 million over the figure for 1975. Iron ore royalties accounted for 87 percent of the total. Full details are contained in Table 2 of Part 2 of this report.

IRON ORE

The quantity of iron ore for local use and export rose only marginally from 85 million tonnes in 1975 to 85.6 million tonnes in 1976; but the value however, rose substantially by $90 million to $841 million due mainly to higher prices and a more favourable exchange rate.

ALUMINA

Alcoa of Australia (W.A.) Limited continued to increase production of alumina from bauxite mined at Jarrahdale and Del Park and fed to the company's refineries at Kwinana and Pinjarra respectively. Production increased from 2.2 million tonnes in 1975 to 3.1 million tonnes in 1976 the latter having an estimated value of $250 million.

NICKEL

The total value of nickel in concentrates, briquettes and powder amounted to an estimated $228.8 million compared with $183.8 million in 1975. This increase was largely due to higher prices and not to production which rose only marginally. Nickel concentrates and nickel ore produced during the year increased by 39 465 and 976 tonnes respectively above the figures for 1975.

The price per lb quoted by Inco, Ltd for four inch square electrolytic nickel cathodes F.O.B Fort Colbourne, Canada, (the price upon which nickel royalties are calculated) which had stood at US $2.20 from 29th August, 1975, rose to US $2.41 as from 1st October, 1976.

PETROLEUM

(Crude Oil and Natural Gas)

Sales of crude oil from Barrow Island during 1976 were 11.2 million barrels valued at $30.9 million compared with 12.8 million barrels at $28.7 million in 1975, a decline of 1.6 million barrels.

As from 18th September, 1976, the price of Barrow Island crude oil f.o.b. Kwinana was increased by the Commonwealth Government from $2.73/barrel to $2.88/barrel.

The Dongara and Mondarra gas fields supplied a total 832.6 million cubic metres of natural gas valued at $7.7 million to sales outlets at Perth-Fremantle-Kwinana-Pinjarra area.

It is now estimated that approximately 28% of the in-place reserves at Dongara and Mondarra have been produced.

Petroleum exploration drilling operations increased marginally in terms of rig months during 1976 from the low level of 1975: an overall rig activity increase of 18.5 percent occurred, namely from 16 rig months in 1975 to 18.8 rig months in 1976.

GOLD

The estimated value of gold received at the Perth Mint during 1976 was $25 570 928, a decrease of $3 316 252, but the quantity was 7 266.138 kg compared with 6 989.754 kg in 1975. This decrease in value was due to a serious falling off of the world price of gold.

The weighted average price obtained for Western Australian gold as recorded by the Department of Mines for 1976 computed to $A 109.46 per fine ounce (troy) as against $A 128.54 for 1975.

Details of gold production reported to the Department as distinct from that received at the Mint are set out in Table 1 of Part 2 of this report. The quantity of auriferous ore treated during the year was 951 028 tonnes compared with 1 270 000 tonnes in 1975, and the average number of persons engaged in gold mining fell from 1 808 in 1975 to 1 153 in 1976.

COAL

Coal production from the Collie Coal Field during the year showed an increase of 154 749 tonnes (7 per cent) over that for 1975 and was an all-time record for the field.

Figures for the last three years were:—

	1974	1975	1976
Tonnes	1 446 048	2 113 979	2 268 727
Total Value	$9 144 982	$15 073 668	$20 468 874
Average Value per Tonne	$6.324 1	$7.130 5	$9.022 2
Average Effective Workers	685	836	860
Proportion of Deep Mined Coal	33·95%	26·08%	24·34%

OTHER MINERALS

Other minerals to yield over a million dollars for the year were: Salt $23.3 million, Ilmenite $16.8 million, Rutile $15.96 million, Zircon $12.46 million, Leucoxene $1.3 million, Tin Concentrates $2.46 million, Tanto/Columbite $1.3 million, Copper (by-products of Nickel Mining) $1.3 million, Limestone $1.1 million; while Pig Iron valued at $4.9 million was produced by the Wundowie Iron and Steel Industry.

OUTLOOK

The year 1976 saw some improvement in world mineral and metal markets and some lessening of the inflation rate at home while devaluation of the Australian Dollar in November also assisted the mineral export trade. Despite industrial unrest which curtailed production during the year, some growth was maintained and it is hoped that this will increase in the ensuing year.

PART 2–COMPARATIVE STATISTICS

TABLE 1

SUMMARY

Mineral Production: Quantity, Value, Persons Engaged

	1975	1976	Variation
IRON ORE—			
Tonnes	85 253 013	**85 572 799**	+ 319 786
Value ($A)	$755 720 026	**$845 993 361**	+ $90 273 335
Persons Engaged	4 525	**4 813**	+ 288
ALUMINA—			
Tonnes	2 230 255	**3 120 057**	+ 889 802
*Value ($A)	$161 479 900	**$249 604 540**	+ $88 124 640
Persons Engaged	2 072	**2 367**	+ 295
NICKEL—			
Tonnes (Ore and Concentrates)	490 385	**464 826**	— 25 559
Value ($A)	$183 788 642	**$228 832 749**	+ $45 044 107
Persons Engaged	2 767	**2 489**	— 278
PETROLEUM—CRUDE OIL—			
Barrels	12 867 769	**11 197 157**	— 1 670 612
†Value ($A)	$28 695 124	**$30 915 627**	+ $2 220 503
Persons Engaged	110	**104**	— 6
GOLD—			
Reported to Department (Mine Production)—			
Ore Treated (Tonnes)	1 270 168	**951 028**	— 319 140
Gold (Kilograms)	7 105	**7 091**	— 14
Average Grade (grams per tonne)	5·6	**7·5**	+ 1·9
Persons Engaged	1 808	**1 153**	— 655
Mint and Export (Realised Production)—			
Gold (Kilograms)	6 990	**7 266**	+ 276
Estimated Value ($A) (including Overseas Gold Sales Premium)	$28 887 180	**$25 570 928**	— $3 316 252
COAL—			
Tonnes	2 113 979	**2 268 727**	+ 154 748
Value ($A)	$15 073 668	**$20 468 874**	+ $5 395 206
Persons Engaged	836	**860**	+ 24
MINERAL BEACH SANDS—			
Tonnes	806 517	**1 157 497**	+ 350 980
Value ($A)	$36 326 714	**$46 976 589**	+ $10 649 875
Persons Engaged	878	**944**	+ 66
OTHER MINERALS—			
Value ($A)	$30 668 593	**$42 241 108**	+ $11 572 515
Persons Engaged	690	**616**	— 74
TOTAL ALL MINERALS—			
Value ($A)	$1 240 639 847	**$1 490 603 776**	+ $249 963 929
Persons Engaged	13 686	**13 346**	— 340

* Value computed by Department of Mines based on the price for alumina f.o.b. Jamaica.
† Based on the price assessed from time to time by the Industries Assistance Commission for Barrow Island crude oil at Kwinana.

TABLE 1 (*a*)

Quantity and Value of Minerals other than Gold and Silver produced during 1975 *and* 1976
Western Australia

Mineral	1975		1976		Increase or Decrease for Year Compared with 1975	
	Quantity	Value	Quantity	Value	Quantity	Value
	Tonnes	$	Tonnes	$	Tonnes	$
Alumina (from Bauxite)	2 230 255	161 479 900	**3 120 057**	**249 604 540**	+ 889 802	+ 88 124 640
Antimony	....	....	**309**	**379 660**	+ 309	+ 379 660
Barytes	778	14 688	**12 099**	**1 330 890**	+ 11 321	+ 1 316 202
Building Stone (Quartzite)	509	5 320	**524**	**6 630**	+ 15	+ 1 310
(Quartz)	5 076	116 360	**4 091**	**81 482**	— 985	— 34 878
(Spongolite)	....	....	**57**	**828**	+ 57	+ 828
Clays (Bentonite)	938	11 613	**564**	**5 076**	— 374	— 6 537
(Cement Clay)	59 825	148 325	**46 265**	**115 002**	— 13 560	— 33 323
(Fire Clay)	204 094	92 161	**222 523**	**141 436**	+ 18 429	+ 49 275
(White Clay—Ball Clay)	575	6 792	**555**	**6 552**	— 20	— 240
(Brick, Pipe and Tile Clay)	22 410	22 056	....	....	— 22 410	— 22 056
(Kaolin)	1 779	10 751	**524**	**5 144**	— 1 255	— 5 607
Coal	2 113 979	15 073 668	**2 268 728**	**20 468 874**	+ 154 749	+ 5 395 206
Cobalt (by-product of Nickel Mining)	57	153 406	**195**	**594 014**	+ 138	+ 440 608
Copper (By-product of Nickel Mining)	678	515 721	**1 420**	**1 337 683**	+ 742	+ 821 962
Copper Ore and Concentrates	....	....	**6 200**	**910 000**	+ 6 200	+ 910 000
	Carats		Carats		Carats	
Emeralds (cut)	1 304	5 250	....	....	— 1 304	— 5 250
	Tonnes		Tonnes		Tonnes	
Felspar	701	17 621	**498**	**14 840**	— 203	— 2 781
Glass Sand	107 306	105 408	**109 543**	**75 661**	+ 2 237	— 29 747
Gypsum	109 229	322 184	**122 377**	**323 146**	+ 13 148	+ 962
Iron Ore (Pig Iron Recovered)	62 987	5 136 216	**56 521**	**4 931 874**	— 6 457	— 204 342
(Exported and locally used)	79 637 369	665 880 227	**79 942 758**	**746 070 201**	+ 305 389	+ 80 189 974
(Pellets)	5 552 666	84 703 583	**5 630 041**	**94 991 286**	+ 107 375	+ 10 287 703
Limestone	1 081 654	1 256 455	**705 031**	**1 078 919**	— 376 623	— 177 536
Magnesite	5 119	102 244	....	....	— 5 119	— 102 244
Manganese (Metallurgical Grade)	11 140	195 938	....	....	— 11 140	— 195 938
Mica	87	1 218	**1 850**	**7 400**	+ 1 763	+ 6 182
Mineral Beach Sands (Ilmenite)	666 721	14 960 955	**937 271**	**16 795 059**	+ 270 550	+ 1 834 104
(Monazite)	2 851	469 349	**2 286**	**394 578**	— 565	— 74 771
(Rutile)	36 298	5 476 700	**83 584**	**15 963 819**	+ 47 286	+ 10 487 119
(Leucoxene)	10 296	1 417 436	**9 066**	**1 332 859**	— 1 230	— 84 577
(Zircon)	90 351	14 002 274	**125 242**	**12 457 553**	+ 34 891	— 1 544 721
(Xenotime)	....	....	**48**	**32 721**	+ 48	+ 32 721
Nickel Concentrates	418 025	177 828 528	**457 490**	**222 787 660**	+ 39 465	+ 44 959 132
Nickel Ore	72 360	5 960 114	**73 336**	**6 045 089**	+ 976	+ 84 975
Ochre	....	....	**1 025**	**17 214**	+ 1 025	+ 17 214
	kg		kg		kg	
Palladium (By-product of Nickel Mining)	108	267 240	**247**	**301 930**	+ 139	+ 34 690
Platinum (By-product of Nickel Mining)	45	178 236	**98**	**394 553**	+ 53	+ 216 317
Ruthenium (By-product of Nickel Mining)	6	8 221	**14**	**23 046**	+ 8	+ 14 825
	bbls		bbls		bbls	
Petroleum—Crude Oil (barrels)	12 867 769	28 695 124	**11 197 157**	**30 915 627**	— 1 670 612	+ 2 220 503
	$m^3 10^3$		$m^3 10^3$		$m^3 10^3$	
Natural Gas ($m^3 10^3$)	832 171	5 337 272	**832 621**	**7 661 819**	+ 450	+ 2 324 547
	Tonnes		Tonnes		Tonnes	
Condensate	3 745	N.A.	**2 949**	N.A.	— 796	N.A.
Salt	3 629 328	17 138 054	**3 714 164**	**23 323 839**	+ 84 836	+ 6 185 785
	kg		kg		kg	
Semi-precious Stones	7 425	3 814	**5 099**	**3 382**	— 2 326	— 432
	Tonnes		Tonnes		Tonnes	
Talc	48 336	N.A.	65 270	N.A.	+ 16 934	N.A.
Tanto/Columbite Ores and Concentrates	150	850 214	**118**	**1 348 307**	— 32	+ 498 093
Tin Concentrates	967	3 607 289	**602**	**2 462 252**	— 365	— 1 145 037
Vermiculite	268	3 350	....	....	— 268	— 3 350
		1 211 581 275		**1 464 742 445**		+ 253 161 170

TABLE 1 (*b*)

Quantity and Value of Gold and Silver received at the Perth Mint during the years 1975 *and* 1976

Mineral	1975		1976		Increase or Decrease for Year Compared with 1975	
	Quantity	Value	Quantity	Value	Quantity	Value
	kg	$	kg	$	kg	$
Gold	*6 989·754	†28 887 180	*7 266·138	25 570 928	+ 276·384	— 3 316 252
Silver	*2 020·662	171 392	*2 110·045	**186 403**	+ 89·383	+ 15 011
Total		29 058 572		**25 757 331**		— 3 301 241
Grand Total		1 240 639 847		**1 490 499 776**		+ 249 859 929

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

TABLE 2

ROYALTIES

Mineral	Royalty Collected		Increase or Decrease Compared with 1975	
	1975	1976		
Alumina	596 484.81	**985 182.24**	+	388 697.43
Amethyst	2.49	**.42**	—	2.07
Barytes	38.63	**595.40**	+	556.77
Bentonite	51.19	**28.20**	—	22.99
Beryl	1.20	....	—	1.20
Building Stone	520.95	**136.16**	—	384.79
Chalcedony	1.42	**5.21**	+	3.79
Clay	15 380.63	**12 333.59**	—	3 047.04
Coal	53 670.19	**51 702.31**	—	1 967.88
Cobalt	1 309.26	**2 962.62**	+	1 653.36
Emeralds	16.50	**12.83**	—	3.67
Felspar	37.46	**26.39**	—	11.07
Glass Sand	6 306.49	**3 825.97**	—	2 480.52
Green Beryl	....	**1.05**	+	1.05
Gypsum	5 302.45	**5 137.57**	—	164.88
Ilmenite	79 315.97	**208 234.48**	+	128 918.51
Iron Ore	38 807 645.52	**40 713 012.43**	+	1 905 366.91
Lepidolite	2.50	....	—	2.50
Leucoxene	1 719.51	**6 183.09**	+	4 463.58
Limestone	39 708.98	**23 564.48**	—	16 144.50
Magnesite	755.76	....	—	755.76
Manganese	2 582.51	....	—	2 582.51
Mica	6.80	**69.13**	+	62.33
Monazite	2 193.55	**2 506.77**	+	313. 22
Moss Opal	21.05	**8.98**	—	12.07
Natural Gas	271 206.85	**467 245.88**	+	196 039.03
Natural Gas-Condensate	6 496.81	**5 522.33**	—	974.48
Nickel	1 513 336.95	**2 205 454.82**	+	692 117.87
Ochre	40.50	**10.16**	—	30.34
Oil (Crude)	1 216 838.90	**1 330 900.55**	+	114 061.65
Palladium	804.81	**644.57**	—	160.24
Platinum	569.20	**886.60**	+	317.40
Quartz (Semi-precious)	.07	**242.59**	+	242.52
Ruthenium	29.47	**59.45**	+	29.98
Rutile	5 520.20	**206 106.28**	+	200 586.08
Salt	187 852.89	**241 404.34**	+	53 551.45
Talc	5 057.57	**5 709.29**	+	651.72
Tanto-Columbite	4 000.98	**5 281.07**	+	1 280.09
Tin	206.04	**132.98**	—	73.06
Vermiculite	13.19	....	—	13.19
Xenotime	37.58	**156.92**	+	119.34
Zircon	6 592.95	**167 475.92**	+	160 882.97
Total	42 831 680.78	**46 652 763.07**	+	3 821 082.29

TABLE 3

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

Goldfield	Reported Yield		Percentage for each Goldfield		*Average Yield per tonne of ore treated	
	1975	**1976**	1975	**1976**	1975	**1976**
	kg	**kg**	Per cent.	**Per cent.**	grams	**grams**
Kimberley	....	....	....	....	....	....
West Kimberley	....	....	....	....	....	....
Pilbara	36·113	**163·942**	·53	**2·31**	8·1	**10·1**
West Pilbara	....	....	....	....	....	....
Ashburton	....	....	....	....	....	....
Gascoyne	4·465	....	·06	....	....	....
Peak Hill	·107	**4·315**	....	**·06**	3·5	**3·6**
East Murchison	1·599	**12·276**	·02	·17	29·1	**107·6**
Murchison	8·027	**54·627**	·12	**·77**	2·4	**13·0**
Yalgoo	16·668	**10·229**	·24	**·15**	27·1	**14·1**
Mount Margaret	36·806	**41·839**	·54	**·59**	4·8	**5·7**
North Coolgardie	12·714	**24·430**	·18	**·35**	6·6	**11·1**
Broad Arrow	44·709	**39·160**	·65	**·55**	4·1	**29·2**
North-East Coolgardie	·506	**2·081**	·01	**·03**	2·9	**7·0**
East Coolgardie	5 124·093	**3 493·554**	74·64	**49·32**	4·7	**4·6**
Coolgardie	85·034	**104·921**	1·24	**1·48**	6·1	**7·5**
Yilgarn	55·692	**87·613**	·81	**1·24**	12·2	**11·0**
Dundas	1 438.150	**3 044·941**	20·95	**42·98**	11·1	**22·1**
Phillips River	....	....	....	....	....	....
South West Mineral Field	....	....	....	....	....	....
State Generally	·287	....	·01	....	....	....
	6 864·970	**7 083·928**	100·00	**100·00**	5·4	**7·4**

* Averages exclude alluvial and dollied gold, but include gold won by treatment of sands.

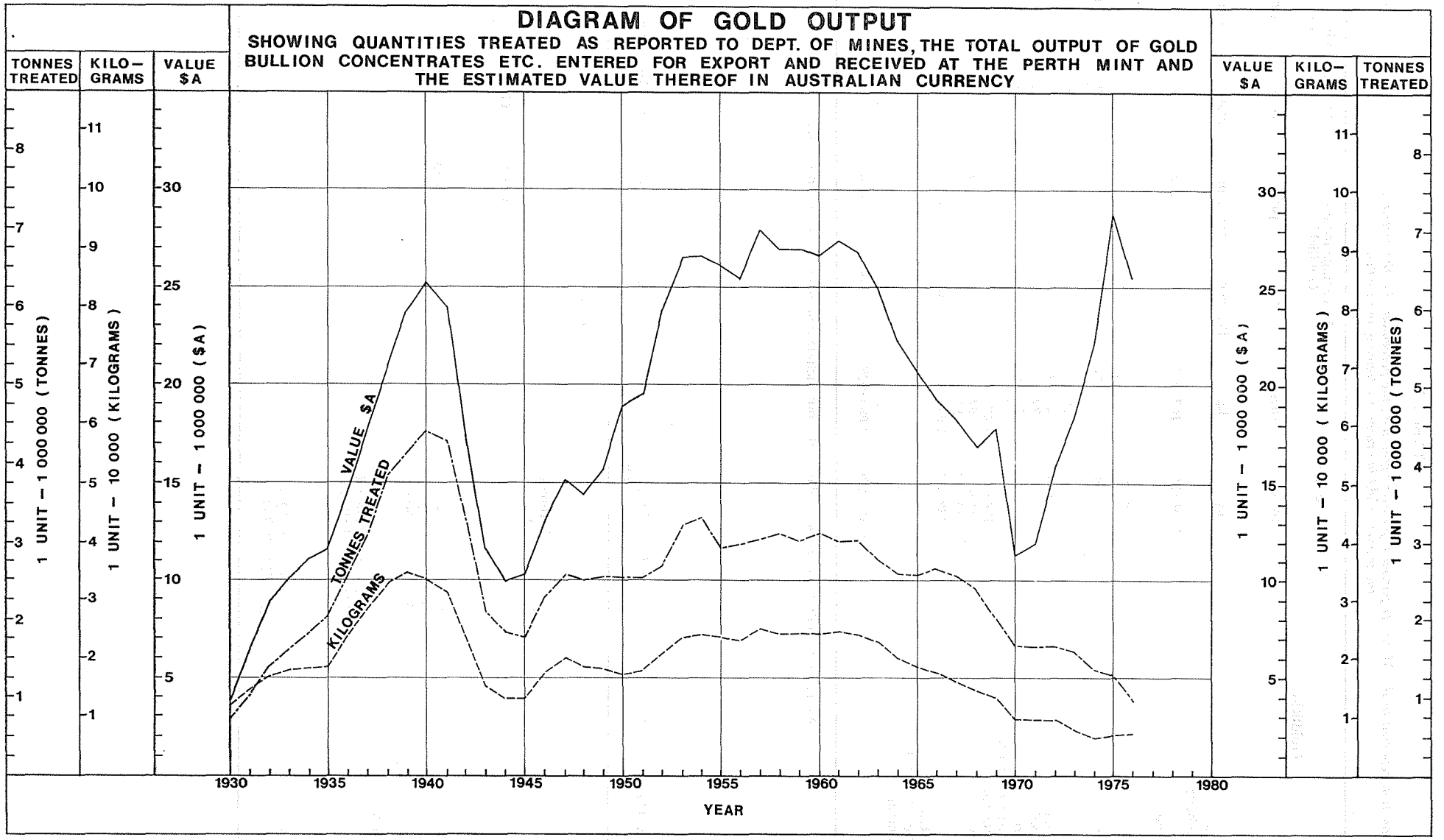
TABLE 4

Total Coal Output from Collie River Mineral Field, 1975 *and* 1976, *Estimated Value therefrom, Average Number of Men Employed and Output per man.*

Year	Total Output	Estimated Value	Men Employed			Output per Man Employed		
			Above Ground	Under Ground	Open Cuts	In Open Cuts	Under Ground	Above and Under Ground
Deep Mining—	Tonnes	$A	No.	No.	No.	Tonnes	Tonnes	Tonnes
1975	551 305	5 625 307	114	332	....	....	1 661	1 236
1976	552 292	6 960 615	120	328	....	....	1 684	1 290
Open Cut Mining—								
1975	1 562 673	9 448 360	....	....	390	4 007	....	....
1976	1 716 435	13 508 259	....	....	411	4 176	....	....
Totals—								In All Mines
1975	2 113 979	15 073 668	114	332	390	....	....	2 529
1976	2 268 727	20 468 874	120	328	411	....	....	2 641

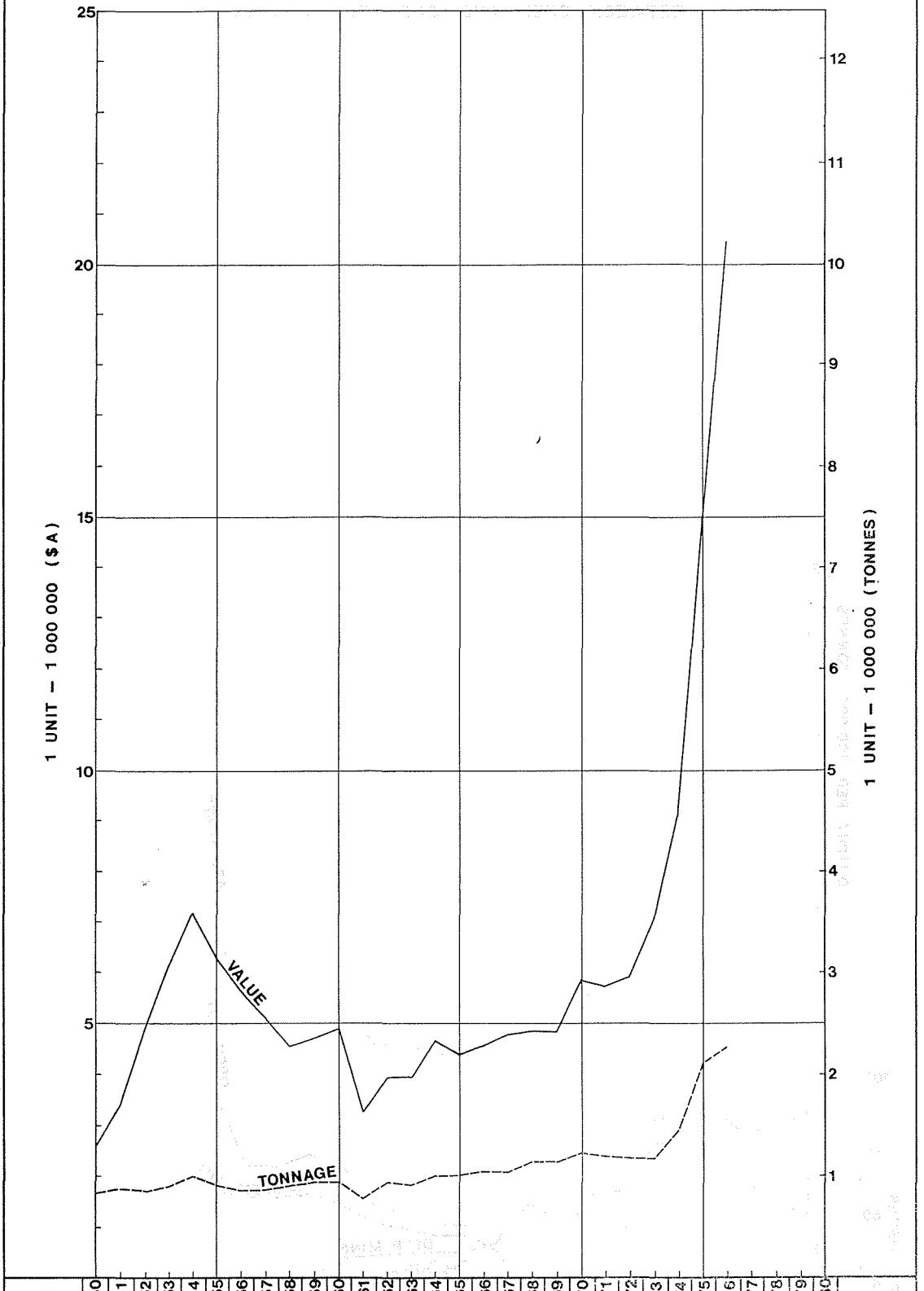
DIAGRAM OF GOLD OUTPUT

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



GRAPH OF COAL OUTPUT

SHOWING QUANTITIES AND VALUES AS REPORTED TO DEPT. OF MINES



YEAR	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	YEAR
VALUE $A	2,575,498	3,433,576	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	4,816,725	4,804,089	5,827,291	5,734,353	5,907,162	7,048,726	9,144,982	15,073,668	20,468,874					VALUE $A
TONNES	827,421	862,093	843,790	900,405	1,034,687	918,298	843,330	852,120	884,860	932,159	937,197	778,030	933,864	916,980	1,003,268	1,009,691	1,078,126	1,079,199	1,104,831	1,108,033	1,216,957	1,190,429	1,167,544	1,171,069	1,446,048	2,113,979	2,268,728					TONNES

GRAPH OF TREND IN COAL OUTPUT

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

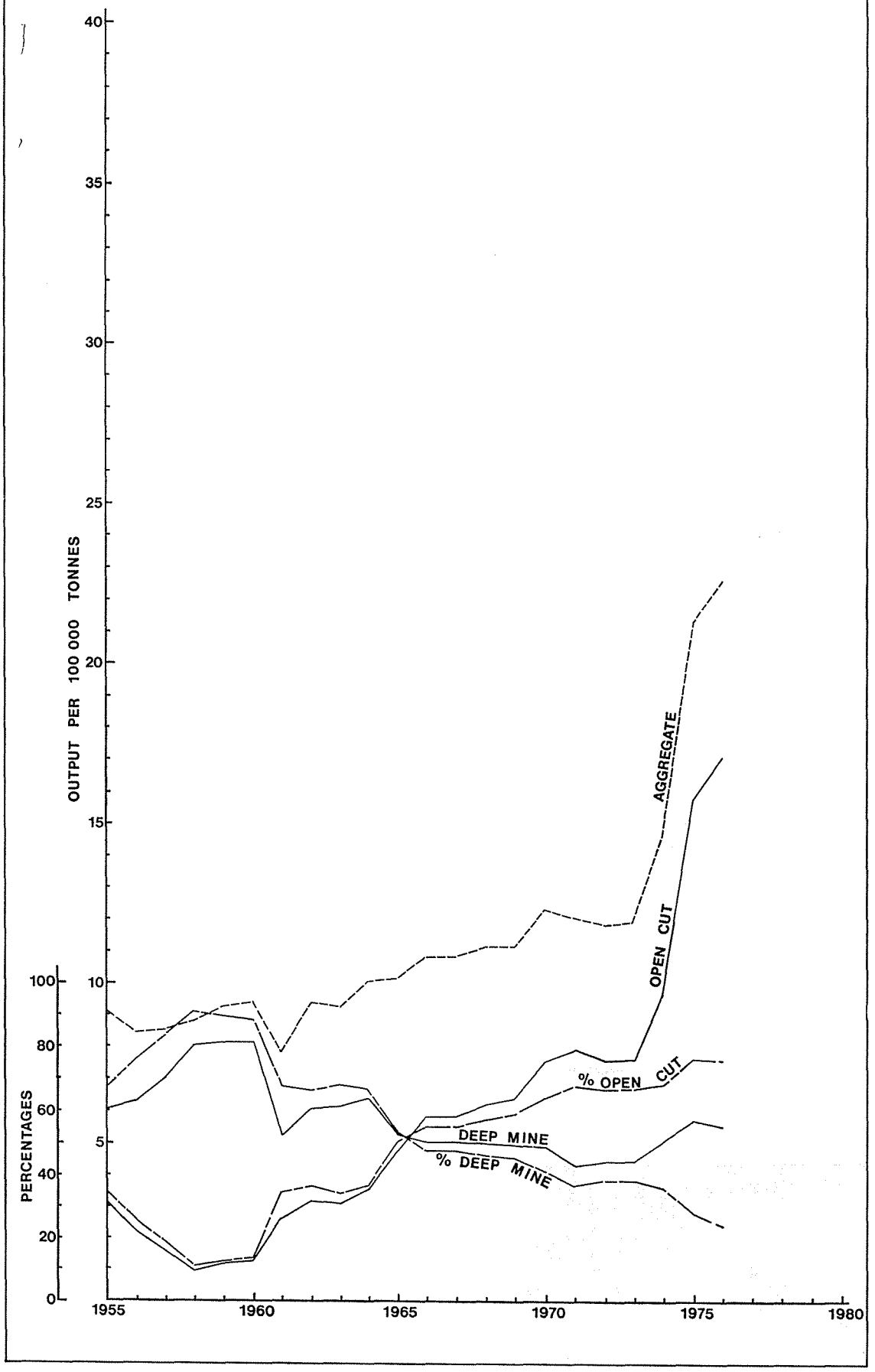


TABLE 5

MINING ACT, 1904

LEASES AND OTHER HOLDINGS UNDER VARIOUS ACTS RELATING TO MINING

Total Number and Area of Mining Tenements applied for during 1976 *and in force as at* 31*st December*, 1976 (*compared with* 1975)

	Applied for				In Force			
	1975		1976		1975		1976	
	No.	Hectares	No.	Hectares	No.	Hectares	No.	Hectares
Gold—								
Gold Mining Leases	336	2 710	**232**	**1 851**	2 403	19 276	**2 321**	**18 642**
Dredging Claims	26	2 982	....	....	6	561	**4**	**395**
Prospecting Areas	304	2 587	**251**	**2 082**	289	2 430	**216**	**1 763**
Temporary Reserves	5	603	**42**	**4 908**	6	679	**45**	**5 227**
Totals	671	8 882	**525**	**8 841**	2 704	22 946	**2 586**	**26 027**
Coal—								
Coal Mining Leases	98	7 421	**134**	**16 201**	128	14 864	**130**	**15 076**
Prospecting Areas	36	41 472	**4**	**4 788**	4	3 576	....	....
Temporary Reserves	8	131 670	....	....	12	156 391	**3**	**3 922**
Totals	142	180 563	**138**	**20 989**	144	174 831	**133**	**18 998**
Other Minerals—								
Mineral Leases	94	10 803	**44**	**4 266**	637	58 880	**815**	**80 450**
Dredging Claims	32	2 891	**5**	**171**	209	8 211	**217**	**8 663**
Mineral Claims	3 251	344 071	**6 483**	**726 492**	11 581	1 173 304	**11 163**	**1 137 588**
Prospecting Areas	18	154	**25**	**193**	14	116	**22**	**192**
Temporary Reserves	18	184 380	**146**	**2 380 959**	272	4 416 528	**439**	**6 845 282**
Totals	3 413	542 299	**6 703**	**3 122 081**	12 713	**5 657 039**	**12 656**	**8 072 175**
Other Holdings—								
Miners' Homestead Leases	....	....	....	....	322	13 428	**306**	**12 575**
Miscellaneous Leases	5	96	**1**	**2**	110	776	**104**	**836**
Residence Areas	....	....	....	....	48	17	**49**	**18**
Business Areas	....	....	**1**	**1**	16	6	**15**	**6**
Machinery Areas	1	2	**2**	**1**	24	34	**28**	**47**
Tailings Areas	....	....	....	....	27	42	**25**	**40**
Garden Areas	12	23	**6**	**7**	84	140	**86**	**138**
Quarrying Areas	23	185	**30**	**273**	158	1 312	**178**	**1 504**
Water Rights	7	5 504	**5**	**30**	104	848	**106**	**314**
Licenses to Treat Tailings	71	....	**87**	....	132	....	**69**	....
Totals	119	5 810	**132**	**314**	1 025	16 603	**966**	**15 478**
Grand Totals	4 345	737 554	**7 498**	**3 142 225**	16 586	5 871 419	**16 341**	**8 132 678**

TABLE 5 (*a*)

SPECIAL ACTS

Leases applied for during 1976 *and in force as at* 31*st December*, 1976 (*Compared with* 1975)

	Applied for				In Force			
	1975		1976		1975		1976	
	No.	Hectares	No.	Hectares	No.	Hectares	No.	Hectares
Bauxite	....	....	....	....	7	1 269 618.00	**7**	**1 269 618.00**
Iron	....	....	**1**	**31 880.00**	8	255 457.85	**9**	**293 567.93**
Salt	....	....	....	....	4	242 755.16	**5**	**257 465.16**
Totals	....	....	**1**	**31 880.00**	19	1 767 831.01	**21**	**1 820 651.09**

TABLE 5 (*b*)

PETROLEUM ACTS

Permits, Licenses and Leases applied for during 1976 *and in force as at* 31*st December*, 1976 (*Compared with* 1975)

Holding	Applied for				In Force			
	1975		**1976**		1975		**1976**	
	No.	Blocks	No.	Blocks	No.	Blocks	No.	Blocks
Onshore—								
Petroleum Act, 1967—								
Exploration Permits	1	3	**11**	**96**	28	1 755	**31**	**1 219**
Production Licenses	....	....	....	....	2	9	**2**	**9**
Petroleum Leases (Barrow Island)	....	....	....	....	1	8	**1**	**8**
Totals	1	3	**11**	**96**	31	1 772	**34**	**1 236**
Offshore—								
Petroleum (Submerged Lands) Act 1967—								
Exploration Permits	2	385	**18**	**4 014**	19	2 231	**21**	**2 643**
Production Licenses	1	5	....	....	....	....	....	....
Petroleum Leases (Barrow Marine)	....	....	....	....	1	12	**1**	**12**
Totals	3	390	**18**	**4 014**	20	2 243	**22**	**2 655**
Grand Totals	4	393	**29**	**4 110**	51	4 015	**56**	**3 891**

(A block contains between approximately 75 km² to 85 km² and the numbers given above include part blocks)

Holding	Applied for				In Force			
	1975		**1976**		1975		**1976**	
	No.	Km	No.	Km	No.	Km	No.	Km
Onshore—								
Petroleum Pipelines Act, 1969—								
Pipeline Licenses	....	....	....	....	5	444·9	**5**	**444·9**
Totals	....	....	....	....	5	444·9	**5**	**444·9**

TABLE 5 (*c*)

MINING ACT, 1904

Leases in Force as at 31st December, 1976 in each Goldfield, Mineral Field or District

Goldfield, Mineral Field, or District	Gold Mining Leases		Mineral Leases		Miner's Homestead Leases		Miscellaneous Leases	
	No.	Hectares	No.	Hectares	No.	Hectares	No.	Hectares
Ashburton	5	48·50	9	980·91	....	....	2	41·87
Black Range	11	81·71	10	1 082·39	....	....	....	....
Broad Arrow	37	249·68	10	1 187·43	....	....	....	....
Bulong	34	281·77	1	9·68	....	....	....	....
Collie	....	....	58	6 759·85	....	....	....	....
(Private Property)	....	....	2	210·00	....	....	....	....
Coolgardie	144	1 090·03	373	41 800·07	21	744·17	3	11·72
Cue	32	281·17	1	41·18	4	450·33	....	....
Day Dawn	44	373·92	....	....	1	8·09	....	....
Dundas	487	4 358·61	....	....	17	365·33	....	....
East Coolgardie	378	2 748·11	4	363·51	60	1 314·30	62	518·76
Gascoyne	7	57·44	1	3·23	....	....	....	....
Greenbushes	....	....	74	3 967·55	6	168·14	....	....
Kanowna	52	437·84	5	221·34	12	284·03	....	....
Kimberley	1	9·00	1	121·40	....	....	....	....
Kunanalling	23	185·38	....	....	2	210·43	....	....
Kurnalpi	12	115·97	....	....	....	....	....	....
Lawlers	36	265·43	8	966·97	....	....	....	....
Marble Bar	235	1 884·95	138	16 194·38	....	....	11	79·67
Meekatharra	108	884·64	....	....	11	754·98	1	0·40
Menzies	61	513·68	1	28·73	7	299·43	....	....
Mount Magnet	107	772·08	....	....	1	4·00	....	....
Mount Malcolm	55	430·91	....	....	....	....	....	....
Mount Margaret	47	440·65	59	6 011·46	7	23·43	....	....
Mount Morgans	52	463·34	1	12·14	....	....	....	....
Niagara	7	42·71	....	....	....	....	....	....
Northampton	....	....	4	28·36	....	....	....	....
(Private Property)	....	....	1	9·70	....	....	....	....
Nullagine	22	155·72	....	....	2	8·89	2	19·42
Peak Hill	24	180·17	7	347·14	4	99·94	....	....
Phillips River	4	21·36	12	107·09	106	5 882·90	....	....
(Private Property)	....	....	14	1 691·19	....	....	....	....
South West	....	....	31	2 945·65	....	....	....	....
(Private Property)	....	....	16	1 340·00	....	....	....	....
Ularring	24	192·03	....	....	....	....	....	....
West Kimberley	....	....	63	5 484·20	....	....	6	52·43
West Pilbara	13	119·53	9	149·75	3	14·15	10	91·00
Wiluna	4	34·00	23	2 659·50	17	1 572·50	2	1·21
Yalgoo	36	240·83	3	185·74	....	....	....	....
Yerilla	48	370·30	....	....	1	4·04	....	....
Yilgarn	154	1 162·10	6	615·01	24	366·51	5	19·86
(Private Property)	17	148·06	....	....	....	....	....	....
Outside Proclaimed	....	....	....	....	....	....	....	....
Totals	2 321	18 641·62	945	95 525·55	306	12 575·09	104	836·34

	No.	Hectares
Gold Mining Leases on Crown Land	2 304	18 493·56
Gold Mining Leases on Private Property	17	148·06
Mineral Leases on Crown Land	912	92 274·66
Mineral Leases on Private Property	33	3 250·89
Miner's Homestead Leases on Crown Land	306	12 575·09
Other Leases on Crown Land	104	836·34
Other Leases on Private Property	....	....

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TABLE 5 (*d*)

MINING ACT, 1904

Claims and Authorised Holdings in Force at 31st December, 1976 in each Goldfield, Mineral Field or District

Goldfield, Mineral Field or District	Prospecting Areas		Dredging Claims		Mineral Claims		Residence Areas		Business Areas		Machinery Areas		Tailings Areas		Garden Areas		Quarrying Areas		Water Rights	
	No.	Hectares	No.	Hectares	No.	Hectares	No.	Hectares	No.	Hectares	No.	Hectares	No.	Hectares	No.	Hectares	No.	Hectares	No.	Hectares
Ashburton	....	....	....	....	227	23 078·33	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Black Range	1	9·20	....	....	257	26 599·48	3	1·20	....	....	....	....	....	....	....	....	....	....	....	....
Broad Arrow	25	181·36	....	....	79	8 599·39	1	0·40	....	....	....	....	....	....	....	....	....	....	4	3·62
Bulong	4	29·12	....	....	91	10 674·98	....	....	....	....	....	....	....	....	....	....	....	....	1	5·66
Collie	....	....	....	....	....	....	....	....	....	....	1	2·00	....	....	....	....	1	4·00	....	....
(Private Property)	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Coolgardie	45	385·55	....	....	365	35 893·36	4	1·60	....	....	1	0·40	....	....	8	12·52	29	251·17	5	18·60
Cue	8	71·75	....	....	341	37 209·89	....	....	....	....	1	2·02	....	....	....	....	1	9·71	....	....
Day Dawn	2	19·42	....	....	44	4 629·98	....	....	....	....	....	....	....	....	4	8·08	....	....	....	....
Dundas	8	68·38	....	....	240	19 440·97	....	....	....	....	....	....	1	2·02	....	....	3	24·27	2	4·85
East Coolgardie	15	116·12	....	....	113	11 968·07	30	12·00	....	....	2	2·82	10	18·57	12	21·80	10	75·23	12	12·57
Gascoyne	....	....	2	165·91	206	18 700·21	....	....	....	....	....	....	....	....	....	....	3	27·40	....	....
Greenbushes	....	....	....	....	1	8·00	1	1·00	....	....	....	....	....	....	9	21·00	....	....	2	15·00
Kanowna	4	38·84	....	....	114	12 784·36	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Kimberley	....	....	....	....	979	111 680·24	....	....	....	....	....	....	....	....	4	5·40	12	101·00	....	....
Kunanalling	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	3	14·56
Kurnalpi	9	87·39	....	....	78	8 713·43	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Lawlers	....	....	....	....	826	89 404·98	....	....	....	....	....	....	....	....	....	....	3	29·10	....	....
Marble Bar	6	51·69	196	7 363·41	891	84 073 ·70	....	....	2	0·80	8	19·91	1	2·02	19	31·59	36	310·31	24	159·59
Meekatharra	8	75·65	4	394·90	308	35 222·39	....	....	....	....	....	....	....	....	....	....	....	....	3	3·01
Menzies	6	38·82	....	....	225	23 940·93	....	....	....	....	....	....	....	....	1	0·40	....	....	4	4·02
Mount Magnet	18	160·13	....	....	96	11 320·23	....	....	....	....	....	....	....	....	5	1·61	....	....	3	2·00
Mount Malcolm	9	87·31	....	....	407	44 892·56	....	....	....	....	....	....	....	....	9	14·12	1	2·02	3	1·20
Mount Margaret	3	14·51	....	....	230	26 056·02	....	....	....	....	2	3·97	5	9·90	2	2·82	7	67·53	1	0·40
Mount Morgans	6	45·71	....	....	141	15 545·33	....	....	....	....	....	....	....	....	....	....	....	....	1	0·40
Niagara	2	14·56	....	....	19	1 961·67	....	....	....	....	1	1·00	....	....	....	....	2	11·73	3	2·40
Northampton	....	....	....	....	52	2 624·98	....	....	....	....	....	....	....	....	....	....	....	....	....	....
(Private Property)	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Nullagine	4	27·60	8	419·81	284	15 353·52	....	....	....	....	1	0·40	3	1·60	2	1·61	....	....	11	11·27
Peak Hill	4	32·38	....	....	127	10 233·90	....	....	1	0·40	4	7·02	1	2·02	3	5·99	7	67·90	2	8·53
Phillips River	1	0·75	....	....	240	22 319·31	....	....	....	....	1	0·80	1	0·80	....	....	1	2·02	....	....
(Private Property)	....	....	....	....	108	11 600·93	....	....	....	....	....	....	....	....	....	....	....	....	....	....
South West	3	29·13	9	698·47	547	43 740·92	....	....	....	....	....	....	....	....	....	....	1	8·09	1	2·83
(Private Property)	....	....	....	....	691	56 861·31	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Ularring	6	58·26	....	....	47	4 897·20	....	....	....	....	1	0·40	2	1·61	....	....	....	....	3	1·60
West Kimberley	1	9·60	1	121·40	409	46 280·79	....	....	....	....	2	4·04	....	....	....	....	18	129·59	2	19·42
West Pilbara	3	19·33	2	15·37	526	46 486·14	4	1·60	6	2·40	....	....	....	....	4	7·67	43	389·19	9	16·94
Wiluna	....	....	....	....	613	70 673·77	....	....	....	....	1	0·40	1	1·21	....	....	....	....	1	0·40
Yalgoo	12	116·52	....	....	781	97 355·59	....	....	6	2·40	....	....	....	....	....	....	2	11·70	....	....
Yerilla	....	....	....	....	9	990·49	....	....	....	....	....	....	....	....	....	....	....	....	5	4·82
Yilgarn	18	112·35	....	....	444	45 148·54	6	0·65	....	....	2	2·00	....	....	4	2·99	1	9·71	1	2 816 m²
(Private Property)	....	....	....	....	6	554·44	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Outside Proclaimed	....	....	....	....	2	67·98	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Totals	231	1 901·43	222	9 179·27	11 163	1 137 588·31	49	18·45	15	6·00	28	47·18	24	39·75	86	137·60	181	1 531·67	106	313·69

TABLE 6

MEN EMPLOYED

Average number of Men employed in Mining during 1975 *and* 1976

Goldfield	District	Gold		Other Minerals		Total	
		1975	**1976**	1975	**1976**	1975	**1976**
Kimberley	....	....	....	....	....	....	....
West Kimberley	....	....	....	373	**379**	373	**379**
Pilbara	Marble Bar	35	**19**	908	**934**	943	**953**
	Nullagine	....	**95**	....	....	....	**95**
West Pilbara	....	3	....	2 300	**2 397**	2 303	**2 397**
Ashburton	....	....	....	112	**104**	112	**104**
Gascoyne	....	3	....	233	**180**	236	**180**
Peak Hill	....	5	**18**	1 036	**1 204**	1 041	**1 222**
East Murchison	Lawlers	....	....	....	....	....	....
	Wiluna	....	**1**	....	....	....	**1**
	Black Range	2	**2**	....	....	2	**2**
Murchison	Cue	1	**7**	3	**2**	4	**9**
	Meekatharra	10	**26**	....	....	10	**26**
	Day Dawn	2	**5**	....	....	2	**5**
	Mt. Magnet	4	**16**	....	....	4	**16**
Yalgoo	....	10	**10**	4	**4**	14	**14**
Mt. Margaret	Mt. Morgans	4	**2**	....	....	4	**2**
	Mt. Malcolm	27	**28**	....	....	27	**28**
	Mt. Margaret	11	**5**	406	**403**	417	**408**
North Coolgardie	Menzies	15	**12**	70	....	85	**12**
	Ularring	24	**7**	....	....	24	**7**
	Niagara	8	**3**	....	....	8	**3**
	Yerilla	5	**4**	....	....	5	**4**
Broad Arrow	....	27	**16**	405	**82**	432	**98**
North-East Coolgardie	Kanowna	2	**2**	....	....	2	**2**
	Kurnalpi	2	**2**	....	....	2	**2**
East Coolgardie	East Coolgardie	1 211	**495**	....	....	1 211	**495**
	Bulong	9	**5**	....	....	9	**5**
Coolgardie	Coolgardie	70	**38**	1 905	**2 020**	1 975	**2 058**
	Kunanalling	15	**19**	....	....	15	**19**
Yilgarn	....	63	**105**	149	**149**	212	**254**
Dundas	....	240	**211**	2	**2**	242	**213**
Phillips River	....	....	....	....	....	....	....
South-West Mineral Field	....	....	....	3 048	**3 393**	3 048	**3 393**
Northampton Mineral Field	....	....	....	....	....	....	....
Greenbushes Mineral Field	....	....	....	88	**80**	88	80
Outside Proclaimed Goldfield	....	....	....	....	....	....	....
Collie Goldfield	....	....	....	836	**860**	836	**860**
Total—All Minerals	....	1 808	**1 153**	11 878	**12 193**	13 686	**13 346**

	1975	**1976**
Minerals Other than Gold—		
Alumina (from Bauxite)	2 072	**2 367**
Barytes	4	**10**
Building Stone	5	**6**
Clays	20	**19**
Coal	836	**860**
Copper Ore and Conc.	....	**11**
Emeralds	3	....
Felspar	8	**6**
Glass Sand	14	**11**
Gypsum	9	**8**
Iron Ore	4 525	**4 813**
Limestone	37	**22**
Mica	2	**2**
Mineral Beach Sands	878	**944**
Nickel	2 767	**2 489**
Petroleum (Crude Oil)	110	**104**
(Natural Gas)	7	**7**
Salt	425	**393**
Semi Precious Stones	6	**6**
Talc	15	**20**
Tanto Columbite	2	**2**
Tin	131	**93**
Vermiculite	2	....
Total—Other Minerals	11 878	**12 193**

PART 3—STATE BATTERIES

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

From inception to the end of 1976, gold, silver, tin, tungsten, lead, copper and tantalite ores to the value of $46 282 643 have been treated at the State Batteries. $44 099 129 came from 3 950 555 tonnes of gold ore, $487 852 from 85 368 tonnes of tin ore, $44 185 from 4 365.8 tonnes of tungsten ore, $1 560 634 from 71 198.2 tonnes of lead ore, $11 932 from 224.0 tonnes of copper ore, $73 459 from 2 192.8 tonnes of tantalite ore, and silver value at $5 452 recovered as a by-product from the cyaniding of gold tailings.

During the year 40 748.3 tonnes of gold ores were crushed for 255.972 kilograms bullion, estimated to contain 216.934 kilograms fine gold equal to 5.32 grams per tonne. The average value of sands after amalgamation was 2.20 grams per tonne, making the average head value 7.52 grams per tonne. Cyanide plants produced 48.900 kilograms of fine gold, giving a total estimated production for the year of 257.834 kilograms of fine gold valued at $871 165.

The working expenditure for the year for all plants was $1 458 127 and the revenue was $203 667 giving a working loss of $1 254 460 which does not include depreciation, interest or Superannuation. Since the inception of State Batteries, the Capital expenditure has been $2 040 023 made up of $1 506 140 from General Loan Funds: $449 067 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 $241 647 compared with $192 835 for 1975.

The actual expenditure from inception to the end of 1976 exceeds revenue by $11 527 910.

PART 4—GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

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

In an effort to provide a better water supply for Rottnest Island a detailed sedimentological study was made and test bores recommended. A suitable water supply was located and is being developed by the Department of Public Works.

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

In August the International Geological Congress was held in Australia for the first time and the Survey made a major contribution by arranging and providing leaders for three Congress Excursions and Co-leaders for a further two Congress Excursions. Four staff members of the Survey presented papers at the Congress.

A series of four lectures on the geology of the Pinjarra 1:250 000 geological map was given, followed by a two-day excursion to inspect the field occurrences. It proved popular with 70 attending the lectures and 58 participating in the field trip.

PART 5—GOVERNMENT CHEMICAL LABORATORIES

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

(1) Agricultural Chemistry
(2) Food and Industrial Hygiene
(3) Industrial Chemistry
(4) Mineral
(5) Toxicology and Drug
(6) Water
(7) Engineering Chemistry (Bentley)
(8) Metallurgical Laboratory (Kalgoorlie)

Early in 1976 the Food, Drug, Toxicology and Industrial Hygiene Division was split into two Divisions, namely the Food and Industrial Hygiene Division and the Toxicology Division. This separation has made for greater specialisation and efficiency within both the new Divisions.

Work in the Laboratories continues to increase generally and in particular samples received for analysis totalled 30 692—ten per cent more than the figure for 1975.

PART 6—EXPLOSIVES BRANCH

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

The issue of Shotfirer's Permits and the training of shotfirers continued at a high level of priority and out of 240 applicants 213 qualified as shotfirers to use explosives throughout the State.

Despite an increase of explosives licences from 477 in 1975 to 650 in 1976, consumption of explosives in Western Australia fell from 80 800 tonnes in 1975 to 62 120 tonnes in 1976.

Licences for storage of flammable liquids increased slightly to 4 900 for 1976 as compared with 4 802 in the previous year.

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

Under arrangement with this Department, the State Public Health Department continued the periodic X-ray examination of mine workers throughout the year and some 30 mine sites were visited.

A total of 11 954 examinations were made of which 5 788 were under the Mine Workers' Relief Act and 6 166 under the Mines Regulation Act. Of the latter 5 715 were re-examinees. In addition, Provisional Certificates were issued to 464 persons in isolated country areas.

Compensation under the Miner's Phthisis Act paid during the year was $4 964 compared with $5 273 in the previous year. The number of beneficiaries under the Act as on 31/12/76 was 23, being 2 ex-miners and 21 widows.

PART 8—SURVEYS AND MAPPING BRANCH

Cadastral surveys carried out numbered 1 489, a decline of 730 as against the figure for 1975; and 4 915 applications for various kinds of mining tenements and 266 applications for Temporary Reserves were received for processing during 1976.

In the Photographic Section the output increased by 37 per cent. On the large camera, 1 755 items were put through, 64 metal plates made, 2 528 items processed using the vacuum frames, and general process work on the enlarger accounted for 7 404 items of which 1 827 were colour.

A great deal of microfilming was carried out and a programme of mining tenement registers was completed with 70 rolls of 35 mm film. Interest in the petroleum relinquishment package data continued and 614 duplicate rolls of 35 mm film were sold from over 52 original rolls.

PART 9—STAFF

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

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

B. M. ROGERS,
Under Secretary for Mines.

Department of Mines,
Perth.

DIVISION II

Report of the State Mining Engineer for the Year 1976

Under Secretary for Mines:

I hereby submit the 1976 Annual Report for the State Mining Engineers Branch which is divided into the following sections:

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

Port Hedland Inspectorate—by G. J. Dodge, Mining Engineer—Senior Inspector of Mines.

Kalgoorlie Inspectorate—by I. W. Loxton, Mining Engineer—Senior Inspector of Mines.

Perth Inspectorate—by G. J. Dodge, Mining Engineer—Senior Inspector of Mines.

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

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

Board of Examiners for Mine Managers and Underground Supervisors Certificates—by W. J. Cahill, Secretary.

Board of Examiners for Quarry Managers Certificates—by J. A. Suda, Secretary.

Ventilation Board—by J. A. Suda, Secretary.

MINERAL, METAL AND COAL PRODUCTION

In Western Australia's mineral, metal and coal production for the 1976 calendar year, the value of iron ore production was again the highest at $841 061 487 followed by alumina at $249 604 540, then nickel ore and concentrates at $228 832 749, gold at $23 644 412, salt at $23 323 839 and coal at $20 468 874. Further information on mineral, metal and coal production and producers is given in separate reports by the various Senior Inspectors of Mines.

On 5th April, 1976 the Mines Regulation Act, 1946-1974 and Regulations came into force. The Act had been amended and the Regulations had been completely re-written in an attempt to meet more adequately the requirements of present day mining practices.

ACCIDENTS

There were 11 fatal and 685 serious mining accidents reported for the year compared with 18 fatal and 826 serious accidents for the previous year.

DRILLING OPERATIONS

As part of the State-wide groundwater investigation the Drilling Section was responsible for the drilling of 5 558 metres in 106 bores, the development of 40 aquifiers in 30 bores and the testing of 20 aquifiers in 10 bores. The total metreage drilled was well below that for 1975 (13 367 metres in 685 bores) and was partly due to the fact that no seismic shot holes were drilled and partly because drilling was suspended to carry out a programme of developing and pump testing existing bores.

Exploratory drilling for water was carried out at sites in the Moora, Eneabba, Bunbury/Yoganup, Joondalup, Fortescue Valley and Canning Basin. In addition drilling for groundwater sampling was carried out in the Manjimup woodchip area and a bore was drilled for the Public Works Department in the Australind area to provide information on the effect of the La Porte Titanium plant effluent on groundwater in that area.

STAFF

Appointments—

Shenton, E. F., Mining Engineer—Special Inspector of Mines (Ventilation)	14/6/76
Diamantes, P. J., Mining Engineer—District Inspector of Mines	12/10/76
Edlington, W. B., Mining Engineer—District Inspector of Mines	13/10/76

Promotions—

Dodge, G. J., Mining Engineer—Senior Inspector of Mines	25/2/76

Transfers—

Ibbotson, A. W., Mining Engineer—District Inspector of Mines to Mining Engineer—District Inspector of Mines (Rehabilitation)	19/7/76
van der Hoek, B. J. D., Mining Engineer—District Inspector of Mines, Kalgoorlie to Perth	6/9/76
Griffin, R. J., Mining Engineer—District Inspector of Mines, Port Hedland to Perth	1/12/76

A. Y. WILSON,
State Mining Engineer.

27th May, 1977.

MINERAL AND METAL PRODUCTION ACCIDENT STATISTICS AND MINE INSPECTION

J. M. Faichney—Mining Engineer/ Principal Senior Inspector of Mines

MINERAL AND METAL PRODUCTION

Production is shown in the following tables:

Table 1 — Mineral and Metal Output

Table 2 — Mine Development

Table 3 — Principal Gold Producers

Table 4 — Overseas Iron Ore Exports

Table 5 — Nickel Producers

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

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

TABLE 1

Mineral and Metal Output (excluding Petroleum)

Mineral Production	1975		1976	
	Production	Value	Production	Value
	Tonne (t)	$A	Tonne (t)	$A
Alumina	2 230 255	161 479 900	3 120 057	249 604 540
Antimony	....	....	309·40	379 660
Barytes	778	14 688	12 099	1 330 890
Bentonite	938	11 613	564	5 076
Building stone	5 585	121 680	4 672	88 940
Clays	288 683	280 085	269 867	268 134
Coal	2 113 979	15 073 668	2 268 728	20 468 874
Cobalt	57·28	153 406	194·80	594 014
Copper—Metal	678	515 721	1 419·97	1 337 683
—Ore and Concentrates	....	....	6 200	910 000
Emeralds—Carats (cut)	1 304	5 250	....	....
Felspar	701	17 621	498	14 840
Glass Sand	107 306	160 562	109 543	Not available
Gold (kg)	7 104·98	28 330 022	7 091·42	23 644 412
Gypsum	109 229	322 184	122 377	323 146
Ilmenite	619 964	14 960 955	914 280	16 795 059
Ilmenite (upgraded)	46 757	Not available	22 991	Not available
Iron Ore	85 190 035	750 583 810	85 572 799	841 061 487
Iron Ore—Pig Iron	99 225	5 136 216	91 924	4 931 874
Leucoxene	10 296	1 417 436	9 065·50	1 332 859
Limestone	1 081 654	1 256 455	705 031	1 078 919
Magnesite	5 119	102 244	....	....
Manganese	11 140	195 938	....	....
Mica	87	1 218	1 850	7 400
Monazite	2 851	469 349	2 286	394 578
Nickel Ore and Concentrates	490 385	183 788 642	530 826	228 832 749
Ochre	....	....	1 025	17 214
Palladium (kg)	108·17	267 240	247·28	301 930
Platinum (kg)	44·99	178 236	98·21	394 553
Ruthenium (kg)	5·63	8 221	14·36	23 046
Rutile	36 298	5 476 700	83 584·40	15 963 819
Salt	3 629 328	17 138 054	3 714 164	23 323 839
Semi-precious Stones	7·42	3 814	5·10	3 382
Silver (kg)	2 020·66	171 392	2 110·05	186 403
Talc	48 336	Not available	65 270	Not available
Tanto-Columbite	150·10	850 214	118·38	1 348 307
Tin Concentrate	967·25	3 607 289	602·02	2 462 252
Vermiculite	268	3 350	....	....
Xenotime	....	....	48	32 721
Zircon	90 351	14 002 274	125 242·46	12 457 553
Totals	....	1 206 105 447	....	1 449 920 153

NOTE: The value of the mineral and metal output is not complete as the value of some minerals or metals are not available for publication.

TABLE 2

Reported Mine Development

Mining District	Mine	Shaft Sinking (Metres)	Decline and Incline (Metres)	Driving and Cross Cutting (Metres)	Rising and Winzing (Metres)	Exploratory Drilling (Metres)	Total (Metres)
Gold—							
East Coolgardie	North Kalgurli Mines Ltd.	....	....	....	....	255	255
	Kalgoorlie Mining Associates	20	175	2 172	430	4 708	7 505
Coolgardie	Two Boys Gold Mine	....	....	10	....	....	10
Dundas	Central Norseman Gold Corporation N.L.	....	....	1 467	433	11 367	13 267
Yilgarn	Marvel Loch Gold Mine	367	194	....	....	264	825
	W.A. Gold Development	....	....	100	24	....	124
North Coolgardie	Espacia Gold Mine	....	....	100	10	....	110
Pilbara	Mulga Mines Ltd.	....	600	228	56	79	963
	Totals in Gold Mines	387	969	4 077	953	16 673	23 059
Nickel—							
Coolgardie	Western Mining Corporation Ltd. (Kambalda Nickel Operations)	675	5 442	13 139	3 419	26 669	49 344
	Anaconda (Aust.) Inc.	....	....	1 117	475	5 280	6 872
	Metals Exploration N.L.	51	....	954	447	1 396	2 848
	Selcast Exploration Ltd.	....	....	842	293	1 196	2 331
Broad Arrow	Western Mining Corporation Ltd. (Great Boulder Operations)	....	....	515	409	212	1 136
Mount Margaret	Western Mining Corporation Ltd. (Windarra Project)	....	849	2 857	872	11 957	16 535
East Murchison	Agnew Mining Co.	29	220	....	....	....	249
	Totals in Nickel Mines	755	6 511	19 424	5 915	46 710	79 315
Iron—							
West Kimberley	Dampier Mining Co. Ltd. (Cockatoo Is.)	....	238	....	....	....	238
Peak Hill	Mt. Newman Mining Co. Pty. Ltd.	....	....	....	204	....	204
	Totals in Iron Mines	....	238	....	204	....	442

TABLE 3

Principal Gold Producers

Mine	1975			1976		
	Tonnes Treated	Yield Kilograms	Grams Per Tonne	Tonnes Treated	Yield Kilograms	Grams Per Tonne
Kalgoorlie Lake View Pty. Ltd.	433 899	2 272·86	5·2	22 423	143·62	6·4
Kalgoorlie Lake View Pty. Ltd. (Mt. Charlotte)	610 849	2 657·42	4·4	713 647	2 891·75	4·0
Kalgoorlie Lake View Pty. Ltd.	....	....	....	....	*374·56	....
Central Norseman Gold Corporation	129 479	1 436·80	11·1	137 902	3 039·93	22·0
North Kalgurli Mines Ltd.	28 617	116·81	4·1	....	....	....
Mulga Mines Ltd.	....	....	....	15 164	146·19	9·6
Minor Producers	67 324	621·08	9·2	61 891	487·88	7·9
Total State Production	1 270 168	7 104·97	5·6	951 027	7 083·93	7·4

* From mill clean-up.

NOTE: The calculated value of the gold produced in 1976 was $23 644 412 which includes $17 852 874 distributed by the Gol Producers Association from the sale of 7 857·65 kilograms of gold at an average premium of $2 272.04 per kilogram.

TABLE 4
Overseas Iron Ore Exports

Company	Sales Tonnes	Grade % Fe
Hamersley Iron Pty. Ltd.	34 579 537	63·83
Mt. Newman Mining Co. Pty. Ltd.	21 007 585	63·00
Cliffs W.A. Mining Co. Pty. Ltd.	11 948 746	59·31
Goldsworthy Mining Ltd.	7 213 535	63·02
Dampier Mining Co. Ltd.	2 587 889	67·59
Totals	77 337 292	62·96

TABLE 5
Nickel Producers

Product and Producer	Centre	Quantity Tonnes	Grade % Ni	Value $
NICKEL CONCENTRATES				
Western Mining Corporation Ltd.	Kambalda	271 294	12·43	136 034 038
Western Mining Corporation Ltd. (Windarra)	Windarra	136 142	10·65	55 481 192
Western Mining Corporation Ltd. (Great Boulder)	Scotia	10 662	14·40	6 200 843
Selcast Exploration Ltd.	Emu Rock	11 655	16·99	8 349 739
Anaconda Australia Inc.	Redross	27 237	14·98	16 721 848
Total Concentrates		456 990	12·21	222 787 660
NICKEL ORE				
Metals Exploration N.L.	Nepean	73 336	2·92	6 045 089

DIAGRAM OF FATAL ACCIDENTS

SEGREGATED ACCORDING TO CLASS OF MINING

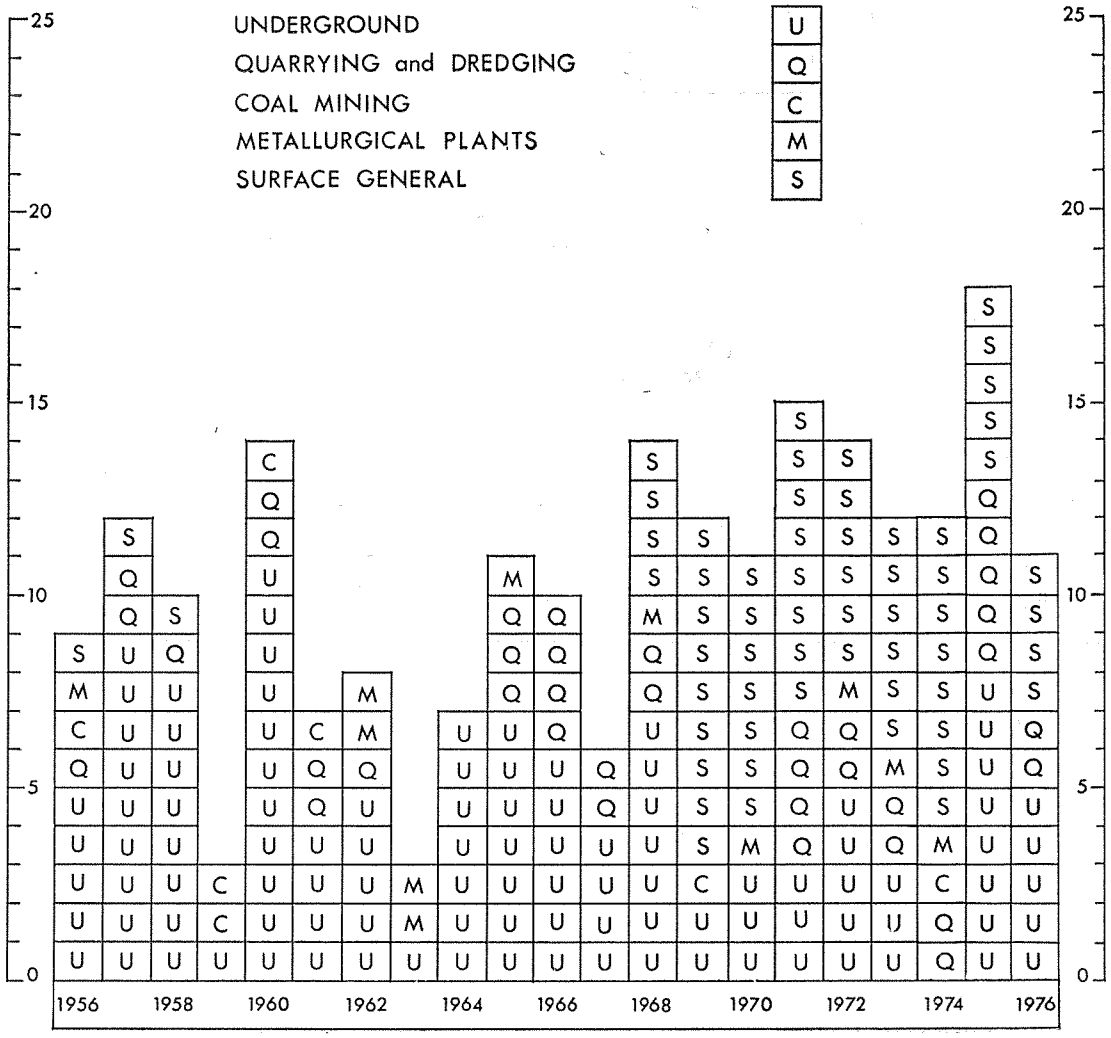

TABLE "A"

SERIOUS ACCIDENTS FOR 1976

Class of Accident	West Kimberley	Pilbara	West Pilbara	Peak Hill	Gascoyne	Murchison	Yalgoo	East Murchison	Mount Margaret	Broad Arrow	East Coolgardie	Coolgardie	Dundas	Yilgarn	South West	Greenbushes	Collie	Total
Major Injuries (exclusive of fatal)—																		
Fractures—																		
Head	....	1	2	....	....	....	....	....	....	....	....	....	....	....	....	....	....	3
Shoulder	....	....	2	....	....	....	....	....	....	....	....	....	....	....	....	....	1	3
Arm	....	....	4	....	....	....	....	....	....	....	1	3	....	....	4	....	....	12
Hand	....	3	1	....	....	....	....	....	1	....	....	4	....	....	....	....	1	10
Spine	....	....	2	....	....	....	....	....	....	....	....	....	....	....	....	....	....	2
Rib	....	....	....	....	2	....	....	....	....	....	....	....	....	....	2	1	....	5
Pelvis	....	....	....	....	....	....	....	....	....	....	....	1	....	....	....	....	....	1
Thigh	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Leg	....	....	....	....	....	....	....	....	....	....	....	4	....	....	3	....	....	7
Ankle	....	....	....	....	....	....	....	....	....	....	....	....	....	....	1	....	1	2
Foot	....	....	1	....	....	....	....	2	1	1	....	4	....	....	3	....	....	12
Amputations—																		
Arm	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Hand	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Finger	....	1	2	1	....	....	....	....	....	1	....	3	....	....	1	....	....	9
Leg	....	....	....	....	....	....	....	....	....	....	1	....	....	....	....	....	....	1
Foot	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Toe	....	....	1	....	....	....	....	....	....	....	....	1	....	....	....	....	....	2
Loss of Eye	....	....	....	....	....	....	....	....	....	....	1	....	....	....	....	....	....	1
Serious Internal	....	....	....	....	....	....	....	....	....	....	1	....	....	....	....	....	....	1
Hernia	....	1	....	1	1	....	....	....	....	....	....	3	....	1	....	....	1	8
Dislocations	....	2	....	1	....	....	....	....	....	....	....	2	....	....	2	....	....	7
Other Major	....	1	2	....	1	....	....	2	2	....	....	5	....	....	1	....	....	14
Total Major	....	9	17	3	4	....	....	4	4	2	4	30	....	1	17	1	4	100
Minor Injuries—																		
Fractures—																		
Finger	....	3	1	1	....	....	....	....	....	....	1	8	2	....	4	....	3	23
Toe	....	1	....	....	....	1	....	....	....	1	1	6	....	....	....	1	1	12
Head	....	3	3	....	....	....	....	....	....	....	1	3	1	....	10	2	....	23
Eyes	....	....	4	....	....	....	....	....	1	1	....	3	....	1	6	....	....	16
Shoulder	....	....	1	....	1	....	....	....	1	1	5	4	1	....	2	....	3	19
Arm	1	....	5	....	....	....	....	....	....	....	3	5	2	....	7	....	4	27
Hand	2	....	4	....	....	....	....	1	....	2	16	46	5	1	10	....	5	92
Back	1	13	17	2	7	....	....	....	....	9	14	32	5	1	32	....	30	163
Rib	....	....	....	....	....	....	....	....	....	....	....	1	....	....	4	....	....	5
Leg	....	4	9	3	2	....	....	....	2	3	9	30	....	1	14	....	7	84
Foot	....	3	6	....	1	....	....	....	....	1	11	13	1	....	16	....	4	56
Other Minor	1	2	11	....	....	1	1	....	....	2	4	18	1	1	11	....	12	65
Total Minor	5	29	61	6	11	2	1	1	4	20	65	169	18	5	116	3	69	585
Grand Total	5	38	78	9	15	2	1	5	8	22	69	199	18	6	133	4	73	685

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

TABLE "B"

ACCIDENTS SEGREGATED ACCORDING TO MINERAL MINED AND PROCESSED

Mineral	Men Employed	Accidents		
		Fatal	Serious	Minor
Bauxite (Alumina)	2 507	....	50	71
Coal	857	....	73	473
Gold	1 098	1	60	186
Ilmenite etc.	996	....	46	144
Iron	11 186	6	135	745
Nickel	3 782	3	284	770
Salt	464	....	20	91
Tin	115	....	4	10
Other Minerals	318	1	1	8
Rock Quarries	277	....	12	31
Totals	21 600	11	685	2 529

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	....	....	....	....	....	....	....	....	....	....	....	5	....	5
Pilbara	1	....	....	....	....	....	....	....	....	1	4	37	5	38
West Pilbara	....	....	....	....	....	....	....	....	....	....	1	78	1	78
Ashburton	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Peak Hill	....	....	....	....	....	....	....	....	....	....	....	9	....	9
Gascoyne	....	....	....	....	....	....	....	....	....	....	....	15	....	15
Murchison	....	....	....	....	....	....	....	....	....	....	....	2	....	2
East Murchison	....	....	....	2	....	1	....	....	....	1	....	1	....	5
Yalgoo	....	....	....	....	1	1	....	....	....	....	....	....	1	1
Northampton	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Mount Margaret	....	2	1	3	....	....	....	....	....	1	....	2	1	8
North Coolgardie	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Broad Arrow	....	....	....	....	....	....	....	....	....	18	....	4	....	22
North East Coolgardie	....	....	....	....	....	....	....	....	....	....	....	....	....	....
East Coolgardie	....	1	....	1	....	....	....	....	....	16	....	51	....	69
Coolgardie	....	1	1	27	....	4	....	1	1	129	....	37	2	199
Yilgarn	....	....	....	....	....	....	....	....	....	2	....	4	....	6
Dundas	....	....	....	1	....	....	....	....	....	6	....	11	....	18
Phillips River	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Greenbushes	....	....	....	....	....	....	....	....	....	....	....	4	....	4
South West	....	....	....	....	....	....	....	....	....	....	1	133	1	133
Collie	....	....	....	5	....	....	....	....	....	49	....	19	....	73
Nabberu	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Warburton	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Eucla	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Total for 1976	1	4	2	39	1	6	....	1	1	223	6	412	11	685
Total for 1975	1	4	3	31	1	2	....	1	3	297	10	491	18	826

ACCIDENT STATISTICS

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

There were 11 (18) fatal and 685 (826) serious accidents. (The figures for the previous year are shown in brackets.)

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

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

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

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

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

Name and Occupation	Date	Mine	Details and Remarks
Lauritsen, R. E. (Miner)	5/2/76	Minefields Exploration N.L. (Mt. Mulgine)	Collapsed whilst supporting another miner who was affected by fumes and fell from ladders to bottom of exploration shaft.
Fox, M. (Boilermaker-Welder)	9/3/76	Wundowie Charcoal Iron & Steel	Struck on the head by the revolving blades of a mill when inspecting the clearance at a gate which he had installed.
Rourke, M. (Scraper operator)	10/3/76	Western Mining Corporation Ltd. (Kambalda Nickel Operations)—Silver Lake Mine	A large rock fell from the hanging wall whilst he was scraping ore.
Sandeman, H. (Mechanical Loader Operator)	30/4/76	Western Mining Corporation Ltd. (Kambalda Nickel Operations)—Silver Lake Mine	Pinned against the wall of a mill-hole by a mechanical loader whilst loading ore.
Clough, M. (Truck driver)	25/5/76	Goldsworthy Mining Ltd.—Shay Gap	The 75 ton truck he was positioning at the waste dump for unloading went over the edge.
Alfeldi, J. (Permanent way Inspector)	27/5/76	Mt. Newman Mining Co. Pty. Ltd.—Railway	Driving a Hi-rail vehicle and ran into the rear of an empty ore train which was entering a siding.
Neville, J. C. (Jumbo drill operator)	2/7/76	Western Mining Corporation Ltd. (Windarra Project)	He was struck by a large slab of rock which fell from the back of the drive.
Cantley, P. (Trainee Bulldozer driver)	12/7/76	Hamersley Iron Pty. Ltd.—Paraburdoo	The bulldozer on which he was a passenger rolled over the edge of a ramp in the quarry and he was crushed.
Jones, R. A. (Trades Assistant)	13/7/76	Mt. Newman Mining Co. Pty. Ltd.—Port Hedland	Crushed by a control gate in a chute whilst assisting with replacement of wear plates.
Somerville, J. G. (Locomotive Driver)	5/11/76	Mt. Newman Mining Co. Pty. Ltd.—Railway	Trapped in cab of locomotive when the train crashed through a workshop on a spur line at Cowra siding.
Richardson, G. E. (Machine miner)	9/11/76	Mt. Prophecy Gold Mine—Bamboo Creek	Died from injuries received when he returned to the drive face too soon after lighting explosive charges.

WINDING MACHINERY ACCIDENTS

A number of accidents involving winding machinery and associated shaft equipment were reported and investigated. The necessary action to repair any damage and eliminate hazards were taken. Brief details are as follows:

Overwinds (1). The winding engine driver at the Andrews Shaft of Selcast Exploration fell asleep whilst three men were ascending in a skip and was awakened when the skip hit the detaching plate. Fortunately the men were standing on a platform suspended from the side of the skip and although the skip went through the tipping motion the men were not tipped out and no injuries resulted.

Cage/Skip Hang-ups (6). Four of these accidents occurred in shafts operated by Western Mining Corporation Ltd. (Kambalda Nickel Operations.)

The cage in the north haulage compartment of the Silver Lake Shaft came to a sudden stop on a rock protruding into the shaft between No's 9 and 10 levels. The rock was sitting on a shaft set opposite the loading pocket. Two men in the cage sustained leg injuries.

The left-hand skip in the Juan haulage shaft jammed in the sky-shaft when descending from the tipping position and about 50 metres of slack rope occurred. Before the rope could be rewound the skip freed itself and dropped in the shaft. Arrester gear is not fitted to these skips as the shaft has steel sets and skids. The skip attachments were dismantled and inspected, the rope cut and a non-destructive test carried out on it, before the equipment was placed back in operation.

On another occasion in the Juan shaft the right-hand skip was overloaded with ore and a rock caught between the shaft wall and the skip. This caused the winder motor to throw out on overload when power was applied and the winding rope to pull through the rope clips for about 10 centimetres. It was necessary to cut the rope and fit new rope clips.

Due to faulty locking arms the right-hand skip in the Durkin haulage shaft jammed in the tipping tracks. Reconditioned locking arms were fitted to the skip.

The left-hand skip in the Reward Shaft of Kalgoorlie Mining Associates' Mt. Charlotte mine jammed in the skyshaft when descending from the tipping position. A small stone had wedged between the skip and the skyshaft structure. Some rope unwound. It was necessary to replace the skip as some damage resulted.

The loaded right-hand skip in the Andrew Shaft at Selcast Exploration jammed about 15 metres above the loading pocket as the locking arms on the door had not properly latched allowing the tub to open. Some damage was caused to the tub and its door.

Miscellaneous (12). Six of these mishaps occurred in various shafts of Western Mining Corporation Ltd (Kambalda Nickel Operations).

On two separate occasions the skips in the Silver Lake haulage shaft were severely twisted when a missing roller on the latches of the skips prevented the tubs swinging out to allow the dirt to be tipped.

Three 3 metre lengths of 10 centimetre diameter pipe loaded in the top deck of Durkin service shaft slid forward during the ascent of the cage and struck a shaft set about 6 metres above the No. 5 level. The cage was badly damaged and a sill plate at the No. 4 level plat was dislodged.

The gate of the cage was left open at the No. 11 level plat on the Silver Lake Shaft and was knocked off when the cage was moved up in response to a signal given at the No. 5 level. No-one was in the cage.

Again at the Silver Lake Shaft a truck fell into the shaft because the cage was shifted whilst a truck of spillage from the shaft was tipped into the nearby mullock pass and the cage was not in position when the truck was returned. The winder driver had received one long signal bell and raised the cage accordingly. There was no damage to the shaft.

A slack rope condition occurred when the cage bottomed on a build-up of spillage in the Silver Lake Shaft. It was necessary to cut 10 metres of rope off the conveyance end due to damage to the rope.

The right-hand skip in the Juan haulage shaft had to be replaced as its bridle was twisted when brought into the tipping position. The damage was caused by a missing roller on a locking arm.

The gate of the cage in the Service Shaft at the Mt. Charlotte mine of Kalgoorlie Mining Associates was apparently not fully closed and struck a shaft set as the cage ascended from No. 8 level. The gate was dislodged and fell down the shaft.

Three mishaps occurred in the Andrews Shaft of Selcast Exploration. Two of these were similar and occurred during the change-over from cage to skip. The weight of the disconnected winding rope between the winding engine drum and the sheave wheel caused the rope to be dragged from the skyshaft and fall on the ground in front of the winder house. On the first occasion a hemp rope used to lash the winding rope to the skyshaft broke, but on the second occasion the skipman failed to secure the winding rope. A swinging clamp has now been attached to the headframe and is used to secure the rope.

In the other mishap the skipman forgot to close the gate to the cage when on the No. 6 level and it was torn off when the cage moved away.

At the Perseverance shaft of Agnew Mining Co. Pty. Ltd. two men were injured whilst working on a shaft sinking stage which fell about thirteen metres to the bottom. The surface crane used to suspend the stage was overloaded when an additional weight of steel concrete formwork was applied to the crane.

Decline Accidents (3). These three accidents occurred in the Otter Juan decline of Western Mining Corporation Ltd. (Kambalda Nickel Operations.)

A man received fractured legs when passing between a truck and a front end loader which were stopped temporarily in the decline. The loader stalled as it was about to move off and rolled down against the truck. An air leak in the braking system of the loader also contributed.

The driver of a Kiruna truck was injured when thrown out as it struck the wall whilst being driven around a bend. A deformed steering ram was discovered after the accident but it is not known if it was deformed before the impact.

A "buggy" hit the wall of the decline and the driver received a back injury in another mishap. The cause was not determined as, although the track rod was broken, it is believed that it broke on impact.

PROSECUTIONS

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

Two miners were found guilty of breaching regulation 8.23 (1) by working in a development end before ventilating equipment had been installed. The ducting was 30 metres from the development face they were bogging.

A miner was charged with failing to use water to suppress dust whilst scraping contrary to regulation 8.18 (2). It was withdrawn when it was learnt that he had left his employment and the State.

Four complaints were made against the "agent" of a quarry operator claiming that on three separate dates he operated a crushing and screening plant without appliances to control and suppress the emission of dust contrary to regulation 8.8 (1); and that he failed to ensure that the air breathed by persons employed in the plant complied with the standards of purity required contrary to regulation 8.8 (2). One complaint was found to be proved and the agent was fined $250.00 with costs of $3.10. The two similar complaints were dismissed. On the fourth complaint the defendant was found not guilty and costs of $50.00 were allowed.

CERTIFICATES AND PERMITS

Certificate of Exemption: There were no applications for exemption under Section 46 of the Mines Regulation Act.

Sunday Labour Permits: Five permits were issued covering twelve shifts and involving seventy-three men. The work consisted of making a decline safe for normal work to proceed; to modify a penthouse thereby avoiding serious loss of time in the subsequent working of the mine; rising to re-establish primary ventilation after a collapse of ground curtailed all ore production; a safety inspection of workings following a substantial underground pillar blast; and to commence a crosscut off a main drive which entailed the breaking of air, water and power mains and would have caused a serious disruption to the normal working of the mine.

Permits to Fire Outside Prescribed Times: Four permits were issued and all were subject to special conditions such as the posting of warning notices notifying all mine personnel, the prevention of persons entering the area before firing, and exhausting the resultant fumes directly to the surface. Firing within ¾ of an hour of the recognised firing times was prohibited.

Permits to Rise: When the new regulations to the Mines Regulation Act became effective on the 5th April, the necessity to obtain permission to rise more than 9.15 metres was deleted. Prior to this date, however, fourteen permits totalling 333 metres were issued in the year. Only one of these was risen on a borehole, the others used the conventional method. Eight of them were for ore passes, four were to test the ore structure and the remainder for access and ventilation purposes.

Authorised Mine Surveyors Certificates: The Survey Board issued initial certificates to Messrs R. S. Davidson, J. E. McLarty, J. J. Samson and S. D. Stewart.

Regulation 10.4 of the Mines Regulation Act which came into effect on the 5th April, 1976, requires that a person who was registered under the Mines Regulation Act, 1906-1945, or is the holder of a current Certificate under the revoked regulations, as a person authorised to make surveys and draw plans, shall make application to the Mines Survey Board for the grant of a Certificate as an Authorised Mine Surveyor under the new regulations. A new and renumbered certificate has been prepared and thirteen were issued as follows:—

R. S. Davidson—Certificate No. 001.
V. Cavallaro—Certificate No. 002.
R. J. Crew—Certificate No. 003.
W. Janssen—Certificate No. 004.
J. K. N. Lloyd—Certificate No. 005.
J. E. McLarty—Certificate No. 006.
M. K. Quartermaine—Certificate No. 007.
A. M. Siggins—Certificate No. 008.
R. J. Thomson—Certificate No. 009.
T. W. Van Raven—Certificate No. 010.
H. L. Burrows—Certificate No. 011.
J. J. Samson—Certificate No. 012.
S. D. Stewart—Certificate No. 013.

MINE INSPECTION

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

The working places on all mines were inspected to ensure compliance with the Mines Regulation Act and the frequency of inspections was in accordance with past years.

Staff in the three metalliferous inspectorates has been stabilised by the transfer of some inspectors and the appointment of new staff.

The introduction of the new mining regulations on 5th April, 1976 was accomplished without too many complications. No major changes were effected to the regulations dealing with underground mining but other areas of the mining industry have now been regulated. These are those of machinery in mines, occupational diseases, shaft sinking, safety and protection in quaries, dredging, treatment plant, and railway operations on mines. These are the company owned railways used for hauling iron ore from the mine

sites to the ports at the coast. Regulations were also made to specify the qualifications and other requirements needed for Quarry Manager's Certificates of Competency and Service and Restricted Quarry Manager's Certificates of Competency and Service as provided for in the Mines Regulation Act. The duties of these Managers, Underground Managers and Shift Bosses are also prescribed. To assist in the assimilation of the regulations, question and answer sessions have been held in the major centre of the three metalliferous inspectorates. It was necessary to amend the Code of Signals for hoisting in shafts after opposition to some of the changes effected in an endeavour to have a standard code throughout Australia. The amendments recognised that changes were necessary but preference for some of the original Code was evident. Some other amendments to the regulations to correct minor errors could be effected in the coming year.

VENTILATION

Two sections have now been established in the Branch to deal with ventilation matters. The existing section at Kalgoorlie will continue to handle the ventilation of the underground gold and nickel mines with their associated treatment plants. The other section, based at Perth, will deal with the ventilation of the mines in the Perth and Port Hedland inspectorates in which are the major iron ore mines, mineral sands mining, bauxite mining and major hard rock quarries.

All mines, crushing and treatment plants throughout the State were inspected by the staff of the two sections on a regular basis. Dust concentrations or dust counts, temperature and humidity conditions, and ambient gas levels, were checked in all working areas.

Assistance was given to some companies to overcome dust problems in surface operations, and suggestions for improving ventilation conditions in underground mines were made.

931 gravimetric dust samples were collected from all sources of which 180 or 19 per cent exceeded the T.L.V. (Threshold Limit Value) for the particular dust sampled. Although emphasis has been placed on gravimetric sampling the konimeter was used when problems were encountered with the gravimetric dust sampling instruments. A total of 617 konimeter dust samples were taken and the average count was 176 p.p.c.c. Only twelve per cent of the samples taken had a count in excess of 300 p.p.c.c.

Positional gravimetric sampling of the intakes to and exhausts from underground mines was commenced to determine the overall dustiness and whether the dust was being removed from the working areas through the exhaust outlets.

Personal sampling of men working in all facets and categories of the mining operations was carried out on a regular basis and, after some initial "problems", are now being undertaken with relative ease.

In all the underground mines the dust problems encountered were mostly attributable to individual miners failing to ensure that secondary ventilation was adequate, whilst the lack of maintenance on dust suppression and dust collection systems was the cause of dust in most crushing plants.

Primary airflows in underground mines were generally adequate. Reduced airflows in the Silver Lake and Hunt mines were traced to salt depositions which damaged the blades and bearings on the fans. A stoppage of work resulted when the airflow through the Regent mine of Central Norseman Gold Corporation deteriorated appreciably. It was eventually traced to the primary ventilation fan on the No. 22 level which had been affected by rust and had shed a blade causing major damage. Repairs were effected but it may be necessary to install a new fan.

Forty-three permits to use diesel engined equipment in underground workings in the Kalgoorlie inspectorate were issued. Undiluted diesel exhaust gas concentrations for carbon monoxide were made on 221 vehicles and only three per cent exceeded the Threshold Limit Value of 2500 p.p.m.

Only four per cent of the tests made for nitrous fumes on vehicles exceeded the T.L.V. of 2000 p.p.m.

Regular sampling of the lead in the air in gold assay offices was continued. An improved exhaust system added to one office resulted in considerably lower lead concentrations. Sampling of the urine from men involved in the handling of lead and mercury to ascertain the hazard to which they are exposed was continued.

The handling of Cyanide and Xanthate chemicals was investigated and improvements were noted when automatic drum tipping devices within enclosed cabins were installed.

Measurements to determine the concentrations of sulphur dioxide, ammonia, toluene, hydrogen sulphide and hydrogen cyanate were made at various sites.

Seventeen men were affected by fumes but fortunately none was fatal. Six of them were affected by carbon monoxide escaping from blast furnaces. Four men were affected when handling explosives and three fumings were due to inadequate ventilation at their underground working place. One fuming was attributed to sulphur dioxide and the other three were due to handling chemicals. All of these fuming accidents were investigated and the appropriate action taken where necessary.

Six fires occurred in underground mines where diesel engined equipment is used. The ignition of oil was the cause in all cases and were mainly due to broken oil lines. One incident occurred in an underground garage when an "oxy torch" being used to cut the top off an oil drum caused the drum to ignite. Smoke flowed through the compressed air lines when residual lubricating oil in an air receiver ignited in another incident. All fires were quickly extinguished and action was taken to prevent a repetition of the ignition of oil in the air receiver.

Underground fire fighting and rescue teams have been formed at the Kambalda and Windarra operations of Western Mining Corporation Ltd. These teams are equipped with Drager type self-contained breathing apparatus. Refuge stations and escape routes have been constructed at some mines, and self-rescue breathing equipment is available to workmen employed in underground mines where diesel engined equipment is used.

The members of the Ventilation Board, established under a new Division added to the Mines Regulation Act, visited all major mining operations in the State to explain their objectives and the basis for requiring Companies to establish their own dust sampling programmes. It is hoped that the Companies will thus see the need for improved dust control in treatment plants and ventilation of working places underground and be able to voluntarily meet the more stringent requirements in the new regulations.

GENERAL

Ground vibration measurements were made with the Sprengnether seismograph to satisfy complaints made about quarry blasting and Westrail train vibrations. Measurements were made for the Metropolitan Water Board to ensure that excavations being undertaken nearby would not damage the wall of the Mundaring Weir. Two other complaints about blasting in limestone quarries were satisfied without recourse to vibration measurements.

Rehabilitation of mining sites took place in a number of areas in the south west of the State. The most notable was that in the Greenbushes area. Greenbushes Tin N.L. was successful in having the South West Highway diverted to by-pass the town of Greenbushes thus removing the temporary scars of surface mining from the view of travellers and tourists. It also enabled access to be gained to tin deposits under the Highway. These advantages were not gained cheaply as stringent conditions were imposed for the rehabilitation of all mined areas in the vicinity of Greenbushes. An active rehabilitation programme is now being pursued by the Company.

Although not so spectacular the rehabilitation by Alcoa of Australia (W.A.) Ltd. of mined out bauxite areas at Jarradale and at Del Park and Huntly near Pinjarra, has been proceeding very successfully. During 1976 mined areas totalling 170 hectares were contoured, covered with topsoil, deeply ripped and planted with trees and ground cover. Methods of future rehabilitation are being reviewed by the company in conjunction with research and planning committees to ensure that restoration of the land will be in accord with future use of the areas.

Rehabilitation of mined areas of Western Titanium Ltd. which adjoin the Bussell Highway south of Capel has continued with 58 hectares being rehabilitated in 1976. Tree planting continued and a hectare of land has been planted with grape vines.

A further 13 hectares of ground restored after mining was seeded for pasture in the continuing excellent programme of rehabilitation adopted by Western Mineral Sands Pty. Ltd.

Cable Sands Ltd. is also successfully rehabilitating mined areas in the Stratham area and in the season a crop of oats was growing close to the edge of the tailings discharge mound.

Rehabilitation of mineral sands mining areas in the Eneabba area is also proceeding satisfactorily. This is a relatively new area of mining and rehabilitation will be proceeding almost simultaneously with the mining.

METALLIFEROUS MINING OPERATIONS— KALGOORLIE INSPECTORATE

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

INTRODUCTION

The year 1976 has been a remarkable one for the Kalgoorlie District in that announcements of mergers, mining projects and exploration drilling results have helped the people of the district to be optimistic about the future of the towns of Kalgoorlie and Boulder, even though underground mining on the Fimiston leases of the world famous "Golden Mile" were brought to a standstill and the workings are being allowed to flood.

In May, Kalgoorlie Lake View Pty Ltd announced that they had entered into a partnership with Homestake Gold Ltd (a wholly owned subsidiary of the Homestake Mining Co of America). The formation of the new company, named Kalgoorlie Mining Associates, resulted in the influx of additional capital and continuance of the Mount Charlotte operations seemed assured.

However due to falling world gold prices the newly formed company announced in August that mining operations were to be suspended in November and this was later extended to December. An eleventh hour reprieve due to the devaluation of the Australian dollar and a continual rise in the world price of gold has enabled the company to continue operations.

Agnew Mining Company Pty Ltd announced during the year that they were proceeding with the development of the Perseverance nickel project some 160 km North West of Leonora. The first of the two phase mining and treatment operation involves extraction of high grade massive sulphide ore by conventional cut and fill stoping. It is envisaged that some 2.5 million tonnes of ore a year will be mined when full production is reached.

In October, M.I.M. Holdings Ltd and Western Selcast, partners in the Teutonic Bore joint venture, announced the results of assays from seven diamond drill holes. The highest copper assay recorded was 5.2% over 24.6 metres and augurs well for the potential of the area which is approximately 280 km North West of Kalgoorlie.

Discussions between the Agnew Mining Company and Western Mining Corporation Ltd have resulted in an expansion programme being announced by W.M.C. Ltd for their nickel smelter at Kalgoorlie. The programme, estimated to cost around 30 million dollars, will include the construction of an enlarged flash furnace, boiler, electric furnaces and additional precipitators and preheaters.

Amendments to the Mines Regulation Act were proclaimed and the re-written Mines Regulation Act Regulations were gazetted in April of this year and came into force on April 5. Apart from a few minor problems which shall result in amendments to some regulations and/or sub regulations, the re-written regulations were accepted quite well by private industry.

During the year in conjunction with the local governing bodies a safety campaign was initiated to make safe old mine workings in the vicinity of Kalgoorlie and Boulder. In all, some 187 shafts and a few small open cuts were filled in. Mining tenement holders were also advised of the campaign and it is pleasing to record that they co-operated fully with our requests to either fence or cover old mine openings.

Mining activity and other points of interest which took place in the Mining districts within the Kalgoorlie Inspectorate during 1976 are:

PHILLIPS RIVER MINING DISTRICT

Early in the year Norseman Gold Mines N.L. announced that the second shipment of 12 000 tonnes of magnesite from their Ravensthorpe deposits had arrived in Austria and that test work in Greece on a pilot plant had indicated a satisfactory recovery rate. No other physical mining activity took place on the deposit.

Vermiculite Industries Pty Ltd spasmodically mined 1 124 tonnes of Vermiculite from their deposit located on the banks of the head waters of the Young River. A front end loader was used to extract and stockpile the ore. It was reported that some 724 tonnes were transported to Welshpool for treatment.

Gold prospecting continued on a very limited scale at Kundip and mineral explorers were active in the Kundip and Ravensthorpe areas.

DUNDAS MINING DISTRICT

Central Norseman Gold Corporation N.L. continues to be the major producer of gold within the Kalgoorlie Inspectorate. The company enjoyed a profitable year with high grade ore being mined at the North Royal shaft on the 4 and 5 levels.

The ore from the North Royal open cut was mined and stockpiled and then processed through a washing, straking and flotation plant prior to treatment at the Phoenix Mill.

The Regent shaft continues to contribute ore from twelve working levels between the 14 and 35 levels.

Ore treated during the year amounted to 182 217 tonnes for a recovery of 3 227.70 kilograms of gold and 976.03 kilograms of silver.

Gold prospectors were not very active during the year, although the Norseman State Battery operated throughout the year crushing ore from outside the Dundas Mining District.

The Readymix Group closed down their quarry and crushing operations at Esperance in March of this year after fulfilling their contracts.

Norseman Gold Mines N.L. have taken an option over a deposit of seed gypsum near Norseman and are now investigating the possibility of establishing works for processing gypsum.

YILGARN MINING DISTRICT

The principal mineral being mined in this district continues to be iron ore at Koolyanobbing. Dampier Mining Co Ltd commenced producing ore from "D" deposit during the year and to date some 12 000 tonnes has been mined. Total tonnage of ore mined during the year amounted to approximately 2 207 000 tonnes while 1 951 000 tonnes of waste was removed.

Wundowie Iron and Steel continued mining on a much smaller scale than Dampier Mining Co; 94 000 tonnes of ore was broken at an average of 61.5% Fe and some 24 000 tonnes of waste was removed.

Gold mining activity was confined mainly to the Southern Cross and Marvel Loch areas of the Yilgarn District.

The Marvel Loch Gold Mine commissioned their treatment plant about May but then suspended mining operations in September due to the falling price of gold. Production figures till closure were 7 255 tonnes of ore treated for a return of 7.82 grams per tonne.

The Francis Furness mine have had problems with extracting the gold from ore broken but nevertheless treated 5 400 tonnes of ore for a return of 58.8 kg of gold.

Treatment of tailings at the old Evanston Gold Mine continued during the year and the partners in this project expect to complete the operation in 1977.

Amax Mining (Aust.) Ltd continued exploration drilling at Forrestonia during the year and brief reports were made public of their activities.

W.A. Plaster Mills were responsible for the harvesting of 30 070 tonnes of Gypsum from Lake Seabrook, while another private company harvested 21 371 tonnes from Lake Brown.

COOLGARDIE MINING DISTRICT

Nickel mining companies within this mining district were responsible for the production of approximately 1 680 000 tonnes of nickel ore during 1976.

Western Mining Corporation Ltd continues to be the major producer and during the year ore broken amounted to approximately 1 390 000 tonnes.

An active exploration and development programme enabled the company to maintain ore reserves at 24 334 000 tonnes and grading 3.23% nickel.

The company at the present time has eight production shafts or declines in operation with shaft sinking operations continuing below the 6 level of the Jan shaft. The long shaft sink is at a depth of 465 metres and is scheduled to extend to 940 metres for the total sink.

During the year a sandfill plant was constructed near the Jan shaft and the new town stormwater dam with a capacity of 80 million gallons was completed.

Operation at the Nepean mine of Metals Exploration continued much the same as the previous year with 75 000 tonnes of ore being mined. Sinking of the shaft recommenced but is behind schedule with only 51 metres of advance having been completed.

Production of 91 000 tonnes of ore from the Andrews shaft of Selcast Exploration at Spargoville was below the anticipated figure of 160 000 tonnes mentioned in 1975. Early in the year management decided to change the stoping method to vertical long hole open stoping. Previous to this method being adopted the open stope concept was being used but ore was broken by drilling slightly declined horizontal holes from a central drilling chamber in the ore block. Because of numerous flat joint planes occurring in the ore body fragmentation after blasting was not good and frequent secondary blasting had to be done.

Anaconda Australia Inc. mined 124 510 tonnes of nickel ore for a recovery of 27 238 tonnes of concentrate at 14.98% nickel. This company ships its concentrate to an overseas market through the port of Esperance.

Deepening of the Redross shaft is planned for next year and there is a possibility that the Wannaway shaft may reopen.

Lefroy Salt Pty. Ltd. continued their salt havesting activities at Lake Lefroy but due to poor rainfall during the year only four ponds with an approximate area of 200 hectares remain to be harvested.

Prospecting activity in the district was at a low ebb throughout the year.

EAST COOLGARDIE MINING DISTRICT

The decline in gold mining continued during the year. With the exception of the Mount Charlotte Operations, all underground mining was terminated on the "Golden Mile".

Production from the Fimiston leases amounted to 12 196 tonnes of ore broken and treated from which 88.83 kilograms of gold were recovered.

The Mount Charlotte operations produced 676 203 tonnes of treated ore which resulted in 2 615.22 kilograms of gold being recovered and open cut operations were responsible for the recovery of 97 626 tonnes of ore, for 399.267 kilograms of recovered gold.

The above production figures are from mining tenements held by Kalgoorlie Mining Associates (formerly Kalgoorlie Lake View Pty. Ltd.).

At the Mount Charlotte mine, mining of the Southern Orebody was virtually completed above the 9 level during the year. Work has begun on extending both the haulage and supply shafts to about the 1 450 ft horizon prior to moving the underground crusher to a lower horizon.

No production was recorded from North Kalgurli Mines Ltd. The shafts and pumps were maintained until October, 1976 when it was announced that all underground operations were to cease.

The Croesus plant continued to treat nickel ore from Anaconda Australia Inc. and Selcast Exploration N.L.

At the Fimiston plant of W.M.C. Ltd.—Great Boulder Operations the gold section was closed down after treating 17 569 tonnes of gold ore for a recovery of 56.10 kilograms of gold. This ore was mined from shallow open cuts on the Fimiston leases.

Nickel concentrates were also produced at the Fimiston plant from ore transported by road train from Scotia.

Throughput at W.M.C. Ltd. nickel smelter was comparable with the previous year. Concentrates treated amounted to 282 950 tonnes of an estimated 33 293 tonnes of contained nickel to produce 44 961 tonnes of matte estimated to contain 31 987 tonnes of nickel.

Plant installed during the year included a 20 MW gas turbine and alternator, and a silica flux milling system. A multi million dollar expansion programme is planned for 1977.

The Readymix Group (W.A.) have established a quarry at South Boulder to supply aggregate for local consumption with most of the product going into concrete sleeper manufacture at Parkeston.

Ore supply to the Kalgoorlie State Battery gradually decreased throughout the year, due to a decrease in prospecting activity. However, with the rise in the price of gold and the letting of tributes by Kalgoorlie Mining Associates supply of ore to the Battery is expected to increase during 1977.

NORTH EAST COOLGARDIE MINING DISTRICT

Very limited exploration work was done in this district during the year.

BROAD ARROW MINING DISTRICT

The Scotia nickel mine continued mining on a reduced scale during the year with 79 701 tonnes of ore being broken. Ore treated amounted to 119 196 tonnes which produced 11 188 tonnes of concentrate containing 1 605 tonnes of nickel and 66.3 tonnes of copper.

In October of this year open cut mining was commenced at Siberia for the purpose of providing a lateritic smelter flux for the Kalgoorlie Nickel Smelter.

Tonnage to be removed and stockpiled from the pit area during stage 1 will approximate 75 000 cubic metres of overburden and 125 000 cubic metres of flux material.

Both the above operations are managed by W.M.C. Ltd.—Great Boulder Operations staff.

NORTH COOLGARDIE MINING DISTRICT

The Carr Boyd Rocks nickel mine operated by W.M.C. Ltd.—Great Boulder Operations remained on a care and maintenance basis throughout the year. It seems likely that mining will recommence early in 1977.

Greenbushes Tin N.L. took over the management of the Aspacia Gold Mine during the year. Development on the 3 level included driving North and South on the reef. Development of the northern section of the reef was abandoned after low values were encountered. The west shaft was dewatered, the west lode sampled and management is now preparing to crosscut from the main lode to the west lode.

EAST MURCHISON MINING DISTRICT

Exploration work by major companies is continuing in this district while prospectors have provided a small amount of activity in the Sandstone and Barrambie areas.

A consortium of companies are to do further exploration work on the recently announced Lake Way uranium deposit near Wiluna.

The Yeelirrie Uranium Project and the Mount Keith Nickel Project have remained on a care and maintenance basis throughout the year.

The Readymix Group (W.A.) completed their aggregate contract for Agnew Mining Company Pty. Ltd. in September. The new quarry opened up by this company is approximately one kilometre west of the Agnew nickel deposit.

Agnew Mining Company Pty. Ltd. pursued an active development programme in the Agnew area and apart from surface construction, mining development consisted of 220 metres of decline and 29 metres of shaft sinking.

The decline heading was re-routed after a cave-in of the backs occurred in September which buried the Dosco Road Header. An Alpine Continuous Miner was then used to advance the decline. Advance has been hampered by bad ground conditions which have necessitated the placement of steel support sets at one metre intervals.

Thyssen Mining Construction Australia Pty. Ltd. have been awarded a contract to sink a 7.5 metre diameter concrete lined shaft to a depth of 890 metres at the Agnew Nickel Project. The pre-sink has been completed and winder installations and headframe construction are now in progress.

MOUNT MARGARET MINING DISTRICT

The only significant producer in the district was the Windarra nickel mine. Total tonnage of ore broken to January 11, 1977 amounted to 1 035 941 tonnes of which 371 153 tonnes was produced by underground operations at Mt. Windarra, and 664 788 tonnes from the South Windarra open cut.

A partial floor pillar collapse in July resulted in the closure of the "D" shoot workings for several weeks whilst back fill was introduced into the open stope.

Prospectors in the Leonora district produced small quantities of gold and demand for the Departmental hire compressor reached a level such that another compressor was brought into the district to assist in satisfying prospectors requirements.

A significant copper, zinc and silver discovery in the Teutonic Bore area of this district was announced jointly by M.I.M. Holdings Ltd. and Western Selcast in October. Diamond drilling is continuing in the area.

NABBERU, WARBURTON AND EUCLA MINING DISTRICTS

Mining activity in these districts is dormant, however, in some areas exploration work is still being carried out but no significant mineral discoveries have been made known to date.

STAFF

Mining Engineer and District Inspector of Mines, B. Van der Hoek transferred to the Perth Inspectorate in September. Mr. P. Diamantes commenced duty in October as a Mining Engineer and District Inspector of Mines based in Kalgoorlie.

PERTH INSPECTORATE

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

SOUTH WEST MINERAL FIELD

ALUMINA

Alcoa of Australia (W.A.) Limited—A production of 3 113 874 tonnes of alumina achieved a 40 per cent increase on 1975 output, and was primarily due to the commissioning of the Pinjarra 4th and 5th refinery units. In conjunction with the expansion of the Pinjarra Refinery, the new Huntly minesite located 5.5 kilometres north-west of the Del Park minesite was commissioned in April. These two mines together supplied 6 328 739 dry tonnes of bauxite to Pinjarra Refinery. Shipments of Pinjarra alumina through the new Bunbury Terminal and Harbour Facilities also commenced in April.

The Jarrahdale minesite supplied 4 025 312 dry tonnes of bauxite to the Kwinana Refinery, which was approximately 10 per cent more than in 1975.

The mine pit rehabilitation programme continued to expand in line with the increased production rate. Mining areas totalling 170 hectares were contoured, covered with topsoil, deeply ripped and planted with trees and ground cover. The methods of future rehabilitation are continuing to be reviewed in line with research and land use planning carried out by the company in conjunction with government research and planning committees.

The company's workforce increased during 1976 by 255 to a total of 2 507 of which 486 were involved in bauxite mining and 2 021 were involved in refining and central administration.

BUILDING STONE

Granite Diorite. Producers of crushed granite and diorite continued to be fairly active throughout the year. An average of 214 people were employed on quarry sites throughout the year.

Avon Quarries—Northam. Low demand in the area resulted in a production of only 8 900 tonnes.

Bell Basic Industries Ltd. This company now controls the Maddington quarry previously known as Bell Bros. Quarries Pty. Ltd.

The quarry produced 714 000 tonnes of crushed rock and employed 47 men. Additional screening capacity together with associated conveyors and washing facilities were installed during the year.

Pioneer Concrete (W.A.) Pty. Ltd. The Herne Hill, Carnamah and Walkaway quarries all operated during the year.

Production from all sites amounted to 832 000 tonnes with 43 men being employed.

Quarry Industries Ltd. On completion of the railway ballast contract at Walkaway, Quarry Industries moved to the Public Works Department quarry at Roelands to supply ballast for lines in the South West and rock for Bunbury Harbour groyne work.

Westrail and the Public Works Department shared the costs for the construction of a haulage road to the top of the very high face at the quarry. Systematic benching then commenced at the top of the face. At the completion of the contract, two benches had been well established. Any future mining will reap the benefits of the accessibility prepared during this contract.

Production from Roelands consisted of 60 000 tonnes of ballast and 20 000 tonnes of lump. Large stockpiles of screened aggregates were left on site. At Walkaway, 88 000 tonnes of ballast were delivered.

The Readymix Group (W.A.). Mining at the Gelorup and Gosnells quarries continued throughout the year. A small contract for the supply of groyne facing stone for the new land backed berth at Geraldton Harbour was mined from the Beatenally Hill quarry east of Geraldton. The Albany quarry commenced production of crushed rock in November.

Readymix still decline to supply production figures to this Department.

CLAYS AND SHALES

The Midland Brick Co. Pty. Ltd. remain the largest single producer of clay from pits located in the Toodyay, Herne Hill, Bullsbrook and Muchea areas. Annual production was 750 000 cubic metres. Other producers accounted for approximately 453 000 cubic metres. The industry employed approximately 70 men.

FELSPAR

Only minor tonneages were produced. Two parcels from the Mukinbudin area totalled 220 tonnes.

GYPSUM

Gypsum Industries of Australia Pty. Ltd. produced 31 919 tonnes from Lake Cowcowing.

ILMENITE, LEUCOXENE, MONAZITE, RUTILE, XENOTIME AND ZIRCON

1976 proved to be a difficult one for mineral sands miners. Falling zircon prices, lack of demand and rising costs resulted in operating losses for several companies.

Several companies cut back their mining rate and retreated old tailings and concentrates which contained reasonable percentages of secondary minerals. Most mineral sands plants tend to accumulate large tonneages of reject sands in which the trash minerals such as garnet, stauralite etc. concentrate. Quantities of coarse zircon and some rutile also tend to report in these rejects. Under normal operating conditions these sands create too many operational problems to warrant retreatment. However, in times of reduced production they can be successfully retreated. Consequently, the quantities of minerals tabled below have not necessarily been extracted in their entirety from ore mined during the year and are therefore not a representation of the grade being mined.

MINERAL SANDS PRODUCTION STATISTICS

Company	Number Persons Employed	Tonnes Ore Mined (Millions)	Minerals Produced (Tonnes)						Total
			Ilmenite	Leucoxene	Monazite	Rutile	Xenotime	Zircon	
Allied Eneabba Pty. Ltd.	190	4·106	185 154	....	619	34 381	....	56 176	276 330
Cable Sands Pty. Ltd.	59	0·632	79 477	2 152	95	....	....	2 620	84 344
Jennings Mining Ltd.	196	3·968	128 140	....	....	37 268	....	24 812	190 220
W.M.C. Mineral Sands Operation	112	1·794	....	....	....	8 124	....	3 027	11 151
Western Mineral Sands Pty. Ltd.	37	1·425	208 428	....	....	....	....	....	208 428
Westralian Sands Ltd.	133	1·250	99 452	15 093	1 538	....	....	26 065	142 148
Western Titanium Ltd. (Capel)	193	1·463	203 216	1 107	1 190	2 126	9	19 892	227 540
Western Titanium Ltd. (Eneabba)	76	0·603	....	....	....	2 423	....	7 197	9 620
	996	15·241	903 867	18 352	3 442	84 322	9	139 789	1 149 781

Allied Eneabba Pty. Ltd. Production of 276 000 tonnes of minerals was achieved from the treatment of 4 106 000 tonnes of mineral sands and the retreatment of 50 000 tonnes of pre-production tailings.

The very large dry plant took many months to settle down and produce on a consistent and reliable basis.

Cable Sands Pty. Ltd. Mining continued at the Wonnerup and Stratham properties, but at a rate well below full production capabilities. Like most other mineral sands miners Cables were considerably affected by the decreased demand for minerals, particularly zircon.

Production of 84 300 tonnes of minerals was achieved from the treatment of 632 000 tonnes of mineral sands. This production was a decrease of 102 000 tonnes on the previous year.

At Stratham, 10.5 ha of tailings area was covered with topsoil and planted with oats. Large areas of the pit are being left unfilled at the Wonnerup site at the request of the land owner who wishes to use them for water storage.

Jennings Mining Ltd. Jennings produced 190 220 tonnes of minerals from the treatment of 3 968 000 tonnes of mineral sands.

A mobile wet plant was commissioned during the year. Its function is to treat strand ore and is designed to accept feed of variable grade and composition.

The rail spur was completed during the year and consequently the rail loading facilities were shifted from Dongara to Eneabba.

After being refilled with tailings the mining pits are being progressively returned to productive farm land. 8 000 eucalypts were also planted as part of a wind break programme.

W.M.C. Mineral Sands Operation. W.M.C. experienced a very difficult year and had actually ceased mining by the end of 1976. The dry plant has not performed well and the high stripping ratio added to the difficulties.

Before ceasing mining the company had shifted 1 794 000 tonnes of ore and 1 225 000 bank cubic metres of waste. Of the ore mined, 154 600 tonnes of very high grade material was sent directly to the secondary plant for processing. Rutile and Zircon are the only marketable minerals produced and totalled 11 151 tonnes.

Approximately 15 ha of land was rehabilitated by seeding with pasture grasses during the winter months.

Western Mineral Sands Pty. Ltd. Dredging of the dunal system just north of Capel continued throughout the year. 1 425 000 tonnes of ore was dredged and treated for a recovery of 208 428 tonnes of ilmenite and 61 882 tonnes of secondary mineral concentrates which were sold to Westralian Sands.

13 ha of previously mined ground was rehabilitated and added to the cattle farm operated by the company.

Westralian Sands Ltd. Westralian Sands suspended mining operations for several months at their Yoganup minesites. The dry plant continued to operate throughout the year treating mineral concentrates from a number of sources.

From Mineral Claim 675H. 794H and 801H at Yoganup Extended 900 000 tonnes of ore yielded 84 344 tonnes of heavy mineral concentrates. In conjunction with Mid East Minerals 350 000 tonnes were mined from Sussex Location 1 near Busselton, and 31 800 tonnes of heavy mineral concentrates were recovered. In addition, 37 900 tonnes of concentrates from stockpiles and 61 880 tonnes from Western Mineral Sands were delivered to the dry plant. From these concentrates 142 000 tonnes of minerals were recovered.

A programme of treatment plant modification had been almost completed at the close of 1976, the alterations having been designed to improve separation techniques and to add a zircon cleaning unit to the circuit.

67016—(3)

Western Titanium Ltd. (Capel). Western Titanium mined and treated 1 463 000 tonnes of ore and re-treated 89 700 tonnes of old tailings for a recovery of 227 540 tonnes of minerals.

The production of upgraded ilmenite (90% + TiO_2) was cut back by the closure of the No. 1 plant. Reported production for the year was 22 991 tonnes.

Fifty eight hectares were rehabilitated to pasture land. Previously established pasture continued to regenerate satisfactorily. The tree planting programme is continuing and one hectare of land was planted with grape vines.

Western Titanium Ltd. (Eneabba). During the year this company commissioned a new mining and treatment operation at Eneabba and ore handling facilities at the Port of Geraldton.

The ore is pushed into heaps by tracked dozers and then fed to a conveyor system using rubber tyred loaders. As the distance between the ore body and pumping plant increases additional mobile conveyors will be introduced into the system.

Many problems have been encountered in the system and several modifications to plant design had to and still are being made.

The primary wet plant and secondary plant have functioned reasonably well.

Ore mined and treated totalled 603 000 tonnes from which 2 423 tonnes of rutile and 7 197 tonnes of zircon were recovered. Ilmenite production figures have not been supplied.

IRON

Australian Iron and Steel Limited. Pig iron production for the year was 699 356 tonnes—this was 2½% down on the previous year.

An average of 350 men were employed.

The only new plant installed was an additional ore feed bin in the sinter plant.

Wundowie Iron and Steel. 56 836 tonnes of pig iron was produced from 92 072 tonnes of ore railed from Koolyanobbing. This represents a decrease of 10% on the previous year's production.

An average of 76 men were employed.

LIMESTONE

The bulk of quarried limestone continues to be used for road base material. Two small crushing plants supply a sized material but the majority is won using bulldozers which firstly rip and then crush the limestone with their tracks.

The cement producers continue to mine their own limestone. Cockburn cement obtain the bulk of their requirements by dredging lime sands in Cockburn Sound.

Approximately 70 men were employed on limestone production during 1976.

NICKEL

Western Mining Corporation Ltd. Production from the nickel refinery at Kwinana was slightly below that of 1975 with a metallic nickel production of 21 828 tonnes. By-products produced were:—ammonium sulphate 136 098 tonnes copper sulphide 2 490 tonnes and mixed sulphides 894 tonnes.

The 50 000 t.p.a. ammonia plant was commissioned early in the year and full design production was achieved in April.

Equipment installations and modifications to existing plant to increase nickel output to 30 000 tonnes/annum were completed during the year.

Two plants have been installed on the refinery site to collect and purify waste CO_2 gas being discharged from the ammonia plant. One is owned by C.I.G., the other by Carba (Aust.) Ltd. The C.I.G. plant supplies CO_2 back to Western Mining Corporation and retains the surplus for general marketing. All production from the Carba plant is sold by that company to industry generally.

The average number of persons employed at the refinery during 1976 was 473.

SAND

There are 36 sand pits operating in the metropolitan area employing approximately 120 men. The manpower figure does not include truck drivers who operate on a sub-contract system.

Many of the pits are small and privately owned and the bulk of the sand excavated is used for filling purposes. Of the larger pits three are producing silica sand for export, namely, Bell Basic Industries Ltd. at Canning Vale, Pioneer Concrete (W.A.) Pty. Ltd. at Jandakot and The Readymix Group at Jandakot.

At the end of the year there were only two dredges operating in sand pits. Calsil Brick have a small dredge for obtaining silica sand for their own use and Cooper Sand Supplies are commissioning a new dredge at their sand pit in Canning Vale.

TALC

Three Springs Talc Pty. Ltd. The production of 51 227 tonnes of saleable talc was 1 263 tonnes below the 1975 figure. However the tonneage railed increased by 17 144 tones to 56 748 tonnes.

The above production was recovered from the mining of 58 725 tonnes of ore. The stripping of waste for the development of new benches along the eastern wall continued throughout the year.

GREENBUSHES MINERAL FIELD

TIN—TANTALITE CONCENTRATES

Greenbushes Tin N.L. Greenbushes Tin had an eventful year during which they finally got the Balingup-Bridgetown Road diverted to by-pass Greenbushes townsite, thus removing the main highway from the centre of the mining leases and thereby enabling the company to mine deposits of mineral known to exist on the original highway reserve.

Reported production during 1976 was quoted as being—

1 099 348 cubic metres mined

1 099 165 cubic metres treated

680 tonnes of tin/tantalite concentrates.

The estimated value of this production is given as $4 400 000 and 101 persons, including 20 contractor's employees, were engaged on this production.

The company has evolved an efficient treatment process and is able to maintain good continuity of plant operation. The development of deep pit excavations down to rock which is too hard to excavate with the equipment being used, has given the management a better insight into the character of mineral deposition.

The Greenbushes area has been a focal centre for critics of mining for several years, consequently when the company sought to have the highway diverted some fairly stringent rehabilitation conditions were imposed as part of the re-alignment agreement.

Greenbushes Tin N.L. have actively pursued a programme of rehabilitating those mined areas which are readily visible to the public and their overall mining programme has been designed with the object of progressive rehabilitation where possible.

Although there are still signs of antagonism from some of the traditional opponents of mining, the opening of the highway re-alignment has resulted in a greatly reduced volume of public criticism of mining at Greenbushes.

NORTHAMPTON MINERAL FIELD

There was no mining activity in the Northampton Mineral Field during 1976.

YALGOO GOLDFIELD

Geological exploration was again focused on much of the Yalgoo Goldfield during 1976. However, the only reported mineral production other than gold was 278 tonnes of felspar produced from Mineral Claims 59/5800 and 59/5987 some 5 km south of Paynes Find; 0.6 tonnes of tantalite obtained from Mineral Claim 59/5052 at Dalgaranga; and a small

quantity of scheelite mined from claims in the Melville area north of Yalgoo and tested for concentrate recovery at the Northampton State Battery.

The felspar produced from the Paynes Find area was transported to Perth for metallurgical testing.

At Golden Grove, Electrolytic Zinc Company of Australia Limited has continued the exploration of copper-zinc gossans which were discovered in 1971 and optioned to Amax Exploration who then merged with Electrolytic Zinc in a joint exploration venture.

Some 77 diamond drill holes totalling 43 440 metres have been drilled to date and have delineated a total of 13.5 million tonnes of ore averaging 3.59% Cu. The tonneage of zinc mineralisation is relatively small.

The location and associated high costs of bringing this deposit into production will probably delay its exploitation but it does represent a significant resource for the future.

At Mt. Mulgine, Minefields Exploration N.L. carried out an exploratory shaft sinking programme for the purpose of checking diamond drilling indications and to obtain samples for metallurgical tests. The area being examined contains ores of tungsten and may prove to be an economic project.

GOLD

A total of 954 tonnes of ore crushed at the Paynes Find State Battery yielded a total of 24.530 kilograms of gold bullion.

552 tonnes yielding 21.199 kg of gold were mined from the "Ark" Gold Mining Lease 1063. This mine is the mainstay of the Paynes Find area and should continue to yield modest tonneages of ore while the price of gold remains favourable.

The balance of the ore crushed came from small prospecting groups and from screened dump material. 402 tonnes of sundry parcels yielded 3.331 kg of gold bullion.

MURCHISON GOLDFIELD

A number of minor gold producers are still active throughout the Murchison. Mineral production is insignificant but a number of companies are still actively searching for base metals.

GOLD

Mt. Magnet District—Hill 50 Gold Mine. Hill 50 Gold Mine ceased operations after 40 years of mining. In that time the mine produced 3 220 000 tonnes of ore for a return of 42 174 kg of gold being a recovery of 13.1 grams/tonne. The mine has not been abandoned as a reasonable tonneage of mineable ore still exists below the stoped out areas. At current gold prices it is uneconomical to continue mining.

A total of 855 tonnes of ore crushed at Boogardie State Battery during 1976 yielded 2.971 kg of gold and a further 1.507 kg was obtained from the smelting of gold concentrates obtained by operators of cone concentrators.

The principal producer was Mr. J. Delfante who crushed 605 tonnes of ore for a return of 1.962 kg of gold. A further 1.156 kg of gold was obtained from cone concentrates.

Cue—Day Dawn Districts. Activity was directed towards heap leaching gold bearing sands from the Great Fingal Mine at Day Dawn. Initial results appeared to be encouraging but the venture folded up towards the middle of the year, presumably because of extraction problems.

Meekatharra District. A total of 2 801 tonnes of ore from the Murchison Goldfield was crushed at the Meekatharra State Battery for a return of 18.204 kg of gold at an average plate return of 5.4 grams/tonne.

The greatest portion of this throughput came from the "Haveluck" Gold Mining Lease 2015 which produced 1 786 tonnes of ore for a yield of 3.716 kg of gold.

The "Est" Gold Mining Lease 2186 produced 410 tonnes of ore for a plate return of 9.201 kg of gold. The sands assayed 5.5 grams/tonne. Unfortunately, the gold appeared to cut out and the partners had to abandon the lease.

Another crushing of interest was produced from the "Ingliston Consols" Gold Mining Lease 51/2139. 245 tonnes crushed yielded 1.951 kg of gold bullion but the actual return of fine gold was only about 5 grams/tonne. This mine is believed to have potential at depth.

Towards the end of 1976 the Canadian Mining Group, Derry Michener and Booth Pty. Ltd. of Toronto, began treating lump ore from the "Haveluck" Gold Mine to test its suitability to a heap leaching process. Success with this trial could result in some extension of heap leaching trials with other types of gold ores.

LOWER PEAK HILL GOLDFIELD

GOLD

From Gold Mining Lease 611P at Peak Hill, Messrs Spencer and Coumbe crushed 460 tonnes at Meekatharra for a return of 1.803 kg of gold averaging 3.9 grams/tonne. The sands averaged 2.9 grams/tonne.

The same syndicate also crushed 415 tonnes of material from Gold Mining Lease 613P which is in the same locality. This parcel yielded 1.998 kg at an average of 4.8 grams/tonne with the sands assaying 2.9 grams/tonne.

Spencer and Coumbe also smelted a total of 0.822 kg of gold which had been recovered from concentrates of a cone concentrator used on Gold Mining Lease 609P and 610P.

TALC

Westside Mines N.L. Westside Mines N.L. were the sole mineral producers in this area. 31 500 tonnes of material was mined of which 17 000 tonnes was selected for crushing and screening, resulting in a recovery of 9 200 tonnes of + 25 mm talc.

A number of modifications were made to the plant during the year. Dust emission has been a considerable problem which has not yet been fully overcome.

PORT HEDLAND INSPECTORATE

Prepared by G. J. Dodge,
Mining Engineer-Senior Inspector of Mines

The Mining Industry continued to grow in terms of size, capital investment and numbers employed. Most iron ore companies continued to expand their facilities to permit increased production. The iron ore industry alone now employs in excess of 10 600 people.

The gold/antimony mine at Blue Spec commenced production in April and the Telfer gold project was nearing production at the end of the year.

BARITE

Dresser Minerals International Inc. Low product demand is still preventing Dresser from maintaining a full scale mining operation relative to the potential of the ore body. All production temporarily ceased on the 1st November after 40 000 tonnes of waste and 6 800 tonnes of ore had been mined.

COPPER

Whim Creek Consolidated N.L. A short term mining operation was carried out on a chalcocite ore body at Whundo between May and October. From the open cut which is approximately 200 m x 90 m x 40 m deep, 319 000 tonnes of waste and 6 200 tonnes of ore at 27% copper were mined.

Mining and crushing was conducted on a contract basis thus permitting a high stripping ratio because of low capital outlay. Further ore is available and may be mined if the first operation proves to be financially successful.

CRUSHED ROCK

The Readymix Group (W.A.) and Pioneer Concrete (W.A.) Pty. Ltd. operated a series of quarries for the production of road, railway and concrete materials.

Most quarries operate on an intermittent basis, with plant and equipment being shifted from one site to another as required.

At Yaringa the Pioneer Group produced 186 000 tonnes or road material for the Main Roads Department. The Readymix Group operated quarries at Turner River and Q6 on the Mt. Newman railway, but decline to release production figures.

GOLD

Mulga Mines Pty. Limited. The official opening of the Blue Spec Mine took place on 9th September 1976, but full production had commenced in April.

Mining is by cut and fill stoping using conventional air leg drills, blut small diesel powered loaders and trucks for mucking and hauling. Access to each stope horizon is by cross cuts driven off a decline which commences at the 4 level. Ore is trucked up the decline to an ore pass at the shaft. Cement is added to a mixture of tailings and natural sand and is pumped into the stopes as fill.

In their first year of operation the company treated 18 267 tonnes of ore for a recovery of 218.2 tonnes of 16% antimony concentrate and 196.56 kilos of gold bullion containing 177.439 kg of gold. Development consisted of: declines 600 metres; driving 228 metres; rising 56 metres. Exploration diamond drilling totalled 79 metres. An average of 105 personnel were employed on the minesite.

The company reported ore reserves of 80 000 tonnes averaging 4.63% Sb and 45 grams Au per tonne.

Telfer Project. Construction and quarry development continued throughout 1976 at this project. By the end of the year most of the township and associated amenities had been completed, the power house was operational, and the treatment plant, workshops and office facilities were well under way. Gold production had been scheduled to commence late in 1976, but delays in construction prevented this target being met. Mine development continued, resulting in waste stripping being well advanced at the end of the year.

Mining is by conventional open cut methods using crawler drills, large rubber tyred loaders and 50 tonne dump trucks. Waste removal is being done on contract by Quest Mining, while the ore is being mined by the company. A total of 1 249 000 tonnes of ore and waste were mined, the ore being stockpiled in front of the crusher. By the end of the year the company was employing a mine work force of 115.

The open cut is designed to permit ore removal to a depth of 50 metres which is the limit of oxidation. Ore reserves to that depth are reported as 3 900 000 tonnes at 9.6 grams/tonne.

Comet Gold Mines. Reconditioning of the treatment plant and power house was undertaken throughout the year. In conjunction with this, tailings retreatment was continued as facilities permitted. Retreatment of 1 787 tonnes resulted in a recovery of 9.83 kg of gold and 2.99 kg of silver. Underground operations remained on care and maintenance throughout the year.

Big Stubby M.C's 884-1070. Exploration diamond drilling continued throughout the year. A total of 26 holes have now been completed. Mr. S. H. Stubbs reports that results are encouraging as mineralisation containing copper, lead, zinc, silver and gold has been found over a large area.

IRON

Although the number of personnel employed by the five operating companies increased by 804 to 10 632, the tonnage of ore broken decreased by 29.077 million tonnes to 102.234 million tonnes on 1975 figures. However, ore shipped was only marginally affected with a drop of 1.031 million tonnes to 84.279 million tonnes. Industrial disputes were one of the major causes of production losses.

The companies reported a combined total tonnage of ore and waste mined of 156.792 million tonnes and used 53 630 tonnes of explosives.

Production and Shipping (Million Tonne Units)

Company	Persons Employed	Ore Broken	Ore Shipped			Total
			Lump	Fines	Pellets	
Hamersley Iron	4 159	47·172	17·138	17·418	1·547	36·103
Mt. Newman Mining	3 205	32·232	14·055	11·083	....	25·138
C.R.R.I.A.	1 530	12·645	....	8·586	4·294	12·880
Goldworthy Mining	1 360	7·158	3·857	3·354	....	7·211
Dampier Mining	378	3·027	2·947	....	....	2·947
Totals	10 632	102·234	37·997	40·441	5·841	84·279

Hamersley Iron Pty. Ltd. At Mt. Tom Price 28.897 million tonnes of ore and 3.030 million tonnes of waste were mined from thirteen benches using five rotary drills, eight-9 m^3 shovels, 31-120B and five-3200B Wabco trucks.

At Paraburdoo 18.275 million tonnes of ore and 5.365 million tonnes of waste were mined from eight benches using three rotary drills, six-9 m^3 shovels, 22-100 tonne KW Dart and eight-120B Wabco trucks.

Shipments of ore totalled 36.103 million tonnes at an average grade of 63.8% Fe. In achieving their output, the company employed 4 159 persons, drilled 383 700 metres of blast holes, consumed 19 372 tonnes of explosives, 394 million kWh of electricity and 8.8 million kilolitres of water.

During the year the company carried out a major overhaul of the pellet plant, including the relining of the furnace, and commenced a programme of modifications to ore handling equipment to incorporate dust suppression facilties. A decision was taken during 1976 to proceed with the construction of a concentration plant at Mt. Tom Price to treat 13 million tonnes/annum of low grade ore. Site clearing was commenced. Construction is expected to take approximately 2½ years.

Mt. Newman Mining Company Pty. Ltd. At Mt. Whaleback 32.232 million tonnes of ore and 27.510 million tonnes of waste were mined. Shipments of ore totalled 25.139 million tonnes at an average grade of 63.68% Fe.

Expansion of mine and port facilities to enable a 40 million tonne/year production continued throughout the year. A seven day week, round the clock mining roster was introduced, even so, production of ore was down by more than 12 million tonnes on the previous year. A high percentage of this reduction being due to industrial disputes.

In achieving the above outputs the company employed 3 205 people, drilled 574 800 metres of blast holes and consumed 22 578 tonnes of explosives and 4.524 million kilolitres of water.

During the year the No. 2 Rail Car Dumper was commissioned at Port Hedland. At Newman, 10-3200 Wabco trucks, 3-Series 3 BE drills, and 1-2800 P & H shovel were added to the production fleet. The company also set up a separate division to construct and maintain haul roads and have purchased 2-Ingersol Rand Compactor/Rollers.

Goldsworthy Mining Limited. At Goldsworthy, 1.409 million tonnes of ore and 7.181 million tonnes of waste were mined during the year. The high waste to ore ratio being brought about by the continuation of the programme to strip the hanging wall of the pit.

At Shay Gap 5.749 million tonnes of ore and 8.315 million tonnes of waste were mined.

The company employed an average of 1 360 people throughout all operations. Ore shipments totalled 7.211 million tonnes at an average grade of 63.01%, this figure being only 50 000 tonnes down on 1975.

In achieving their output the company drilled 157 000 metres of blast holes, consumed 5 950 tonnes of explosives, 2.136 million kilolitres of fresh and 0.755 million kilolitres of salt water.

The only major new equipment added during the year was a Bucyrus/Erie blast hole drill.

Cliffs Robe River Iron Associates. At Pannawonica, mine production was increased by 1.762 million tonnes to 12.645 million tonnes. No waste was broken during the year.

All ore is crushed and ground at Cape Lambert. Approximately 30% is pelletised, the remainder being shipped as a—6 mm sintering fines. Ore shipped totalled 12.5 million tonnes at an average grade of 59.23% Fe.

In all, the company employs 1 530 people of whom 1 100 are at Cape Lambert. In achieving the above outputs, 134 300 metres of blast holes were drilled and 4 569 tonnes of explosives were consumed. Water consumption by the company amounted to 2.866 million kilolitres of fresh and 33 000 kilolitres of salt.

During 1976 a Joy RR11 blast hole drill and a standby Merrlees V16 Diesel generating unit were added to the mine site and Lambert power house respectively. Dust suppression and spillage collection equipment was expanded throughout the Cape Lambert plant resulting in substantial improvement to dust suppression generally.

Dampier Mining Limited-Koolan Island. At Koolan, 12 metre benches are mined by conventional open cut methods utilising rotary and percussion drills, electric power shovels, rubber tyred loaders and 85 tonne off-highway trucks. Ore mined totalled 2.382 million tonnes while waste amounted to 2.986 million tonnes. The company shipped 2.333 million tonnes of ore at an average grade of 67.2% Fe.

In achieving the above outputs the company drilled 54 868 metres of rotary holes, 18 433 metres of percussion holes and consumed 1 073 tonnes of explosives. The average number of people employed was 278.

During 1976, 4-85 tonne trucks, 1-GD60 rubber tyred rotary drill and 1-HDC-F crawler drill were added to the mining equipment. The company is planning to increase ore production to 3 million tonnes per annum in 1977.

Cockatoo Island. Ore available for mining by open cut methods is almost depleted. Ore mined amounted to 645 100 tonnes. Waste removed totalled 171 000 tonnes. The company shipped 613 391 tonnes at an average grade of 68.9% Fe.

All production drilling is done by percussion drills using 165 mm diameter bits. These drilled 7 457 metres of holes in which were charged 88 tonnes of explosives. An average of 100 people were employed on the island.

Feasibility studies as to the viability of underground mining continued throughout the year. In conjunction with these studies the decline was driven a further 238 metres, ceasing in November after having advanced a total of 343 metres from the entrance.

SALT

Salt producers reported the harvesting of 4.946 million tonnes and shipments of 3.906 million tonnes. The companies report that a total area of 20 592 ha are now being utilised in the production of salt.

Texada Mines Pty. Ltd.—Lake McLeod. Texada harvested 1.616 million tonnes of raw salts and shipped 1.040 million tonnes of clean, washed salt. The company employed an average of 166 people.

Dampier Salt Limited—Dampier. Operation continued throughout the year, with shipments totalling 1.5 million tonnes. The company has requested that other relevant figures be withheld from publication.

Leslie Salt Company—Port Hedland. Production of raw salt amounted to 1 103 521 tonnes and 1 030 607 tonnes of clean, washed salt were shipped.

The workforce was increased to 58, and work was commenced to increase crystallizer capacity by approximately 20%.

Shark Bay Salt. This company has requested that all information be withheld from publication.

TIN

Pilbara Concentrates. Extensive alterations were made to the plant during the year. An 8 cubic metre scraper with an airconditioned cabin has been added to the mining equipment. Production of tin concentrate totalled 37.20 tonnes.

Mining operations are being phased out in the Mooleyella area close to the Brockman River and will recommence approximately 4 kilometres to the north east.

COAL MINING

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

Another record annual output of coal was achieved by the coal industry at Collie during 1976. The output of 2 268 731 tonnes was an increase of 154 749 tonnes or 7.32 per cent on the previous year's output of 2 113 982 tonnes. Whilst the increase was significantly below the 667 934 tonnes or 46.2 per cent increase achieved in 1975, the development of the industry continued towards meeting the greater requirements for coal which must come in the future.

There was a slight reduction in the proportion of underground mined coal down from 26.08 to 24.34 per cent of the total output, produced from Western No. 2 Colliery. The two open cuts, Western No. 5 and Muja produced 75.66 per cent of the output.

The total value of the coal produced during 1976 was $20 468 874, an increase of $5 395 203 compared with the 1975 value of $15 073 671.

Western Collieries Ltd. Western No. 2 Mine.

This colliery produced an output of 552 294 tonnes of coal, an increase of only 987 tonnes over the previous year's output of 551 307 tonnes.

The workings are now very extensive at this colliery where the bord and pillar system of mining is practiced and production levels are over one half of a million tonnes of coal per annum.

Towards the end of May, work commenced on the construction of three portals for the development of new entries into the mine from the South East. Good progress was made on initial opening out work in dry and quite dusty conditions in the places opened out in the Wyvern Seam from the South Wall of No. 1 Bay at Western No. 5 Open Cut. These places are at a direct line distance of 6.4 kilometres from the terminated drivage faces of the No. 1 West District Development Headings. They are 4 kilometres by road from the mine office and 1.2 kilometres in a direct line from the No. 6 East District Development Headings. As a common ventilation system will be established when headings from the new entries are connected with No. 6 East District, approval was granted for the separate workings to be regarded as a part of Western No. 2 Colliery.

Mining on first working was completed in No. 4 West District "F" Panel and in No. 1 West District. Apart from the separate new entries area, work was undertaken in widespread areas of Nos. 6 West and East Districts, Nos. 2 and 3B West Districts and No. 4B East District.

The ventilation flows were satisfactory for the operation of mobile diesel engined vehicles which are in wide use throughout the mine. The use of diesel powered front end loaders is being extended as scoop loading is being phased out.

Hydraulically induced weight was experienced in a number of different areas where this phenomenon would normally be expected in the conditions prevailing at the mine. Various different supports systems are approved for application in the widely different conditions.

There were considerable extensions to the surface coal handling and crushing installations adjacent to the railway sidings. Coal from this colliery and from Western No. 5 Open Cut Mine is handled by these installations.

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

The output of 666 164 tonnes was an increase of practically 13.0 per cent over the 1975 output of 589 465 tonnes and was the greatest percentage increase for any mine on the field.

At the Wyvern Seam Excavations, coal winning was completed from the South end of No. 2 Bay, and from No. 3 Bay in the area to the North of the road and creek which were on overburden across the excavations. The road and creek were, thereafter, diverted on to backfill and final overburden removal was accomplished over the strip of steeply dipping Wyvern Seam Coal.

Difficulties were encountered with prolifically water bearing strata at the separate "N9" Excavation opened out on the Neath Seam in an area where the Cardiff Seam occurred as oxidised "smut" coal. Ultimately, good progress was made at this excavation from where practically all of the coal was won out by the end of the year.

Early in the year, a channel was excavated to facilitate the permanent diversion of a portion of the South Branch of the Collie River. This work which was necessary in relation to proposals for opening out the Western Nos. "5A" and "5B" Areas over the Cardiff and Neath Seams on the West bank of the river, was carried out systematically and satisfactorily.

Good progress was made on bush clearing and opening out at the Western No. 5A Area from where topsoil was separately stockpiled from other overburden. A considerable area of Neath Seam coal was exposed down from the "blind outcrop".

At the North end of the main excavations on the Cardiff-Neath Seams work continued satisfactorily on overburden removal and coal winning from areas of the two seams. Some instability which was evident in the strata along the highwall and the terminal West Wall necessitated special precautions during working. Overburden was being satisfactorily and safely backfilled to the rise side of the coal winning and overburden removal excavations.

There is a very considerable range and diversity of scrapers, loaders, trucks and other earth moving equipment at the mine where all new entrants are receiving systematic training. Equipment replacements were complementary to the objective of maintaining safe conditions. Older Cat 988 Wheel Loaders without ROPS covers were taken out of service and replaced by new relatively stable Michigan 475B Loaders as part of the programme to increase overburden removal and coal production.

The Griffin Coal Mining Company Ltd.—Muja Open Cut

With an output of 1 050 273 tonnes or 77 063 tonnes more than the previous year's output of 973 210 tonnes, this colliery became the first mine in Collie to produce one million tonnes in one year.

On Block No. 7, across the short axis of the Muja Formation Basin, coal was won from eight seams between and inclusive of "Ate" and "Hebe". At the end of the year the only remaining exposed coal in the Block was that in a considerable area of the Hebe Seam. The final stages of overburden removal were in progress in this area where the complete and continuous exposure of overburden and coal faces along the high wall from the surface down to the Hebe Seam give the appearance of a very systematically planned operation.

Special precautionary measures were taken to stabilise the backwall where a creep occurred at the East Section, North Extension. Multiple seam coal winning and removal of intervening overburden was carried out safely near this area where the excavations were benched in the steeply inclined strata. Several spontaneous combustion outbreaks were experienced during excavation of Hebe Seam coal over old underground workings in East Section Panel No. 6 where special techniques were introduced to safely win the steeply dipping coal near the fault line. Coal was won from a considerable area of the Iona Seam adjacent to this panel.

At the North Extension Excavation, removal of the thick laterite capping was completed and forward stripping via mobile elevating scrapers continued down through the Nakina Formation to the stage at which hydraulic excavators, rope shovels, and wheel loaders shall continue the work of intercepting and exposing seams in the coal measures. The scrapers will be diverted to forward stripping on Block No. 8.

Revised backfilling procedures incorporating 20 m high uncompacted lifts of overburden with 25 m wide benches between successive lifts and an overall slope angle 22½° were introduced where overburden is being backfilled at the South West of the mine.

General

There were 546 reported accidents of which 473 were minor and 73 were classified as serious where an employee was absent from work for fifteen days or more. With 857 persons employed, the labour force in the industry was virtually the same as that for the previous year. There were 327 persons in underground or predominantly underground occupations.

Over fifty million tonnes of coal have now been produced from the coalfield during the practically 78 years since mining commenced at Collie in 1898. Of the 50 349 255 tonnes produced during this period, 4 382 712 tonnes or 8.74 per cent was produced during the past two years.

DRILLING OPERATIONS

D. A. MacPherson—Drilling Engineer

During 1976 the Drilling Section was responsible for the drilling of 5 558 metres in 106 bores, the development of 40 aquifers in 30 bores and the testing of 20 aquifers in 10 bores. The work was all carried out by Departmental employees and equipment.

The total meterage drilled is well below that for 1975 (13 367 metres in 685 bores) partly because no seismic shot holes were drilled, and partly because drilling was discontinued for some months to allow development and testing of a number of existing bores. Future procedure will be to carry out any development and testing required on bores as soon as they are drilled, instead of drilling all bores on a project and then carrying out the development and testing. The purpose of the change is to provide a more even flow of information to clients, and to allow earlier commencement of water level recording on projects.

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

Comments on staff and plant matters are also given.

BOORAGOON

This job located near the coast approximately 70 kilometres north of Perth, was undertaken at the request of the Metropolitan Water Supply, Sewerage and Drainage Board, and was financed by that board. The job consisted of cleaning out an abandoned and plugged oil investigation bore, perforating the casing at a selected depth, and developing and testing the bore to provide water levels, water quality, aquifer information and a long term deep aquifer water level measuring facility.

The work was carried out at the beginning of the year and no further involvement in this job is envisaged.

MOORA LINE

This job forms part of the State wide ground water investigation conducted by the Geological Survey of Western Australia, and is financed by the Department of Mines. The Moora Line commences at Moora and runs west to within 3 miles of the coast.

The job is required to provide information on stratigraphy and ground water conditions to a projected depth of 762 metres at selected sites on the line. This is generally effected by drilling one bore to target depth to provide strata samples, geophysical bore logs, and side wall cores. This bore is then cased to bottom, cemented and perforated at two intervals, each perforated interval is isolated by packers and developed and airlifted to provide accurate water samples and water level measurements for the aquifers at the perforated intervals. Subsequent bores may be drilled at the same site to provide water quality and water level measurements for aquifers at other levels. The bores are left in suitable condition for continuous water level measurements.

Work was commenced early in the year by recovering a stuck drill string at Site 3. Drilling operations were then completed at Sites 3, 4 and 6. Work was then discontinued to allow moving the rig to more urgent work and towards the end of the year development of the existing bores was commenced and was in progress at the end of year.

ENEABBA LINE

This job forms part of the State wide ground water investigation conducted by the Geological Survey of Western Australia and is financed by the Department of Mines. The Eneabba Line commences about 24 kilometres West of Winchester and runs West along the Carnamah/Eneabba road and continues West past Eneabba to within 8 kilometres of the coast. The job is required to provide information on stratigraphy and ground water conditions to a projected depth of 762 metres at selected sites on the line. This is generally effected by drilling one bore to target depth to provide strata samples, geophysical bore logs and side wall cores. This bore is then screened at a selected depth and airlifted to provide accurate water samples and water level measurements for the aquifer at the selected depth. Subsequent bores are drilled at the same site to provide water quality and water level measurements for aquifers at different depths. The bores are left in suitable condition for continuous water level measurements.

The drilling on this job was completed during 1974. No work was carried out during 1975, due to plant and financial limitations. During 1976 development and testing was carried out on existing bores at Sites 8, 9, 10 and 11 on the line, and some bore repair work was done at Site 7.

At Sites 8 and 9 a number of aquifers in each bore were developed and separately tested, using explosive perforation of cemented bore casings to tap the aquifers and using compression packers to isolate the aquifers for individual testing. The system worked well and its use is being extended to other jobs.

This job has now been closed down and it is not expected that any more work will be done in the area for some years.

BUNBURY/YOGANUP

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

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

Towards the end of the year, development and testing on the previously drilled Picton Line Bore 1 was carried out. Six separate aquifers were investigated using explosive perforations to tap the aquifers and compression packers to isolate each aquifer for individual testing.

Automatic recording equipment was used to record the variables during the testing. Some difficulties were experienced with this equipment, but the overall results were satisfactory, and provided considerably more information than is obtained by normal manual recording methods.

BUNBURY SHALLOW JOB

This job (previously called Bunbury Job) forms part of the State wide ground water investigation carried out by the Geological Survey of Western Australia and is financed by the Department of Mines The work is being done in the Bunbury/Busselton area. The job is required to provide information on stratigraphy and ground water conditions to a projected depth of 100 metres at selected sites in the area. This is being done by drilling one bore at each site to target depth to provide strata samples and geophysical bore logs. This bore is then screened and tested. On completion of the main bore, one or two shallower bores are drilled at each site to provide additional information on water levels in the area.

The work was in progress at the start of the year. It was continued until the field unit had to be moved for more urgent work elsewhere. It is expected that further work will be carried out during 1977.

LA PORTE

This job consisted of constructing and developing one bore in the effluent disposal area of the La Porte titanium white processing plant at Australind. The work was carried out for, and financed by the Department of Public Works.

The bore was designed to provide information about the effect of the mine effluent on ground water in the area.

MANJIMUP WOODCHIP INDUSTRY

This job forms part of an investigation into the effects of logging for the Manjimup Woodchip Industry on the ground water regime in the area. The work is being carried out for an investigating committee and is financed by the Department of Mines. The work consists of drilling a bore by continuous coring hollow auger methods at each of a number of selected sites and completing the bores as water sampling and water level measurement points for long term recording of ground water variations in the area. At specially selected points coring is continued into bedrock by diamond drilling methods and casing cemented down to bedrock to provide information on water movements in the bedrock of the area.

The work was commenced early in 1976 and proceeded smoothly to completion. No further drilling work is expected.

A small bore testing programme will be carried out in 1977.

FORTESCUE VALLEY

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

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

During 1976 some of the bores were located in a suspected old connecting valley between the Fortescue and Robe River Systems. The remainder of the work was carried out up stream of Millstream Homestead.

Difficulties were experienced in part of the work due to the desired bore depths exceeding the capacity of the plant in use, and consequently some bores were left for future completion by larger plant.

It is expected that the work will be resumed in 1977.

CANNING BASIN

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

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

During 1976 most of the bores on this job were developed ready for testing during 1977. Testing could not be done during 1976 as the Geological Survey had specified use of automatic recording of test variables to provide better information particularly during the early part of the tests. Suitable automatic recording equipment was unavailable.

A bore at one site which had been flowing uncontrolled due to construction faults was plugged with cement.

It is expected that testing of existing bores will be completed in 1977.

JOONDALUP

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

At the start of 1976 all work on the job had been completed except for two special requirement sites. Work on these commenced late in 1976 and, at the end of the year, work at one site was nearly completed.

The work at each of the special sites consists of drilling a bore to bedrock to provide strata samples and geophysical bore logs, followed by construction of a screened bore to a selected depth to provide water quality and water level information from that depth. A final bore 2 metres deep is drilled at each site to provide water level information in the top soil layers in the area.

It is expected that this job will be completed early in 1977.

STAFF

No staff changes in the section took place during 1976.

PLANT

During 1976 no new items of major plant were received.

A Ruston Bucyrus cable tool drilling rig was sold during the year, and an F 20 Mindrill diamond drilling rig was also sold. These items had reached the end of their economic life.

Various other items of plant and equipment which had reached the end of their economic life were sold and where necessary replaced.

TABLE SHOWING WORK CARRIED OUT DURING YEAR ENDED 31/12/76

Place	Purpose	Type of Work	Done By	No. of Bores	No. of Aquifers	Meterage
Booragoon (Moore River)	Groundwater Investigation	Development	Dept. of Mines	1	1	....
		Aquifer testing	Dept. of Mines	1	1	....
Moora Line	Groundwater Investigation	Rotary Drilling	Dept. of Mines	4	....	1 847
		Development	Dept. of Mines	3	3	....
Eneabba Line	Groundwater Investigation	Development	Dept. of Mines	8	13	....
		Testing	Dept. of Mines	8	13	....
Bunbury (Deep Aquifers)	Groundwater Investigation	Development	Dept. of Mines	1	6	....
		Testing	Dept. of Mines	1	6	....
Bunbury (Shallow Aquifers)	Groundwater Investigation	Rotary Drilling	Dept. of Mines	21	....	1 289·5
La Porte	Investigation of Effluent disposal	Rotary Drilling	Dept. of Mines	1	....	62
		Development	Dept. of Mines	1	1	....
Manjimup	Investigation of effects of logging on groundwater	Rotary (Auger) Drilling	Dept. of Mines	42	....	647
Fortescue Valley	Groundwater Investigation	Rotary Drilling	Dept. of Mines	34	....	1 571
Canning Basin	Groundwater Investigation	Development	Dept. of Mines	16	16	....
		Plugging	Dept. of Mines	1	....	....
Joondalup	Groundwater Investigation	Rotary Drilling	Dept. of Mines	4	....	141·5
			Totals—			
			Drilling	106	....	5 558
			Developing	30	40	....
			Testing	10	20	....
			Plugging	1	....	....

BOARD OF EXAMINERS

FOR MINE MANAGER'S AND UNDERGROUND SUPERVISOR'S CERTIFICATES

W. J. Cahill—Secretary

Herewith I submit the Annual Report on the activities of the Board of Examiners for the year, 1976.

Mining Law Examinations

Two examinations were again held in 1976—the normal examination in April and a special examination in December—in conjunction with the Underground Supervisor's examination. Details of each examination are as follows:—

April 2, 1976—

Entries	16
Admitted	16
Pass	10

The date originally set for this examination was April 5, 1976, but in view of the new regulations being promulgated on that date, the examination date was amended to April 2, 1976. The names of the successful candidates were:—

Bartlett, P. M.
Diamantes, P. J.
Fraser, R. D.
Harken, R. M.
Rimes, M. J.
Robertson, G. E.
Jeppesen, G.
Jardine, G. H.
Philpott, M. W.
Stark, T. A.

This was the last examination covering the old regulations.

November 19, 1976—

Entries	15
Admitted	15
Pass	8

The names of the successful candidates were:—

Bullo, V. A.
Denbrok, R. P.
Lloyd, R. J.
McAlister, J.
Watson, A.
Mein, E. S. M.
Elvish, K. J.
Pearce, P. I. B.

This was the first Mining Law examination covering the new regulations and did not include questions on the Mining Act.

Underground Supervisor's Examination

The normal date for this examination is the first week in September each year. However, in 1976, due to the absence of the Secretary on long service leave, the examination was not held until November 19, 1976.

November 19, 1976—Entries were attracted from the following centres:—

Kalgoorlie	20
Norseman	3
Nullagine	2
Southern Cross	3
Laverton	1

The following number of applications were accepted:—

Kalgoorlie	16
Norseman	3
Nullagine	2
Southern Cross	2

Results were as follows:—

Passed	19
Failed	4

Certificates of Competency have been approved for issue to the successful candidates as follows:—

Kalgoorlie:

Bartlett, A. P.
Biddle, R. F.
Booth, H. M.
Bullo, V. A.
Conway, F. L.
Demler, B. W.
Denbrok, R. P.
Franklyn, L. E.
Helenius, U. U.
Kaserer, K. J.
Nagy, I.
Ravlich, J. J.
Snell, W. E.

Norseman:

Bojesen, F. W.
Gallagher, V.
Rumble, M. T.

Nullagine:

Hassan, G. (Restricted to Mulga Mines Operations of Blue Spec Project).
Missler, W.

Southern Cross:

Elvish, K. J.

In addition to the above approvals by ordinary examination method, the following certificates have also been approved for issue:—

Patterson, B. S., Palmer, A. J., Owens, A. D., Jardine, G. H., Bartlett, P. M. (By virtue of having passed the Mining Law examination for Mine Manager Certificate of Competency and producing evidence of required practical experience and holders of Mining Degree).

Gardener, J. E. (Examined orally at Agnew by I. W. Loxton and A. C. Cruickshank on 11/8/1976. Certificate restricted to Agnew Decline Development Operations).

Mine Manager's Certificates

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

Smith, G. M.
Diamantes, P. J.
Boving, N. O.
Davis, C. W.
Philpott, M. W.
Jeppesen, G.
Harding, C. G.
Sheppard, I.

General

In 1976, in compliance with the new regulations, a second Chamber of Mines representative in Mr. Colin Cruickshank, joined the Board of Examiners. The structure of the Board now being:—

Chairman—Mr. A. Y. Wilson.

Members—Dr. I. O. Jones (Principal of W.A.S.M.), Mr. J. Faichney (Senior Inspector of Mines), Mr. N. R. Hooker, Mr. C. Cruickshank (Chamber of Mines Reps.), Mr. W. J. Cahill (Secretary).

Owing to the absence of the Secretary on Long Service Leave, only three meetings were held during the year. During the Secretary's absence, Mr. J. M. Murphy of the School of Mines acted on his behalf and dealt with any urgent correspondence and applications received.

In view of the lateness of the Underground Supervisor's Examination (November 19, 1976) the Board had no time in which to visit outlying areas for the oral examinations and candidates from those areas were examined at Kalgoorlie, an exception being Nullagine, where candidates were examined in the Oral Section by Mr. Cruickshank and Mr. Faichney.

BOARD OF EXAMINERS

FOR QUARRY MANAGER'S CERTIFICATES

J. A. Suda—Secretary

The Mines Regulation Act, Regulations, 1976, Part 3 provides for the issue of Quarry Manager's Certificates and Restricted Quarry Manager's Certificates of Service and Competency.

For the purpose of granting these certificates a Board of Examiners consisting of the following personnel was established:

The State Mining Engineer; the Principal Senior Inspector of Mines; the Director, Technical Education Division, Education Department of Western Australia and two persons nominated by the Chamber of Mines of Western Australia.

Three meetings of the Board were held during 1976, the inaugural meeting being held at Mineral House on 21st May, 1976.

During 1976 twenty applicants were issued with Quarry Manager's Certificates of Service and seven applicants were issued with Restricted Quarry Manager's Certificates of Service. Ten applicants for certificates were unsuccessful.

The names of the successful applicants were:—

Quarry Manager's Certificate of Service

Simpson, F.
Cornelius, R. J.
Roberts, J.
Francis, B. M.
Brown, P. E.
Osborne, G. A.
Gunn, I. L.
Maher, B. J.
Bale, M. D.
Joyce, M. C.
Blackburn, J. D.
Ford, A. T.
Salisbury, J.
Smith, M. K.
Davey, J. M.
Fitzgerald, A. C.
Giles, A. D.
Fairhead, R.
Forrest, M. W.
Treagus, A. G.

Restricted Quarry Manager's Certificate of Service

De Lacy, J.
Stone, G. R.
Purdy, R. W.
Riddick, C. J.
Robbins, J. W.
Whitaker, A. L.
Mitchell, A. S.

Quarry Manager's Certificate of Competency

No certificates were issued during 1976.

VENTILATION BOARD

J. A. Suda—Secretary

The Ventilation Board was established under the provisions of the Mines Regulation Act, 1946-1974 and Regulations and consists of five members: Mr. A. Y. Wilson, State Mining Engineer (Chairman); Dr. A. G. Cumpston, Director—Occupational Health; Mr. J. M. Faichney, Principal Senior Inspector of Mines; Mr. R. Powell, Senior Engineer, Clean Air; Mr. I. Loxton, Senior Inspector of Mines, Kalgoorlie.

The Ventilation Board met seven times during 1976 and members made an inspection of most underground, open cut and mineral sands mining operations in the State during the year.

The purpose of these visits was to explain to each company its obligations under the provisions of Part 8—Ventilation and Control of Dust and Atmospheric Contaminants contained in the new regulations and also to discuss sampling strategy outlined in a publication it had prepared entitled "Requirements for the Evaluation of Dust Concentrations in the Mining Industry".

Under the requirements each company is required to forward to the Board, monthly records of dust sampling surveys of its mining operations. These sampling returns are to be data processed and computerised for record purposes and returns are required from each company commencing January 1977.

DIVISION III

Report of the Superintendent of State Batteries—1976

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, 1976.

Crushing Gold Ores

One 20 head, six 10 head, and seven 5 head mills crushed 40 748.3 tonnes of ore made up of 311 separate parcels, an average of 131.0 tonnes per parcel. The bullion recovered amounted to 255.972 kilograms, estimated to contain 216.934 kilograms of fine gold, equal to 5.32 grams per tonne of ore.

The average value after amalgamation but before cyaniding was 2.20 grams per tonne, giving an average value of ore received of 7.52 grams per tonne, compared with 7.91 grams per tonne for 1975.

The cost of crushing the 40 748.3 tonnes was $28.66 per tonne. In 1975 54 048.6 tonnes were crushed at the gold plants, for a cost of $20.19 per tonne.

Cyaniding

Six plants treated 17 728 tonnes of tailings from amalgamation for a production of 48.900 kilograms of fine gold. The average content was 4.00 grams per tonne before cyanidation, while the residue after treatment was 1.14 grams per tonne giving a theoretical recovery of 71.4%. The actual extraction was 68.8%. The cost of cyaniding was $14.90 per tonne, higher than the previous year when 11 163 tonnes were treated at a cost of $13.70 per tonne.

Silver recovered by the cyaniding of gold tailings was valued at $467.33.

TREATMENT OF ORES OTHER THAN GOLD

Lead Ores

There was no lead ore treated in 1976.

Tungsten Ores

The Northampton Battery crushed 27.2 tonnes of scheelite ore for a recovery of 503 kilograms of concentrates.

Tin Ore

The Marble Bar Magnetic Plant treated 2.31 tonnes of alluvial tin concentrates for a recovery of 1.43 tonnes of high grade concentrates.

Value of Production

The estimated value of production from the State Batteries since their inception, excluding the value of gold tax paid to the Commonwealth is:

	1976 $	Since Inception $
GOLD		
Gold	871 165	44 099 129
OTHER METALS		
Silver	467	5 452
Tin (Concentrate)	6 918	487 852
Tungsten (Concentrates)	2 590	44 185
Copper (ores for Agricultural use)	....	11 932
Lead and Zinc (Concentrates)	....	1 560 634
Tantalite-Columbite (Concentrates)	....	73 459
Total other metals	$9 975	$2 183 514
Grand total	$881 140	$46 282 643

FINANCIAL

	Tonnes	Expenditure $	Receipts $	Loss $
Crushing—Gold mills	40 748.3	1 167 942	114 058	1 053 884
Crushing—Northampton Lead Plant	27.2	25 981	82	25 900
Magnetic Separator	2.3	112	93	19
Cyaniding	17 728.0	264 092	89 434	174 657
	58 505.8	$1 458 127	$203 667	$1 254 460

The loss of $1 254 460 is an increase of $154 616 on the previous year. It does not include depreciation and interest on capital. Capital expenditure, all from Consolidated Revenue Fund was incurred as follows:

	$
Coolgardie (Conversion to A/C power)	604.00
Kalgoorlie (Purchase of Plant)	5 050.00
Meekatharra (Bin and Conveyors)	792.44
Sandstone (Erection of Camps)	6 247.94

Cartage Subsidy

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

Year	Tonnes Crushed	Tonnes Subsidised	% Subsidised
1974	48 374·70	18 954·25	39·18
1975	54 383·6	12 555·0	23·09
1976	40 775·5	8 317·21	20·39

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

Administrative

Expenditure was $241 647, equal to $4.13 per tonne crushed and cyanided, compared with an expenditure of $192 835, $2.94 per tonne for 1975.

	1975 $	1976 $
Salaries	82 549	115 407
Pay Roll Tax	43 026	50 500
Workers' Compensation	55 797	65 918
Travelling and Inspection	4 903	6 093
Sundries	6 560	3 729
	$192 835	$241 647

Staff

Senior Manager H. A. G. Ball and Manager A. J. Steel retired. Manager R. Stevens resigned. Manager W. J. Crew was appointed Senior Manager, and Foreman L. A. Boyle was appointed Manager.

Except for service in the Army during the war, Harry Ball had been continuously employed by the State Batteries since 1937. He was appointed Manager in 1950, and Senior Manager in 1969. His ability, energy and experience made him a most valuable Officer of the Branch.

Albert Steel has also given long and valuable service, being continuously employed since 1950 and a Battery Manager since 1955.

General

The average price of gold for 1976 was nearly $20 per ounce lower than in 1975. This caused big reductions in the tonnage of ore crushed and the amount of gold recovered by amalgamation, and a

very big reduction in the value of the gold recovered. The lower tonnage crushed, and increases in salaries, wages and the cost of supplies caused a big increase in the cost per tonne crushed. With the devaluation of the $A late in 1976, and increases in the world price of gold in early 1977, there should be an increase in gold ore crushed at the State Batteries during 1977.

Cyaniding of tailings continued satisfactorily, although some recoveries were low particularly at Sandstone. The tailings at Sandstone had accumulated slowly for 25 years and included some sulphide material that had partly oxidised, causing treatment difficulties.

There was no lead ore crushed for the year, but the Northampton Battery treated 27.2 tonnes of scheelite ore. There is likely to be more scheelite ore in 1977, and as the price of lead is rising, there is also likely to be lead ore crushed.

K. M. PATERSON,
Superintendent State Batteries.

Schedule No. 1

NUMBER OF GOLD ORE PARCELS TREATED, TONNES CRUSHED, GOLD YIELD BY AMALGAMATION AND HEAD VALUES FOR THE YEAR ENDING 31st DECEMBER, 1976

Battery	Number of Parcels Treated	Tonnes Crushed	Yield by Amalgamation		Amalgamation Tailings Content Fine Gold Kilograms	Contents of Ore—Fine Gold	
			Bullion Kilograms	Estimated Fine Gold Kilograms		Kilograms	Grams Per Tonne
Boogardie	25	890·5	5·049	4·279	0·802	5·081	5·70
Coolgardie	40	7 213·6	26·776	22·692	12·461	35·153	4·87
Kalgoorlie	61	7 423·8	62·958	53·356	14·991	68·347	9·20
Laverton	6	170·0	1·673	1·418	0·429	1·847	10·86
Leonora	32	7 623·0	32·283	27·360	17·817	45·177	5·92
Marble Bar	16	1 368·0	12·200	10·340	3·465	13·805	10·09
Marvel Loch	36	3 920·0	40·586	34·396	9·768	44·164	11·26
Meekatharra	24	4 010·0	25·492	21·604	11·752	33·356	8·32
Menzies	20	1 215·3	10·643	9·020	3·781	12·801	10·53
Norseman	8	3 112·6	8·923	7·562	4·087	11·649	3·74
Ora Banda	23	2 476·0	8·611	7·298	5·813	13·111	5·29
Paynes Find	10	747·5	14·313	12·130	2·770	14·900	19·93
Sandstone	1	97·0	0·840	0·712	0·412	1·124	11·58
Yarri	9	481·0	5·625	4·767	1·344	6·111	12·70
	311	40 748·3	255·972	216·934	89·692	306·626	7·52

Average Per Parcel .... 131·02 tonnes
Average Yield by Amalgamation (Fine Gold) .... 5·32 grams per tonne
Average Value of Tailings (Fine Gold) .... 2·20 grams per tonne

Schedule No. 2

DETAILS OF EXTRACTION TAILINGS TREATMENT 1976

Battery	Tonnes Treated	Head Value		Tail Value		Calculated Recovery		Actual Recovery	
		Grams Per Tonne	Total Content Kilograms	Grams Per Tonne	Total Content Kilograms	Kilograms	%	Kilograms	%
Leonora	6 600	2·95	19·476	0·72	4·776	14·700	75·5	15·319	78·7
Marvel Loch	1 307	4·43	5·789	1·44	1·877	3·912	67·6	4·079	70·5
Menzies	4 650	4·18	19·458	1·03	4·796	14·662	75·4	12·588	64·7
Norseman	1 314	5·43	7·131	1·77	2·320	4·811	67·5	4·368	61·3
Sandstone	3 187	4·91	15·639	1·76	5·618	10·021	64·0	9·952	63·6
Yarri	670	5·23	3·501	1·29	0·866	2·635	75·3	2·594	74·1
	17 728	4·00	70·994	1·14	20·253	50·741	71·4	48·900	68·8

Schedule No. 3

DIRECT PURCHASE OF TAILINGS YEAR ENDED 31st DECEMBER, 1976

Battery	Tonnes of Tailings Purchased	Initial Payment to $28.00 per ·0311 kg
		$
Boogardie	18·4	65.60
Coolgardie	449·5	638.23
Kalgoorlie	768·6	1 538.45
Laverton	100·8	163.79
Leonora	541·8	880.36
Marble Bar	255·9	508.57
Marvel Loch	205·2	184.53
Meekatharra	77·4	453.70
Menzies	9·9	94.52
Ora Banda	139·5	53.04
Paynes Find	207·0	590.54
Sandstone	87·3	38.69
Yarri	81·9	21.58
	2 943·2	5 231.60

Schedule No. 4

STATEMENT OF RECEIPTS AND EXPENDITURE FOR YEAR ENDED 31st DECEMBER, 1976

Milling

Battery	Tonnes	Management and Supervision	Wages	Stores	Expenditure Total Working	Cost Per Tonne	Repairs and Renewals	Sundries	Gross Expenditure	Cost Per Tonne	Receipts	Receipts Per Tonne	Profit	Loss
		$	$	$	$	$	$	$	$	$	$	$	$	$
Boogardie	890·5	11 975.53	14 362.11	3 830.71	30 168.35	33.88	3 623.89	9 581.96	43 374.20	48.71	2 757.78	3.09	....	40 616.42
Coolgardie	7 213·6	19 351.73	48 382.85	12 297.75	80 032.33	11.09	12 219.78	30 590.00	122 842.11	17.03	18 679.45	2.58	....	104 162.66
Cue	....	....	....	....	....	....	....	....	....	....	1 440.00	....	1 440.00	....
Kalgoorlie	7 423·8	27 325.83	172 268.71	24 410.73	224 005.27	30.17	18 918.16	57 061.52	299 984.95	40.41	20 487.54	2.75	....	279 497.41
Lake Darlot	....	....	2 983.70	155.39	3 139.09	....	294.12	10.11	3 443.32	....	....	....	....	3 443.32
Laverton	170·0	9 071.48	9 313.82	2 053.91	20 439.21	120.23	896.91	2 224.06	23 560.18	138.59	438.00	2.57	....	23 122.18
Leonora	7 623·0	18 108.25	58 979.31	11 978.58	89 066.14	11.68	9 862.33	38 932.04	137 860.51	18.08	20 889.00	2.74	....	116 971.51
Marble Bar	1 368·0	17 292.25	27 695.09	8 449.03	53 436.37	39.06	14 698.29	9 706.58	77 841.24	56.90	3 995.16	2.92	....	73 846.08
Marvel Loch	3 920·0	12 185.65	46 212.12	9 003.35	67 401.12	17.19	4 523.28	17 174.03	89 098.43	22.73	11 429.53	2.91	....	77 668.90
Meekatharra	4 010·0	11 974.25	48 302.38	9 766.23	70 042.86	17.47	16 906.01	21 310.43	108 259.30	27.00	9 087.30	2.26	....	99 172.00
Menzies	1 215·3	6 152.66	31 428.66	6 329.93	43 911.25	36.13	2 606.59	6 407.79	52 925.63	43.55	3 561.16	2.93	....	49 364.47
Norseman	3 112·6	10 984.43	30 766.99	5 175.64	46 927.06	15.08	2 451.20	14 681.79	64 060.05	20.58	7 992.50	2.56	....	56 067.55
Nullagine	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Ora Banda	2 476·0	17 576.72	37 722.27	11 153.04	66 452.03	26.84	8 245.77	7 102.47	81 800.27	33.04	7 395.50	2.98	....	74 404.77
Paynes Find	747·5	4 708.10	11 988.22	2 491.01	19 187.33	25.67	1 258.61	2 827.81	23 273.75	31.14	2 244.50	3.00	....	21 029.25
Peak Hill	....	....	....	....	....	....	....	....	....	....	220.00	....	220.00	....
Sandstone	97·0	734·99	6 176.30	610.10	7 521.39	77.54	2 427.95	1 587.68	11 537.02	118.94	291.00	3.00	....	11 246.02
Yarri	481·0	7 915.41	11 133.91	3 149.55	22 198.87	46.15	1 597.98	4 284.35	28 081.20	58.38	1 587.00	3.29	....	26 494.20
Head Office	....	....	....	....	....	....	....	....	....	....	1 562.31	....	1 562.31	....
Sub total	40 748·3	175 357.28	557 716.44	110 854.95	843 928.67	20.71	100 530.87	223 482.62	1 167 942.16	28.66	114 057.73	2.80	3 222.31	1 057 106.74
Marble Bar (Mag. Plant)	2·31	50.00	50.00	....	100.00	43.29	....	11.75	111.75	48.38	92.64	40.10	....	19.11
Northampton	27·2	9 248.60	4 071.33	981.18	14 301.11	525.77	10 939.07	741.08	25 981.26	955.19	81.60	3.00	....	25 899.66
Total	40 777·81	184 655.88	561 837.77	111 836.13	858 329.78	21.05	111 469.94	224 235.45	1 194 035.17	29.28	114 231.97	2.80	3 222.31	1 083 025.51

Operating Loss $1 079 803.20

Schedule No. 5

STATEMENT OF RECEIPTS AND EXPENDITURE FOR YEAR ENDED 31st DECEMBER, 1976

Cyaniding

Battery	Tonnes	Management and Supervision	Wages	Stores	Expenditure Total Working	Cost Per Tonne	Repairs and Renewals	Sundries	Gross Expenditure	Cost Per Tonne	Receipts	Receipts Per Tonne	Profit	Loss
						$	$	$	$	$	$	$	$	$
Kalgoorlie	....	....	....	300.59	....	....	....	....	300.59	....	....	....	....	300.59
Leonora	6 600	758.17	28 498.69	12 487.45	41 744.31	6.32	409.29	42 511.43	84 665.03	12.83	37 070.94	5.61	....	47 594.09
Marvel Loch	1 307	....	6 423.72	2 938.95	9 362.67	7.16	13.43	5 542.28	14 918.38	11.41	6 581.01	5.03	....	8 337.37
Menzies	4 650	4 851.90	35 102.56	9 158.29	49 112.75	10.56	4 357.52	25 303.10	78 773.37	16.94	5 256.89	1.13	....	73 516.48
Norseman	1 314	....	7 518.73	3 731.64	11 250.37	8.56	....	5 437.76	16 688.13	12.00	2 042.36	1.55	....	14 645.77
Sandstone	3 187	479.19	20 162.33	7 646.06	28 287.58	8.87	3 710.70	14 439.67	46 437.95	14.57	4 033.97	1.26	....	42 403.98
Yarri	670	3 203.14	14 005.18	1 818.84	19 027.16	28.40	633.40	2 647.85	22 308.41	33.30	1 584.70	2.36	....	20 723.71
*Head Office	....	....	....	....	....	....	....	....	....	....	37 184.74	....	37 184.74	....
Total	17 728	9 292.40	111 711.21	38 081.82	159 085.43	8.97	9 124.34	95 882.09	264 091.86	14.90	93 754.61	3.19	37 184.74	207 521.99
Less Interest Paid to Treasury											4 320.00			4 320.00
									264 091.86		89 434.61		37 184.74	211 841.99

Operating Loss $174 657.25

* Profit on Gold Released by Reserve Bank and Sold on the Open Market.

STATE BATTERIES
TRADING AND PROFIT LOSS ACCOUNT FOR THE YEAR ENDED 31st, DECEMBER, 1976

1975			1976	
$	$		$	$
		Trading Costs—		
786 601		Wages	867 497	
127 372		Stores	149 918	
79 067		Repairs, Renewals and Battery Spares	120 594	
286 680		General Expenses and Administration	324 438	
	1 279 720			1 462 447
		Earnings —		
	175 557	Milling and Cyaniding Charges		207 987
	1 104 163	**Operating Loss for Year**		1 254 460
		Other Charges—		
63 457		Interest on Capital	63 457	
31 884		Depreciation	29 020	
20 918		Superannuation—Employers Share	35 987	
	116 259			128 464
	1 220 422	Total Loss for Year		1 382 924

STATE BATTERIES BALANCE SHEET AS AT 31st DECEMBER, 1976

FUNDS EMPLOYED

Capital—		
Provided from General Loan Fund	1 506 140	
Provided from Consolidated Revenue Fund	449 067	
		1 955 207
Reserves—		
Commonwealth Grant—Assistance to Gold Mining Industry	57 244	
Commonwealth Grant—Assistance to Metalliferous Mining	27 572	
		84 816
Liability to Treasurer—		
Interest on Capital		2 887 898
Other Funds—		
Provided from Consolidated Revenue Fund (Excess of payment over collections)		11 527 910
		16 455 831
Deduct—		
Profit and Loss:		
Loss at Commencement of Year	14 892 044	
Loss for Year	1 382 924	
Total Loss from Inception		16 274 968
		$180 863

EMPLOYMENT OF FUNDS

Fixed Assets—		
Plant, Buildings and Equipment	1 945 125	
Less Depreciation	1 688 298	
		256 827
Current Assets—		
Debtors	43 269	
Stores	67 848	
Battery Spares	41 501	
Purchase of Tailings:		
Treasury Trust Account	44 817	
Tailings not Treated	53 000	
Estimated Gold Premium	11 157	
		261 592
Total Assets		518 419
Deduct—		
Current Liabilities: Creditors	75 917	
Liability to Treasurer (Superannuation—Employers Share)	248 665	
Purchase of Tailings:		
Creditors	1 817	
Estimated Premium Due	11 157	
		337 556
		$180 863

DIVISION IV

Annual Report of the Geological Survey Branch of the Mines Department for the Year 1976

CONTENTS

REPORTS

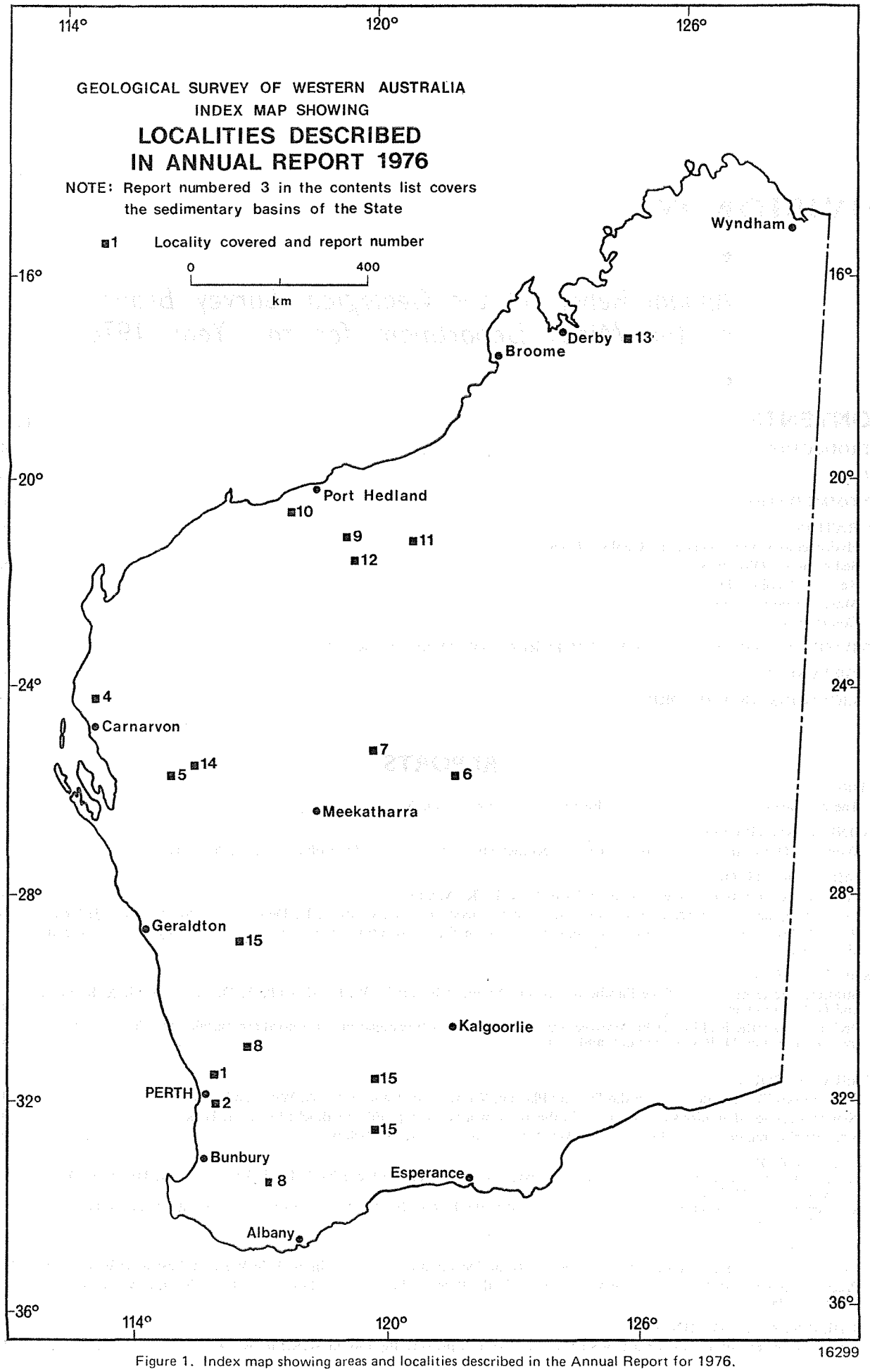

Figure 1. Index map showing areas and localities described in the Annual Report for 1976.

LIST OF FIGURES

67016—(4)

DIVISION IV

Annual Report of the Geological Survey Branch of the Mines Department for the Year 1976

Under Secretary for Mines:

For the information of the Honourable Minister for Mines I submit my report for 1976 on the activities of the Geological Survey of Western Australia together with selected reports on investigations and studies made for Departmental purposes.

INTRODUCTION

There is definite evidence that the downward trend in exploration levelled off in the first half of 1976 and in the second half an upward trend developed which is expected to continue in 1977. This opinion is based on the amount of work commitments associated with the increased applications for tenements rather than on financial commitments which are subject to inflationary trends.

This upward trend is illustrated best in the number of new temporary reserves approved during 1976 for minerals other than gold and iron. This showed a marked increase as compared with 1975, and, as 34 per cent of the applications were applied for and approved during the last quarter of 1976, intention of increased activity in 1977 is indicated.

Year	*Temporary Reserves Approved* (excluding gold, iron and coal)
1973	182
1974	47
1975	20
1976	117

The applicants in 1976 are committed to a minimum work expenditure of over $3.7 million on exploration during the first 12 months for which the reserves are held.

Oil and gas exploration stabilized and the amount of work done during 1976 was similar to 1975, both on and offshore. There was promise at the end of the year that there would be an upturn of activity during 1977.

Year	Total wells drilled	Total metrage	Seismic (km)	
			Land	Marine
1971	29	70 620	2 744	19 933
1972	29	102 876	3 266	43 218
1973	22	63 612	1 776	14 904
1974	21	48 172	559	11 815
1975	6	17 115	484	2 733
1976	6	22 171	443	2 599

The only significant discovery during the year was gas in Parentie No. 1 on Barrow Island, which was a follow-up to two previous deep test wells, Biggada No. 1 and Barrow Deep No. 1.

A number of areas, both onshore and offshore, were offered for public tender. Although there was considerable interest shown in the areas concerned, the number of tenders actually received was disappointing.

In the early part of the year, interest in mineral exploration was directed mainly towards uranium throughout the State, but with the announcement of the good copper-zinc-silver values located in drilling near Teutonic Bore, 60 km north of Leonora, much attention was concentrated on this area and this type of mineralization. This discovery of copper-zinc mineralization in a volcanogenic environment produces a new sphere for prospecting. It is probably as important to copper exploration in this State as the discovery of Kambalda was to the nickel exploration.

Iron ore exploration has continued in the Hamersley Range on a limited scale without any major new discoveries. Exploration for iron should expand again as 85 new temporary reserves were approved late in 1976. Several companies are involved and a minimum of $1.7 million should be expended on exploration. No new large iron ore sales contracts eventuated to warrant the development of new mines, although the two major production companies each expanded their capacity to 40 million tonnes per year.

Following decisions to develop the Alwest area in conjunction with Alcoa and to build a new alumina refinery near Wagerup, bauxite investigations were recommenced near the end of the year. Also the Mitchell Plateau deposit is being reconsidered to decide if it is possible to plan production on a limited scale.

Probably due to the economic situation, prospecting and exploration for nickel was sluggish. Work continued in the Forrestania area, and an announcement was made to proceed with the development of the Perseverance nickel occurrence near Agnew.

Despite difficulties in marketing its products, the heavy mineral sands industry continued to develop, with three plants now in operation near Eneabba and one at Jurien Bay. A new deposit at Cataby, West Dandaragan, has been proved and awaits development.

Uranium has been the most sought after mineral throughout the State. Exploration has been directed mainly towards calcrete drainages of the inland. However, the search has also extended to the sedimentary basins and hardrock areas. Although further uranium mineralization has been located, particularly in the calcrete and inland lakes areas, no economic deposits, such as that at Yeelirrie, have been confirmed.

Exploration for copper-zinc deposits developed rapidly in the eastern goldfields after the discovery of the Teutonic Bore deposit in acid volcanic rocks. Exploration continues at Golden Grove for copper and near Kundip for copper-gold ores.

In the Kimberley region exploration has been active, particularly for diamond, following the announcement of the location of 160 microdiamonds totalling seven carats, with the biggest stone being 0.42 carat. Elsewhere in the Kimberley region, exploration for lead at Sorby Hills, nickel at Sally Malay near Turkey Creek, and copper near Halls Creek continues.

Gold prospecting declined during the year but the price improvement during the latter part of the year prevented closure of the last mine at Kalgoorlie. Further increase in the price of gold is required to stimulate prospecting for this metal.

The International Geological Congress was held in Australia for the first time during August and this Survey made a major contribution by arranging and providing leaders for three Congress Excursions, namely: Denovian Reef Complexes of the Canning Basis (P. E. Playford), Archaean Geology and Mineral Deposits of the Eastern Goldfields (R. D. Gee), and Geology of the Hamersley Basin (A. F. Trendall). Co-leaders were provided for two Congress Excursions, namely: Archaean Geology of the Yilgarn Block (I. R. Williams), and the Mining Centres of Southern and Western Australia (J. H. Lord).

Staff members of the Survey presented the following papers at the Congress:

The Western Australian Shield .. by R. D. Gee.

The Pilbara and Yilgarn Archaean Blocks of Western Australia .. by R. D. Gee.

Geochemistry of Archaean felsic to ultramafic metasediments in relation to crustal evolution, northeastern Yilgarn Block, Western Australia .. by R. J. Marston.

Heavy mineral deposits in Western Australia .. by J. L. Baxter.

Relict early Cainozoic drainages in arid Western Australia .. by W. J. E. van de Graaff *et al.*

A series of four lectures on the geology of the Pinjarra 1:250 000 geological map was given, followed by a two-day excursion to inspect the field occurrences. It proved popular with 70 attending the lectures and 58 participating in the field trip.

In an effort to provide a better water supply for Rottnest Island a detailed sedimentological study was made and test bores recommended. A suitable water supply was located and is being developed by the Department of Public Works. Providing it is managed carefully, the supply should be satisfactory for the island.

Regional geological mapping of the State continues (see Fig. 2) with only 10 sheets remaining in the 175 sheet programme.

STAFF

There were several resignations from the professional staff during the year for several reasons. No difficulty was experienced in recruiting replacements to fill the vacancies.

There continues to be a considerable movement of general and clerical division officers.

PROFESSIONAL

Appointments

Name	Position	Effective Date
Marston, R. J., B.Sc. (Hons.), Ph.D.	Geologist L3	2/2/76
Moncrieff, J. S., B.Sc. (Hons.)	Geologist L1	16/2/76
Wharton, P. H., B.Sc. (Hons.)	Geologist L1	11/5/76
Blight, D. F., B.Sc. (Hons.), Ph.D.	Geologist L1	6/9/76
Cameron, J. F., B.A.	Geologist L1	20/9/76
Furness, L. J., B.Sc. (Hons.), M.App.Sc.	Geologist L1	30/11/76

Promotions

Bunting, J. A.	Geologist L2	22/6/76
Hickman, A. H.	Geologist L2	22/6/76
Wilde, S. A.	Geologist L2	22/6/76

Resignations

Campbell, J. M.	Geologist L1	2/4/76
Drake, J. R.	Geologist L1	15/4/76
Harley, M. M.	Geologist L1	2/9/76

CLERICAL AND GENERAL

Appointments

Horley, J. R.	Geological Assistant	7/1/76
Willis, B. J., B.Sc.	Technical Officer	19/1/76
Miller, I. S.	Clerk	15/3/76
Baggott, S.	Geophysical Assistant	21/4/76
Smith, P. C.	Typist	17/5/76
Domahidy, G.	Core Librarian	5/7/76
Black, A.	Typist	5/10/76
McDonald-Goodall, A.	Technical Assistant	13/12/76

Resignations

Butherway, P.	Geophysical Assistant	27/2/76
Hargrave, D.	Typist	12/5/76
Ridley, J. L.	Typist	5/10/76

Transfer In

Lapthorne, J.	Senior Clerk	12/10/76

Transfer Out

Hewitt, P. A.	Clerk	24/3/76
Wells, R.	Core Librarian	15/4/76
McNamara, T.	Senior Clerk	21/5/76
Green, M.	Technical Assistant	16/9/76

ACCOMMODATION

In August twenty geologists were moved to office accommodation at 196 Adelaide Terrace. This has caused considerable inconvenience because of the need for staff to commute some 800 m to Mineral House for administrative, library and laboratory services.

Although subdivision of the space vacated is not yet complete, it will eventually ease overcrowding of geological staff in Mineral House and increase library space to provide a microfilm viewing and printing room and additional stack area.

OPERATIONS

HYDROGEOLOGY AND ENGINEERING GEOLOGY DIVISION

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

Hydrogeology

Exploratory drilling for groundwater resource assessments and water supply investigations was reduced in 1976 compared with the previous year. The aggregate depth of newly completed bores exceeded 7 000 metres.

Three deep exploratory bores have been drilled in Perth Basin west of Moora and another near Bunbury has been comprehensively test pumped to determine aquifer characteristics. Three other deep bores at Eneabba have also been tested. In the Perth metropolitan area three deep stratigraphic bores have been drilled. They provide important new information aiding the continuing study of water resources in the Perth region. Some additional shallow drilling has been completed in the Lake Thompson area for water resources evaluation and also in the Osborne Park area for sanitary land-fill studies.

Thirteen bores drilled east of the present Mirabooka water supply scheme have resulted in the discovery of a deep sand-filled trough, which adds substantially to the water resources of the area. A further nine bores were drilled in the same vicinity, at Mussel Pool, for special land-use studies.

Geological and hydrological surveys have been conducted on Rottnest Island and have resulted in the successful establishment of a new water supply scheme based on shallow groundwater.

Further drilling has been carried out in the Bunbury region as part of an investigation of the complex aquifer systems in that area. Detailed hydrogeological studies have commenced west of Leschenault Inlet to aid the management of acid-effluent disposal and minimize any environmental effects.

Work on the West Canning Basin study, east of Port Hedland, has been confined to preparing all the completed bores for comprehensive hydraulic testing in the coming year. In the West Pilbara, good progress has been made with drilling near Millstream. In all, 32 boreholes were drilled. A preliminary interpretation of the results indicates that substantial additional water yields will be possible from the limestone and weathered bedrock aquifers. Based on specially cored bores, joint studies with Public Works Department engineers have also resulted in improved estimates of groundwater storage in the limestone aquifer.

Inter-departmental studies of the effects on stream and groundwater hydrology of bauxite mining in the Darling Range and the Manjimup woodchip industry have continued. A total of 159 additional observation bores have been drilled by Alcoa, the Mines Department, and the Public Works Department. They aggregate 4 126 metres of drilling.

The demand for advisory services has continued at about the same level as last year; 80 inspections were undertaken for private landholders requiring advice on groundwater. Three field inspections were carried out for local authorities and a further four for the Department of Conservation and Environment. Liaison with other government departments regarding groundwater exploration and development, as well as research studies, has continued.

Engineering Geology

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

Department of Public Works:

(a) Cooya Pooya proposed dam site—geological mapping, geophysics and trenching.

(b) Robe River proposed dam site "D"—geological mapping, geophysics, drilling and trenching.

(c) Sherlock River proposed dam site—geological mapping, geophysics, drilling and trenching.

(d) Booyeemala proposed dam site—geological mapping.

(e) Port Denison—continued geological mapping and drilling of proposed quarry sites.

(f) Minor investigations including core logging for the foundation studies for new berths at Geraldton and Bunbury Harbours.

Metropolitan Water Board:

(a) Wungong Dam—continued geological mapping in the foundation area during construction.

(b) South Canning proposed dam site—geological mapping, geophysics and drilling for the foundation study of a new layout.

(c) North Dandalup proposed dam site—drilling in two proposed borrow areas.

(d) Victoria Dam—geological mapping for an alternative site.

(e) Beenyup Tunnel—geological mapping in the outlet cut during construction.

(f) Minor investigations associated with the safety review of existing dams.

W.A. Government Railways:

Geological advice given to aid the selection and development of quarry sites in five areas.

SEDIMENTARY (OIL) DIVISION

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

The processing of voluminous petroleum exploration data from relinquished and surrendered permit areas continued during the year, and is now largely complete. Petroleum exploration continued at a low level, but many vacant areas were made available for application by prospective explorers during the year, and activity is expected to increase in the near future as new companies enter petroleum exploration in this State.

Mapping continued in the Carnarvon Basin, and was completed on the Quobba 1:250 000 Sheet and on the Phanerozoic parts of the Mount Phillips, Glenburgh, and Byro Sheets. Compilation of geophysical maps covering the southern and central parts of the basin as far north as latitude 23°S was largely completed.

The Canning Basin mapping project was continued, in conjunction with the Bureau of Mineral Resources. Mapping of the Mount Anderson and Derby 1:250 000 Sheets was completed during the year.

The geology and groundwater prospects of Rottnest Island was investigated in detail and a programme of drilling recommended which proved successful.

REGIONAL GEOLOGY DIVISION

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

Regional mapping continued on the Precambrian portion of the State for publication at a scale of 1:250 000 (Fig. 2). Field mapping on Rudall, Collie, Wiluna, Kingston, Stanley, Nabberu and Southern Cross was completed.

Mapping on the following sheets is progressing toward completion in 1977: Mount Phillips (90 per cent completed), Glengarry (80 per cent).

Mapping in the Bangemall Basin was concluded with the completion of field work on Stanley and Nabberu. Re-appraisal work was undertaken in the previously mapped western and northeastern portions of the Basin in order to integrate the mapping for recent years.

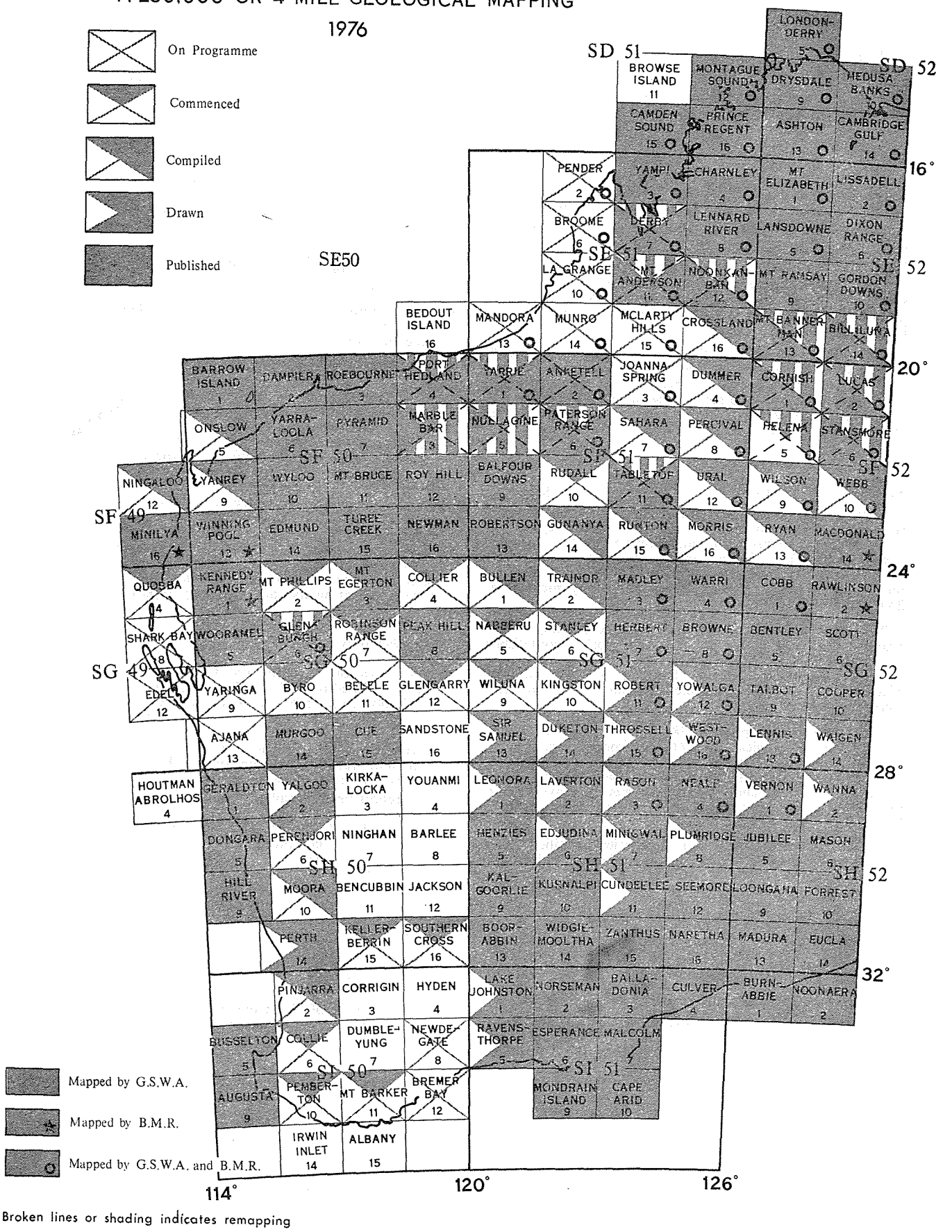

Figure 2. Progress of 1 : 250 000 or 4-mile geological mapping at end of 1976.

MINERAL RESOURCES DIVISION

J. G. Blockley (Supervising Geologist), J. D. Carter, R. J. Marston (Senior Geologists), J. L. Baxter, A. H. Hickman, S. A. Wilde, S. L. Lipple, K. H. Green.

Mapping of the Collie 1:250 000 Sheet was completed and results are being compiled. The Perenjori and Pemberton 1:250 000 Sheets were commenced during the year. Compilation of the Precambrian parts of the Port Hedland, Moora and Pinjarra 1:250 000 Sheets was finished and preliminary Explanatory Notes were issued for Pinjarra. All field work towards a Bulletin on the Pilbara Block has now been carried out.

Manuscripts on the State's tin and kaolin deposits were completed. The task of revising the copper Bulletin was again taken up, field work finalized and writing begun.

Further investigations were made of the barite deposits near Cooke Bluff Hill and the results compiled as a proposed record.

Sundry work included an assessment of limestone resources in the South West Metropolitan Corridor and an investigation of ore reserve computation techniques at Kalgoorlie.

During the year the Division answered about 250 enquiries from the public and other government departments and dealt with some 210 requests for access to company reports. About 500 new accessions were added to the collection of mineral exploration data administered by the Division, a decrease of 185 on 1975.

COMMON SERVICES DIVISION

Petrology (W. G. Libby, J. D. Lewis, D. F. Blight)

A continued increase in demand for petrological services resulted in the production of 118 petrological reports on 2 246 samples. More than one thousand further samples were classified by thin section for incorporation into the petrology data system. Over the past decade the average number of samples reported has increased by more than 235 samples per year.

The GSWA/WAIT co-operative geochronology programme continued during the year with work accomplished on sixteen projects. The results of three of these, the Gascoyne Regional, Tangadee Rhyolite, and East Margin Yilgarn projects were published. Four further projects were added for 1977.

The laboratory prepared 2 782 thin sections, of which 2 317 were petrological and 465 sedimentological. Thin sections stained for determination of carbonate or K-feldspar numbered 250. There were 12 heavy mineral determinations, 31 sieve analyses and 51 specific gravity determinations. Samples crushed for chemical or geochronological analysis numbered 501

The Government Chemical Laboratories identified many mineral samples and provided access to the X-ray diffractometer.

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

There was a reduction in geophysical well-logging activity in 1976 when 191 water bores were logged as compared with 258 in 1975. Cumulative total depths amounted to 20 900 m (29 900 in 1975) and logs recorded by various methods were equivalent to about 48 800 m of hole.

Numerous dam sites were investigated by seismic refraction surveys; they included the Sherlock, Robe and Cooya Pooya sites in the Pilbara, and, near Perth, the South Canning and Churchmans Brook localities. Five paired catchments, intended to assess salinity problems associated with the Manjimup woodchip industry, were also investigated.

Experimental ground magnetic observations clearly delineated the margins of the Bunbury Basalt. The location of areas not underlain by basalt is of material assistance to water-boring contractors. Successful application of a technique for deriving pseudovelocity logs from resistivity well-logs aided correlation of seismic events in the Carnarvon Basin.

As a result of various groundwater salinity monitoring projects, water sample conductivity measurements increased to 1 030. Normal electronic instrument servicing and calibration facilities were provided.

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

Requests for palaeontological information involved more long-term project work and consequently fewer (48) reports were written this year. Work continued on the palynology of Cretaceous rocks in the Perth Basin and on the Devonian faunas from the Canning Basin. Regional mapping of the Carnarvon Basin resulted in extensive collections of samples ranging in age from Permian to Quaternary. Detailed studies were made on stromatolites and microfossils from the Bangemall Basin.

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

Work on the 1:50 000 Urban Geology map series was continued with the completion of one sheet (Mandurah) and the completion of field mapping on ten sheets (Pinjarra, and nine sheets in the Dampier-Roebourne area).

A study of aggregate and dimension stone in the Perth region was completed and the results will be issued as a Record.

The appraisal of mineral tenement applications in the South West Mineral Field continues, with a view of protecting the environment while encouraging mining.

Examinations were made of a number of temporary excavations in and around Perth to expand knowledge of geological strata in the urban area.

Liaison with, and supplying geological information to, other departments and instrumentalities continues to occupy a large part of the section's activities and has included: studies of the geology of the Southeast, Northwest and Eastern (Perth Urban) Corridors; a study of the limestone resources in the area around the proposed Joondalup sub-regional centre; provision of geological maps and data for the System 6 study; a study of sediments and erosion problems at Lake Dumbleyung; provision of information on gravel resources in the Shire of Serpentine-Jarrahdale; attendance at meetings of several inter-departmental committees; and the assessment of various departmental and company reports.

Geochemistry (R. Davy)

The various reports on the geochemical study of Archaean bedrock of the Rason, Laverton, and Leonora 1:250 000 Sheet areas were completed. These are available through the Report series, and as file reports.

Investigations on the sulphur dioxide prospecting technique for identification of ore bodies at depth were carried out at Golden Grove, Burbidge, and Forrestania. A report on the results is included in this Annual Report.

A study of the mineral content of groundwater at Del Park was continued, and results made available in the Record Series.

The results of chemical and X-ray diffraction analyses of certain bauxites were completed by the Government Chemical Laboratories, and a report on the investigations completed.

A study of the mineralization in the Bangemall Basin was commenced.

The service of the Government Chemical Laboratories in the provision of chemical analyses is gratefully acknowledged.

Technical Information (W. B. Hill, M. E. Wenham, J. F. Cameron, and S. M. Fawcett)

Although the number of enquiries from the public has decreased over the last few years, there has been an increase in the number of manuscripts received by this section for preparation for the printer and proof-reading. One Bulletin was marked for the printer and sent to the press, and work continued on proof-reading of the two already at the press. Twenty-two records were edited and four Explanatory Notes published. One new information pamphlet was issued, and seven were reprinted. The stratigraphic nomenclature index was revised and updated.

Requisitions raised on the Surveys and Mapping Branch for drafting services and photography for the Survey totalled 1 129. Photocopying for the public of out-of-print publications numbered 1 058 requisitions, many of which contained several items.

During the year this section dealt with 764 requests for information including rock identification, and 1 526 members of the public visited the library for research purposes. Book loans to the staff totalled 5 621, and loans to other libraries 202.

ACTIVITIES OF THE COMMONWEALTH BUREAU OF MINERAL RESOURCES

Geological and geophysical projects carried out by the Bureau of Mineral Resources included the following:

(i) Preparation of a Bulletin on the Officer Basin as a joint project with this Survey.

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

(iii) Continuation of rock collection in the Pilbara area to test for trace element characteristics.

(iv) Completion of the aeromagnetic survey of the Officer Basin.

(v) Airborne magnetic and radiometric survey of Hyden, Newdegate and Dumbleyung 1:250 000 Sheets.

(vi) Preparation to use iron ore quarry blasts as seismic sources for a crustal structure survey in the Pilbara area.

PROGRAMME FOR 1977

HYDROGEOLOGY AND ENGINEERING DIVISION

A. Hydrogeology

1. Continuation of the hydrogeological survey of the Perth Basin including deep drilling, test pumping and report on Moora, Eneabba and Quindalup lines and at Irwin View.
2. Hydrogeological investigations and/or exploratory drilling for groundwater in the following areas:
   (a) West Canning Basin—test pumping and report writing.
   (b) Fortescue River area—continuing drilling and testing to assess the calcrete and other aquifers including Fortescue-Robe coastal areas and Millstream-Karratha pipeline.
   (c) Yule, De Grey and Gascoyne Rivers—continuing periodical reassessments.
   (d) East Pilbara—bore census and reconnaissance.
3. Town water supply investigations and/or drilling for the following: Albany, Bunbury, Geraldton and others as required.
4. Hydrogeological investigations for Metropolitan Water Supply Board.
   (a) regional studies.
   (b) deep drilling—Becher Point, Jandakot.
   (c) shallow drilling—Gnangara Mound, Mirrabooka East, Jandakot, Lake Thompson, Keysbrook, and Jandabup.
   (d) study of areas such as Hertha Road/Jones Street, Gnangara liquid waste, Alcoa red mud lake areas, etc. for pollution control.
   (e) study of water balance in coastal lakes.
5. Interdepartmental studies concerning groundwater salinity problems in the Darling Range area.
6. Continuation of bore census of selected areas.
7. Miscellaneous investigations and inspections as required by government departments and the public.

B. Engineering Geology

1. Pilbara area—further investigations of proposed dam sites at Cooya Pooya, Robe, Sherlock and Booyeemala.
2. Gascoyne River—investigations for a 'turkey nest' reservoir site.
3. Darling Range area—continuing investigations on Wungong, South Canning, North Dandalup and Victoria dam sites and Wungong Tunnel, commencing investigations on Marrinup Brook site and safety reviews of existing dams.
4. Miscellaneous investigations as required by government departments including quarry sites for Westrail, advice for Harbours and Rivers Branch of the Public Works Department.

SEDIMENTARY (OIL) DIVISION

1. Maintain an active interest in the progress and assessment of oil exploration and potential in Western Australia.
2. Continuation of the surface mapping and sub-surface study of the Carnarvon Basin including the Ajana, Yaringa, Edel and Wooramel 1:250 000 Sheets.
3. Continuation of geological mapping of the Canning Basin in conjunction with the Bureau of Mineral Resources on the Pender, Broome, La Grange, Mandora, Munro, McLarty Hills, Joanna Springs, Anketell, Paterson Range and Yarri 1:250 000 Sheets.
4. Continue the compilation of Bulletin on further studies of the Devonian reef complexes of the Lennard Shelf, Canning Basin.
5. Revise the Phanerozoic geology of the State for a revision of the 1:2 500 000 geological map.
6. Minor geological investigations as required.

REGIONAL GEOLOGY DIVISION

1. Continuation of the mapping of the Gascoyne Province on the Mount Phillips, Glenburgh and Byro 1:250 000 Sheets.
2. Completion of mapping on the Glengarry Sheet and continuing into the Belele 1:250 000 Sheet.
3. Commencement of mapping on the Mount Barker, Bremer Bay and Newdegate 1:250 000 Sheets.
4. Compilation and completion of the mapping and Bulletin on the Bangemall Basin.
5. Recapitulation and compilation of mapping on the Nabberu Basin and the commencement of a Bulletin.
6. Revision of the Precambrian geology of the State for a new 1:2 500 000 map.

MINERAL RESOURCES DIVISION

1. Maintain records and assess mineral exploration in Western Australia.
2. Completion of a Bulletin on the copper resources of Western Australia.
3. Completion of a Bulletin on the reassessment of the regional and economic geology of the Pilbara Block.
4. Continuation of regional mapping of the Darling Range area on the Pemberton and Perenjori 1:250 000 Sheets and a study of the bauxite occurrence. Also mapping the Precambrian portion of the Ajana Sheet.
5. Commence a regional study of the nickel occurrences in Western Australia for a future Bulletin.
6. Conduct a detailed study of the stratigraphy of the Marra Mamba Iron Formation.
7. Miscellaneous minor mineral investigations as required.

COMMON SERVICES DIVISION

Petrology

1. Carry out petrological investigations as required by other Divisions.
2. Petrological study of the transition between the Gascoyne Province, and the adjacent Yilgarn Block.
3. Petrological study of the transition between the Yilgarn Block and the Albany-Fraser Province near the south coast.
4. A study of the granulite facies in the Collie area.

Palaeontology

1. Carry out palaeontological investigations as required by other Divisions.
2. Continuing a study of the Devonian stromatoporoids from the Lennard Shelf, Canning Basin.
3. Continuing a study of the stratigraphic palynology of the Cretaceous Yarragadee Formation.
4. Commence a detailed palynological study on the Warnbro Group of the Perth Basin.
5. Completion of a study of stromatolites from the Bangemall Basin.
6. Study of the macrofossils from the Carnarvon Basin as required by basin study group.

Geophysics

1. Well logging as required on groundwater drilling projects.
2. Seismic surveys for dam sites at Booyeemala Creek (West Pilbara), Victoria Reservoir, South Canning Spillway and Marrinup Brook.
3. Seismic surveys for groundwater on the De Grey River, Robe River, Albany and Esperance.
4. Trial geophysical surveys over the southern portion of the Darling Fault and also testing the possibility of mapping the subsurface occurrence of Bunbury Basalt.

Geochemistry

1. Continuation of the examination of the nature of the anomalous lead/zinc in parts of the Bangemall Basin.
2. Regional geochemical study of a belt of greenstones located near Mount Saddleback.
3. A study of the mercury content of sulphides in Western Australia.
4. Geochemical study of Mount McRae Shale in the Hamersley Basin.
5. Regional geochemical study of the Mundaring batholith.

Environmental Geology

1. Compilation of urban geology 1:50 000 mapping completed on the Dampier-Roebourne area.
2. Commencement of urban studies and mapping in the Port Hedland area.
3. A study of sand resources in the Perth metropolitan area.
4. Attend to environmental geological problems as required.

PUBLICATIONS AND RECORDS

Issued during 1976

Annual Report, 1975.

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

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

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

Geological map of Kalgoorlie 1:1 000 000 Sheet (SH/51 International Grid).

Geological map of Esperance 1:1 000 000 Sheet (SI/51 International Grid).

Regional interpretation map of the Archaean geology, southeastern part of the Yilgarn Block 1:1 000 000.

In press

Bulletin 124: The geology of the Perth Basin.

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

Geological map of Cundeelee 1:250 000 Sheet (SH/51-11 International Grid) with explanatory notes.

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

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

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

Geological map of Laverton 1:250 000 Sheet (SH/51-2 International Grid) with explanatory notes.

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

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

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

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

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

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

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

In preparation

Bulletin 125: Quaternary molluscs of the western part of the Eucla Basin.

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

Report 4: A comparative study of the geochemistry of Archaean bedrock in part of the northeast Yilgarn Block.

Report 5: Devonian atrypid brachiopods from the reef complexes of the Canning Basin.

Geological maps 1:250 000 with explanatory notes, the field work having been completed: Billiluna, Bullen (formerly Buller), Collie, Collier, Crossland, Dummer, Helena, Kingston, Lennis, Marble Bar, Moora, Mount Bannerman, Mount Egerton, Nabberu, Ningaloo—Yanrey, Nullagine, Onslow, Paterson Range, Perth, Pinjarra, Port Hedland, Robert, Robinson Range, Rudall, Runton, Sir Samuel, Southern Cross, Stanley, Stansmore, Tabletop, Throssell, Trainor, Waigen, Wanna, Webb, Westwood, Wiluna, Yarrie, Yowalga.

Urban geological maps 1:50 000: Gingin, Mandurah, Moore River.

Records produced

1976/1 Wells drilled for petroleum exploration in W.A. to the end of 1975, by K. A. Crank.

1976/2 Yule River dam site: geological report, by J. M. Campbell (Restricted).

1976/3 Fluorite porphyry at Ngarrin Creek, Yarrie, by A. H. Hickman.

1976/4 Geophysical investigations for the Albany town water supply, 1975, by D. L. Rowston (Restricted).

1976/5 Fortescue Valley investigation, Weelumurra Creek seismic refraction survey, by I. R. Nowak (Restricted).

1976/6 Syenitic rocks of the Fitzgerald Peaks, near Norseman, Western Australia, by J. D. Lewis and C. F. Gower.

1976/7 Rottnest Island: geology and groundwater potential, by P. E. Playford.

1976/8 Explanatory notes on the Sir Samuel 1:250 000 geological sheet, Western Australia, by J. A. Bunting and S. J. Williams.

1976/9 West Canning Basin groundwater, geophysics final report, by D. L. Rowston (Restricted).

1976/10 Yule River groundwater reassessment, by W. A. Davidson (Restricted).

1976/11 Limestone resources of the Lake Joondalup-Quinns Rock area, by R. H. Archer (Confidential).

1976/12 Explanatory notes on the Mount Egerton 1:250 000 geological sheet, Western Australia, by P. C. Muhling, A. T. Brakel, and W. A. Davidson.

1976/13 The mineral content of the Del Park groundwater and its origins, by R. Davy.

1976/14 Geology and hydrology of the Albany-Mount Barker area, by K.-J. B. Hirschberg (Restricted).

1976/15 Explanatory notes on the Precambrian rocks of the Pinjarra 1:250 000 geological sheet, Western Australia, by S. A. Wilde.

1976/16 Explanatory notes on the Yarrie 1:250 000 geological sheet, Western Australia, by A. H. Hickman and R. J. Chin.

1976/17 Kaolin in the southwest of Western Australia, by S. L. Lipple.

1976/18 Stirling Range area: notes on bore sites suggested as district watering points, by R. E. J. Leech and J. S. Moncrieff (Restricted).

1976/19 Collie Basin groundwater resources, by K.-J. B. Hirschberg (Restricted).

1976/20 Review of aggregate and dimension stone in the Perth region, by R. H. Archer.

1976/21 Geraldton Harbour, proposed Number Five Berth: geological report, by G. Klenowski (Restricted).

1976/22 Barite deposits near Cooke Bluff Hill, Port Hedland 1:250 000 Sheet, by A. H. Hickman.

1976/23 Measurement of the specific yield of a carbonate aquifer—an unconventional approach, by J. C. Barnett, D. B. McInnes and C. A. Waterton.

1976/24 Definitions of some new and revised rock units in the Canning Basin, by R. W. A. Crowe and R. R. Towner.

1976/25 Chemical composition of the Brockman Iron Formation, by A. F. Trendall and R. S. Pepper.

Reports in other publications

Baxter, J. L., 1976a, Archaean banded iron formation, *in* Knight, C. L. (ed.), Economic geology of Australia and Papua New Guinea, Metals: Australasian Inst. Mining Metall. Monograph 5, p. 202-204.

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———— 1976b, Lead and copper deposits of the Northampton Block, *in* Knight, C. L. (ed.), Economic geology of Australia and Papua New Guinea, Metals: Australasian Inst. Mining Metall. Monograph 5, p. 409-410.

———— 1976c, Peak Hill manganese deposits, W.A., *in* Knight, C. L. (ed.), Economic geology of Australia and Papua New Guinea, Metals: Australasian Inst. Mining Metall. Monograph 5, p. 1021.

———— 1976d, Pilbara manganese province, W.A., *in* Knight, C. L. (ed.), Economic geology of Australia and Papua New Guinea, Metals: Australasian Inst. Mining Metall. Monograph 5, p. 1019-1020.

———— 1976e, Sundry mineralization in the Archaean of the Western Australian Shield, *in* Knight, C. L. (ed.), Economic geology of Australia and Papua New Guinea, Metals: Australasian Inst. Mining Metall. Monograph 5, p. 211-214.

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———— 1976d, The Western Australian Shield: Int. Geol. Cong. XXV Abs., p. 708.

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J. H. Lord,
Director.

22nd February, 1977.

THE HYDROGEOLOGY OF THE MIRRABOOKA EAST AREA, PERTH

by A. D. Allen

ABSTRACT

The Mirrabooka East area is underlain by a complex sequence of ?Pliocene-Holocene surficial formations resting unconformably on the Early Cretaceous Osborne Formation. The base of this sequence consists of sand up to 90 m thick in a north-south channel, 1 to 3.5 km wide eroded into the Osborne Formation. This is overlain by a more extensive sequence of beds 27 to 52 m thick which are mainly sandy in the northwest and which interfinger with predominantly clayey beds in the east and south. A complex southeasterly flowing groundwater system directly recharged from rainfall occurs in the surficial formations. Where it meets the clayey beds it is split into an upper non-pressure system discharging via springs and soaks, and a lower pressure system which probably discharges into the Swan River. Throughflow in the area is conservatively estimated to be 7.5×10^6 m^3/y. The groundwater ranges in salinity from 130 to 400 mg/l TDS but will require treatment for pH, turbidity, colour, and iron before use in public water supply.

INTRODUCTION

PURPOSE AND SCOPE

The Metropolitan Water Supply Sewerage and Drainage Board (MWB) abstract shallow unconfined groundwater for the Mirrabooka Scheme, immediately to the west of the Mirrabooka East area. The scheme has a maximum capacity of 12.5×10^6 m^3/y, but considerably more water is needed to meet the current and future demands of the service area.

It was known from previous exploratory drilling and from private boreholes, that the surficial formations from which the Mirrabooka Scheme draws its groundwater supplies became more clayey in an easterly direction. They are therefore likely to yield smaller supplies of groundwater.

An exploratory drilling programme to define the eastern limit of an expanded production borefield was carried out by the MWB in collaboration with the Geological Survey. The results of this investigation are described in the present paper.

LOCATION AND TOPOGRAPHY

The Mirrabooka East area is situated about 17 km northeast of Perth. It is bounded to the north by Gnangara Road; to the south by Marshall Road; and to the east and west by Beechboro and West Swan Roads respectively (Figs. 3 and 6).

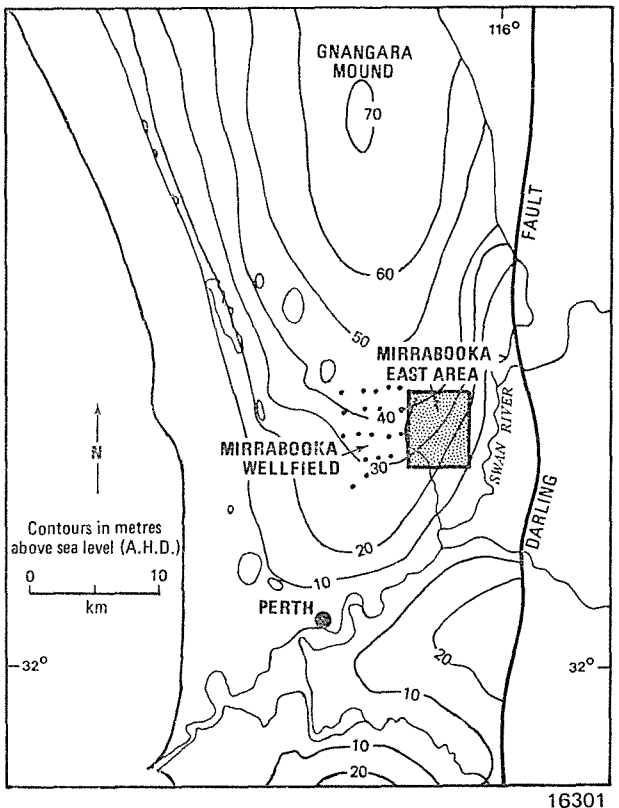

Figure 3. Location map of the Mirrabooka East area.

The area is about 40 km^2 in extent and slopes down towards the southeast. It has an elevation of about 45 m near Gnangara Road falling to about 20 m along West Swan Road. The topography is relatively smooth above the 30 m contour but becomes uneven and dissected at lower elevations. Unlike most other areas of the coastal plain it is incised by several poorly defined drainage systems, the largest of which is Bennet Brook.

Along the drainage systems there are important wetland areas which total 15 km^2 in extent. In their natural state they support dense scrub, rushes or paperbark trees. They may be subject to flooding in the winter, while in the summer the water table is less than 1 m below the surface. Where the wetlands have been cleared for pastoral purposes they are usually traversed by a system of shallow open drains connected to the main drainage lines and support dense pasture.

CLIMATE

The climate is Mediterranean in character with a cool wet season from May to September and a warm dry season from November to March, with transition periods in April and October (Anon, 1969).

The average annual rainfall based on rainfall records from Henley Park and Caversham (Table 1) is about 855 mm of which about 90% falls between April and October. The hottest month is February when the mean maximum temperature is 31.9°C and the coolest month is July when the mean maximum temperature is 18.1°C. The average annual evaporation interpolated from Bureau of Meteorology maps is about 1 778 mm or about twice the annual average rainfall.

TABLE 1. AVERAGE MONTHLY RAINFALL AT CAVERSHAM AND HENLEY PARK

	Yrs	J	F	M	A	M	J	J	A	S	O	N	D	Year
Caversham, 1917–1955	38	6	10	17	49	120	179	171	139	94	53	20	12	857 mm
Henley Park, 1913–1963	47	8	13	19	44	117	173	177	131	77	54	24	13	850 mm

PREVIOUS WORK

The hydrogeology of the area was first described by Morgan (1964a, 1964b) who proposed an informal subdivision of the stratigraphy of the surficial formations and who gave a general account of the groundwater occurrence. Bestow (1970a, 1970b, 1971a, 1971b) presented a water table map covering part of the area and calculated the water balance and analyzed pumping test results from the adjacent Mirrabooka area. Later Balleau (1972a, 1972b, 1973) reanalyzed the pumping test data from Mirrabooka and noted wide areal variations in rainfall recharge on the northern and western fringes of the area. Allen (1976) gave a regional account of the hydrogeology of the coastal plain including generalized data for the area.

DRILLING AND SAMPLING

Twenty exploratory bores varying from 40 m to 80 m in depth and having an aggregate depth of 1 220 m were drilled between November 1975 and March 1976. The bores were drilled along four east-west lines, five bores per line, and about 1 km apart. The lines are about 2 km apart and form extensions to the existing lines of Mirrabooka Scheme production bores (Fig. 3).

The bores were numbered in sequence with the bores of the Mirrabooka Scheme and are distinguished from the Mirrabooka bores by the prefix ME (Mirrabooka East). The apparently inconsistent number ME81 results from the fact that there is already a bore Mirrabooka 90 (M90) in the Mirrabooka Scheme.

The drilling was done by two contractors using cable-tool drilling rigs. Each contractor drilled ten sites along two lines proceeding along each line from west to east.

During drilling, samples were collected at 2 m intervals for geological logging and sieve analysis. At the completion of drilling or after the bores had been cased and completed they were geophysically logged (gamma ray) to assist correlation between bores and to define bed boundaries.

The bores were cased with 75 mm class 9 PVC casing slotted through the saturated thickness of the "superficial formations" or the "channel sand" (described later) if it was encountered. An exception to this procedure was ME190 which was accidently left slotted in the Osborne Formation.

Graded gravel was used to fill the annulus between the borehole and the casing as the working steel casing was withdrawn. The use of the gravel envelope was to support the walls of the bore and to minimize clogging of the slots in the casing. After the gravel had been put into place the bore was bailed for 2 hours to settle the gravel envelope and to obtain an initial water sample for analysis. The PVC casing was left projecting about 0.3 m above the surface and for protection a short length of steel casing fitted with a hinged cap was sleeved over it and set in a cement block.

After completion of the bore the natural surface and reference points on the steel casing were levelled to an accuracy of 0.001 m. Further water samples were later collected with a portable submersible pump which yielded water at rates of up to 3.78 l/sec. The pump was operated for periods of 15 minutes to 2 hours depending on the drawdown. The bores were then left, and water levels in them measured at monthly intervals.

A summary of the drilling data is given in Table 2, and analyses of water samples are given in Table 4. Bore logs are available on file at the Geological Survey or the Metropolitan Water Board; sludge samples are stored at the Survey core library, and water level data are available from the Water Board's water levels retrieval system (GROWLS).

TABLE 2. SUMMARY OF BORE DATA

Bore No.	Commenced	Completed	R.L.n.s. m A.H.D.	R. L. steel casing m A.H.D.	R.L. P.V.C. casing m A.H.D.	Depth (m)	Slotting (m)	R.L. R.W.L. (m)	Date	Base Superficial Formations (m)	Underlying formation
50	1/12/75	4/12/75	37·329	38·121	....	46	0–46	28·66	9/3/76	42·0	Osborne Fm
60	8/12/75	11/12/75	25·222	25·859	25·684	40	0–32	23·44	9/3/76	Not reached	....
70	12/12/75	5/1/76	20·378	21·472	21·432	80	40–80	20·65	9/3/76	31·5	Channel sand
80	20/11/75	26/11/75	21·200	22·240	....	60	30–60	20·51	9/3/76	29·5	Channel sand
81	8/1/76	19/1/76	21·485	22·187	22·141	80	0–22	19·49	9/3/76	27·0	Osborne Fm
150	2/12/75	8/12/75	36·189	36·628	....	45	0–42	31·94	8/3/76	42·0	Osborne Fm
160	1/12/75	15/12/75	31·835	32·216	....	60	0–60	28·75	8/3/76	37·5	Channel sand
170	17/12/75	22/12/75	29·225	29·995	....	65	40–65	25·91	8/3/76	37·5	Channel sand
180	9/12/75	18/12/75	29·408	29·780	....	71	44–66	24·94	8/3/76	41·0	Channel sand
190	22/12/75	7/1/76	24·017	24·483	24·495	60	32–60	24·04	8/3/76	28·5	Osborne Fm
250	22/1/76	30/1/76	39·251	39·866	39·738	70	0–50	36·43	8/3/76	47·5	Osborne Fm
260	4/2/76	15/2/76	41·880	42·609	42·451	80	50–80	31·61	8/3/76	49·0	Channel sand
270	19/2/76	26/2/76	36·760	37·510	....	66	44–66	32·09	8/3/76	46·5	Channel sand
280	1/3/76	6/3/76	35·440	36·160	....	60	46–60	n.a.	....	42·0	Channel sand
290	11/3/76	15/3/76	33·620	34·360	....	41	0–25	n.a.	....	24·5	Osborne Fm
350	5/1/76	9/1/76	45·261	45·574	....	60	0–48	42·04	5/3/76	52·0	Osborne Fm
360	12/1/76	16/1/76	44·562	44·909	....	60	0–48	41·33	5/3/76	47·0	Osborne Fm
370	21/1/76	28/1/76	43·825	44·249	43·830	60	48–60	34·31	5/3/76	50·0	Channel sand
380	30/1/76	4/2/76	41·507	41·894	41·712	60	0–45	39·42	5/3/76	44·0	Osborne Fm
390	6/2/76	13/2/76	42·049	42·513	42·234	56	0–42	36·85	5/3/76	51·0	Osborne Fm

n.s. natural surface A.H.D. Aust. Height Datum R.W.L. Rest water level

GEOLOGY

STRATIGRAPHY

The Mirrabooka East area lies towards the eastern edge of the Perth Basin. It is underlain by more than 7 500 m of sedimentary rocks (Jones and Pearson, 1972) of which only the ?Pliocene-Holocene surficial formations 30 to ?200 m thick are of immediate concern.

The presently accepted subdivision of the surficial formations is based on surface geological mapping and limited borehole data (Playford and others, in press). However the subsurface geology of these formations is more complex than suggested by the mapping and for this reason it is preferred to recognize a bipartite division of the ?Pliocene-Holocene formations into the "channel sand" and the "superficial formations". In addition, the fact that the ?Pliocene-Holocene formations form a single aquifer system is a further justification for simplifying the nomenclature.

The stratigraphic subdivisions used in this report are given in Table 3, and are described separately below.

TABLE 3. STRATIGRAPHIC SEQUENCE

Formal age	Formation	Maximum thickness (m)	Lithology	Remarks
Quaternary-Late Tertiary	'Superficial formations'*	60	Sandy calcarenite, fine sand, feldspathic coarse sand, sandy clay, medium sand	Mapped as Bassendean Sand and Guildford Formation; becoming more clayey in east and south of area
			? UNCONFORMITY	
? Late Tertiary	'Channel sand'*	50+	Fine-medium slightly silty well sorted sand	Unnamed formation, possibly equivalent to the Rockingham Sand
			? UNCONFORMITY	
Early Cretaceous	Osborne Formation	150	Green glauconitic sandy siltstone, black sandy slightly glauconitic shale	Forms basement to 'channel sand' and 'superficial formations'

* Informal names used in this paper

Osborne Formation

The Osborne Formation (McWhae and others, 1958) consists of a green, glauconitic, sandy siltstone with minor beds of fine glauconitic sand, and glauconitic, black sandy shale. It is about 150 m thick and is unconformably overlain by the "channel sand" and the "superficial formations". The Osborne Formation was deposited in a marine environment and, based on microplankton studies, is of Early Cretaceous Cenomanian-Albian age (Cookson and Eisenack, 1958).

"Channel Sand"

The name "channel sand" is an informal name used here for a sequence of light-grey or greenish-grey fine to coarse, well-sorted sand. This contains minor layers of silty sand, pyrite-cemented sand, and frequent heavy mineral and glauconite grains. The unit unconformably overlies the Osborne Formation and infills a deep channel 1 km to 3.5 km wide to which it is apparently restricted. It is disconformably overlain by the "superficial formations" and is 91.5 m thick in Pacminex No. 1 bore and 67.5 m thick in MWB Whitfords Line No. 4 bore. The degree of sorting of the sands, the presence of heavy minerals, and absence of alluvial sediments indicate that the formation was deposited in a marine environment, possibly a submarine channel. The glauconite and many green-stained quartz grains present in the beds are probably derived from the Osborne Formation.

Beds belonging to the "channel sand" were first described by Morgan (1964a) from Gnangara No. 7 bore and later by Barnes (1971) from Pacminex No. 1 bore. The age of the beds is uncertain. Edgell (1963) examined samples from Gnangara No. 7 bore and concluded on the basis of contained spores and pollens that they were of Quaternary age, although the possibility of contamination could not be excluded. Subsequently other samples taken from the beds have proved barren. The beds have lithological similarities (apart from a difference in colour, produced by the weathering of glauconite) with the Rockingham Sand (Passmore, 1970).

"Superficial formations"

The name "superficial formations" includes all the Late Tertiary-Quaternary sediments with the exception of the "channel sand". They consist of several units separated by disconformities. At the base is a discontinuous bed of yellow-brown to grey, sandy calcarenite, overlain by light grey and green, fine and very coarse bimodal sand containing local concentrations of heavy minerals. This in turn is overlain by beds of grey, medium-coarse feldspathic sand which interfinger to the east with beds of clay, and clayey sand. Finally this unit is overlain by a light grey, fine to medium sand interbedded with a few thin layers of clay or clayey sand. A layer of limonite-cemented sand of variable thickness is developed throughout the area at the water table. This is referred to as "coffee rock".

The "superficial formations" unconformably overlie the Osborne Formation, and are believed to overlie the "channel sand" disconformably. However the possibility exists that this sand was deposited after the basal calcarenite was laid down and subjected to erosion.

The "superficial formations" range from ?Pliocene to Holocene in age (Playford and others, in press).

STRUCTURE

The Osborne Formation dips gently to the west and forms a basement to the overlying "channel sand" and "superficial formations". Locally it has been deeply eroded to produce a northerly trending submarine channel infilled with predominantly sandy sediments. Elsewhere the basement is overlain by a sequence of flat-lying younger sediments about 40 m thick. Sections illustrating the structure are given in Figure 4.

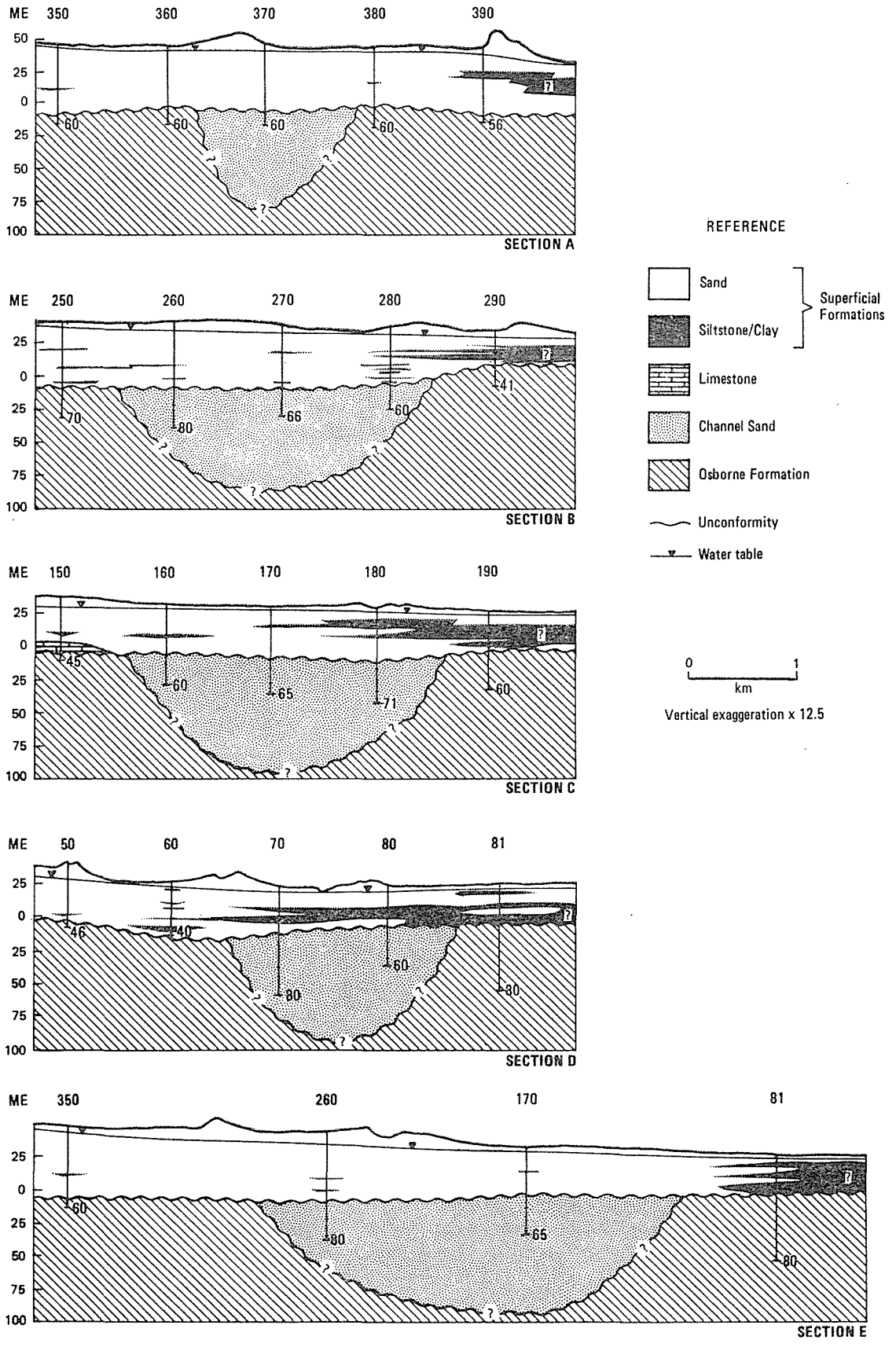

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Figure 4. Cross sections showing structure.

HYDROLOGY

SETTING

The Mirrabooka East area is situated in the south-eastern corner of the Gnangara Mound (Fig. 3) which is a regional body of generally unconfined groundwater (Allen, 1976) occurring in the "superficial formations" and "channel sand". The groundwater originates from rainfall recharge and moves under gravity to be discharged at the boundaries of the flow system, formed by the sea and the major rivers situated around the periphery of the mound. Discharge is also by evapotranspiration from wetlands and vegetation; by downward leakage into underlying formations; and by drainage works and groundwater usage.

GROUNDWATER FLOW SYSTEM

A major groundwater flow system occurs in the "superficial formations". It is in hydraulic connection with flow systems in underlying formations.

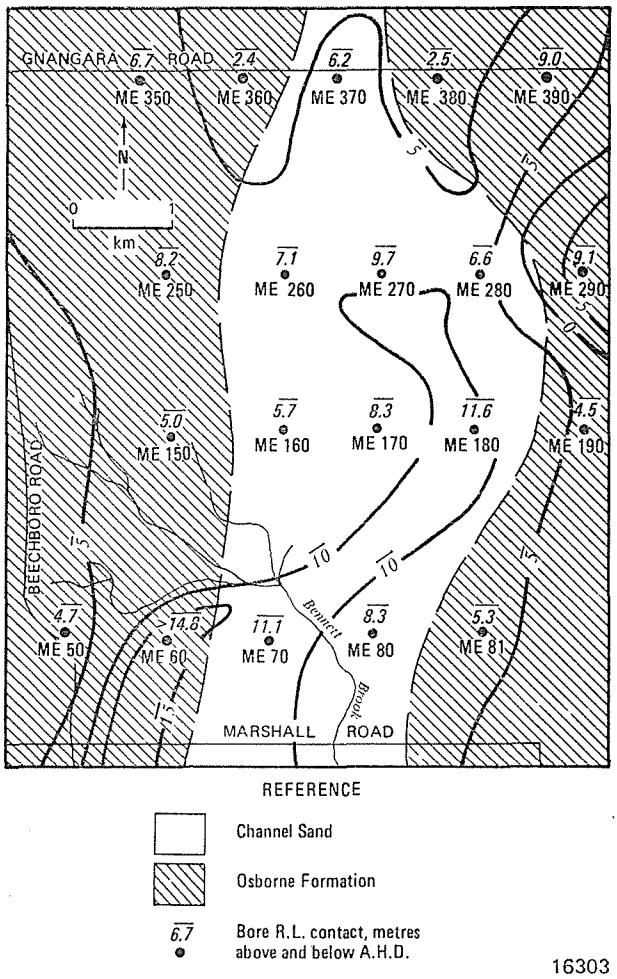

Figure 5. Subcrop map and contours on base of superficial formations.

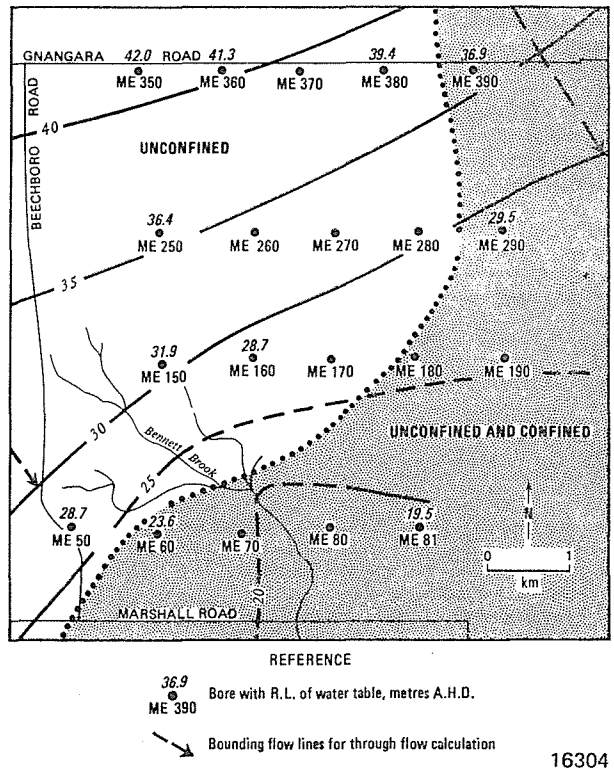

Figure 6. Water table contours (metres), March 1976.

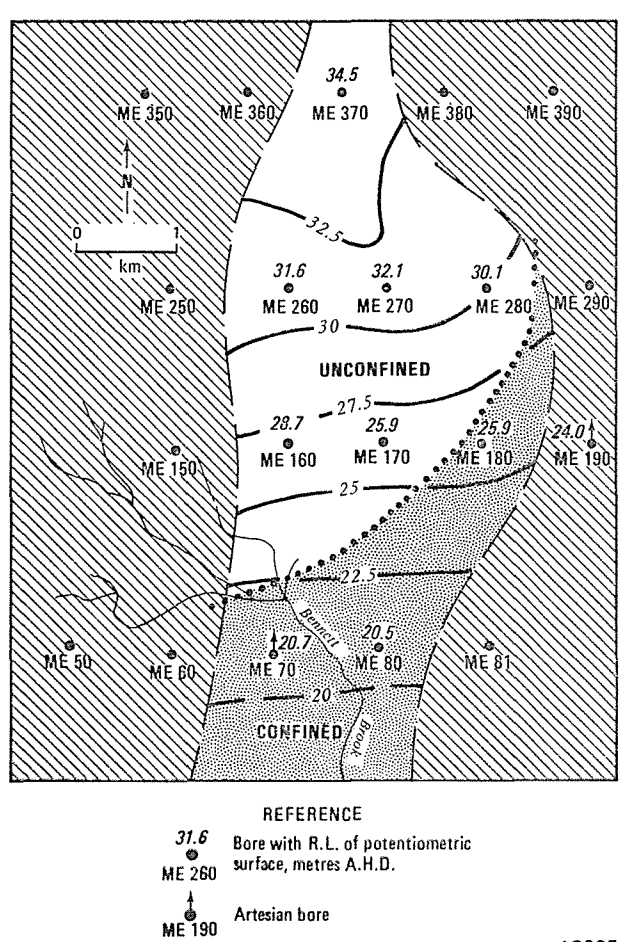

Figure 7. Isopotential contours (metres) for channel sand, March 1976.

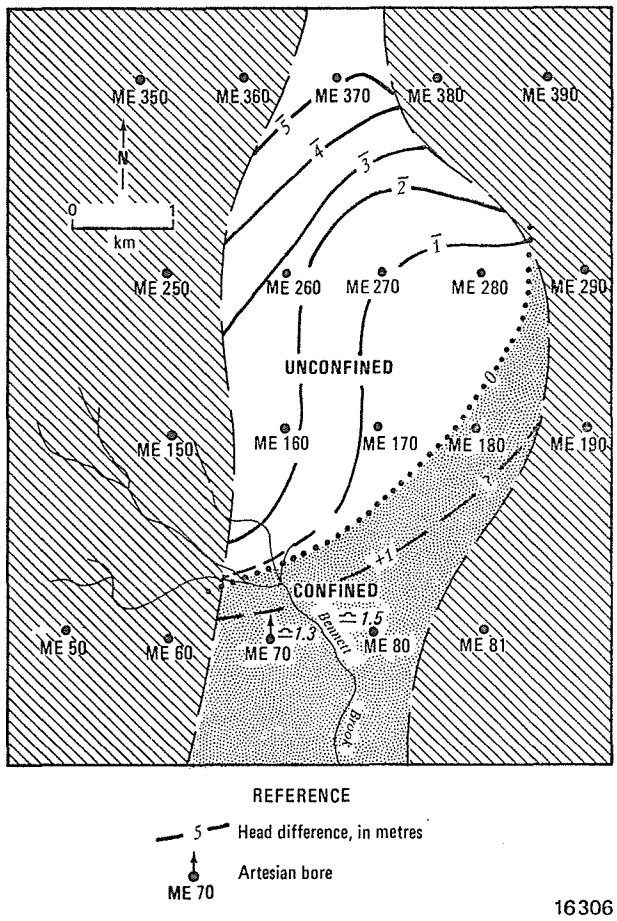

Figure 8. Difference in head between the isopotential surface (channel sand) and the water table, March 1976.

"Superficial formations" flow system

The configuration of the water table based on data from eleven of the bores for March 1976, is given in Figure 6. Because of the relative sparseness of control points the map is necessarily generalized, in particular, adjacent to the drainage lines where the water table contours must be more complex than shown, and also in the vicinity of the 20 m topographic contour where the water table and the surface contours converge and steep groundwater gradients must occur.

The water table contours show that the groundwater flows in a general southeasterly direction and has a gradient of about 3 m per kilometre. In the northwest of the area where the "superficial formations" consist predominantly of sand the groundwater is unconfined. However toward the east and south where the "superficial formations" become predominantly clayey (Section C, Fig. 4) the groundwater flow system is effectively split into an upper unconfined flow system in relatively thin beds of sand resting on the underlying beds of clay, and a confined system within and beneath the clayey beds.

In addition to splitting the flow system the "superficial formations" are less permeable and considerably thinner as a result of the decrease in topographic elevation (Section E, Fig. 4). Together these factors reduce the transmissivity of the "superficial formations" with the result that only a small proportion of the throughflow is transmitted, presumably to be discharged in the Swan River, while the rest is discharged into springs and soaks where it is lost by evapotranspiration or run-off.

"Channel sand" flow system

The groundwater flow system in the "channel sand" is in hydraulic continuity with those in the "superficial formations" and in the Osborne Formation. It is unconfined except where it is overlain by beds of clay in the "superficial formations" in the southern part of the area (Fig. 7).

The configuration of the isopotential surface in the "channel sand" groundwater system (Fig. 7) is based on data from nine bores slotted to varying depths in the upper 50 m of the "channel sand". It slopes downward in a southerly direction more or less at right angles to the long-axis of the channel, and has a gradient of about 2.9 m per kilometre.

The elevation of the water table and the potentiometric head in the "channel sand" groundwater system show considerable variation over the area. The head differential between the two surfaces drawn by overlaying Figures 6 and 7 is given in Figure 8. This shows that in the northern part of the area the head in the "channel sand" is about 5 m lower than in the "superficial formations" while in the southern part of the area it is several metres above the water table. The convergence and crossing over of the potentiometric surface in the "channel sand" with the water table takes place in the zone of transition between sandy and clayey "superficial formations" (Fig. 6).

Osborne Formation flow system

Although the Osborne Formation is composed mainly of siltstone and shale it does contain some minor beds of sand. These, and perhaps to a limited extent the siltstones, transmit small quantities of groundwater.

Bore ME190 was accidently left cased in the Osborne Formation. The bore flowed and was found to have a head comparable with that in the "channel sand". This probably results from the interception of minor permeable zones in the formation which are in hydraulic continuity with the "channel sand" in the west (Fig. 4, Section C).

GROUNDWATER RESOURCES

The complexity of the flow systems in the "superficial formations", "channel sand" and Osborne Formation, together with lack of data on stream flow, and evapotranspiration, make it impossible to prepare a reliable water balance for the area. Therefore the indicated groundwater resources are estimated by calculating throughflow for the area. These calculations are also approximate because of downward head potentials above the "channel sand" and convergence of flow lines around drainage lines and discharge areas.

The throughflow in the "superficial formations" is estimated across the 30 m groundwater contour (Fig. 6). This was chosen because it is well controlled by borehole data; because in this area the "superficial formations" are predominantly sandy; and because the downward head potential relative to the "channel sand" is minimal.

The annual throughflow (Q) was estimated from the following form of the Darcy equation:

$$Q = 365 \times T \times I \times L \quad \ldots\ldots (1)$$

where T is the transmissivity
I is the hydraulic gradient
L is the width of the flow cross section.

The transmissivity is estimated to be the adopted average hydraulic conductivity for the Gnangara Mound of 15 $m^3/d/m^2$ (Allen, 1976) multiplied by the average saturated thickness (35 m) obtained by comparison of Figures 5 and 6. The gradient was measured along nine equally spaced flow lines, averaged, and found to be 1:310. The width of the flow section spanning the proposed borefield is 8 km (Fig. 6).

Solving equation (1) for the given values:

$$Q = \frac{365}{1} \times \frac{15}{1} \times \frac{35}{1} \times \frac{1}{310} \times \frac{8\,000}{1}$$

$$= 4.945 \times 10^6 m^3/y$$

$$= \text{Say } 5 \times 10^6 m^3/y.$$

The throughflow in the "channel sand" cannot be accurately determined from available hydraulic data. However the order of magnitude may be derived by making the following assumptions: (1) flow past the 22.5 m isopotential contour is planar with a gradient of 7.5:2 500 (Fig. 7); (2) the channel is 95 m deep (based on Pacminex No. 1) and 2 400 m wide (i.e. rectangular in cross section); and (3) that the hydraulic conductivity of the "channel sand" is 10 $m^3/d/m^2$.

Substituting assumed and derived values in equation (1) and solving:

$$Q = \frac{365}{1} \times \frac{10}{1} \times \frac{95}{1} \times \frac{7{\cdot}5}{2\,500} \times \frac{2\,400}{1}$$

$$= 2.496 \times 10^6 \text{ m}^3/\text{y}$$

$$= \text{Say } 2.5 \times 10^6 \text{ m}^3/\text{y}.$$

Summing the throughflow calculations the indicated throughflow for the area is about 7.5×10^6 m³/y.

GROUNDWATER QUALITY

On completion of each bore it was bailed for two hours, and a sample taken for analysis. Later most of the bores were resampled by pumping with a small submersible pump. The results are given in Table 4.

TABLE 4. WATER ANALYSES

Bore	Lab. No.	pH	Turbidity (APHA units)	Colour (APHA units)	Odour	T.D.S. (evap) mg/l	NaCl mg/l	Cl mg/l	Alkalinity (as $CaCO_3$) mg/l	Hardness (as $CaCO_3$) mg/l	Ca mg/l	Fe mg/l	Free CO_2 mg/l	Remarks
50	26131/75	6·9	....	160	Oily	390	204	124	....	155	....	....	....	Bailed 9/12/75
60	26366/75	6·2	....	320	H_2S	330	165	100	....	85	....	....	....	Bailed 12/12/75
	11127/76	5·6	850	530	Musty	300	160	....	22	....	7	1·3	111	Pumped ½ hour at 2·3 l/s
70	865/76....	6·7	....	20	Oily	270	152	92	....	75	....	....	....	Bailed 13/1/76
	11128/76	5·8	150	10	Nil	170	106	....	25	....	7	0·05	79	Pumped ½ hour at 1·9 l/s
80	25287/75	6·3	....	50	Oily	460	317	192	....	128	....	....	....	Bailed 1/12/75
	10730/76	6·2	14 000	30	Nil	170	101	....	48	....	11	0·10	61	Pumped ½ hour at 2·8 l/s
81	2468/76	7·0	....	50	Nil	340	226	137	....	68	....	....	....	Bailed
	10733/76	5·7	3 800	1 500	Musty	400	138	....	48	....	5	2·4	192	Pumped ½ hour at 3·8 l/s
150	27483/75	6·5	....	125	Oily	310	175	106	....	100	....	....	....	Bailed 9/12/75
	11130/76	5·4	450	130	Nil	240	158	....	15	....	4	0·2	119	Pumped ½ hour at 3·2 l/s
160	26927/76	5·5	....	60	Oily	260	185	112	....	45	....	....	....	Bailed 6/12/76
	11131/76	5·0	< 5	55	H_2S	240	170	....	5	....	3	0·4	100	Pumped ½ hour at 0·3 l/s
170	103/76....	6·8	....	38	Oily	330	213	129	....	104	....	....	....	Bailed 5/1/76
	11132/76	5·5	1 000	35	Nil	160	106	....	15	....	2	2·1	95	Pumped ½ hour at 1·9 l/s
180	27484/75	6·0	....	< 10	Oily	180	109	66	....	63	....	....	....	Bailed 9/12/75
	11133/76	6·3	17 500	30	Nil	170	94	....	53	....	14	1·6	53	Pumped ½ hour at 1·9 l/s
190	1415/76	6·7	10	20	Oily	420	120	73	....	170	....	....	....	Bailed
	11129/76	6·8	95	10	Nil	250	87	....	103	....	22	0·05	33	Pumped ½ hour at 0·3 l/s
250	2467/76	6·4	....	150	Nil	880	410	249	....	248	....	....	....	Bailed
	11203/76	5·4	950	90	H_2S	180	101	....	12	....	4	0·60	96	Pumped ½ hour at 3·8 l/s
260	4255/76	6·5	8 000	< 5	Earthy	280	157	95	60	....	....	....	....	Bailed
270	11204/76	5·4	12 000	100	H_2S	140	97	....	15	....	2	0·80	119	Pumped ½ hour at 1·7 l/s
280	11205/76	5·7	2 000	25	Paraffinic	150	101	....	15	....	2	1·9	60	Pumped ½ hour at 1·3 l/s
290	11206/76	6·2	175	40	Nil	170	110	....	45	....	6	3·5	57	Pumped ½ hour at 2·8 l/s
350	866/75	5·5	....	< 10	Previous contents	500	269	163	....	150	....	....	....	Bailed 13/1/76
	4728/76	5·4	1 400	35	H_2S	170	130	79	15	....	3	0·6	119	Pumped ½ hour at 3·8 l/s
360	1416/76	6·0	4 500	40	Oily	390	204	124	....	110	....	....	....	Bailed
	4727/76	5·5	3 500	90	H_2S	190	138	84	18	....	3	3·0	114	Pumped ½ hour at 3·8 l/s
370	2195/76	6·7	....	15	Present	250	162	98	80	....	....	....	....	Bailed 3/2/76
	15712/76	5·6	9 000	21	H_2S	160	115	....	20	....	2	0·37	100	Pumped 5¾ hrs at 0·8 l/s
380	2466/76	6·8	....	100	Present	290	186	113	....	63	....	....	....	Bailed
	4726/76	5·4	2 200	100	H_2S	250	180	109	18	....	4	0·3	143	Pumped ¼ hour at 3·8 l/s
390	4256/76	6·2	4 500	< 5	Earthy	200	119	72	60	....	....	....	....	Bailed
	4725/76	4·7	95	5	Present	130	97	59	3	....	3	0·1	120	Pumped ½ hour at 1·5 l/s

Comparison between the analyses of the bailed samples and the pumped samples shows that the total dissolved solid content of pumped samples is invariably the least. The reason for this may result from the bailing-process sampling a mixture of drilling water and groundwater, or from the fact that the best quality water is obtained from the most permeable bed(s) which also yield most of the water.

Comparison of the analyses from the "channel sand" and "superficial formations" shows that groundwater from the two systems is chemically very similar. However the physical properties of turbidity and colour are somewhat different. The "superficial formations" appear to have a generally higher colour content but lower turbidity than the "channel sand". The colour content is due to the presence of organic compounds which have been observed to occur in the highest concentration near the water table, and to decrease with depth. The turbidity results from the occurrence of kaolin in the aquifers. This varies significantly between different bores in both the "superficial formations" and "channel sand" and it is not possible to generalize about its occurrence.

The range of the more important chemical and physical properties is given in Table 5.

TABLE 5. RANGE OF PHYSICAL AND CHEMICAL COMPONENTS AFFECTING GROUNDWATER QUALITY (PUMPED SAMPLES)

pH	Turbidity APHA units	Colour APHA units	TDS (evap) mg/l	Fe mg/l	Free CO_2 (by calculation) mg/l
		'Superficial formations'			
4·7–6·8	95–900	5–1 500	130–400	0·05–3·5	33–192
		'Channel sand'			
5·0–6·3	10–17 500	<5–100	140–280	0·05–2·1	53–119

The data show that the water would need correction for pH, and treatment for turbidity, colour and iron before it could be used in a public water supply scheme.

DEVELOPMENT

The drilling programme has defined the easternmost extent of prospective sections of the "superficial formations." Thus the lithology at ME60, 70, 80, 81, 190 and 290 is not suitable for the construction of production bores in the "superficial formation", whereas they can be established at the remaining sites.

The lithology of the "channel sand" suggests that production bores could obtain economic yields of water from this formation, at sites ME70, 80, 160, 170, 180, 260, 270, 280 and 370. Confined conditions occur at ME70, 80 and 180, and abstraction at these sites may lead to mutual interference. A further complication is that the channel walls may behave as barrier boundaries and large drawdowns could be experienced in these production bores.

The presence of the "channel sand" provides a degree of flexibility to the proposed groundwater scheme. Should production bores in the "superficial formations" produce unacceptable water table drawdowns, bores in the "channel sand" could be used. They would produce water mainly from the "channel sand", as well as some water by induced downward leakage from the "superficial formations". However because of stratification the effect of this is expected to be smaller and more widespread than for abstraction directly from the "superficial formations".

Any pumping scheme based on the "superficial formations" will draw water from storage, underflow, and from the direct infiltration of rainfall. The effect will be to cause a small but widespread lowering of the water table and a reduction of spring flow which will cause a contraction of seepage areas. However such abstraction will probably have no effect on swamps in the low lying areas in the south and east which are maintained by essentially perched groundwater.

The lowering of the water table will cause a substantial decrease in transpiration losses (Bestow, 1971a) so that considerably more water than suggested by the underflow calculations can be abstracted.

CONCLUSIONS

The occurrence of groundwater in the Mirrabooka East area is complicated by the geology. A large proportion of the area is the site of groundwater discharge, where groundwater is lost by evapotranspiration or discharged via surface drains into the major streams.

The effect of a groundwater scheme would be to utilize this otherwise unused groundwater. Any undesirable effects caused by an expected widespread but small lowering of the water table could be offset to some extent by utilizing the "channel sand".

Based on conservative throughflow calculations at least 7.5×10^6 m³/y of groundwater can be obtained from the area. A small lowering of the water table and clearing for pasture will substantially decrease evapotranspiration losses with the result that considerably more water than indicated by the throughflow calculation can be obtained.

Groundwater from the area would be suitable for public water supply after treatment.

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WUNGONG DAM – THE INFLUENCE OF ENGINEERING GEOLOGY STUDIES

by E. P. O'Driscoll and G. W. A. Marcos

ABSTRACT

Wungong dam site in the Darling Range is underlain by an Archaean basement complex. Starting in 1922, geological investigations continued intermittently until 1975, when construction began. Initially planned as a concrete structure, for engineering reasons this was changed to earth fill. As a result of detailed geological investigations, the centre line was moved and rotated to avoid a landslip area; the spillway was relocated on the opposite bank to reduce foundation difficulties; the control tower was moved for a similar reason; and the design finally adopted was for a composite earth and rock fill structure with a clay corewall. Predicted subsurface geological conditions proved remarkably reliable, despite poor outcrops which necessitated more than usual use of exploratory drilling and seismic refraction.

LOCALITY

Originally referred to as Lower Wungong Damsite, Wungong Dam is on Wungong Brook about 32 km south-southeast from Perth (Fig. 9).

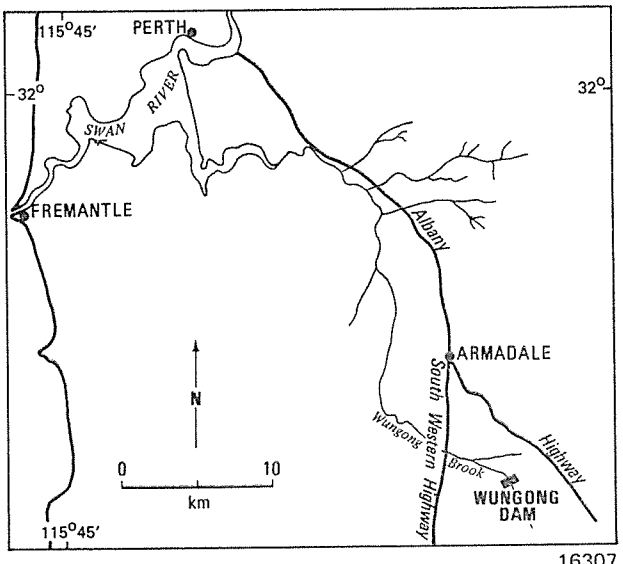
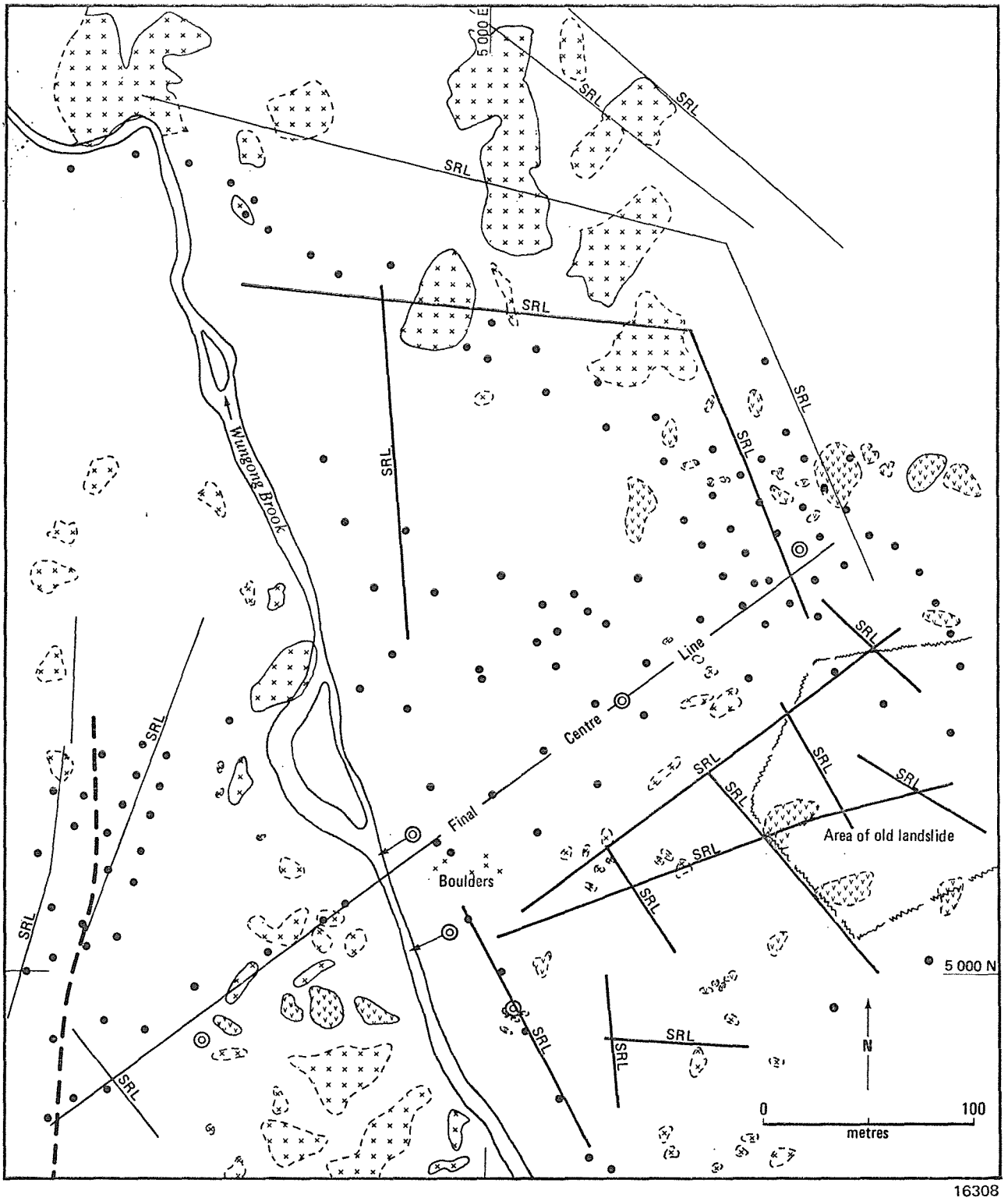


Figure 9. Locality plan, Wungong Dam.

GEOLOGY

ENVIRONMENT

The geological environment is the usual one for a dam in the ranges close to the Darling Fault. The country rock consists of Archaean igneous and metamorphic rocks intruded by variably dipping mafic dykes, the whole having once formed part of a peneplain covered by laterite. Beneath the laterite is a zone of weathered rock which may be as much as 30-35 m thick, predominantly of sandy kaolinitic material, the depth to its base having been controlled



REFERENCE

Soils

Granitic rocks, outcrop and big boulders

Dolerite

Geological boundaries
Accurate
Approximate
Possible fault, concealed
Airtrack holes
Diamond drillholes
SRL Seismic refraction lines

Figure 10. Site plan showing outcrop, geophysical traverses, and drillholes.

during weathering by the existence of sheet or pressure-relief joints. Although much has been removed by subsequent erosion, the valley flanks and floors are still fairly extensively covered by colluvium and slope wash, which conceal the underlying rocks and make factual mapping difficult. The weathered material varies in mineralogical composition even over short distances, depending on the nature of the parent rock and other factors. Its engineering properties also differ, necessitating careful investigation of borrow areas for suitable spoil, and supervision of its excavation.

Because of the poor exposure of basement rock at the site of the structure, a common difficulty in the Darling Range, field investigation must include more subsurface probing by drilling and geophysics than is usually the case.

ROCK TYPES

The Archaean basement rock comprises banded granitic gneiss, migmatitic gneiss and even-grained granite, with minor pegmatite and quartz veins. Deciding on a suitable name for common reference in itself is a difficulty, because the rock is not always gneissic or even granitic. Around Wungong the granitic phase is tonalitic, while the origin of the migmatite is obscure. The physical properties of the hard rocks and the overlying weathered material vary from site to site in ways important to the engineer, and at each new structure it is necessary to decide on a name for reference, and specify in some detail the types of rock to which this name refers. Furthermore, to avoid misunderstanding it sometimes has been found desirable to use a different name even for fairly similar suites of rocks, when investigators and design engineers move their attention from one area to another. At Wungong the term "granitic rock" has been adopted.

Doleritic dykes are common, varying in width from a few centimetres to possibly 50 m or so. They pose a nomenclature difficulty because the rock is usually a metadolerite, quite often with relatively abundant free quartz. Many dykes appear to have been injected along almost vertical joint planes, narrow intrusions sometimes being offset along minor joints, but they may also unpredictably cut across the present joints, or unexpectedly divide. Being well jointed, narrow dykes tend more readily than the country rock to be softened by weathering, especially at locations where they intersect. This necessitates prediction of stability problems for concrete structures such as at the original site of the Wungong inlet tower; or the increase in the volume of excavation in a small area, when hard basement is needed beneath a foundation.

ROCK STRUCTURE

Structurally the granitic rock usually has a southeasterly foliation with a westerly dip, the variable joints having a predominantly northeasterly master direction. Shearing has been superimposed, so that in some places the rock is closely fractured.

In both granitic and doleritic rocks it was difficult to determine from surface outcrops just what the joint patterns and frequencies were, and therefore to predict rock strengths and excavation characteristics. Even the sheet joints were found to be more strongly developed in the right bank than the left, and to occur as deeply as 22 m below the top of the hard rock.

GEOLOGICAL INVESTIGATIONS

Concrete wall

Geological studies for the building of a concrete structure in the general area were spasmodically conducted from 1922 to 1952. They included three diamond drillholes and 78 pits, but the geological structure was still unresolved and no centre line had been selected (of four being considered) when investigations were discontinued. They were not resumed until 1960, when construction methods and materials had changed. The use of earth or rock fill and other alternatives to concrete meant that design engineers needed rather different and in some ways more comprehensive geological information about foundation conditions, and the availability of materials (Fig. 10).

Earth fill wall

A centre line for an earth fill dam had to be tentatively chosen; and the thickness, nature, and state of consolidation of the subsoil became important, because whereas a rigid concrete wall would be keyed into hard rock, much of the weathered zone material could possibly be left unexcavated beneath the foundations of a homogeneous earth fill structure. On the other hand, possible leakage could be more critical beneath the structure or around the flanks. Because the straight course of the river along its deeply incised valley might have been fault-controlled, the possibility of leakage along a shatter zone crossing beneath the wall existed for any type of structure. This was therefore checked by two inclined diamond drillholes, which detected no zone of weakness.

For the earth fill structure a large volume of suitable clayey materials would be needed for the wall and its impermeable core, and its availability from borrow areas below full supply level and within economic transport distance had therefore to be investigated by drilling. Dimension stone would also be required as protection for the wall face, which meant finding a suitable quarry site nearby.

Recent experience has shown that some of the weathered material overlying basement rock is unsuitable for use, its physical properties especially when emplaced as compacted fill being adversely affected by the presence of minerals such as halloysite and mica. Because some *in situ* soils might not be removed by excavation, but left in place to form part of the foundations, careful sampling by drilling beneath the wall area would be needed.

From 1960 to 1965, a renewed and more intensive investigation of the wall area was continued along a specific centre line, including geologic mapping, hammer seismic traverses, auger and diamond drilling, and soil sampling for laboratory tests. This disclosed a substantial variation in the thickness of weathered material suitable for leaving undisturbed beneath an earth fill structure; and also that the volume of fill could be reduced if the centre line were slightly rotated and moved less than 100 m upstream. A new centre line was therefore adopted.

At this stage the investigation was interrupted, work being transferred to a site on the South Dandalup River where a dam was subsequently constructed.

Work was resumed at Wungong in 1972, and the geological conditions beneath the wall, the control tower, and the proposed spillway on the left bank were now examined in detail, particular interest being centred on the depth to hard rock and the variations in the nature of the overburden.

Earlier attempts to supplement exploratory drilling by seismic work had been unsuccessful because of the very shallow depth which could be probed by hammer seismic methods. More sophisticated seismic refraction equipment was now available, and proved very valuable in use, enabling a reasonably accurate assessment to be made of bed-rock depths along the length of each traverse. In critical areas such as the spillway centre line, the method was capable of indicating deep bed-rock depressions of limited area, whose presence would have remained undetected by drilling except on an uneconomically closely spaced grid.

As information accumulated, the siting of the traverse lines and of the supplementary drillholes was under constant review by the geologist.

Seismic refraction methods were found to be capable of indicating the probable depth of the contact between slopewash and the underlying soft weathered bedrock material which was in an undisturbed state and could be left in place. Seismic methods had an important advantage over drilling, which was much slower because each bore always had to be continued on for 3 m or so into hard rock to ensure that the drill hole had not encountered a boulder, or an unweathered kernel of hard rock rather than true basement. Furthermore, to manoeuvre a drilling plant on steep slopes was sometimes slow and difficult.

Seismic refraction work is not a substitute for drilling, but it does indicate target areas at which the drilling should be directed, and the two methods were successfully used in conjunction at Wungong. More than 2 500 m of seismic refraction lines were accompanied by about 250 additional drillholes and pits. The results of this work meant several changes in design.

(i) There was an old landslip mass on the right bank. The centre line of the dam was therefore moved to avoid this unstable area.

(ii) A spillway on the left bank could have its downstream end anchored on a stable mass of gneiss, but the depth to sound bedrock beneath its centre line was very variable, and there were several deep depressions which posed stability problems. The left bank was considered so unsatisfactory that the spillway site was moved to the right bank, where three possible lines were considered, which meant extra mapping, seismic investigation, and drilling. It also meant designing a fully concrete-lined spillway.

(iii) The intake tower site upstream of the dam toe was underlain by both gneiss and dolerite, and these two different rock types were differentially and deeply weathered. To provide adequate stability, excavations for the tower would be expensive enough to warrant moving the structure elsewhere, which in fact was done for this and other design reasons. The tower site was moved farther downstream and placed inside the dam toe. The culvert on the right bank was then moved slightly uphill.

Figure 11 shows the final dam site layout.

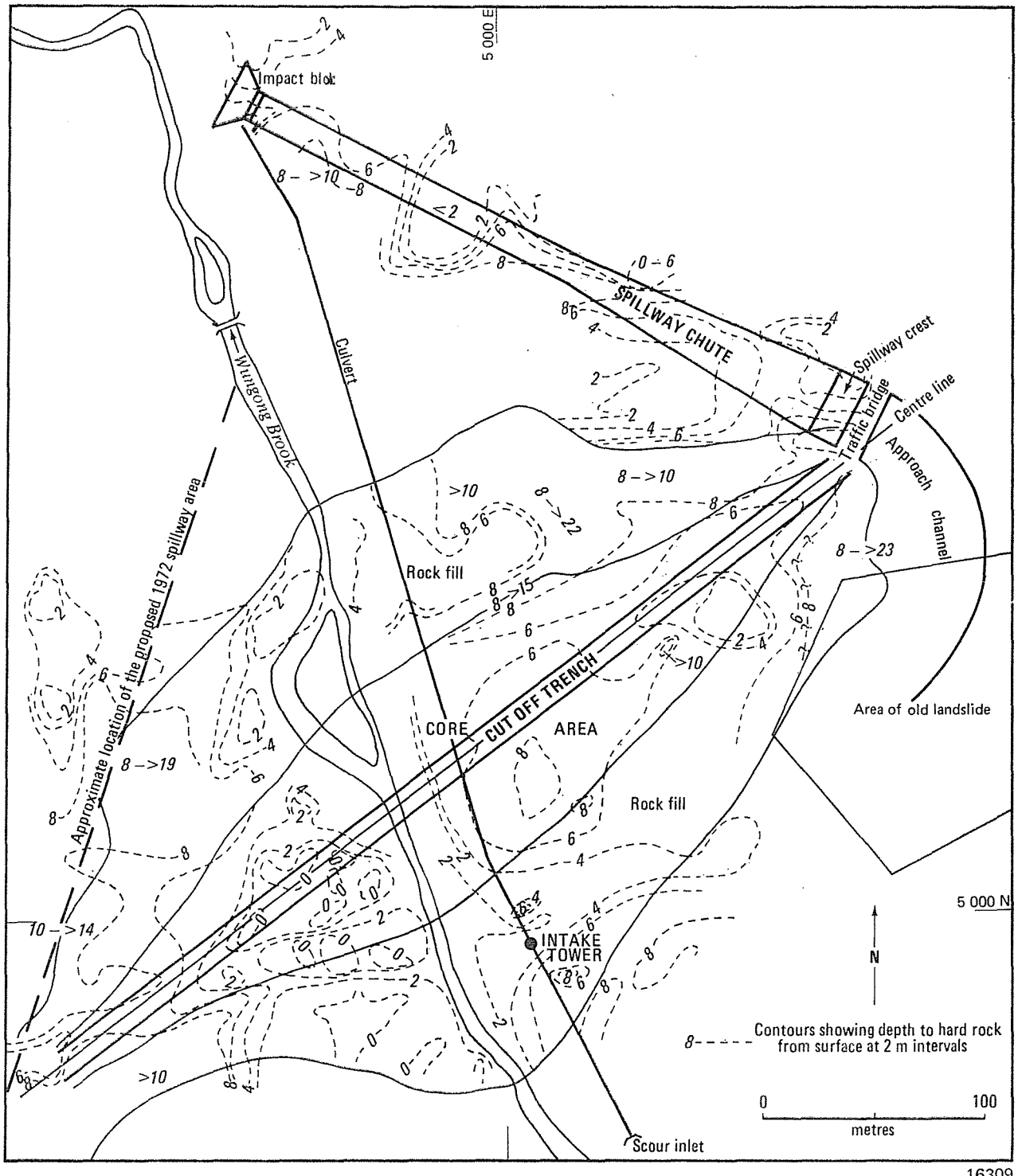


Figure 11. Site plan showing bed-rock depths, and final position of structure.

Composite earth and rock-fill wall

While the above investigations were proceeding, extensive drilling in the earth borrow and rock quarry areas had shown that suitable earth fill was not as readily available as expected. The engineers decided again to change the design, this time from an earth fill to a composite earth and rock-fill structure with a wide impervious clay core. This in itself posed two further problems. Firstly, material beneath the wall area consisted of three layers; slope wash which would have to be removed from beneath all parts of any structure; weathered rock material which could be left in place beneath emplaced earth fill but not rock fill; and hard rock. Becuse the weathered rock layer could not be left as a foundation beneath rock fill, a substantial extra volume of excavation would now be needed. Secondly, much greater quantities of rock were needed for the rock fill. Fortunately, an examination of two quarry sites showed that one about 6 km upstream from the dam site could supply all that was needed.

CO-OPERATION

By December, 1976, excavation work at the site was far enough advanced to check the reliability of what had been predicted. Time and warrantable expenditure both tend to restrict geological investigations, against which must be weighed the likelihood of undetected subsurface conditions causing trouble during construction. Whether to extend investigations or to intensify them in particular areas must be decided in consultation between geologist and engineer, and involves mutual appreciation of the problems involved. At Wungong several design modifications resulted from frequent discussions, and the predicted subsurface geological conditions correspond with those exposed during excavation, with two minor exceptions. One inclined dolerite dyke less than 10 m wide was found, the weathered margin of which apparently had been reached in one airtrack borehole, although the material recovered had not been correctly identified. In another place, weathering at the point of intersection of several nearly vertical dykes was deeper than expected. These had no serious adverse effects, and the successive changes in the position and design of the structure, which resulted from progressive geological and other investigations, were fully justified. These decisions were made by the engineers, to whom the value of geological investigations greatly depends on how well these are performed within the limits of available finance; and on how well the results are interpreted and presented for their information. Wungong Dam is a good example of co-operation and communication, (Table 6).

ACKNOWLEDGEMENT

The writers are grateful to the Metropolitan Water Board for facilities granted and for permission to use information included in this report.

TABLE 6. SUMMARY OF PROGRESS

Period	Type of construction planned	Methods of investigation	Resultant engineering action	Comment
1922–1952	Concrete wall	Pits; diamond drilling; geological mapping		Investigations incomplete; geological structure not resolved; four possible centre lines still being considered
1960–1965	Earth fill wall; spillway on left bank	Geological fact mapping; hammer seismic refraction; drilling; soil sampling	(i) Centre line tentatively chosen (ii) Centre line moved slightly upstream to reduce volume of fill needed	General geological conditions apparent Detailed information needed of foundation area
1972–1975	(i) Earth fill wall	Geological mapping; drilling; seismic refraction	(i) Spillway removed from left bank to right bank (ii) Centre line slightly rotated and moved upstream (iii) Control tower site moved downstream	(i) Original spillway centre line underlain by depressions in bedrock which posed stability problems (ii) This avoided placing the abutment on a landslip area, right bank (iii) Original site underlain by two differentially weathered rock types posing stability difficulties
	(ii) Combination earth and rock fill with impervious clay core	Rock quarries drilled. Site investigations continued	Redesign of structure	Insufficient suitable earth fill material economically available. New design meant more excavation for placement of rockfill, and more dimension stone needed
1976	Construction commenced	Progress geological mapping during construction		Subsurface conditions found to match predictions closely

PETROLEUM EXPLORATION IN WESTERN AUSTRALIA IN 1976

by K. A. Crank

ABSTRACT

The low level of activtiy in oil exploration in Western Australia continued in 1976.

Only six wells were completed in the year, the same number as in 1975, and two were drilling ahead at the end of the year for a total of 22 171 metres, an increase of 5 056 metres over 1975. Drilling activity was restricted to the Carnarvon Basin, apart from a shallow stratigraphic test hole drilled onshore in the Bremer Basin. The only significant discovery during the year was at Perentie No. 1 on Barrow Island a follow-up to West Australian Petroleum Pty Ltd's deep tests of previous years, Biggada No. 1 and Barrow Deep No. 1.

Geophysical activity, consisting of land and marine seismic surveys and a limited amount of magnetic and gravity surveys, increased threefold compared to the very low level of 1975.

INTRODUCTION

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

	Wells completed		Wells drilling on 31st December	
	1975	1976	1975	1976
New field wildcats	5	5	1	1
Extension wells	0	0	0	1
Deeper pool tests	1	0	0	0
Stratigraphic tests	0	1	0	0
	6	6	1	2

Total effective drilling: 1975—17 115 m
1976—22 171 m

Only one successful well was drilled in 1976, Perentie No. 1, a new field wildcat on Barrow Island classified as a shut-in gas well.

Geophysical survey and surface geological survey activity for 1976 is shown below (with 1975 figures in brackets):

Type of survey	Line km	Party months or geologist months
Land seismic	443 (484)	....
Marine seismic	8 599* (2 737)	....
Magnetic	490 (Nil)	....
Gravity marine....	108 (Nil)	....
Geological	....	3·0 (5·0)

* This does not include 7 757 line kilometres of marine seismic conducted outside permit areas by Geophysical Services International which was classed as a "Scientific Investigation".

PETROLEUM TENEMENTS

During the year two onshore permits were surrendered in the Canning Basin (EP 32, EP 34). Surrender was pending on one offshore permit in the Perth Basin (WA-20-P) and on two onshore permits, EP 70 in the Canning Basin, and EP 85 in the Perth Basin. Eight onshore permits were partially relinquished: EPs 40, 41, 54, 61, 62, 63, 65 and 66. Two new offshore and seven new onshore tenements were granted during 1976. Large areas are currently available for application in all basins.

Petroleum Tenements current on December 31st, 1976 are shown in Figure 12, and the following tabulation lists details of the various holdings.

PETROLEUM TENEMENTS UNDER THE PETROLEUM (SUBMERGED LANDS) ACT, 1967

Exploration permits

Number	No. of graticular sections	Expiry date of current term	Registered holder or applicant
WA-1-P R1	178	14/11/79	Woodside Oil N.L., Woodside Petroleum Development Pty. Ltd., Mid-Eastern Oil N.L., North West Shelf Development Pty. Ltd., BP Petroleum Development Aust. Pty. Ltd., California Asiatic Oil Co.
WA-13-P R1 Part 1	110 ⎫ 194	29/8/79	West Australian Petroleum Pty. Ltd.
R1 Part 2	84 ⎭		
WA-14-P R1 Part 1	77 ⎫ 198	28/8/79	
R1 Part 2	121 ⎭		
WA-16-P R1	40	16/4/80	Arco Aust. Ltd., Australian Aquitaine Petroleum Pty. Ltd., Esso Exploration and Production Aust. Inc.
WA-18-P R1	105	16/4/80	
WA-19-P R1	49	20/3/80	Alliance Oil Development Aust. N.L.
WA-20-P* R1	15	10/10/79	West Australian Petroleum Pty. Ltd.
WA-23-P R1	199	3/10/79	
WA-24-P R1	104	17/10/79	
WA-25-P R1	128	16/10/79	
WA-28-P R1 Part 1	52 ⎫ 178	24/3/80	Woodside Oil N.L., Woodside Petroleum Development Pty. Ltd., Mid-Eastern Oil N.L., North West Shelf Development Pty. Ltd., BP Petroleum Development Aust. Pty. Ltd., California Asiatic Oil Co.
R1 Part 2	126 ⎭		
WA-29-P R1 Part 1	36 ⎫ 120	18/5/80	Woodside Oil N.L., Woodside Petroleum Development Pty. Ltd., Mid-Eastern Oil N.L., North West Shelf Development Pty. Ltd., BP Petroleum Development Aust. Pty. Ltd., California Asiatic Oil Co.
R1 Part 2	84 ⎭		
WA-31-P R1	80	18/5/80	Woodside Oil N.L., Woodside Petroleum Development Pty. Ltd., Mid-Eastern Oil N.L., North West Shelf Development Pty. Ltd., BP Petroleum Development Aust. Pty. Ltd, California Asiatic Oil Co.
WA-32-P R1	100	2/7/80	Woodside Oil N.L., Woodside Petroleum Development Pty. Ltd., Mid-Eastern Oil N.L., North West Shelf Development Pty. Ltd., BP Petroleum Development Aust. Pty. Ltd., California Asiatic Oil Co.
WA-33-P R1	194	18/5/80	
WA-34-P R1	149	2/7/80	
WA-35-P R1	123	2/7/80	
WA-36-P R1	18	18/5/80	Woodside Oil N.L., Shell Development (Aust.) Pty. Ltd., Woodside Petroleum Development Pty. Ltd., Mid-Eastern Oil N.L., North West Shelf Development Pty. Ltd., BP Petroleum Development Aust. Pty. Ltd.
WA-37-P R1	59	2/6/80	
WA-58-P	222	11/7/82	Western Energy Pty. Ltd.
WA-59-P	190	18/6/82	Esso Exploration and Production Aust. Inc., Western Mining Corp. Ltd.
WA-62-P	226	Appn.	Oxoco-International Inc., Mid-American Oil Co., Peyto Oils Ltd., Voyager Petroleums Ltd., Australian Oil & Gas Corp. Ltd., Bridge Oil Ltd., Endeavour Oil Co. Ltd., AAR Ltd., Offshore Oil N.L.
WA-63-P	250	Appn.	
WA-64-P	22	Appn.	Offshore Oil N.L., Southern Cross Exploration N.L., Hallmark Minerals N.L.
WA-65-P	235	Appn.	Getty Mining Pty. Ltd.
WA-66-P	239	Appn.	Meekatharra Minerals (Aust.) Pty. Ltd.
WA-67-P	226	Appn.	
WA-68-P	249	Appn.	Oxoco-International Inc., Mid-American Oil Co., Peyto Oils Ltd., Voyager Petroleums Ltd., Bridge Oil Ltd.
WA-69-P	251	Appn.	
WA-70-P	251	Appn.	Getty Oil Development Co. Ltd., Union Texas Australia Inc.
WA-71-P	251	Appn.	Crusader (Surat) Pty. Ltd.
WA-72-P	242	Appn.	Oberon Oil Pty. Ltd.
WA-73-P	251	Appn.	Magnet Metals Ltd., Malita Exploration Pty Ltd.
WA-74-P	253	Appn.	Pelsart Oil N.L.
WA-75-P	247	Appn.	
WA-76-P	251	Appn.	

Production Licenses

WA-1-L	5	Appn.	Woodside Oil N.L., Shell Development (Aust.) Pty. Ltd., Woodside Petroleum Development Pty. Ltd.

* Surrender pending

PETROLEUM TENEMENTS UNDER THE PETROLEUM ACT, 1936

Petroleum Leases

Number	Area (square kilometres)	Expiry date of current term	Holders
1H	160	9/2/88	West Australian Petroleum Pty. Ltd.
2H	160	9/2/88	

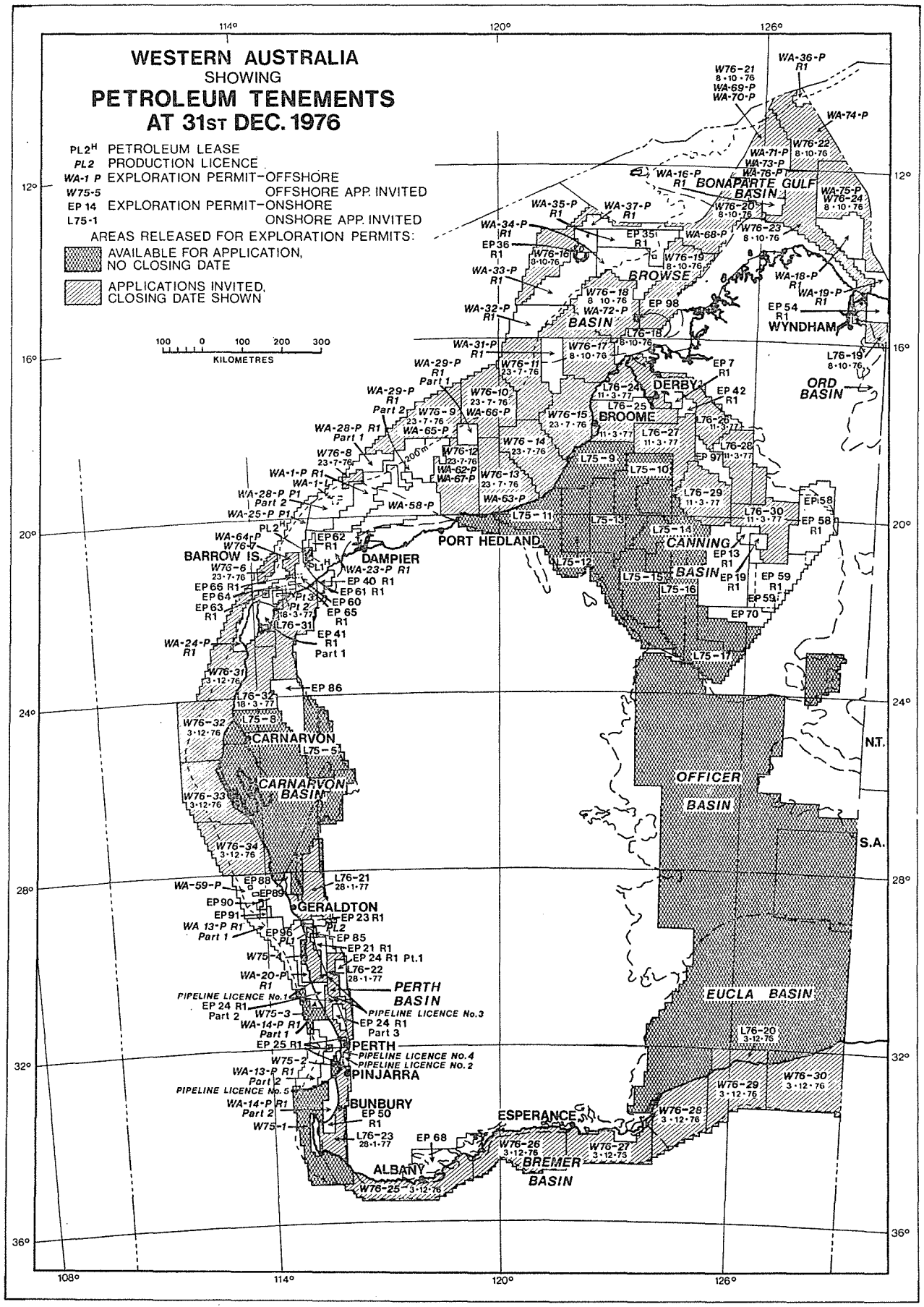


Figure 12. Petroleum tenements at 31st December 1976.

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PETROLEUM TENEMENTS UNDER THE PETROLEUM ACT, 1967

Exploration permits

Number	No. of graticular sections	Expiry date of current term	Registered holder or applicant
EP 7			
R1	24	27/8/80	
EP13			
R1	23	27/8/80	
EP19			
R1	18	27/8/80	
EP21			
R1	32	26/7/80	West Australian Petroleum Pty. Ltd.
EP 23			
R1	33	6/8/80	
EP 24			
R1 Part 1	39		
R1 Part 2	24 } 85	6/8/80	
R1 Part 3	22		
EP 25			
R1	36	6/8/80	
EP 35			Woodside Oil N.L., Woodside Petroleum Development Pty. Ltd., Mid-Eastern Oil N.L., North West Shelf Development Pty. Ltd., BP Petroleum Development Aust. Pty. Ltd., California Asiatic Oil Co.
R1	1	15/4/81	
EP 36			
R1	1	15/4/81	
EP 40			
R1	19	26/7/81	West Australian Petroleum Pty. Ltd.
EP 41			
R1 Part 1	102		
R1 Part 2	1 } 106	18/7/81	West Australian Petroleum Pty. Ltd.
R1 Part 3	3		
EP 42			
R1	19	1/9/80	
EP 50			
R1	18	1/9/80	West Australian Petroleum Pty. Ltd.
EP 54			
R1	47	22/9/80	Alliance Oil Development Aust. N.L.
EP 58	200	20/7/76	AAR Limited, Australian Aquitaine Petroleum Pty. Ltd., Abrolhos Oil and Investments Ltd., Ashburton Oil N.L., Flinders Petroleum N.L., Longreach Oil Ltd., Pursuit Oil N.L.
R1	150	Appn.	
EP 59	186	18/7/76	
R1	139	Appn.	
EP 60	2	Appn.	
EP 61			
R1	4	19/9/81	
EP 62			
R1	8	19/9/81	West Australian Petroleum Pty. Ltd.
EP 63			
R1	4	19/9/81	
EP 64	1	Appn.	
EP 65			
R1	2	19/9/81	West Australian Petroleum Pty. Ltd.
EP 66			
R1	1	19/9/81	
EP 68	175	27/7/77	W. I. Robinson
EP 70*	71	25/9/77	AAR Limited, Australian Aquitaine Petroleum Pty. Ltd., Abrolhos Oil and Investments Ltd., Ashburton Oil N.L., Flinders Petroleum N.L., Longreach Oil Ltd., Pursuit Oil N.L.
EP 85*	4	19/7/80	Endeavour Oil Co. N.L., Target Minerals N.L., IOL Petroleum Ltd., AAR Limited Alliance Minerals (Aust.) N.L.
EP 86	118	9/1/80	XLX N.L.
EP 88	1	18/6/81	Esso Exploration & Production Aust. Inc., Western Mining Corp. Ltd.
EP 89	2	18/6/81	
EP 90	4	18/6/81	
EP 91	7	18/6/81	
EP 96	3	3/11/81	XLX N.L.
EP 97	64	16/9/81	Whitestone Petroleum Aust. Ltd., Amax Iron Ore Corp., Pennzoil Producing Aust. Ltd., Australian Consolidated Minerals Ltd.
EP 98		Appn.	Oberon Oil Pty. Ltd.

Production Licenses

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

* Surrender pending

PETROLEUM TENEMENTS UNDER THE PETROLEUM PIPELINES ACT, 1969

Pipeline licenses

Number	Expiry date of current term	Registered holder or applicant
1	1/12/91	California Asiatic Oil Co., Texaco Overseas Petroleum Co., Shell Development (Aust.) Pty Ltd., Ampol Exploration Ltd.
2	1/12/91	
3	1/12/91	
4	1/12/91	
5	1/12/91	

DRILLING

The positions of wells drilled for petroleum exploration in Western Australia during 1976 are shown in Figures 13 and 14. Details relating to wells drilled during the year are given in Table 7. All petroleum exploration wells drilled in Western Australia up to the end of 1976 are listed in the Geological Survey Record 1977/1 (Crank, 1977). A summary of the principal results of drilling in each basin during the year is as follows:

BREMER BASIN

Silfar Pty Ltd (W. I. Robinson) completed a stratigraphic test, Ocumup No. 1 in the onshore Bremer Basin. The well was plugged and abandoned at total depth 83 metres after reaching Precambrian basement. There were no oil or gas shows.

CARNARVON BASIN

Two wells were completed by the Woodside (formerly BOCAL) group in the Carnarvon Basin during 1976. Lewis No. 1A was located on the Legendre-Rosemary Trend in the Dampier sub-Basin about 20 km southwest of Legendre No. 1. The well was abandoned as a dry hole after reaching a total depth of 3 400 m. No shows of oil or gas were encountered. Withnell No. 1 was drilled near the south end of the Madeline Trend in the Dampier sub-Basin. There were many gas shows but no effective reservoir was encountered, and the well was plugged and abandoned after reaching a total depth of 4 650 m. Woodside was drilling an extension well, North Rankin No. 5, at the end of the year.

Wapet completed one offshore and two onshore wells in 1976. Spar No. 1 was drilled 50 km west-northwest of Barrow Island to test an interpreted large domal structure within the Barrow sub-Basin. Several formation tests were made in this well including 15 formation interval tests. Two successful drillstem tests were over the intervals 3 289 to 3 311 m and 2 621 to 2 630 m, the former flowing at the rate of 1.7×10^3 m^3 gas/day and the latter at a maximum of 311×10^3 m^3 gas/day with 250 barrels of condensate per day. The well was plugged and abandoned at a total depth of 3 721 m and was considered to be non-commercial.

Two wells were drilled on Barrow Island by Wapet. Perentie No. 1 was a deep test-well drilled at the southern end of the island where potential gas production was discovered at a depth similar to that discovered in Barrow Deep No. 1 and Biggada No. 1 which were drilled in 1973 and 1975 respectively. Whitlock No. 1 was drilled to a total depth of 2 400 m, on a small domal feature to the north of Barrow Field. Testing results were disappointing, with no significant hydrocarbon production, and the well was plugged and abandoned.

PERTH BASIN

At the end of the year, Wapet was drilling one well, Denison No. 1, on a fault block to the west of Dongara Gas Field.

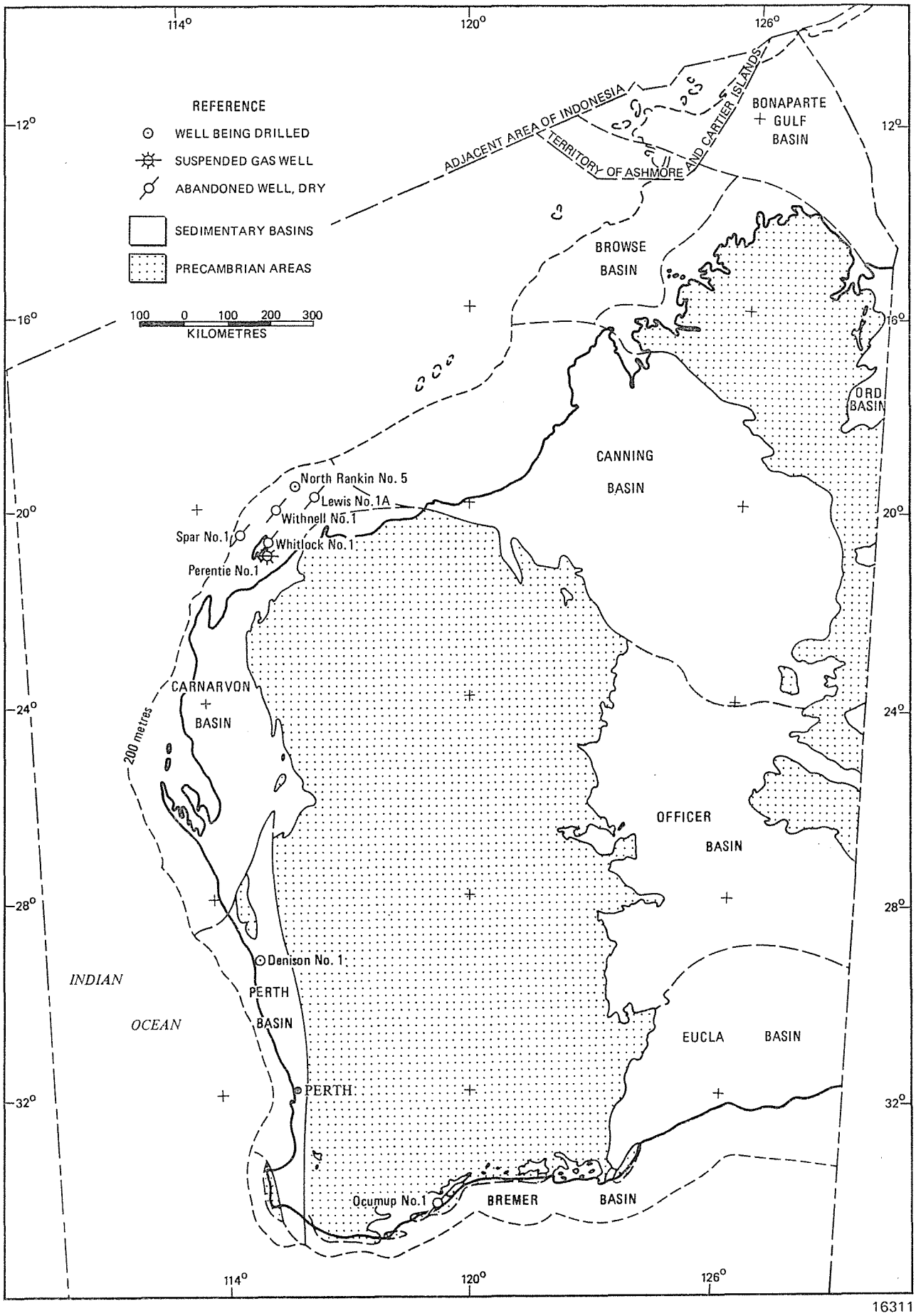

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Figure 13. Wells drilled for petroleum exploration in W.A. during 1976.

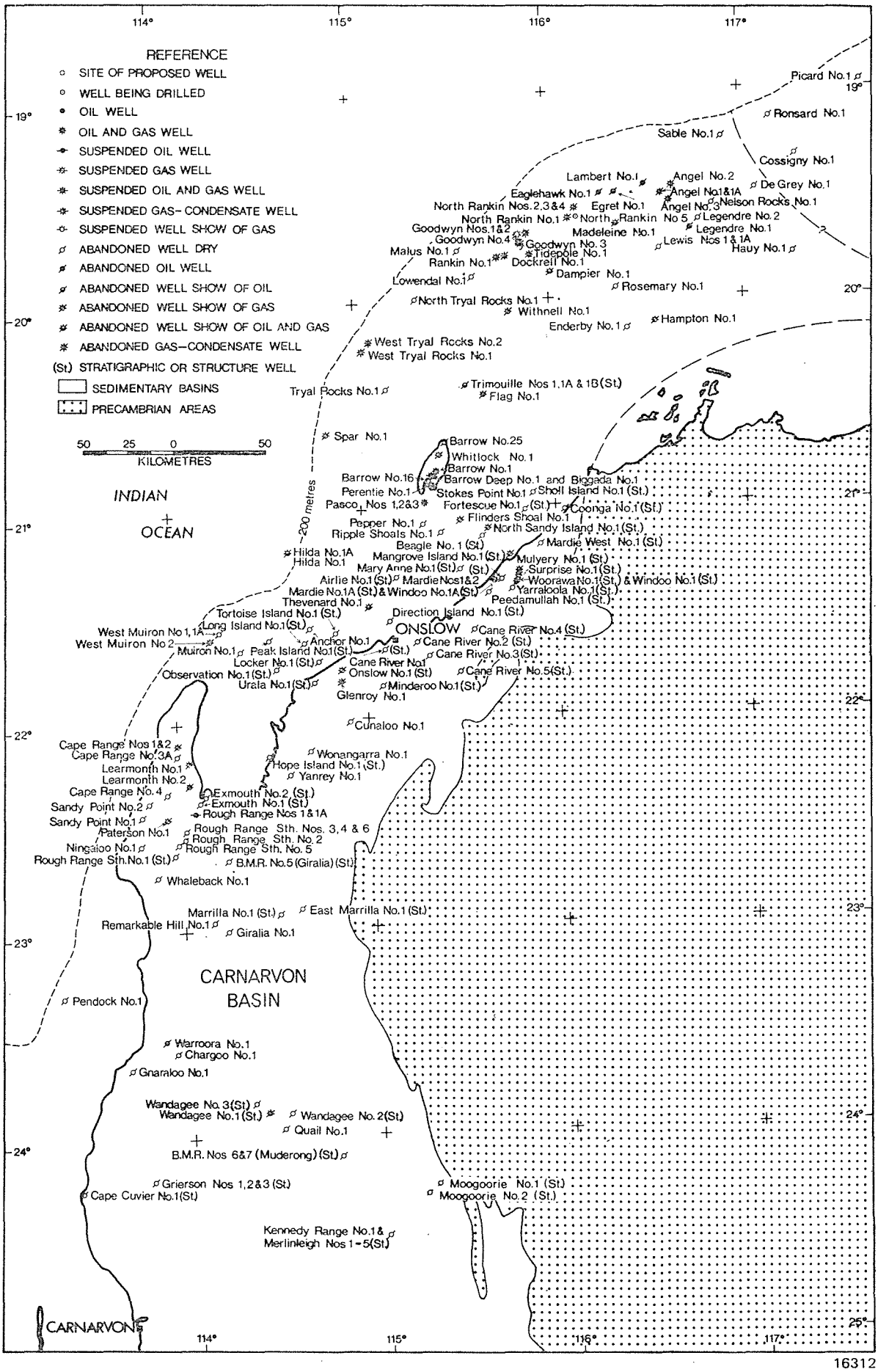

Figure 14. Northern Carnarvon and southwestern Canning Basins showing wells drilled for petroleum to 31st December 1976.

TABLE 7. WELLS DRILLED FOR PETROLEUM EXPLORATION IN WESTERN AUSTRALIA DURING 1976

Basin	Well	Concession	Operating company	Type	Position		Elevation and water depth (metres)			Dates			Total depth (or depth reached) m	Bottomed in	Status on 31/12/76
					Latitude south ° ′ ″	Longitude east ° ′ ″	GL	RT	WD	Commenced	Reached TD	Rig released			
Perth	Denison No. 1	PL2	Wapet	NFW	29 13 32	114 57 17	27	35	....	23/12/76	....	....	969	....	Drilling
Carnarvon	North Rankin No. 5	WA–28–P	Woodside	EXT	19 34 19	116 09 30	....	30	123	8/10/76	....	....	3 048	....	Coring
	Perentie No. 1	PL 1H	Wapet	NFW	20 53 02	115 23 41	7	15	....	14/1/76	7/5/76	21/6/76	3 900	M. Jurassic	Shut-in gas well
	Spar No. 1	WA–25–P	Wapet	NFW	20 36 54	114 53 07	....	30	116	25/6/76	26/8/76	30/9/76	3 721	?U. Jurassic	Gas shows, p & a
	Whitlock No. 1	PL 1H	Wapet	NFW	20 43 46	115 24 56	41	49	....	8/7/76	1/8/76	10/8/76	2 400	?U. Jurassic	Gas & oil shows, p & a
	Withnell No. 1	WA–28–P	Woodside	NFW	20 01 11	115 48 15	....	30	75	5/3/76	16/6/76	23/6/76	4 650	M. Jurassic	Dry, p & a
	Lewis No. 1A	WA–1–P	Woodside	NFW	19 47 36	116 36 04	....	30	60	24/12/76	19/2/76	4/3/76	3 400	M. Jurassic	Dry, p & a
Bremer	Ocumup No. 1	EP68	Silfar	STR....	34 23 45	119 12 53	38	40	....	15/6/76	29/6/76	30/6/76	83	Precambrian	Dry, p & a

Woodside = Woodside Petroleum Development Pty. Ltd.
Wapet = West Australian Petroleum Pty. Ltd.
Silfar = Silfar Pty. Ltd.
EXT Extension test well

NFW = New field wildcat well
STR = Stratigraphic well
p & a = Plugged and abandoned

GEOPHYSICAL SURVEYS

SEISMIC

During 1976 seismic surveys were conducted in the Perth, Carnarvon, Canning, Browse and Bonaparte Gulf Basins. Details are as follows:

SEISMIC SURVEYS

Basin	Tenement	Company	Line kilometres	
			Marine	Land
Perth	EP 21	West Australian Petroleum Pty. Ltd.	....	21
,,	EP 23	,, ,, ,,	....	2
,,	EP 24	,, ,, ,,	....	42
,,	WA–13–P	,, ,, ,,	333	....
,,	WA–14–P	,, ,, ,,	484	....
,,	WA–20–P	,, ,, ,,	1	....
Carnarvon/ Perth	WA–59–P	Esso Exploration and Production Inc.	2 404	....
Carnarvon	EP 41	West Australian Petroleum Pty. Ltd.	65	....
,,	WA–23–P	,, ,, ,,	172	....
,,	WA–24–P	,, ,, ,,	196	....
,,	WA–25–P	,, ,, ,,	66	....
,,	WA–1–P	Woodside Petroleum Development Pty. Ltd.	304	....
,,	WA–28 P	,, ,, ,,	894	....
Canning	EP 97	Whitestone International Inc.	....	378
,,	WA–31–P	Woodside (Amax Petroleum (Aust.) Inc.—farminee)	116	....
Browse	WA–32–P	Woodside Petroleum Development Pty. Ltd.	294	....
,,	WA–33–P	,, ,, ,,	687	....
,,	WA–34–P	,, ,, ,,	658	....
,,	WA–35–P	,, ,, ,,	639	....
,,	WA–37–P	,, ,, ,,	408	....
Bonaparte Gulf	WA–16–P	Acro Australia Ltd.	145	....
,,	WA–18–P	,, ,,	571	....
,,	WA–19–P	Alliance Oil Development (Aust.) N.L.	94	....
,,	WA–36–P	Woodside Petroleum Development Pty. Ltd.	3	....
Outside Permit Areas	....	Woodside Petroleum Development Pty. Ltd.	64	....
		Totals	8 599	443

GRAVITY

Gravity surveys were carried out in conjunction with offshore seismic surveys in the Browse Basin as follows:

GRAVITY SURVEYS

Basin	Tenement	Company	Line km
Browse	WA–33–P	Woodside Petroleum Development Pty. Ltd.	39
,,	WA–37–P	,, ,, ,,	69
		Total	108

MAGNETOMETER

Magnetometer surveys conducted in conjunction with offshore seismic surveys were as follows:

MAGNETOMETER SURVEYS

Basin	Tenement	Company	Line km
Browse	WA–33–P	Woodside Petroleum Development Pty. Ltd.	213
,	WA–35–P	,, ,, ,,	1
,,	WA–37–P	,, ,, ,,	274
Outside permit areas	....	,, ,, ,,	2
		Total	490

GEOLOGICAL SURVEYS

XLX N.L. carried out two party months of surface geological surveys in the Carnarvon Basin (EP86) and WAPET spent one party month in the Canning Basin (EPs 7 and 42).

REFERENCES

Crank, K. A., 1977, Wells drilled for petroleum exploration in W.A. to the end of 1976: West. Australia Geol. Survey Rec. 1977/1.

EMERGENT QUARTERNARY MARINE DEPOSITS IN THE LAKE MACLEOD AREA, W.A.

by P. D. Denman and W. J. E. van de Graaff

ABSTRACT

Two emergent marine erosion terraces and terrace deposits, now at 2 to 4 m and 7 m above Mean Low Water Springs level, occur along the east shores of Lake Macleod. Two similar terraces and deposits occur on the coast at Cape Cuvier and Red Bluff, where their elevations are 1 to 3 m higher.

Correlation with Cape Range and Shark Bay units indicates that the terraces and terrace deposits are of Pleistocene age.

Late Quaternary tectonism is indicated in the area by the fact that the terraces and marine deposits are folded along the Cape Cuvier Anticline. In addition the terraces are at higher elevations than those on the east side of Lake Macleod. This together with previous work indicates the Western Australian coast between North West Cape and Shark Bay has been tectonically unstable during the Quaternary.

The elevation of shoreline features and distribution of marine deposits indicate that the Macleod Pleistocene marine embayment extended over an area 50 per cent greater than Lake Macleod, and was open to the ocean at both its southern and northern ends. This configuration allowed normal oceanic salinities to exist in the embayment, and permitted the growth of corals that mark the shoreline benches.

INTRODUCTION

Emergent Quaternary deposits have been studied at six localities in the Lake Macleod region. Associated emerged marine erosion terraces are exposed at four of the localities. The purpose of the study was to estimate levels of emergence relative to present sea level, and to determine whether Quaternary tectonism has occurred, as in the Cape Range area where emerged Pleistocene marine terraces have been uplifted and warped (van de Graaff and others, 1976). U/Th series dating on corals is being done to establish absolute ages and correlations between the two areas.

Two of the localities described are coastal—Cape Cuvier and Red Bluff; and four are marginal to Lake Macleod-Texada road pits, Grierson Anticline, Yankie Tank Anticline and Chirrida Anticline (Fig. 15). Vertical sections for four of the locations are shown in Figures 16 to 19.

Condon (1954) recorded marine deposits on the shores of Lake Macleod consisting of calcarenite and molluscan coquinite, which extend from "below the lake floor to about 20 feet above it". He notes (1955) that such deposits extend north of the lake and along the Lyndon and Minilya Rivers (Fig. 15). He did not mention any emerged terraces. Teichert (1957, p. 70) comments on "the remarkable terrace which is cut into the west flanks of the anticlines on the east side of

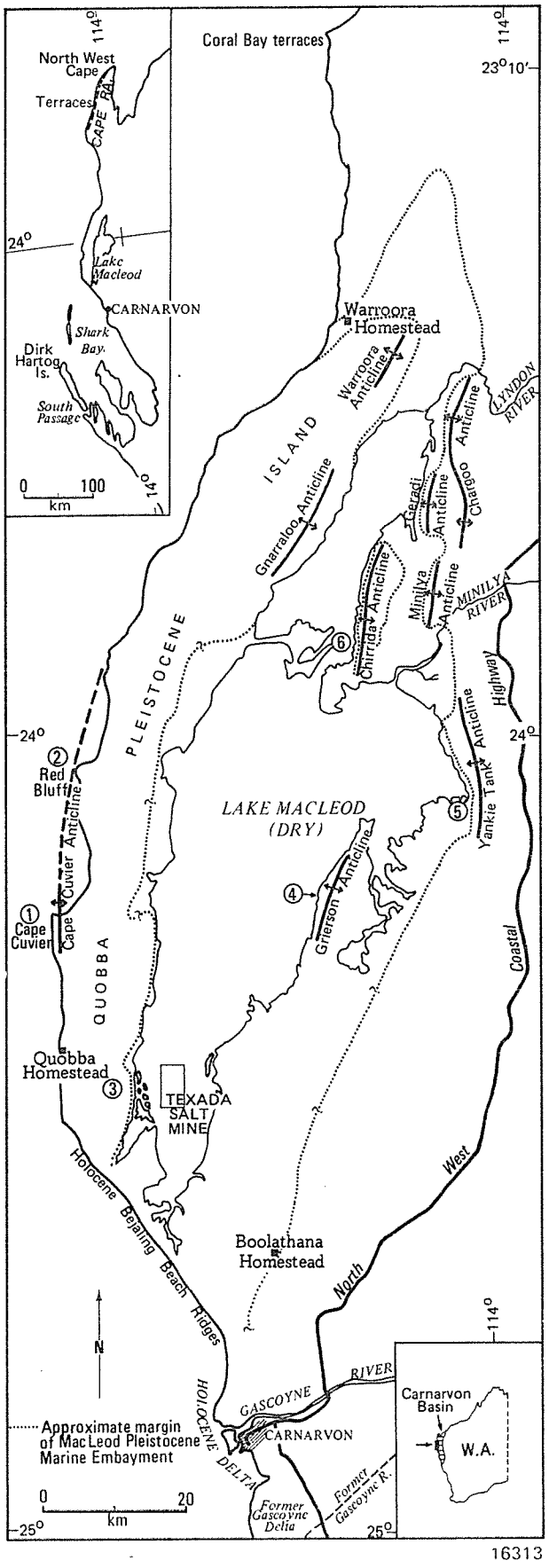

Figure 15 Locality map of the Lake MacLeod area. Measured Sections: (1) Cape Cuvier, (2) Red Bluff, (3) Texada Road Pits, (4) Grierson Anticline, (5) Yankie Tank Anticline, (6) Chirrida Anticline.

this generally dry lake". "This terrace . . . along the entire west side of Chirrida anticline . . . lies at 11 to 12 feet above lake bottom . . . and consists of loose deposits, partly shell layers and partly sand". Condon (1954) correlated the marine deposits with the Bundera Calcarenite of Cape Range which has been redefined by van de Graaff and others (1976) to comprise two members, the Jurabi and Tantabiddi Members, each containing marine and eolian facies. The deposits described in this paper correlate to some degree in lithology and stratigraphy with the Bundera Calcarenite, and it seems likely that equivalents of both members are present. Correlation with the Shark Bay sequence, described by Logan and others (1970), is yet to be made. The eolianite underlying the marine deposit at Cape Cuvier and Red Bluff looks identical to the eolian facies of the Bundera Calcarenite in the Cape Range area, but as it extends below sea level it may be older, as it must have formed during a low-sea-level stand. It is equivalent to part of the Tamala Limestone (Playford and others, in press), which is a Quaternary eolianite unit mapped from Shark Bay southwards.

The coastal sections were measured by Brunton compass from the high water mark on the shore, which is assumed to be the Mean High Water Springs level (MHWS). The levels of the erosional terraces and *in situ* coral shown in the sections are given relative to the Mean Low Water Springs level (MLWS) which is 0.9 m below MHWS at Carnarvon (Aust. Nat. Tide Tables, 1976). We consider the MLWS level to be the most meaningful level as:

(1) the erosional terraces are assumed to have formed by mechanical erosion in the surf zone (Gill, 1976), at surf base (Russell, 1964) or by a combination of surf erosion, biocorrosion and chemical erosion in the tidal zone (Hodgkin, 1964, 1970), and

(2) coral growth requires permanent submergence and the highest level given by *in situ* coral is likely to be close to the former mean low water springs level. Present-day reefs on this coast do not appear to grow above lowest tide level.

The levels for the Lake Macleod sections are based on detailed ground surveying carried out for West Australian Petroleum Pty Ltd by Ray Geophysics (1955, 1956), supported by spot heights and contours from 1:100 000 scale maps and field measurements. These surveyed levels are above mean sea level and have been reduced by 0.5 m to be consistent with MLWS levels, though this degree of accuracy is not implied The surveyed data were plotted on 1:40 000 air-photographs before section drawing. The Yankie Tank section (Fig. 18) may be unreliable due to lack of survey data at that location and to a discrepancy between data from Ray Geophysics and the 1:100 000 map. Here Brunton levels to the local lake bed were used to produce section A, and section B is mainly based on photo-interpretation.

DESCRIPTION OF LOCALITIES

CAPE CUVIER (Fig. 16)

Two marine erosion terraces with overlying marine deposits occur at Cape Cuvier. The lower is well exposed, although discontinuously, from the point at Cape Cuvier southward, and occurs at 3 to 7.4 m above MLWS level (Fig. 16, Sections A, B). Very little of the upper terrace is preserved, being exposed at only one location 100 m south of the point (Fig. 16, Section B), where the terrace is at 10 m and overlying algal limestone at 10.5 m above MLWS level. The existence of the upper terrace and terrace deposit here is supported by a remnant marine deposit containing an *in situ* coral at 9.4 m elevation, 100 m to the north (Fig. 16, Section A).

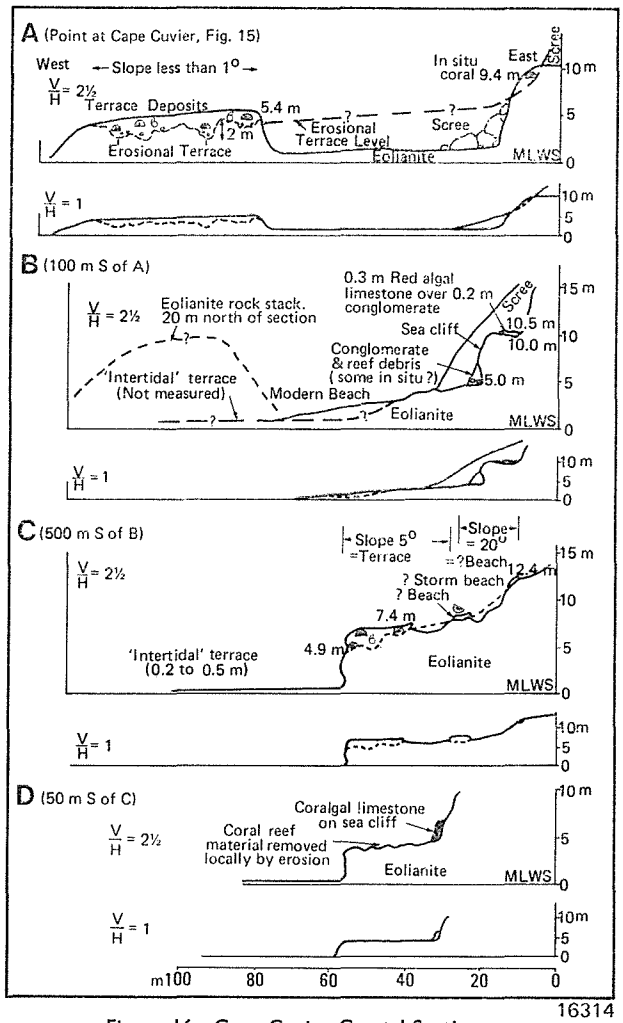

Figure 16 Cape Cuvier Coastal Sections.
Section A is at the point of the Cape: 113°23′30″E, 24°13′15″S.

The lower erosional terrace, cut into fine- to medium-grained quartzose calcarenite (eolianite) has a very irregular surface with pockets to at least 2 m depth. It is covered by reef deposits of coral-algal boundstone and calcarenite to calcirudite, commonly containing pebbles and cobbles at the base. At one location (Fig. 16, Section C) ?beach facies of cemented calcarenitic reef detritus was observed at a higher level (7-12 m) to the east. Outcrops such as that of Figure 16, Section C indicate that in most places the terrace is preserved only close to the original shoreline, but an outlier shows that at about 100 m from the former shore, the terrace has a gentle slope of less than 1° (Fig. 16, Section A). It appears to steepen to about 5° near the former beach, which sloped at 20° or more (Fig. 16, Section C). The beach deposit occurs at 5 m or more above the low-water level indicated by *in situ* corals. Such features were also recorded from this region by Russell (1964) who cautioned against using beach deposits as former sea-level indicators. The features suggest that eolianite headlands with occasional rock stacks alternated with small bays at 50 to 500 m intervals along the former shoreline.

The upper erosional terrace, at about 10 m (Fig. 16, Section B), is irregular on a 0.1 to 0.2 m scale, and is overlain by 0.1 to 0.2 m of eolianite conglomerate, and this in turn by 0.3 m of hard, laminated red-algal limestone, the surface of which is relatively smooth. In Figure 16, Section A, an *in situ* coral at 9.4 m occurs with coquinite and reef detritus on an irregular steep surface assumed to be part of a sea cliff. This deposit is correlated with the upper terrace. Unfortunately, at the point of the Cape, scree resulting from the construction of salt-loading facilities has either covered or destroyed significant parts of the terraces and terrace deposits.

RED BLUFF

An erosional terrace with overlying marine deposits about 40 m wide is exposed at Red Bluff. The lowest exposed part of the terrace is at 3.2 m and the highest *in situ* coral at 10.6 m. A cover of loose blocks of reefal terrace deposits above about 8 m obscures the terrace deposit/bedrock relationships at the level where an upper terrace would be expected. The terrace level of 3.2 m compares closely with the lower terrace at Cape Cuvier, and the *in situ* coral at 10.6 m compares with the coral on the upper terrace deposit at Cape Cuvier, so that the presence of two terrace levels at Red Bluff is inferred, the lower being at 3 to ?5 m and the upper (obscured) at about 8 m.

TEXADA ROAD PITS

In situ compound corals up to 2 m diameter in a weathered groundmass of mollusc-rich calcarenite-calcirudite form the marine deposits exposed between 1.3 m and –0.5 m. No erosional terrace is exposed but to the north the deposits are backed at intervals by eolianite cliffs along the west shore of the lake. About 22 km north of the pits corals and molluscs are abundant on the lake shore at –1 m; and 3 km inland to the west, at about 4 m, is an exposure of possible beach material—cemented coral and shell fragments in interlaminated coarse- and medium- to fine-grained quartzose calcarenite.

GRIERSON ANTICLINE (Fig. 17)

The west flank of this anticline shows a clear terrace, cut in Miocene Trealla Limestone, at about 2 m elevation (Fig. 17). No marine deposits are preserved on the terrace but coral and shell fragments remain as float. In a gully 1 to 2 m deep, a lithified conglomerate is exposed, consisting of abundant molluscs and coral fragments, with rounded Trealla Limestone pebbles and cobbles. The roundness suggests extensive reworking, as on a beach. It is very similar to Mowbowra Conglomerate of the North West Cape (Fig. 15) (van de Graaff and others, in prep.).

On the east flank of the anticline two levels of marine deposits occur, which appear to overlie terraces cut in the underlying Trealla Limestone. The upper deposits at about 7 m elevation are poorly exposed, but the corals found appeared to be in growth position. The extent of the lower unit is indicated by rare shelly calcarenite outcrops and fairly common 10 to 100 m patches of coquinite float. It is extensive in this area, continuing more than 5 km east of Grierson Anticline, and about 50 km south to Boolathana homestead, and over 20 km to the northeast to the Yankie Tank Anticline area (Fig. 15). Through this extensive area the ground elevation is mostly below 3 m, and in many places near the lake shores it is below 0 m. Definite *in situ* fossil shells and corals have very rarely been found on this terrace (e.g. Fig. 18, Section A).

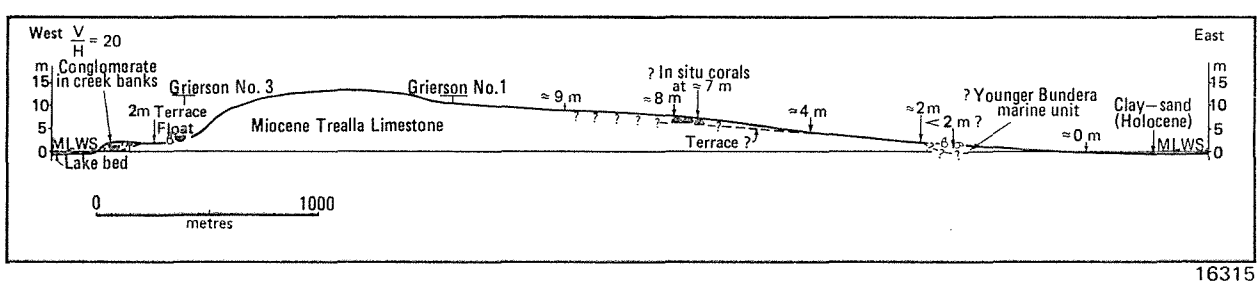

Figure 17 Grierson Anticline Section showing relationship of the upper and lower units of the Bundera Calcarenite to present-day mean low water level (MLWS).
The Section is from 113°45′15″E, 24°12′00″S to 113°48′00″E, 24°12′30″S, through Grierson No. 1 Well.

YANKIE TANK ANTICLINE (Fig. 18)

On the west flank of this anticline are two clear bench levels, at about 2 to 4.5 m and 7 to 8 m elevation. Erosion terraces are not exposed, being veneered by more recent sand and colluvium, with remnants of marine deposits indicated by shell float on both benches. The only *in situ* coral located was about 1 m elevation (Fig. 18, Section A). About 100 m north of this, the banks of a small gully showed patches of lithified conglomerate derived from Trealla Limestone and coral pieces, at about the same level, and this may represent the level of the lower terrace. The upper level has been traced for at least 5 km to the south (Fig. 18, Section B) and 1 km to the north. The lower level, a continuation of that on the east side of Grierson Anticline, can be traced northward to the Chirrida-Minilya Anticlines region (Fig. 15), though it is mostly covered by more recent alluvium and colluvium. Because of this, the elevations of both the marine deposits and the erosional terrace below, are unknown, but ground elevations throughout the area, which is inferred to be underlain by marine Bundera Calcarenite (Fig. 15), are mostly below 3 m elevation.

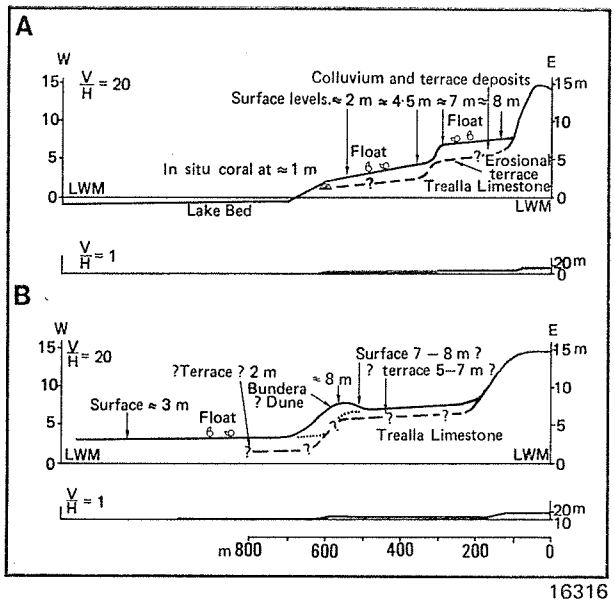

Figure 18 Yankie Tank Anticline Sections.
Section A is centred at 113°13′10″E, 24°4′30″S. Section B is 2 km south of A.

CHIRRIDA ANTICLINE (Fig. 19)

Air-photographs show a terrace 100 to 200 m wide close to the lake shore, extending for about 18 km along the west flank of this anticline. It was examined at one locality 4 km from the south end. Here the erosional terrace was not exposed, but is veneered by 1 to 2 m of sand (elevation 3 to 4 m). Trealla Limestone crops out on the lake edge, and the terrace cut in this limestone may be at 1 to 2 m elevation. A seismic shot hole on the terrace showed about 2 m of sand over Trealla Limestone, and the spoil contained shell and coral fragments, so the terrace may be thinly covered by marine Bundera Calcarenite.

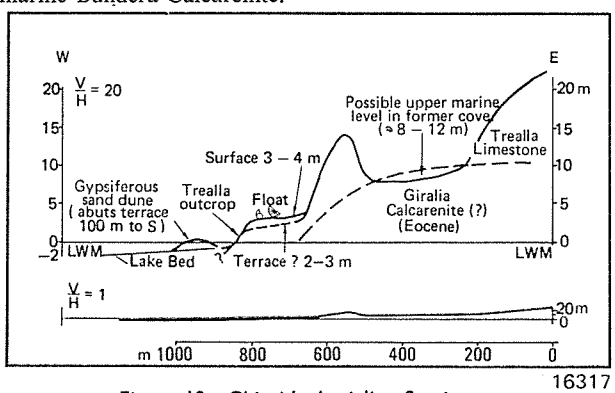

Figure 19 Chirrida Anticline Section.
The Section is centred at 113°48′20″E, 23°53′5″S.

OTHER LOCALITIES

Two distinct erosional terraces, both sloping from north to south, are cut into a headland of Pleistocene eolianite 1.5 km south of Coral Bay (Fig. 15). Over a distance of 150 m the lower terrace, containing pockets of cemented calcarenite, shells and coral pieces, slopes from 3 to 5 m above Mean Low Water Springs level. The upper terrace, poorly preserved over some 50 m, is at 6.9 to 7.6 m elevation.

At Boolathana homestead (Fig. 15), dam spoil comprising fragamental fossiliferous beach or near-shore facies of Bundera Calcarenite, occurs at 2 to 3 m elevation. This rock type is seen in numerous road pits 7 to 8 km to the southwest at 0 to 1 m elevation.

DISCUSSION

1. Emergent marine erosion terraces and terrace deposits occur extensively throughout this area, with elevations ranging from below present sea-level to some 10 m above it. At Cape Cuvier *in situ* corals and algal material occur at two levels, 3 to 7.4 m and 9.4 to 10.5 m (Fig. 16, sections A to D). Section A (Fig. 16) is discontinuous and the relationships between the terrace and its deposits on the west side at 3 to 5 m and those on the east side at 9 to 10 m, are not seen. The deposits could be interpreted as having formed on the same sloping terrace, but this does not explain why the reef top on the west side is at about 5 m when, 70 m to the east, *in situ* coral occurs at 9 m. Section B (Fig. 16) 100 m to the south, shows the existence of two terraces, at about 5 m and 10 m, indicating that the west and east sides of the point section (Fig. 16, Section A) were cut by two different sea levels. Evidence on the east side of the lake supports the interpretation of different sea levels, which here cut a lower erosional terrace at about 2 m and an upper one at about 7 m above modern Low Water Springs level.

2. The Lake Macleod region is characterized by pronounced structural control of the landforms, with the elevated areas coinciding with anticlines and the depressions coinciding with synclines. Playford and Cockbain (1976) inferred a similar configuration for the Shark Bay area as Dirk Hartog Island overlies a known anticline in Tertiary rocks. These and other fold structures in the northern part of the Carnarvon Basin are commonly considered to have formed after the early Miocene and before the late Pliocene (Johnstone and others, 1976), but in recent years evidence has come to light to indicate that, for at least some of the folds, tectonism continued into the Quaternary and probably is continuing today. In the Shark Bay area Logan and others (1970, p. 82) suggested tectonic movement took place in the Pleistocene and also mentioned "the possibility that uplift also has occurred in the Holocene". Playford and Cockbain (1976) believe that the emergence of the older stromatolites is most likely to be a result of periodic uplift in Holocene times. Van de Graaff and others (1976) established Quaternary tectonism in the Cape Range area. At Cape Cuvier similar Quaternary tectonism is proved by the tilting of the terraces and their deposits. This tilting is clearly shown by the maximum elevations of *in situ* corals and of the erosional terraces, which drop progressively away from the anticlinal axis on both the east and the west flank of the anticline (Fig.20). Directions of tilt are the same as dip directions of the underlying folded Miocene rocks. The landward slope of the terrace on the east flank of the anticline strongly suggests warping, as coastal terraces normally slope seaward. In addition the Cape Cuvier terraces and marine deposits have greater elevations, by 1 to 3 m, than those east of Lake Macleod. This indicates late Quaternary uplift on the Cape Cuvier axis relative to the anticlines to the east. Elevations of the marine terrace deposits on the anticlines east of Lake Macleod may also have been affected by late Quaternary tectonism, but altimetric and geological control is insufficient to prove this. However there is no obvious indication of warping, and for the Lake Macleod region these terraces may be taken to indicate Quaternary sea levels of approximately 2 to 4 m and 7 m above present Mean Low Water Springs level.

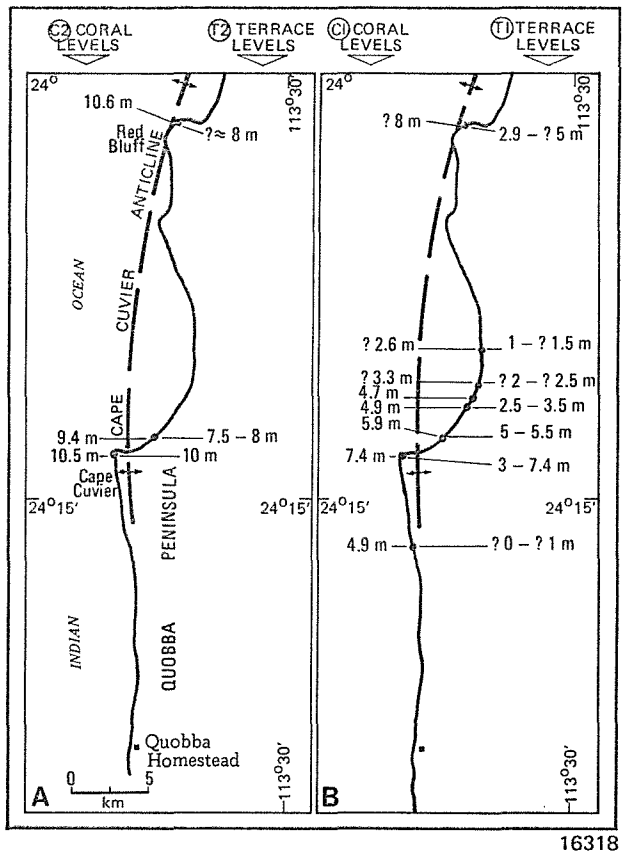

Figure 20 Fossil shoreline features in the Cape Cuvier Anticline Area.
Elevations in metres above Mean Low Water Springs level:

A. Upper Erosional Terrace (T2) and highest in situ fossil coral (C2).

B. Lower Erosional Terrace (T1) and highest in situ fossil coral (C1).

3. Altimetric data in the Warroora homestead-Lyndon River area show a broad area below the 5 m contour with a 2 to 3 km-wide connection to the sea. The occurrence of corals up to 7 m elevation thus indicates the MacLeod embayment was open to the sea both in the north and the south. This is supported by the earlier mapping of Condon (1955) who mapped Pleistocene "marine coquinoid calcarenite" in these northern areas. This and the altimetric data combine to suggest the embayment margin shown in the northern part of Figure 15. A northern connection with the sea also explains the prevalence of oceanic salinities in the lake area, as indicated by the abundant corals. If the embayment had been open only in the south, one would expect higher salinity gradients than would allow coral growth (e.g. Heckel, 1972), as is the case in Shark Bay (Hagan and Logan, 1974). The extent of the original embayment indicated by mapping of Pleistocene marine sediments, must have been about 50 per cent greater than the present area of the lake, with a southern opening to the ocean about 25 to 30 km wide. The Quobba Pleistocene Island (Fig. 15) would have had a northern strait similar to today's Dirk Hartog Island (Fig. 15 inset) and its 3 km-wide South Passage, which allows oceanic salinities east of the island (Logan and Cebulski, 1970). The closing of the northern end of the embayment appears to have been mainly a matter of a relative drop in sea level although some coastal dune building took place. In the south however, the shifting of the Gascoyne Delta and building up of the Bejaling Beach Ridges, described by Johnson (1974), appear to have been important factors in the closing of the embayment.

4. Tentative correlation of the terraces and terrace deposits with the Bundera Calcarenite units of the Cape Range and with radiocarbon dating at Shark Bay (Noakes and others, 1967) indicates the terraces and terrace deposits are older than 40 000 years and probably not older than the Riss-Würm Interglacial, or about 150 000 years.

CONCLUSIONS

1. Emergent marine erosion terraces overlain by marine deposits occur at 2 to 4 m and at 7 m above Mean Low Water Springs level along the east side of Lake Macleod. Two similar terraces and deposits occur on the coast at Cape Cuvier and Red Bluff but at elevations 1 to 3 m higher than those east of the lake.

2. Late Quaternary tectonism is indicated by the slope of the terraces and marine deposits in the Cape Cuvier region and by their greater elevations compared with those to the east. This evidence of folding, together with previous work, indicates that the Western Australian coast between North West Cape and Shark Bay has been tectonically unstable during the Quaternary.

3. The marine erosion terraces and terrace deposits may have emerged because of a Pleistocene eustatic sea level fall, or as a result of uplift due to tectonism or, most likely, a combination of both.

4. The elevation of shoreline features and distribution of marine deposits indicates that the Macleod Pleistocene marine embayment was open to the ocean at both its southern and northern ends. This configuration allowed normal oceanic salinities to exist in the embayment, and permitted the growth of corals that mark the shoreline benches.

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REVISED STRATIGRAPHIC NOMENCLATURE AND INTERPRETATIONS IN THE EAST-CENTRAL CARNARVON BASIN, W.A.

by W. J. E. van de Graaff, R. M. Hocking, and P. D. Denman

ABSTRACT

Stratigraphic nomenclature for the Lower Permian sequence in the Carnarvon Basin is simplified by changing the Lyons "Group" to formation rank, and its constituent "formations" to members of local significance only. The names "Nunnery Sandstone", and "Congo", "Monument", "One Gum", and "Curbur Formations", which have been used for various parts of the basal sandstone unit of the Wooramel Group, are discarded in favour of Moogooloo Sandstone.

The unconformity between the Callytharra Formation and the Moogooloo Sandstone marks a period of regional uplift with local faulting and tilting, and widespread subaerial erosion with karst development in places.

A new type section for the ?Tertiary Pindilya Formation is proposed, as the original type section consists of Permian Moogooloo Sandstone and is invalid.

INTRODUCTION

In 1976 the Phanerozoic sections of the Mount Phillips, Glenburgh and Byro 1:250 000 Sheet areas were mapped as part of the Carnarvon Basin mapping project. The area mapped covers the Bidgemia and Byro sub-Basins, and the easternmost part of the Merlinleigh sub-Basin (Fig. 21).

Condon (1967) presented a detailed nomenclature for the stratigraphic sequence in the area, and his scheme has essentially been followed in recent publications (e.g. Playford and others, 1975; Johnstone and others, 1976). Condon's terminology, which to a large extent follows usage in earlier publications by himself and his co-workers (e.g. Condon, 1954; Konecki and others, 1958) needs revision. Our reasons are the non-recognition of the formations of the Lyons "Group", the wish to stress the lateral continuity of the Moogooloo Sandstone, to simplify nomenclature, and the original selection of invalid type sections for the "Nunnery Sandstone", "One Gum Formation", and Pindilya Formation.

No nomenclature changes are yet proposed for the Carrandibby and Callytharra Formations, Jimba Jimba Calcarenite, Billidee, Keogh, Coyrie, and Madeline Formations, Bogadi Greywacke, and Warra Warringa Formation.

LYONS FORMATION

The name "Lyons Conglomerate", used by Maitland (1912) for the Permian glacial sediments in the Gascoyne River area, was changed to "Lyons Series" by Raggatt (1936) and was again amended to "Lyons Group" by Teichert (1950). Condon (192a, b; 1967) recognized the following formations within that group: "Austin Formation", "Coyango Greywacke", "Dumbardo Siltstone", "Koomberan Greywacke", "Mundarie Siltstone", "Thambrong Forma-

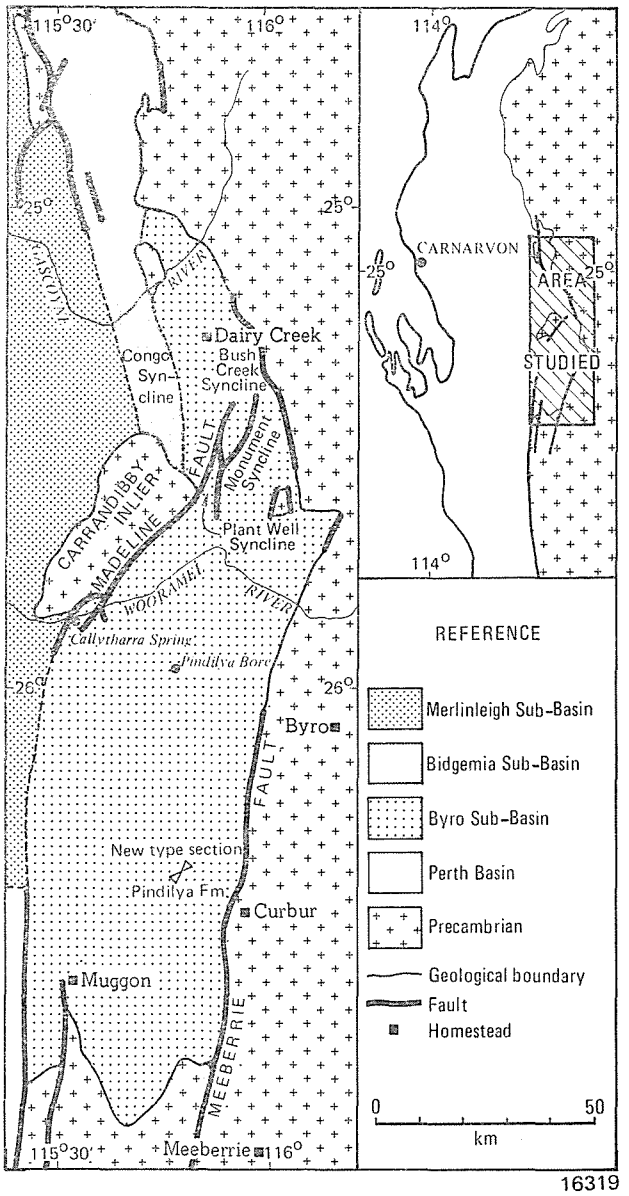

Figure 21. East–central Carnarvon Basin – localities discussed.

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tion", and "Weedarra Shale". These formations were mapped in the Kennedy Range and Glenburgh 1:250 000 Geological Sheet areas by photo interpretation after completion of the field work (Condon, 1967, p. 14). However, Playford and others (1975) doubted whether they were valid mappable units. We have been unable to map these formations, although locally rock types have been found that fit the description of a formation previously mapped at that spot. Just as commonly, the exposed rocks do not resemble the formation descriptions at all. We therefore propose to change the Lyons "Group" to formation status, with the seven component formations being reduced to member rank. These members are of limited areal extent due to facies changes.

Konecki and others (1958) interpreted the contact between the Lyons Formation and the overlying Callytharra Formation as a disconformity. This contention is based on the absence of the Carrandibby Formation away from the Carrandibby Inlier. Condon (1962b, 1967, p. 14) however, considered the contact as an angular unconformity. This was based on his interpretation of virtually all faults in the Carnarvon Basin as angle-of-rest or abutment unconformities (Condon, 1956; 1968). Within the study area we have not seen any evidence of an unconformable relationship between these two units; on the contrary, gradational contacts between Lyons Formation and Callytharra Formation suggest a conformable relationship. The Carrandibby Formation is considered to be a lateral equivalent of the upper part of the Lyons Formation.

MOOGOOLOO SANDSTONE

The Moogooloo Sandstone, which is the basal unit of the Wooramel Group in the study area, was mapped by Condon (1962b; 1967, p. 84) as far south as the Congo Syncline. The formation consists of interbedded medium- to very coarse-grained to pebbly sandstone with minor interbeds of siltstone and fine-grained sandstone.

Lithologically very similar units, with identical stratigraphic position, crop out in the Bush Creek, Monument and Plant Well Synclines. In the Bush Creek Syncline these sediments have been called "Congo Formation", whereas in the other two synclines they were previously mapped as "Monument Formation" (Konecki and others, 1958; Condon, 1962b; 1967). Because of the homotaxial stratigraphic position and the lithological similarities we propose to drop the names "Congo Formation" and "Monument Formation" in favour of Moogoloo Sandstone.

On the southeastern side of the Carrandibby Inlier the basal sandstone unit of the Wooramel Group has previously been mapped as "Nunnery Sandstone" and "One Gum Formation". These two units have only been recognized in the vicinity of the type localities. In this area the Madeline Fault abruptly changes course from a northeasterly trend to an easterly trend for about 5 km, and then reverts to a northeasterly trend. Because of this change in course, a number of splay faults have formed to alleviate space problems. Previous workers mapped the splay faults that cut across the strike of the sequence, but did not recognize the most important subsidiary fault parallel to the strike, which causes a partial repetition of the basal sandstone unit of the Wooramel Group. The intense crumpling and drag folding in interbedded siltstone and sandstone, which occurs along part of the fault trace, was mistaken by Konecki and others (1958, p. 32) for synsedimentary slumping. This "slumping" they considered to mark the contact between the "Nunnery Sandstone" and the "One Gum Formation". In our structural interpretation, the "One Gum Formation" is largely a repetition by faulting of the "Nunnery Sandstone" which unconformably overlies the Callytharra Formation. Moreover, as both units are lithologically similar to the Moogooloo Sandstone, we propose to drop the names "Nunnery Sandstone" and "One Gum Formation" in favour of Moogooloo Sandstone.

On the Byro Sheet area the basal part of the Wooramel Group was mapped by Konecki and others (1958) as "Cubur Formation". In the type area along the northern part of the Meeberrie Fault (new name), the "Curbur Formation" unconformably overlies ?Carrandibby Formation or Lyons Formation. This resembles the situation west of Callytharra Spring, where the lithologically similar Moogooloo Sandstone oversteps the Carrandibby and Lyons Formations. Because of this we propose to drop the name "Curbur Formation" in favour of Moogooloo Sandstone. The sequence overlying the "Curbur Formation" was mapped by Konecki and others (1958) as Madeline Formation. It is, however, more similar to the generally well-bedded Keogh Formation and we map it as such.

SIGNIFICANCE OF PRE-MOOGOOLOO SANDSTONE UNCONFORMITY

The unconformity between the Moogooloo Sandstone and the underlying Callytharra Formation represents a major break in sedimentation. During this break significant erosion and gentle regional tilting took place, as well as localized, more pronounced tilting on the southern side of the Carrandibby Inlier.

The importance of this period of erosion is demonstrated in the Bidgemia—Congo Syncline area, by the presence beneath the Moogooloo Sandstone of stack-like pinnacles and mounds up to 30 m high, formed of resistant calcarenites of the Callytharra Formation. The "stacks" which were briefly described by Condon (1967, p. 85; 1968, p. 48) have been partly exhumed in the area centred on lat. 25°08'15"S, long. 115°36'45"E. They are elongate and aligned in rows in a roughly rectangular ground plan. The main elongation and alignment trends 120°-130°, reflecting a master-joint orientation which is clearly visible on aerial photographs. The joints were eroded out to form corridors 5 m to over 20 m wide, and these are filled with Moogooloo Sandstone which drapes over the "stacks" Clearly, deposition of the Moogooloo Sandstone was influenced by the joint-controlled erosional topography on the lithified and jointed Callytharra Formation. The basal part of the Moogooloo Sandstone that fills the corridors consists of fine- to medium-grained sandstone with rare trace fossils that indicate a shallow-marine origin. No coarse-grained siliciclastic deposits or limestone conglomerates have been seen overlying or between the "stacks". The known area with easily recognizable "stacks", i.e. higher than a few metres, measures about 11 km by 8 km (about 65 km^2) and the area where "stacks" are common is of the order of 330 km^2.

Condon (1962b; 1967, p.85) and Playford and others (1975) interpreted these pinnacles as sea stacks. We do not see how an extensive field of closely spaced sea stacks could be formed and preserved under the high-energy conditions prevailing along modern coasts with stacks. The large areal distribution and the lack of coarse-grained clastics, however, can be understood if the pinnacles and mounds formed a cone or tower-karst terrain with corridors, which was flooded and covered by sediment when the sea transgressed the area at the start of Moogooloo Sandstone deposition. The usage of the terms cone- and tower-karst does not imply that a tropical or subtropical origin is inferred for these forms. A cool to temperate climate is more likely to have prevailed during the Early Permian.

Further to the south, where the Callytharra Formation consists of less resistant, impure limestones, the evidence for important erosion is not as spectacular as in the Bidgemia area. South of the Congo Syncline the relatively pure, cross-bedded calcarenites of the upper Callytharra Formation disappear, and the formation consists of calcareous shale, marl and impure limestone. This facies transition represents a change from a relatively high-energy, shallow-marine environment to a lower energy, somewhat deeper environment. Significant uplift must therefore have occurred in these areas where this deeper water facies has been subaerially eroded prior to deposition of the Moogooloo Sandstone.

In the Callytharra Spring area both significant tectonic tilting, and reversal of movement along the Madeline Fault, took place prior to deposition of the Moogooloo Sandstone. West of Callytharra Spring flat-lying Moogooloo Sandstone, previously mapped as Pindilya Formation, progressively oversteps the Callytharra, Carrandibby, and Lyons Formations, which have an average tilt of about 8°. This tilting is due to the uplift of the Carrandibby Inlier along the Madeline Fault, which is a normal fault with east-block-down displacement. The type section of the Callytharra Formation is located on the up-thrown (western) block, and is about 100 m thick. A monotonous, poorly bedded claystone and siltstone sequence forms the upper 40 m of the type section. The fine grainsizes and the monotonous aspect of the sequence indicate a quiet, probably somewhat deeper

marine environment for this part of the section. In the nearest occurrence of Callytharra Formation on the down-thrown block, about 10 km to the northeast, this upper unit of claystone and siltstone is very thin or absent. This suggests more erosion prior to Moogooloo Sandstone deposition on the present down-thrown block than on the up-thrown block, which in turn suggests reversal of movement along the Madeline Fault in this area.

Just to the south of Callytharra Spring, at the "type" locality of the Pindilya Formation (see section on Pindilya Formation) movement of the Madeline Fault ceased during deposition of the Moogooloo Sandstone. At the southern end of the exposed Madeline Fault, the Moogooloo Sandstone consists of flat-lying sandstone and siltstone. Within this little-deformed sequence is a local, angular unconformity with beds tilted up to 15° because of fault drag along the Madeline Fault. The tilted sequence is unconformably overlain by flat-lying beds of identical facies which have not been noticeably affected by the Madeline Fault. Within 125 m the angular unconformity changes into a disconformity marked by scattered pebbles within an undisturbed flat-lying sequence.

The unconformity between the Callytharra Formation and the Moogooloo Sandstone thus represents a period of regional uplift and sub-aerial erosion, with locally important faulting and karst development.

PINDILYA FORMATION

The name Pindilya Formation was proposed by Konecki, Condon, Dickins, and Quinlan *in* McWhae and others (1958) for a ?Tertiary sandstone and conglomerate unit which unconformably overlies the Permian sequence in the Byro sub-basin and the southern part of the Bidgemia sub-basin. The "type" section is at lat. 25°53'24"S, long. 115°43'00"E, about 3 km southwest of Callytharra Spring. The "type" section which is 30 m thick, and its neighbouring cliffs, were carefully examined by us, and we consider that they consist of typical Moogooloo Sandstone. However, we do recognize a ?Tertiary sandstone and conglomerate unit which has the stratigraphic relationships and lithology of the Pindilya Formation as mapped by previous workers. Neither the current Australian Code of Stratigraphic Nomenclature nor its proposed revision are clear about procedures to follow in this situation. To avoid proliferation of names we propose to designate a new type section for the Pindilya Formation, and a full definition is given below:

Derivation of name: Pindilya Bore on Byro Staton, lat. 25°57'36"S, long. 115°46'12"E, Glenburgh Sheet area.

Distribution: Occurs as mesa cappings in the Dairy Creek-Muggon area.

Revised type section locality: Lat. 26°22'39"S, long. 115°47'24"E, Curbur Station, Byro Sheet area; on the western side of a low mesa, where the track from Salt Well to Swelt Bore joins the fence.

Lithology: Sandstone and granule to pebble conglomerate; commonly silcreted. At the revised type section the formation overlies with a sharp, erosive contact a well-developed soil that formed in Permian claystone. The basal 1.7 m consists of indistinctly bedded, well-sorted pebble conglomerate with pebbles ranging in size from 0.2 cm to 3 cm. This conglomerate unit grades up into 1.1 m of more distinctly bedded, very coarse-grained sandstone to granule conglomerate. The whole sequence is intensely silcreted.

Thickness: 2.8 m at the type locality; maximum thickness of up to about 5 m in karst-type solution pipes; commonly only a thin veneer of weathered-out pebbles.

Age: Morphostratigraphic and lithostratigraphic relations suggest a correlation with the Eocene Merlinleigh Sandstone.

Fossils: The only fossils found *in situ* are root casts. Konecki and others (1958, p. 56) stated: "Poorly preserved fossils (bryozoans, corals) were found on the surface of the basal siltstone of the One Gum Formation in its type section; these fossils were in similar chalcedonic preservation to those in the Merlinleigh Sandstone. Pindilya Formation caps nearby mesas." Because of their chalcedonic preservation the fossils, which were not determined, were thought to be derived from the Pindilya Formation. Our re-examination of the locality produced no further evidence as to whether these fossils are indeed from this formation.

Relationships: The Pindilya Formation unconformably overlies the Permian sequence. The unconformity is commonly marked by deep solution pipes that formed during a later period of lateritic weathering.

Mappability: The Pindilya Formation is a widespread mappable unit, but its recognition by photo-interpretation is difficult. The formation was laid down on an ?Early Tertiary erosion surface, and after erosion and dissection of both the pre-existing landscape and its Pindilya cover, intense lateritization and silcretization took place. These two types of duricrust have photopatterns which are little affected by changes in bedrock. Because of this it is difficult or impossible to determine by photo- interpretation whether or not a particular hill top has been completely stripped of its cover of Pindilya Formation.

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STRATIGRAPHIC TERMINOLOGY OF THE EARAHEEDY GROUP, NABBERU BASIN

by W. D. M. Hall,* A. D. T. Goode,* J. A. Bunting, and D. P. Commander

ABSTRACT

A sequence of Lower Proterozoic rocks in the eastern part of the Nabberu Basin is defined as the Earaheedy Group. Two subgroups are recognized, which reflect two major transgressive-regressive cycles of sedimentation. The lower is the Tooloo Subgroup, which consists of a basal clastic unit (Yelma Formation) overlain by iron-formation and shale (Frere Formation) with a carbonate and clastic unit (Windidda Formation) at the top. The Minigarra Subgroup consists of three predominantly clastic formations (Wandiwarra Formation, Princess Ranges Quartzite and Wongawol Formation) overlain by the Kulele Creek Limestone, with a clastic and minor carbonate unit (Mulgarra Sandstone) at the top of the sequence. The Earaheedy Group is possibly equivalent to parts of the Padbury Group in the western part of the Nabberu Basin, and either unconformable on, or equivalent to, parts of the sequence in the Glengarry Sub-basin.

INTRODUCTION

Lower Proterozoic sedimentary rocks flank the northern margin of the Archaean Yilgarn Block over a distance of 700 km between longitudes 117°E and 124°E. They are overlain unconformably in the north by the Middle Proterozoic Bangemall Group, in the east by Phanerozoic sediments of the Officer Basin, and in the west they become involved in the Gascoyne Mobile Belt. The term Nabberu Basin was introduced by Hall and Goode (1975) to include the repository of all these Lower Proterozoic rocks. Bunting and others (1977) express doubts on the validity of the term, but for the purposes of the present paper the term Nabberu Basin is used in the sense of Hall and Goode. The eastern part of the basin now forms a broad, east-southeast-trending synclinorium with a gently dipping southern limb and a tightly folded, and in places overturned northern limb. In the Glengarry Sub-basin gently folded sediments extend southwards onto the Yilgarn Block, and to the west the Padbury Group (Barnett, 1975) is tightly folded between Archaean basement highs.

Geologists of the Broken Hill Proprietary Co. Ltd (B.H.P.) began mapping the eastern part of the Nabberu Basin in 1973 and subsequently continued westwards into the Peak Hill and Robinson Range 1:250 000 Sheet areas and eastwards into the Stanley and Kingston 1:250 000 Sheet areas. New stratigraphic names were invoked to describe the sequence in the eastern part of the Nabberu Basin. These names have appeared in publications without adequate definition.

Systematic mapping of the eastern part of the Nabberu Basin by the Geological Survey of Western Australia began in the Kingston Sheet area in 1975, although parts of the southern and eastern edges had been mapped in 1973 (Bunting and Chin, 1975; Bunting, Jackson and Chin, 1975) and in 1972 by the Bureau of Mineral Resources (Jackson, in prep.). Mapping was completed in the Nabberu, Stanley and Wiluna 1:250 000 Geological Sheet areas in 1976 and mapping in the Glengarry 1:250 000 Geological Sheet area is in progress.

The purpose of this paper is to define the stratigraphic units used by B.H.P. which, with minor modifications, were used in the G.S.W.A. mapping.

STRATIGRAPHY

The area occupied by the Earaheedy Group is shown in Figure 22. Eight formations are recognized, comprising some 6 000 m of shallow water marine sediments. The type sections have all been established on the southern limb of the main synclinorium because of relatively easy access, better exposure and lack of structural complexity compared with the northern limb.

The unconformity between the Earaheedy Group and the underlying Archaean granitic and metamorphic rocks is well exposed in parts of the southern limb of the synclinorium, over the Malmac Dome (Horwitz, 1976) and in the northwest Nabberu Sheet area. To the west, however, the Earaheedy Group appears to be underlain by a thick sequence of sedimentary and basaltic rocks which may be either equivalent to, or unconformable beneath, the Yelma Formation. A similar situation exists along the central part of the northern limb of the synclinorium where a mixed unit of slate, phyllite, arenite and chert lies north of, and stratigraphically below, the arenites of the Yelma Formation. For the present these older rocks are excluded from the Earaheedy Group.

The division of the Earaheedy Group into the Tooloo and Miningarra Subgroups is based on the recognition of two distinct cycles of sedimentation, each comprising a transgressive phase followed by a period of regression. The subgroups are locally separated by a disconformity.

TOOLOO SUBGROUP

The Tooloo Subgroup consists of the Yelma, Frere and Windidda Formations.

Yelma Formation

The Yelma Formation is named from exposure 6 km northwest of Yelma outstation in the Kingston Sheet area. It is the unit of medium to coarse-grained quartz-rich clastic rocks which lies unconformably on the Archaean basement and conformably below the Frere Formation. At the type section, between grid references 473711 and 473712 on the Kingston Sheet, the formation is about 130 m thick. It thins to about 10 m in the southeastern part of the basin (Bunting and others, 1975).

The type Yelma Formation consists of buff-weathering, white to cream, medium to very coarse-grained, clean quartz sandstone, in places arkosic, with minor bands of quartz pebble or quartz cobble conglomerate near the base. The sandstone is generally flat bedded, with occasional cross bedding and ripple marks, and rare mud pellets. Thin chert and silicified carbonate beds occur locally within the sandstone along the southern limb of the synclinorium. On the northern limb the formation is much thicker (up to 500 m) and contains shale and chert beds. It is equivalent to the Malmac Formation of Horwitz (1976).

Frere Formation

The Frere Formation is a sequence of dominantly ferruginous chemical sediments and fine-grained clastics with minor carbonates and is named from the Frere Range along the northern side of Lake Nabberu in the Nabberu Sheet area. The base is taken at the top of the quartz sandstone of the Yelma Formation. In the Kingston Sheet area the top is taken at the first carbonate band which marks the base of the Windidda Formation, whereas to the west and around the northern side of the synclinorium, it is taken at the base of the fine-grained clastic sediments of the Wandiwarra Formation in which there are only rare and thin bands of iron-formation.

The type section is in the Frere Range in the Nabberu Sheet area, between grid references 364804 and 367809, where the middle part of the formation is well exposed in gorges. The total thickness of the formation is estimated to be 1 300 to 2 000 m, shallow dips making accurate measurement difficult.

*Broken Hill Proprietary Co. Ltd, Melbourne

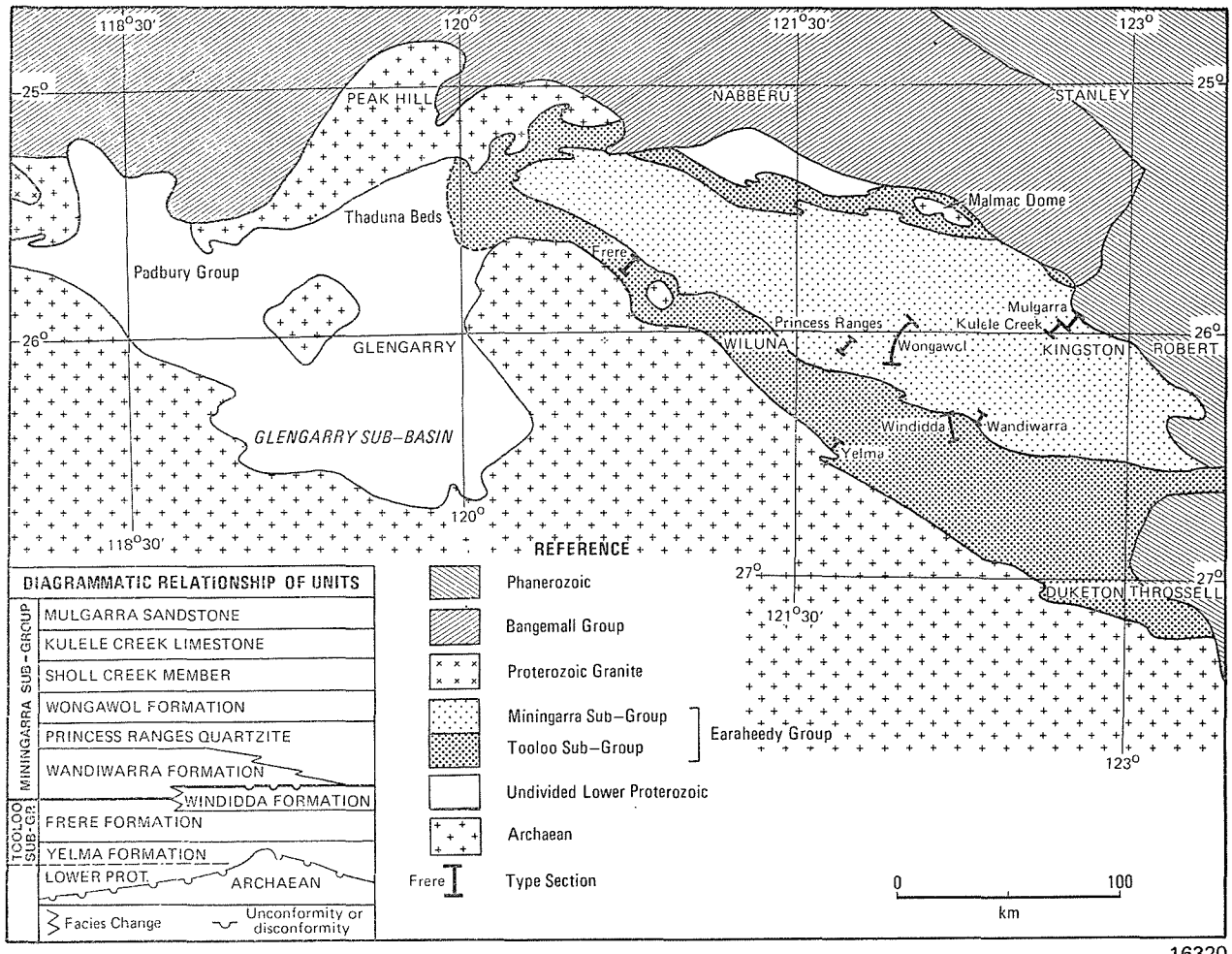

Figure 22. Regional setting of the Earaheedy Group.

The most conspicuous rock type is a clastic or pelletal-textured ferruginous chert in which rounded to angular grains of chert or ferruginous chert are set in a chert matrix. Locally this iron-formation is prominantly meso-banded, consisting of alternating layers of pelletal ferruginous chert and nonpelletal chert or hematitic shale. The ferruginous chert pellets are occasionally oolitic.

Clastic sequences up to 100 m thick form the bulk of the Frere Formation in the southeast part of the basin where the predominant rock type is buff, brown or maroon shaley siltstone with minor fine-grained sandy shale. The siltstone beds are finely laminated, with small-scale cross-bedding, and include thin chert bands in places.

Along the northern limb of the synclinorium the shale units have a strong slaty cleavage.

Stromatolitic carbonate, which marks the boundary between the Yelma and Frere Formations at several localities along the southern limb of the synclinorium, also occurs within the Frere Formation. These carbonate units form lenticular bodies up to 20 m thick and several kilometres long.

Windidda Formation

The Windidda Formation is that unit of carbonate and fine-grained clastic sediments lying between the Frere Formation and the Wandiwarra Formation. The base is taken at the base of the first carbonate unit above the thick iron-formations of the Frere Formation, and the top is the top of the uppermost carbonate-clast conglomerate band on which the sandstone of the Wandiwarra Formation rests. The type section is between points 8 km south and 5 km north-northwest of Windidda homestead, between grid references 533714 and 530727. Here the formation is approximately 1 200 m thick.

In the type section a basal unit consisting of a few metres of brown ankeritic carbonate with chert and stromatolitic bands is overlain by grey to pink laminated limestone. The limstones are locally conglomeratic and are interbedded with calcareous shales. The shales become more common higher in the sequence. The top of the Windidda Formation is not exposed in the type section, but about 25 km to the west-northwest the top is marked by a prominent 1 to 2 m-thick band of intraformational limestone conglomerate.

The Windidda Formation is confined to the southeastern limb of the synclinorium. In the Nabberu Sheet area, and along the northern limb, the stratigraphic position of the Windidda Formation is occupied by siltstone and fine-grained sandstone indistinguishable from similar rocks of the Wandiwarra Formation. This probably represents a deeper water facies in which carbonates were not deposited. A local disconformity occurs at the top of the formation where it is overlain by the transgressive Wandiwarra Formation.

MININGARRA SUBGROUP

The Miningarra Subgroup consists of the Wandiwarra Formation, Princess Ranges Quartzite, Wongawol Formation, Kulele Creek Limestone and Mulgarra Sandstone.

Wandiwarra Formation

The Wandiwarra Formation is named from Wandiwarra Well, 12 km east of Windidda homestead in the Kingston Sheet area, and is the unit of medium to fine-grained clastic sediments between the uppermost carbonate member of the Windidda Formation and the lowermost mature quartzite of the Princess Ranges Quartzite. In the type section (between grid references 547722 and 548724) it consists of

fine-grained, pink to grey, finely laminated, cross-bedded micaceous sandstone with occasional ripple marks and small mud pellets. Interbedded with the fine-grained sandstone are 1 to 2 m bands of grey-brown, impure micaceous quartz arenite, and finely laminated micaceous shale. Total thickness in the type section is 350 m.

Where the Wandiwarra Formation overlies carbonates of the Windidda Formation, the basal bed is a poorly sorted glauconitic sandstone, but where the carbonates are absent, in the northern and central parts of the synclinorium, the shale unit overlying the Frere Formation is taken as the base of the Wandiwarra Formation.

The contact between the Wandiwarra Formation and the overlying Princess Ranges Quartzite is diachronous: the mature quartzites marking the base of the Princess Ranges Quartzite rest directly on the Windidda Formation in the east; to the west the Wandiwarra Formation thickens and the first mature quartzite appears higher in the sequence.

Princess Ranges Quartzite

The Princess Ranges Quartzite is named from the Princess Ranges in the Kingston Sheet area. It is the unit of predominantly medium to coarse-grained, quartz-rich clastic rocks that lies conformably between the Wandiwarra and Wongawol Formations. The base and the top are respectively, the bottom of the first massive, pale, crystalline quartzite overlying the Wandiwarra Formation; and the last bed of similar quartzite beneath the Wongawol Formation. The type section is along the unnamed creek that crosses the Princess Ranges between grid references 479762 and 483764.

The Princess Ranges Quartzite is dominated by three main units of massive orthoquartzite interbedded with fine sandstone and sandy siltstone. The formation is about 200 m in thickness at the type section, but it thickens to the southeast due to the diachronous nature of the lower contact.

The diagnostic rock type is a medium to coarse-grained, supermature, quartz-cemented orthoquartzite. Glauconite is present in some units, and fine lamination, cross bedding, ripple marks and mud pellets are common. Ferruginous spots up to several centimetres across give the quartzite a speckled or blotchy appearance. The spots are probably weathered rhombs of carbonate cement.

Wongawol Formation

The Wongawol Formation ("Wongawol Sandstone" of Hall and Goode, 1975) is named from Wongawol homestead in the Kingston Sheet area, and is the unit of fine-grained sandstone, siltstone and minor carbonate rocks between the Princess Ranges Quartzite and the Kulele Creek Limestone. The type section is along the Wiluna-Carnegie road between grid references 504752 (Kingston Sheet) and 513777 (Stanley Sheet).

The lower part of the Wongawol Formation is a monotonous sequence of grey to pinkish brown, finely laminated, very fine sandstone and siltstone. Abundant sedimentary structures include small-scale festoon cross-bedding, ripple marks, small scour channels, load casts, slump rolls and rare mud cracks.

Thin carbonate beds and carbonate breccia beds are interbedded with the sandstone in the upper part of the Wongawol Formation. The *Sholl Creek Member* (equivalent to "Sholl Creek Formation" of Hall and Goode, 1975) is taken from the lowermost carbonate bed to the top of the Wongawol Formation, and is well exposed along Sholl Creek between grid references 531779 and 528786 (Stanley Sheet). The base of the member marks a transition towards carbonate sedimentation, but the basal carbonates are lenticular. The Sholl Creek section supplements the Wongawol Formation type section, the corresponding part of which is poorly exposed. The most abundant rock type in the Sholl Creek Member is a fine-grained, arkosic micaceous sandstone similar to that in the lower part of the Wongawol Formation. In addition to the carbonate interbeds, micaceous maroon and chocolate shales are also interbedded and these become abundant towards the top of the Sholl Creek Member.

Total thickness of the Wongawol Formation is estimated at 2 000 m, of which the upper 600 m constitute the Sholl Creek Member. However, the shallow dips and gentle folds make calculations difficult, and these figures may be over-estimates. The formation represents a transition from shallow water clastic to carbonate sedimentation.

Kulele Creek Limestone

The Kulele Creek Limestone, which is named from Kulele Creek in the Stanley Sheet area, is the formation of carbonate and minor clastic sediments lying between the Wongawol Foramtion and the overlying Mulgarra Sandstone. The formation is about 300 m thick at the type section, which is in the vicinity of Mount Throssell between grid references 581767 (Kingston Sheet) and 586770 (Stanley Sheet). The base of the Kulele Creek Limestone is taken at the appearance of metre-thick stromatolitic carbonate and cross-bedded calcarenite beds, a horizon which approximately corresponds to the predominance of carbonate beds over shale beds, as distinct from the reverse in the upper part of the Wongawol Formation. The top is taken at the top of a thick carbonate band beneath the arenite of the Mulgarra Sandstone.

The Kulele Creek Limestone consists of bands of calcarenite, carbonate conglomerate, stromatolitic limestone, oolitic limestone and purple shale, commonly forming cyclic sequences 5 to 10 m thick. The stromatolites form domal structures several metres across, commonly with carbonate clasts and ooliths in the interdomal areas. These are particularly well preserved in an outlier of the lower part of the sequence, 60 km west of the type section, at grid reference 516777 (Stanley Sheet). Several prominent sandstone bands occur in the Kulele Creek Limestone between 150 and 200 m above the base.

The Kulele Creek Limestone conformably overlies the Sholl Creek Member of the Wongawol Formation, and the top is marked by the sudden incoming of a transgressive arenite sequence.

Mulgarra Sandstone

The Mulgarra Sandstone is named from Mulgarra Pool in the northeast corner of the Kingston Sheet area. Its type section is in the Timperley Range area between grid references 589767 (Kingston Sheet) and 594776 (Stanley Sheet), where it is only poorly exposed. Total thickness is probably greater than 100 m. At the base, a thick quartz arenite rests with a sharp, probably disconformable, contact on the underlying Kulele Creek Limestone.

The dominant lithology is a medium-grained grey to brown ferruginous quartz arenite with minor glauconite. The middle part of the exposed sequence contains minor shale and carbonate bands. Sedimentary structures include shale pellets, small slump rolls, small cross beds and rare load casts.

The Mulgarra Sandstone is the youngest known unit of the Earaheedy Group. It is exposed only in the extreme eastern part of the Nabberu Basin where it occupies the centre of the synclinorium.

AGE AND REGIONAL CORELATIONS

The Earaheedy Group is considered to be Lower Proterozoic in age for several reasons. The group unconformably overlies Archaean rocks and is unconformably overlain by the Bangemall Group which has been dated at about 1 100 m.y. The thick pelletal iron-formations of the Frere Formation are of the Lake Superior type which is generally considered characteristic of the Lower Proterozoic. Microfossils from the Frere Formation are identical to those from the Lower Proterozoic Gunflint and Biwabik Iron Formations of the Lake Superior district (Walter and others, 1976).

Glauconite from the Yelma Formation in the Duketon Sheet area (southeast Nabberu Basin) gave K-Ar ages of around 1 700 m.y. and Rb-Sr ages of between 1 590 and 1 710 m.y. (Preiss and others, 1975). Horwitz (1975) reports a K-Ar age of 1 685 m.y. for glauconite which, using his coordinates, comes from the base of the Wandiwarra Formation in the northwest corner of the Kingston Sheet area. Because of the possibility of argon loss these must be regarded as minimum ages.

Relationships between the Earaheedy Group and the Lower Proterozoic Padbury Group (Barnett, 1975) to the west are uncertain. Pelletal iron-formations are present in the Padbury Group, although they are a minor constituent, and a correlation of at least the upper part of the Padbury Group with the Frere Formation is possible. The bulk of the Earaheedy Group may therefore be younger than the Padbury Group.

The Glengarry Sub-basin (Fig. 22) contains a basal quartz arenite unit overlain by a mixed unit of shale, marl, carbonate, greywacke and arenite. This mixed unit is probably a facies variant of the Thaduna Beds. It is not clear at present whether the basal arenite is a diachronous shore facies of the mixed unit and continuous with the Yelma Formation, or whether the Yelma Formation is unconformably above the entire sequence in the Glengarry Sub-basin.

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PRELIMINARY SYNTHESIS OF LOWER PROTEROZOIC STRATIGRAPHY AND STRUCTURE ADJACENT TO THE NORTHERN MARGIN OF THE YILGARN BLOCK

by J. A. Bunting, D. P. Commander, and R. D. Gee

ABSTRACT

An east-west elongated synclinorium, filled with Lower Proterozoic sediments, unconformably overlies the northern margin of the Yilgarn Block and is unconformably overlain by the Middle Proterozoic Bangemall Group. Two sub-basins are described. The western, Glengarry Sub-basin, contains the oldest sediments, which are a basal sandstone followed in the southeast by a shelf sequence of shales, marls and carbonates and in the northwest by an axial sequence of shale, arkose, greywacke and interbedded basalt. The youngest sediments in the sub-basin are the thick coarse-grained clastics, iron-rich shales and banded iron-formation of the Padbury Group. The Earaheedy Group occupies the eastern (Earaheedy) sub-basin and unconformably overlies part of the older sequence in the Glengarry Sub-basin. The basal pelletal iron-formations and iron-rich shales are possible equivalents of the upper part of the Padbury Group. The succeeding quartzites, fine sandstones and limestones are the youngest rocks in the basin.

The Lower Proterozoic rocks are located on an east-west trending junction between Archaean granite-greenstone and gneissic terrains, marking the transition from cratonic to mobile basement, and the basin structure is related to this underlying major crustal suture. On the southern margin of the present extent of the Lower Proterozoic rocks, the sediments are relatively flat lying on the Kingston Platform. The Stanley Fold Belt lies to the north of the Kingston Platform and is an arcuate zone of tight folding. In the centre the north-northwest trending Wiluna Arch narrows the present basin extent, and the sediments there are faulted by the Celia Lineament. In the extreme west, sediments have been involved in the dynamothermal metamorphism associated with the Proterozoic Gascoyne Province, forming banana-shaped synclinal zones truncated by the basement highs of the Yarlarweelor Gneiss Belt, and the Marymia Dome. Within the fold belt narrow zones occur where tectonically active basement has controlled sedimentation and extrusion of basic volcanics. The Goodin Dome is associated with such zones. In the east, tight folds are oriented east-west and are overturned to the south. Granite basement comes to the surface in the Malmac Dome.

Correlation between these Lower Proterozoic rocks and the Hamersley Basin has been suggested by several previous authors, but is considered to be unlikely due to differences in lithology and radiometric ages.

INTRODUCTION

A complex arcuate belt of Lower Proterozoic sedimentary rocks lies with marked angular unconformity on the Archaean Yilgarn Block along its northern margin, and is unconformably overlain by Middle Proterozoic rocks of the Bangemall Basin. Hall and Goode (1976) introduced the term "Nabberu Basin" to include all these lower Proterozoic rocks, and this term has been subsequently used in a number of publications. However, in view of the uncertainties over relationships between the two sub-basins (described below) we feel that it is premature to say whether the sub-basins have sufficient stratigraphic and structural unity to justify inclusion within a single named (Nabberu) basin; it may be that when better evidence is available concerning their relative ages it will be more appropriate for each to be raised to basin status. We nevertheless find the term Nabberu Basin convenient in describing these rocks, and use it in this paper in the sense of Hall and Goode, with the proviso that further work is required to prove its validity.

Systematic mapping by the Geological Survey of Western Australia has previously skirted around this basin (Bunting and Chin, 1975; Barnett, 1975), and only recently have programmes been directed to the basin itself. Although much of this current work is incomplete, and previously

mapped areas need further reappraisal, a preliminary synthesis of recent mapping is warranted, particularly in view of the considerable differences of opinion that are emerging regarding the stratigraphy, age and evolution of the basin. This paper is based on systematic mapping of the Kingston, Stanley, Nabberu, Glengarry and Robinson Range 1:250 000 Sheet areas, and a re-examination of the Peak Hill Sheet area. This re-examination, which has resulted in a major reinterpretation of the earlier work by MacLeod (1970), but still left many problems outstanding, was an attempt to relate the Lower Proterozoic rocks (formerly thought to be Archaean) of Robinson Range (Barnett, 1975) to those rocks in the Glengarry and Nabberu Sheet areas.

STRATIGRAPHY AND SEDIMENTATION

The usage of the term Nabberu Basin, given in the introductory section, refers only to the present aspect of the unit, rather than its palinspastic limits before the tectonic effects of the Gascoyne Province, or the unconformable deposition of the Bangemall Group. The basin is broadly synclinorial, and neither the southern unconformity with the Archaean Yilgarn Block, nor the basement highs along the northern margin signify its shape as a sedimentary basin, although the basement highs may have directly influenced sedimentation.

For description and analysis of the basin, it has been divided into sub-basins (Fig. 23). Here again, the areas (or volumes) occupied by these sub-basins do not necessarily describe the original extent of the sub-basin.

GLENGARRY SUB-BASIN

This sub-basin contains the oldest rocks in the Nabberu Basin. It is presently revealed as a lobe or embayment of transgressive shelf-type sediments onto the Yilgarn Block, together with a mixed sequence of arkose, greywacke and mudstone in the axial portion abutting the Marymia and Goodin Domes, and a younger succession (Padbury Group) of coarse-grained clastics passing upwards into iron-rich shale and banded iron-formation (Fig. 24).

The stratigraphy is not fully known, due mainly to complex facies changes within the flysch-type sequence in the axial portion. However, a relatively simple stratigraphy is recognized in the shelf-type sequence in the

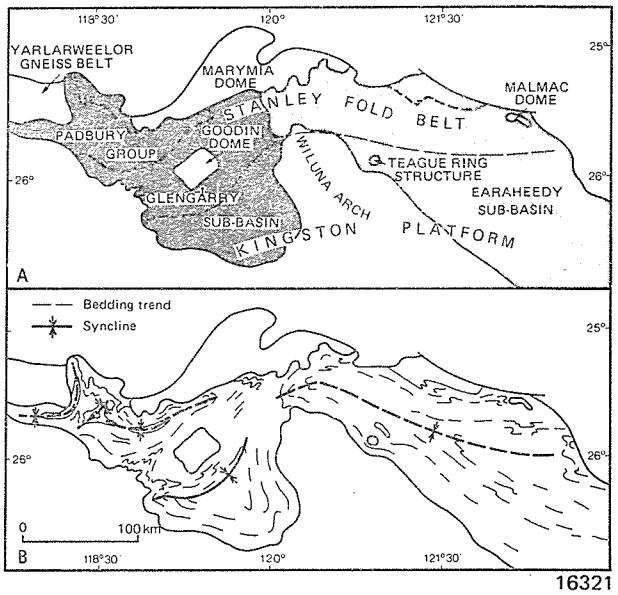

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Figure 23. A – Major structural units of the Nabberu Basin.
B – Lithological trends and major synclines of the Nabberu Basin.

lobe to the south, as outlined below. The terms Finlayson Sandstone and Maraloou Formation are new names and will be defined by Elias and Bunting (in prep.).

Finlayson Sandstone

This is a basal formation, consisting of fine-grained, supermature, silica-cemented quartz arenite with interbedded shales. The sandstone displays cross bedding and ripple marks and is considered to be a transgressive beach deposit. It is about 1 000 m in thickness, and blankets the contact along the entire southern extent of the unconformity. It appears to floor the entire sub-basin, since it occurs around the Goodin Dome, and identical quartz arenites occur along the tectonized northern margin with the Marymia Dome north of Thaduna.

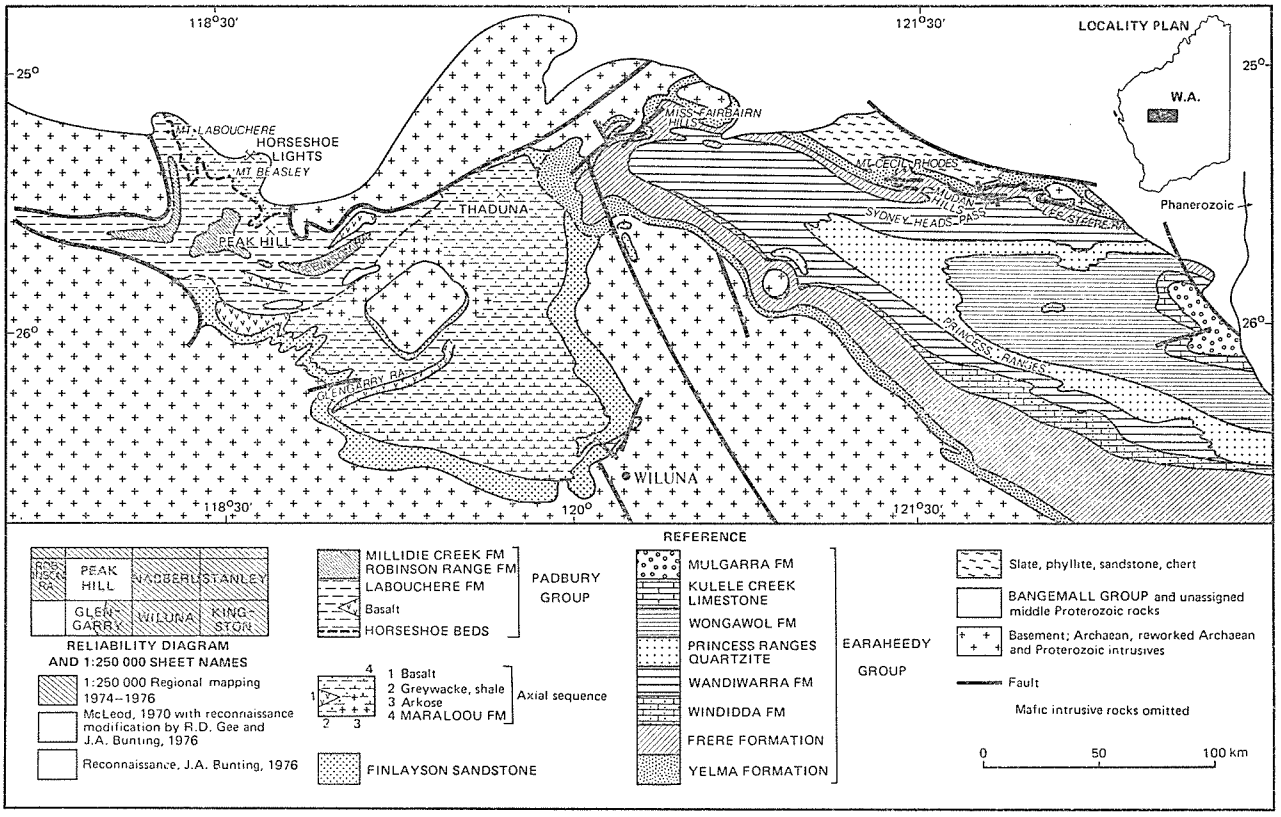

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Figure 24. Stratigraphy of the Nabberu Basin.

Maraloou Formation

This overlies the Finlayson Sandstone and consists of interbedded shale, siltstone, marl, stromatolitic carbonate, silicified carbonate and thin arenite beds. It is about 1 000 m in thickness in the southern lobe, and thickens considerably to the north and west toward the axial portion of the sub-basin, where arkose, greywacke and basalt become important. At the furthest traceable westerly extent along the southern margin, the level of the Maraloou Formation (immediately overlying the Finlayson Sandstone) is occupied by talcose siltstone and magnetite-rich lithic wacke with abundant cross bedding.

The Axial Sequences

Thick interbedded cleaved greywacke and purple slate containing volcanic debris (Trendall, 1970) occur in the Thaduna area, where they have been called Thaduna Beds (MacLeod, 1970). The stratigraphic position and significance of these rocks have long been a mystery. MacLeod envisaged them to have accumulated from turbidity currents flowing off an actively rising and eroding volcanic pile. This model is supported by the association of greywacke and basalt elsewhere in the axial portion of the Glengarry Sub-basin, particularly on the southern sides of basement highs.

Sequences of arkose, up to 400 m thick, occur in areas lacking the basalt volcanicity, for example on the northern side of the Goodin Dome where they overlie poorly developed Finlayson Sandstone, and in the nose of the Robinson Range Syncline. Interbedded greywacke and arkose also occur east of the Glengarry Range.

A thick sequence of mafic greywacke and purple slate occurs in the Horseshoe Lights mine area, apparently conformably below the Horseshoe Beds (MacLeod, 1970). These are identical to, and are here correlated with, the Thaduna Beds, and are considered to be the northwesterly extension of the rocks of the axial sequence beneath the Padbury Group. These rocks pass downwards (northeasterly) into recrystallized chert, quartz-muscovite-albite schist and sheared felsic volcanic agglomerate.

The greywacke rocks of the Horseshoe Lights mine area were mapped as "Peak Hill Beds" by MacLeod (1970). However, this stratigraphic term is not used here, because the Peak Hill Beds were intended for those rocks in the Peak Hill mine area, which are now largely assigned to the Labouchere Formation.

These thick greywacke, shale, basalt and arkose sequences in the axial part of the sub-basin are a deeper water facies of the shelf sediments represented by the Maraloou Formation.

Padbury Group

The Padbury Group occupies a complex-shaped synclinal zone in the western part of the Nabberu Basin. The group was defined by Barnett (1975) after mapping in the Robinson Range Sheet area, to include the conformable sequence of Labouchere, Robinson Range and Millidie Creek Formations. The lower two of this group were extensions of the stratigraphic units of MacLeod (1970) in the Peak Hill Sheet area.

The reappraisal in the Peak Hill mine-Horseshoe Lights mine area has cast doubts on the identity of the Peak Hill Beds. This term was applied to quartz-muscovite phyllite, chlorite schist, conglomerate and quartz arenite in the Peak Hill mine area, but these are now considered to be the direct continuation of the arenaceous Labouchere Formation from the type section at Mount Labouchere. The Labouchere correlatives at the Peak Hill mine area are in tectonic contact with the reworked Archaean basement rocks in the Marymia Dome, and so the stratigraphically lower units are structurally eliminated.

Stratigraphic units lower than the Labouchere Formation, which include the type Horseshoe Beds (banded iron-formation) and a thick greywacke sequence, do occur in the Mount Beasely-Horseshoe Lights mine area. The greywacke is correlated with the Thaduna Beds.

The Horseshoe Beds, a unit of laminated iron oxide and chert with hematitic maganiferous shale, 100 m thick, can be followed apparently conformably beneath the Labouchere Formation to the Peak Hill mine area, where it is structurally cut out against the Marymia Dome. It does not reappear on the southern side of the Robinson Range Syncline.

The Labouchere Formation therefore appears to be the lowest continuous unit of the Padbury Group, below which there may be a regional disconformity. In this synthesis, the Horseshoe Beds are grouped with the axial sequence, although their exclusion from the Padbury Group is arbitrary and provisional at this stage.

The stratigraphy of the Padbury Group is summarized below.

Labouchere Formation (lowermost): This is 5 000 m thick, and consists of mature quartz arenite, granule and boulder conglomerate, sericitic schistose sandstone, sericitic and chloritic phyllite and lenticular basalts. The boulder conglomerates are unusual, consisting of boulders, up to 2 m in diameter, of mature quartz arenite very similar to the Finlayson Sandstone, in a semimature quartz arenite matrix. Another unusual rock type is talc-chlorite phyllite, in which ghost outlines of rod-shaped clasts of talc-chlorite rock up to 10 cm in diameter, can be recognized in a similar matrix.

Robinson Range Formation: This is about 3 500 m thick, consisting dominantly of hematitic phyllite, commonly with small porphyroblastic magnetite, and laminated quartz-magnetite-hematite-chlorite rocks.

Millidie Creek Formation: This is at least 1 500 m in thickness, and consists of hematitic shale, feldspathic wacke, chert, carbonate, and prominent banded iron-formations. The iron-formations are chert-magnetite-hematite rocks, and clastic oolitic textures have been observed.

In summary, the rocks of the Padbury Group are dominated by iron-rich shales, banded iron-formation and shallow water arenaceous rocks. This contrasts with those in the axial sequence, but has broad similarities with the Earaheedy Group.

EARAHEEDY SUB-BASIN

The eastern part of the Nabberu Basin is occupied mainly by the Earaheedy Group, a shelf-facies sequence of shale, sandstone, limestone and pelletal iron-formation, 6 000 m in thickness. New stratigraphy has been presented (Hall and others, 1977), and this group will be fully described in later publications.

Two cycles of marine transgression and regression have been recognized, the first cycle deposited arkose, sandstone and conglomerate of the Yelma Formation directly onto the peneplaned Archaean basement to the south, and onto Glengarry Sub-basin sediments to the west. This was followed by shallow water deposition of pelletal iron-formation of the Frere Formation and stromatolitic limestone and shale of the Windidda Formation.

A disconformity is present at the base of the Wandiwarra Formation, a shallow water shale and sandstone unit with edge-wise limestone breccia, marking the beginning of the second transgressive cycle. This is overlain by the mature, orthoquartzitic Princess Ranges Quartzite, then interbedded fine sandstone, siltstone, mudstone and limestone of the Wongawol Formation. This unit probably records the deepest marine deposition in the Earaheedy Group and is overlain by the Kulele Limestone, which contains reef stromatolites and calcarenites. The highest unit is the Mulgarra Sandstone which resembles the Wongawol Formation.

A sequence of magnetite phyllite, schistose wacke, and chert occurs below the Earaheedy Group on the northern side of the Earaheedy Sub-basin. Its stratigraphic position is uncertain, but it lies below the basal unit of the Earaheedy Group, and consists of phyllitic and schistose rocks of higher metamorphic grade than the adjacent Earaheedy Group. An unconformity, or more probably, a tectonised unconformity, is inferred, but not established. These rocks are included in the Earaheedy Sub-basin for convenience, but possibly correlate with rocks in the Glengarry Sub-basin.

REGIONAL CORRELATIONS

Earaheedy and Glengarry Sub-basins

Lithological contrast is the basis for distinction between these two sequences. This distinction even extends to the basal orthoquartzitic sandstones of each basin. The Yelma Formation is less well sorted and much more feldspathic than the Finlayson Sandstone. Each formation displays its identifying features for distances of over 300 km.

The nature of the boundary between the two sequences has not been conclusively established, but the regional pattern of rock distribution and structure (Fig. 24) is *prima facie* evidence that the Earaheedy Group unconformably overlies the rocks of the Glengarry Sub-basin. Thus lithological trends in the Thaduna area appear to be truncated by the closure of the Yelma Formation around the regional syncline.

This interpretation conflicts with that of Horwitz (1975) who infers that the rocks of the Glengarry Sub-basin are younger than the basal formation of the Earaheedy Group. It also does not accord with Hall and Goode (in prep.) who equate the Yelma Formation and Finlayson Sandstone, and postulate that the Maraloou Formation is an offshore facies of the Yelma-Finlayson unit.

Padbury Group—axial sequence

The Padbury Group (from the Labouchere Formation upwards) undoubtedly overlies the rocks of the axial sequence north of the Goodin Dome and in the Horseshoe Lights mine area. The outstanding question is the nature and status of the dividing surface, whether it is conformable or unconformable. Possible correlatives of the Labouchere Formation may exist in the axial sequence east of the Glengarry Range.

Earaheedy-Padbury Groups

In view of the above relationships, it is possible that the Earaheedy and Padbury Groups may be facies variants of temporal equivalents. Both contain shale, carbonates, quartz arenite, and more significantly pelletal-textured iron-formation. These textures, whilst not being common in the Robinson Range and Millidie Creek Formations are sufficiently distinctive and rare in Western Australia to suggest a correlation with the Frere Formation. Precise correlation can be rejected as thicknesses, lithologies and sequences do not match at the formation level.

However, it may be that the Millidie Creek-Robinson Range interval is a deeper water facies of the Frere Formation. In this respect it is notable that Hall and Goode (in prep.) consider the Frere Formation to have formed in shallow water progressively deepening to the north and west.

STRUCTURE

WILUNA ARCH

The regional structure of the Nabberu Basin is an arcuate synclinorium in which fold trends swing from east-northeast in the west to east-southeast in the east (Fig. 23). The inflection of the arc lies on the narrowest part of the basin. This corresponds to the separation of the Glengarry and Earaheedy Sub-basins, and is a structural culmination, caused by a broad gentle northwest-trending high called the Wiluna Arch.

A north-northwest trending fault lies centrally in the Wiluna Arch in the Archaean basement. It cuts the unconformity and displaces the Yelma and Frere Formations. It seems to be a young expression of the Celia Lineament (Gower, 1974; Bunting and Williams, 1976), a major lineament that has played a role in greenstone belt evolution in the Archaean.

The Wiluna Arch and the Celia Lineament are examples of the north-northwest structural grain of the Yilgarn Block influencing the evolution of the Nabberu Basin.

KINGSTON PLATFORM

The term platform is used in the sense of Gary and others (1972), and is applied to that part of the Yilgarn Block that is covered by gently tilted Nabberu Basin sediments.

The demarcation between the Kingston Platform and the Stanley Fold Belt is taken as the appearance of minor folds with related slaty cleavage. It is postulated that this line represents, in the cover sequence, the buried expression of the northern margin of the Yilgarn Block. South of this line the basement escaped post-Archaean dynamothermal reworking.

Two directions of minor folds, lacking related slaty cleavage, are recognized in that part of the Kingston Platform occupied by the Earaheedy Sub-basin; (1) an early period of monoclinal to asymmetrical folds with axial surfaces striking 300° and dipping steeply north; (2) open symmetrical folds with axes trending approximately 030°. A late period of warping along north-south axes has resulted in gentle dome and basin style of folding in the vicinity of the main synclinorial axis north of the Princess Ranges.

Teague Ring Structure

Only the Teague Ring Structure disturbs the gentle undulatory nature of the Kingston Platform. It contains a circular core of adamellite and syenite surrounded by a circular rim syncline in the cover sequence. Steeper dips on the northeastern arc than on the southwestern arc define a plane of symmetry trending approximately 040°.

Two possible explanations for this unusual structure were advanced by Butler (1974); a meteorite impact, and a diapiric intrusion. Horwitz (1975) suggested an origin by interference of mild folds. There is sufficient evidence to relate this structure to both the regional structural pattern, and the occurrence of syenite. The favoured interpretation involves cold re-emplacement of a plug of syenite, possibly at high strain rates, by localized compression stresses related to the regional 300° fold trend. Further work including radiometric dating of the syenite is being undertaken on this structure.

STANLEY FOLD BELT

This term is applied to that part of the basin that is affected by moderate to tight folding, low grades of metamorphism, cleavage generation and the tectonic emplacement of basement domes. It is the easterly continuation of the intense dynamothermal Proterozoic deformation that affected the Archaean basement and Lower Proterozoic supracrustal rocks of the Gascoyne Province.

Western part

Four main synclines arranged in a crude echelon fan are recognized in the western part of the Stanley Fold Belt. The westernmost syncline is banana shaped in plan, being an arcuate structure trending approximately north-south and wrapping around the bulbous eastern edge of the Yarlarweelor Gneiss Belt. The western limb of this syncline is sheared out and is completely missing. The next syncline to the east is an irregularly crumpled amoeboid-shaped structural basin that displays both north-south trends and east-northeast trends. The Robinson Range Syncline further to the east again has a banana shape but is oriented east-northeast and is arcuate to the southwestern edge of the Marymia Dome. The easternmost syncline, on the southern side of the Goodin Dome, is north-northeasterly in trend and defines the transition into the Kingston Platform in the Glengarry Sub-basin. All these folds result from the interaction of the regional east-northeast trend and the interference effects of rising and merging basement domes, and demand at least two phases of regional folding. Regional and minor structures along the contacts indicate that the Yarlarweelor Gneiss Belt has been upthrust towards the east and the Marymia Dome upthrust towards the south.

Evidence of polyphase deformation on a minor scale is common. This includes transposition of phyllitic schistosity to produce a second generation phyllitic schistosity, refolded structures in the Peak Hill mine area, and a number of late penetrative strain-slip and crenulation cleavages.

In the area surrounding the Goodin Dome, folds on north-northeast axes are developed in corridors on either side of the rhomb-shaped dome. Shadow effects are present adjacent to the northeastern and southwestern faces of the dome implying basement block tectonics. Deformation in the flanking corridors has certainly affected the

basement as the unconformity on the southwestern margin of the Glengarry Sub-basin is tightly folded. This north-easterly fold trend continues into the Thaduna area where the fold plunges are variable.

West-to-east transition

Interference fold patterns are again developed in the connecting zone between the eastern and western parts of the Stanley Fold Belt, in the Miss Fairbairn Hills area. Domes and basins are developed particularly along the unconformity of the Yelma Formation and the underlying granite. This gives the false impression of intrusive domes. These interference patterns are related to the easterly transition from east-northeast to east-southeast fold trends.

The age relations of the regional folds in this part of the fold belt need to be resolved as they should provide valuable evidence on the relative ages of the sequence in the Glengarry Sub-basin, and the Earaheedy Group. The folding may either be the result of one phase of arcuate, non-cylindroid folding that swings in harmony with the inferred buried position of the stabilized Yilgarn Block, or the expression of regional folding of the Earaheedy Group still later than the polyphase deformation to the west.

Eastern part

The transition from the Kingston Platform to the Stanley Fold Belt is quite rapid, and was originally mapped as an unconformity by Talbot (1928). Within the fold belt concentric-style folds, generally with very gentle east-southeast plunging axes, progressively tighten and increase in amplitude to the northeast. At the same time the folds develop asymmetry indicating overfolding from the north-east, and slaty cleavage becomes stronger.

Deformation is most intense along the northern margin of the basin, in the zone from Malmac Dome to 80 km to the west-northwest. Granite basement of presumed Archaean age (Horwitz, 1975) is exposed in the Malmac Dome which is unconformably beneath the Yelma Formation. On the southern side, the Yelma Formation dips off the dome quite steeply and is immediately involved in folding; however, on the actual dome and to the north, dips are gentle. Here again, basement has participated in the deformation.

Subparallel ridges of Yelma and Frere Formations extending west-northwest from the Malmac Dome outline large tight parasitic folds with strong slaty cleavage. Axial surfaces dip steeply north and the long limbs are generally overturned. To the east of Sydney Heads Pass, folds display Z-symmetry and plunge west at 10-20°, whereas those to the west near Mount Cecil Rhodes display S-symmetry and plunge 30-60° east. This change in plunge may represent a late synclinal cross fold. The western group of parasitic folds contain numerous sinistral faults. Small steep north-dipping thrusts associated with the asymmetric folds in the Sydney Heads Pass area indicate shortening and hence compression from the north. The contact between the Yelma and Frere Formations in the Mudan Hills and Lee Steere Range is faulted for much of its length, and a fault breccia is developed at the contact. This dislocation is subparallel to the bedding and is folded by the main deformation, but it is not clear whether the dislocation is due to an early thrust fault, or to slippage due to competency differences during folding.

STRUCTURAL DOMES IN THE STANLEY FOLD BELT

Considerable importance is attached to the granitoid domes that occur in the Stanley Fold Belt, as they all appear to have been emplaced into the deformed strata, yet no evidence of intrusive contacts with the sediments of the Nabberu Basin have been observed. The whole Nabberu Basin is singularly devoid of any granite, pegmatite or aplite dykes and veins. Undoubted unconformable contacts with the Yelma Formation are observed on the Malmac Dome and in the zone of interference domes and basins at the eastern end of the Marymia Dome.

Goodin Dome

The actual contact with this dome has not been observed but two lines of evidence point to an unconformable contact:

(a) the presence of the Finlayson Sandstone on the southern sides of the dome,

(b) the presence of arkose draped around the northern sides of the dome.

These observations further suggest that the granite, which is presumed to be Archaean, was a basement high during sedimentation.

Yarlarweelor Gneiss Belt

This is part of the basement that forms the western termination of the Nabberu Basin, and provides clues to the nature of the Marymia Dome. The belt consists of gneissic granitoid with abundant remnants of lineated quartzite, metamorphosed banded iron-formation, metasedimentary calc-silicate rocks, mafic and ultramafic pods of granulite or amphibolite facies metamorphism and quartz-muscovite schist. Elias and Williams (in prep.) consider this assemblage to be an older Archaean gneiss terrain, folding; however, on the actual dome and to the north, intruded by Proterozoic granites, and subsequently retrogressed by discrete mylonitic and cataclastic shear zones.

Intense shearing and mylonitization is a feature of the Padbury Group contact, and possibly about 5 km of sedimentary thickness is missing at the contact. Infolded wedges of Padbury Group also occur within retrogressed zones in the gneiss.

The Yarlarweelor Gneiss Belt is considered to be a bulbous segment of basement that has risen upwards and eastwards, possibly driven by rising Proterozoic granites well within the bulb, to become tectonically emplaced into the overlying sediments. It therefore has some features of a mantled gneiss dome.

Marymia Dome

This dome also contains the metamorphic rocks and gneissic granitoid that suggest an Archaean gneiss terrain, together with granulated granitoids of more magmatic appearance. These assemblages appear to be more prevalent in the southwestern half, whereas in the northeastern part granite-greenstone assemblages make an appearance.

Where it abuts the correlative of the Labouchere Formation along the western part of the southern margin, the contact is sinuous, but strictly concordant over a distance of 30 km. Along the length of this contact, no evidence of granitoid intruding sediment has been observed. Where observed, the actual contact is a shear zone, in places a mylonite, dipping steeply toward the granitoid. Penetrative cataclasis is prevalent in the granitoid, and shallow plunging fold mullions and phyllitic schistosity are developed in the adjacent quartz arenite and pelite. Here again, possibly in excess of 5 km of sedimentary sequence has been thrust out by movement on this contact.

The southwest part of the Marymia Dome is considered to represent the easterly continuation, beneath the Stanley Fold Belt, of the Yarlarweelor Gneiss Belt; and to be a tectonically activated basement segment that, in this area, moved upwards and to the south. By analogy with the gneiss belt, it is possible that intrusive Proterozoic granites occur in the dome. The northeast part of the dome displays few reworking effects and contains possible greenstone belt remnants.

SUMMARY OF TECTONIC EVOLUTION

TIMING OF EVENTS

The only geological constraints on the age of the basin are:—

1. the Earaheedy Group and the sequence in the Glengarry Sub-basin lie, with marked angular unconformity, on the Archaean Yilgarn Block, and
2. both sequences are folded and are overlain with angular unconformity by the Bangemall Group of about 1.1 b.y.

Further evidence is provided by K-Ar and Rb-Sr isotopic dates (Preiss and others, 1975; Horwitz, 1975) of around 1.6-1.7 b.y. for glauconite from sandstones of the Earaheedy Group.

The possibility of a correlation with the Hamersley Basin (about 2.2-2.0 b.y.) is immediately raised, when considering the gross regional symmetry between the Yilgarn and Pilbara Blocks, and by the collective similarity of the sequences. Indeed, this view has recently become popular (Horwitz, 1976; Hall and Goode, 1975), despite the difference in the ages quoted above.

Despite attempts to demonstrate similarities of thickness, lithology and sequence (Horwitz, 1976), we can see no basis for correlation, and are more impressed by the many differences between the Hamersley and Nabberu Basins, and the mounting evidence for regional unconformities in the pre-Bangemall sedimentary sequences across the northern margin of the Yilgarn Block. We believe that, at this stage of our knowledge, it is equally likely that the Nabberu Basin relates to the supracrustal rocks of the Gascoyne Province. The Nabberu Basin and particularly the Earaheedy Group could then be considerably younger than the Hamersley Basin, and we are inclined to accept the 1.7 b.y. K-Ar age as close to a true age.

There is, however, scope for extending the Padbury Group and the sequence in the Glengarry Sub-basin well back into the Lower Proterozoic. Although we prefer to interpret as Archaean the granites that are unconformably overlain by the Yelma Formation on the northeast of the Marymia Dome, the possibility that these are Proterozoic Gascoyne Province-type granites of about 1.6-1.7 b.y. (de Laeter, 1976) cannot be overlooked. This would demand that the Glengarry Sub-basin formed, was folded, intruded by granite and eroded before formation of the Earaheedy Group. The evaluation of this model, against the alternative facies change model, as presented in this paper, requires more detailed work in the critical, but poorly exposed areas, north and east of Thaduna.

BASEMENT CONTROL OF BASIN DEVELOPMENT

The primary location of the Nabberu Basin is the east-west trending junction of Archaean granite-greenstone terrains, and Archaean gneiss terrains. The influence of the respective north-northwest and east-northeast basement trends is apparent throughout sedimentation and deformation.

Initial downwarping occurred in the Glengarry Sub-basin and was even and gentle, allowing for the accumulation of 1 000 m of dominantly mature sandstone. Accelerated subsidence about active hinge lines and fractures was caused by fragmentation of basement. These fractures were related to the major crustal suture. Mafic volcanicity along parts of these fractures provided detritus for turbidity currents that fed into deep, probably fault-bounded, troughs.

As these troughs filled and basement activity relaxed, sedimentation again became widespread and of a stable shelf type. A new broad basin formed where the Padbury Group was deposited, consisting of a thick arenaceous blanket, followed by large thicknesses (about 4 km) of ferruginous chemical sediments.

According to the facies equivalent model, at the same time as Padbury Group sedimentation, a new gentle downwarp formed to the east on the eastern side of the Wiluna Arch to become the Earaheedy Sub-basin. A marine transgression deposited sandstones and clastic iron-formation in a much thinner and more shallow-water variant of the temporal equivalent, the Padbury Group. The succeeding sedimentation in the Earaheedy Sub-basin is younger than any other sequence in the Nabberu Basin.

All deformation in the Nabberu Basin is the result of basement block and fold movements, with a strong upthrust component from the north. The main synclinorium marks the boundary between mobile and cratonic basement, which in turn reflects a major suture within the Archaean crust.

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FOSSILIFEROUS TERTIARY DEPOSITS ON THE DARLING PLATEAU, WESTERN AUSTRALIA

by S. A. Wilde and J. Backhouse

ABSTRACT

Fossils are recorded from Muradup, 240 km southeast of Perth, and from Calingiri, 120 km northeast of Perth. They occur in sediments that form part of the Darling Plateau, a laterite-capped surface that overlies the southwestern part of the Precambrian Yilgarn Block. The plateau has been dissected by erosion and the sediments are preserved along drainage divides.

The fossiliferous deposits consist of silicified conglomerate, grit and sandstone, and are correlated with the Eocene Kojonup Sandstone on the basis of their preserved flora and geomorphic position. They indicate that the influence of the Eocene marine transgression was more widespread than is commonly recognized. Comparison with unfossiliferous deposits in a similar geomorphic setting in southwestern Australia suggests that these need not necessarily be of pre-Tertiary age.

INTRODUCTION

The Darling Plateau (Jutson, 1934) is the undulating, laterite-capped surface that forms the southwestern part of the Precambrian Yilgarn Block. It extends southward from near New Norcia almost to the south coast, a distance of about 460 km. It is separated from the Perth Basin to the west by the Darling Scarp and has been dissected by erosion (Finkl, 1971; Bettenay and Mulcahy, 1972).

Churchill (*in* McWhae and others, 1958) described Tertiary sediments containing plant fossils from near Kojonup, 150 km southeast of Perth. He defined these as the Kojonup Sandstone and made a tentative correlation, on the basis of similarities of the preserved flora, with the Eocene Plantagenet Group (Cockbain, 1968b) that occurs along the southwestern coast of Western Australia.

In the course of regional geological mapping in the southwestern Yilgarn Block, other localities with similar lithologies, and also containing plant remains, have been found (Fig. 25). The type section of the Kojonup Sandstone was visited in order that a detailed comparison could be made. The nature of these plant remains, the host lithology, and the distribution of the deposits in relation to the present geomorphology are of importance in elucidating the early Tertiary evolution of the Darling Plateau.

DISTRIBUTION

Plant remains were found near Muradup, 18 km west-southwest of Kojonup and at two localities near Calingiri, 120 km northeast of Perth. The fossils occur in sequences of silicified conglomerate, grit and sandstone and, in common with the Kojonup Sandstone, occur on present drainage divides (Fig. 25).

THE KOJONUP SANDSTONE

The type section of the Kojonup Sandstone (Churchill, *in* McWhae and others, 1958) is located on the property of "Half Moon", 7.2 km west-southwest of the Kojonup townsite. The rocks crop out in the headwaters of a north-flowing creek and upslope on the flanks of the divide separating Kojonup Brook and the Balgarup River (Fig. 26a), at a height of approximately 320 m above sea level.

The unit unconformably rests on Archaean migmatite and consists of a silicified basal conglomerate overlain by a sequence of grey to white silicified grit, orthoquartzite and sandstone. The strata appear to be flat lying and Churchill esimated the maximum thickness of the unit as 14.3 m. The upper part of the sequence is strongly lateritized. Churchill referred to other exposures of the formation, about 16 km south and southeast of Kojonup. These were not visited by the authors but are believed to be near Ngopitchup Swamp along the Kojonup/Balgarup/Gordon drainage divide.

At the type locality, the basal conglomerate consists of rounded pebbles of white quartz, up to 8 cm diameter, in a matrix of silicified, subrounded quartz grains. The sandstone is composed of fairly well-rounded grains of white quartz (0.4 mm average diameter) in a silica cement. Some ripple-marked surfaces are present. The grey orthoquartzite units are quite massive and boundaries between quartz grains and silica cement are not distinct.

Plant remains are locally abundant, particularly in the upper parts of the sequence. Specimens collected during this study, together with material housed in the Western Australian Museum, include species of *Nothofagus, Ficus, Apocynophyllum, Banksia* and *Grevillea*. In addition, the following species were recorded by Churchill (1961): *Araucaria derwentensis* Selling, *Phyllites yallournensis* Cookson and Duigan, *Agathis* sp., *Cyclosorus* sp., *Dacrydium* sp., *Livistonia* sp., *Lomatia* sp., and *Sterculia* sp. Rootlets and worm burrows are present and Churchill also recorded the tracks of a "two-toed animal of unknown affinities".

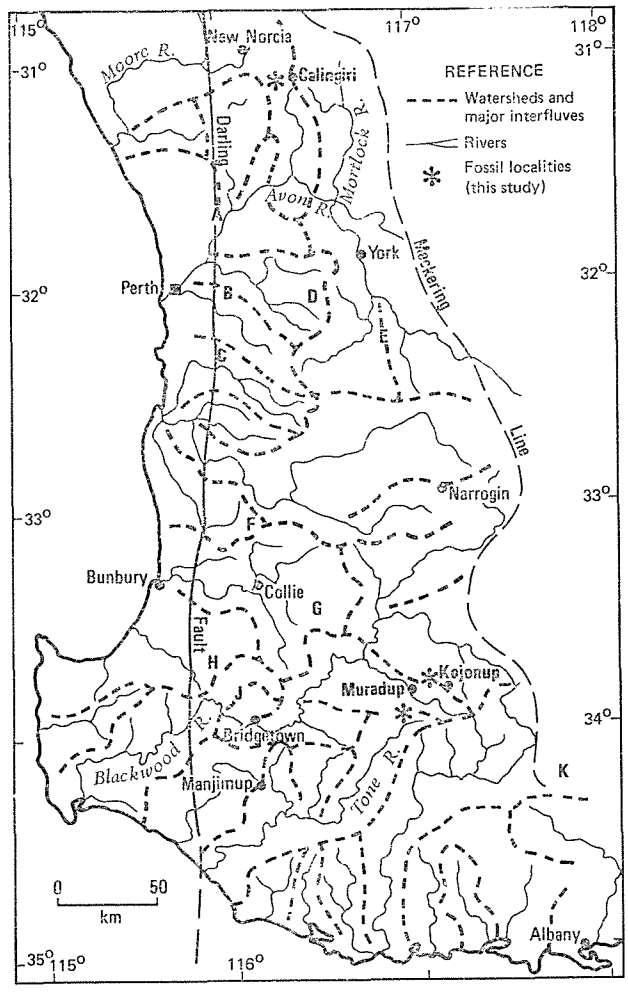

Figure 25. Major drainage features west of the 'Meckering Line' and localities mentioned in text.

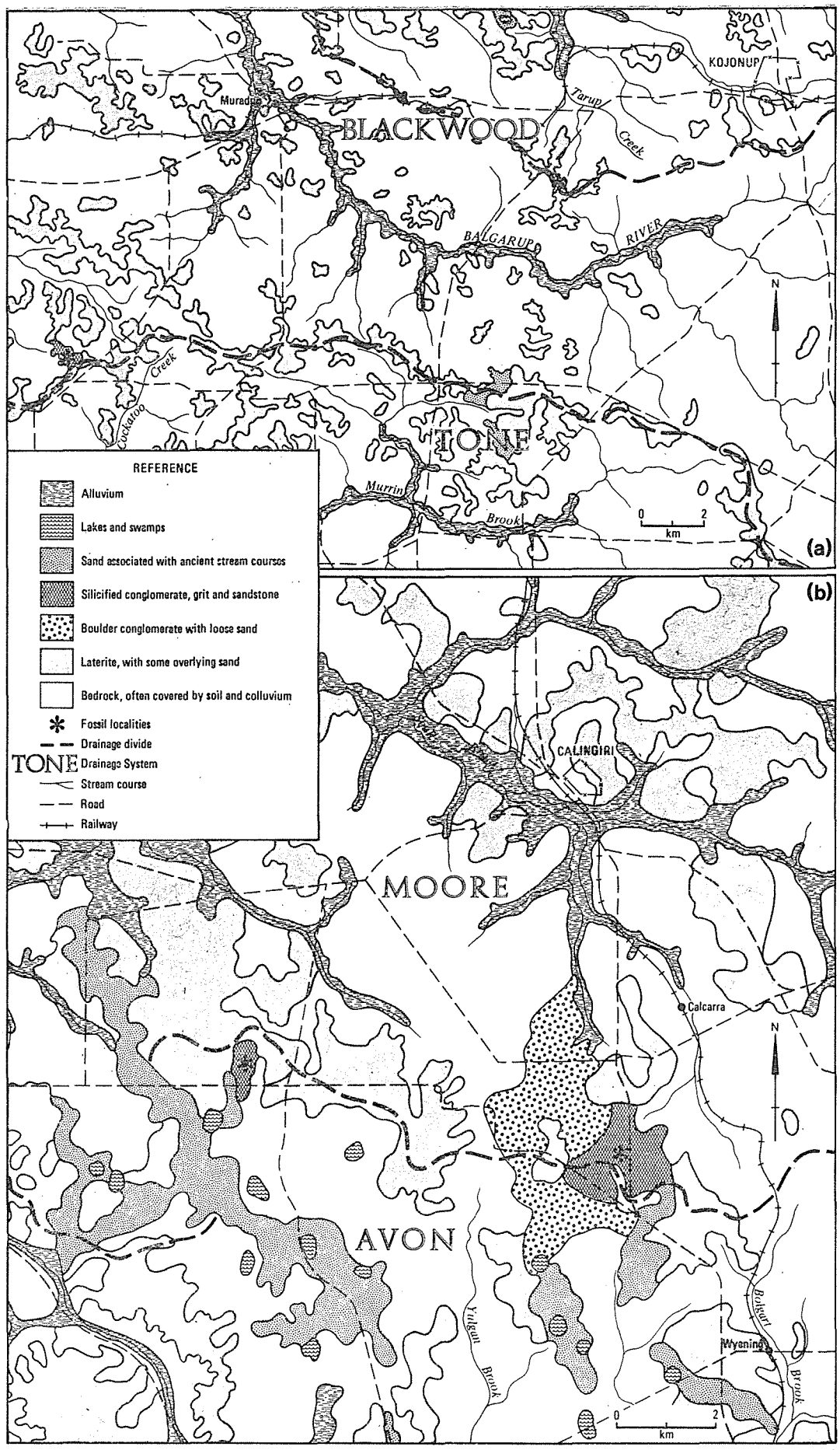

Figure 26. Location of fossiliferous deposits in (a) the Kojonup area and (b) the Calingiri area.

MURADUP LOCALITY

A small exposure of fossiliferous strata occurs on the property of "Na Laura", 10 km southwest of Muradup and 26 km west-southwest of Kojonup (Fig. 26a). A sequence of silicified grit and sandstone, about 3 m thick, directly overlies Archaean migmatite and is preserved on the drainage divide separating the Tone and Blackwood (Balgarup) river systems. The flat-lying strata crop out over an area of approximately 4 ha and are 310 m above sea level. The unit passes laterally into ferruginous duricrust, typical of the Darling Plateau.

The basal unit is a coarse-grained cemented grit that consists of angular to subangular grains of white quartz (3 mm average diameter) in a finer-grained matrix of subangular to subrounded quartz grains (0.2 mm average diameter) enclosed in a silica cement. A few larger fragments of feldspathic material are present. The rocks have a rather mottled appearance due to partial lateritization, which has mainly affected the matrix cement. A fine-grained, flaggy sandstone, identical to the main type at Kojonup, overlies the grit and is well exposed around it.

In contrast to the type section of the Kojonup Sandstone, abundant plant remains are preserved in the coarse-grained sediments at Muradup and are virtually absent in the sandstones. The flora consists of:—

Gymnospermae: *Araucaria* sp., *Podocarpus* sp., *?Sequoia* sp. Monocotyledonae; *?Typha* sp.

Dicotyledonae: *Nothofagus* sp., *Banksia* spp., *?Lomatia* sp., *?Eucalyptus* sp.

incerta sedis: *Phyllites yallournensis* Cookson and Duigan.

Several unidentified angiosperm leaves are also present, together with a number of fruiting bodies (Fig. 27). In addition, a nonmarine bivalve belonging to the family Unionidae occurs with the plant remains.

CALINGIRI LOCALITIES

Fossil plant remains were found at two localities near Calingiri (Fig. 26b). At 6 km due south of the townsite Wilde and Low (1975) described a "flaggy silcrete" deposit associated with sand rich in quartz cobbles. These deposits are 290 m above sea level and occur on the major drainage divide between the Moore, Avon and Mortlock river systems.

The deposits overlie metamorphic rocks of the Jimperding Metamorphic Belt (Wilde and Low, 1975). The boulder bed is presumed to underlie the subhorizontal "flaggy silcrete", since it occurs at a slightly lower topographic level. It contains well-rounded pebbles and boulders of white quartz and quartzite, up to 40 cm across, in a matrix of unconsolidated white sand. Rare pebbles of weathered dolerite are also present. The proportion of boulders to sand varies at the surface and there is some local cementation resulting from lateritization. The "flaggy silcrete" is essentially a silicified sandstone with units of silicified feldspathic grit. The deposit is poorly sorted and consists of rounded to angular fragments of quartz and altered feldspar up to 10 mm in diameter in a poorly sorted matrix of subrounded quartz grains (0.2 mm diameter) cemented with silica. Ripple-marked surfaces are present.

Plant remains occur within the flagstone, but are sparse. They consist of a few unidentified leaves scattered on the bedding surfaces and more numerous roots perpendicular to the bedding.

Fossil leaves are also present at Location 2807, 9 km southwest of Calingiri and 8 km west of the above locality (Fig. 26b). Specimens were previously deposited with the Western Australian Museum by Mr. A. J. Dean in 1967. The leaves are preserved in a fine-grained silicified sandstone, identical to deposits at Muradup and Kojonup. The sandstone crops out over 2 ha and is at the same height (290 m above sea level) as the adjacent laterite. The unit lies on the divide between the Moore and Avon drainage systems and the sandstone and laterite form part of the same surface that slopes rather steeply southward.

A small pocket within the sandstone, only a few square metres in area, contains an abundance of fossil leaves. They are less well preserved than at Kojonup or Muradup and can only be tentatively assigned to the angiosperm genera *Eucalyptus, Lomatia* and *Apocynophyllum* (Fig. 27).

REGIONAL SETTING

OTHER TERTIARY DEPOSITS IN SOUTHWESTERN AUSTRALIA

Tertiary fossils have been recorded from along the southwest coast of Australia and northward around the Stirling Range (the Plantagenet Group—Cockbain, 1968b), from Lake Cowan, near Norseman (the Eundynie Group—Cockbain, 1968a), from Coolgardie, 530 m east of Perth, (the Rollos Bore Beds—Balme and Churchill, 1959; Playford and others, 1975) and from Darkin Swamp, about 65 km east of Perth (Balme, pers. comm., 1976). Palaeontological evidence indicates an Eocene age for these deposits. The Kings Park Formation (Playford and others, 1975) is of Paleocene age and occurs near Perth in the subsurface of the Perth Basin.

The Eocene deposits consist of a variety of lithologies including sand, sandstone, siltstone, clay, lignite and spongolite, often overlying a basal conglomerate. The deposits at Coolgardie were laid down in a coastal lake or lagoon, whereas the sequences at Lake Cowan and near the present south coast are mainly beach and marine deposits. The foraminifers and nautiloids from the Plantagenet Group indicate warm, shallow seas with locally quiescent conditions to account for the spongolite and coastal lake or deltaic conditions for the formation of lignite. Fossil leaves are locally abundant, especially near the Stirling Range (Churchill, 1961; Western Australian Museum collection).

There are other deposits on the Darling Plateau of probable Tertiary age, but these are apparently devoid of fossils. The most extensive are the Nakina Formation, near Collie (Playford and others, 1975) formerly referred to as the "Collie Lake Beds" (Lord, 1952), and the "Old Alluvium" at Greenbushes (Hobson and Matheson, 1949). These deposits are lateritized and consist of clay, sand and grit horizons overlying a basal conglomerate. A number of conglomeratic deposits, also pre-dating laterite formation, occur on the Darling Plateau between Walyunga, 30 km northeast of Perth (Wilde and Low, 1975) and the south coast. Included in these are the deposits at Rolystone and Jarrahdale (Wilde, 1976), Harvey (Churchward and Bettenay, 1973) and Kirup (Finkl, 1971; Taylor, 1971) which have been considered either Tertiary (Playford and others, in press) or Mesozoic (Finkl, 1971; Churchward and Bettenay, 1973) in age.

GEOMORPHIC SETTING

The Darling Plateau has been extensively dissected by rejuvenation of the drainage. The "Meckering Line" (Mulcahy, 1967) represents the inland limit of rejuvenation, to the east of which is an ancient system of broad, sluggish drainage channels with salt lakes. Two stages of rejuvenation can be recognized west of the "Meckering Line" (Bettenay and Mulcahy, 1972); an early stage that resulted in the formation of broad, mature valley forms with well-developed, deep weathering profiles, and a later stage that produced more youthful valley forms, generally devoid of deep weathering profiles.

However, remnants of the old landscape, as recognized east of the "Meckering Line", are preserved locally along divides and major interfluves in the zone of rejuvenated drainage (Mulcahy and others, 1972; Bettenay and Mulcahy, 1972; Wilde, 1976). The oldest recognizable alluvial valley form is the Goonaping type valley (Mulcahy and others, 1972) which includes Darkin Swamp from which Eocene spores and pollen grains have been recorded (Balme, B. E., pers. comm., 1976). Fossil leaves were also reported from near Mount Kokeby (Feldtman, 1919) in another Goonaping type valley, although no specimens are available. These drainage deposits are thus of great antiquity and were laid down in channels that remained stable over a considerable period of time.

In several areas ribbons of reworked sands, accompanied by lakes and swamps, are associated with the Goonaping type valleys. These overlie, or form part of, the laterite plateau surface and appear to define old stream courses. In many remnant areas of the Darling Plateau, Goonaping type valleys are absent and only the ribbons of sand occur; this is true for the Calingiri localities (Fig. 26b). It is suggested that these sands may represent reworked Goonaping type material or, more likely, that they represent vestiges of an even older drainage system that may be equated with the sands occurring along divides and interfluves in the Bridgetown area and recognized as defining old stream courses (Finkl, 1971). The "Old Alluvium" at Greenbushes and most of the conglomeratic deposits on the Darling Plateau are also preserved along drainage divides.

CORRELATION AND PALAEOGEOGRAPHIC IMPLICATIONS

At least four species in the preserved flora from Muradup were also recorded by Churchill (1961) from the Kojonup Sandstone. The Muradup locality is 17 km west of the type section of the Kojonup Sandstone and both lie on the Blackwood watershed (Fig. 26a). The lithologies are also similar and the Muradup locality may be considered as part of the Kojonup Sandstone. Churchill (*in* McWhae and others, 1958) tentatively correlated the Kojonup Sandstone with the Eocene Plantagenet Group.

The fossil remains from Calingiri are less well preserved and cannot be identified with any certainty, partly due to the general lack of published information on Australian Tertiary floras. However, although they appear to differ somewhat from those in the Kojonup Sandstone, they occupy a similar geomorphic position, being preserved along a major watershed and forming part of the lateritized plateau surface. Local environmental differences and floral diversity in the Eocene (Churchill, 1973) similar to that in the present day Western Australian flora, could account for the differences at Calingiri. On the available evidence, the deposits at Calingiri are equated with the Kojonup Sandstone and are thus considered to be of Eocene age.

The discovery of a nonmarine unionid bivalve at Muradup confirms a fluviatile environment of deposition for the Kojonup Sandstone. The occurrence of Eocene deposits as far inland as Coolgardie and Calingiri indicates that the effects of the well-documented Eocene marine transgression were widespread over southwestern Australia. The change from freshwater coastal lake and fluviatile conditions at these localities to interdeveloped marine and non-marine sequences to the south suggests that there was an extensive drainage system developed on a land surface of low relief. This is also indicated by the shallow-water lithologies and fossil remains in the Plantagenet Group (Cockbain, 1968b). The Kojonup, Muradup and Calingiri localities are now about 300 m above present sea level and post-Eocene uplift of this order has been suggested (Churchill, 1973). Using the present 300 m contours, Churchill has shown that there would have been numerous islands bordering an irregular coastline with broad estuaries. Conditions were tropical, with possible development of mangrove swamps; mangrove pollen has been identified from the Plantagenet Group (Churchill, 1973).

It is significant that most of the Tertiary deposits in the southwestern Yilgarn Block are underlain by a basal conglomerate. Hobson and Matheson (1949) considered that the conglomerate at the base of the "Old Alluvium" at Greenbushes was a beach deposit. Although it cannot be proved at this stage that all the conglomerates represent beach deposits, it would seem likely that they formed as a result of the Eocene marine transgression.

Certain units that are older than the Goonaping type valleys, and which form part of the Darling Plateau, have previously been considered pre-Tertiary in age; these include the Harvey Beds (Churchward and Bettenay, 1973) and the Kirup Conglomerate (Finkl, 1971). However, the recognition of Eocene deposits in a similar geomorphic position at Muradup and Calingiri (and Kojonup) indicates that units forming part of the Darling Plateau are not necessarily pre-Tertiary.

ACKNOWLEDGEMENT

We wish to thank the Western Australian Museum for the loan of certain specimens pertinent to this study.

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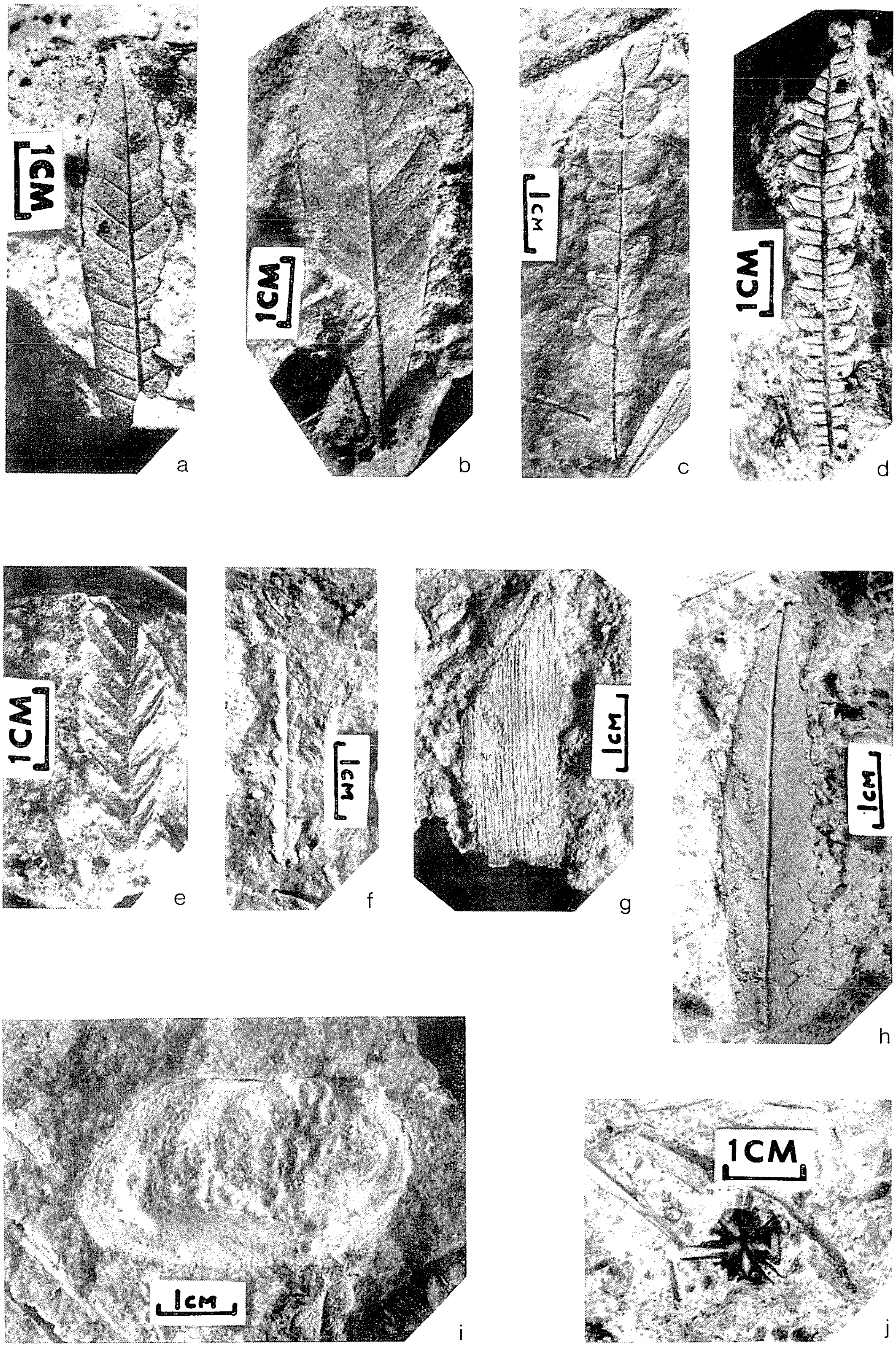
Figure 27. Fossils from Calingiri and Muradup. (a) *Apocynophyllum* sp., Calingiri, F 6420/b. (b) Angiosperm leaf, gen. and sp. indet., Calingiri, F 6420/a. (c) *Phyllites yallournensis* Cookson and Duigan, Muradup, F 9346/m. (d) *Banksia* sp., Muradup, F 9346/a. (e) *?Sequoia* sp., Muradup, F 9346/2. (f) *Banksia* sp., Muradup, F 9346/v. (g) *?Typha* sp., Muradup, F 9346/x. (h) Angiosperm leaf, gen. and sp. indet., Muradup, F 9346/q. (i) Unionid bivalve, Muradup, F 9346/w. (j) Fruiting body, Muradup, F 9346/l.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NEW AND REVISED DEFINITIONS OF ROCK UNITS IN THE WARRAWOONA GROUP, PILBARA BLOCK

by A. H. Hickman

ABSTRACT

Six Archaean formations, the North Star Basalt, the McPhee Formation, the Mount Ada Basalt, the Towers Formation, the Apex Basalt and the Euro Basalt are defined for the first time. The Marble Bar Chert Member is redefined as a member of the Towers Formation.

NEW ROCK UNITS

Table 8 compares the stratigraphic subdivision of the Warrawoona Group given by Lipple (1975, Table 9) with that now adopted. Table 9 presents formal definitions of the newly recognized rock units.

TABLE 8. STRATIGRAPHIC SUBDIVISION OF THE WARRAWOONA GROUP: NEW AND REVISED ROCK UNITS

	Lipple, 1975	Present subdivision	
Salgash Subgroup	Wyman Formation	Wyman Formation	
	Pillow basalt and chert	Euro Basalt	
	Panorama Formation	Panorama Formation	
	Pillow basalt and chert	Apex Basalt	
	Marble Bar Chert	Towers Formation	basalt and chert
			Marble Bar Chert Member
	Pillow basalt		basalt and chert
	Duffer Formation	Duffer Formation	
Talga Talga Subgroup	Basalt with subordinate ultramafic and chert units	Mount Ada Basalt	
		McPhee Formation	
		North Star Basalt	

REFERENCES

Lipple, S. L., 1975, Definitions of new and revised stratigraphic units of the eastern Pilbara Region: West. Australia Geol. Survey Ann. Rept 1974, p. 58-63.

TABLE 9. DEFINITIONS OF NEWLY RECOGNIZED ROCK UNITS

Name	Derivation of name	Distribution	Type section	Thickness and lithology
North Star Basalt	North Star mine (lat. 21°00′50″S, long. 119°49′30″E)	50 km² S and E of McPhee Reward mine (lat. 21°00′10″S, long. 119°49′30″E)	Along road from Great Northern Hwy to McPhee Reward mine	2 000 m. Massive and pillow basalt; local dolerite and gabbro; felsic lava (100 m) at top
McPhee Formation	McPhee Reward mine	Nimerry Creek (lat. 20°58′50″S, long. 119°58′10″E) to Pyramid Well (lat. 21°07′00″S, long. 119°47′20″E)	Gorge at McPhee Reward mine	50–200 m. Carbonate-quartz (±chlorite) schist and metasediments
Mount Ada Basalt	Mount Ada mine (lat. 21°25′40″S, long. 119°36′40″E)	100 km² NE and SW of McPhee Reward mine	NW of McPhee Reward mine	2 000–2 500 m. Massive and pillow basalt; minor chert and dolerite
Towers Formation	Towers mine (lat. 21°16′20″S, long. 119°47′40″E)	2 km² at Salgash mining centre (lat. 121°16′45″S, long. 119°47′35″E)	Towers mine. Good exposures at Marble Bar Pool (lat. 20°11′00″S, long, 119°42′40″E)	500 m. Three chert members separated by basalt, felsic lava and minor ultramafic rock
Apex Basalt	Apex mine (lat. 21°16′20″S, long. 119°48′00″E)	25 km² S of Salgash mining centre	Chinaman Creek W from Marble Bar Pool	1 500–2 000m. Pillow basalt and local high-magnesia basalt
Euro Basalt	Euro mine (lat. 21°17′50″S, long. 119°48′15″E)	10 km² SW of Euro mine	SW of Euro mine	2 000 m. Pillow basalt; minor chert and felsic lava
Marble Bar Chert Member	The Marble Bar at Marble Bar Pool	The Marble Bar	Marble Bar Pool	100 m. Red and white and grey and white banded chert

STRATIGRAPHIC RELATIONS OF ROCKS WITHIN THE WHIM CREEK BELT

by A. H. Hickman

ABSTRACT

The Whim Creek Group is a late Archaean succession of relatively undeformed volcanic and sedimentary rocks about 1 km in thickness. Two formations, the Mallina Formation and the Constantine Sandstone, included in the group by Fitton and others (1975), are now assigned to the Gorge Creek Group. The slate at Whim Creek copper mine overlies the Mons Cupri Volcanics whereas the Mallina Formation underlies this unit. A regional unconformity, said by Fitton and others to separate Upper from Lower Archaean rocks in the Pilbara Block, is not substantiated.

INTRODUCTION

Between the Sherlock River and Mount Negri in the western part of the Pilbara Block a northeast-trending belt of Archaean volcanic rocks flanks the southeastern margin of the Caines Well Granite (Fitton and others, 1975). These rocks occupy a synclinal structural unit, here referred to as the Whim Creek Belt, which is 80 km long and, over the greater part of this distance, about 5 to 10 km wide. Previous geological investigation of the area has been largely concentrated on mineralized rocks in the vicinity of Whim Creek copper mine. Accounts of this part of the belt are given by Blatchford (1921), Finucane and Sullivan (1939), Low (1963), Miller and Gair (1975) and Reynolds and others (1975).

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The purpose of this paper is to examine the stratigraphic affinities of the rocks within the Whim Creek Belt. In this context, previous relevant publications are those by Woodward (1911), Low (1963), Ryan and Kriewaldt (1964), Ryan (1965), Fitton and others (1975) and Miller (1975).

Woodward (1911), on a geological sketch map of Western Australia, shows the Whim Creek Belt as composed of "metamorphic greenstones" older than the "Nullagine Series" (said to be Palaeozoic). Low (1963, p. 57) states that rocks in the Whim Creek area include sandstone, grit and slate with interbedded felsic lava, tuff and volcanic agglomerate, "rather strongly resembling Nullagine Rocks". Workers prior to Low had differed on the age of the succession: Blatchford (1921) favoured a correlation with rocks now termed Proterozoic, but Finucane and Sullivan (1939) thought the slate at Whim Creek was probably of "Mosquito Creek Series" age (Archaean).

Ryan and Kriewaldt (1964) describe facies changes in the Archaean of the west Pilbara. At Whim Creek a volcanic facies is said to pass laterally southeastwards into a sedimentary facies, the latter being deposited in a relatively unstable trough. In 1965 Ryan correlated rocks of the Whim Creek area with the "Warrawoona Succession" of the east Pilbara and regarded them as entirely older than the "Mosquito Creek Succession". Ryan adds, however, that "The sandstone succession at Mt. Constantine is overlain to the north by shale" (now correlated with Mosquito Creek Formation) "which is in turn overlain by volcanic rocks in the syncline southwest of Whim Creek".

Miller (1975) includes Ryan and Kriewaldt's trough of sedimentation within the "Pilbara eugeosyncline". The volcanic rocks of the west Pilbara are described as being of volcanic arc origin while the sediments are said to have been deposited in a trench. Whim Creek is positioned on the northern margin of the trench.

Fitton and others (1975) present a 1:250 000 stratigraphic map covering much of the west Pilbara and revise the area's stratigraphic succession. Earlier correlations between the western and eastern parts of the Pilbara Block (Ryan, 1965) are abandoned, chiefly because of Fitton's findings in the area around the Pilbara mining centre. Here, the "sedimentary succession" of Ryan's "Roebourne Group" is now mapped as *overlying* the "volcanic succession". This discovery dispenses with the need to envisage rapid lateral facies changes between the thick Archaean volcanic and sedimentary successions of the east and west Pilbara.

The recognition by Fitton and others (1975) that the Archaean stratigraphic succession of the west Pilbara is similar to that previously established in the east Pilbara (Hickman and Lipple, 1975) is an important contribution to our knowledge of Pilbara Block stratigraphy. The authors state, however, that the main purpose of their paper is "to describe a regional unconformity in the Archaean and to draw attention to a large complex of layered basic sills that essentially hugs the unconformity". Fitton and others (1975) interpret the regional unconformity as marking a major hiatus in deposition, and use it to separate "Lower" from "Upper" Archaean rocks. The rocks of the Whim Creek Belt belong entirely to their Upper Archaean and part of the evidence for the unconformity is drawn from this area.

STRATIGRAPHY

Most of the Archaean stratigraphic units named on Figure 28 were originally defined by Fitton and others (1975). The sequence indicated on the reference panel of the figure differs from that presented by Fitton in several important respects (Table 10). In particular, it will be noted that the present interpretation places the Mallina Formation and the Constantine Sandstone below the mid-Archaean "regional unconformity" of Fitton and others (1975) and assigns these formations to the Gorge Creek Group rather than the Whim Creek Group. The stratigraphic relationships of *Abu* (Fig. 28) are also discussed below.

TABLE 10. ARCHAEAN STRATIGRAPHIC SUCCESSION OF THE WHIM CREEK BELT

Fitton and others, 1975		This paper	
	Negri Volcanics: mainly terrestrial basic to acidic lavas including spinifex-textured basic rocks. Fine-grained sediments and local conglomerates towards top.		*Negri Volcanics:* variolitic and vesicular basalt. Includes sediments southwest of Mons Cupri.
			Unconformity
			Quench-textured basalt, high magnesia basalt, with gabbroic and ultramafic sills.
			Relations uncertain
			Silicified and epidotized basalt. Local felsic lava. Slate, 2 m thick, near base.
Local unconformity		Unconformity	
WHIM CREEK GROUP	*Mallina Formation*	WHIM CREEK GROUP	Slate Tuff, well-bedded Slate (e.g., at Whim Creek) Local conglomerate
	Constantine Sandstone		
	Mons Cupri Volcanics: Tuff and sediment. Agglomerate. Mount Brown Rhyolite Member. Felsic lava and tuff.		*Mons Cupri Volcanics:* Agglomerate and tuff. Mount Brown Rhyolite Member
	Warambie Basalt		*Warambie Basalt*
Regional unconformity		Unconformity	
GORGE CREEK GROUP	Banded iron-formation, chert, quartzite and shale.	GORGE CREEK GROUP	*Mallina Formation* *Constantine Sandstone* Banded iron-formation.

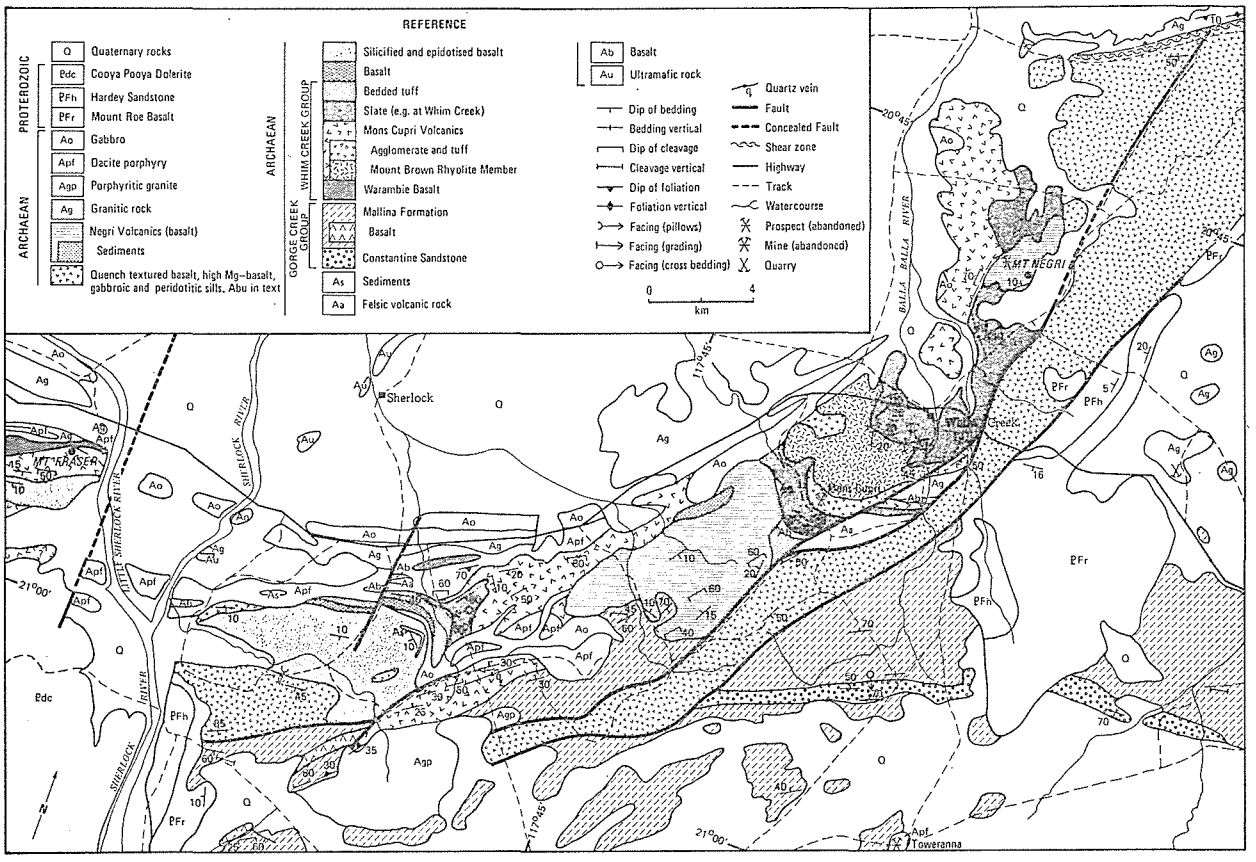

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Figure 28. Geological map of the Whim Creek area.

MALLINA FORMATION AND WHIM CREEK GROUP

The Mallina Formation (Fitton and others, 1975) is a thick succession of psammitic to pelitic rocks which are probably chiefly of turbiditic origin. As noted by various workers the unit is lithologically very similar to the Mosquito Creek Formation of the east Pilbara.

Fitton and others (1975) correlate the Mallina Formation with the slate at Whim Creek mine, but no reasons are given for this interpretation. Certainly the slate at Whim Creek lithologically resembles more pelitic parts of the Mallina Formation, but several stratigraphic problems are raised by the correlation. Firstly, the Constantine Sandstone is absent at Whim Creek, yet elsewhere in the Pilbara it is generally thickly developed below the Mallina Formation. Secondly, the Warambie Basalt and Mons Cupri Volcanics are absent beneath the Constantine Sandstone in other areas of the Pilbara. Thirdly, the slate at Whim Creek is only about 100 m thick, contains thin volcanic units and is overlain by tuff and lava, whereas the Mallina Formation is between 2.5 km (Fitton and others, 1975) and 15 km (Miller, 1975) thick and virtually devoid of volcanic intercalations.

The slate at Whim Creek *overlies* the Mons Cupri Volcanics, but the writer's mapping (Fig. 28) 15 km southeast of Sherlock indicates that the Mallina Formation *underlies* the Mons Cupri Volcanics, both formations dipping northwest at approximately 30°.

REGIONAL MID-ARCHAEAN UNCONFORMITY

One of the five localities in the Pilbara where Fitton and others state that the regional unconformity can be observed lies 2 km outside the western margin of Figure 28. Here, on a road from the North West Coastal Highway to Pyramid Station about 3 km south of the highway, the Warambie Basalt is said to unconformably overlie steeply inclined metabasalt of the Teichmans Group (equivalent to the Warrawoona Group).

An unconformity does exist at this point but its regional extent cannot be ascertained. Bedding attitudes within the Whim Creek Group range up to about 30° and, apart from being cleaved, the succession is relatively underformed. In view of the prevalence of dips greater than 45° in rocks of the Warrawoona and Gorge Creek Groups over most of the Pilbara, it seems probable that deposition of the Whim Creek Group followed a period in which the older Archaean rocks were considerably deformed. Thus an unconformity may be accepted between the Gorge Creek Group and the Whim Greek Group, but it is emphasized that the Constantine Sandstone and the Mallina Formation do not belong to the Whim Creek Group. Consequently the unconformity beneath the Warambie Basalt cannot be equated to unconformities beneath the Mallina Formation.

Whether or not a regional unconformity exists within the Gorge Greek Group or between this unit and the Warrawoona Group is a question beyond the scope of this paper. The writer expresses the opinion, however, that such a regional hiatus is not present. Local unconformities and disconformities exist at all levels of the Archaean layered succession but a single break, separating one group of older rocks from another group of younger, has not been recognized.

The succession of the Whim Creek Group is not repeated elsewhere in the Pilbara. Not only is its outcrop of small areal extent but its thickness is no more than 1 km (the average combined thickness of the Gorge Creek and Warrawoona Groups exceeds 20 km). Geochronology carried out by G. C. Sylvester (in press) indicates that intrusive rocks of the Mons Cupri area are between 2.7 and 2.4 b.y. old.

NEGRI VOLCANICS AND HIGH MAGNESIAN BASALT

As can be seen from Figure 28 the most extensive volcanic unit of the Whim Creek Belt is that labelled *Abu*. Fitton and others (1975) include this sequence of quench-textured mafic and ultramafic rocks within the Negri Volcanics. Mount Negri, situated about 6 km north of Whim Creek, is composed of subhorizontal flows of variolitic basalt. To the north and east of the hill are large outcrops of lithologically different basalt. Much of this basalt is

extremely fine grained and fractures conchoidally. At first sight it appears siliceous, but the rock has a high specific gravity and commonly exhibits a fine spinifex texture. Other parts of the sequence include more coarsely spinifex-textured varieties, pillowed ultramafic flows and stratiform bodies (interpreted as sills) of gabbroic and ultramafic rocks. The rocks are typically massive, but pillowed units and spinifex zones show that dips are moderate south of Whim Creek and near the Sherlock River. The lithological differences between the variolitic basalt of Mount Negri and *Abu*, combined with the presence of consistently steeper dips in the latter, indicate that the two units are not conformable.

As can be seen from Figure 28, contacts between *Abu* and other rocks of the area are generally faulted. Near Sherlock River relations to *Ax* are uncertain because of incomplete exposure and a general absence of well-defined bedding planes. Approximately 20 km southwest of Roebourne rocks similar to *Abu* form part of the Teichmans Group, so that the unit may be older than the Whim Creek Group.

If *Abu* does not belong to the Negri Volcanics the relationship between the latter and the Fortescue Group cannot be directly demonstrated. Field evidence that the Whim Creek Group is Archaean rather that Proterozoic also becomes limited to an unconformable relationship between the Mount Roe Basalt and the Warambie Basalt near Warambie.

STRUCTURE

The Whim Creek Belt is bounded by major faults and, on the basis of stratigraphy, would appear to be a graben. Within the confines of these faults the Whim Creek Group is folded gently about northeast-trending axes. The folds plunge northeast and southwest, possibly because of open cross-folding, although this is uncertain. Miller and Gair (1975) recognize an east-trending anticline between Mons Cupri and Whim Creek.

A steep axial plane cleavage strikes northeast along the length of the belt, and affects all rocks, including the Negri Volcanics. At Whim Creek this cleavage is a true slaty cleavage inclined southeastwards at about 30° to 40° and is crenulated by a later nonpenetrative cleavage striking northwest. Kink bands which deform the slaty cleavage resemble D3 structures in the east Pilbara (Hickman, 1975).

CONCLUSIONS

The Whim Creek Group is a late Archaean volcanic sequence, relatively thin compared to the rest of the Archaean succession and of limited areal extent. The mid-Archaean regional unconformity recognized by Fitton and others (1975) has not been substantiated by regional geological mapping carried out by the Geological Survey of Western Australia. The Mallina Formation and Constantine Sandstone, placed by Fitton and others (1975) in the Whim Creek Group, belong to the Gorge Creek Group.

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GEOCHRONOLOGICAL DATA CONCERNING THE EASTERN EXTENT OF THE PILBARA BLOCK

by J. R. de Laeter,* A. H. Hickman, A. F. Trendall, and J. D. Lewis

ABSTRACT

The Pilbara Block, in the northwest part of Western Australia, is the smaller of the two major Archaean cratonic areas of the State. The bulk of its granitic rocks have Rb-Sr isochron ages of about 3.0 b.y., with initial $^{87}Sr/^{86}Sr$ ratios (R_i) of about 0.702. In the eastern part of the block post-tectonic "younger" granites, 2.7-2.6 b.y. old with an R_i about 0.73, intrude the older granites and are thought to be derived anatectically from them. Rb-Sr data are reported from three rock bodies spaced along an east-west transect across the largely obscured eastern edge of the block. At the eastern end of the transect the Mount Crofton Granite, which intrudes folded Proterozoic sediments of the Yeneena Group, has a concordant total-rock and biotite age close to 600 m.y.; the R_i of about 0.71 indicates that it cannot have been derived by melting of underlying Archaean granitic crust. At the western end of the transect the Cookes Creek Granite gives a broadly concordant total-rock and biotite age of 2.6 b.y. with an R_i of about 0.73; in both respects, and in other features, it belongs with other younger granites of the Pilbara Block. Between these, in the centre of the transect, granites with a pervasive cataclastic foliation in the southern part of the Gregory Granitic Complex, in the vicinity of Lookout Rocks, give a well-defined 2.65 b.y. total-rock isochron, with an R_i of about 0.71; discordant biotites give an age of 1.2 b.y. Geological and previous Rb-Sr evidence argue that the foliation cannot be older than 2.4-2.2 b.y., so that the total-rock age has survived its imposition. The biotite age may record either the age of the foliation or of a later event. The comparatively low R_i at Lookout Rocks suggests that between this area and the Cookes Creek Granite lies the eastern edge of the older granitic crust of the Pilbara Block.

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INTRODUCTION

The Pilbara Block is an area of Archaean rocks covering about 56 000 km² of the northwest part of Western Australia, between approximate latitudes 20° and 22°S and longitudes 116° and 121° E; it has a crudely triangular shape, with a short eastern side running north-south and longer north and south sides converging towards a western apex. The Archaean age of two generations of granite within it is established by Rb-Sr ages of 2 951 and 2 606 m.y., reported by de Laeter and others (1975) and by a similar range of Pb-Pb ages reported by Oversby (1976). Ages for the older granites, of 3 050 m.y. and 3 125 m.y., reported by Compston and Arriens (1968) and de Laeter and Blockley (1972) respectively, have wide uncertainty limits which include the more reliable ages already noted.

The northern boundary of the Pilbara Block is formed either by the Indian Ocean coastline or by overlying Phanerozoic sediments of the Canning Basin. The southern margin is defined by the unconformable base of the Proterozoic Fortescue Group, of the Hamersley Basin. On the most recent edition of the State geological map (G.S.W.A. 1973), and in a recent formal representation of Precambrian subdivisions (G.S.W.A., 1975, p. 29), the eastern edge of the Pilbara Block is shown as a continuation of the same unconformity, following an irregular north-south course within the rough longitude limits 120°20′-40′E. However, Hickman (1975a), after remapping of the Nullagine 1:250 000 Sheet area, which covers much of the relevant ground, shows a narrow north-south belt of Archaean and Proterozoic granitic rocks some 50-70 km farther east, and isolated from the main mass of the Pilbara Block by Fortescue Group and younger rocks. This roughly 10-km wide belt of granitic and related rocks, called by Hickman (1975a, b) the Gregory Granitic Complex, extends for nearly 100 km from the Yarrie Sheet area in the north to the Balfour Downs Sheet area in the south. On the earlier edition of the Nullagine Sheet (Noldart and Wyatt, 1962) this belt was included within the "Gregory Range Granite", and was regarded as Proterozoic. It was also mapped as Proterozoic on the Balfour Downs Sheet (de la Hunty, 1964).

Remapping of the Nullagine Sheet revealed that a large part of the "Gregory Range Granite" was composed of felsic lava, now named the Koongaling Volcanics, apparently belonging to the Fortescue Group. The remainder was found to include granophyre and several different types of granitic rock. Each of these various types is broadly restricted to a particular part of the belt, suggesting that either they represent distinct zones within a heterogeneous intrusion or they form individual plutons. Because mapping did not establish which of these alternative explanations was correct Hickman (1975a) introduced the term Gregory Granitic Complex to include the granophyre and all the granitic rocks.

The map appearing as Figure 29 illustrates the disposition of the rock units referred to above, and includes further information, dealt with subsequently. Blockley and de la Hunty's (1975, p. 115-6) account of the components of the "Gregory Range Granite", was compiled from the best information available in 1971, and is superseded by later parts of this paper.

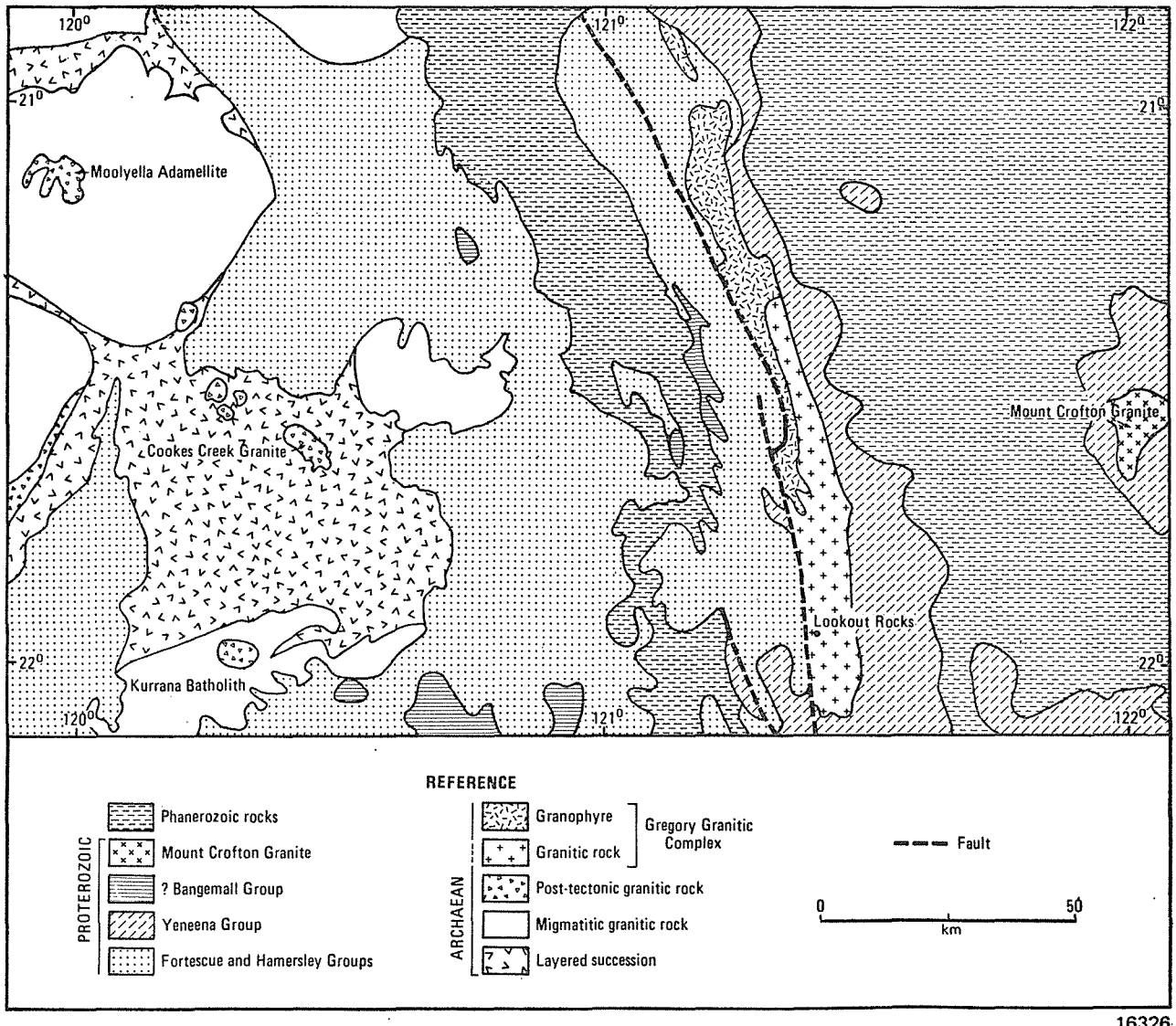

Figure 29. Simplified geological map of the eastern marginal area of the Pilbara Block.

Hickman (1975a) did not provide explicit reasons for assigning an Archaean age to the granitic rocks of the complex, but gave the southern part the same lithological description as sheared granite and adamellite of the Kurrana Batholith (Fig. 29), a unit forming part of the Pilbara Block and known to be of Archaean age. Considerations not mentioned were the fact that the granophyre (regarded as a feeder of the Koongaling Volcanics) is generally far less deformed than the granitic rocks in the south, and also that the granitic rocks do not intrude or visibly metamorphose the Fortescue Group. He was also aware of the preliminary isotopic data mentioned by Blockley and de la Hunty (1975, p. 115) which, though of uncertain significance because of sampling problems, did indicate that at least part of the complex might be Archaean.

In 1975, as now, the only unequivocal geological evidence for the age of the rocks was that on the eastern side they are unconformably overlain by gently dipping sandstone of Lower or Middle Proterozoic age (Yeneena Group, Williams and others, 1976). On the western side, the contact between the complex and the Fortescue Group is tectonic in the south and tectonic or gradational (granophyre-Koongaling Volcanics contact) in the north.

The purposes of this paper are to record Rb-Sr whole-rock and mineral analyses of rocks from the southern part of the Gregory Granitic Complex which confirm their age as Archaean, to report additional Rb-Sr data from other rock units to the east and west, and to discuss the implications of all the data for regional geological history.

EXPERIMENTAL PROCEDURE

The experimental procedure for Rb-Sr analyses used in this laboratory are essentially the same as those described by Lewis and others (1975) and de Laeter and Abercrombie (1970).

The value of $^{87}Sr/^{86}Sr$ for the NBS 967 standard measure during this project was $0.710\,2 \pm 0.000\,1$, normalised to a $^{88}Sr/^{86}Sr$ value of 8.375 2. The value of 1.39×10^{-11} yr^{-1} was used for the decay constant of ^{87}Rb. The measured Rb/Sr and $^{87}Sr/^{86}Sr$ ratios, as well as the calculated $^{87}Rb/^{86}Sr$ ratios are given in Tables 12-14. Errors accompanying the data are at the 95 per cent confidence level. Regression analyses of the data were carried out using the least squares programme of McIntyre and others (1966).

COOKES CREEK GRANITE

GEOLOGICAL RELATIONSHIPS

The position of the Cookes Creek Granite (Noldart, 1960, p. 141) is shown on Figure 29. It crops out over 40 km^2 at the junction of Cookes Creek with the Nullagine River, about 45 km northeast of Nullagine.

The granite is a stock intruded into Archaean basaltic rocks of the Warrawoona Group (Hickman, 1975a). Its margins are irregular and discordant to the bedding of the greenstones, and appear to be intrusive on all sides. The enveloping greenstones are not visibly disrupted by the intrusion, indicating that emplacement was passive. At the southeastern contact of the mass, dykes of granitic rock intrude adjacent sandstone, gabbro and ultramafic rock. Sandstone near the contact is spotted and extensively recrystallized, apparently due to contact metamorphism. Granitic rock next to the contact contains about 70 per cent quartz and is rich in aluminous minerals. The main body of the stock is a poorly foliated or nonfoliated, coarse to medium-grained granite or adamellite. In places it is porphyritic and a cataclastic foliation is developed near minor faults. Faults and joints are a conspicuous feature of the stock, and, because the topography is rugged and the exposure good, these appear as well-defined lineaments on aerial photographs. Faults and joints trending north are offset by faults striking at 100°. Another set of lineaments, commonly intruded by quartz, trends north-northwest. Some of the quartz veins contain fluorite and barite, and at the Cookes Creek mining centre others have been worked for wolframite and scheelite.

Hickman (1975b) notes that the Cookes Creek Granite intrudes the core of a syncline, and interprets it as a post-tectonic intrusion, similar in many respects to the "tin granites" of the Pilbara Block. One of these, the Moolyella Adamellite (shown on Fig. 29), was dated by de Laeter and Blockley (1972) at 2 670 ± 95 m.y.

MATERIAL ANALYSED

Five samples (18415, 16, 17A, 17B, 18) collected from a restricted area near where the track from Mosquito Creek crosses Cookes Creek (lat. 21°37′52″S, long. 120°26′17″E) were analysed. Samples 18417A, 17B, and 18 were collected from the creek bed, no more than 30 m apart; 18415 and 16 come from an excavation close to the track about 150 m south of the crossing. They include equigranular and porphyritic varieties.

Sample 18417A is an equigranular coarse-grained adamellite containing masses of anhedral quartz up to 6 mm across, smaller subhedral to anhedral prisms of albite (An_5) and plentiful interstitial microcline. Minor biotite has been entirely chloritized and the albite is slightly sericitized. The chlorite is associated with accessory zircon and secondary sphene and fluorite. Fluorite also occurs, with a little carbonate, in minor fractures and shears within the rock. Specimen 18415 is a leucocratic variety with prominent mylonitic zones, apparent only in thin section, in which small masses of fluorite are developed. Sample 18417B is a medium-grained, leucocratic aplite similar in mineralogy to 18417A.

Sample 18418 is a porphyritic adamellite containing subhedral phenocrysts of perthitic microcline up to 2 cm long, subhedral to anhedral oligoclase (An_{25}) prisms, interstitial quartz and minor green biotite. Accessory apatite, zircon, sphene, epidote, and metamict allanite are present. The sphene contains metamict zones and is a pale brown low birefringence variety. Minor secondary fluorite is associated with the biotite.

Specimen 18416 was collected from a dyke-like pod and consists of a mass of pale bleached biotite with lesser microcline and fluorite. A little quartz is present, along with accessory zircon and secondary rutile.

Chemical compositions of the two main granite types are given in Table 11.

TABLE 11. CHEMICAL COMPOSITION OF THE COOKES CREEK GRANITE

	18417A	18418
SiO_2	76·3	71·2
Al_2O_3	12·1	13·9
Fe_2O_3	0·4	1·0
FeO	1·51	2·75
MgO	0·00	0·5
CaO	0·51	1·79
Na_2O	3·72	3·88
K_2O	4·3	4·4
H_2O^+	0·77	0·80
H_2O^-	0·10	0·13
CO_2	0·19	0·07
TiO_2	0·17	0·49
P_2O_5	0·02	0·11
MnO	0·04	0·06
Total	100·1	101·0
Trace elements (ppm)		
Li	50	170
Ba	170	580
Rb	420	355
Sr	40	120
Sn	10	5
Zr	130	190
U	3	4
F	2 240	1 880

Analyst: N. Marsh, West. Australia Government Chemical Laboratories.

TABLE 12. ANALYTICAL DATA FOR FIVE TOTAL-ROCK SAMPLES AND TWO BIOTITE CONCENTRATES FROM THE COOKES CREEK GRANITE

Sample	Rb (ppm)	Sr (ppm)	Rb/Sr	$^{87}Rb/^{86}Sr$	$Sr^{87}/^{86}Sr$
Total rocks					
18418	360	110	3·25 ± 0·03	9·7 ± 0·1	1·084 1 ± 0·001 1
18417A	418	31	13·5 ± 0·1	45·2 ± 0·5	2·341 1 ± 0·002 3
18415	495	23	21·1 ± 0·2	74·8 ± 0·7	3·017 2 ± 0·001 0
18417B	490	14	35·1 ± 0·3	161 ± 1	6·768 ± 0·008
18416	2 600	40	65·6 ± 0·6	561 ± 5	20·78 ± 0·04
Biotites					
18418	1 650	21	78 ± 2	526 ± 8	14·380 ± 0·014
18416	3 000	37	81 ± 2	1 640 ± 20	62·051 ± 0·062

RESULTS

The data from the five total rocks and from biotite fractions separated from two of them appear in Table 12, and are displayed in Figure 30. It is clear from inspection that 18415 falls below a line well defined by the remaining four total-rock samples. These yield a Model 1 isochron of 2 568 ± 37 m.y. with an initial $^{87}Sr/^{86}Sr$ ratio (R_i) of 0.730 7 ± 0.009 7. This age and R_i are closely controlled by samples 18416 and 18418 respectively.

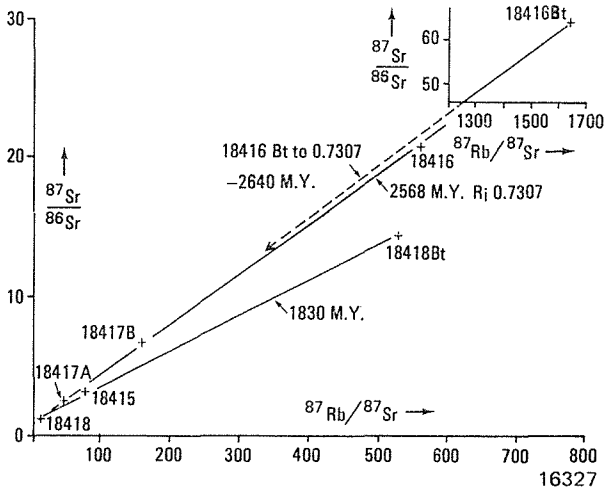

Figure 30. Isochron diagram of five total–rock samples from the Cookes Creek Granite and of biotites concentrated from two of them. The 1 830 m.y. line joins total rock 18418 with its separated biotite. The crosses marking analyses are symbolic only, and do *not* represent error limits.

The separated biotite 18416 yields an age of 2 700 m.y. when joined to its total-rock point, but this figure implies an impossible, negative, R_i. The biotite was separated from a different part of the sample from that used for the total-rock analysis, and this anomalous result can only be accounted for by slight inhomogeneity within the sample. We know of no mechanism whereby granite biotite can acquire an anomalously high Rb-Sr age, and conclude that the real age of the granite probably lies within both the error limits of the total-rock age and those of a model age for the biotite which accepts the computed R_i. These limits, an upper of 2 605 m.y. for the total-rock isochron, and a lower of 2 607 m.y. for the biotite, marginally fail to overlap, but this margin is trivial, and for purposes of later discussion we refer to this granite as showing a concordant total-rock and biotite age of about 2 600 m.y.

The green biotite in sample 18418 clearly records a discordant age of 1 830 m.y., and it may be that the position of the mylonitic rock 18415, which records a model age (R_i 0.73) of 2 170 m.y. reflects a partial response to this event.

GREGORY GRANITIC COMPLEX

GEOLOGICAL RELATIONSHIPS

The background to the introduction of the name Gregory Granitic Complex by Hickman (1975a) has already been given above; the complex includes both granophyre and granitic rocks and is shown in Figure 29. We are concerned here with the geological relationships only of that part of the complex in the Lookout Rocks area, from which the analysed samples were collected.

This part of the complex contains schistose to well-foliated granite and adamellite. On the west side these granitic rocks are separated from lava and sedimentary rocks of the Forescue Group by a major north-striking fault filled with quartz. On the east side they are unconformably overlain by gently east-dipping sandstone of the Yeneena Group, and to the north a foliated hornblende granite is exposed. In the field this rock is distinct from the foliated granite of the Lookout Rocks area; it is finer grained, more massive, and spotted with hornblende. The granite and adamellite of the Lookout Rocks area is locally flaggy, and in such cases primary igneous textures have been destroyed by shear. This tectonic foliation (S5) strikes north-northwest, and dips steeply southwestwards or northeastwards in the western part of the complex and gently westwards or sub-horizontally in the eastern part. A structural interpretation (Hickman, 1975a, Fig. 3) equates a north-northwest-trending anticlinal fold of S5 with folds of similar orientation which affect rocks of the Yeneena Group to the east. The S5 foliation in the granitic rocks is also correlated with an axial plane cleavage related to upright tight-to-isoclinal folds in the Fortescue Group immediately west of the complex. This correlation is based on similarity of orientation and on photo-interpretation. No locality affords a well-exposed, non-tectonic contact between the Fortescue Group and the granitic rocks.

The lithological similarity between the granite at Lookout Rocks and the granite and adamellite of the Kurrana Batholith has already been noted. Bouguer anomaly patterns (Hickman, 1975a, Fig. 6) do not rule out the possibility that the two masses are continuous at depth beneath the Fortescue Group. The strong tectonic foliation of the Kurrana Batholith is clearly Archaean in age, however; since it is unconformably overlain by the Fortescue Group.

MATERIAL ANALYSED

Twelve total-rock samples were analysed, together with separated biotites from two of these. Nine of these samples, collected by two of us in 1976 specifically for geochronology, came from two sampling points, situated respectively 1.8 km on a bearing of 328° from Lookout Rocks (45756A-E) and 1.6 km on a bearing of 342° from Lookout Rocks (45757A-D). The remaining three samples include one (13891) collected by H.W.B. Talbot (1920, pp. 129 and 187) in 1914 about 1 km due north of Lookout Rocks and two samples (16446, 7) collected by J. G. Blockley in 1969, respectively 9.0 and 10.6 km from Lookout Rocks on a bearing of 170°.

Samples 45756A-E were spaced at roughly equal intervals over an east-west distance of about 150 m along the crest of a low ridge. A, B, D, and E have an identical macroscopic appearance; they are fresh, coarse, pink, gneissic granites in which the thin dark streaks of biotite and hornblende which define the foliation enclose feldspars

about 1 cm in diameter. Sample 45756C is a finer-grained and more massive, darker pink, rock in which the feldspars do not exceed a diameter of 2-3 mm. Samples 45757A-D come from about 1 km farther east, at the south foot of the same ridge, and have a maximum separation of 50 m. A and B are almost identical in appearance to 45756A, B, D and E, but more strongly foliated. Sample 45757C was taken from a very strongly sheared band about a metre wide within this granite, in which its components have apparently been ground to form a black streaky mylonite. Sample 45757D forms a halfway stage between C and the gneissic granite of A and B; it is an augen gneiss in which the dark streaks of mylonitised material enclose remnants of granitic material.

Along the whole ridge including the 45756 and 45757 sampling points, the foliation of the gneissic granite and of its mylonitic derivatives maintains a very consistent direction, striking 320-325° and dipping at about 80° eastwards.

In thin section this foliation, the S5 of Hickman (1975a, b), dominates the general appearance of the rocks. Mineralogically, and in initial texture, all these rocks were clearly granites, with patches of coarse quartz mosaic, and anhedral potassic feldspars and sodic plagioclases about 5 mm across forming the main components; less abundant biotite and hornblende were supplemented by accessory sphene, apatite, zircon, fluorite and opaques.

But the post-crystallization imposition of the strong foliation has been accompanied in all these rocks, including the more massive 45756C, by strong cataclastic deformation of all the major minerals. The quartz is streaked out into complex wisps and ribbons, and the feldspars are broken down into smaller grains, in which the twin laminae are kinked or bent. Even the biotite is strongly broken and twisted, and has not since recrystallized. It is clear that the development of the foliation has been associated with an intense and penetrative late cataclasis.

Samples 13891, 16446, and 16447 are coarse pink foliated granites closely similar to the 45756-7 samples in macroscopic appearance, mineralogy, and in the association, beneath the microscope, of the foliation with pervasive cataclasis.

RESULTS

The data from the 12 total-rock samples analysed, and from biotite fractions separated from two of them, appear in Table 13 and are also displayed in Figure 31. The total-rock data are well aligned on a Model 3 isochron of 2 651 ± 60 m.y.; the two biotites, when joined with their parent rocks, give closely similar ages with a mean near 1 200 m.y.

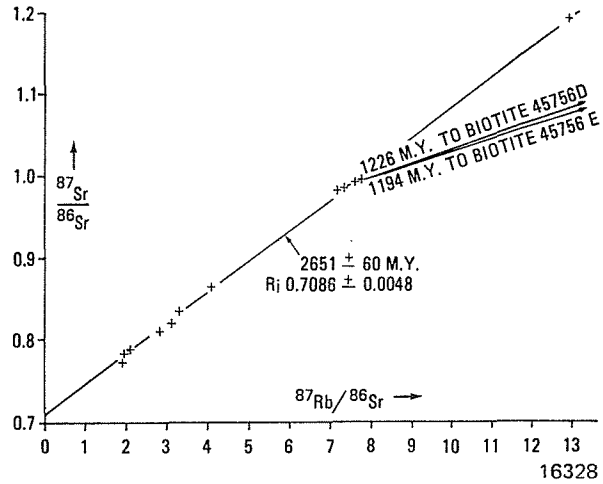

Figure 31. Isochron line of twelve total–rock samples from the southern (Lookout Rocks) area of the Gregory Granitic Complex and of biotites concentrated from two of them. Crosses marking analyses are symbolic only, and do *not* represent error limits.

MOUNT CROFTON GRANITE

GEOLOGICAL RELATIONSHIPS

The Mount Crofton Granite (Chin and Hickman, in prep.) underlies an area of approximately 150 km² in the Paterson Range 1:250 000 Sheet area (Fig. 29). The pluton is composed of medium to coarse-grained, unfoliated biotite granite with marginal pegmatitic and late aplitic phases. Its intrusive relationship to the Yeneena Group is visible 100 m south of the road linking Port Hedland and Telfer, about 15 km northwest of Mount Crofton. On a regional scale its contacts cut sharply across pre-existing fold structures in the neighbouring Proterozoic sedimentary rocks. Thus, the Mount Crofton Granite postdates the Yeneena Group and the main episode of deformation in the Paterson Province.

MATERIAL ANALYSED

The exact locations, and petrographic descriptions, of eight total-rock samples of the Mount Crofton Granite used for Rb-Sr isotopic analysis were given by Trendall (1974) and are not repeated here. Biotites were separated from four of the coarse granites among Trendall's samples.

RESULTS

Analytical results for the four biotite samples are given in Table 14. The ages given by projecting each biotite analysis to its parent total rock are, in the numerical order of the table, 568, 580, 592 and 580 m.y., so that there is little scatter about the mean of 580 m.y.

TABLE 13. ANALYTICAL DATA FOR TWELVE TOTAL-ROCK SAMPLES AND TWO BIOTITE CONCENTRATES FROM GRANITIC ROCKS OF THE LOOKOUT ROCKS AREA

Sample	Rb (ppm)	Sr (ppm)	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
Total rocks					
45757C	115	176	0·65 ± 0·01	1·89 ± 0·03	0·774 31 ± 0·000 71
45757D	116	170	0·68 ± 0·01	1·97 ± 0·04	0·784 01 ± 0·000 74
45757B	111	105	1·06 ± 0·01	3·11 ± 0·04	0·821 45 ± 0·000 79
45757A	126	91	1·39 ± 0·02	4·08 ± 0·07	0·865 17 ± 0·000 64
45756B	172	71	2·41 ± 0·04	7·15 ± 0·08	0·984 14 ± 0·000 76
45756E	166	68	2·45 ± 0·04	7·30 ± 0·08	0·984 90 ± 0·000 83
45756A	168	66	2·54 ± 0·04	7·60 ± 0·09	0·991 71 ± 0·000 89
45756D	171	66	2·60 ± 0·04	7·69 ± 0·09	0·993 67 ± 0·000 83
45756C	171	40	4·28 ± 0·06	12·93 ± 0·15	1·191 5 ± 0·000 94
13891	....	....	0·70 ± 0·01	2·03 ± 0·02	0·788 51 ± 0·000 81
16447	....	....	0·96 ± 0·01	2·79 ± 0·03	0·810 52 ± 0·000 73
16446	....	....	1·13 ± 0·01	3·30 ± 0·03	0·834 32 ± 0·000 81
Biotites					
45756E	700	40	17·6 ± 0·4	56 ± 1·0	1·805 02 ± 0·001 2
45756D	615	42	14·6 ± 0·3	46 ± 1·0	1·653 61 ± 0·001 1

Note: In Tables 11, 12, and 13 the Rb and Sr concentrations have been determined by X-ray fluorescence spectrometry. We believe the values are accurate to ± 7 per cent. The Rb/Sr values do not correspond exactly with the ratios that would be derived from the separate Rb and Sr values listed.

TABLE 14. ANALYTICAL DATA FOR FOUR BIOTITE CONCENTRATES FROM THE MOUNT CROFTON GRANITE

Sample	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
30555	111 ± 2	427 ± 9	4·101 1 ± 0·005 1
30558	188 ± 4	953 ± 20	8·433 9 ± 0·008 4
30559	140 ± 3	601 ± 12	5·678 0 ± 0·004 8
30562	179 ± 4	876 ± 18	7·809 5 ± 0·007 3

DISCUSSION

The three rock bodies from which we report data are about equally spaced along a roughly east-west transect across the eastern margin of the Pilbara Block, and their Rb-Sr systematics thus have an important bearing on its history. The mean biotite age of 580 m.y. from the Mount Crofton Granite, the easternmost of the three, is slightly younger than the two alternative ages, 612 and 594 m.y., suggested by Trendall (1974) to be interpretable from his total-rock analyses from this body. The new data lend greater support to the second of these, with an interpretation of the younger biotite age as an expression of the delay in cooling to the biotite blocking temperature. However, the implied interval of 14 m.y. for this is notably longer than estimates for some eastern Australian granites with more precise Rb-Sr control (Williams and others, 1975; Roddick and Compston, 1976).

The intervals between all these interpretable ages are trivial within the broader time scale of this discussion, and Trendall's (1974) earlier conclusion that the Mount Crofton Granite is a diapiric granite emplaced about 600 m.y. ago, and that it had a prior crustal history no longer than 30-60 m.y., remains valid. This granite cannot have been anatectically derived from an underlying extension of the granitic crust of the Pilbara Block, if this bore any resemblance in Rb-Sr chemistry to Pilbara Block granites studied by de Laeter and Blockley (1972), de Laeter and others (1975), Oversby (1976), or by us in this paper. If the rising diapir penetrated such material it must have done so with minimal contamination by radiogenic strontium.

At the western end of the transect, the data from the Cookes Creek Granite indicate similar general concordance between total-rock and mineral ages; apart from biotite 18416 and total-rock 18415, to which this discussion returns later, the body has an undisturbed age of about 2 600 m.y. This is close to the previously reported ages of other "younger" granites from the eastern Pilbara Block, at Moolyella (de Laeter and Blockley, 1972) and Cooglegong (de Laeter and others, 1975). It is consistent also with Hickman's (1975b) designation of the Cookes Creek Granite, from field evidence, as an Archaen "post-tectonic granite". Like the other younger granites its R_i of 0.7307 is also consistent with a derivation from older granitic crust by partial melting.

With these two very different situations, both in age and origin, at each end of the transect the position in the centre is of critical significance. Here, in the Lookout Rocks area of the Gregory Granitic Complex, the total-rock isochron gives an age closely similar to that of the Cookes Creek Granite. There are, however, two important differences. Firstly, the R_i of 0.7086 is substantially lower than that of the Cookes Creek Granite or the other younger granites; this point is taken up in later discussion.

Secondly, the two Lookout Rocks biotites both give a much younger age, of 1 200 m.y., than the total rock isochron; the significance of these two ages needs assessment in the light of both the geological and other isotopic evidence.

The S5 foliation in the Lookout Rocks area equally affects both the granitic rocks and the adjacent Fortescue Group, the age of which thus sets an upper limit on the age of the granitic rocks. The lowermost lavas of the Fortescue Group were probably erupted about 2 330 m.y. ago (Lewis and others, 1975), although Trendall (1976), in a review of the evidence, has pointed out that the possible age limits imposed by the available data are about 2 700-2 200 m.y. Hickman and de Laeter (1977) have subsequently presented new evidence which can be interpreted as indicating deposition of the Fortescue Group at 2 650 m.y. However, if the Fortescue Group is younger than this, the age recorded by the total-rock samples from the Lookout Rocks area must be interpreted as a real emplacement age which has survived the imposition of the younger S5 foliation. The relative immobility of Rb and Sr during the presumably low-temperature development of this foliation appears consistent with its strongly cataclastic petrographic expression.

If this interpretation is correct, it is not at present possible to assign a definite geological significance to the 1 200 m.y. biotite age, but some limitations can be suggested. The S5 foliation is truncated by, and is therefore older than, the Yeneena Group; it is also deformed by folding correlated with that of the Yeneena Group in the Paterson Province (Hickman, 1975a). Folds in the Yeneena Group are known to pre-date the Bangemall Group (Williams and others, 1976) which is dated at about 1 100 m.y. (Compston and Arriens, 1968; Gee and others, 1976). The Yeneena Group unconformably overlies the Rudall Metamorphic Complex (Williams and others, 1976; Chin and others, in prep.), provisionally dated by one of us (JRdeL) at about 1 500 m.y. (noted in Blockley, 1974). This figure must be treated with caution pending the results of further work in progress, but it suggests, in conjunction with the points already given, that deposition and deformation of the Yeneena Group occurred between 1 500 and 1 100 m.y.

Thus if the 1 200 m.y. biotite be assumed to be the age of the S5 foliation, which is the most immediately attractive hypothesis, it follows that both the deposition and folding of the Yeneena Group took place in a comparatively short, but not impossible, period between 1 200 and 1 100 m.y. Alternatively, our 1 200 m.y. age from Lookout Rocks may be related to the concurrent folding of S5 and the Yeneena Group. If this is so, there is no sign, in our data from the Lookout Rocks area, of any isotopic effect of S5 earlier than 1 200 m.y. but younger than the Fortescue Group.

The 18418 biotite age of 1 800 m.y. from the Cookes Creek Granite falls in this expected interval, but without further work we cannot do more than indicate the possibility of a relationship. Both that age, and the updating of the mylonitic total rock 18415 are clearly related to unknown regional events that only slightly affected this granite.

We return finally to the significance of the low R_i of the 2 650 m.y.-old granitic rocks of the Lookout Rocks area, which we see as an important result of this study. Arriens (1971) first focussed attention on the statistically sharp contrast between periods of largescale granite generation in the two major Archaean areas of Western Australia, the Pilbara and Yilgarn Blocks. In the Pilbara Block the greatest volume of granite is of approximately 3 000 m.y. age, with R_i of about 0.702. In the Yilgarn Block the greatest volume of granite has an age range about 2 700-2 600 m.y., with a similar R_i. In the eastern part of the Pilbara Block the post-tectonic younger granites have the same age, but have R_is close to 0.73, and occur in relatively small stocks cutting the older granites, from which they are presumed to be anatectically derived.

We suggest the possibility that this later granite-forming event was of vast extent and applied equally to areas of earlier-formed thick granitic crust, and to areas not so covered. In the latter, large volumes of low-R_i granites were generated, but in the former the main effects were the the generation of high-R_i material by partial crustal melting at low levels and its upward diapiric penetration in small volumes. In this concept the presence of a low-R_i granite with a 2 650 m.y. age in the Gregory Granitic Complex shows the real existence, between it and Cookes Creek, of an "edge" to the older granitic material of the Pilbara Block. In a petrogenetic, but not necessarily tectonic, sense we picture the granitic rocks in the Lookout Rocks area as more closely related to the Yilgarn Block than the Pilbara Block.

ACKNOWLEDGEMENTS

The authors would like to thank Mr D. J. Hosie of the Department of Physics, Western Australian Institute of Technology, for technical assistance during the project.

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THE DEPOSITIONAL ENVIRONMENT AND AGE OF A SHALE WITHIN THE HARDEY SANDSTONE OF THE FORTESCUE GROUP

by A. H. HICKMAN and J. R. de LAETER*

ABSTRACT

Boron, gallium and rubidium analyses support lithological and stratigraphic evidence that shale collected from the Hardey Sandstone, a formation of the Fortescue Group, was deposited in a fresh-water environment. Rb-Sr isotope analysis indicates that the age of the shale may be between 2 700 and 2 600 m.y., but whether or not this date is a true reflection of the unit's depositional age is uncertain. The possibility that the Hardey Sandstone is 2 600 m.y. old has important implications as to the age of the Proterozoic/Archaean unconformity in the Pilbara Block.

INTRODUCTION

The Hardey Sandstone (MacLeod and others, 1963) conformably overlies the oldest formation of the Lower Proterozoic Fortescue Group in the Pilbara, the Mount Roe Basalt (Kriewaldt, 1964). In many areas this basalt is absent and the sandstone rests directly on steeply inclined Archaean rock. The age of the formation therefore approximates to the age of the Proterozoic/Archaean unconformity, currently the subject of a regional investigation programme.

PREVIOUS GEOCHRONOLOGY

Previous geochronological work relevant to the age of the Hardey Sandstone indicates that it exceeds 2 200 m.y., the reported age of the Weeli Wolli Formation in the Hamersley Group (de Laeter and others, 1974), and that it is close to 2 329 ± 89 m.y., the age of the Black Range Dyke (Lewis and others, 1975), which may be a feeder to the Mount Roe Basalt. The younger age limit for the Hardey Sandstone is firmly established by the age of a major dacite sill which intrudes it. This sill, the Spinaway Porphyry, was dated by Trendall (1975) at 2 124 ± 195 m.y. The older age limit for the formation is far less well defined. South of Nullagine the Cajuput Dyke, a dolerite of the same orientation, composition and size as the Black Range Dyke, is unconformably over lain by shale, pisolitic tuff, sandstone and conglomerate of the Hardey Sandstone. The two dykes probably belong to the same intrusive suite; B. J. J. Embleton (pers. comm.) states that the two dykes are palaeomagnetically indistinguishable.

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PALAEOGEOGRAPHY

Deposition of the Fortescue Group commenced in a number of separate basins, the positions of which closely correspond to areas of Archaean greenstones (Hickman and Lipple, 1975; Hickman, 1975a). Where the Proterozoic/Archaean unconformity overlies granitic rocks, the Mount Roe Basalt and the Hardey Sandstone are almost invariably absent, some younger formation of the Fortescue Group resting on the surface of erosion. The thickness of the Mount Roe Basalt in the central parts of the basins is 300 m, and the Hardey Sandstone locally exceeds 1 000 m. Towards the basin margins both formations become thinner, the sandstone eventually overlapping the basalt before it too wedges out against the Archaean basement.

On a regional scale the Fortescue Group north of the Fortescue River exhibits a progressive onlap southwards across Archaean granitic rocks underlying the Chichester Range. Thus the overall palaeoslope during deposition of the Hardey Sandstone in this northern area was downwards towards the north, a conclusion supported by a limited number of palaeocurrent determinations from cross bedding and ripple marks. Poor sorting in much of the Hardey Sandstone, the common occurrence of lenticular conglomerate units, trough-type cross bedding and the absence of carbonate units suggest that the formation is of fluviatile rather than marine origin. At Nullagine a basal conglomerate (Beatons Creek Conglomerate Member) of the formation has been mined for gold. The gold occurs as fine flakes and rounded particles in the matrix of the conglomerate which contains large angular and subrounded clasts of Archaean sedimentary and granitic rocks. This conglomerate is almost certainly alluvial.

SHALE

The subject of this paper is a grey, fine-grained shale member of the Hardey Sandstone. The shale is about 20 m thick and extends 30 km acoss the Meentheena Basin (Fig. 32), a structural unit defined by Hickman (1975b). Similar rock occurs at the same stratigraphical position at Taylor Creek (60 km to the southwest) and Glenn Herring (100 km to the west), but it is uncertain as to whether or not these widely scattered outcrops represent remnants of a once continuous sheet. Obviously, the shale marks a temporary regional cessation in the influx of coarse detritus to the basins, but it has so far been impossible to determine if the deposit is of marine, estuarine or freshwater origin.

Fifty shale samples, each weighing 20 to 50 gm, were collected from the outcrop, the location of which is shown on Figure 32. Sampling was carried out over a distance along strike of 30 m and across a 2 m vertical section. Microscopic examination reveals the shale to be a recrystallized silty clay; micaceous minerals, strongly orientated in the plane of bedding, make up over 60 per cent of the rock. Quartz clasts, partly recrystallized, attain a maximum diameter of 0.05 mm but are generally 0.01 to 0.02 mm. No feldspar is visible. The size and abundance of quartz grains varies across bedding producing a weak banding. An X.R.D. examination of two samples revealed the presence of chlorite and muscovite, but no kaolin or montmorillonoid minerals. Illite was not detected, possibly due to the abundance of muscovite, but perhaps more probably because of the degree to which the rock has been recrystallized.

All the samples collected were flake-shaped, broken parallel to bedding so that no more than a 5 mm interval was normally represented. Some samples were consequently finer grained than others.

Each sample was powdered to below 200 mesh using a Tema mill.

PALAEOENVIRONMENTAL ANALYSIS

Degens and others (1975) constructed a triangular diagram to illustrate that fresh-water and marine shale

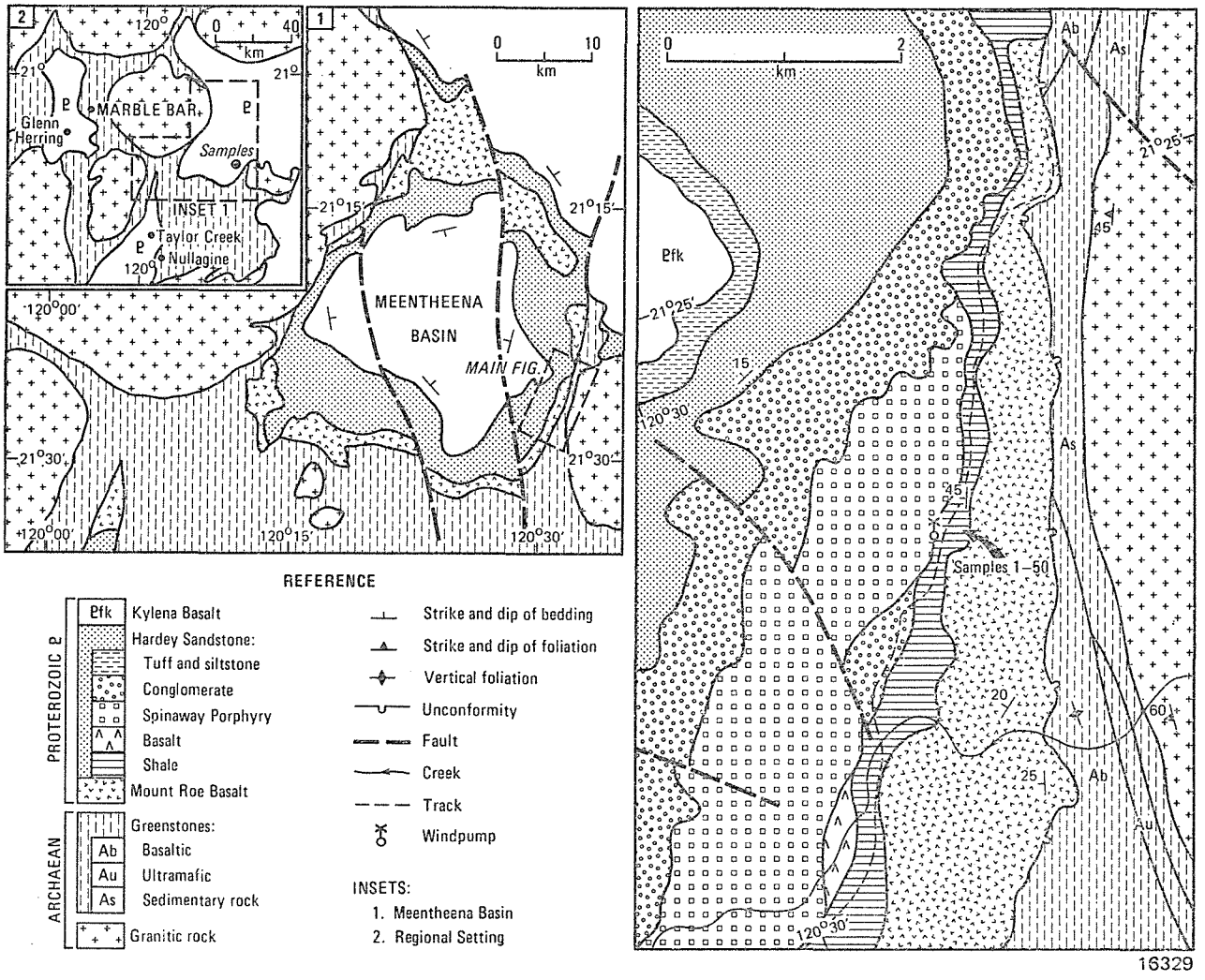

Figure 32. Geological setting and sample locality of a shale within the Hardey Sandstone.

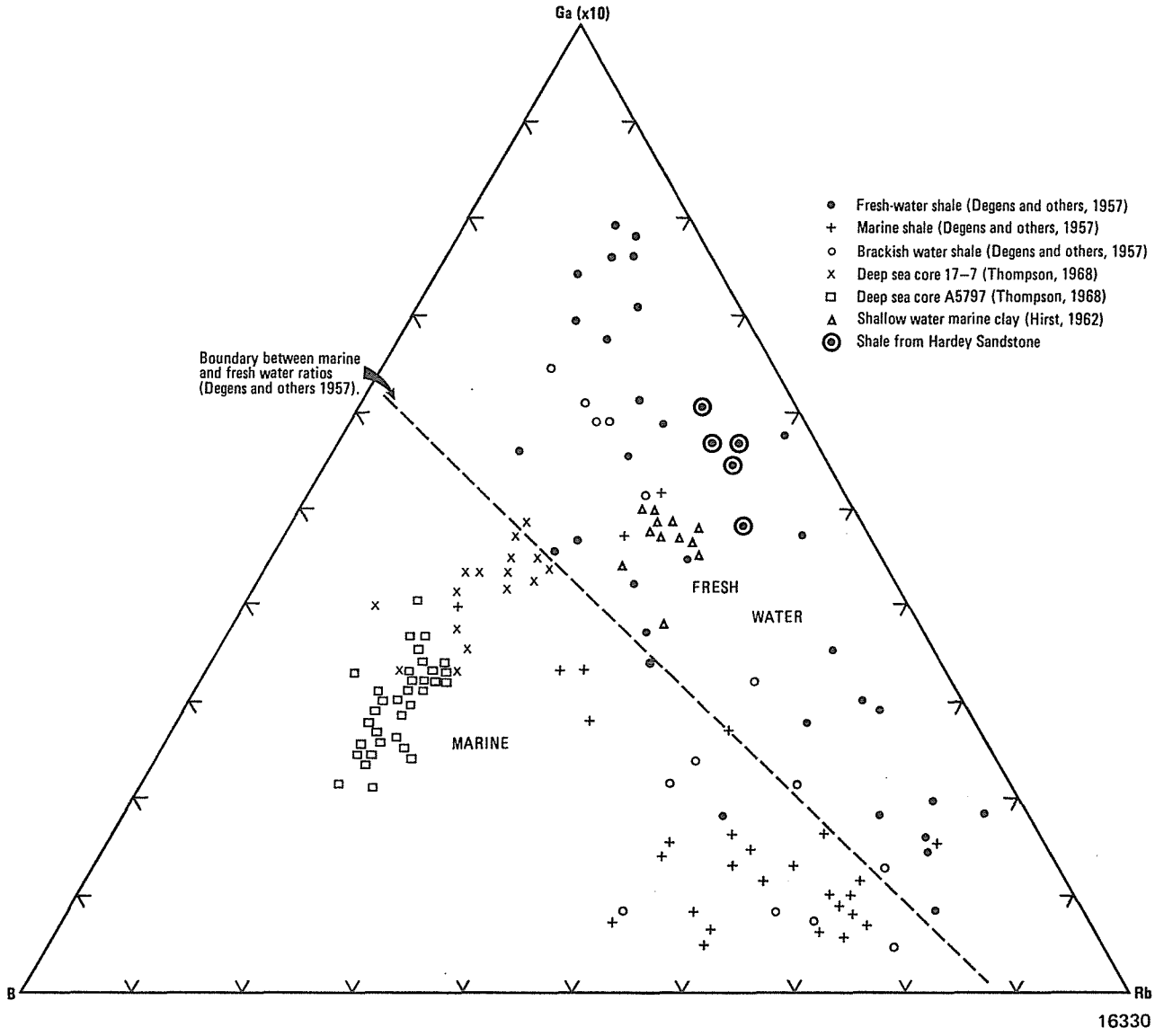

Figure 33. Relative abundance of gallium, rubidium, and boron in shale from the Hardey Sandstone compared with marine and fresh–water shale.

samples can be distinguished on the basis of their relative gallium, rubidium and boron contents. This diagram has since been employed by other workers (Degens and others, 1958; Thompson, 1968; El-Askary and El-Mahdy, 1976) and is repeated, with the addition of new data, in Figure 33.

Boron was first used as an indicator of palaeosalinity by Goldschmidt and Peters (1932) who recognized a difference in the boron content of various marine and nonmarine sedimentary rocks. Landergren (1945, 1958) examined the usefulness of the element in distinguishing marine and fresh-water clay deposits. According to Ernst (1970) boron is present in sea water with a concentration of 4.8 mg/1 whereas its concentration in river water is only 0.01 mg/1. The boron contents of shales are far higher than those of igneous rocks. Concentration in the depositional environment is generally explained by incorporation of the element into illite, where it either substitutes for aluminium (Harder, 1961) or silicon (Walker and Price, 1963). Degens and others (1957) demonstrate that boron increases with the illite:Kaolinite ratio and that illite predominates in the marine environment. Walker and Price (1963) found that illite from freshwater shale contains only about one-third as much boron as illite from marine shale. Tourmaline also contributes boron to sediments but as Hirst (1962) points out, tourmaline contents are normally so low as to only account for up to about 3 ppm in most rocks.

Gallium substitutes for aluminium in clay minerals, and a strong positive correlation exists between the two elements in sedimentary rocks. Hickman (1972) examined over 300 inter-element correlations in 100 samples of Precambrian slate from the Scottish Highlands and found the correlation between gallium and aluminium to be second strongest after that between rubidium and potassium. Hirst (1962) states that the gallium:aluminium ratio is fairly constant through widely differing sedimentary facies and also in igneous rocks. He concludes that gallium enters depositional basins structurally combined within the lattices of degraded clay minerals and that there is little separation of gallium and aluminium during weathering and transportation. Degens and others (1957) explain their observation that fresh-water sediments contain more gallium than marine sediments as a consequence of the fact that kaolinite (relatively concentrated in the fresh-water environment) contains more aluminium than does illite.

Rubidium substitutes for potassium in feldspar, mica and illite. According to Ernst (1970) potassium is strongly adsorbed on clay minerals during diagenesis and is used in the reconstruction of micas. Degens and others (1957, Fig. 7) found that rubidium content increases as the illite: kaolinite ratio increases, the element thus being concentrated in marine sediments.

Table 15 presents average contents of boron, gallium and rubidium in various shale, clay and mud deposits known to be of either marine or fresh-water origin.

TABLE 15. MEAN B, Ga AND Rb CONCENTRATIONS (ppm) IN MARINE AND FRESH-WATER ARGILLACEOUS SEDIMENTS

Rock type	Age	B	Ga	Rb	Reference
Marine					
Shale	Carboniferous	115	8	281	Degens and others, 1957
Mud	Recent	140	....	....	Landergren, 1945°
Clay	Early Jurassic	75	....	....	Landergren, 1945°
Shale	Ordovician	75	....	....	Landergren, 1945°
Shale	Cambrian	100	....	....	Landergren, 1945°
Shale	Early Jurassic	115	....	....	Landergren, 1945°†
Shale	Carboniferous	130	....	....	Ostram, 1957†
Shale	Carboniferous	100–200	....	....	Ernst and others, 1958*
Deep water sediment	Recent	300	....	....	Goldberg and Arrhenius, 1958**
Clay	Recent	79	20	150	Hirst, 1962
Argillaceous sediment	Recent	90	20	....	Potter and others, 1963
Shale	Phanerozoic	124	25	....	Potter and others, 1963
Shale	Carboniferous	150	....	....	Porrenga, 1963*
Deep Water sediment	Recent	135	....	....	Landergren, 1964**
Shale	Carboniferous	96	....	....	Curtis, 1964
Deep water clay	Recent	320	18	110	Thompson, 1968
Deep water clay	Recent	180	19	104	Thompson, 1968
Argillaceous sediment	Camb.-Ord.	141	....	....	Shaw and Bugry, 1965
Argillaceous sediment	Devonian	278	....	....	Shaw and Bugry, 1965
Argillaceous sediment	Carboniferous	172	....	....	Shaw and Bugry, 1965
Argillaceous sediment	Jurassic	153	....	....	Shaw and Bugry, 1965
Brackish					
Shale	Carboniferous	92	14	186	Degens and others, 1957
Shale (or fresh-water)	Carboniferous	78	....	....	Eagar and Spears, 1966
Argillaceous sediment	Triassic	95	....	....	Shaw and Bugry, 1965
Shale	Cretaceous	110	....	....	Tourtelot, 1964†
Fresh-water					
Shale	Carboniferous	44	17	139	Degens and others, 1957
Underclay (or brackish)	Carboniferous	72	76	200	Degens and others, 1958
Shale	Carboniferous	15–45	....	....	Ernst and others, 1958*
Argillaceous sediment	Recent	46	14	....	Potter and others, 1963
Argillaceous sediment	Phanerozoic	40	16	....	Potter and others, 1963
Shale	Carboniferous	50	....	....	Porrenga, 1963*

* Harder, 1970; † Shaw and Bugry, 1966; ° Goldschmidt, 1958: ** Thompson, 1968.

CHEMISTRY OF THE SHALE

The powdered samples were first analyzed for rubidium and gallium (Table 16), then combined to form five composites (using equal weights of the initial samples) on the basis of rubidium:gallium ratio. These composites were analyzed for boron, gallium, rubidium and potassium (Table 17).

TABLE 16. Ga, Rb CONTENTS (ppm) AND Rb: Ga RATIOS OF THE FIFTY SHALE SAMPLES

GSWA No. (32656)	Lab. No. (1974)	Ga	Rb	Rb: Ga
1	7416	18	133	7·4
2	7417	18	134	7·4
3	7418	24	162	6·8
4	7419	16	138	8·6
5	7420	20	139	7·0
6	7421	19	136	7·2
7	7422	21	146	7·0
8	7423	18	165	9·2
9	7424	18	158	8·8
10	7425	17	127	7·5
11	7426	17	140	8·2
12	7427	16	147	9·2
13	7428	42	155	3·7
14	7429	29	143	4·9
15	7430	22	157	7·1
16	7431	21	148	7·0
17	7432	20	146	7·3
18	7433	26	159	6·1
19	7434	23	148	6·4
20	7435	25	140	5·6
21	7436	25	128	5·1
22	7437	26	141	5·4
23	7438	25	138	5·5
24	7439	28	147	5·2
25	7440	26	142	5·5
26	7441	27	137	5·1
27	7442	20	149	7·5
28	7443	27	149	5·5
29	7444	24	141	5·9
30	7445	18	135	7·5
31	7446	25	143	5·7
32	7447	21	123	5·9
33	7448	16	158	9·9
34	7449	19	150	7·9
35	7450	18	125	6·9
36	7451	20	169	8·5
37	7452	26	148	5·7
38	7453	19	142	7·5
39	7454	23	172	7·5
40	7455	22	127	5·8
41	7456	21	150	7·1
42	7457	25	146	5·8
43	7458	19	123	6·5
44	7459	17	133	7·8
45	7460	21	120	5·7
46	7461	16	151	9·4
47	7462	15	139	9·3
48	7463	16	137	8·6
49	7464	18	142	7·9
50	7465	17	138	8·1

Analysts: R. W. Lindsey and J. Gamble, West. Australia Government Chemical Laboratories.

TABLE 17. B, Ga, Rb and K_2O CONTENTS OF FIVE COMPOSITE SAMPLES

Composite sample	B (ppm)	Ga (ppm)	Rb (ppm)	K_2O per cent
A(7)	28	22	139	3·34
B(13)	40	28	144	3·41
C(15)	39	25	149	3·47
D(7)	37	24	157	3·62
E(8)	42	19	160	3·72
Mean	37	24	150	3·51

Note: Figures in parentheses refer to number of samples in each composite.
Analysts: R. W. Lindsey and J. Gamble, West. Australia Government Chemical Laboratories.

Methods of analysis

A part of each shale sample was decomposed using a mixture of hydrofluoric, nitric and perchloric acids and fumed to dryness. The resulting salts were dissolved in hydrochloric acid and made to volume so that they contained 2 000 mg/l of potassium as potassium chloride. The determination of rubidium was performed on a Varion-Techtron (No. 5) atomic absorption spectrophotometer. Gallium was determined photometrically using rhodomine B.

Boron was determined using the following procedure. The samples were attacked by fritting with a sodium carbonate-zinc oxide mixture. A water extract of the frit was acidified and complexed with a zirconium salt to avoid interference from fluoride. Boron was then extracted into a solution of 2-ethylhexane-1, 3-diol in chloroform. The chloroform was evaporated off at low temperature and the remaining solution treated with a solution of Curcumin in glacial acetic acid followed by 1:1 v/v sulphuric acid-acetic acid mixture. After 1 hour reaction time the solution was diluted to 100 ml with alcohol and the boron content determined spectrophotometrically.

Potassium was determined by the following method. Samples were treated with a mixture of hydrofluoric, nitric, perchloric and hydrochloric acids, fumed to dryness, taken up in 5 ml 1:1 sulphuric, 5 ml hydrochloric and 5 ml hydrofluoric acids, again evaporated and fumed to dryness. The resulting contents were dissolved in a small volume of water and three drops of hydrochloric acid, and made to a standard volume. An aliquot was taken, and after the addition of a radiation buffer solution, potassium was determined using a flame emission spectrophotometer.

Results

When the results presented in Table 17 are plotted onto Figure 33 it is clear that the shale member of the Hardey Sandstone falls well within the fresh-water field. The same result occurs when the data are plotted on alternative palaeosalinity diagrams such as presented by Degens and others (1957, Ga:B) and Walker and Price (1963, K_2O: adjusted B). Thus, on the basis of element ratios and observed boron content (comparison with data presented in Table 15) the shale appears to be of fresh-water origin. This interpretation agrees with that reached on stratigraphic and lithological grounds (noted above).

GEOCHRONOLOGY

The experimental procedures of Rb-Sr isotopic analysis are essentially the same as those described by Lewis and others (1975). The value of $^{87}Sr/^{86}Sr$ for the NBS 987 standard measured in this laboratory is 0.7102 ± 0.0001, normalized to a $^{88}Sr/^{86}Sr$ value of 8.3752. The value of 1.39×10^{-11} yr^{-1} was used for the decay constant of ^{87}Rb. The measured Rb/Sr and $^{87}Sr/^{86}Sr$ ratios, as well as the calculated $^{87}Rb/^{86}Sr$ ratios are given in Table 18. Errors accompanying the data are at the 95 per cent confidence level. The data are plotted in Figure 34.

TABLE 19. VARIATION OF ISOCHRON AGE WITH INITIAL $^{87}Sr/^{86}Sr$ RATIO

Initial $^{87}Sr/^{86}Sr$ ratio		Age (m.y.)
MODEL 3 Derived R_i*	0·694 95 ± 0·012 93	2 765 ± 151
MODEL 2 Assumed R_i*	0·697 5	2 736 ± 9
	0·700 0	2 708 ± 9
	0·702 5	2 680 ± 10
	0·705 0	2 652 ± 11
	0·707 5	2 624 ± 12
	0·710 0	2 595 ± 13

* Initial ratio

It can be seen that increasing the initial ratio reduces the slope of the isochron to give successively younger ages. An increase of 0.0025 initial ratio gives an approximate decrease of 28 m.y. in the age. The error limits calculated from the isotopic data give an upper limit in initial ratio of 0.708 and a lower limit in the age of 2 615 m.y. The isotopic age of 2 765 ± 151 m.y. is realistic and meaningful, although the experimental data give only a rough assessment of the true initial ratio, and hence no isotopic evidence as to the origin of the shale.

TABLE 18. ANALYTICAL DATA FOR THE SHALE MEMBER WITHIN THE HARDEY SANDSTONE

Sample	Rb (ppm)	Sr (ppm)	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
7439	148	78	1·91 ± 0·02	5·63 ± 0·06	0·916 70 ± 0·000 91
7448	147	75	1·96 ± 0·02	5·78 ± 0·06	0·920 61 ± 0·000 86
7416	133	66	2·02 ± 0·02	5·96 ± 0·06	0·928 87 ± 0·000 73
7427	142	69	2·05 ± 0·02	6·01 ± 0·06	0·929 41 ± 0·000 68
7432	152	70	2·16 ± 0·02	6·38 ± 0·06	0·945 02 ± 0·000 97
7455	122	55	2·23 ± 0·02	6·59 ± 0·07	0·953 31 ± 0·000 48
7421	140	62	2·26 ± 0·02	6·68 ± 0·06	0·956 97 ± 0·000 88

Note: The Rb and Sr concentrations have been determined by X-ray fluorescence spectrometry. We believe the values are accurate to about ± 7 per cent. The Rb/Sr ratios do not correspond exactly with the ratios that would be derived from the separate Rb and Sr values listed.

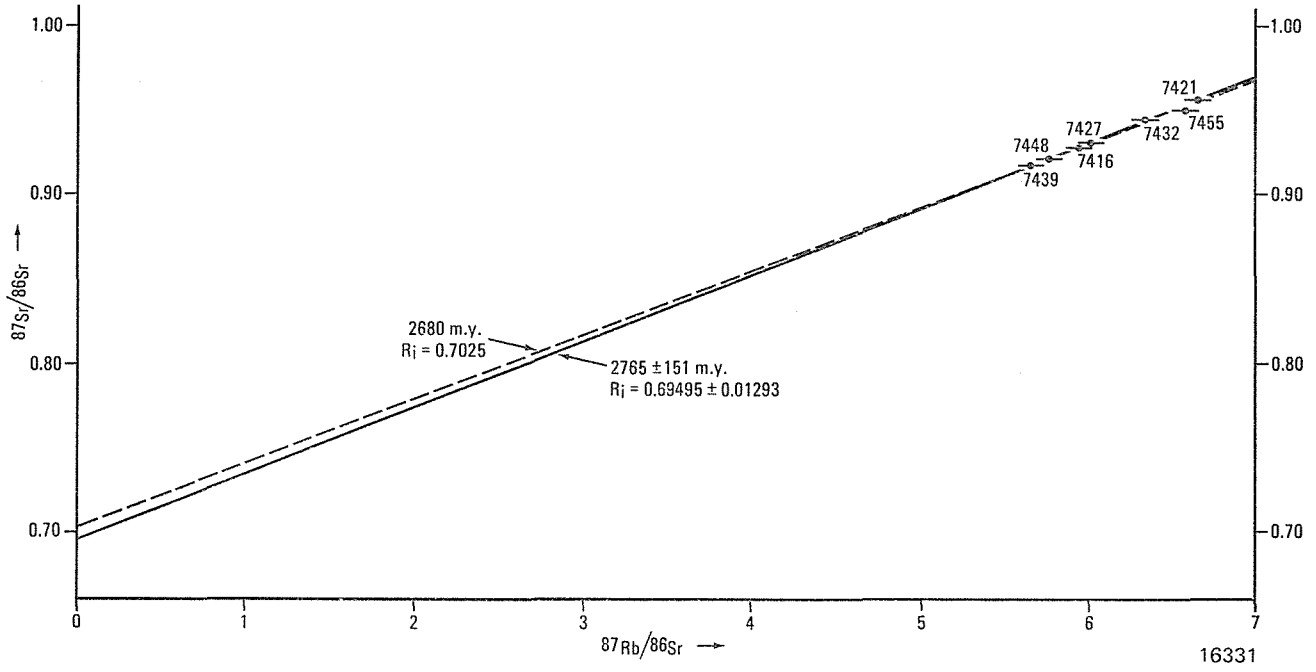

Figure 34. Isochron plot for data of Table 18.

The seven points form an isochron, which, using the regression analysis of McIntyre and others (1966), give a Model 3 isochron of 2 765 ± 151 m.y. with an initial $^{87}Sr/^{86}Sr$ ratio of 0.69495 ± 0.01293. An initial ratio of 0.69495 is geologically and theoretically untenable (Faure and Powell, 1972, p. 45). To illustrate the effect of forcing the isochron to pass through an assumed initial ratio, 0.0025 increments have been added to the calculated initial ratio of 0.69495 as given in Table 19.

DISCUSSION

The fresh-water origin of the shale is reasonably well established, but the age computed for the rock raises several interesting problems.

Veizer and Compston (1976) present evidence to show that the primary Sr isotopic composition of sedimentary carbonate rocks has varied through geological time. At about 2 500 m.y. the $^{87}Sr/^{86}Sr$ ratio of carbonate rocks was similar to that of the contemporaneous upper mantle, and approximately 0.7025. Assuming this initial ratio, an age of 2 680 m.y. is calculated for the shale.

It will be appreciated from earlier references to previous geochronological work in the Pilbara that such an old age for the Hardey Sandstone is unexpected, yet even assuming an initial $^{87}Sr/^{86}Sr$ ratio of 0.710 (the highest common value noted by Veizer and Compston (1976) for Phanerozoic rocks) the age of the shale is computed at 2 595 m.y. The question therefore arises as to whether 2 700-2 600 m.y. is the true age of the Hardey Sandstone or whether the result merely testifies to a substantial component of Archaean detritus.

The "post-tectonic granites" (Hickman, 1975b) or "tin granites" (Blockley, 1970; de Laeter and Blockley, 1972) of the Pilbara Block range in age from 2 700-2 600 m.y., and have always been regarded as Archaean. Unfortunately, there are no contacts between dated plutons of this type and the Fortescue Group. The only granitic rocks observed to intrude the Fortescue Group are small stocks of hornblende adamellite which appear to be unrelated to the post-tectonic granites (Hickman, 1975a). In view of the large area of outcrop of the Fortescue Group (approximately 40 000 km²) in the Pilbara this negative evidence suggests that the Fortescue Group probably post-dates the 2 700-2 600 m.y. granites. The Cooglegong Adamellite (dated by de Laeter and others (1975) at 2 606 ± 128 m.y.) is intruded by the Black Range Dyke, so that if the latter belongs to the same suite as the Cajuput Dyke (see above) the Hardey Sandstone must be younger than these granites. The presence of detrital cassiterite (almost certainly derived from the post-tectonic granites) in the Beaton Creek Conglomerate Member of the Hardey Sandstone lends further support to this relationship.

As noted above microscopic examination of the shale reveals no identifiable clastic component, but the rock is recrystallized. It is possible that the samples contain mica derived from an Archaean source region. Palaeogeographical evidence indicates that such a source region lay to the south of the Meentheena Basin. The closest principal source of mica in this direction is the Mosquito Creek Formation, a relatively late Archaean succession of metamorphosed turbidite sediments.

If mica derived from Archaean rocks is obscuring the true age of the shale, the fact that the resulting isochron is a straight line demands acceptance of thorough mixing of this material with authigenic clay. The initial $^{87}Sr/^{86}Sr$ ratio of such a mixture would be higher than that of the water in the depositional basin. If the true age of the shale is 2 400 m.y., for example, this initial ratio would probably have been about 0.73. However, the error limits computed from the raw data indicate that the minimum age of the rock is about 2 600 m.y., a figure which imposes a maximum initial ratio of 0.71. A variable initial $^{87}Sr/^{86}Sr$ ratio through the shale, perhaps resulting from sedimentary differentiation, might conceivably result in a straight isochron giving an erroneously old age, but no other examples of such a process are known.

It is concluded that the true age of the Hardey Sandstone may be about 2 600 m.y., but this figure must be treated with caution. In particular, it is hard to reconcile such an old age with that of 2 329 m.y. obtained on the Black Range Dyke (Lewis and others, 1975), previously considered to be slightly older than the formation.

ACKNOWLEDGEMENTS

The authors would like to thank Mr. D. J. Hosie of the Department of Physics, Western Australian Institute of Technology, for technical assistance during the project.

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REVIEW OF THE REPORTED OCCURRENCE OF FAMENNIAN (LATE DEVONIAN) ATRYPID BRACHIOPODS IN WESTERN AUSTRALIA

by K. Grey

ABSTRACT

The anomalous occurrence of Famennian (late Late Devonian) atrypid brachiopods recorded by Veevers (1959a) is discussed. Considerable doubt now exists that atrypids occur in any locality of undoubted Famennian age in Western Australia. This provides further evidence for the world-wide extinction of atrypids at the end of the Frasnian (early Late Devonian).

INTRODUCTION

With the exception of two doubtful occurrences, members of the brachiopod order Atrypida are believed to have undergone world-wide extinction at the end of the Frasnian (early Late Devonian). Boucot, Johnson and others (1965), in the Treatise on Invertebrate Paleontology, give the range of the atrypids as Middle Ordovician to Late Devonian. Ager, Copper and others (1967), give the oldest occurrence as being Llanvirnian, the youngest as late Frasnian. Two doubtful Famennian records are also mentioned, one by Mansuy (1912) from Indo-China, and one by Veevers (1959a) from the Canning Basin of Western Australia. Copper (1973), in a synopsis of atrypid relationships and their ranges, does not extend the group beyond the Frasnian.

ATRYPIDS IN WESTERN AUSTRALIA

The first major systematic publication on the atrypid brachiopods of Western Australia was that of Coleman (1951, 1952). Veevers (1959a, 1959b) made a comprehensive systematic study of the brachiopod faunas of the Canning Basin, and revised the atrypid species described by Coleman. The species were further discussed by Roberts (1971) in work on the brachiopod faunas from the Bonaparte Gulf Basin. Two of the species *Spinatrypa prideri* (Coleman) and *Desquamatia (Synatrypa) kimberleyensis* (Coleman) were recorded from samples of Famennian age by Veevers, implying a longer range for the atrypids in Western Australia than is known in the rest of the world—with the exception of the record from Indo-China.

Recent work in Russia, Europe, and North America, has shown the need for a re-appraisal of atrypid taxonomy. As part of the revision of Western Australian atrypids (Grey, in preparation), six critical samples described by Veevers (1959a) were borrowed from the Bureau of Mineral Resources.

Veevers (1959a) recorded atrypids from 3 samples which he considered to be Famennian in age. These were K289 and K503 from the *proteus* zone, and Ld29 from the *scopimus* zone. Three other atrypid-bearing samples (Ld8, Ld31 and 0/73) from the northern end of the Oscar Range have also been examined. These samples were considered to be Frasnian in age by Veevers (1959a), but occur in areas where the rocks are now regarded as Famennian.

SAMPLE K 289

B.M.R. registered fossil number F18632, described as "DF2 Al South of Burramundi Range (Base of Fairfield Beds in section DF2)—*proteus* zone". Veevers (1959a) recorded the following species:

Camarotoechia lucida = *Ptychomaletoechia lucida*
Atrypa desquamata kimberleyensis = *Desquamatia (Synatrypa) kimberleyensis*
Athyris oscarensis
Schizophoria sp. cf. *S.stainbrooki*

The sample locality can be shown to lie within the Nullara Limestone which is of Famennian age (Playford and Cockbain, 1976). However, the lithology of the portion of the sample which was examined is typical of the Sadler Limestone, showing the type of silicification known only from that formation. Although *Ptychomaletoechia lucida* is restricted to the Famennian, (Roberts 1971, p. 150), *Athyris oscarensis* occurs in both the *proteus* and the *saltica* zone. *Schizophoria* sp. cf. *S. stainbrooki* cannot be regarded as definitive of any zone. Finally, the portion of the sample examined contains the stromatoporoid *Amphipora*, which is not known to occur above the Frasnian in the Canning Basin.

There is conflicting evidence for the age of this sample, and it seems reasonable to suppose that it has become contaminated by material from the Sadler Limestone. Roberts and others (1972, p. 472) also comment on the probable mixing of material from this locality. This sample cannot, therefore, be regarded as an authentic record of Famennian atrypids.

Of the atrypids present, only one can be identified as *Desquamatia (Synatrypa) kimberleyensis.* The remainder are either *Spinatrypa prideri*, or are too poorly preserved for identification.

SAMPLE K 503

B.M.R. registered fossil number F18641, described as "Geikie Gap area (?Fairfield Beds)—*proteus* zone". Veevers (1959a) recorded the following species:

?Spinatrypa aspera prideri = *Spinatrypa prideri*
Schizophoria pierrensis

Approximately 40 specimens from this sample were examined and were identified as *Spinatrpya prideri.* An undescribed spiriferid is also present, and the same form has been observed in material of Frasnian age (Grey, 1974).

The locality lies in an area mapped as Pillara Limestone, which is now restricted to the Frasnian (Playford and Cockbain, 1976).

SAMPLE Ld 29

B.M.R. registered fossil number F18560, from Wire Spring, described as "(Napier Formation)—*?scopimus* zone". The following species were recorded by Veevers (1959a):

Pugnax hullensis
Atrypa desquamata kimberleyensis = *Desquamatia (Synatrypa) kimberleyensis*

Pugnax hullensis, regarded by Veevers as being restricted to the Famennian, has also been recorded from the Frasnian by Grey (1974); and the faunal evidence which previously supported a Famennian age must now be regarded as inconclusive.

The main problem in accepting this sample as an authentic record of Famennian atrypids lies in the fact that the precise locality is not known. No air-photo data were supplied, and, therefore, although Wire Spring itself lies within the Napier Formation, and nearby outcrops are of Famennian age, it is not certain that the sample in question came from the immediate vicinity of Wire Spring. Until atrypids are collected from this part of the Napier Formation, the validity of this sample must be questioned.

SAMPLE Ld8

B.M.R. registered fossil number F18546, from Morown Yard, described as "(Oscar Formation)—*saltica* or *torrida* zone". The following species were recorded by Veevers:

Atrypa desquamata kimberleyensis = *Desquamatia (Synatrypa) kimberleyensis*
Uncinulus wolmericus = *Flabellulirostrum wolmericum*

This sample was re-examined because the description of the locality as Morown Yard suggested a possible origin from the Famennian. There is, however, no evidence to suggest a Famennian age. The locality is mapped as Pillara Limestone, and the faunal evidence indicates that the outcrop is of Frasnian age.

SAMPLE Ld31

B.M.R. registered fossil number F18564, from Elimberrie Spring described as "(Napier Formation)—*apena* zone". The following fossils were recorded by Veevers (1959a):

Crurithyris apena
Hypothyridina margarita
Pugnax sp. cf. *P. pugnus*
?Atrypa desquamata kimberleyensis = *Desquamatia (Synatrypa) kimberleyensis* cf. *Schizophoria stainbrooki*

This sample was re-examined because of its proximity to material known to be of Famennian age. The locality is in the core of a bioherm within the Famennian part of the Napier Formation. However, on the basis of the fauna, there is no reason to doubt that the sample is of Frasnian age.

SAMPLE 0/73

B.M.R. registered fossil number F18573, from Palm Spring, described as "(Oscar Formation)—*apena* or *saltica* zone" and containing the following fossils (Veevers, 1959a):

Hypothyridina margarita
Nervostrophia bunapica
Pugnax sp. cf. *P. pugnus*
P. sp. cf. *P. acuminatus*
Atrypa desquamata kimberleyensis = *Desquamatia (Synatrypa) kimberleyensis*
?Crurithyris apena

This sample was examined because of its proximity to known Famennian material. It is regarded as being part of the Pillara Limestone, and there is no reason to doubt the Frasnian age indicated by the fauna.

OTHER RECORDS OF FAMENNIAN ATRYPIDS FROM WESTERN AUSTRALIA

Teichert (1949, p. 23) records *Atrypa* ?sp. ind. from the *Productella* zone (Veevers' *proteus* zone). This specimen has not been located, and no locality details are given. The identification is tentative and in view of the lack of information it is impossible to assess the significance of the record.

A specimen of *Atrypa reticularis teicherti* Coleman, from the type collection of the Geology Department of the University of Western Australia, is described in the catalogue, but not in the literature, as being from rocks of Famennian age. The specimen was illustrated by Coleman (1951, Pl. 100, Figs. 6-10) but incorrectly numbered as 26893a. The correct number is 26273e (not 25893 as indicated in the catalogue) and the specimen is from the type locality. Lithological and other evidence confirm a Frasnian age for this sample (Grey, in preparation).

ATRYPIDS FROM INDO-CHINA

Mansuy (1912) describes atrypids from the Frasnian and Famennian of Yunnan. These atrypids, in particular *Atrypa bodini* Mansuy (Pl. 8, Fig. 10, Pl. 9, Fig. 11) show a close similarity to specimens from Western Australa (Grey, in preparation). Specimens from Ta-Hi-Ti (now in North Vietnam) are described as Famennian in age (Mansuy 1912) though the fossil evidence for this would now appear doubtful, as both Grabau (1931) and Alekseeva (1962) have commented. Russian specimens of *Spinatrypa bodini* (Mansuy) are known only from the Frasnian. Fontaine (1967) in a review of the stratigraphy of Cambodia, Laos and Vietnam, states that the Famennian has never been described with certainty from North Vietnam. Therefore, the Indo-Chinese record of Famennian atrypids must be regarded as a doubtful occurrence.

CONCLUSIONS

Of the six atrypid samples examined, it seems unlikely that any can be regarded as of Famennian age. The faunas described from localities Ld8, Ld31, and 0/73, all indicate a Frasnian age, and there is no stratigraphical evidence to suggest that these could be Famennian.

The three remaining samples were all described as Famennian by Veevers, but there is now considerable doubt regarding the authenticity of these samples. K289 presents conflicting evidence, and must be regarded as contaminated. K503 is Frasnian. The dating of Ld29 is equivocal; however, the complete lack of locality data prevents this being considered as a valid record of the occurrence of Famennian atrypids. The other Western Australian records of Famennian atrypids cannot be confirmed.

This study shows that the presence of Famennian atrypids in the Canning Basin has not been proved. The factors suggesting a Famennian age for the localities under consideration are ambiguous. On such slender evidence, the occurrence cannot be regarded as valid.

There is no evidence elsewhere, with the exception of the very doubtful record from Indo-China (Mansuy, 1912), to suggest that the atrypids extended into the Famennian, and it seems reasonable to conclude that in Australia, as in the rest of the world, the atrypids became extinct at the end of the Frasnian.

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PRECAMBRIAN STROMATOLITES AS PROVENANCE INDICATORS IN THE PERMIAN LYONS FORMATION, CARNARVON BASIN

by K. Grey, W. J. E. van de Graaff, and R. M. Hocking

ABSTRACT

Proterozoic stromatolites occur as erratics in the Lower Permian Lyons Formation of the east-central Carnarvon Basin, and in two cases have been matched with stromatolites from localities in the Henry River area of the Middle Proterozoic Bangemall Basin. The pin-pointing of the source areas of the erratics indicates a north to south movement of ice across the Bangemall Basin to the Gascoyne River area. This direction of ice movement is consistent with that indicated by striated glacial pavements.

INTRODUCTION

During the Early Permian, large areas of Australia were subjected to glaciation. In Western Australia, continental and marine glacial sediments indicate that Early Permian ice-centres were located on the Yilgarn, Pilbara, and Kimberley Blocks (Crowell and Frakes, 1971), and on the Musgrave Block (Jackson and van de Graaff, in prep.).

The Permian glacial deposits of the Carnarvon Basin are mapped as the Lyons Formation ("Lyons Group" of Teichert, 1950; Condon, 1954, 1967; amended van de Graaff and others, 1977). It was described by Condon (1967, p. 12) as a sequence ". . . related genetically to glaciation and consisting of siltstone, quartzwacke and boulder beds". The earlier authors considered the Lyons Formation to be mainly a marine glacial deposit, with lesser amounts of glacio-lacustrine and fluvioglacial sediments. Our recent field work supports these interpretations.

Crowell and Frakes (1971) in their review of the Early Permian glaciation in Australia claimed that direct evidence for glaciation in the Carnarvon Basin is scanty, but considered that important ice-rafting in a marine environment took place. They postulated a glacial centre on the Yilgarn Block, to the east of the central Perth Basin, with glacial imprint lessening northwards as distance from this source increased.

In contrast to this, erratic boulders collected in 1976 indicate that a derivation from a northerly direction is more probable for at least some of the ice-rafted material. The boulders consist of stromatolite fragments which are similar to forms occurring in the Irregully Formation (Middle Proterozoic, 1 100 m.y. old) in the Bangemall Basin. This basin lies northeast of the Lyons Formation outcrop-area, and extends in a northwest direction (Fig. 35, inset). Several forms of stromatolite are present in the basin, and lithologies show a fairly wide variation and restricted distribution. As a result, the provenance of the erratics can be determined with considerable confidence.

DESCRIPTION OF GLACIAL ERRATICS

Sample F9477, collected from locality 44517 is a large boulder of *Baicalia capricornia* Walter. The lithology consists of a dark blue-grey limestone which weathers to a light brown along the edges of the laminae. Sample F9478 from locality 30122, is a laminate or cumulate form which cannot be given a specific name because it does not show column development. It is probably the basal part of *Baicalia capricornia* and has a similar lithology to F9477.

Samples F9479 and F9480 also from locality 30122, are extremely well-preserved specimens of a small form of *Conophyton*. The samples contain a series of discrete, steep-sided cones with occasional bridges. The cones are approximately 15 to 20 cm high, and at least one is curved near the tip. The specimens are almost completely replaced by silica.

PROVENANCE

Stromatolite localities in the Bangemall Basin have been recorded by Daniels (1968, 1969 and 1970) and Walter (1972). Recent field work in the basin has shown the presence of previously undescribed forms; from these studies it is evident that both stromatolite-form and lithology vary widely, and show restricted distributions within the basin. This is an important factor in determining the provenance of the glacial erratics.

The stratigraphy and facies variation in the basin have been described by Brakel and Muhling (1976) and Williams and others (1976). Stromatolites are rare in the more arenaceous facies of the eastern and central areas of the basin. Where they do occur, laminate and cumulate forms predominate. Large forms of *Conophyton* and some *Baicalia capricornia* are present; lithologies are either pink or cream dolomite, or light-grey or dark-grey limestone, and show minor silicification. On the basis of known localities, an origin east of Long. 116° seems unlikely.

West of Long. 116° stromatolite localities are more abundant. Stromatolites at localities in the Parry Range and adjacent areas are heavily slicified, elsewhere lithologies are varied but consist of dark-grey limestones and cream dolomites. Small specimens of *Conophyton* occur in a north-south band extending from the Parry Range to Milly Spring. *Baicalia capricornia* is found near the Henry River East Branch. From this it is evident that the most probable source for the glacial erratics lies along the western margin of the Bangemall Basin.

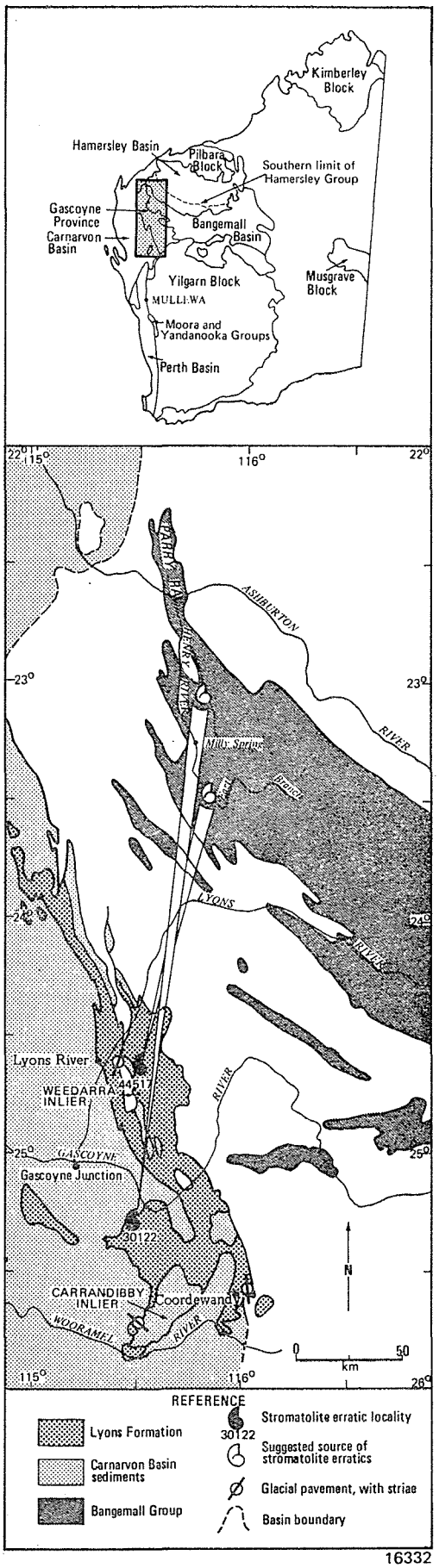

Figure 35. Location of glacial–provenance indicators in the eastern Carnarvon Basin, and suggested source of stromatolite erratics from the Bangemall Basin.

Within the north-south band of *Conophyton* localities, considerable variation of form, size and lithology occurs. Discrete cones are most common to the south of the Ashburton River in the Wongida Creek area, and cones of approximately 15 to 20 cm were observed to the west of the track which crosses Wongida Creek. The lithology at this locality is very similar to that observed in samples F9479 and F9480, and many of the cones have curved tips which may be either tectonic in origin or a growth characteristic. To the north and south of this locality, the cones are usually of a different size and are frequently laterally linked. *Conophyton* is extensively exposed at Milly Spring, where it shows considerable variation in size and also has curved tips. Frequently, the cones are not discrete at this locality. The *Conophyton* cones which are present in the glacial erratics, are sufficiently distinctive for an origin from the Wongida Creek-Milly Spring area to be considered as most probable.

Well preserved specimens of *Baicalia capricornia* are found in a dark blue-grey limestone at the type locality near the Henry River East Branch (Walter, 1972). Elsewhere, preservation is poor, and the lithology is variable; replacement by a green carbonate occurs at some localities. The area around the type locality is therefore regarded as the most probable origin for the glacial erratics containing *Baicalia capricornia*.

DIRECTION OF ICE MOVEMENT

On the basis of both stromatolite form and lithology, the glacial erratics collected from the Lyons Formation have been derived from the Henry River area to the north-northeast. It is unlikely that material could have been derived from areas further east because of the differences in form and lithology. The remarkable resemblance to stromatolites from known localities is good evidence for movement of ice from north to south in the Gascoyne River area.

Scarce pebbles and cobbles of banded iron-formation containing bright red jasper occur in some Lyons Formation boulder beds. One of these, collected from locality 44517, originated from either the Boolgeeda Iron Formation or the Weeli Wolli Formation in the Hamersley Group (Dr. A. F. Trendall, pers. comm. 1977), indicating transport from the north to northeast (Fig. 35, inset). This supports the northerly derivation deduced from the stromatolite erratics.

Glacial pavements at the base of the Lyons Formation are known from three localities. The pavements on the west side of the Carrandibby Inlier and to the east of Coordewandy homestead, which were described by Konecki and others (1958), have striations tending 315° and 352° respectively. The third pavement, which is on the western side of the Weedarra Inlier (approximately 7 km east of Lyons River homestead and 650 m south of the track to Deathtrap Outcamp) has striations trending 030°. The Lyons River and Coordewandy striated pavements are consistent with the north-south movement of ice indicated by the stromatolite erratics. The north-westerly trend of the Carrandibby Inlier pavement may be due to local factors, as the Carrandibby Inlier was a positive area during the Early Permian.

Further south, in the Perth Basin northeast of Mullewa, there is evidence for the northward movement of ice. In tillite of the Permian Nangetty Formation, Playford and others (in press) record boulders from every known formation of the Proterozoic Yandanooka Group, which crops out near the Darling Fault between Carnamah and Mingenew (Fig. 35). Stromatolites derived from the Coomberdale Chert in the Proterozoic Moora Group also occur as glacial erratics in the Nangetty Formation (Logan and Chase, 1961). It is difficult to account for this disparity in the direction of movement unless converging ice sheets were present.

CONCLUSIONS

Likely source areas for erratics, and the trends of striations on the two northernmost pavements are strongly indicative of a north to south direction of ice movement in the Gascoyne River area, with established transport distances of about 250 km. The direction of ice movement indicates that this part of the Carnarvon Basin was covered by an ice cap and/or ice shelf, which moved south from the Hamersley Basin/Pilbara Block region. Between the Wooramel River and Mullewa, about 400 km to the south, no evidence to indicate ice-transport directions is known. South of Mullewa, however, a northward movement of ice has been proved.

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PRELIMINARY EVALUATION OF THE USE OF SULPHUR DIOXIDE AS A PROSPECTING TOOL IN W.A.

by R. Davy and M. Stokes*

ABSTRACT

Preliminary sampling for sulphur dioxide in drillhole air (soil air) over sulphide bodies has been inconclusive. Sulphur dioxide was readily detectable, though at a low concentration (4 μg SO_2/m^3 air), in traverses over a sulphide body (at Golden Grove), and the highest values outlined the mineralized zone on one traverse. Using the same technique, sulphur dioxide was detected in one hole out of sixteen at two other areas, Burbidge and Forrestania. However, extended time sampling at Forrestania showed that very small amounts of sulphur dioxide (1.5 μg SO_2/m^3 air) could be detected.

It is concluded that the method shows some promise, but that the parameters of sulphur dioxide evolution and detection are not yet fully worked out. Much additional test work is needed.

INTRODUCTION

Sulphur dioxide is used as a prospecting tool for sulphide ore bodies in parts of Europe and in North America. Kahma (1965), Nilsson (1971), and Kahma and others (1975) report on the use of dogs to detect sulphur dioxide released by oxidizing ore minerals. Kahma commented that a dog located 1 330 sulphide-bearing boulders in a test field, whereas a prospector only managed to find 270, ". . . even though the man knew he was taking part in a test in competition with a dog" (Kahma and others, 1975, p. 3).

The present interest in sulphur dioxide lies in its use for the identification of concealed sulphide-bodies. It was hoped that the testing of shallow boreholes over geophysical anomalies might, if sulphur dioxide proved absent, obviate the need for diamond drilling. Restriction of diamond drilling to areas with known sulphide would be a major saving during exploration programmes.

Literature on the scientific detection of sulphur dioxide generated by concealed ore-bodies is still sparse. A comprehensive paper by Rouse and Stevens (1971) evaluates the method, and gives case studies over various vein, porphyry-type disseminated sulphides, and sandstone-type disseminated sulphides which were buried to depths of up to 30 m in Canada and the U.S.A. Other case histories have been given by Meyer and Peters (1973) for Newfoundland, and Fisher (1976) for Colorado.

In Western Australia, testing at Mount Keith (approximately 75 km south-southeast of Wiluna), and at Nepean (26 km south of Coolgardie) was a failure, possibly because of inadequate analytical methods (detection limit 10 ppb) and, particularly at Mount Keith, unfavourable geological conditions (C.R.M. Butt, pers. comm.).

This paper reports on preliminary tests carried out over buried sulphides at three locations on the Yilgarn Block: Golden Grove, Burbidge, and Forrestania (Fig. 36).

*Public Health Department

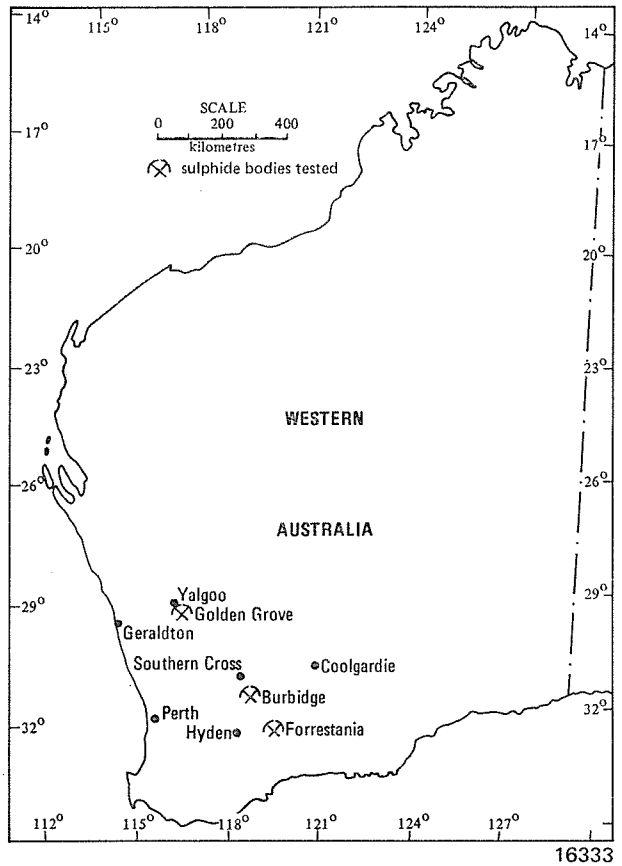

Figure 36. Locations sampled for sulphur dioxide concentration.

At each locality the dominant sulphide is pyrite or pyrrhotite, but varying proportions of base-metal-iron sulphides are also present. The ore bodies do not reach the surface, though, in each area, gossanous ironstone capping has been a surface indicator of buried sulphides. No mining has taken place at Golden Grove or Forrestania, but the site chosen at Burbidge included the floor of a shallow open-pit left after the removal of the ironstone capping ("laterite") during previous gold mining.

Drilling at Golden Grove and Forrestania had been carried out previously for companies holding the present tenements. Rotary holes at Burbidge were drilled in 1972, and diamond drilling has been carried out by the present operators.

Holes were drilled through laterite and clay at Burbidge, weathered bedrock and very shallow residual soils at Golden Grove, and colluvium and residual soils at Forrestania.

METHODS

The method used for collection and detection of SO_2 is that used by the Public Health Department of Western Australia. A diagrammatic sketch of the apparatus used is given in Figure 37.

Most sampling was carried out in rotary air-blast drillholes of various depths; three samples were taken from diamond drillholes which extended to greater depths.

Plastic tubing was fed to the bottom of the hole or 5 m (whichever was reached first), and the hole sealed from atmospheric air with a plastic plate and packed soil. Air was drawn from the holes through a filter to a gas absorber by means of a suction pump. The volume passed was measured using a combination of gas meters and flow meters. Depending on the capacity of pumping 1 to 2 m^3 air were collected in the 24 hour period. The power sources were 6V or 12V batteries.

The initial runs were carried out for a standard 24 hour sampling time. An extended run of 4 days sampling time was later carried out at Forrestania. Samples were stored in a refrigerator, and brought to Perth for analysis.

The method of analysis used is a modified West-Gaeke method, itself modified from Scaringelli and others (1974).

Sulphur dioxide from the soil air is tapped by absorption in a solution of sodium (or potassium) tetrachloromercurate (II), with the production of a non-volatile dichlorosulphito-mercurate complex. This complex resists direct oxidation, but is temperature dependent, and decomposes slowly at temperatures above 15°C. Interference from oxides of nitrogen and from heavy metals is eliminated by addition of sulphamic acid, ethylene-diamine-tetracetic acid (in the form of the disodium salt) and phosphoric acid; determination of the isolated sulphur dioxide is based on a red-violet colour, produced by addition of para-rosaniline methyl sulphonic acid (this colour is also temperature dependent). The absorbance of the solution is read at 548 nm using a spectrophotometer with an effective band width of 15 nm.

Detection is an absolute 2 μg in 50 ml reagent. The detection limit can be lowered with an increase in sampling time—with passage of a larger volume of air.

RESULTS

Sixteen samples were taken at each site during the initial sampling.

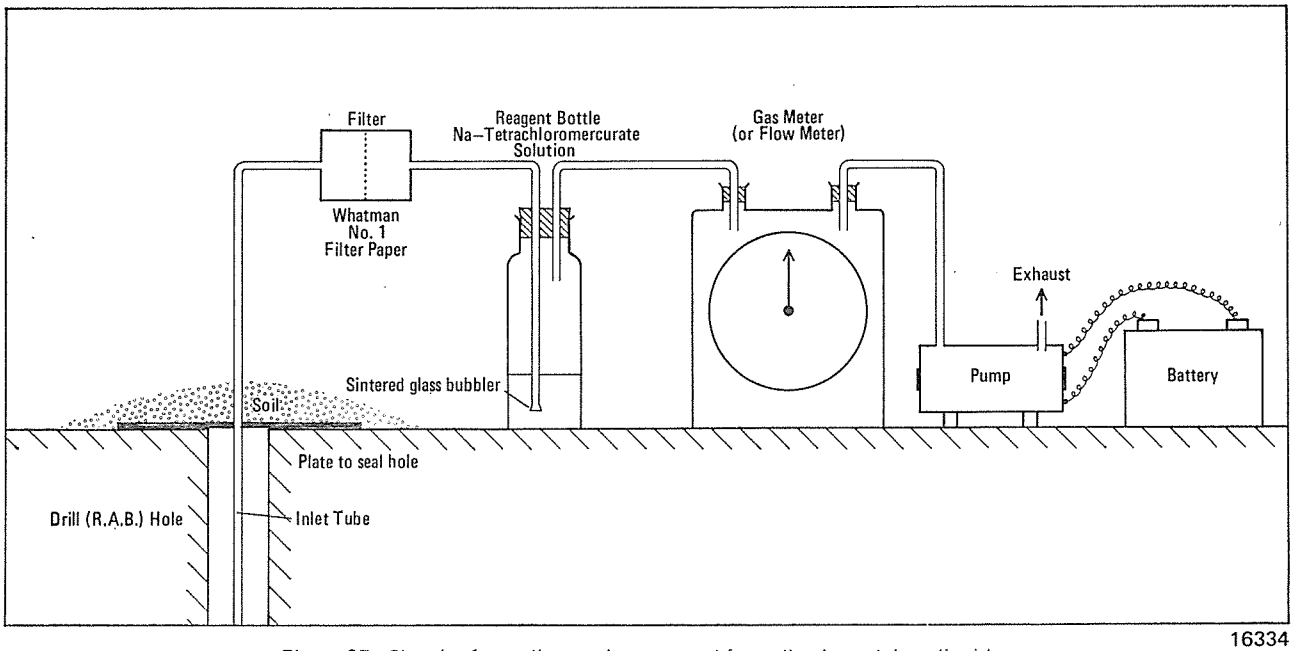

Figure 37. Sketch of sampling equipment used for collecting sulphur dioxide.

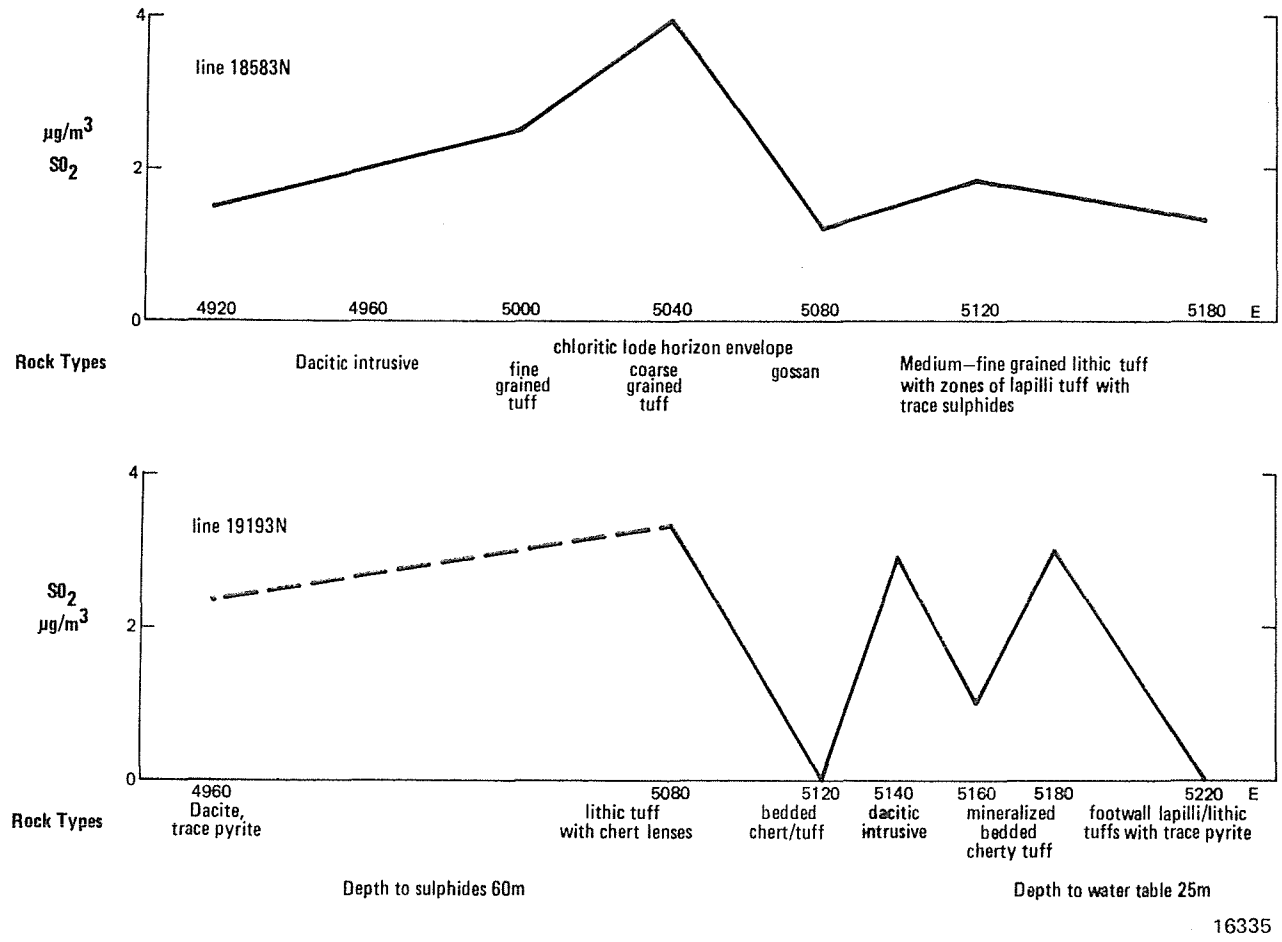

Figure 38. Sulphur dioxide profiles at Golden Grove.

Golden Grove

Golden Grove lies approximately 70 km southeast of Yalgoo. The project is currently operated by the Electrolytic Zinc Co. of Australasia Ltd.

Pyrite-magnetite-chalcopyrite lenses occur within a sequence of acid tuffs; the lithology along the traverse lines is given in Figure 38.

Samples were taken from shallow, rotary air-blast holes which had been drilled into weathered bedrock. Residual soil sulphides are absent at the surface, but occur about 60 m from the surface. The water table is approximately 25 m below ground level.

Samples were taken in May 1976 during a spell of fine calm weather with warm days (20-25°C) and cool to cold nights (0-10°C). Rain (17.5 mm) fell the night before sampling commenced.

The results of the two traverses are given in Table 20, and are presented diagrammatically in Figure 38.

TABLE 20. RESULTS AT GOLDEN GROVE

Sample Site Grid location	Depth of hole (m)	SO_2($\mu g/m^3$)	Remarks
18583N 4920E	3·5	1·5	hanging wall, trace pyrite
4960	3·3	2·0	
5000	1·5	2·5	lode horizon envelope
5040	1·6	3·9	
5080	3·5	1·2	
5120	2·2	1·8	footwall
5180	3·1	1·3	
19193N 4960E	2·0	2·4	hanging wall, traces pyrite
5080	3·0	3·3	
5120	1·5	0·0	
5140	2·0	2·9	
5160	2·3	1·0	lode horizon
5180	2·2	3·0	footwall, traces pyrite
5220	1·75	0·0	
19319N 4600E	3·2	0·0	alluvium over unmineralized acid intrusive
19600N 5100E	....	0·0	atmospheric sample

The traverse along line 19193N was carried out on the two days immediately following the rain (four samples per day). Results along this traverse (the lower profile in Figure 38) are ambiguous; the ore zone itself is low, but it is flanked by high values. The results along line 18583N (610 m to the south) reach a maximum over the known lode (and suggest a subsidiary peak in the footwall zone).

No sulphur dioxide was obtained from a hole drilled in alluvium over a barren acid intrusive (19310N, 4600E) and no sulphur dioxide was detected in a sample of atmospheric air.

Burbidge

The old Great Victoria gold mine at Burbidge lies about 42 km southeast of Southern Cross. The property is currently under investigation by the Minerals Department of Esso Australia Ltd.

At Burbidge a massive pyrrhotite-pyrite body occurs between footwall amphibolites, and overlying "spotted schists" and other metasediments. The metasediments contain disseminated pyrite. A massive ironstone capping ("laterite") has been worked for gold, and the "laterite" had been removed from part of the zone leaving a shallow open cut 2 to 3 m deep.

Percussion holes had been drilled to 180 m on behalf of previous operators in 1972. A few diamond holes have been drilled on behalf of the current operators.

Sampling of soil air was on a grid patern, mainly in the air-blast holes, and included lode, and both footwall and hanging wall sites. Most samples were collected from a depth of 5 m. Sampling was carried out in July 1976 under calm dry conditions. Day temperatures were 10-15°C, overnight —2 to +5°C.

The water table is lower than at Golden Grove—an estimated 60-90 m—and sulphides are present at depths varying from 60 to 100 m. Massive sulphides were identified in five deep percussion holes in the hanging wall and over the lode, at depths of 90 to 140 m. Disseminated sulphides occurred at 70 to 90 m.

The only hole from which sulphur dioxide was recorded was B22, which was sunk to a depth of 7.6 m from a site in the hanging wall. The SO_2 value was 2.2 $\mu g/m^3$.

One hole, B3, near the lode-hanging wall contact, had been expected to show sulphur dioxide, since a pungent acrid smell was noticeable, but showed none. Possibly mercaptans or even hydrogen sulphide were present.

A sample drawn from the atmosphere showed no sulphur dioxide.

Forrestania

The camp at Forrestania lies approximately 85 km east-southeast of Hyden, and 160 km south-southeast of Southern Cross. Samples were collected on leases currently operated by Amax Exploration (Australia) Inc. Sampling was carried out in August 1976 in dry weather with day temperatures 10 to 18°C and night temperatures of 0 to 5°C.

Apart from the hills of banded iron-formation known as "Ironcaps", outcrop is rare, and considerably weathered when it does occur. Amax Exploration have systematically tested the area using rotary air-blast drilling to bedrock, supplemented by limited diamond drilling. Near the surface most holes pass through residual soils, or colluvium; a few penetrate the badly weathered rock.

Initially, samples were taken on four short traverses over mineralized and unmineralized contacts. These traverses were at:

(a) "New Morning" where thin zones of massive sulphide separate serpentinite from metasediments.

(b) "North Ironcap" where mineralization occurs as disseminated sulphides, and thin zones of massive sulphide in a thin zone of chert associated with a contact between ultramafic rocks ("high-magnesian basalts") and metasediments.

(c) "Western Belt" where no sulphide mineralisation was known, but where there was a surface geochemical anomaly in cap rock over weathered dunite.

(d) "Seagull" where mineralization consists of disseminated sulphide in the basal zones of an ultrabasic rock near, but apparently unrelated to, its contact with a barren "high magnesian basalt".

Five holes were sampled at New Morning, four at North Ironcap, three in the Western Belt and four at Seagull.

Sulphides were present at approximately 60 m at New Morning, at 165 m at North Ironcap, and at approximately 70 m at Seagull.

One hole only, at line 396N, 1244.OE, at Seagull, showed sulphur dioxide—a value of 3 $\mu gSO_2/m^3$.

In view of these results, it was decided to carry out extended sampling in holes over mineralization at Forrestania. Tests were carried out at two of the sites originally chosen, New Morning and Seagull, and over two other mineralized areas, Digger Rocks and Flying Fox. Digger Rocks was chosen because fresh sulphide, as stringers locked in quartz and other, secondary, silica, had been identified at the surface.

At Digger Rocks, ferruginous cap rock extends to 20 to 30 m from the surface. Sulphides occur immediately below this cap rock. The water table is at 20 m. At Flying Fox, the depth to sulphides is 80 m, to the water table at least 120 m.

The sampling time was extended to four days. This meant that 3 to 12 m^3 of air passed through the sampling bottles (the actual volume depending on the suction of the pumps and the "running down" of the batteries). Flow meters were used to monitor the flow at 12 hour intervals, and the total volume passed was estimated to about 15% accuracy. Results are given in Table 21.

TABLE 21. RESULTS OF EXTENDED TIME TESTS UNDERTAKEN AT FORRESTANIA

Area	Grid location	Volume air passed (m^3)	$SO_2(\mu g/m^3)$
Digger Rocks	490N 307·0E	8	1·4
	492N 307·5E	2	1·0
Seagulle	396N 1242·75E	8	....
	1243·75E	8	....
New Morning	186N 1071·0E	8	....
	1071·5E	3	....
	1072·0E	3	....
Flying Fox	932N 1106·5E	6	0·5
	1107·0E	6	0·4

Depth of sampling: 5m
Air Blast holes.

The repeat tests over the sites used initially showed no sulphur dioxide (that is the concentration of sulphur dioxide was less than 0.2 to 0.5 $\mu g/m^3$ depending on the volume of air passed). However small but detectable amounts of SO_2 were obtained from the other two zones. Two samples from Digger Rocks gave values of 1.4 and 1.0 $\mu g/m^3$ SO_2. Two samples from the other mineralized zone gave 0.5 and 0.4 $\mu g/m^3$ SO_2 respectively.

DISCUSSION

The results presented above demonstrate that this method, like any other remote sensing technique, is not infallible, but that, given the right conditions, it could be helpful in exploration.

Readily detectable sulphur dioxide was found at Golden Grove, but levels at Burbidge and Forrestania were so low that the use of SO_2 detectors is not likely to be economic. The results do show, however, that, despite the highly oxidized state of the near surface rocks and soils, despite the considerable depth to fresh sulphide, and despite the fact that the bulk of the fresh sulphide is known to occur only below the water table, some sulphur dioxide is present.

Rouse and Stevens (1971) discuss qualitatively the solubility of sulphur dioxide in water, but consider that a fluctuating water table with some "seasonal" drying out of the rock may release sulphur dioxide and allow it to migrate upwards. As part of their general comments, they prefer to see some part of the sulphide deposit in a moist area above the water table to ensure that oxidation is taking place. In the areas tested here, as far as is known from diamond drill data, the sulphides occur below the water table. As sulphur dioxide is measurable over sulphides, and not in barren areas, particularly at Golden Grove, there is the inference that some oxidation is still taking place. The low levels shown at Forrestania by the extended trial imply that oxidation is presently occurring in this area at a very slow rate. The same possibly applies at Burbidge, though extended time sampling was not attempted there.

In the tests carried out for this report there was no attempt to measure or compare seasonal variations, though the holes at Golden Grove were sampled in warmer weather than at the other two places. Diurnal variations in temperature and pressure were noted at both Golden Grove and Burbidge, but there were no striking differences to explain the sulphur dioxide found in one case but not in the other. Extended trials, at different times of year should be used to test the influence of the weather.

A possible, though doubtful, reason for the lack of sulphur dioxide at Burbidge and Forrestania may be the poor permeability of the overlying weathered material. At Forrestania relict sulphide does occur in at least two gossans with the sulphide totally enclosed in silica. Where fractures or cavities exist there is no near surface sulphide, and it is the lack of access for water and air which has allowed retention of the sulphide.

Comparisons with other published data

Of the three papers cited earlier, Fisher (1976) is the least instructive. He gives no absolute values but expresses maximum readings as up to three times background. He does comment that ventilation of the sulphide-rich area by drillholes may have caused the release of additional sulphur dioxide.

Meyer and Peters (1973) report values up to 3.2 ppb (9 $\mu g/m^3$) at two sites over shallow sulphides in Newfoundland. They obtained much higher values in the vicinity of tailings dumps, but noticed that the actual values they obtained varied by factors up to 25 depending on the weather. High values were found on warm sunny days, low values on cool, overcast days.

Rouse and Stevens (1971) sampled both air and soil air, the latter commonly at 15 cm (6 in.) depth. At Central City, Colorado, over a sulphide vein buried at 3 to 5 m (10-15 ft) values of just over 40 ppb (114 $\mu g/m^3$) were reported. Similar readings were obtained at the New Orphan Boy mines, Alma, Colorado, but background readings were 1-15 ppb (28-42 $\mu g/m^3$). The anomaly:background ratio was 3:6.

Over disseminated sulphides in igneous rocks, at depths up to a maximum of approximately 30 m (100 ft), values of 25 ppb (72 $\mu g/m^3$) were obtained at various sites in Colorado and New Mexico compared with a background of 8 ppb (23 $\mu g/m^3$). At the Lornex orebody, covered by more than 60 m (200 ft) of glacial till soil—gas values reached 18 ppb (51 $\mu g/m^3$).

Rouse and Stevens also investigated uraniferous pyritiferous sandstone (with disseminated sulphides) with similar values. No depths are mentioned.

The results reported here are very much lower with a highest value of 4 $\mu g/m^3$ (1.4 ppb). This appears to be a function of deeper ore bodies covered by water, and the fact that oxidation is proceeding very slowly at the present time. It would be interesting to compare the values obtained in winter for this study with the results of repeat samples taken in the height of summer. If Meyer and Peters (1973) findings are correct, values in Western Australia may also increase in summer.

Sulphur dioxide in the atmosphere

Sulphur dioxide is monitored on a weekly basis in the Perth area by the Public Health Department. Readings for central Perth range from 5-100 $\mu g/m^3$ with an average of 14 $\mu g/m^3$ over the year. Near the coast, at Wembley Downs, the annual average is 2 $\mu g/m^3$ for the year; inland at the W.A. Institute of Technology it is 9 $\mu g/m^3$ per year.

The atmosphere was sampled at Golden Grove and at Burbidge, but no sulphur dioxide was recorded in a 24 hour period.

The low values obtained for soil gas, however, demonstrate the necessity of determining the concentration in the atmosphere near the sampling points. Very little human activity can produce amounts which could, in Western Australian conditions at least, give apparent major anomalies.

Oxidizing vegetable matter

No attempt has been made to determine the sulphur dioxide producing potential of decaying plants. The lack of sulphur dioxide in many areas, mineralized as well as non-mineralized, suggests that vegetation cannot be a major factor in the production of unusual sulphur doixide values.

Prospects for the method

Now that outcrop areas in most of Australia have been prospected attention has turned to the identification of concealed ore bodies.

This method is not selective for base metals, but, if sulphur dioxide can be shown to be present, may help identification of the location of sulphide bodies. Wildcat sulphur dioxide prospecting is not considered economically feasible, but the method is considered to be most applicable when geophysics has shown the presence of electromagnetic, induced potential, or self potential anomalies. These geophysical techniques do not discriminate between anomalies caused by sulphides, magnetite or graphite. The ideal situation for the sulphur dioxide prospecting technique is to have a sulphide body oxidizing above the water table, and buried under 10 to 15 m of sand or alluvium.

For the method to be effective, the geophysical anomalies need to be accessible for testing by sampling from shallow auger holes preferably at depths no greater than 3 m. The inference is that, in the Golden Grove area this may be possible, at Burbidge and Forrestania it is not.

One limiting factor is the time taken for sampling. Once the method appears viable, however, it is anticipated that more rapid collecting techniques, or agents which absorb sulphur dioxide more rapidly, will be developed.

Much additional test work is needed to establish the parameters of the method and its applicability in other parts of Western Australia.

CONCLUSIONS

Preliminary sampling for sulphur dioxide in drillhole air (soil air) over sulphide bodies has been inconclusve. Sulphur dioxide has been readily detectable, though at a low concentration, in traverses over a sulphide body at Golden Grove, and the highest values outlined the mineralized zone on one traverse. Using the same technique, sulphur dioxide was recognised in one hole out of sixteen at both Burbidge and Forrestania. However extended-time sampling showed that very small amounts of sulphur dioxide could be detected at Forrestania.

It is concluded that the method shows some promise, but that the parameters of sulphur dioxide evolution and detection are not yet fully worked out. Much additional test work is needed.

ACKNOWLEDGEMENTS

The very considerable help and support supplied by the Electrolytic Zinc Co. of Australasia Ltd at Golden Grove, Esso Australia Ltd. at Burbidge, and Amax Exploration (Australia) Inc. at Forrestania is gratefully acknowledged.
Analyses for sulphur dioxide were carried out by the Public Health Department in Perth.

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APPENDIX

SAMPLE SITES AT BURBIDGE AND FORRESTANIA

BURBIDGE

The following percussion holes were sampled:
B1, 3, 4, 5, 7, 14, 15, 17, 20, 21, 22, 23, 38, 39.

One diamond drill hole was sampled:
GV1, located 10 m north-northwest of B18.

An atmospheric sample was also taken near hole B11.

FORRESTANIA

Sample sites were as follows:

New Morning Line 816N
Air Blast holes 1071.OE, 1071.5E, 1071.75E, 1072.OE
Diamond Drill hole NMD 4 (started at 1072.6E)

North Ironcap Line 22N
Air Blast holes 112.1E, 112.3E, 112.5E, 112.7E

Western Belt Line 516N
Air Blast holes 1058.5E, 1059.25E, 1059.5E

Seagull Line 396N
Air Blast holes 1242.75E, 1243.75E, 1244.OE, 1245.75E

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DIVISION V

Report of the Head of The Petroleum Branch for the Year 1976

Under Secretary for Mines

I hereby submit my Annual Report for the Petroleum Branch for 1976.

PETROLEUM RESERVES

The proved and probable recoverable petroleum reserves of the State are estimated to stand at 19.10 x 10^6m^3 of oil and 424.31 x 10^9m^3 of raw gas. These reserves are exclusive of those discoveries which may be significant but are still awaiting further evaluation such as Scott Reef, Tern, Tidepole and the gas-condensate discovery made during the year by WAPET at Spar No. 1, located approximately 50 km west-northwest of Barrow Island. The breakdown between basins and fields is given in Tables 1A and 1B. Oil and natural gas reserves were decreased during the year by the extent of production from the Barrow Island and Perth Basin fields. The gas reserves of the Dongara Field were revised downwards as a result of pressure surveys carried out within the reservoir. Minor increases in the gas reserves for Barrow Island resulted from the drilling of the Perentie No. 1 well and from a geological review of the Barrow Island area.

TABLE I

ESTIMATE OF PROVED AND PROBABLE RECOVERABLE PETROLEUM RESERVES (UNDISCOUNTED) IN WESTERN AUSTRALIA AS AT 31st DECEMBER, 1976

IA UNDEVELOPED FIELDS

Company	Basin and Field	Oil 10^6m^3	Condensate, C5+ 10^6m^3	Raw gas[1] 10^9m^3
	CARNARVON BASIN			
W.P.D.[2]	Angel	....	9·47	40·35
W.P.D.	Goodwyn	0·20	14·94	72·78
W.P.D.	North Rankin	....	29·17	242·67
WAPET[3]	West Tryal Rocks	....	3·94	58·91
	PERTH BASIN			
WAPET	Yardarino	neg.	....	0·04
	Sub Total	0·20	57·52	414·75

IB PRODUCING FIELDS

Company	Basin and Field	Oil 10^6m^3	Condensate and Plant Products 10^6m^3	Processed gas 10^9m^3
	CARNARVON BASIN			
WAPET	Barrow Island	18·89	0·31	1·84
	PERTH BASIN			
WAPET	Dongara	0·01	0·03	7·43
WAPET	Mondarra	....	neg.	0·29
	Sub Total	18·90	0·34	9·56
	Grand Total	19·10	57·86	424·31

Notes: 1. Raw gas figures include the C5+ fraction together with the minor quantities of inerts present in the well stream. However, in the case of the West Tryal Rocks Field inerts have been deducted from the raw gas.
2. Woodside Petroleum Development Pty. Ltd.
3. West Australian Petroleum Pty. Ltd.

1976 OFFSHORE DRILLING OPERATIONS

OPERATOR	CONTRACTOR	RIG	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
BOCAL	ODECO	'OCEAN DIGGER'	LEWIS No.1A 3400m PLUGGED and ABANDONED		WITHNELL No.1 4650 m PLUGGED and ABANDONED							NORTH RANKIN No.5		
WAPET	ODECO	'OCEAN DIGGER'							SPAR No.1 3721m PLUGGED and ABANDONED					

1976 ONSHORE DRILLING OPERATIONS

WAPET	SHELF DRILLING CO.	RIG 12		PERENTIE No.1 3900 m COMPLETED GAS WELL						WHITLOCK No.1 2400 m SUSPENDED			DENISON No.1	
W.I. ROBINSON	BETTINI BROS.	MAYHEW 1000						OCUMUP No.1 83 m P&A						

0 5 10 15 20 25 30 days

Figure 1. Drilling operations during 1976.

PETROLEUM EXPLORATION OPERATIONS

Petroleum exploration drilling operations increased marginally in terms of rig months during 1976 from the low level attained during 1975. An overall rig activity increase of 18.5 per cent occurred namely from 16 rig months in 1975 to 18.8 rig months in 1976. Onshore drilling activity increased 21.5 per cent from 5.9 rig months in 1975 to 7.17 rig months in 1976, and offshore activity increased 16.7 per cent from 10 rig months in 1975 to 11.7 rig months in 1976.

Marine seismic surveys conducted by permittees, in terms of line kilometres increased by 214 per cent from 2 737 in 1975, to 8 599 km in 1976. Taking into account the additional 7 757 line kilometres conducted outside permit areas by G.S.I. in their Scientific Investigation an increase of 496 per cent in offshore seismic activity occurred. Land seismic surveys declined by 8.5 per cent from 484 in 1975 to 443 in 1976.

Of the total 22 171 metres of hole drilled during the year, 21 119 metres (95%) was confined to two drilling rigs operating in the North West Shelf area, where one offshore rig (the semi-submersible Ocean Digger) drilled 14 819 metres (67%) and one onshore rig (National 110 DE, on Barrow Island) drilled 6 300 metres (28%) of hole. On completion of its exploration drilling on Barrow Island the National 110 DE rig was occupied for 7 weeks on a workover operation on Biggada No. 1 well and then temporarily stacked. The rig was later brought to Dongara to drill the Denison No. 1 well where an additional 969 metres of hole was made to the year's end.

Three tropical cyclones were active in the areas of petroleum operations, namely cyclones Vanessa, Wally and Alice, of which two (Vanessa and Wally) affected petroleum activities. All three cyclones occurred during the early part of the year. The Ocean Digger was blown 55 metres off location during cyclone Wally. There was no loss of life or injury as a result of these weather disturbances. However, there was appreciable loss of drilling operation time and an estimated deferrment of Barrow Island production amounting to 97 150 barrels.

APPRAISAL AND DEVELOPMENT

Barrow Island Field

(Operator—West Australian Petroleum Pty. Limited.)

WAPET drilled two exploration wells on the island and Biggada No. 1, drilled in 1975, was tested. Perentie No. 1 was drilled to a depth of 3 900m to investigate the Middle Jurassic gas and condensate sands encountered in the Barrow Island Deep No. 1 and Biggada No. 1 wells. Whitlock No. 1 was drilled to a total depth of 2 400 m to evaluate a possible oil accumulation in the Dupuy Sands. Both wells proved disappointing. The 11 250′ sand in Biggada No. 1 produced only a small flow of gas on test, the formation being tight.

Well servicing and remedial work was carried out throughout the year using the Ideco H-35 rig together with the Cooper well-servicing unit. The status of the 511 wells within the field, as at the end of 1976, is shown in Table II.

TABLE II

BARROW ISLAND FIELD WELL STATUS BY RESERVOIRS AT 31st DECEMBER, 1976

Number of wells

Reservoir	Flowering	Pumping	Gas lift	Closed in	Water injection	Water source	Water disposal	Total
Lower Gearle	....	....	....	1	....	....	....	1
Windalia	4	178	88	20	184	9	7	490
Muderong	4	3	1	....	....	....	....	8
Jurassic 5 500′	....	....	....	1	....	....	....	1
Jurassic 6 200′	....	....	....	1	....	....	....	1
Jurassic 6 600′	....	1	....	1	....	....	....	2
Jurassic 6 700′	1	2	....	2	....	....	....	5
Jurassic 3 550 m	....	....	....	1	....	....	....	1
Jurassic 11 250′	....	....	....	2	....	....	....	2
Total number of wells	9	184	89	29	184	9	7	511

The status of wells at the end of the year with respect to the principal reservoir, the "Windalia Sand Member" of the Muderong Shale, is shown in Figure 2.

Eighteen East-West high water-cut producing wells were converted to water injection wells as a result of water break-through owing to preferred permeability in that direction. A limited re-stimulation project involving the hydraulic fracturing of 6 Windalia wells was carried out using a super-emulsifrac process in order to evaluate the suitability of an oil water emulsion carrying fluid.

North Rankin Field

(Operator—Woodside Petroleum Development Pty. Ltd.)

Further appraisal of the field was initiated by the spudding of North Rankin No. 5 in the last quarter. At the end of the year the gas-bearing Triassic reservoir section was being cored. The North Rankin/Kendrew experimental seismic survey was carried out over the field in preparation for a 1 000 km detailed survey planned to be undertaken following the removal of the "Ocean Digger" unit and its anchoring system from the centre of the field.

The consortium was granted Access Authority No. 38SL over parts of WA-23-P and WA-59-P in order to investigate a possible pipeline route, a marine terminal and approach channels necessary to accept shipping (see Figure 3).

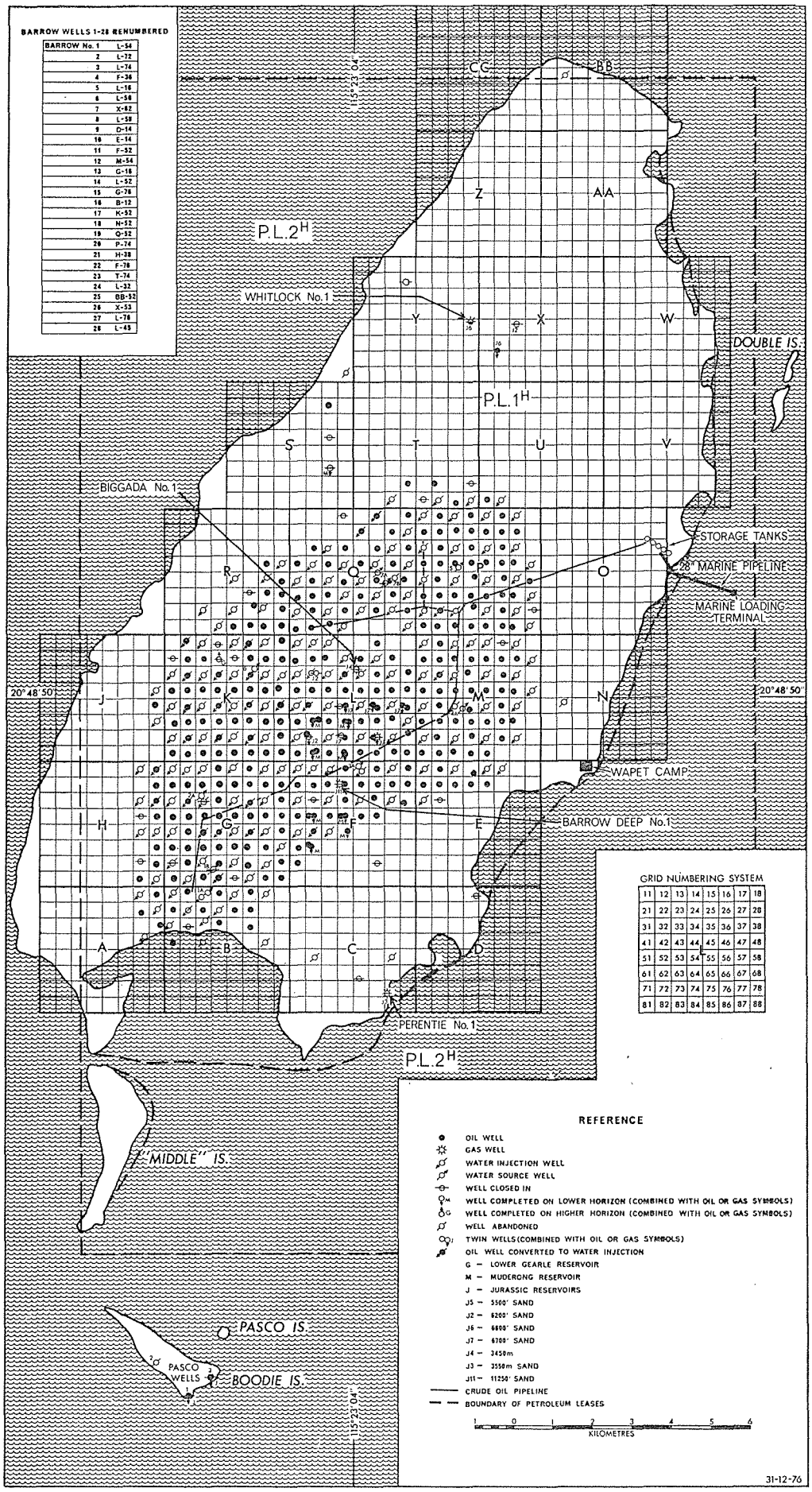

Figure 2. Barrow Island Field, northern Carnarvon Basin. Status of wells with respect to the "Windalia Sand" reservoir on 31st December, 1976.

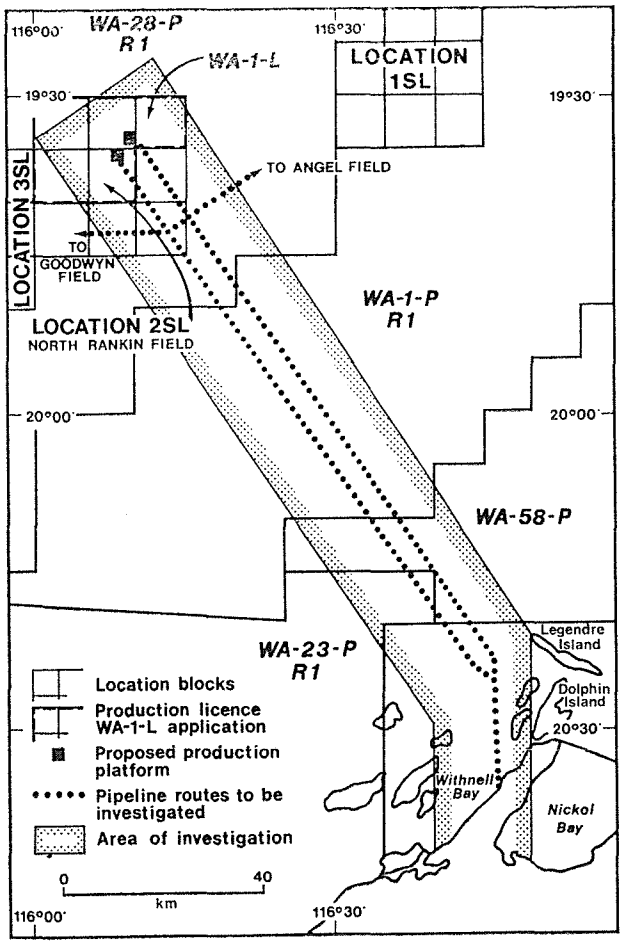

Figure 3. North Rankin to Dampier proposed pipeline route investigation.

Dongara and Mondarra Fields

(Operator—West Australian Petroleum Pty. Limited.)

A pressure survey was undertaken in order to obtain data to determine more accurately reserve estimates of the Dongara and Mondarra Fields. In order to maintain gas deliverability from the Dongara/Mondarra Fields, four 1200 horsepower compressors were installed in 1976. The status of wells in these fields is shown in Figure 5.

Prolonged testing of the oil leg, which was commenced in July 1975 with the object of establishing the productive potential and individual characteristics of each of the five oil wells, was continued throughout the year. Test Production was from wells 10 and 17. The average daily production of oil from the wells during 1976 was 31 m^3.

PETROLEUM PRODUCTION

Barrow Island Field

The total production and disposal of liquids and gas produced at Barrow Island is shown in Table III. Of the associated gas produced with the crude oil some 12.5% is used as field fuel and the remainder flared after the extraction of the plant products (liquid petroleum gas and natural gasoline). The natural gasoline is mixed with the crude oil, while the liquid petroleum gas is either sold to market in the Northwest of the State, or, if these are not available, blended in with the crude oil. The daily average production of crude oil for each month from the start of production until the end of 1976 is shown in Figure 4.

As from the 18th September, 1976, the price of Barrow Island crude f.o.b. Kwinana was increased from $2.73/barrel to $2.88/barrel. The total royalty paid on sales during 1976 increased by 10 per cent to $1 277 850 (Table III).

A breakdown by reservoirs of the annual and cumulative production for the Barrow Island field is given in Table IV.

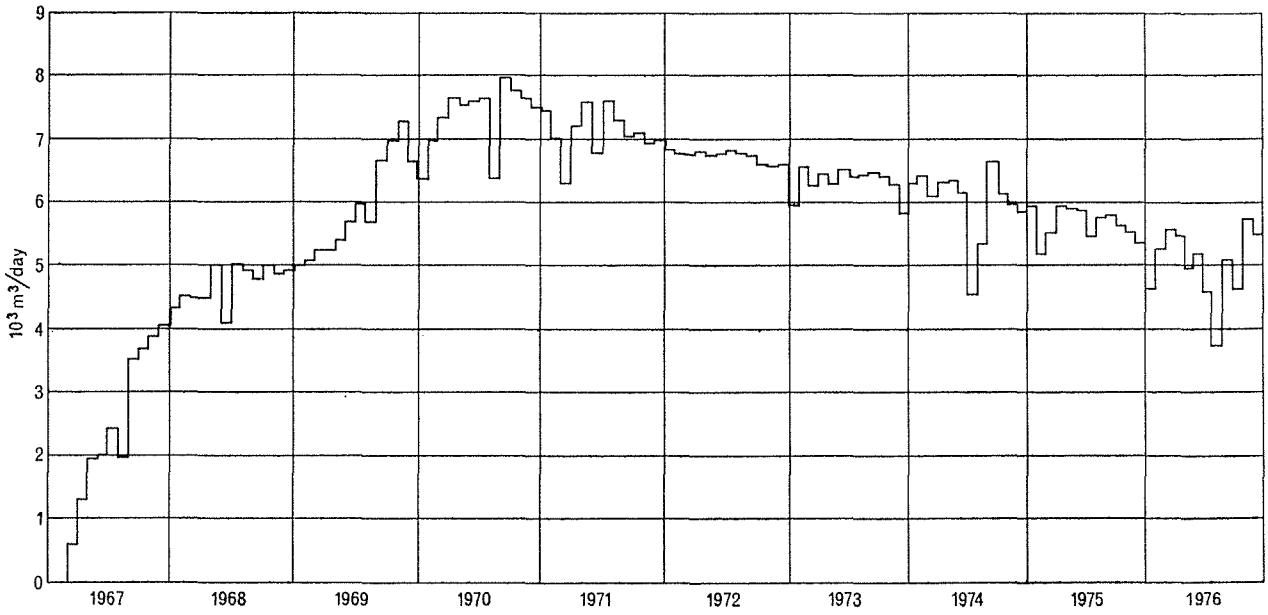

Figure 4. Barrow Island Field (Petroleum Lease 1H), northern Carnarvon Basin. Average daily production of crude oil month by month between March, 1967 and 31st December, 1976.

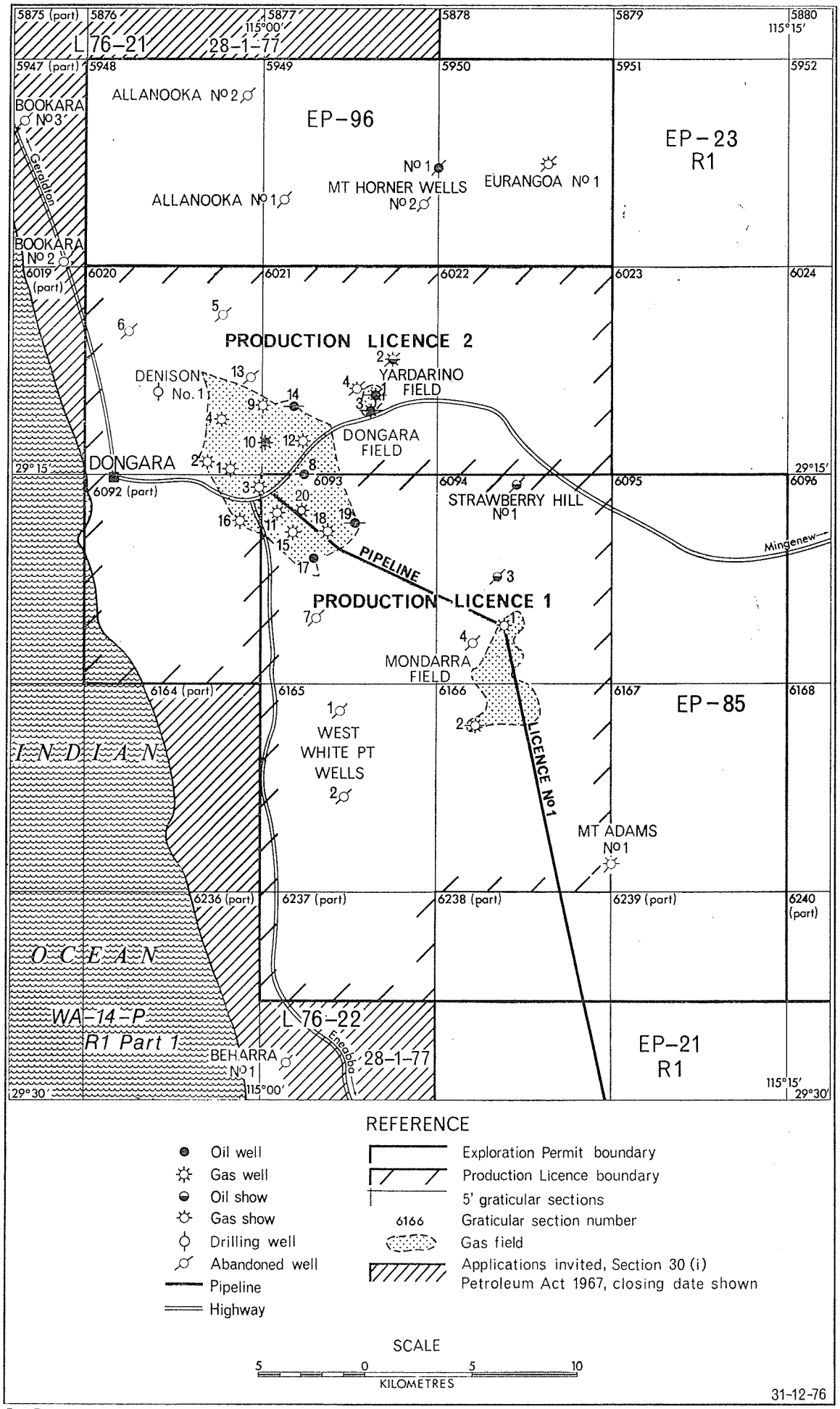

Figure 5. Dongara area, northern Perth Basin. Status of petroleum tenements and wells at 31st December, 1976 (1: 1 000 000 Map Series, Perth Sheet).

TABLE III

BARROW ISLAND FIELD OIL AND GAS DISPOSAL DURING 1976

	Oil	Natural gasoline	Liquefied petroleum gas	Gas
	m^3 (bbls)	m^3 (bbls)	m^3 (bbls)	$10^3 m^3$
Total Production	1 822 782 (11 464 932)	3 348 (21 058)	3 443 (21 657)	130 591
Field Fuel	....	....	401 (2 522)	16 294
Sales	1 768 848 (11 125 697)	....	2 634 (16 567)	....

Royalty paid on petroleum sales during 1976 = $A 1 277 850

Dongara, Mondarra and Gingin Fields

Table V shows the quantities of the various types of petroleum produced from the northern Perth basin during 1976 together with the cumulative production since 1971.

Gas production from all three fields averaged 2.3 x 10^6 m^3/day, an increase over the 1975 figures of 3.2%. It is now estimated that approximately 28% of the in-place gas reserves at Dongara and Mondarra have been produced. At the end of January, 1976 the Gingin Field failed to sustain further production. The facilities and spur pipeline were removed and subsequently installed at Dongara No. 8 in preparation to testing the oil leg at that location.

The monthly gas production from the northern Perth Basin between 25th October, 1971 and 31st December, 1976 is shown in Figure 6.

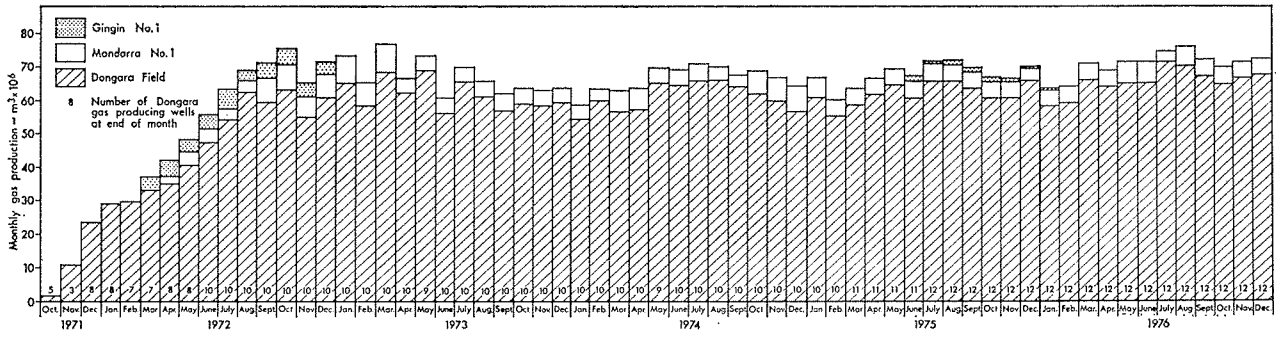

Figure 6. Dongara, Mondarra and Gingin Fields, northern Perth Basin. Monthly gas production between 25th October, 1971 and 31st December, 1976.

PETROLEUM PIPELINES

Dongara to Pinjarra Natural Gas Pipeline

(Operator—West Australian Natural Gas Pty. Ltd.)

The Branch has worked in close liaison with the pipeline operator and the public authorities initiating public works during the year to ensure the continued safe operation of the pipeline. A total of 236 transmittals, each covering multiple work proposals, were received from the various Public Utilities and processed with reference to petroleum pipelines during 1976.

SAFETY

A summary of all accidents reported from the petroleum exploration production and pipeline industry during 1976 is presented in Table VI. No fatalities occurred. The frequency rate and severity rate variations by quarters for 1976 are shown in Figure 7 which also shows those of 1975 for comparison.

There were no accidents reported either for the West Australian Petroleum Pty. Ltd. producing gas field at Dongara or the West Australian Natural Gas Pty. Ltd. pipeline operations.

TITLES

Offshore (see Table VII and Figure 8)

Some 29 areas were advertised inviting applications for petroleum exploration permits, thus completing the offer of all vacant offshore areas relinquished during 1974-1975. Four areas were made available for application without a closing date. Eighteen permit applications were received. Of these one was granted, two competitive applications were refused and the remainder were pending at the end of the year. One permit applied for in 1975 was granted, six Access Authorities were granted and consent was given for Scientific Investigation No. 10, a major geophysical survey of the Exmouth Plateau by Geophysical Service International.

Major changes took place in the structure of the North West Shelf Joint Venturers consortium. For offshore permits 28, 29 and 31 to 35 the permittee constitution on 1st January, 1976 was:—

Woodside Oil No Liability,

Shell Development (Australia) Pty. Ltd., and

BOCAL Pty. Ltd. (Operator).

On 31st December, 1976 the permittee constitution of these permits was:—

Woodside Oil No Liability

Woodside Petroleum Development Pty. Ltd. (Operator)

Mid Eastern Oil No Liability

North West Shelf Development Pty. Ltd.

BP Petroleum Development Australia Pty. Ltd., and

California Asiatic Oil Company.

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TABLE IV
BARROW ISLAND FIELD: PETROLEUM PRODUCTION DURING 1976

Reservoir	Production for year 1976					Cumulative Production				
	Oil m^3 (bbls)	N.G. m^3 (bbls)	L.P.G. m^3 (bbls)	Gas 10^3m^3	Water m^3 (bbls)	Oil m^3 (bbls)	N.G. m^3 (bbls)	L.P.G. m^3 (bbls)	Gas 10^3m^3	Water m^3 (bbls)
Lower Gearle	7 845 (49 341)	....	....	1 192	68 (429)	29 047 (182 700)	....	....	3 681	176 (1 108)
Windalia	1 777 931 (11 182 829)	3 348 (21 058)	3 443 (21 657)	109 793	756 889 (4 760 680)	20 143 972 (126 701 552)	16 950 (106 609)	16 835 (105 887)	1 861 683	5 102 414 (32 093 164)
Muderong	19 026 (119 667)	....	....	2 848	11 348 (71 379)	213 592 (1 343 451)	....	....	32 789	69 464 (436 917)
Jurassic 6 600′	5 050 (31 762)	....	....	332	13 500 (84 913)	68 446 (430 510)	....	....	23 132	128 951 (811 074)
Jurassic 6 700′	12 657 (79 610)	....	....	5 977	11 238 (70 685)	209 241 (1 316 081)	....	....	116 145	79 576 (500 515)
Jurassic 3 550 m	100 *(629)	....	....	4 229	41 (255)	100 *(629)	....	....	4 229	41 (255)
Jurassic 11 250′	174 *(1 094)	....	....	6 220	69 (432)	461 *(2 897)	....	....	17 869	184 (1 160)
Total	1 822 783 (11 464 932)	3 348 (21 058)	3 443 (21 657)	130 591	793 153 (4 988 773)	20 664 859 (129 977 820)	16 950 (106 609)	16 835 (105 887)	2 059 528	5 380 806 (33 844 193)
Cumulative totals for reservoirs which did not produce in 1976						12 009 (75 534)	....	....	98 442	36 002 (226 447)
Cumulative grand totals						20 676 868 (130 053 354)	16 950 (106 609)	16 835 (105 887)	2 157 970	5 416 808 (34 070 640)

Water injected during 1976 = 5 217 241 m^3 (32 815 400 bbls). Cumulative water injected = 42 663 498 m^3 (268 344 870 bbls).

NOTES:

1. *Denotes condensate which is blended with crude for sale.
2. Metric standard conditions for both gas and oil are 15°C and 101·325 kPa.
3. Where oil is expressed in barrels, imperial standard conditions are used, i.e. 60°F and 14·73 psia.

TABLE V

DONGARA, MONDARRA AND GINGIN FIELDS: PETROLEUM PRODUCTION DURING 1976

Field	Number of producing wells at 31/12/1976	Production for year 1976				Cumulative production			
		Gas 10^3m^3	Condensate m^3 (bbls)	Oil m^3 (bbls)	Water m^3 (bbls)	Gas 10^3m^3	Condensate m^3 (bbls)	Oil m^3 (bbls)	Water m^3 (bbls)
Dongara	13	782 735	3 233 (20 355)	11 351 (71 395)	3 764 (23 695)	3 643 605	18 547 (116 657)	16 734 (105 253)	15 451 (97 184)
Mondarra	1	57 089	682 (4 289)	....	497 (3 126)	279 861	4 836 (30 417)	....	1 522 (9 573)
Gingin	....	597	34 (214)		110 (692)	48 561	3 164 (19 901)		3 488 (21 939)
Total	14	840 421	3 949 (24 838)	11 351 (71 395)	4 371 (27 493)	3 972 027	26 547 (166 975)	16 734 (105 253)	20 461 (128 696)

Total gas sold in 1976 = 861 269 x 10^3m^3. Total royalties paid on petroleum sales during 1976 = $A 504 974.61

NOTES:

1. Metric standard conditions for both gas and oil are 15°C and 101·325 kPa.
2. Where oil is expressed in barrels, imperial standard conditions are used, i.e. 60°F and 14·73 psia.

TABLE VI

ACCIDENT STATISTICS RELATING TO THE PETROLEUM EXPLORATION, PRODUCTION AND PIPELINE INDUSTRY DURING 1976

PETROLEUM INDUSTRY CATEGORIES

	Drilling Activities		Barrow Island Oilfield	Dongara Gasfield	Natural Gas Transmission Pipeline	Seismic Activities		Totals
	Onshore	Offshore				Onshore	Offshore	
NATURE OF INJURY			**NUMBER OF INJURIES**					
Head	....	5	6	1	....	....	1	13
Eye	....	5	24	....	....	....	....	29
Trunk	....	8	18	2	....	....	....	28
Arm	....	3	13	1	....	....	....	17
Hand	....	6	23	2	1	....	....	32
Leg	1	5	7	....	....	....	....	13
Foot	....	4	5	....	....	....	1	10
Occupational diseases	....	....	1	....	....	....	....	1
Other injuries and shock	....	2	....	....	....	....	....	2
AGENCY OF INJURY			**NUMBER OF INJURIES**					
Machinery in operation	....	2	4	....	....	....	....	6
Vehicles	....	....	3	....	....	....	....	3
Tools-hand	....	4	12	....	1	....	....	17
Tools-power	....	....	....	....	....	....	....	....
Manual handling	....	7	24	1	....	....	....	32
Harmful contacts	....	2	20	....	....	....	....	22
Persons falling or striking	....	8	15	2	....	....	1	26
Objects flying or falling	1	10	19	1	....	....	....	31
Other	....	3	1	....	....	....	....	4
MAGNITUDE OF INJURY			**NUMBER OF ACCIDENTS**					
Minor	....	29	63	4	1	....	....	97
Serious	1	6	31	....	....	....	1	39
Fatal	....	....	....	....	....	....	....	....
TIME FACTOR			**EXPOSURE TIME AND TIME LOST**					
Thousands of manhours exposure	19	190	329	19	17	6	13	593
Manhours lost*	16	488	2 168	....	....	....	280	2 952

* A nominal 8 hour day is assumed.

TABLE VII

DEALINGS UNDER THE PETROLEUM (SUBMERGED LANDS) ACT 1967, DURING 1976.

(Abbreviations are listed after Table VIII)

(a) ADVERTISEMENTS (SECTION 20)

Area Number	Basin	Date gazetted	Closing date	No. of Blocks
"Closing date" areas (Section 20, (1))				
W76–6	Carnarvon	19/3/76	23/7/76	25
W76–7	Carnarvon	19/3/76	23/7/76	22
W76–8	Carnarvon/Canning	19/3/76	23/7/76	16
W76–9	Canning	19/3/76	23/7/76	235
W76–10	Canning	19/3/76	23/7/76	239
W76–11	Canning/Browse	19/3/76	23/7/76	277
W76–12	Canning	19/3/76	23/7/76	226
W76–13	Canning	19/3/76	23/7/76	250
W76–14	Canning	19/3/76	23/7/76	247
W76–15	Canning	19/3/76	23/7/76	248
W76–16	Browse	4/6/76	8/10/76	202
W76–17	Canning/Browse	4/6/76	8/10/76	248
W76–18	Browse	4/6/76	8/10/76	242
W76–19	Browse	4/6/76	8/10/76	233
W76–20	Browse/Bonaparte Gulf	4/6/76	8/10/76	249
W76–21	Bonaparte Gulf	4/6/76	8/10/76	251
W76–22	Bonaparte Gulf	4/6/76	8/10/76	253
W76–23	Bonaparte Gulf	4/6/76	8/10/76	254
W76–24	Bonaparte Gulf	4/6/76	8/10/76	247
W76–25	Bremer	6/8/76	3/12/76	274
W76–26	Bremer	6/8/76	3/12/76	324
W76–27	Bremer	6/8/76	3/12/76	236
W76–28	Eucla	6/8/76	3/12/76	280
W76–29	Eucla	6/8/76	3/12/76	279
W76–30	Eucla	6/8/76	3/12/76	388
W76–31	Carnarvon	6/8/76	3/12/76	234
W76–32	Carnarvon	6/8/76	3/12/76	250
W76–33	Carnarvon	6/8/76	3/12/76	248
W76–34	Carnarvon	6/8/76	3/12/76	249
			Sub-total	6 676
"No closing date" areas (Section 20, (3))				
W75–1	Perth	2/7/76	....	231
W75–2	Perth	2/7/76	....	16
W76–3	Perth	2/7/76	....	44
W75–4	Perth	2/7/76	....	14
			Sub-total	305
			Grand total	6 981

(b) EXPLORATION PERMIT APPLICATIONS AND GRANTS (SECTIONS 21 AND 22)

Application or Permit Number	Area Number	Applicant	Date	Basin	No. of Blocks	Status	Operative Date
WA–58–P	....	W.E.	17/10/75	Carnarvon/Canning	222	Granted	12/7/76
WA–59–P	W75–5	Esso/WMC	7/1/76	Perth/Carnarvon	190	Granted	19/6/76
WA–60–P	W76–5	Ampol/Shell	9/1/76	Perth/Carnarvon	190	Refused	30/6/76
WA–61–P	W76–5	XLX N.L.	9/1/76	Perth/Carnarvon	190	Refused	30/6/76
WA–62–P	W76–12	Oxoco *et al*, 1	21/7/76	Canning	226	Pending	....
WA–63–P	W76–13	Oxoco *et al*, 1	21/7/76	Canning	250	Pending	....
WA–64–P	W76–7	Offshore *et al*	21/7/76	Carnarvon	22	Pending	....
WA–65–P	W76–9	Getty *et all*	22/7/76	Canning	235	Pending	....
WA–66–P	W76–10	Meekatharra	23/7/76	Canning	239	Pending	....
WA–67–P	W76–12	Meekatharra	23/7/76	Canning	226	Pending	....
WA–68–P	W76–20	Oxoco *et al*, 2	5/10/76	Browse/Bonaparte Gulf	249	Pending	....
WA–69–P	W76–21	Oxoco *et al*, 2	5/10/76	Bonaparte Gulf	251	Pending	....
WA–70–P	W76–21	Getty *et al* 2	7/10/76	Bonaparte Gulf	251	Pending	....
WA–71–P	W76–21	Crusader	8/10/76	Bonaparte Gulf	251	Pending	....
WA–72–P	W76–18	Oberon	8/10/76	Browse	242	Pending	....
WA–73–P	W76–21	Magnet *et al*	8/10/76	Bonaparte Gulf	251	Pending	....
WA–74–P	W76–22	Pelsart	8/10/76	Bonaparte Gulf	253	Pending	....
WA–75–P	W76–24	Pelsart	8/10/76	Bonaparte Gulf	247	Pending	....
WA–76–P	W76–21	Pelsart	8/10/76	Bonaparte Gulf	251	Pending	....

(c) SPECIAL AUTHORITIES AND CONSENTS (SECTIONS 112 AND 123)

(AA = Access Authority—Section 112

SI = Scientific Investigation—Section 123)

Number	Applicant	Basin or area	Operating permit	Permit or area	Period
AA35SL	ARCO *et al*	Bonaparte Gulf	WA-16-P, WA-18-P	Vacant	5/3/76- 4/4/76
AA36SL	WAPET	Perth	WA-14-P	Vacant	13/3/76-12/5/76
AA37SL	BOCAL *et al*	Bonaparte Gulf	WA-36-P	Vacant	10/3/76- 9/4/76
AA38SL	Woodside *et al* 1	Carnarvon	WA-28-P	WA-23-P and WA-58-P	20/12/76-19/6/77
AA39SL	WAPET	Carnarvon	WA-24-P	Vacant	24/12/76-23/1/77
AA40SL	WAPET	Carnarvon	WA-25-P	Vacant	24/12/76-23/1/77
SI10SL	G.S.I.	Exmouth Plateau	....	Vacant	4/7/76- 3/1/77

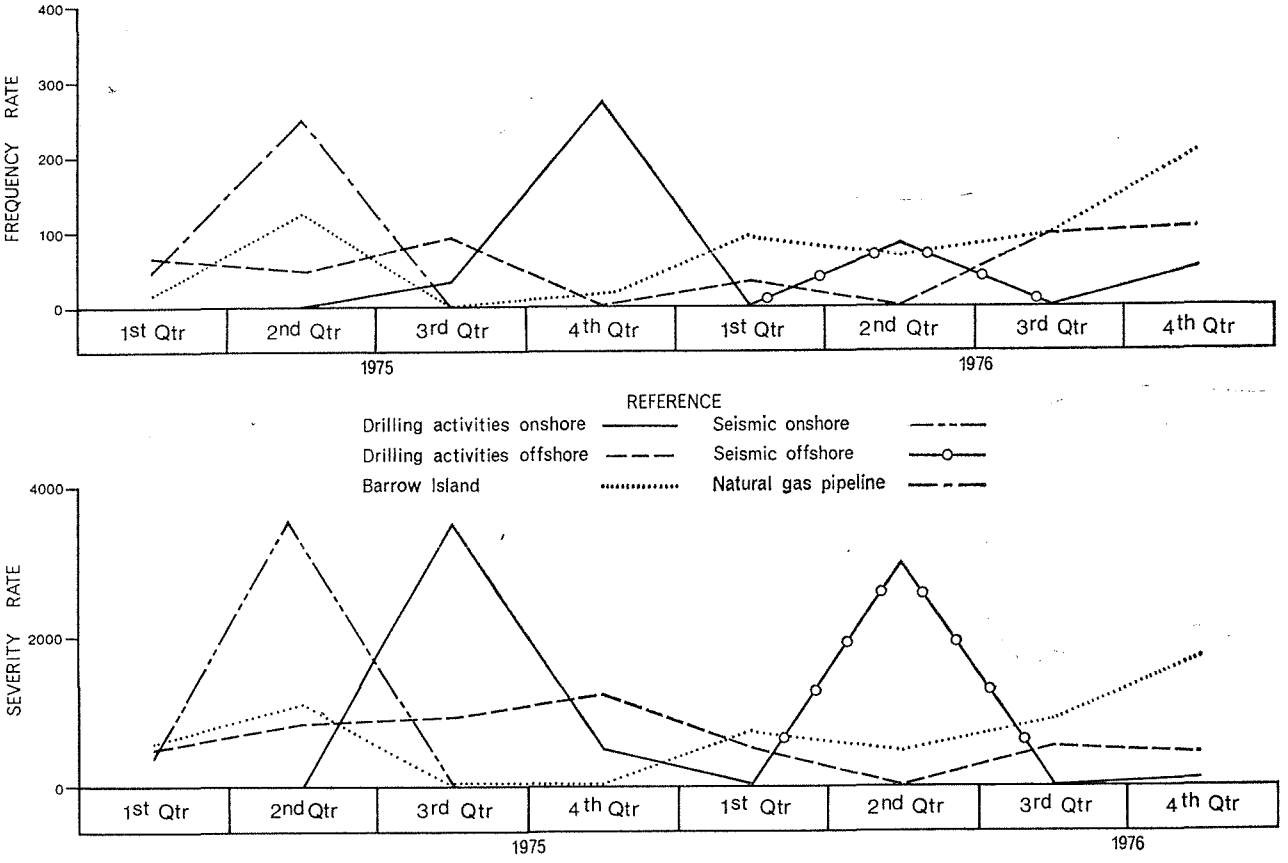

Figure 7. Series injuries in the petroleum exploration, production and pipeline industries. Frequency and severity rates
Figure 8. Petroleum tenements affected by dealings, and areas advertised for petroleum exploration, during 1976.

Onshore (See Table VIII and Figure 8).

Fifteen onshore areas were advertised inviting applications for permits and 13 areas were made available without a closing date. Eleven applications for exploration permits were submitted; six were granted, four were refused and one remained pending at the end of the year.

STAFF

The staff of the Petroleum Branch during 1976 were as follows:—

A. J. Sharp—Senior Petroleum Engineer (Level 5) and Acting Branch Head.

A. H. Pippet—Reservoir Engineer (Level 4).

P. H. J. Hammett—Petroleum Engineer (Operations) (Level 4).

R. N. Cope—Production Geologist (Level 4).

I. M. Dienaar—Typist/Receptionist (C-V), 1/1/76-31/12/76.

A. J. SHARP,
Acting Head.

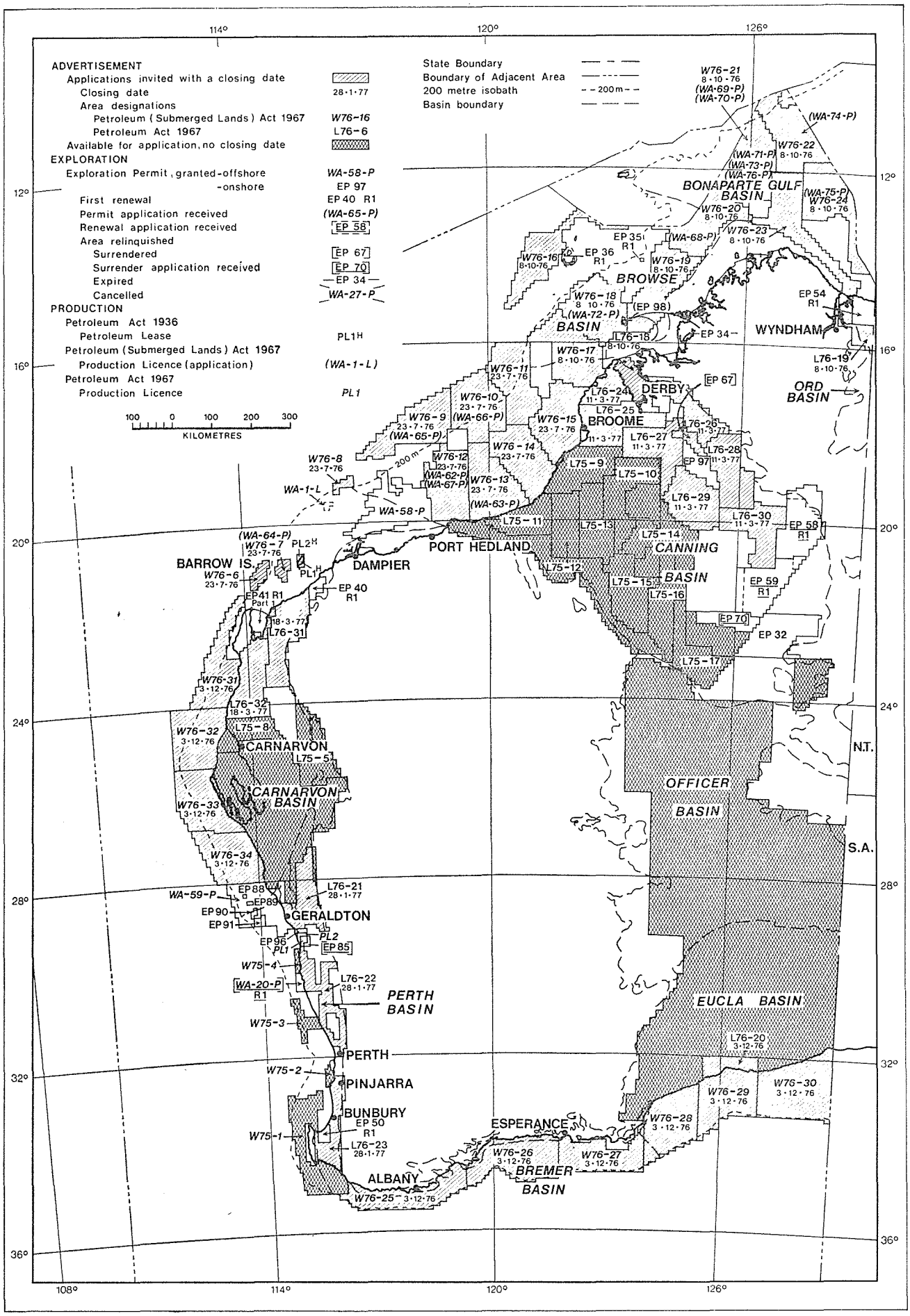
ADVERTISEMENT
Applications invited with a closing date
Closing date 28·1·77
Area designations
Petroleum (Submerged Lands) Act 1967 W76-16
Petroleum Act 1967 L76-6
Available for application, no closing date
EXPLORATION
Exploration Permit, granted-offshore WA-58-P
-onshore EP 97
First renewal EP 40 R1
Permit application received (WA-65-P)
Renewal application received EP 58
Area relinquished
Surrendered EP 67
Surrender application received EP 70
Expired EP 34
Cancelled WA-27-P
PRODUCTION
Petroleum Act 1936
Petroleum Lease PL1H
Petroleum (Submerged Lands) Act 1967
Production Licence (application) (WA-1-L)
Petroleum Act 1967
Production Licence PL1
State Boundary
Boundary of Adjacent Area
200 metre isobath
Basin boundary
100 0 100 200 300
KILOMETRES
114°
120°
126°
108°
12°
16°
20°
24°
28°
32°
36°
BONAPARTE GULF BASIN
BROWSE BASIN
WYNDHAM
ORD BASIN
DERBY
BROOME
PORT HEDLAND
CANNING BASIN
DAMPIER
BARROW IS.
CARNARVON
CARNARVON BASIN
OFFICER BASIN
EUCLA BASIN
PERTH BASIN
GERALDTON
PERTH
PINJARRA
BUNBURY
ESPERANCE
ALBANY
BREMER BASIN
N.T.
S.A.
W76-21 8·10·76 (WA-69-P) (WA-70-P)
(WA-74-P)
W76-22 8·10·76
(WA-71-P) (WA-73-P) (WA-76-P)
W76-20 8·10·76
W76-23 8·10·76
W76-24 8·10·76
(WA-75-P)
(WA-68-P)
EP 35 R1
EP 36 R1
W76-16 8·10·76
W76-19 8·10·76
W76-18 8·10·76
(EP 98)
(WA-72-P)
EP 54 R1
EP 34
L76-18 8·10·76
W76-17 8·10·76
L76-19 8·10·76
W76-11 23·7·76
W76-10 23·7·76
(WA-66-P)
L76-24 11·3·77
L76-25
EP 67
W76-9 23·7·76 (WA-65-P)
W76-15 23·7·76
11·3·77
L76-27 11·3·77
L76-26 11·3·77
L76-28 11·3·77
EP 97
W76-14 23·7·76
W76-12 23·7·76 (WA-62-P) (WA-67-P)
W76-13 23·7·76 (WA-63-P)
W76-8 23·7·76
200 m
WA-1-L
WA-58-P
L75-9
L75-10
L76-29 11·3·77
L76-30 11·3·77
EP 58 R1
L75-11
L75-13
L75-14
L75-12
L75-15
L75-16
EP 59 R1
(WA-64-P)
W76-7 23·7·76 PL2H
W76-6 23·7·76 PL1H
EP 40 R1
EP 41 R1 Part 1
18·3·77
L76-31
EP 70
EP 32
L75-17
W76-31 3·12·76
L76-32 18·3·77
L75-8
W76-32 3·12·76
L75-5
W76-33 3·12·76
W76-34 3·12·76
WA-59-P
EP 88
EP 89
EP 90
EP 91
L76-21 28·1·77
EP 96 PL1
PL2
EP 85
W75-4
WA-20-P R1
L76-22 28·1·77
W75-3
W75-2
W75-1
EP 50 R1
L76-23 28·1·77
L76-20 3·12·76
W76-29 3·12·76
W76-30 3·12·76
W76-28 3·12·76
W76-26 3·12·76
W76-27 3·12·76
W76-25 3·12·76

TABLE VIII

DEALINGS UNDER THE PETROLEUM ACT, 1967, DURING 1976
(Abbreviations are listed after the table)

(a) ADVERTISEMENTS, SECTION 30)

Area Number	Basin	Date Gazetted	Closing Date	No. of Blocks
"Closing date" areas (Section 30(1))				
L76–18	Browse	4/6/76	8/10/76	1
L76–19	Bonaparte Gulf	4/6/76	8/10/76	76
L76–20	Eucla	6/8/76	3/12/76	81
L76–21	Perth	1/10/76	28/1/77	170
L76–22	Perth	1/10/76	28/1/77	163
L76–23	Perth	1/10/76	28/1/77	135
L76–24	Canning	12/11/76	11/3/77	199
L76–25	Canning	12/11/76	11/3/77	196
L76–26	Canning	12/11/76	11/3/77	172
L76–27	Canning	12/11/76	11/3/77	184
L76–28	Canning	12/11/76	11/3/77	200
L76–29	Canning	12/11/76	11/3/77	200
L76–30	Canning	12/11/76	11/3/77	200
L76–31	Carnarvon	26/11/76	18/3/77	200
L76–32	Carnarvon	26/11/76	18/3/77	200
			Sub-total	2 377
"No closing date" areas (Section 30 (3))				
L75–5	Carnarvon	2/4/76	....	188
L75–6	Carnarvon	2/4/76	....	137
L75–7	Carnarvon	2/4/76	....	133
L75–8	Carnarvon	2/4/76	....	132
L75–9	Canning	2/4/76	....	200
L75–10	Canning	2/4/76	....	200
L75–11	Canning	2/4/76	....	146
L75–12	Canning	2/4/76	....	138
L75–13	Canning	2/4/76	....	172
L75–14	Canning	2/4/76	....	193
L75–15	Canning	2/4/76	....	194
L75–16	Canning	2/4/76	....	200
L75–17	Canning	2/4/76	....	192
			Sub-total	2 225
			Grand total	4 602

(b) EXPLORATION PERMIT APPLICATIONS AND GRANTS (SECTIONS 31 AND 32)

Application or Permit Number	Area Number	Applicant	Date	Basin	No. of Blocks	Status	Operative Date
EP 87	....	Elvet	9/12/75	Perth	3	Withdrawn	4/3/76
EP 88	L75–1	Esso/W.M.C.	7/1/76	Carnarvon	1	Granted	19/6/76
EP 89	L75–2	Esso/W.M.C.	7/1/76	Carnarvon	2	Granted	19/6/76
EP 90	L75–3	Esso/W.M.C.	7/1/76	Perth	4	Granted	19/6/76
EP 91	L75–4	Esso/W.M.C.	7/1/76	Perth	7	Granted	19/6/76
EP 92	L75–1	Ampol/Shell	9/1/76	Carnarvon	1	Refused	30/6/76
EP 93	L75–2	Ampol/Shell	9/1/76	Carnarvon	2	Refused	30/6/76
EP 94	L75–3	Ampol/Shell	9/1/76	Perth	4	Refused	30/6/76
EP 95	L75–4	Ampol/Shell	9/1/76	Perth	7	Refused	30/6/76
EP 96	....	XLX N.L.	9/6/76	Perth	3	Granted	4/11/76
EP 97	....	Whitestone *et al*	11/8/76	Canning	64	Granted	17/9/76
EP 98	L76–19	Oberon	8/10/76	Browse	1	Pending	....

(c) EXPLORATION PERMIT EXPIRIES AND RENEWALS (SECTIONS 39 TO 42)

Permit Number	Basin	Permittee	No. of Blocks	First Term Expiry Date	Status	No. of Renewed Blocks
EP 34	Browse	Bocal *et al*	1	15/4/76	Expired	....
EP 35	Browse	Bocal *et al*	1	15/4/76	Renewed	1
EP 36	Browse	Bocal *et al*	1	15/4/76	Renewed	1
EP 40	Carnarvon	WAPET	67	26/7/76	Renewed	19
EP 41	Carnarvon	WAPET	180	18/7/76	Renewed	106
EP 50	Perth	WAPET	110	1/9/75	Renewed	18
EP 54	Bonaparte Gulf	Alliance	123	22/9/75	Renewed	47
EP 58	Canning	A.A.R. *et al*	200	20/7/76	Pending	(150)
EP 59	Canning	A.A.R. *et al*	186	20/7/76	Pending	(139)
EP 61	Carnarvon	WAPET	4	19/9/76	Renewed	4
EP 62	Carnarvon	WAPET	8	19/9/76	Renewed	8
EP 63	Carnarvon	WAPET	4	19/9/76	Renewed	4
EP 65	Carnarvon	WAPET	2	19/9/76	Renewed	2
EP 66	Carnarvon	WAPET	1	19/9/76	Renewed	1

(d) EXPLORATION PERMIT SURRENDERS (SECTION 98)

Permit Number	Basin	Permittee	Date Surrender	No. of Blocks	
				Original	Renewed
EP 32	Canning	Beach *et al*	23/1/76	200	200
EP 67	Canning	WAPET	25/6/76	29	29
Totals				229	229

(e) SPECIAL AUTHORITY (SECTION 106)
(AA = Access Authority)

Number	Applicant	Basin	Operating Permit	Permit or Area	Period
AA4	Whitestone *et al*	Canning	EP 97	Vacant	17/9/76–16/12/76

Abbreviations:

A.A.R. *et al*	A.A.R. Limited Abrolhos Oil and Investments Ltd. Australian Aquitaine Petroleum Pty. Limited Ashburton Oil No Liability Flinders Petroleum No Liability Longreach Oil Limited Pursuit Oil No Liability
Alliance	Alliance Oil Development Australia N.L.
Ampol	Ampol Exploration Limited
ARCO *et al*	Arco Australia Limited Australian Aquitaine Petroleum Pty. Ltd. Esso Exploration and Production Australia Inc.
Beach *et al*	Beach General Exploration Pty. Ltd. Australian Aquitaine Petroleum Pty. Limited
BOCAL *et al*	Bocal Pty. Ltd. Shell Development (Australia) Proprietary Limited Woodside Oil No Liability
Crusader	Crusader (Surat) Pty. Ltd.
Elvet	Elvet Exploration Pty. Ltd.
Esso	Esso Exploration and Production Australia Inc.
Getty *et al* 1	Getty Mining Pty. Limited Phillips Australian Oil Company Hematite Petroleum Pty. Ltd. The Shell Company of Australia
Getty *et al* 2	Getty Oil Development Company Limited Union Texas Australia Inc.
G.S.I.	Geophysical Service International
Meekatharra	Meekatharra Minerals (Australia) Pty. Ltd.
Magnet *et al*	Magnet Metals Limited Malita Exploration Pty. Ltd.

Oberon	Oberon Oil Pty. Ltd.
Offshore *et al*	Offshore Oil N.L. Southern Cross Exploration N.L. Hallmark Minerals N.L.
Oxoco *et al* 1	Oxoco International Inc. Mid American Oil Company Peyto Oils Ltd. Voyager Petroleums Ltd. Australian Oil and Gas Corporation Ltd. Bridge Oil Limited Endeavour Oil Company N.L. A.A.R. Limited Offshore Oil N.L.
Oxoco *et al* 2	Oxoco International Inc. Mid American Oil Company Peyto Oils Ltd. Voyager Petroleums Ltd. Bridge Oil Limited
Pelsart	Pelsart Oil N.L.
Shell	Shell Development (Australia) Pty. Limited
WAPET	West Australian Petroleum Pty. Limited
W.E.	Western Energy Pty. Ltd.
W.M.C.	Western Mining Corporation Limited
Woodside *et al* 1	Woodside Oil No Liability Woodside Petroleum Development Pty. Ltd. Mid Eastern Oil No Liability North West Shelf Development Pty. Ltd. B P Petroleum Development Australia Pty. Ltd. California Asiatic Oil Company
Woodside *et al* 2	Woodside Oil No Liability Woodside Petroleum Development Pty. Ltd. Mid Eastern Oil No Liability Shell Development (Australia) Proprietory Limited North West Shelf Development Pty. Ltd. B P Petroleum Development Australia Pty. Ltd.
Whitestone *et al*	Whitestone Petroleum Australia Ltd. Amax Iron Ore Corporation Pennzoil Producing Australia Ltd. Australian Consolidated Minerals Ltd.

DIVISION VI

Report of the Superintendent Surveys and Mapping for the Year 1976

The Under Secretary for Mines

For the information of the Hon. Minister, I submit my report of the activities of the Survey and Mapping Division for the year ended 31st December, 1976.

The Division is divided into three branches directly responsible to my Assistant Mr. S. M. Hocking, as follows:—

Surveys, under the supervision of the Draftsman in Charge, Mr. W. R. Moore.

Mapping, under the supervision of the Draftsman in Charge, Mr. D. T. Pearce.

Public Plans, under the supervision of the Draftsman in Charge, Mr. D. J. Pollard.

The total membership of the staff now totals 119 comprising the following categories:

Professional	63
Clerical	10
General	28
Technical	5
Trainee Draftsmen	13
	119

The cost of cadastral surveys for the year dropped to $507 291 (see graph). This falling off is not expected to continue because in the last half of the year the deposited survey fees exceeded the withdrawals, for the first time since the peak of the mining upsurge of 1970-71 and the accumulated balance which was $1 858 377 at the beginning of the year, now stands at $2 030 158 as at 31st December.

All dealings under the Petroleum legislation in both the "on-shore" and "off-shore" areas, and under the Petroleum Pipelines Act, are being handled expeditiously and all maps show the up-to-date situation at any given time.

Cartography, in connection with the requirements of the Geological Survey Division and the cadastral maps for the mining industry generally, are being handled expeditiously by the Mapping and Public Plans Branches.

Itemised reports of the activities of the three branches of the Division are appended hereto.

A. A. HALL,
Superintendent,
Surveys and Mapping.

SURVEY BRANCH

1. *SURVEY ACTIVITY*

1.1 *Field.* Surveys of mining leases, claims, special act mining leases and other tenements were carried out during the year by Licensed Surveyors by commission from the Department and in accordance with its regulations and requirements. Survey work done is summarised in the following table:—

Number of Surveyors	29
Number of tenements surveyed	1 489
Number of field books lodged	214
Number of connection points established (horizontal)	41
Total boundary line run	2 860 km
Total traverse line run	8 km
Total area delineated by survey	101 232 ha
Total distance travelled (positioning)	29 642 km
Total value of cadastral survey	$486 197
Total value of connection survey	$ 21 094
	$507 291

1.2 *Surveyors.* The work performed by Survey Practitioners is itemised in the following table:—

Surveyor	Surveys	Hectares
Ranieri Bateman & Associates—		
*J. S. Ranieri	115	10 632
G. G. Bateman	26	2 896
M. M. Fisher & Associates—		
M. M. Fisher	182	8 386
E. J. Still	16	1 596
F. R. Rodda & Associates—		
*F. R. Rodda	144	15 056
D. F. V. Wilson & Associates—		
D. F. V. Wilson	166	3 260
Bennetti Croghan & Associates—		
*R. J. Benetti	62	4 177
K. J. Croghan	35	3 688
McCarthy Smirk & Associates—		
J. Zuideveld	95	8 702
M. R. Piowczyk-Kruk		
M. R. Piowczyk-Kruk	123	12 332
A. K. King & Co.		
K. M. Edwards	92	4 214
K. R. Maquire	20	488
M. J. Byrne & Associates—		
*M. J. Byrne	39	354
Kimberley F. Patterson—		
R. G. Agnew	69	2 943
Associated Surveys Pty. Ltd.—		
D. J. McGay	55	4 167
G. E. Roughan	10	1 014
McKimmie Jamieson & Partners—		
A. E. Smythe	17	456
I. F. Moss	43	1 844
M. J. McKimmie	1	10
R. J. Rule—		
R. J. Rule	34	3 652
Hille and Thompson—		
P. J. Hille	61	4 839
A. G. Thompson	5	578
H. W. Denton—		
H. W. Denton	33	2 050
Alan R. Williams—		
A. R. Williams	36	3 497
L. J. Burkett—		
L. J. Burkett	6	374
I. M. Gordon—		
I. M. Gordon	3	19
P. Meleng —		
P. Meleng	1	8
	1 489	101 232

* Includes connection surveys.

1.3 *Field Inspections.* Survey activities in the field and associated marking and other procedures were inspected by senior officers of this Branch as follows:—

1.3.1 *Laverton Area.* A considerable number of mineral claim surveys exist within the area centred on Laverton and a reconnaisance was made to determine the best places for connection of these into the existing geodetic stations. Suitable sites and connection points were located. This project is planned for implementation in the coming year. (Stewart-MacFarlane).

1.3.2 *Kalgoorlie Area.* At the same time as the investigation of Laverton, the opportunity was taken to check out the sites and relocation activity being undertaken in the survey remarking programme of the leases on the Golden Mile. This was found to be proceeding very satisfactorily. (Stewart—MacFarlane.)

1.3.3 *Ravensthorpe.* An officer accompanied surveyor J. Ranieri in the course of his reconnaisance of the Ravensthorpe area with a view to the interconnection of claims and the geodetic Stations. The general pegging and survey marking situation of claims in the Mt. Desmond, Kundip area was also inspected. (Clift.)

1.3.4 *Mooloo Downs.* Due to the known existence of a complex overpegging situation and a lack of recent survey marks generally it was decided to initiate a survey in this area. This matter arose in November and due to the lateness of the season and the impracticability of mounting a full survey operation at that time it was arranged to accomplish an inspection and preliminary location survey by the surveyor and an officer from this Branch to resolve some of the issues prior to continuation of survey in the coming season. Considerable benefit was found to accrue from this activity. (Dawson.)

1.4 *Cadastral Surveys.* These surveys of tenement boundaries, totalling 1489, were carried out at many localities throughout the State. Tenements surveyed were of all types with an increasing number of the smaller size of tenement coming into prominence. These do not require a pro-rata reduction in survey work when compared to the larger tenements and this is reflected in the various cost ratios. It became increasingly evident towards the end of the year that a lot of the prospectively important ground has now been surveyed and future work will consist of additional peggings and re-marking of old tenements being now re-applied for. This indicates the value of initial surveys forming the fundamental framework for positioning and positive identification, both on the ground and on plans, for future applications.

1.5 *Connection Projects*

1.5.1 *Kalgoorlie Lease Re-surveys.* Following the initial investigation and computations carried out in 1975, this project was brought close to completion and, being successful, was extended to the north end to cover the Mt. Charlotte area. This system, utilizing pre-calculated co-ordinates, electronic distance measuring techniques, with radiation from a control point for re-locating, remarking and re-measuring of surveys of original gold mining leases will be fully documented in a special report. Its success can be gauged from the fact that much of the original portions of the intensely mined and developed areas on this field have now been readily located, re-marked and accurately re-measured in a manner much more efficient than would be possible utilising conventional means. (Surveyors: M. J. Byrne and T. G. Moran.)

1.5.2 *Gullewa.* A set of 3 stations connecting mineral claims to the geodetic stations. (Surveyor F. R. Rodda.)

1.5.3 *Youanmi-Wyemandoo.* This project comprised a set of observations and radiations connecting onto tenement surveys at Youanmi and surrounding areas. (Surveyor: F. R. Rodda.)

1.5.4 *Ravensthorpe.* This project entailed observation of a pattern of measurements from 5 new stations onto the existing four geodetic stations in the area extending from Ravensthorpe to Kundip and east to Bandalup.

TABLE OF CONTROL

Project	Number of Stations (Adjustable)	Number of Stations (Radiations)	Number of Lines	Number of Angles
Kalgoorlie	15	11	37	58
Gullewa	3	....	4	5
Youanmi	....	6	6	5
Ravensthorpe	5	1	6	10
	23	18	53	78

1.6 *G.S.W.A. bore levels.*

1.6.1 *Bunbury.* Levels for water drilling sites near Bunbury were carried out.

1.6.2 *Collie.* A set of levels on bores and water levels on old open cuts at Collie were carried out.

2. *OFFICE ACTIVITY*

This work consisted essentially of survey instruction, survey examination, general drafting, geodetic computation and computations concerned with the calculation of A.M.G. co-ordinates throughout the mining tenement survey network. The progress made in the work involved with this last aspect is outlined in the following table:—

2.1 *Table of Co-ordinate Traversing.*

Project	Area covered North/South (km)	Area covered East/West (km)	Total length of traverses (km)	Total number of traverses
Agnew-Leinster	85	x 39	1 931	276
Hyden-Forrestania	92	x 35	1 288	132
Gullewa	36	x 34	406	41
Youanmi	38	x 43	702	54
Kalgoorlie*	8	x 2	100	91
			4 427	594

*The Kalgoorlie Project traversing generated co-ordinates for 715 lease corners of which a total of 201 have been located, re-marked and re-established in the field. See also paragraph 1.5.1.

3. *STAFF.*

The Branch is currently fully staffed but the accommodation is becoming cramped.

4. *STANDARD PLANS.*

All new surveys are being charted on the standard plans. During the year the sets of plans which had been built up and used within the Survey Branch and variously known as "Plot Sheets" or "Survey Plots" were integrated with the Standard Plan series of the Department. They have been labelled therein as PROVISIONAL STANDARD PLANS. It was thus able to achieve the situation of all surveys being now charted on a standard plan (normal or provisional). It is the intention that these provisional sheets will be progressively replaced as new plots are made from the large volume of data accumulating under the various co-ordinate programmes listed in paragraph 2.1.

Computer plots were prepared for the following projects:—

	Number at 1: 50 000	Number at 1: 10 000	other
Barrambie	4	4	....
Agnew-Leinster	8	....	....
Gullewa	3	....	....
Golden Grove	5	....	....
Hyden-Forrestania	7	....	....
North Pole	1	....	3
	28	4	3

5. *COMPUTER SYSTEM DEVELOPMENT*

The systems in use are performing satisfactorily and are adequately satisfying the current needs:

5.1 *H.P. 9810* This is used for the bulk of the normal day to day survey computation.

5.2 *PDP 11/40* Housed in the Chemical Laboratories with a terminal in this Branch. A system for storage and computation of statistics for the survey accounts has been developed and is code named "SURVACT".

The SURVACT System is an inter-related set of programmes and permanent data files residing on disk storage on the PDP 11/40 Computer. The system has been designed for the computer processing and recording of survey accounts and related statistical data at present processed by manual procedures by clerical staff within the Surveys Section. The accurate recording and checking of account data on the present account forms will still be required, however, once this data has been correctly input to the computer account file, all further processing required for the production of account reports and summaries will be automatically handled by the system.

A number of different types of statistical summaries can be produced from the master account file by means of the application programme ACTSUM. The options available are as follows:—

5.2.1 Total account summary for each division together with grand total.

5.2.2 Grand total of all divisions.

5.2.3 Account summary for a given division.

5.2.4 Account summary for a given survey company with options 5.2.1—5.2.3 above applying to accounts for that company.

The HP plotter has now been interfaced with this computer and can now be used on either system.

It is planned that in the coming year this terminal will be used for the recording of dust samples under an extended programme for the monitoring of ventilation in mines and mine sites by arrangement with the State Mining Engineers' Branch.

5.3. *CYBER 172*—Main Roads Department. This continues to be used for data associated with the LACORD, CADMAPS or VARYCORD type programmes.

6. *PETROLEUM*

Petroleum drafting activity has been in the nature of preparation of descriptions for tenement renewals and preparation of plans for renewal documents. More attention is now being given to promoting the areas available for application by advertisement in appropriate journals both within and outside Australia. All unoccupied prospective areas, both onshore and offshore are now officially grazetted as available for application. Maps and plans as necessary have been drafted for these purposes together with the continual updating of the State Petroleum Tenement Map and the various Public Plan series.

The State Map continues to be the principal vehicle for public use. As well as daily demand, the map is distributed quarterly when 87 copies are distributed to 53 subscribers.

MAPPING BRANCH

The Mapping Branch was called on to provide a heavy programme of mapping and drafting work throughout the year. Details of each section's work is set out below.

Cadastral Mapping

6 sheets at 1:100 000 on A.M.G. were completed covering Lennard River and a further 6 sheets of Noonkanbah were prepared.

On 1:50 000 scale a total of 57 sheets on A.M.G. were completed covering Leonora, Roebourne and Dampier.

A revision programme continued and a total of 108 sheets at 1:50 000 scale covering Edmund, Youanmi, Jackson, Sandstone, Hyden, and Mt. Phillips was completed.

Geological Mapping—1:250 000 Series

The printing of the 1:250 000 series 1st edition coloured maps has been financed for many years by the Commonwealth Government through the Bureau of Mineral Resources.

However, due to heavy cuts in budgets, no map was printed during the year. Six maps were awaiting publication at the end of the year, they being Edjudina, Lake Johnston, Ravensthorpe, Yalgoo, Leonora and Laverton.

There were 6 1st edition maps in progress during the year, Marble Bar, Nullagine, Sir Samuel, Duketon, Mt. Egerton and Perth.

Preliminary edition maps, which are usually printed in 3 colours were completed of Paterson Range, Yarrie and Pinjarra with Pinjarra only being printed.

New preliminaries were commenced of Onslow, Ningaloo-Yanrey, Runton, Bullen, Trainor, Port Hedland and Robinson Range.

Due to the increase in field work by G.S.W.A., this section was heavily loaded during the year and indications are for an even heavier load next year.

Geological Project Section

This section was also under heavy pressure with many projects in progress or commencing.

Three maps at 1:1 000 000 scale were completed and published of the Kalgoorlie-Esperance area.

The Urban Geology series at 1:50 000 scale was continued with the preliminary sheet of Mandurah being completed and 1st editions in full colour of Gingin and Moore River being commenced.

Bulletin work continued on Tin and the Perth Basin with colour plates at scales of 1:100 000, 1:500 000 and 1:1 000 000.

Revision of the State map at 1:1 000 000 scale continued although there were frequent stoppages due to pressure of other work.

Nearly 600 drawings were prepared for various publications such as Annual Report, Bulletins, Reports, Pamphlets, Record publications of the various branches including Government Chemical Laboratories and Explosives.

Drawings were prepared for many 35 mm slides both colour and black and white for staff members giving lectures locally, interstate and overseas.

The acquisition of an I.B.M. Selectric type composer, greatly facilitated the setting of type for various jobs. Also the texts for various publications were set out on the machine, giving a much better presentation.

Microfilm

Filming continued throughout the year at the P.W.D. and the M.R.D. as previously. Again, much unnecessary effort and travelling was expended due to us not having our own camera.

Preparation was difficult due to lack of staff but the programme of mining tenement registers was completed with 70 rolls of 35 mm film duplicated and available for use.

Interest in the Petroleum relinquishment package data continued and 614 duplicate rolls of 35 mm film were sold from over 52 original rolls.

The programme of work for the Railways was completed and 35 rolls were completed, put onto aperture cards and duplicated.

Old Mineral Claim files were filmed for Records Branch so that the files themselves can be destroyed. Over 400 rolls of 16 mm film covering mineral claim files are now available.

Photographic Section

This section was again under pressure because the increase in drafting work generates much more process and camera work.

Overall, the output from this section increased by 37% despite difficulties brought about by lack of space and staff. Overtime was continued to meet some of the demands.

On the large camera, 1 755 items were put through, 64 metal plates were made, 2 528 items were processed using the vacuum frames and general process work on the enlarger accounted for 7 404 items of which 1 827 were colour.

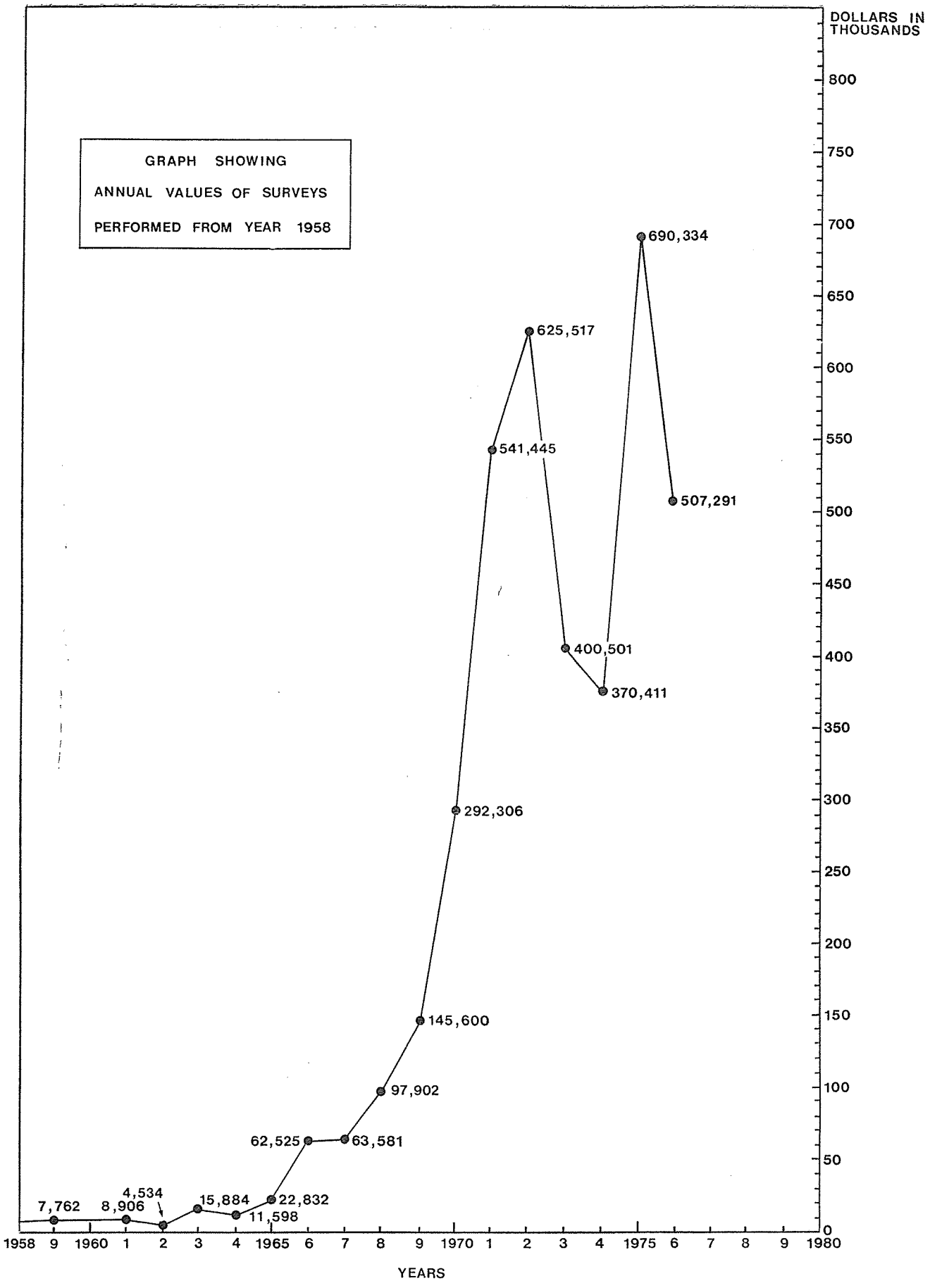
GRAPH SHOWING
ANNUAL VALUES OF SURVEYS
PERFORMED FROM YEAR 1958
DOLLARS IN THOUSANDS
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
690,334
625,517
541,445
507,291
400,501
370,411
292,306
145,600
97,902
63,581
62,525
22,832
15,884
11,598
4,534
8,906
7,762
1958 9 1960 1 2 3 4 1965 6 7 8 9 1970 1 2 3 4 1975 6 7 8 9 1980
YEARS

Photo copies of plans numbered 2 650 while 34 315 paper prints and transparencies were made on the printing machine.

Mounting of plans was again steady with 1 021 items.

In all, the supervisory staff of all sections were under constant pressure to meet demands of increased volumes and time schedules. As this trend appears to be continuing an examination of resources will be necessary in the near future to be able to adequately cope with the demands.

APPLICATIONS AND PUBLIC PLANS BRANCH

The following applications were received and processed during 1976:—

Mineral Claims	4 209
Mineral Leases	81
Gold Mining Leases	222
Licenses to Treat Tailings	41
Prospecting Areas	234
Coal Mining Leases	86
D.C's, W.R's, G.A's, Q.A's, T.L's, M.H.L's, R.A's, R.L's, M.Y.L's, D.L's etc.	42
	4 915

Applications for Temporary Reserves were handled in the section for the following Minerals:—

Iron	37
Gold	52
Coal	Nil
Other Minerals	177
	266

A back log of 130 applications for Iron Temporary Reserves was dealt with on the 29th November, 1976, resulting in 79 Iron Temporary Reserves being created at that date.

Head Office Plan Sales totalled $7 858.70 as follows:—

Dyelines	8 630
Micro, Photocopies	3 655
Transparencies	125
Gold Bearing Areas Maps	63
State Maps	200
Gazatteers	118
Mineral Occurrence Maps	192
T.R. Iron Lists	28
T.R. Other Minerals Lists	36

Updating Public Plans and replacing 40 and 80 Chain Plans by 1:50 000 has continued.

No overtime has been worked and no significant accumulation has occurred.

DIVISION VII

Government Chemical Laboratories Annual Report—1976

Under Secretary for Mines

I submit the Annual Report for 1976 on the activities of the Government Chemical Laboratories for the calendar year of 1976.

Administration

From the beginning of the year the former Food, Drug, Toxicology and Industrial Hygiene Division was split into two, the Food & Industrial Hygiene Division and the Toxicology and Drug Division. The benefit of this split soon became obvious through increased specialisation by the staff concerned creating more efficient service to the two main client Departments concerned of Public Health and Police.

The Laboratories now consist of eight Divisions: Agricultural Chemistry Division, Food and Industrial Hygiene Division, Industrial Chemistry Division, Mineral Division, Toxicology and Drug Division and Water Division on the Plain Street site, the Engineering Chemistry Division at Bentley and the Kalgoorlie Metallurgical Laboratory at Kalgoorlie.

Officers of the Laboratories served on about 30 various statutory or ad hoc committees, covering a wide range of activities in which we are involved. Mr. Goodheart as the State representative on the Australian Coal Industrial Research Laboratories Ltd and Mr. Burns as our representative on the Standards Association of Australia, Iron Ore Analysis Committees were involved in interstate travel for meetings of these organisations. A number of officers continue to serve on the executive committees of several scientific societies covering the various disciplines within the Laboratories. The National Association of Testing Authorities again called on our staff to assess and re-assess several local laboratories for registration.

Staff

At the end of the year the establishment of the Laboratories was as follows:

Professional	79
General	45
Clerical	11
Wages	2
Total	137

The main staff changes during the year were the appointments of Messrs. V. J. McLinden and F. E. Uren to the positions of Chief of the Toxicology and Drug Division and Chief of the Food & Industrial Hygiene Division respectively.

One new position of a level 2 Chemist and Research Officer as a professional assistant to the Director and Deputy Director was approved late in the year; no appointment has been made at this stage. This is the first new position approved since 1973.

Restriction on staff growth is still a major problem in coping with the increasing volume and complexity of work on which there is no growth restriction. Within the Mines Department itself, growth in the Geological Survey and State Mining Engineer Branches have generated work for which we have had no compensating growth. This recruiting restriction has been a compounding situation over the past 3-4 years and without any relief, the only solution appears to be strict order of priorities on work and considerably lengthening delays for work for which we see less justification.

Accommodation

During the year the alterations to the Agricultural Chemistry Division to incorporate our PDP 11/40 computer were completed, along with alterations to several rooms in that Division for instruments attached to the computer.

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The Plain Street building now has a mixture of fairly recently renovated rooms and a large number of older areas that need alterations or renovations to make them more useful for modern instrumentation and techniques.

There is a very definite need to provide air-conditioning for staff as well as instruments to make hot summer conditions more bearable. Much of the building is now 35 years old and the continual increase in instrumentation with their subsequent heat out-put, makes conditions in certain areas very trying in hot weather. It is hoped that finance will be made available in the coming year to start alleviating these conditions.

No start has yet been made on extensions to the Water Division for the Australian Water Resources Council Net-Work Survey or on the additional pilot plant and storage space required for the Engineering Chemistry Division at Bentley.

The Kalgoorlie Metallurgical Laboratories building at Kalgoorlie is still living on borrowed time pending a decision on the future extension of the School of Mines. Renovations during the year have improved working conditions in the building.

Library

Additional modern shelving space and new catalogue drawers have helped to make better use of our cramped library space. During the year 2 628 new items were added consisting of 286 monographs, 2 070 journal issues and 344 official publications. A further 3 new journals were added to our collection and 6 were discontinued.

Equipment

The main equipment received during the year included a 10 head sample changer for the X-ray fluorescence spectrometer, another gas chromatograph, an updating kit for the amino acid analyser, an infrared gas analyser and disc cartridges and memory management kit for the computer.

There have been prolonged delays in interfacing various instruments to the PDP 11/40 computer. It is hoped that these will all be connected in the next few months.

New equipment costs and maintenance costs have become a major concern. Prices have escalated enormously during the year due to inflation and devaluation. Much of our older instrumentation has become obsolete or too expensive to repair, so very major increases in equipment expenditure will have to occur in the coming years.

General

There has been an increase in sample receival of nearly 10 per cent compared with 1975 and that is 530 more samples than our previous record year of 1974. We are not able to cope with this volume of work requested by client departments or carry out anywhere near the number of research projects that are necessary. Many of our client departments have grown in staff numbers resulting in additional work being sent to us but we have not had the corresponding staff increases to cope. Every effort is being made by use of the computer and automated instrumentation to handle the volume of work received. Increased heavy expenditure in this area is going to be essential to try and give a reasonably rapid service to our client departments.

Most of the increased volume of work has come from the Agriculture Department and some re-organisation of our Agricultural Chemistry Division will be necessary to cope with this continuing load.

Over the past few years there has been a definite policy followed of referring as much as possible of the public work to private analysts. In many cases this still cannot be carried out by private analysts as they are not equipped to do much of the work requested. In 1966, 19.8 percent of our samples were from the general public, in 1976 only 6.6 percent were from the general public. This reduction has been mainly in water and mineral samples and of course due to the large overall increase in work for Government Departments.

The number and source of work or samples received in 1976 and their allocation to various Divisions is given in Table I.

TABLE 1.
SOURCE AND ALLOCATION OF WORK 1976

Source	Agricultural Chemistry Division	Engineering Chemistry Division	Food and Industrial Hygiene Division	Industrial Chemistry Division	Mineral Division	Toxicology and Drug Division	Water Division	Total
STATE—								
Aboriginal Lands Trust	....	....	....	....	17	....	....	17
Agriculture Department	13 432	8	603	....	2	128	25	14 198
Agriculture Protection Board	....	....	....	....	....	1	....	1
Conservation & Environment Department	....	....	33	1	....	....	20	54
Consumer Affairs Bureau	....	....	....	8	....	....	4	12
Department of Industrial Development	....	....	....	....	....	....	1	1
Education Department	21	....	....	9	....	....	....	30
Fisheries and Wildlife Department	....	....	150	....	9	....	58	217
Geological Survey	10	....	....	....	700	....	313	1 023
Government Chemical Laboratories	22	61	32	5	191	18	19	348
Government Stores Department	....	....	35	....	8	....	....	43
Labour and Industry Department	....	....	157	....	4	....	....	161
Leschenault Inlet Advisory Committee	....	....	....	....	....	....	50	50
Main Roads Department	....	....	12	1	18	....	1	32
Medical Department	....	....	....	11	....	....	....	11
Metropolitan Water Board	....	....	70	....	....	....	2 619	2 689
Mines Department	....	....	14	....	570	....	....	584
Peel Inlet Advisory Committee	....	....	....	....	....	....	81	81
Police Department	....	....	....	....	51	1 624	....	1 675
Public Health Department	181	2	1 709	3	780	7	65	2 747
Public Works Department	....	....	211	32	18	....	2 581	2 842
Regional Administrator of the North West	....	6	....	....	6	....	....	12
Road Traffic Authority	....	....	....	....	34	1 501	....	1 535
State Energy Commission	....	7	....	....	3	....	....	10
State Housing Commission	....	....	....	5	12	....	6	23
Swan River Conservation Board	....	....	....	....	....	....	238	238
Westrail	....	....	....	....	4	....	....	4
COMMONWEALTH—								
Various departments	9	....	28	....	....	3	....	40
PUBLIC—								
Free	....	....	....	....	23	....	1	24
Pay	128	118	324	130	229	551	510	1 990
TOTAL	13 803	202	3 378	205	2 679	3 833	6 592	30 692

The summarised reports of the various individual Divisions which follow, again emphasise the range of work and functions of the Laboratories. One illustration of the need to utilise the expertise of several Divisions to solve a problem was the investigation of the problem of popping or pitting of wall plaster. This problem, a major one in the building industry affecting a large number of the community, was undertaken to identify the cause, prevent its continuation and devise a treatment for affected walls. The cause of the problem and the elimination of the cause from current material was readily achieved and the building industry again had confidence in the use of traditional lime and plaster products. A satisfactory treatment for affected walls was found after several months of experimentation and trials, however the building industry were less willing to try this treatment and have generally preferred to wait till popping had ceased due to natural hydration of affected lime plaster.

In recent years there has been an increasing complexity and variety in the problems presented to us in consumer protection, environmental monitoring, drugs, pesticide residues, heavy metals, chemicals in food, water pollution, waste disposal and toxic hazards. These have all presented interesting challenges and it is pleasing to record the excellent way that staff have responded this year to these challenges.

R. C. GORMAN,
Director.

AGRICULTURAL CHEMISTRY DIVISION.

General

The year's operations saw the beginning of efforts to reorganise the Division to permit more time to be spent on research and investigation to develop more efficient procedures for the handling of service work for other departments. It became evident that in order to cope with increased quantity and variety of work it would be necessary to introduce a fresh approach based on greater instrumentation and miniaturisation of procedures.

The benefits of the introduction of a section devoted to soil chemistry, and of other changes made during the year were sufficiently established to justify persevering with the changes in anticipation that the amount of work outstanding will be reduced to a level commensurate with a satisfactory service.

Staff members attended a number of conferences, field days, lectures and symposia, and talks given by Division members as part of staff training were continued. An in-service refresher course in atomic absorption spectroscopy was initiated.

Publications

A paper entitled "The Determination of Boron in Plant Tissue by Atomic Absorption Spectrometry" by R. R. Elton-Bott was published in Analytica Chimica Acta, volume 86 p. 281.

A Report of Investigations No. 11 "A Survey of Total Mercury in Human Hair" by N. L. Wilson, G. D. Williams and Z. E. Spadek was issued.

Nature of Samples

Fluctuations in the types of sample dealt with demonstrate the changing nature of the work and the need for constant review of procedures and staff organisation.

Receivals totalled 13 803 and the nature and sources of samples is shown in Table 2.

TABLE 2
AGRICULTURAL CHEMISTRY DIVISION

	Agriculture Department	Departmental	Education Department	Geological Survey of W.A.	Other	Pay	Public Health Department	Total
ANIMAL—								
Bone	97	....	....	....	....	....	....	97
Faeces	24	....	....	....	....	....	....	24
Liver	56	....	....	....	....	....	....	56
Various	10	....	....	....	....	....	....	10
CEREAL—								
Barley	9	....	....	....	....	3	....	12
Maize	115	....	....	....	....	....	....	115
Oats	3	....	....	....	....	9	....	12
Various	4	....	....	....	....	6	....	10
Wheat	2 330	....	....	....	....	....	....	2 330
FERTILISER—								
Fertiliser Act	60	....	....	....	....	....	....	60
Various	62	....	....	....	....	16	....	78
HORTICULTURE—								
Apple leaves	487	....	....	....	....	....	....	487
Cauliflower leaves	11	....	....	....	....	....	....	11
Cherry leaves	10	....	....	....	....	....	....	10
Citrus leaves	41	....	....	....	....	....	....	41
Grapevine leaves	222	....	....	....	....	....	....	222
Peach leaves	37	....	....	....	....	....	....	37
Pear leaves	33	....	....	....	....	....	....	33
Plum leaves	22	....	....	....	....	....	....	22
Tomato	22	....	....	....	....	....	....	22
Various	44	....	....	....	....	....	....	44
MISCELLANEOUS—								
Filter paper	....	....	....	....	....	....	164	164
Rapeseed	26	....	....	....	....	....	....	26
Sheepskin trimmings	18	....	....	....	....	....	....	18
Sunflower seeds	18	....	....	....	....	....	....	18
Various	21	22	9	4	3	9	17	85
PASTURE AND STOCK FOOD—								
Birdwood grass	24	....	....	....	....	....	....	24
Clover	35	....	....	....	....	....	....	35
Feed residue	183	....	....	....	....	....	....	183
Feeding stuff	223	....	11	....	....	14	....	248
Feeding Stuffs Act	55	....	....	....	....	....	....	55
Hay	302	....	....	....	....	....	....	302
Lucerne	29	....	....	....	....	....	....	29
Lupins	2 024	....	....	....	....	4	....	2 028
Lupin seed	46	....	....	....	....	3	....	49
Pasture	2 047	....	....	....	....	....	....	2 047
Silage	28	....	....	....	....	....	....	28
Various	268	....	....	....	6	7	....	281
SOIL—								
Soil	4 386	....	1	6	....	57	....	4 450
TOTAL	13 432	22	21	10	9	128	181	13 803

The increase of 2 600 samples compared with 1975 confirmed the continuation of a sudden increase in work which occurred in 1974. Thus the average number of receivals per year for 1974-6 was 13 000 compared with 7 300 for the years 1969-73. At the end of the year 7 300 samples remained outstanding compared with 5 300 at the beginning of the year.

The increase in receivals was due almost entirely to a more than two-fold increase in the number of soil samples. There was a marked increase in work on lupin plants and seeds and fewer samples of apple and orange leaves.

Soil

The major part of the work on soil arose from investigations of the use of chemical analyses as aids for measuring the responsiveness of soils to phosphatic and nitrogenous fertilisers and the effects of various tillage practices.

Phosphorus

The continued revision by the Department of Agriculture to improve the 'Decide' method for predicting requirements for phosphatic fertiliser of cereals and pastures showed that 0.5 M sodium bicarbonate (1 : 100, 16 hours), the standard extractant for estimating residual phosphorus, was not completely effective for estimating residual phosphate in sandy soils having low phosphate adsorption capacity where leaching of phosphate was likely. Better correlations with plant yields were sought using an acid extractant, 0.5 M sulphuric acid (1 : 10, 3 hours) as used by Powrie in South Australia on similar soils.

Results from two trials testing residual values of previously applied superphosphate showed the levels of acid extractable phosphorus were about twice the bicarbonate extractable but levels were mostly below 20 ppm acid extractable P and no better relationship to plant yield was found.

In a group of soils from sites of trials on either new or old land, this two-fold difference in extractable phosphorus was again evident for sandy soils, but on better types of soil the acid solution extracted about five times the level of phosphorus extracted by sodium bicarbonate.

Comparison of these two extractants was extended to trials comparing the effectiveness of superphosphate, Christmas Island C grade rock phosphate (C grade ore) and calcined rock phosphate (calciphos) as sources of fertiliser phosphorus on three soil types, one a deep sand which was sampled at 10 cm intervals down the profile to follow phosphate leaching patterns. These analyses are conducted on one gram of soil which has had no preparative treatment apart from screening through a 2 mm sieve and some difficulty was experienced with sub-sampling for analysis from samples taken from plots which had received high rates (1 000 kg P/ha) of C grade ore or calciphos.

Results showed marked differences in the proportions of phosphorus extracted by the two solutions and that the differences increased as the rate of applied fertiliser increased. Sodium bicarbonate extracted very little phosphorus from soils treated with calciphos or C grade ore compared with amounts extracted by sulphuric acid as shown in Table 3.

TABLE 3

RESIDUAL PHOSPHORUS IN SANDY SOIL

COMPARISON OF TWO EXTRACTANTS

Fertiliser	Superphosphate	C grade ore
Rate, kg P/ha	80	1 200
Extractant	Phosphorus, P parts per million	
0·5 M sodium bicarbonate	8	8
0·5 M sulphuric acid	27	160
conc. perchloric acid	50	900

Higher values for both extractants were obtained on the site on gravelly soil where leaching was less likely. On sand low values of 20 ppm P were obtained for superphosphate plots compared with 130 ppm for calciphos plots at equivalent fertiliser rate of 200 kg P/ha indicating that leaching had occurred.

Some measure of the relative solubility of phosphorus from calcined and uncalcined ore was obtained by extraction of the fertilisers with 0.5 M sulphuric acid. About 90 percent of the total P in calciphos, and about 20 percent of the total P in C grade ore was extracted. The acid extractant may be a more useful indicator of soil phosphorus status where residual phosphorus from slowly available types of fertiliser is being estimated.

The von Stieglitz soil test for phosphorus (0.005 M sulphuric acid, 1 : 200 16 hours) has been used in Queensland sugar cane areas for many years for advising on fertiliser programmes. Four samples of Cununurra clay from the Ord River sugar cane pilot farm were extracted with three different solutions with the results shown in Table 4. The bicarbonate and von Stieglitz tests extracted similar amounts of phosphate but the 0.5 M sulphuric acid extraction (Powrie), as was found with heavier soils of the South West, gave results four to five times greater than the bicarbonate extraction.

TABLE 4

ORD RIVER SOIL

PHOSPHORUS BY VARIOUS EXTRACTANTS

Sample	Bay 1A	Bay 1B	Bay 3A	Bay 3B
Extractant	Phosphorus, P parts per million			
0·5 M sodium bicarbonate	3	5	7	10
0·005 M sulphuric acid	7	8	8	15
0·5 M sulphuric acid	20	26	31	40
conc. perchloric acid	100	110	130	140

About one quarter to one fifth of the total phosphorus (perchloric acid digestion) was extracted by the Powrie test which was similar to the proportion (one sixth) removed by this extractant from a single sample of sandy soil with residues of C grade rock phosphate referred to in Table 3.

Samples from calibration trials and requests by district advisers for soil tests to assist in recommending rates of phosphate fertiliser resulted in 1 735 analyses for 0.5 M sodium bicarbonate extractable phosphorus being carried out. These were handled by improving the system of operations to minimise manual steps. The fabrication of a roller type shaking machine, the use of a prototype automatic dispenser and design of containers to allow multiple extractions in centrifuge tubes simplified the preparation of extracts for presentation to an automated colorimetric step. Read-out by chart will eventually be replaced by computer print-out. Interference by organic matter in some soils was overcome by addition of 2.5 ppm of polyacrylamide to the sodium bicarbonate extraction solution.

Nitrogen

Work on samples from trials in 1975 to look for a soil test for nitrogen on wheat crops was completed. In addition to the determination of components which influence the nitrogen status of the soil, ammonia and nitrate fractions and aerobic and anaerobic incubatable nitrogen were estimated. A rapid alkaline distillation fraction was also examined by a method based on that of Osborne, J. Aust. Inst. Agric. Sc. June 1973, for New South Wales soils. The relationship obtained for W.A. wheatbealt soils, 0-10 cm samples, was $Y = 0.00175X - 0.00636$, $r = 0.982$ where Y = Total (Kjeldahl) nitrogen, percent and X = Alkaline distillable nitrogen, parts per million.

The test might prove useful as a rapid means of checking nitrogen status. The chemical work on the second year of sampling was not completed at the end of the year.

Preliminary studies of the effects of cultivation practices on nitrogen release involved estimations of ammonia and nitrate in 516 samples of soil from plots sampled regularly at weekly or fortnightly intervals. Treatments included chemical weed control and degrees of mechanical cultivation. Analyses were carried out immediately on receipt of the samples. Five sites were sampled, but some were affected by the dry season and overall results were inconclusive. In all cases there were effects on levels of ammonia and nitrate released. At Mount Barker zero tillage produced higher levels of ammonia than minimum tillage which again gave higher levels than reduced or

normal tillage. On the other hand nitrate levels were higher in normal and reduced tillage plots than in zero and minimum tillage plots and reached a peak about two weeks after seeding but then decreased to very low levels. The nitrate levels in zero tilled plots rose sharply a month after seeding and remained high until the end of the trial.

Wheat yields from experimental plots which were previously sown to sweet lupins were greater than from plots which were previously sown to wheat. An explanation was sought in terms of chemical parameters such as organic carbon and nitrogen in its various forms. None of the soil properties measured explained the differences in yields from selected plots showing greatest variations in yields.

The opportunity was taken to compare methods of determining nitrate in soil extracts. A selective-ion electrode procedure gave results in good agreement with the ultra-violet spectrophotometric method. A link to the computer was provided to handle the absorbance data from the spectrophotometer.

Potassium

Potassium extracted by 0.5 M sodium bicarbonate as used for phosphorus tests was determined on over 600 samples both as a diagnostic aid in assessing the status of pasture soil for advisory purposes and in selection of experimental sites for investigations of potassium nutrition of lupins.

Extraction with boiling 1 M nitric acid (1 : 10, 10 minutes) has also been used for potassium in recent years but is not favoured. The results are dependent on the time of boiling and the method was found to be less precise and to require more operator attention than the bicarbonate test.

Leaching of potassium fertiliser is severe on sandy soils (1 per cent clay, 2 milliequivalent/100 g or less cation exchange capacity) as shown by residual bicarbonate extractable potassium from a trial near Three Springs sampled at 10 cm intervals to 40 cm depth. Values were all 50 ppm or less, mostly 20 or 10 ppm.

Rubidium was determined in samples of a typical profile of these sandy soils to examine the possibility of using changes in the ratio Rb:K in soil extracts by the "reverse tagging" technique (Hafez and Stout, Soil Sc. Soc. Am. Proc., 1973, 37, 572) to follow the movement of fertilizer potassium due to leaching. The rubidium levels were from five to twenty times lower than in soils used by Hafez and Stout, ranging from 0.019 to 0.024 ppm rubidium which necessitated a tedious 10 fold concentration step before determination of rubidium by atomic absorption. It was concluded that "reverse tagging" was not feasible for a large scale experiment on these soils and that leaching could be followed as easily by either direct tagging of potassium fertiliser with a rubidium salt or by direct measurement of potassium, in view of the low levels of extractable potassium in the unfertilised soil.

Trace Elements

There was a sufficient increase in the use of the analysis of copper, manganese and zinc in various soil extractants for diagnostic purposes to justify an examination of the merits of the different extractants in terms of effectiveness as diagnostic aids and for convenience of use. The most used procedure is copper extracted by 0.2 M ammonium oxalate as described in previous Annual Reports, and continued experiments on residual copper in soils again contributed most toward chemical work in the trace element field.

Ammonium oxalate extractable copper and zinc were determined in soils from experiments in the Lake Grace district to measure the distribution of these elements within and between drill rows. Within rows the total copper and zinc were about 3 and 6 ppm respectively for nil treatments. Copper increased to about 10 ppm in fertilised rows. Between rows samples showed no change in total copper indicating limited movement of fertiliser from the drill rows. This was confirmed by the percentage of the total copper which was extracted by ammonium oxalate from within rows. This ranged from about 20 per cent of the total in nil treatments to about 80 per cent for fertilised rows while between rows only about 25 per cent of the total was extracted.

Manganese availability to plants and lupins in particular was estimated by several extraction procedures. EDTA 0.05 M, pH 7 extracted more than 1 M ammonium acetate pH 4.8 which extracted more than "easily reducible" (1 M ammonium acetate pH 7, 0.2 percent hydroquinone) manganese in some soils, while in others the easily reducible form was greater than that extracted by 1 M ammonium acetate pH 4.8.

Zinc in two soils extracted by ammonium oxalate or ammonium carbonate—EDTA solutions gave similar results suggesting that for some soils one extractant can be used for estimation of copper and zinc and possibly other elements.

Remote Sensing Project

A considerable amount of chemical work was carried out on soils from the Leonora district in a programme which is attempting to define rangeland conditions by aerial photography. There was very little difference in chemical characteristics of samples from good, medium and poor range conditions.

North-West Soils

A number of samples were dealt with to gather information to aid in solving agronomic problems in the area. A comprehensive analysis of soils from the Oombulgarri Human Development Project was made. The aim is to establish a self-sufficiency in food production at a settlement on the Cambridge Gulf near Wyndham. The soils consisted of 75 to 92 percent fine sand with less than 10 percent clay, pH 5.7 to 7.4 and cation exchange capacity between 2.4 and 7.2 me/100 g. Extractable phosphorus and zinc were low.

Samples from Kununurra were concerned with establishment of rice and the value of tropical legumes such as lab lab in irrigated pastures as a nitrogen source because of the high cost of nitrogenous fertiliser at Kununurra. Lab lab is used in Queensland as a rotation with sugar and is showing promise at the Ord.

A problem with poor growth of bananas involved extensive analysis of soils from good and poor growth areas and comparison with soils from banana growing areas at Carnarvon. The analyses offered a possible explanation of the problem in that extractable phosphorus and zinc were lower in the topsoil of the poor area.

Other

Organic carbon determinations were made to check effects of cultivation hardpans, and effects of early maturing sub-clover varieties on wheat yields in the eastern wheatbelt. Claims that chemical weed control methods caused changes in structural stability and organic carbon content were not confirmed.

Study of regeneration of saltbush and bluebush shrublands in the Eastern Goldfields region after extensive bushfires in 1975 required an estimate of the fertility of soil mounds supporting the shrubs. Comparisons of organic carbon, nitrogen and phosphorus contents did not account for differences between good growth on the mounds and poor growth on inter-mound areas.

Work for private concerns was very limited. Reconstituted soil from mineral sands operations were shown to be very poor and that revegetation would be difficult. Advice was given to a local Council regarding poor growth on cricket pitches, and to persons investigating the commercial planting of nut trees.

Animal

A diagnostic service for examination of liver and kidney specimens from cattle and sheep for cobalt and selenium was maintained to aid in establishing causes of death of stock either from deficiencies in feed or in cases where poisoning through over dosing of these elements was suspected.

Cobalt levels were about 0.02 ppm dry basis in ovine and bovine livers from animals which died in a trial in cobalt deficient land at Denmark Research Station, confirming that cobalt deficiency had contributed to the deaths. Cobalt levels were much higher in a cobalt supplement trial in the same area. Bovine livers ranged from 0.12 to 0.42 ppm dry basis while ovine livers contained from 0.07 to 0.54 ppm dry basis. Copper levels in these samples were quite different being between 14 and 130 ppm in bovine and between 170 and 670 ppm dry basis in ovine livers. Bones, mainly from unhealthy pigs, were examined for ash, calcium, magnesium and phosphorus content.

An unusual enquiry concerned a bovine kidney purchased from a local butcher, which glowed in the dark. No phosphorescence or fluorescence was evident by the time the sample was examined. However similar cases have been reported elsewhere. The phenomenon could be due to certain bacteria which exhibit bio-luminescence.

Fluoride determinations in bones, teeth, blood and rations were associated with re-examination of a problem with guinea-pig colonies which appeared to be due to chronic fluorosis as judged by clinical signs and post-mortem findings associated with the condition known as slobbers. Two organisations, Department of Agriculture and Royal Perth Hospital suffered serious mortalities of guinea-pigs. Similar outbreaks have occurred at intervals since 1971. One sample of commercial feed related to the latest outbreak contained 81 ppm fluoride regarded as being a toxic level in guinea-pig diet and other samples taken about the same time contained 50, 44 and 32 ppm. The fluoride concentrations in bones from animals with slobbers, or which had aborted, were between 2 050 and 2 800 ppm fat free dry basis and in 2 samples of molar teeth 2 000 and 3 050 ppm fluoride was found. Two out of three samples of blood from the affected animals contained 0.27 and 0.30 mg/1, each above the range in plasma of normal domestic animals. The evidence suggested that there was sufficient fluoride in some batches of commercial feed to cause a build-up of fluoride in the bones and teeth of the guinea-pigs and it was recommended that each consignment of commercial feed be examined for fluoride content before being supplied as a ration. A change in formulation of the commercial feed by supplying phosphorus as a phosphate salt instead of rock phosphate was made. This reduced the fluoride content of the feed to about 10 ppm in one sample which was analysed and at the end of the year no further serious cases of slobbers had been reported, although there was a minor outbreak with some deaths in the Department of Agriculture animal house. The situation should be watched because if guinea-pigs come under undetected stress from chronic fluorosis, use of the animals for other tests might lead to misleading conclusions.

Forty nine samples of porcine bone from the conclusion of a trial in which pigs were fed rations containing Christmas Island rock phosphate confirmed the uptake of fluoride discussed in the Annual Report, 1975.

Human Tissue

The survey of selenium levels in specimens from cases of infant cot deaths was completed on 76 samples carried over from 1975. A total of 369 specimens from 134 cases were involved in the survey.

Cereal

Wheat

Most of the large number of wheat tops received came from the trials on nitrogen soil tests. These were analysed for nitrogen and the results along with other data will be examined statistically by the Department of Agriculture computer. The associated samples of wheat grain were still being dealt with at the end of the year.

Nitrogen concentration in wheat tops from a continuous cropping trial studying the effects of various nitrogenous fertilisers had a mean of about 1.0 percent and did not vary much with treatment, but over the years yields from sulphate of ammonia fertilised plots have fallen markedly.

Oats

Plant tops from a study of rates of urea and rates of seeding for hay production showed little effect of seeding rate on nitrogen content but a marked increase due to urea. Tops from nil treatments had a mean of 0.88 percent nitrogen and those from 738 kg/ha of sulphate of ammonia had a mean of 2.22 percent.

Chemical composition of State Average Oats for the 1974-5 and 1975-6 seasons are shown in Table 5.

Rice

Rice plants from areas at Kununurra showed symptoms of suspected nutritional disorder. A comprehensive analysis for major and minor elements confirmed a suspected phosphorus deficiency but concentrations of other nutrients appeared satisfactory.

TABLE 5

COMPOSITION OF STATE AVERAGE OATS

	1974–5	1975–76
	as received percent.	
Moisture	9·0	8·7
Ash	2·6	2·5
Crude protein (N x 6·25)	8·0	8·1
Crude fat	7·8	6·6
Crude fibre	9·2	9·7
Nitrogen free extractives	63·4	64·4
Calcium, Ca	0·06	0·08
Phosphorus, P	0·24	0·25
Kernel content	73·1	72·8
	mega joules per kilogram	
Gross energy value	17·8	18·1

Maize

Nitrogen content was compared of maize tops and grain from trials with two varieties planted at different times and several seeding rates and receiving nil or 300 kg/ha of nitrogen fertiliser. Tops from the higher seeding rate plots contained a greater concentration of nitrogen irrespective of whether fertilised or not. Results were very variable and probably reflected the difficulty of subsampling a large plant like maize. Nitrogen in the grain samples showed no marked effects of treatment.

Barley

Certificates were issued for crude protein and moisture contents of samples of barley from grain shipments or for proximate analyses similar to those for State Average Oats to assist the Grain Pool of W.A. in marketing.

Fertiliser

Ninety three samples registered under the Fertilisers Act were received compared with 68 in 1975 and 86 Certificates of Analysis were issued. Deficiencies were found in 28 (33 percent) of the samples examined. Individual deficiencies (39) were relatively fewer than in 1975 and 1974.

Farmers, private concerns and government departments also submitted samples for checks on the specified ingredients of commercial fertiliser mixtures or for an opinion of the fertiliser value of materials such as abattoir waste, fowl manure, cement dust and copper ore. A reflection of increased prices of phosphatic fertiliser were requests for estimations of the water soluble and total phosphorus remaining in stacks of bulk superphosphate after exposure to the weather in farm paddocks.

Phosphate rock from deposits in the Dandaragan area contained from 4.6 to 7.1 percent phosphorus which are similar concentrations to those quoted by Matheson (Mines Department Bulletin No. 4, 1948). A sample of rock phosphate from B.H.P. South deposits in Queensland contained 13.1 percent phosphorus. The fluoride content was 2.9 percent which means that it would not be a satisfactory substitute for Christmas Island rock as a stock food supplement.

A detailed analysis was made of stocks of Christmas Island C grade ore and calcined ore to be used in a comprehensive series of trials throughout the State to evaluate cheaper sources of phosphorus than superphosphate.

Feeding Stuffs

Feeding Stuffs Act

Ninety-eight samples were received compared with 100 in 1975 and Certificates of Analysis were issued for 71 samples. Excesses or deficiencies were found in 59 (83 percent) of the samples examined. Deficiencies were due to crude protein (31), phosphorus (17), sodium chloride (12), calcium (11) and crude fat (9). Excesses were due to crude fat (18), sodium chloride (16), phosphorus (15), crude fibre (14) and calcium (12).

Meatmeal

An important set of data was obtained for animal nutritionists of the Department of Agriculture from a survey of meatmeal quality as judged by the amino acid composition of protein. The survey was conducted on 48 samples collected from 15 manufacturers over a period of nine months. Up to four samples were taken from each manufacturer. The amino acid analyser commissioned in 1974 made the survey possible, since manual procedures are too time consuming. Values for amino acids and crude protein showed small variations within samples from the same manufacturer indicating satisfactory process control but large variations were evident between manufacturers. The mean values obtained for amino acids of

importance in broiler rations were similar to those found in a study in Victoria as shown in Table 6. Glycine in W.A. samples was slightly higher.

TABLE 6

MEAN VALUES OF AMINO ACIDS IN MEATMEAL

No. of samples	Victoria 20	Victoria 6	Western Australia 48	Western Australia (Range)
	g per 16 g N			
Arginine	6·6	6·3	6·9	(5·9–8·6)
Lysine	5·6	6·0	5·0	(3·9–6·8)
Histidine	2·2	2·6	1·9	(1·4–2·7)
Methionine	1·4	1·4	1·4	(1·2–1·7)
Methionine + Cystine	2·1	2·0	2·2	(1·6–3·9)
Glycine	13·4	13·2	17·3	(9·3–23·7)
Phenylalanine	3·8	4·0	3·6	(2·8–5·2)
Phenylalanine + Tyrosine	6·2	6·2	6·3	(4·6–9·0)
Leucine	7·0	7·3	6·6	(4·6–9·8)
Isoleucine	3·0	2·5	2·5	(2·0–3·3)
Threonine	3·8	3·7	3·6	(2·6–4·7)
Valine	5·3	5·7	5·5	(4·1–9·5)

Poultry rations from experimental work were given thorough chemical evaluation including proximate analysis and checks on trace elements and amino acids content.

Lysine is the main amino acid added as a supplement to pig diets in experiments with lupin grain. Confirmation of added synthetic lysine levels found by hydrolysis of feed samples was desirable, by determination of lysine in extracts of the feed. Extraction of samples with 90 percent ethanol removed only half of the added lysine but complete recovery was obtained by either extraction with 5 percent trichloracetic acid or mild hydrolysis with 1 M hydrochloric acid.

Amino acids analyses were included in detailed examination of samples of feed supplements such as casein and meal prepared from rock lobster offal.

Seed from sweet sorghum—millet varieties grown at Kununurra was examined for stock food value. The establishment of a broom millet industry to replace all or part of the 250 tonnes imported into Australia annually would be assisted by breeding of varieties with characteristics suitable for broom-straw, sweet and palatable feed and a low tannin content seed for poultry. The tannin content of three out of four samples examined was 0.8 or 1.2 percent which is above a level of 0.5 percent reported to cause depression of growth in chicks.

Selenium was determined in rations from private properties in the Boyup Brook, Manjimup districts where low selenium levels in feeds are common. Water and feed ingredients from a trial studying selenium deficiency in pigs were checked for selenium content. Water from a bore at Medina where the trial was conducted contained less than 0.001 mg/l of selenium and the content of grain samples used in deficient rations was 0.02 ppm or less and did not explain why pigs which had been fed the rations throughout their lives to maturity had not developed symptoms of selenium deficiency.

A stock lick with no mention on the label of selenium contained 33 ppm.

A problem of poor yolk colour in egg production at a large commercial farm was investigated. Calcium levels in feed samples taken from different parts of the feeder system ranged 2.8 to 10 percent, indicating that segregation of the mixed ration occurred, denying the colouring additive to some birds.

Investigation of the effect of crude fibre content of diets and additives such as pectin which inhibit carcinogens in the bile duct required determination of crude fibre (Weende), acid detergent fibre and neutral detergent fibre. The results indicated that about 15 percent of the fibre content was readily digestible.

Pasture and Hay

The autoanalyser was used for nitrogen, phosphorus and potassium determinations on practically all the pasture and hay samples dealt with. In addition calcium, magnesium, sodium, sulphur, cobalt, copper, molybdenum and zinc were estimated on selected samples, mainly by atomic absorption techniques.

To handle the numbers of samples for autoanalyser and trace element analyses the procedure for wet digestion of the plant material was altered. It is now carried out in test tubes which sit in aluminium blocks resting on hot plates. Efficiency has also been improved by use of automatic diluters and dispensers, but the problem of handling the large amount of data produced had not been resolved by the end of the year. This matter is more pressing with the interfacing of the autoanalyser and computer expected in 1977.

Samples came from twenty trials in the South West and another six locations in the pastoral areas of the State. In many cases where variations in chemical composition were shown to be small, replicate samples were bulked for analysis.

Crude protein was of main interest in studies of fodder conservation methods such as bales, stacks and rolls. In addition, determination of in vitro digestibility is carried out by the Division of Dairying laboratory. The residues from the digestibility determinations were analysed for nitrogen to enable a check on the crude protein content of the digestible fraction of the materials.

The quality of pasture sprayed with a herbicide to control capeweed was better than unsprayed plots when sampled in May but why it was lower for June samples is not known.

At Newdegate Research Station copper levels in pasture on plots which received bluestone at 2.75 to 11 kg/ha in the past were satisfactory when sampled in October. Selenium in grass at 0.20 ppm was adequate for animal health but was low in wheat and barley stubbles at 0.02 ppm.

Samples of tops of Lepidium hyssopifolium which were eaten by sheep in preference to stubble from a trial at Esperance contained between 0.05-0.38 ppm selenium. Barley and lupin stubble from the same trial contained 0.02 ppm.

Clover

Uptake of phosphorus by clover from superphosphate and rock phosphate calcined at 500° C or 900° C was compared. On a sandy soil superphosphate at 50 kg P/ha gave phosphorus concentrations in clover tops slightly greater than from 200 kg P/ha as rock calcined at 500° C and much greater than from rock calcined at 900°C which were only slightly higher than nil treatments. On gravelly soil 50 kg P/ha as super gave concentrations of phosphorus in tops little better than nil treatments but rates of 200 kg P/ha as either of the three fertilisers produced definite increases in phosphorus levels.

Fatty acid composition of clover seed oil was estimated. Results for three varieties are presented in Table 7. The interest arose from overseas reports that feeding of a vitamin E deficient diet containing cotton seed oil to pigs produced muscular dystrophy whereas a diet deficient in vitamin E but containing lard did not. In W.A. white muscle disease occurs in weaners and it was suggested that because their consumption of clover burr could be high the fatty acid composition of the oil in the seed could be involved. The linoleic acid content of cottonseed oil is about 50 percent of the fatty acids in the oil and the clover seed oil was similar in this respect.

TABLE 7

FATTY ACIDS IN CLOVER SEED OIL

Sample		Clare T. brochycalycinum	Geraldton T. subterraneum	Larissa T. yanninicum
		percent. dry basis		
Oil		17·0	16·0	18·1
		percent. of fatty acids		
Fatty Acids:—				
Myristic	14·0	0·1	0·1	0·1
Pentadecanoic	15·0	less than 0·1		
Palmitic	16·0	16·8	16·0	17·2
Palmitoleic	16·1	less than 0·1		
Heptadecanoic	17·0	0·1	0·1	0·1
Stearic	18·0	6·1	6·9	5·0
Oleic	18·1	25·4	20·2	22·8
Linoleic	18·2	48·2	53·2	52·2
Linolenic	18·3	1·3	1·7	1·0
Arachidic	20·0	0·7	0·8	0·6
Eicosenoic	20·1	0·1	0·1	0·1
Behenic	22·0	0·8	0·6	0·6
Erucic	22·1	less than 0·1		
Nervonic	24·1	0·3	0·1	0·4

Other samples examined were related to diagnosis of nutrient deficiencies and comparison of feed values of clover and cereal stubbles in an investigation of the practice in wheat growing areas of joining ewes on cereal stubbles rather than legume based pastures.

Lupin Seed.

A report was prepared which presented information concerning the potential of sweet lupin seed for human consumption. Work was begun on establishing chemical procedures sufficiently sensitive to characterise and quantify the alkaloids present in low concentrations in commercial sweet lupin seed. The work has not advanced greatly, but generally verified work done elsewhere. Gas chromatography methods confirmed that angustifoline, lupanine and hydroxylupanine were present in a sample of commercial flour. The concentration of total alkaloids was 0.02 percent and was too low for a reliable estimate of the alkaloids removed by leaching kernels with an acid aqueous solution in attempts to prepare a product having a higher crude protein content and a bland taste.

Manganese was determined in 365 samples of grain from L. cosentinii and L. angustifolius cultivars in rates of manganese experiments aimed at checking the incidence of split seeds and seed yields against manganese levels in the seeds.

Lupin flour prepared for the Grain Pool of W.A. from dehulled commercial seed including new cultivars Ultra and Marri was certified for crude protein content.

Sweet lupin grain supplements clearly increase lambing percentages. Fractions of lupin grain and a range of protein sources were fed in experiments to determine whether the fertility response is specific to the protein of L. angustifolius cultivars and whether the response is dependent on the time, rate and duration of feeding the supplement. Detailed analyses of the feeds were carried out to establish the relative chemical composition and feed values.

Lupin Plant

Data of the feed value of lupin stubbles for sheep are meagre. Treatment with herbicides for weed control results in changes in composition of the crops and stubbles. The changes were not reflected in the components of a lupin stubble at Badgingarra as measured by crude protein, ash and fibre contents of lupin stalks, leaves, pods and grain and grass components.

Fifteen elements necessary for animal nutrition were determined in separate parts of stubble of lupin varieties angustifolius and albus. Grain, pods, leaves, coarse stems and fine stems were analysed and were shown to contain higher concentrations of crude protein and nutrients than wheat stubble.

Lupin tops sampled at flowering from trials at a number of sites aimed at finding changes in soil fertility caused by a year of sweet lupin crop were analysed for nitrogen in conjunction with the work on changes in soil nitrogen fractions.

Rubidium and potassium in lupin tops from a trial at Three Springs were determined to allow calculation of Rb:K ratios in the crop as part of the investigation of "reverse tagging" discussed earlier in the section on Soil. The effect of potassium fertiliser on the ratio Rb (micromoles):K (millimoles) was very evident. In young plants the ratio was 1.6 in the absence of fertiliser and at 300 kg/ha of potassium chloride it fell to 0.4. These ratios were maintained in later cuts from the trial. Soil extracts had a Rb:K ratio of between 0.6 and 1.4 and potassium chloride fertiliser a ratio of 0.07. The results obtained for the lupin tops are thus consistent with dilution of soil potassium by fertiliser potassium.

Large numbers of samples of material from the same trial were analysed to provide data for following nutrient uptake of lupins on sandy soils. Samples included whole tops and sections of plants such as primary and secondary pods and seeds and mature seed. Different rates of potassium chloride fertiliser from nil to 300 kg/ha had little effect on levels of calcium, magnesium or nitrogen in the various plant parts.

Manganese was determined in samples of seeds from trials studying uptake of the element from residual manganese fertiliser or foliar sprays in studies of the split-seeds problem.

Silage

Comparison of silage made from W.A. blue lupins or New Zealand blue lupins showed W.A. blue produced material having higher fibre, potassium and sodium content but lower soluble carbohydrate, total acids, calcium and magnesium.

Formic acid additive for silage prepared from either wilted or fresh material was the subject of a trial at Bramley Research Station in which it was endeavoured to carry out a nutrient balance by extensive chemical analysis of the pasture used, the residue left after in vitro digestibility of the pasture, the effluents produced at the beginning of the process and the silage produced by each of four methods and fed to growing steers.

Horticulture

Citrus leaves including valencia and navel orange, lemon, mandarin and tangerine from growers' properties in the Harvey to Chittering district were checked for suspected nutrient deficiencies.

Apple, peach, pear, plum and cherry leaves from properties in the Donnybrook and Bridgetown areas were treated similarly and given priority over other work to enable rapid return of results so that fertiliser recommendations to correct deficiencies of nutrients could be given early. Other work on apple leaves came from continuing trials at Stoneville and Manjimup Research Stations and private properties.

Banana leaves from a problem of poor growth at Kununurra appeared to be low to deficient in nitrogen and zinc by New South Wales standards.

Grapevine leaves were submitted for assistance with a variety of problems. Attack by oidium at Gingin where susceptibility to attack was thought to be associated with better nutrition was not verified by analysis. Copper deficiency was suspected on this property but levels were satisfactory. Copper deficiency appeared to be confirmed by low levels in blades and petioles at a Wanneroo property. An indication of the continued interest in newer wine producing areas was the number of samples received from properties in the Busselton area and from a fertiliser trial at Frankland River. Levels of nitrogen in leaf blades from this trial did not account for a significant yield response to sulphate of ammonia. An expected increase in leaf manganese from sulphate of ammonia treatments was shown but the difference could not account for the yields obtained.

Oil Seeds

Twenty samples of different varieties of rapeseed from the Department of Agriculture's breeding programme were examined for the fatty acid composition of the oils. The samples included overseas cultivars and a number of low erucic acid crossbreds developed in W.A. The crossbreds all had less than one percent erucic acid. Two samples of Span variety had 29.9 and 31.7 percent of erucic acid evidently due to natural cross-pollination of this low erucic variety with high erucic varieties in the area. The crossbreds mostly contained less than 0.5 percent erucic acid better than the level of 0.8 percent which is aimed at by breeders in Canada.

Three samples of sunflower seeds from Kununurra contained 19.3 to 19.8 percent of oil. Crude protein in two varieties, Hysun and Sunfola, was 42.7 and 45.8 percent but was lower, 32.5 percent, in Polster variety, which had a correspondingly higher crude fibre content. Sunflower grown at Busselton had higher levels of iron, manganese and zinc in unhealthy than in normal plants which did not explain deficiency symptoms.

Environmental

Our Annual Report for 1975 referred to a joint project to monitor fluoride emissions from brickworks and effects on grapevine leaves in the Middle Swan area. Chemical work involved interpretation of the fluoride content of leaves and lime impregnated filter papers used as static monitors of gaseous fluoride concentration. A report which summarised the conclusions drawn from the data obtained was prepared and submitted to the Sub-committee on Fluoride Emissions, Air Pollution Control Council. Good correlations between fluoride contents of leaves and filter paper monitors were found, and it was shown that filter papers are an inexpensive alternative to instrumental methods of monitoring.

Nine samples of fired and unfired clay bricks made from clay only or clay plus about 20 percent marl were analysed for fluoride to check the effect of the calcareous marl as a means of retaining fluoride in the brick and thus minimising emissions. The results confirmed earlier work in these Laboratories that almost all the fluoride is lost to the atmosphere by firing during normal brick production.

The marl appeared to cause retention of some of the fluoride but this was very dependent on the firing temperature.

A proposed increase in production of the nickel smelter at Kalgoorlie prompted a survey of native vegetation in the area. Concern was felt that death of vegetation may add to the dust hazard. The extent of damage due to sulphur dioxide fumes under existing conditions was evaluated by measuring chloride and inorganic sulphur levels in leaves of affected and unaffected plants of the same species at different distances from the smelter. Results showed a degree of relationship between severity of damage symptoms with inorganic sulphur content.

Miscellaneous

Pollen

Interest in bee pollen as an alleged source of amino acids, xanthophyll, and as a general health food led to analysis of six samples of harvested pollen from areas between Lancelin and Busselton to provide information for buyers of a potential export commodity. The amino acids and crude protein content in one sample from Dwellingup was similar to that of Uniwhite lupin crude protein except that pollen had about half the content of glutamic acid and arginine and was higher in methionine, phenylalanine and lysine. Crude protein was between 21.2 and 30.1 percent. Xanthophyll content of about 0.02 percent or less means that pollens such as those examined would not be an economic source of egg-colouring material for laying hens.

Sheepskin Trimmings

Australian exports of sheepskins in 1972-3 had a value of $110 million. Trimming of waste sections should result in quick drying and effective preservation of the valuable part of the skin. The amounts of wool lost by trimming by different methods and the value of the tissue protein as meatmeal were checked by using a pepsin digestion to separate wool from tissue. The average wool content of eight samples was about 40 percent dry basis. The tissue portion consisted of about 25 percent crude protein and 35 percent fat. Economic considerations would decide how the trimmings should be treated.

Rock Lobster Shells

In the U.S.A. shell waste from crustacea is treated to recover chitin. This is then converted to chitosan, which has applications in industry for water treatment, food thickening and waterproof films. The chitin content of W.A. rock lobster shells was 11.3 percent, similar to that of published figures for freshwater crayfish meal but was much less than for Alaskan king crab (20 percent). Initial attempts to prepare chitosan from the W.A. chitin were not successful.

Other

Other samples included low protein biscuits for confirmation of low nitrogen, potassium and sodium levels, and a mud waste from a sugar refinery on which it was hoped to establish vegetation. The alkalinity and fine particle size of the material would make this difficult.

A mound of spillage material which had accumulated at Esperance wharf was examined for rock phosphate and sulphur content for the contractor engaged to remove the obstruction who wished to know if the material should be sold as a fertiliser or disposed of by dumping. The latter action was recommended.

J. JAGO,
Chief, Agricultural Chemistry Division.

ENGINEERING CHEMISTRY DIVISION

Because the Division is oriented technologically rather than analytically, the projects undertaken tend to be long-term investigations. Some projects, particularly those innovated within the Division are on-going and may recur from year to year in this annual report of activities.

Work sponsored by local industry is generally accorded priority above that of internally innovated work. However momentum is maintained on Departmental projects of probable future importance.

Thus the main activities of the Division for the year again fell into the three categories—

(i) research and development requirements of local industry;
(ii) developmental work on W.A. mineral deposits;
(iii) test programmes, service and appraisal work for other Government Departments.

The first category of work generally arises from the need of developing Companies to have investigational programmes carried out in advance of the building up of their own facilities. As well, larger Companies with considerable test facilities also request the assistance of the Division, because of its expertise in a certain area of technology or because the Division has uniquely suitable test equipment.

The second category of work is usually associated with investigations into processing of W.A.'s natural resources with emphasis on future needs. Work of this nature has paid dividends in the past.

The third group of project initiation is subject to the relatively low level of requirement that other Government Departments have for mineral processing technology. However the Division is called on to contribute to studies and appraisals of mineral processing developments and again in investigational projects of broad significance as indicated below.

Sponsored Work

Projects were again undertaken at the request of an individual or organisation to whom a confidential report was made.

The investigation of the surface treatment of heavy mineral sands continued during the year. The particular problem was the removal of adherent surface staining (mainly iron) from zircon grains and the earlier laboratory defined leaching parameters were re-assessed in larger pilot plant trials. 50 kg batches of treated zircon were prepared for evaluation in the Company's own laboratory and for overseas market appraisal.

The work is continuing and application has been made for a patent in the joint names of the Government and the sponsor Company.

An extension of the project was a series of trials, carried out at the request of another company, to determine the applicability of the surface treatment method to the upgrading of silica to glass sand quality.

A comprehensive programme was required to establish and operate a pilot plant ore dressing circuit for evaluation of the feasibility of processing a scheelite ore-body. The complex circuit used included gravity, flotation and magnetic separation stages. The test work indicated that an economic level of recovery of marketable grade scheelite concentrate should be feasible.

On request, a series of pilot scale trials was conducted in the Division's rotary kiln to assess a range of raw materials of lime manufacturing potential. Pretreatment including washing, drying and classification was required and in all approximately 80 tonnes of material was processed. Optimum processing parameters were defined and the products tested for certain desirable properties.

The Division has previously reported on its own investigational project aimed at aiding utilisation of W.A. diatomite deposits, and the proficiency so acquired was used to assess various samples of local diatomites submitted by a large national Company. After calcination and classification processing, the product samples were assessed for filtration characteristics and various physical and chemical properties with promising results.

Other sponsored projects undertaken during the year included:

(i) Pressure leaching of bauxite for evaluation of residual minerals.
(ii) Processing of a bulk sample of kaolinitic clay to liberate the clay from gangue minerals. The objective was to evaluate dry processing methods of liberation and dispersion with minimal comminution of associated gangue—principally quartz.
(iii) Calcination of bauxite samples to enable assessment of the products for potential use as refractory aggregate for non-skid road surfaces.
(iv) Evaluation of properties of hydrated lime and establishing the relationship between properties and certain usage areas.

(v) An investigation (in conjunction with the Food and Industrial Hygiene Division) was undertaken to determine gaseous emissions from a cupola, and recommendations made to the Company on improved methods of venting.

(vi) On request, several materials such as cement clinker and coal for combustion use were analysed for certain properties.

At frequent intervals during the year, the Division was called upon to evaluate the raw materials and the production methods under development by a local Company for the manufacture of carbonaceous compacts for metallurgical processing. A range of potential binder materials and briquetting methods was explored. This continuing association prompted the Division to institute a comprehensive programme aimed at re-evaluating briquetting parameters defined in extensive earlier work that had been carried out in these Laboratories.

Division-innovated Projects

Carbonaceous Compacts

During 1950-60, these Laboratories formulated a method for producing a substitute coke from Collie coal in the shape of a cylindrical carbonised briquette. The experience gained in all aspects of that project has been made available as required since then. In recent years a local firm has had frequent contact with the Division seeking assistance with the problem of briquetting carbon in several forms including charcoal and coal char. It was thus considered opportune to institute a programme of research to re-evaluate the earlier defined briquetting techniques in terms of the present sources of carbon and binder. The project began towards the end of 1976 and will continue into 1977. The schedule is intended to include some examination of methods of carbonisation and of the bonding characteristics of commercially available binders.

Banded Iron Formation

As part of its programme to evaluate the future long term needs of the State, in 1974 the Division began an investigation into the characteristics of iron values associated with the banded iron formations (BIF) of the Hamersley Basin. These "sub marginal" deposits are vast and offer the possibility of beneficiation after fine grinding as is practised in the taconite processing industry of the U.S.A. During the year a standard Bond grindability test was carried out on a core sample from the Wittenoom area and this indicated that the work index or energy input required to grind the BIF material from the Hamersley Basin was similar to that required for typical American taconite ore.

Further work on the beneficiation of the BIF core samples has produced a bulk sample of concentrate by wet magnetic separation means and trials on the pelletising characteristics of this material are under way. From head material of total iron content of the order of 34 percent, it has been found that a magnetic concentrate analysing approximately 68 percent iron with an iron recovery in excess of 75 percent is achievable.

Copper Hydrometallurgy

A test programme which began in 1974 and was aimed at establishing both the technical and economic feasibility of processing copper by the acetonitrile leaching method continued during the year. The main activity was associated with costing studies and economic comparisons.

Preliminary estimates were completed for two possible applications:

(i) the production of pure copper powder from scrap copper and

(ii) production of copper powder from chalcopyrite type ores.

The findings indicated that both the leach-disproportionation circuit for scrap copper and the double roast-acetonitrile leach process for chalcopyrite could be economic under favourable conditions. However, before reliable comparisons can be made against fully established conventional processing techniques, larger scale testwork is required to verify the acetonitrile process. Because the process has still to be proven beyond the laboratory scale, a review of methods of possible pilot plant development within these Laboratories has been made and is currently being evaluated.

Close collaboration with Professor Parker and the Murdoch Metals Group, the initiators of the acetonitrile process, has been maintained throughout the study of the process.

Projects in Conjunction with other Government Departments.

Scrap Lead Recovery

The preliminary investigation into the recovery of scrap lead from redundant car type batteries was concluded and reported to the Public Health Department. Some degree of success was achieved in separating lead from waste plastic and rubber components by wet gravity separation techniques. Two techniques, jigging and hydraulic sluicing were assessed in the preliminary programme. However, the application of such ore dressing methods is made difficult by the heterogeneous size and shape of the metallic lead resulting from the initial crushing of the batteries. Another problem is that the combined lead content is of fine size and the use of wet gravity methods results in the necessity of recovering a sludge to achieve maximum yield of the valuable lead content. Broadly, batteries consist of a metallic portion (approximately 79 percent) and a non metallic portion (21 per cent). The metallic portion is a mixture of antimonial lead and other lead compounds and the overall lead content of the batteries is of the order of 70 percent.

The trials indicated that the mineral processing methods, which utilised differences in shape and specific gravity between valuable components and gangue material, were capable of producing high grade lead fractions with a moderate recovery.

During the course of a visit to Melbourne, the Chief of Division inspected lead recovery facilities at a commercial site, where improved handling facilities were in use, and recently the responsible Company has established a new treatment facility along these lines in the metropolitan area. Although the severity of the hazard to workers' health should diminish accordingly, there will be a continuing need to monitor the levels of lead in the labour force and to define improved methods of processing.

Pindan Soil Bricks

Experimental work in conjunction with the Office of the North-West and Regional Administration and the State Housing Commission has continued in relation to the use of stabilised Pindan soil from the Broome area for the making of bricks and other structural components.

Considerable testwork was done using both lime and cement separately as the stabilising additive in preparing brick shapes from Pindan soil. The Division's particular responsibility was the use of lime and comparative testing was done with cement used according to a formulation supplied by Mr. C. A. Boundy of the Office of the North West.

The curing conditions for the stabilised bricks were designed to simulate those readily attainable by storing bricks under plastic sheeting in North-West conditions.

The initial testwork was done using 50 mm cubic test pieces and was followed by production of Australian Standard sized bricks singly in a mould. For a later stage of the programme, a custom built hydraulically operated brick machine was used to produce bulk batches (300 bricks) which were then cured under the predetermined conditions.

Representative samples of the batches of lime and cement stabilised bricks were subsequently assessed at the Building Development Laboratory at Morley. In terms of compliance with the relevant codes, the lime stabilised bricks were found to be satisfactory except in respect of drying shrinkage. The cement stabilised bricks were satisfactory apart from drying shrinkage and bond development. These deficiencies are being studied.

With regard to compression strength, which is an important index for constructional materials, the lime stabilised bricks returned values of 32.7 MPa (dry) and 26.7 MPa after soaking in water for 24 hours. The corresponding figures for the cement stabilised bricks were 33.6 MPa (dry) and 19.0 (after soaking). All these values are well in excess of accepted standards for the required application.

The test programme has culminated in the construction of an experimental house at Broome. The house is being built in sections incorporating lime-stabilised and cement

stabilised bricks and walls made of rammed Pindan Soil stabilised with cement. Some preliminary testing of formwork and of commercial rammers to assist the construction programme was also undertaken by the Division. By the end of 1976, the house at Broome had been partly built.

An associated project concerned the use of Pindan soil in the manufacture of flower pots. Several flower pots which had been fabricated from Broome soil mixtures were examined to check the uniformity of compression strength and to qualitatively assess the durability of the pots for specific nursery applications. It was found that incorporation of peat moss assisted achieving coherence in the pot structure especially in damp conditions, and it was anticipated that pots with a higher peat moss content could be expected to allow root development through the pot in the post planting out period.

In Situ Gasification of Coal.

Earlier exchanges with the State Energy Commission had initiated a study into the potential for application of Underground Coal Gasification (UCG) techniques in W.A.

During 1976 available data relating to Collie coal seams was reviewed and re-interpreted and various proposals examined to define an appropriate laboratory research programme. Correspondence was exchanged with overseas groups, who are active in UCG research and recent review reports studied. In general, these appraisals confirm that pilot and developmental work is proceeding at such a level in several overseas countries that decisive information on the all important mining and engineering aspects should become available within the next few years. A laboratory programme will assist the correlation of operational criteria from site to site and it is hoped that a test programme will commence early in 1977.

Defective Plaster Investigation

This Division has contributed to the Laboratories' activities in relation to the problem of defective lime plaster referred to it by the Bureau of Consumer Affairs.

In the latter part of 1975, it had become clearly apparent that the local building industry faced a serious defective material problem. Widespread occurrences of "blowing" of wall plaster were reported both from commercial and residential sources. The blowing, which could variously be described as popping, blistering or spalling became detectable at varying time intervals after the application of the "finish" plaster coat. To expedite a solution to the problem, early in 1976 the Bureau of Consumer Affairs consulted with the major parties involved and these Laboratories undertook an investigation aimed primarily to—

(i) identify the cause of the defects in the plaster
(ii) ensure that the problem was not continuing
(iii) define a method for treatment and repair of the damaged walls.

This Division in conjunction with others of the Laboratories mounted an investigational programme to help elucidate all three aspects and the Engineering Chemistry Division's special emphasis was on (ii) and (iii). However, a detailed theoretical study of possible causes of pitting was made in association with the results of tests carried out both in the laboratory and in site panel trials.

Reassurance on the avoidance of further outbreaks was obtained by reviewing the then current raw material preparation and plastering practice and checking all aspects for compliance with relevant Australian Standards.

With regard to remedial procedures for the affected areas, the main aim was to define a procedure that was simple, cheap and less inconvenient than complete stripping and re-plastering.

Test panels were mounted at two main sites which had defective plaster walls and various methods of treatment were examined. From these studies, a procedure of treatment based on the application of calcium chloride solution was defined and ultimately conveyed to the public.

The work done by several Divisions of these Laboratories on this topic will be collated and reported when appropriate.

Miscellaneous and General

An increasing number of requests was received for the determination of gross energy value on animal feed samples used in nutrition trials.

A range of brief trials was carried out on request to evaluate the prospects of beneficiating various local ores. Typical of these was the testwork aimed at production of a graphite concentrate from a low grade shale.

Numerous requests were received for advice on matters relevant to the activities of the Division. Such requests arose from the general public and from other Government Departments. Examples of the topics on which guidance was given were—

(i) Secondary processing of iron ores and agreements with companies.
(ii) Methods of exfoliating vermiculite.
(iii) Design of a combustion system for volatilisation of arsenic ore.
(iv) Techniques for treating refractory gold ores.
(v) Neutralisation of iron-bearing acidic effluents.
(vi) Economic comparison of ilmenite upgrading processes.

The workshop attached to the Division functioned busily during the year and was engaged on maintenance and fabrication of equipment. A new pilot scale vacuum filtration system was fabricated and a new drive assembly fitted to the rotary kiln. Fully integrated pilot plant rigs were constructed for the testwork on zircon beneficiation and scheelite flotation and a large scale curing chamber adapted for the work on Pindan bricks.

The Chief of Division Mr. B. Goodheart, attended the Third International Conference on Coal Research, which was held in Sydney in October and Mr. L. Brennan attended the Institute of Fuel Conference on Energy Management held in Sydney during November.

Among the visitors to the Division during 1976 were—

Mr. A. Hams—General Manager and Director of Research, Australian Coal Industry Research Laboratories, Sydney.
Mr. G. Bessey—Consultant and former Director of Research of U.K. Lime Association of Welwyn, England.
Dr. S. Dara—Asst. Professor of Applied Chemistry, V.R.C. College of Engineering, Nagpur, India.
Dr. T. Pyle—Head of Metallurgy Department, Kalgoorlie School of Mines.
Dr. B. Walpole—Managing Director, Walpole Ltd. Consultants of Sydney.
Mr. D. Lawson—General Manager International Operations, Hanna Mining Company of U.S.A.

B. A. GOODHEART,
Chief, Engineering Chemistry Division.

FOOD AND INDUSTRIAL HYGIENE DIVISION

This is the first year in which the Food and Industrial Hygiene Division has operated as such. In the split of the old Food, Drug, Toxicology and Industrial Hygiene Division fourteen of the Officers formed this new Division.

There has been an increase this year in the number of samples with an environmental connotation. Gas Chromatographs are the major pieces of equipment used for this type of analysis. Unfortunately the present instruments which the Division has are nearing the end of their economic life. It is hoped to up date the existing equipment with an automated gas chromatograph which will be capable of handling any anticipated increase in this type of work.

Foods

The number of samples received this year was only slightly less than those received in the record year of 1975.

In a survey of vegetable oils packaged in PVC containers three of the 27 oils contained more than the permitted maximum of 0.05 mg/l of vinyl chloride monomer (VCM). In a subsequent survey of 11 oils none of the samples had a VCM level above 0.05 mg/1. It was experimentally demonstrated that oil containing VCM when heated to a normal cooking temperature rapidly lost its VCM content. When 23 of the oils were subsequently examined for correct labelling it was found that one oil labelled "Safflower Oil" contained a large percentage of rape seed oil. Another sample labelled "Blended Vegetable Oil" was composed almost entirely of rape seed oil.

TABLE 8

FOOD AND INDUSTRIAL HYGIENE DIVISION

	Agriculture Department	Conservation & Environment Department	Departmental	Fisheries & Wildlife	Government Stores	Hospitals	Labour & Industry	Mines Department	Main Roads Department	Metropolitan Water Board	Pay	Public Health Department	Public Works Department	Other	Total
FOODS—															
Alcohol	....	....	....	....	....	....	....	....	....	....	....	6	....	4	10
Apples	26	....	....	....	....	....	....	....	....	....	1	2	....	....	29
Bread	....	....	....	....	....	1	4	....	....	....	....	7	....	....	12
Coconut	....	....	....	....	....	....	....	....	....	....	....	295	....	....	295
Coffee	....	....	....	....	....	....	....	....	....	....	....	14	....	....	14
Condiments	....	....	....	....	....	30	....	....	....	....	....	....	....	....	30
Fish	....	....	....	....	....	....	....	....	....	....	....	360	....	....	360
Fruit	6	....	5	....	....	....	....	....	....	....	....	5	....	....	16
Fruit juice	1	....	....	....	....	3	....	....	....	....	....	15	....	....	19
Liquor	....	....	....	....	....	....	....	....	....	....	....	58	....	....	58
Milk	63	....	....	....	....	....	....	....	....	....	....	21	....	....	84
Peanuts	3	....	....	....	....	....	....	....	....	....	....	1	9	....	13
Prawns	....	....	....	....	....	....	....	....	....	....	....	93	....	....	93
Rice	14	....	....	....	....	....	....	....	....	....	....	....	15	....	29
Shark	....	....	....	....	....	....	....	....	....	....	....	145	....	....	145
Tripe	....	....	....	....	....	....	....	....	....	....	....	50	....	....	50
Vegetable oil	....	....	....	....	....	....	....	....	....	....	3	41	....	....	44
Wine	....	....	....	....	....	....	....	....	....	....	....	35	....	....	35
Various	9	....	....	....	....	7	....	....	....	....	7	197	....	1	221
INDUSTRIAL HYGIENE—															
Air	....	....	....	....	....	....	5	4	....	....	1	61	....	1	72
Filters	....	....	....	....	....	....	....	....	....	....	....	14	....	....	14
Investigations	....	....	1	....	....	....	....	....	....	....	....	6	....	....	7
Urine	....	....	9	....	....	5	148	64	....	....	63	95	....	2	386
Various	....	....	7	....	....	2	....	....	....	....	4	13	....	2	28
MISCELLANEOUS—															
Aerial spraying	....	33	....	....	....	....	....	....	....	....	....	....	....	....	33
Animal tissue	108	....	....	....	....	....	....	....	....	....	2	....	....	....	110
Animal toxicology	23	....	....	....	....	....	....	....	....	....	5	....	....	....	28
Fish tissue	....	....	....	150	....	....	....	....	....	....	....	....	....	....	150
Paint	....	....	....	....	....	....	....	....	....	....	....	23	....	....	23
Pasture	71	....	....	....	....	....	....	....	....	....	....	....	....	....	71
Pesticides formulations	11	....	2	....	1	....	....	....	....	....	2	5	....	2	23
Soil	222	....	....	....	....	....	....	....	12	....	3	....	1	2	240
Specimens from patients	....	....	....	....	....	82	....	....	....	....	72	53	....	3	210
Surgical dressings	....	....	....	....	32	....	....	....	....	....	....	....	....	....	32
Water	5	....	6	....	....	....	....	....	....	70	6	23	183	....	293
Various	41	....	2	....	2	1	....	6	....	....	24	71	3	11	161
TOTAL	603	33	32	150	35	131	157	74	12	70	193	1 709	211	28	3 438

A private importer of vegetable oils requested assistance in establishing if the oils he was purchasing were true to label. All the oils were correctly described.

A survey of soluble coffees showed that several samples with different brand names but the same manufacturer had high insoluble residue content. When examined microscopically the insoluble matter contained no coffee fibre or cell tissue. The manufacturer's chief chemist subsequently visited Perth and confirmed that changes in the design of their process equipment were giving a product with high insolubles. It is understood that representations to change the Regulations are to be made by the manufacturer.

A large number of imported frozen fish and prawn samples were examined for total volatile bases. These analyses frequently confirmed the deterioration of the samples due to freezer breakdown whilst at sea.

It was reported last year that high sulphur dioxide content in some sausages was due to insufficient washing of the sausage skins which had been packed with sodium metabisulphite. This year several samples of sausages, skins and ingredients were submitted for sulphur dioxide content. It was again shown that washing of the skins with water gave sausages with satisfactory levels of sulphur dioxide.

The coconut samples received this year have all been free of sulphur dioxide and methyl bromide.

Fifty samples of tripe were examined for pH and formaldehyde. Forty nine of the samples had pH in the range 6.5 to 7.5 and were free of formaldehyde. One sample had a high pH and also contained formaldehyde.

A sample described as a chicken pie was submitted to determine the meat content. The meat material when examined apart from being lower than the required standard was found to contain a portion of tripe.

Samples of peanuts and rice grown and stored in the north of the State have been examined for aflatoxins. Several of the peanut samples contained unacceptable levels of aflatoxins.

The Department of Labour, Shops and Factories Section have submitted samples of bread being sold as milk bread. Several of these samples contained no milk solids. A sample of bread described as a wholemeal milk bread which the Public Health Department submitted was found on examination to be ordinary bread coloured with caramel.

A sample of bread labelled "Low Calorie Loaf" was found to have the constituents of normal bread. Neither the Food and Drug Regulations nor the Bread Act mention a low calorie loaf. In diabetic bread the carbohydrate concentration is lowered by replacing portion of it with protein. As there is only a marginal difference between the energy value of carbohydrate and protein the term "low calorie" is not applicable to bread.

A package of milk being marketed in the north of the State and stated to be reconstituted milk was found to be low in total solids and fat content.

Royal Perth Hospital submitted a number of food and condiment samples for sodium and potassium determinations. This was done to enable the dieticians to compile diets with suitable sodium and potassium balances.

Some samples of instant tea were examined for caffeine and insolubles. All the tea had satisfactory levels of caffeine and low insolubles.

A sample of tea described as low in tannin and free from the "bitter tannin taste" was found to have only a marginally lower tannin content.

Following a complaint about doughnuts which were being sold at a trade fair it was found that the fat in the doughnut mix was rancid.

The fatty acids of four samples of margarine were examined for the presence of erucic acid. No erucic acid was detected in the samples.

Complaints about a foreign taste in apples resulted in some of the apples being submitted for examination. The apples were individually wrapped in diphenylamine impregnated paper wraps and analysis showed that some of the diphenylamine had migrated to the skin of the apple. While the local concentration was high enough to create a bad taste, when the diphenylamine concentration was related to the whole apple the levels found were below those allowed by the Food and Drug Regulations.

The mercury levels of fish and sharks are regularly checked for the Public Health Department. Fish and other marine life is sampled at its point of entry into the State. In most cases the mercury level is below 0.5 mg/kg. Sharks are also sampled from the fish markets. Many of the sharks which are submitted are those which are very large and frequently are in excess of the 0.5 mg/kg level.

Milk, icecream and water samples from this State which are part of the market basket survey undertaken by the National Health and Medical Research Council were analysed this year by this Division and not the Australian Government Analytical Laboratories in Sydney.

A survey of wine and fortified wines showed that most of the wines had the correct spirit strength. A sample of wine stored in a plastic container was kept for two months with periodical checks on the VCM level. No uptake of VCM by the wine was observed. Many of the samples of liquors received have been sent in because of low spirit strength indication when examined by a health surveyor with a hydrometer. It is therefore not surprising that most of the liquor samples are below the required spirit strength.

A sample of Indian Tonic Water was submitted for a quinine determination. The label on the bottle stated a quinine content of 80 mg/1 and 77 mg/1 was found. The Food & Drug Regulations require the quinine content to be greater than 40 mg/1.

Sundry samples examined have included swollen cans for gas determination, foreign substances in foods and food containers, sausages for meat content, tainted meats for nature of taint and apricot kernels for cyanogenic glycosides.

Specimens from patients

The decline in the total number of these samples received is attributable to the deletion of the zinc in seminal fluid samples survey.

Table 9 lists the elements for which the samples were examined.

TABLE 9

SPECIMENS FROM PATIENTS—ANALYSES

Analysis	Number
Antimony	2
Arsenic	87
Copper	3
Lead	98
Manganese	2
Mercury	24
Thallium	28
Zinc	6
Cadmium, Fluorine and Nickel (one of each)	3

During the year some blood lead results showed very high levels. It was observed that all the high lead levels were from samples which were received in tubes which contained Ballotini beads. Unused tubes containing Ballotini beads were obtained and it was found that the beads have a very high lead content. Hospitals and laboratories have been advised of this source of contamination.

Industrial Hygiene

Of the 385 samples of urine 275 were for lead determination. These determinations are used to monitor the uptake of lead of exposed workers. Workers with 80 μg/1 or less lead content account for 61.5 percent of these samples, 90 to 150 μg/1 25.5 percent, 160 to 200 μg/1 6.5 percent, and above 200 μg/1 6.5 percent.

There have been visits to dental surgeries and mine gold rooms to determine the mercury levels in the air. There has also been a marked increase in the number of urine samples received from people exposed to mercury in their employment. There have also again been cases where people with high lead or mercury levels have been transferred to other work until their level falls to a satisfactory level.

Twenty-nine samples of urine for fluoride have been submitted from workers engaged on the addition of fluoride to water supplies. None of these samples have shown abnormal fluoride levels.

During the year six visits were made to ships at Fremantle. One case is of special interest. We had been informed that a container ship had reported a spillage of an unknown substance whilst at sea. A ships officer had been overcome by fumes whilst trying to investigate the trouble. The ships officer had recovered and described the trouble as a suffocating gas. The ship's manifest had shown that drums of methylene chloride were in the area where the trouble had occurred. The drums of methylene chloride were found to be intact. It was subsequently found that the spillage was due to leaking drums of "Vapam" (40 percent solution of sodium N-methyl dithiocarbamate). Vapam as a 40 percent solution is not hazardous but if it is diluted, as it was following this spillage, it generates the highly toxic irritant methyl isothiocyanate. We have written to the Commonwealth Department of Transport advising them of this case and our opinion that this material should be classified as a hazardous cargo. (Vapam is also known as metham sodium).

Officers of the Division have made inspections and taken samples from two establishments where chemicals containing toluene diisocyanate (TDI) are used. In one case our advice reduced the TDI level to below the threshold limit value (TLV).

A complaint from the sterilization section of a hospital was investigated. The sterilization was effected by placing the materials in plastic bags in an atmosphere of ethylene oxide gas. After sterilization the plastic bags are stored in the room. It was found that the concentration of ethylene oxide in this storage area was close to the TLV. The concentration is caused by the ethylene oxide permeating through the plastic bags.

Naphthalene is used at the Perth Museum to control insects in storage cupboards. Following a complaint by Museum staff about the smell, samples of the air were examined for naphthalene. It was found that the concentration of naphthalene in the work area was below the TLV.

Workers in a factory manufacturing DDVP dog and cat flea collars when routinely checked medically showed low cholinesterase levels. Air samples from the factory were not excessive in DDVP concentration. It was observed that the workers were handling the collars with gloved hands. It was demonstrated in the laboratory that these rubber gloves and plastic gloves were permeable to DDVP and therefore most unsatisfactory. We understand that steps are being taken to mechanically handle these collars.

A private firm requested our assistance to check a portion of their factory where a rubber glue was being used. The vehicle for the glue was identified as xylene and its concentration in the air was well below the TLV.

Dust samples from areas where there is a lead hazard and dust samples from a nickel smelter have been examined during this year.

The State Mining Engineer has requested us to examine the exhaust gases of engines to be used underground.

Only 18 samples of air for anaesthetic gases have been received. When our infra red gas analyzer arrives, it is anticipated that further work of this type will be carried out.

Pesticides

Six samples of heptachlor emulsified concentrate have been received in connection with the control of argentine ants. Of the samples received only one was below specification for heptachlor but three produced emulsions which did not meet specifications.

Most of the pesticide emulsion samples which were used for soil treatment for protection of buildings against subterranean termites were found to be not true to label as to identity. Many of the samples were also below the 0.5 percent concentration of pesticide recommended by Australian Standard CA 43 1966 Soil Treatment for Protection of Buildings Against Subterranean Termites.

A sample of household fly spray which had been the subject of a complaint was found to have a high mercaptan content. It appears that the spray was manufactured with non deodorised butane. The product was withdrawn from sale.

The Department of Agriculture submitted three samples of pesticide formulations which are also registered as veterinary medicines. In all three samples the analysis showed that the manufacturers were adhering to the stated formula.

Pesticide Residues

Table 10 gives a summary of the major types and sources of many of the samples received this year.

TABLE 10

PESTICIDE RESIDUE ANALYSIS

Sample	Number
Waters—	
Ord Area	53
South West rivers	124
Metropolitan bores	39
Other sources	57
Soils—	
Ord area	49
Wheat belt	172
Main Roads	12
Bovine fat—Ord area	77
Fish tissue—Ord area	150
Mosquito control	41
Pasture—Ord area	71
Dairy products	71

Only very low insignificant levels of pesticides were detected in groundwater bores used to supplement the metropolitan water supply.

An increasing number of samples are being received from situations where pesticide contamination of drinking water is suspected. Some of these samples have come from farm water tanks where spray drift from aerial spraying or treatment of buildings is suspected. Some samples have come from known accidental contamination of water containing vessels. Our experience is that vessels that have been used to store diluted pesticides or have become accidentally contaminated with pesticides are extremely difficult to decontaminate.

The bovine fat samples and pasture samples from the Ord area were to study the pesticide residues found in cattle and their relationship to the pesticide residues in the pasture on which the cattle were being fed.

The Division has been involved in two separate sampling programmes in connection with the control of mosquitoes. At the request of the Department of Conservation and Environment, a sampling programme was carried out in connection with a trial aerial spraying of the Canning River marshland with "Dibrom". The Public Health Department requested a sampling programme in connection with the use of "Abate" in the Alfred Cove area of the Swan River. In both of these treatments no significant residues were detected 24 hours after the treatment.

Twelve samples of soil were submitted by the Main Roads Department. These soil samples were taken from behind the abutments of a bridge which was put down in the pre organo chlorine pesticide era. Dieldrin emulsion was injected into the soil of the abutment at high pressure. Samples of soil after this treatment had levels which should be satisfactory as a termite deterrent.

Samples of water from a swimming pool showed high levels of pesticide. Investigation revealed that a dividing fence close to the swimming pool had been sprayed to protect it against termites. The pesticide in the pool was probably from spray drift from the fence treatment.

Following the reporting by the press of a pesticide contamination of a pet food in the Eastern States samples of this pet food on sale locally were received. None of reported contamination was found in local pet food samples submitted.

Animal Toxicology

In preparation for the use by the Agricultural Protection Board in W.A. of the chemical "Pindone" as a vermin poison, feeding trials on sheep were conducted. Samples of tissues from sacrificed sheep were examined for pindone residues. It is understood that further work will be carried out before pindone will be used for controlling vermin in this State.

Endrin was detected in a sample of bird seed which had been fed to a large aviary of finches in which many of the birds died. This seed was imported into this State and further checks will be made on fresh imports.

Several samples from animals were examined for pesticide residues. The only residues of toxicological significance were found in two dogs and one pig. In each of these cases ethyl fenthion (Luci Jet) was the organo phosphorus pesticide found in the animals.

Miscellaneous

Twenty-three samples of finger paints were examined for cadmium and lead. The samples did not contain any significant levels of cadmium or lead.

Following the banning in the U.S.A. of the food colour amaranth two samples of egg branding ink were examined. One ink contained erythrosine which is a permitted food colour in W.A., E.E.C. and U.S.A. and the other carmoisine which is permitted in W.A., E.E.C. but not in U.S.A.

The Division assisted the Engineering Chemistry Division in the analysis of flue gases from a cupola furnace and provided information for the development of a chemical scrubber.

Samples of air were obtained from the State Film Library from an area where old cellulose nitrate film was stored. No oxides of nitrogen were detected but it was pointed out that the draughty conditions in the room would rapidly disperse any oxides of nitrogen released by the film. Attention was drawn to the fire danger of old cellulose nitrate film.

The Pharmaceutical Services section of the Public Health Department have been manufacturing a silver sulphadiazine ointment for the treatment of burns. Analysis showed that their product was identical to the very expensive commercial product.

The Government Stores requested the examination of 32 surgical dressings for their compliance with the British Pharmaceutical Codex 1973 standards. The Government Stores also requested our assistance with a problem they were experiencing in their alcohol storage tanks. It was found that the colouration that developed in the alcohol was due to the synthetic rubber in the hoses of the pumps.

A sample of Freon 11 had a lower boiling point than expected and when examined it was found to be contaminated with Freon 12.

A sample described as a water bed additive to control algae was received from the Bureau of Consumer Affairs. The unlabelled bottle contained, along with other materials, pentachlorophenol. As pentachlorophenol and its preparations are Schedule 6 poisons its sale in an unlabelled bottle is a breach of the Poisons Act.

A plastic vessel made of PVC and described as a beer barrel was examined for VCM. The VCM concentration of the PVC was found to be 6 mg/kg. (Food and Drug Regulations limit VCM to 5 mg/kg). A four percent solution of alcohol when stored in the barrel developed a VCM concentration in excess of that allowed by the Regulations (0.05 mg/l).

General

Mr. G. F. Ebell attended the Conference of Residue Chemists held in Melbourne in April.

Mr. G. A. Taylor attended the meeting of Scientific Officers Engaged in the Field of Occupational Health held in Sydney in September.

The Division has handled numerous enquiries for technical information and advice from Government Departments, Instrumentalities and the public during the year.

F. E. UREN,
Chief, Food and Industrial Hygiene Division.

INDUSTRIAL CHEMISTRY DIVISION

The Division dealt with about the usual number of samples during the year. There has also been no falling off in the number of enquiries received, both by telephone and by visit. They have covered a wide range of subjects and as before a large proportion dealt with plastics.

Dr. Smith delivered a number of lectures on the use of plastics to seminars organised by the Plastics Institute of Australia at the University Extension Service, to service clubs, to delegates of the Industrial Design Council and to Engineers of the Public Works Department. He also

gave a talk on the hazards of swimming pool chemicals to factory inspectors of the Department of Labour and Industry.

Dr. Smith was a member of several judging panels for the Industrial Design Council and attended the Oil and Colour Chemists' Association Annual Convention in Queensland.

1. Materials Testing

Paint:

Samples of paint, large flakes and plaster sheet were received from the new Port Hedland Hospital. Paint was flaking from many of the ceilings usually starting over joints in the plaster. It was found that a fine powder, identified as gypsum was present on the surface of the plaster particularly along the edges of the joints and this would cause poor paint adhesion. It was recommended that the plaster surface be brushed down, sealed with a suitable paint sealer and repainted.

Paint flakes from a wharf building at Albany were found to consist of an inorganic zinc silicate primer and two alkyd top coats. Suggestions were made as to why rust was showing up and the paint flaking off.

Twenty four selected samples of paint were compared with the reference samples and test results submitted for the 1976 paint tender. Generally, the samples compared well with the reference samples.

A small offcut from a steel tie bar from the new Jurien Bay Police Station was submitted because of doubt about paint adhesion. The system was a zinc rich primer (inorganic zinc silicate), a tie coat and alkyd top coat. The coating was found to comply with the specification and adhesion was satisfactory for the type of coatings used.

The Tender Board submitted 53 samples of paint and the paint manufacturers supplied test results for examination for the 1977 paint tender. The results of these tests and practical application trials were considered by the Paint Advisory Committee in the recommendations to the Board. Examination of sample of paint flakes from the Boulder Primary School showed that two coats of paint had been applied according to specification. The failure of adhesion was found to be due to the cement render and not the paint.

Building Materials:

The fire test equipment for carrying out AS1530 Part 3 "Early Fire Hazard Test of Materials" is now fully operational and the backlog of samples has been processed. The samples tested include the following: cedar panels, plywood and particleboard panels faced with two different laminated plastic sheet, Stramit panels with 10 different surface finishes, expanded neoprene, flexible polyurethane foams and vinyl flooring.

Seven samples of carpet were submitted to standard tests. A tuft retention test has now been added to these. This is designed to measure the effort required to pull out individual tufts.

Fourteen samples of concrete underlay were tested. The impact test and the hydrostatic pressure test have now been modified. Both are now limit tests in which the drop height in the impact test and the hydrostatic pressure are taken up to a maximum value and not to failure as before.

Main Roads Department submitted a sample of a new grade of multi-ply to be used for concrete formwork. Tests previously applied to other samples were carried out and the material was found to be satisfactory.

Plastics:

Two samples each of plastic foam and adhesive were received for identification and fire testing. The samples of adhesive appeared to be identical with a bituminous base and were found to be not readily flammable.

The State Housing Commission submitted a strip of PVC skirting which had become detached from a wall. The PVC skirting still retained some of the adhesive originally used. This layer was tacky and was easily peeled away from the PVC. It did not appear to be the same as any of the recommended adhesives, all of which gave good bonds.

Nine samples of TV news film were submitted for determination of residual hypo (sodium thiosulphate) or sulphate to check on film deterioration.

The Consumer Affairs Bureau asked for assistance in determining the cause of a colour change in vinyl flooring. It was found that moisture picked up lime from the concrete and caused the fading. The pigment used is clearly alkali sensitive and its use should be discontinued. Later, an identical query was received from the Albany store of a major furniture company. The Consumer Affairs Bureau submitted a discoloured vinyl car top taken from a Datsun sedan. The discoloration was found to be due to dirt and dust firmly adhering to a film of plasticiser that had exuded from the vinyl surfacing. It was not possible to decide whether the problem was caused by faulty manufacture or that the vinyl formulation used, whilst satisfactory in Japan, might not be suitable for Perth's much hotter climate. A sample of steel pipe coated with nylon was submitted by Public Works Department. The coating was spark tested and the thickness of the coating measured. Only one pinhole was located during the spark test and the thickness varied from 0.2 mm to 1 mm. Provided no pinholes are present the coated pipe would be suitable for use as a water line.

Samples of polyethylene bags were submitted from two suppliers for testing for export packing of lamb. The thickness of the polyethylene film was measured and tests for tear resistance, impact resistance and strength of heat seal carried out. Both makes were very similar in properties and should be equally satisfactory.

Two samples of different brands of vinyl flooring were tested for scratch and abrasion resistance, discolouration with iron ore dust, resistance to lime, fastness of colours to light, thickness of vinyl coating, impact resistance, indentation, dimensional stability and the fire test to AS 1530 Part 3. Both samples gave very similar results except that one product was less dimensionally stable.

A plastic throw-away cigarette lighter was submitted by the Consumer Affairs Bureau. This had been involved in a minor fire and was thought to have caused it. Our examination indicated that it was unlikely to have caused the fire but could certainly have contributed to it.

Miscellaneous:

The Fire Brigade submitted a camera in which a mercury battery had exploded and caused a minor fire. No indication of a short circuit could be found but the damage caused by the explosion and fire may have destroyed the evidence.

Fibres present in a dental anaesthetic paste were examined. They were found to be of vegetable origin but were not positively identified. The supplier later advised that the fibres were the hairs from the stems of bracken fern growing in Indonesia. It is claimed that they have a haemostatic action.

The Consumer Affairs Bureau submitted a pair of binoculars, the purchaser having claimed that there were deposits inside the lenses. These were found to be spots of grease, spread by a loose screw.

Tenders for polish were examined in detail and recommendations made on selection to the Tender Board.

Similarly tenders for detergents were also examined in detail and recomendations on selections made to the Tender Board. In addition, later in the year, the specifications for the various items were critically examined and

most were revised to tighten up on composition requirements. Some alterations to the tender schedule were also suggested.

A batch of welding protective cream was prepared for Mechanical and Plant Engineers Depot at Jewell Street. The cream was a dispersion in water of various inert ingredients and suspending agents.

Two samples of drafting film, one of polyester and the other of paper were tested for fire resistance rating according to British Standard BS 2963; 1958: Method A, Vertical Strip Test. Both samples burned readily, the polyester film slowly and the paper rapidly. The fire resistance rating of the polyester film was 138 sec. and of the paper 28 sec.

Two lots of samples of sheets which had been treated with fire retardants were tested for fire resistance rating according to BS 2693: 1958 to determine whether severe laundering had any effect on the treatment. Eight samples were tested and it was found that the treatments generally stood up very well to laundering.

A pair of pyjamas and three quilts were submitted for fire testing by BS 2693: 1958. Two of the quilts were classified as "self extinguishing", the third quilt had a fire resistance rating of 92 sec. and the pyjamas a rating of 105 sec.

Two electrical resistors were submitted each coated with a different protective coating. They were exposed for 500 hours in the standard salt spray cabinet and both appeared to resist the conditions equally well.

In a sample of air conditioning ducting containing rubber gaskets at the joint it was confirmed that the rubber was EPDM rubber as specified and advice on its properties was given.

2. Assistance to Industry

The pilot plant equipment was used to dry and hammer mill a quantity of yeast slurry for a local company.

A local flooring supplier requested examination of a seal in a section of PVC strip which had failed in practice. As required by specification two layers of seam sealer were found. However, in some sections examined it appeared that excess bonding adhesive used on the floor has partly filled the seam and interfered with the application of the sealer, thus producing a weak joint.

A formulation of patching plaster obtained from the Eastern States was submitted for comment by a small local paint company with the complaint that it would not set. This was not surprising since it did not contain any plaster of paris.

A local fibreglass reinforced plastics manufacturer was given advice on the repair of some damaged FRP building panels installed at Esperance. Subsequently, expert testimony was given at a private enquiry held to investigate the problem. The company won their case.

The present leaseholder of the Lake Chandler alunite deposit and tailings dump was given detailed information on the production of potash. At present he is only producing an absorbent material from the tailings.

A local company is interested in developing a cheaper replacement for the stainless steel ties now specified for high rise brick walls. Information was given on coating galvanised ties with plastics and some samples were checked with our spark tester. Many pinholes were found.

Information was provided to an individual on the use of plastics for casting elaborate picture and mirror frames with a view to local manufacture.

A local importer asked for UV exposure tests to be carried out in our weatherometer on PVC cladding. Fourteen samples of different colours and sections were exposed and reported on.

A sample of PVC pipe with a longitudinal crack just below a joint was submitted by a farmer. Visual inspection showed that too much adhesive had been applied to the socket of the joint. When the spigot was pushed home this excess adhesive was squeezed into the pipe and formed a run 18 cm long and up to 2 cm wide. The crack which subsequently occurred coincided exactly with the run of adhesive and it is an example of "solvent cracking" about which there is a specific warning in Australian Standard CA 67-1972.

Information was supplied to an individual developing a new design of solar heat collector. Detailed information was provided on suitable plastics together with possible suppliers.

A series of fabrics in various colour combinations used for women's swimming costumes were exposed in the UV weatherometer for over 200 hours and during this time half of each sample was rinsed regularly in seawater. It was noted that some seawater treated samples suffered worse fading than the untreated samples.

3. Investigational

Popping plaster:

A considerable amount of time was spent in investigating the popping plaster problem in the building industry at the request of the Consumer Affairs Bureau. This Division carried out tests with various surface treatments in an attempt to stop the popping in an existing faulty wall. It was found that the application by brush of a 10 percent calcium chloride solution to the plaster stopped popping after several weeks with no recurrence after a further two months. The experiments then had to be terminated as the site was wanted by the builders. Two other Divisions were concerned in various aspects of the investigation and a composite report is being prepared.

Laporte effluent.

Further work has been done on this problem and an attempt has been made to produce phosphoric acid by reacting the effluent with C grade Christmas Island phosphate rock. This has not so far been successful and in particular unsatisfactory results were obtained in attempting to recover any phosphoric acid by solvent extraction.

Rock lobster shells.

Work was done on a pilot plant scale on production of chitin and chitosan from rock lobster shells. Good quality chitin was prepared but attempts to make chitosan have so far been unsuccessful.

4. Consultative.

A wide range of consultative work was undertaken which involved the Division in literature searches, visits from enquirers and visits to factories. A selection from the enquiries received is given below:

Commercial scale steam distillation of lemongrass oil at Kununurra.
Handling and recycling of plastics and other wastes,
Epoxy and polyester moulds for concrete block making.
Dyeing of flowers and foliage.
Production of methane from animal wastes.
Use of plastics for baths and vanity basins.
Manufacture of dispersions of carbon black and iron oxides for colouring cement and concrete.
Polymer-concrete composite materials.
Materials of construction for tanks for flotation reagents at a nickel mine.
Manufacture of cellular concrete.
Repair and manufacture of plastic swimming pools.
Removal of lime soap deposits from bathroom tiles.
Welding of PVC sheeting in above ground swimming pools.

E. B. J. SMITH,
Chief, Industrial Chemistry Division.

KALGOORLIE METALLURGICAL LABORATORY

General

Two hundred and sixty five confidential certificates were issued during the year, of these nineteen were issued for research work, and the remainder were for the analysis of ores from various sources.

Bullion bars received at the laboratory for assay increased from 40 in 1975 to 45 in 1976, and this trend is expected to continue.

During the past year companies and prospectors were very concerned with the rising cost of materials, and are turning to near surface oxidised gold ores.

Research work during the year covered four gold ores, and three dump samples for gold extraction by cyanidation, and seven sulphide gold ores by various methods such as straking, amalgamation, flotation and roasting, prior to cyaniding.

An unusual problem was found in treating one of the sulphide ores in that the sulphide minerals were coated with a thin layer of gold.

Some work was carried out on a very promising sample of attapulgite, which should find a variety of outlets. A scheelite sample for testwork also showed promise, provided a sufficient tonnage is available for treatment.

The Work Index on two high grade samples of zircon was also carried out.

An outline of the number and type of samples received at the laboratory are shown in Table 11 but it does not show the work involved as many samples were analysed for 6 or 7 metals at the request of clients. More attention is now being paid to the silver content, as the rising price of silver has made its recovery more attractive than in past years.

TABLE 11

KALGOORLIE METALLURGICAL LABORATORY

	Mines Department	Police Department	Public			Total
			Pay	Concession	Free	
Testwork	....	....	....	....	....	....
Gold ores	....	....	13	....	....	13
Gold tailings	1	....	9	....	....	10
Other	....	....	8	....	....	8
Analytical	....	....	....	....	....	....
Copper ore	....	....	24	....	....	24
Gold	....	....	....	....	....	....
Bullion	....	....	45	....	....	45
Cores	....	....	200	....	....	200
Ores	2	12	546	48	2	610
Solutions	....	....	4	....	....	4
Tailings	12	....	387	....	....	399
Screen analyses	....	....	44	....	....	44
Waters	....	....	11	1	....	12
Other	....	....	13	2	....	15
Total	15	12	1 304	51	2	1 384

Work from small companies has been restricted as they are unable to raise exploration capital since mining calls were disallowed as a taxation deduction.

Consultative and Advisory

Companies and prospectors continue to seek advice on treatment problems, and are wise to do so as we are able to help them save money and avoid some of the pitfalls which are not obvious until some research has been carried out.

Equipment

A Philips SP30 spectrophotometer has been received and is working satisfactorily. A Kent Mark 2A lapping and polishing machine and an Oliphant UV 16 Fluorescent Analysis Cabinet have been received and will prove useful tools in the examination of various products.

G. H. MUSKETT,
Officer in Charge,
Kalgoorlie Metallurgical Laboratory.

MINERAL DIVISION

General

A feature of the work of this Division which is common to earlier years is the number and variety of Government client Departments which have submitted samples. Samples were examined this year for nineteen Government sources as well as for the Public.

Two thousand eight hundred and twenty six samples were received, the largest group being dust samples from the Public Health Department, the number of which (783) was reduced from the previous year. The biggest increase was in submissions from the Geological Survey Branch, which were more than doubled. The increase in work load from this source was greater than suggested by the increased number of samples handled because most analyses required were very comprehensive and involved determination of a large number of elements. The ability of the Division to handle this additional work is related to the upgrading of the Division's XRF unit by addition of a 10 head sample changer. Equipment to give further upgrading to the level of full computer control has been ordered this year.

Consistent with the trend in recent years the proportion of work undertaken for the public has again been reduced in accordance with a policy of accepting such work only when local firms are unable to have it done elsewhere. Private work in 1976 consisted of only 11 percent of the total samples registered. A large proportion of this number was derived from investigational projects undertaken by the Engineering Chemistry Division.

While the number of dust submissions by the Public Health Department has decreased this year the introduction of Mines Regulation Act Regulations has been accompanied by a 62 percent increase in dusts from the State Mining Engineer.

Another significant group of samples consisted of mineral specimens acquired by the Division in the course of expanding the mineralogical record of Western Australia and the Mineral Division mineral collection.

Details of the sources and types of samples are shown in Table 12.

Ores and Minerals

Bauxite

Apart from 22 samples submitted this year, examination of bauxites has consisted of those collected earlier by Geological Survey of Western Australia to examine the soil profiles of bauxite-laterites, from the surface down to bed rock, over a large area of the Darling Scarp. One hundred and thirty seven samples were involved. Quantitative estimates were made of 15 species of primary and secondary minerals together with chemical analysis of 14 essential components and 11 trace elements.

At the request of the chairman of the Standards Association of Australia sub-committee on the chemical analysis of bauxite, analysis of 11 samples was undertaken to evaluate an x-ray fluorescence method proposed as a standard. Although these laboratories are not involved in the deliberations of this committee, participation in an inter-laboratory check was considered to be of value.

Clays

The majority of samples submitted were associated with work being done on dam foundations or clays related to regional mapping by the Geological Survey.

Particle sizing and semi-quantitative determinations of clay species were carried out on 17 soils from Churchman Brook, 6 from Wungong and 4 from Robe River dam sites. Five clay residues from the Gregory Gorge dam site required qualitative descriptions.

Clays found at the south-west sites were predominantly kaolin, halloysite, and micaceous types. The north-west clays invariably contained smectite with kaolin, illite, chlorite and possibly palygorskite.

A rock sample from the Wungong dam foundations was examined for the clay minerals formed along the rock surfaces. These were found to be stilbite, a smectite, and chlorite.

Work was completed on eighteen Del-Park pallid-zone bauxites. All soil minerals were determined quantitatively to assist in the geochemical survey of the area. Kaolin, mica, and gibbsite were the major clay minerals in most samples.

Six soils from Armadale, Forrestdale and Gosnells were examined for moisture content, particle size and clay type.

Other clays submitted by the Geological Survey included smectite and a complex mixture of mica, vermiculite and chlorite occurring in different limestone units from the Yanrey area, and nontronite and illite samples associated with calcrete from the Millstream area.

An expanding clay from the Swanview High School site was found to be essentially smectite.

Diatomaceous earth

30 samples of diatomite were examined largely as part of upgrading work conducted by Engineering Chemistry Division.

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TABLE 12

MINERAL DIVISION

	Aboriginal Lands Trust	Geological Survey	Government Chemical Laboratories	Main Roads Department	Mines Department	Police Department	Public Health Department	Public Works Department	Road Traffic Authority	State Housing Commission	Other	Public			Total
												Pay	Concession	Free	
Building Materials	....	....	58	9	....	....	....	10	....	12	2	7	....	....	98
Dusts	....	....	3	....	458	....	777	....	....	....	....	3	....	....	1 241
Forensic Examinations	....	....	....	....	....	58	....	....	4	....	....	....	....	....	62
Geochemistry	....	94	....	....	....	....	....	....	....	....	....	6	1	3	104
Metals and Alloys	....	....	....	....	....	....	....	4	....	....	17	4	....	....	25
Mineral Identifications	17	42	104	....	3	....	....	....	....	....	21	48	40	7	282
Miscellaneous	....	5	3	9	4	....	6	3	....	....	....	13	....	....	43
Ores and Minerals—															
Bauxite	....	11	11	....	....	....	....	....	....	....	....	....	....	....	22
Clay	....	41	....	....	....	....	....	2	....	....	2	8	5	....	58
Diatomite	....	....	1	....	....	....	....	....	....	....	....	18	....	....	19
Gold	....	3	....	....	119	....	....	....	....	....	....	22	21	13	178
Iron	....	5	30	....	....	....	....	....	....	....	....	....	1	....	36
Limestone	....	155	....	....	....	....	....	....	....	....	2	....	....	1	158
Sands	....	7	4	....	....	....	....	....	....	....	....	....	7	2	20
Uranium	....	46	....	....	....	....	....	....	....	....	....	....	....	....	46
Zircon	....	....	19	....	....	....	....	....	....	....	....	49	....	....	68
Other	....	1	9	....	6	....	....	....	....	....	....	19	1	....	36
Silicate Analyses	....	295	....	....	....	....	....	....	....	....	....	2	....	....	297
Thermometer Calibrations	....	....	....	....	....	....	....	....	30	....	3	....	....	....	33
TOTAL	17	705	242	18	590	58	783	19	34	12	47	199	76	26	2 826

Head samples were completely chemically analysed but processed fractions were examined largely for degree of fractionation of skeletons and microscopically evident impurities.

Gold

The number of samples assayed for gold this year was greatly reduced.

The greatest number in one group was 110 from near Halls Creek, taken by the State Mining Engineer in connection with an application for a mining subsidy.

Six umpire samples related to various State Batteries were assayed and two assays from the same source were checked.

Submissions from the public totalled only 56 samples and most were of low value.

Localities from which values above 5 g/tonne were recorded were: 2.5 km North of Dardanup (6.6 g/tonne), Mt. Magnet (28.9 g/tonne crystalline), Gairdner River area (18.4 g/tonne), and 19 km North West of Meekatharra (6 samples 13.8 to 60.3 g/tonne).

Two samples of the Wiluna slag dump were assayed, representing material before and after a client had used a chemical treatment. No extraction of gold was evident.

Iron

Work on iron ores this year consisted almost entirely of two types which were (a) from upgrading studies and (b) studies of methods of analysis for the Australian Standards Association.

(a) Upgrading projects in the Engineering Chemistry Division produced samples of fractions which were examined to determine the movement of iron and impurities (largely silica), with various treatments. Bench scale tests were done on another iron ore to determine the movement of mainly aluminous impurities with gravity separation and dispersion techniques. The aluminous minerals present included kaolin, montmorillonoid, illite, gibbsite, and feldspar. The iron minerals were hematite and goethite.

Although some aluminous minerals separated more readily than others, the heavy liquid separation gave only minor beneficiation due mainly to the intimate association of kaolin and goethite. Separation by aqueous dispersion was little better.

(b) A considerable program of testwork has been entered into in support of the Australian Standards Association's efforts to gain acceptance as International Standards for methods which are applicable to present needs.

Methods being currently used have been shown to be inadequate in a number of circumstances. Lower limits are now being specified for some impurities such as alkalis. Production of pre-reduced pellets has necessitated review of methods used for metallic iron, which have been shown to be unable to analyse some products.

Environmental concern has also produced a need for standard methods for arsenic and other injurious elements at levels not previously of interest in iron ores.

Limestones

The limestone samples examined were largely part of a Geological Survey of Western Australia review of potential commercial deposits in several areas of the South West corridor. Seventy nine samples were examined for lime, magnesia, insoluble material and, in some cases, iron. Lime, CaO, figures ranged from 16 to 49 percent, magnesia, MgO, from 0.4 to 3 percent, and insolubles from 3 to 68 percent.

Development of the Wanneroo-Joondalup area required an examination of limestone deposits in the area for town planning purposes and 43 samples were examined. They ranged from 22-48 percent CaO, 0.5-6.8 per cent MgO, and 11-37 percent insolubles.

A further 33 samples were examined for Geological Survey of Western Australia in connection with the Millstream water storage investigation. Shale and limestone were involved and the ranges were CaO, 0.03-49.8 percent; MgO, 0.1-22 percent; and insolubles, 0.1 to 95 percent.

Samples were also examined from the Halls Creek area for the Department of the North West. Advice was given re possible deposits for lime burning.

Thorium and Uranium

A suite of 170 samples of granitoid rocks from the Laverton-Rason-Leonora map sheet, selected on the basis of elements already reported, was examined to assist in interpretation of the origin of secondary uranium deposits in the area. It was considered possible that uranium levels below the normal for these particular rocks might indicate a history of leaching which produced the secondary uranium minerals.

The distribution of uranium and thorium in granite of several types in the Pilbara Block was examined to assist uranium prospecting in the area.

Zircon

The 68 zircon samples examined were almost entirely related to trials conducted by Engineering Chemistry Division on a process to remove surface iron contamination from beach sands. Total iron, and potassium pyrosulphate extractable iron, were determined and correlated with a yellowness index which is the difference in light reflection from the same surfaces measured under standard conditions, at wave lengths 570 nm and 680 nm.

Zircon samples from a mining company were analysed for 5 elements to establish standards for the firm's x-ray fluorescence analyser.

An interesting radioactive sample from 5 km WNW of Lakeside homestead, Murchison, consisted of an intergrowth of metamict zircon and monazite with very minor feldspar and mica.

Building Materials

The Laboratories were requested, early in the year, to assist the Consumer Affairs Bureau by technical advice related to the generation of pits and popouts in wall plaster applied to Western Australian buildings in the latter half of 1975. The Mineral Division undertook the study of materials remaining at the site of popouts in affected plaster, either at the base of pits or adhering to ejected cones.

In all instances the expanded material, which produced the stress, was readily differentiated by its loose texture and lack of cohesion, from the more dense and compact surrounding plaster, and from dense unexpanded materials in the core.

Common to the non-cohesive material in all cores examined, was a high percentage of portlandite, $Ca(OH)_2$, accompanied in most cases by unhydrated lime, CaO. Some popout cores which were darker than the others also included dark particles which were hard and dense and consisted of one or more of the following compounds: alite, Ca_3SiO_5; tricalcium aluminate, $Ca_3Al_2O_5$; calcium ferrite, $Ca_3Fe_2O_5$; and brownmillerite, $Ca_4Al_2Fe_2O_{10}$. These compounds are products of fusion of lime with impurities bearing silica, alumina, and iron.

It is apparent that the disruptive force involved in ejecting the pops has been due to hydration of lime, CaO, in the set plaster, to portlandite, $Ca(OH)_2$ since the products of the expansion are all derivatives of lime, CaO, and lime is also found in the cores. The presence of silicates, aluminates, and ferrites in the cores (in some cases still occluding unhydrated lime) offers a partial explanation of the retention of this lime in plaster since it has been protected from moisture penetration.

Tests were also conducted to determine whether the source of lime in a wall plaster could be defined from the strontium or magnesium content.

Other building materials examined included concrete aggregates proposed for use in the Fortescue River bridge, and the Middle Branch River bridge, also aggregates from the Turner River, the Gascoyne River and batching plants of concrete suppliers. In instances where chemical "Potential Alkali Reactivity" tests were not conclusive these were followed by "Mortar Bar" tests.

One aggregate examined mineralogically to determine its suitability for concrete contained a high percentage of fibrous tremolite. The possible health hazard in handling this material was drawn to the attention of the Public Health Department.

An aggregate described as being refractory, and imported for a particular project, was examined to determine whether a local source was available. The material had a low level of crystallinity consistent with an artificial slag such as would be produced by fusion of an iron ore with a limestone flux. No Western Australian industry producing this material could be quoted but the production would be simple if an economic quantity was required.

Cores taken from structural concrete in a Public Works Department building had an original mix cement:sand: aggregate of 1:4:6 instead of the recommended 1:2:3.

Another series of samples of set concrete was submitted with a request for the original mix which suggested that "lime" of unknown composition may have been added. An estimate was possible in this instance because it was apparent that little or no lime had been added, but the impossibility of establishing an accurate original mix in the absence of samples of ingredients was stressed. In this instance the verification of the presence of Bondcrete in the mix was requested. Experiments showed that Bondcrete did not have its normal solubility characteristics after admixture in concrete.

Warping of precast panels facing a Government building was shown to be unrelated to sulphate attack from adjacent flues. The mix was that of a white cement and coarse aggregate with no sand or fine aggregate. This mix produced a weak concrete which probably contributed to the warping.

Concrete masonry blocks made commercially in a country town were shown to be free of a tendency to effloresce. Previous work on efflorescent bricks from these works led to recommendations which identified the problem. Alteration of manufacturing technique was able to overcome the trouble.

Concrete masonry blocks manufactured at the La Grange Aboriginal Mission were shown to be susceptible to efflorescence and had a total absorption in some cases in excess of the recommended standard. Later samples were free of efflorescence and had a satisfactory absorption.

A special proprietary grouting material proposed for a key structural role in an elevated water supply tank, but not previously used by Public Works Department, was examined in detail. It proved to consist of quartz grains and alite (tri-calcium silicate) and consequently had no characteristics which would cause it to be rejected for the proposed use.

Dusts

The dust samples examined this year numbered approximately the same as in 1975, but the number was made up of a decrease in submissions from the Public Health Department and an increase by the State Mining Engineer. Samples related to general environment conditions included 340 samples for lead from air sampling in Perth streets and 270 samples from various iron ore environments. Smaller groups were related to cement and lime production and to alumina and graphite in the Cockburn area.

Another group of samples related to the health hazard in the sand blasting industry, from quartz dust.

A large group was submitted for identification of its component materials in order that the source of nuisance could be established.

Public Health Department investigations of dust nuisance in the vicinity of a plywood works produced a need to study the characteristics of various timber sawdusts. Samples of specific types used at the works were obtained by inspectors and these were added to a comprehensive collection donated by the Forests Department.

Samples of air-borne dust from several buildings were examined for asbestos fibre content. Samples related to the mining industry, collected by the State Mining Engineer's Branch, were mostly checks for free quartz but included also were samples for talc and asbestiform fibres. Samples were also submitted for quantitative estimation of carbon from diesel exhausts underground, and also of lead-bearing dust from gold assaying laboratories.

A development in the work for free quartz in dusts has been a change from cellulose acetate filter papers for sample collection to low ash P.V.C. papers. This change has markedly increased the accuracy of x-ray diffraction assessment in the Laboratories. Another advance is the recording in the Laboratories of both pre and post sampling weights of dust collection papers. Previously the estimated weight of quartz was calculated to a percentage of a sample weight supplied by the Inspectors. Consequent to the promulgation of the Mines Regulation Act Regulations, and contributions to the Karratha Dust Symposium in 1975, the Laboratories have been consulted and have demonstrated techniques to Environmental Officers of several iron ore companies. A number of check samples for these firms have also been done.

The subjective nature of the counting technique for determining fibres in air samples has been a concern of the Asbestos Industry Occupational Hygiene committee and also of these Laboratories.

Prepared sample slides secured from N.S.W. have been examined separately by several officers to establish the degree of subjective variation but no N.S.W. figures have been available for comparison. This situation should be improved when the Asbestos Industry Occupational Hygiene Committee circulates slides being prepared for inter-laboratory comparison.

Assistance has also been given to the Mines Inspection staff by examination of size fractions collected by various sampling heads and by a study of the characteristics of various dust collection filters.

Forensic examinations

During the year 5 cases were dealt with involving comparisons of sands and soils. These were a murder at Leighton Beach, rapes at Morley and Mullaloo, the Bunbury woodchip explosion and a murder scene at Bayswater.

In each instance sands from the scene were compared with material from the floor of a vehicle used by a suspect, and the work entailed grain-size analysis, optical mineralogy, x-ray diffraction and gravity separation.

In the Morley case the results were inconclusive due to the offence having occurred in an area where sands from various sources had been dumped. In the Mullaloo case additional samples of sand were submitted from five other Metropolitan beaches for comparison. These showed that sands from the hair of the victim and the suspect's clothing were consistent with having originated from the Mullaloo site.

In the Bunbury case reclaimed sands from the vicinity of the woodchip terminal were found to have very distinctive features which were identified in the sand from the suspect's vehicle. In both the murder cases consistencies were found between sand from the scene and from a vehicle, but the sand in the Bayswater material proved to be of a very common type lacking distinctive features.

Two cases were handled in connection with fires. Residues from the suspected source of a fire in a hall were found to contain potassium nitrate, sulphur and charcoal, indicating a gunpowder mixture had been made. Pieces of partially fused material from a fire in a cement works proved to be residues of substances found in slag wool and ceiling plaster and would not have contributed to the cause of the fire.

Two cases were handled in connection with explosions. Debris from an explosion at Daglish was examined for the nature of the explosive used. Nothing which could have come from a detonator was found, and the results were thus inconclusive. Residue from an explosion at Claremont was found to contain traces of compounds suggesting the explosive mixture was "home made" from common chemicals.

Paint from woodwork at a break and enter site at Albany, and from a pinchbar suspected of having been used in the offence, were found to be closely comparable. Ballast from a broken safe at Leederville was compared with material on a suspect's glove. These were found to be different substances from unrelated sources. Residues from an oil submitted in connection with damage to a marine engine contained carborundum abrasive. Windscreen glass from a hit-run scene was compared with glass from several suspect vehicles. They were all found to be different, especially with respect to thickness of the glass and physical form of fragments.

Geochemical analyses

The geochemical analysis for trace elements as an aid to metal prospecting was largely associated with geological mapping of particular areas by the Geological Survey of Western Australia. Analyses for essential elements in silicate rocks and bauxites were accompanied by trace element analyses.

A re-examination for thorium was made on a suite of samples collected and reported on in previous years. Uranium to thorium ratios of granites in the Pilbara block were reported.

Seventy six gossan samples were scanned by emission spectrography to decide which required more accurate work. Twenty seven elements were reported in ranges which gave a useful guide. For low limits of detection for some elements scanning by x-ray fluorescence has been substituted.

Metal and Alloys

Analyses were made of bird identification bands, used by the Department of Fisheries and Wildlife, which consisted of various metals. Titanium bands are expensive, aluminium is too soft so that markings are lost, and monel metal is rapidly corroded in the stagnant saline water environment of some birds. A recommendation was made for the use of a cupronickel alloy, consisting of approximately 10-30 percent nickel, instead of monel metal approximately 70 : 30 nickel : copper.

Assistance was given to a private firm producing grinding balls for the mining industry. Interest centred on the amount of various added elements which survived the cupellation process. There was evidence of a considerable loss of silicon.

Metal particles removed from the sump of a diesel engine used by Public Works Department had a composition comparable to bearing liners used in the engine.

A check was made on the composition of silver brazing alloys submitted to the Tender Board, to assist selection.

Rapid corrosion of aluminium parts in a water meter was assessed as being due to electrical contact with more noble metals rather than to trace impurities in the aluminium.

A wire cable which had failed while being used to support a bosun's chair was examined for the Department of Labour and Industry. The structure of the cable included vegetable fibre strands carrying a waxy material probably intended to provide lubrication for movement of the metal strands. This lubricating fibre was absent at the break, and while no corrosion products were found which would indicate chemical attack of the cable, it is possible that such attack had occurred with production of soluble products which were later washed away.

The electroplating of hospital bed trolleys was examined to determine whether a base layer of copper had been applied. Copper was present in a layer thinner than specified by the appropriate Australian Standard but the intermediate nickel layer was considerably thicker than the specification.

Mineral Identifications

Samples submitted by the public represented approximately one third of this group. The greatest number however were samples acquired by the Division to expand the Mineral Division Collection, and consequently the mineral record of the State.

A large group was of samples from the Geological Survey Branch requiring specialist mineralogical treatment.

Localities worthy of special mention are those which have continued to yield minerals of great interest: The Carr Boyd Nickel Mine "Glory Hole" dumps are one of the most prolific rare mineral collecting grounds in Western Australia. Glaukosphaerite, carrboydite, chalconatronite, nickelblödite, garnierite, takovite, paratacamite, and a proposed new mineral "georgeite" are among the new minerals collected. Unfortunately sulphide oxidation has destroyed much of the dumps and the minerals are now difficult to find.

Nickelblödite (a nickel sodium sulphate) though first discovered at Carr Boyd Mine, has since been recognised by C.S.I.R.O. officers in samples collected some years previously at Kambalda.

The Milgun Station phosphate deposit contains many rare and recently described phosphate minerals. The minerals collinsite, segelerite, jahnsite, montgomeryite, and foggite have been studied from this deposit.

Archerite, a new potassium hydrogen phosphate, was found in a Nullarbor cave. This mineral is an end member of a series between potassium and ammonium hydrogen phosphate. The other end member is biphosphammite. Associated with archerite are many unusual minerals such as aphthitalite, syngenite, weddellite, taylorite, oxamite, whitlockite, stercorite, newberyite, whewellite, and two further new minerals, one corresponding to ammonium calcium phosphate, the other not yet characterised.

An examination was made of a suite of samples representing the mineralisation in one of four holes drilled at Wongan Hills. The samples were donated by the exploration company and were the first samples available from underground in the area. The results of this work, indicating chalcopyrite, löllingite, marcasite, cubanite, and other minerals in garnetiferous and quartz-grunerite-siderite rocks were conveyed to Geological Survey geologists mapping in the area.

A calcined vermiculite from Young River was examined to determine whether it could be used as support material for hydroponics. The essential requirements are freedom from toxic substances and pH of an aqueous leachate around 6-7. The vermiculite examined yielded a rather more alkaline leachate but it was considered that a dilute sulphuric acid treatment followed by a water wash would give a suitable product.

Mineral Collections

The Divisional collection was further expanded this year to 5841 specimens by the addition of 205. Following an established policy the additions were essentially Western

Australian. Those other included 10 from overseas and 11 from other Australian States. These were acquired because of areas of particular interest for current projects.

The addition of specimen material was greatly assisted by the interest of several mining companies and individuals who donated specimens, and efforts are being made to increase the supply of interesting material from this source.

To further enhance overseas interest in Western Australian mineralogy, "type" specimens of newly described minerals were presented to several National Collections. These include The British Museum, The Smithsonian Institution, and The National Science Museum, Tokyo. Because of this, researchers in the countries represented are able to procure research material without further approaching the original authors. As usual, specimens representative of all newly recorded localities were added to the collection. A list of these minerals follows.

The computer indexing of the collection is near completion and when finished will enable information on minerals and localities to be instantly available. Further work on this system, to make it comprehensive, will entail the checking of the literature for minerals mentioned but not represented in the collection, and also checking of the published catalogues of other Institutions.

New Mineral Localities:

Listed below are localities from which the specific minerals were recorded at the Laboratories for the first time this year.

Greater detail of localities may be available on application depending on the source of the material.

Species identified for the first time in Western Australia are marked with an asterisk *.

The Divisions used are those of Simpson's "Minerals of Western Australia".

North West Division:

Clinobisvanite	Cooglegong
Clinobisvanite	Friendly Creek
Mottramite	Mundong Well
Nitratine	Wanna Station
Uricite	Wanna Station
Whewellite	Wanna Station
Crandallite	Wanna Station
Crocoite	Gifford Creek Station
Clinoclase	Capricorn Range
Bayldonite	Capricorn Range
Duftite	Capricorn Range
Pseudomalachite	Capricorn Range
Cornwallite	Capricorn Range
β-uranophane	Yinnietharra
Chrysoprase	Warrawanda Creek

Murchison Division:

β-uranophane	Austin Downs
Carnotite	24 km. W. of Cue
Paratacamite	Ryansville
Zircon	Lakeside Station
Wolframite	Glen Station

South West Division:

Magnetite	Crows Nest Hill
Chrysoberyl	Smithfield
Arsenopyrite	Greenbushes
Hollandite	Greenbushes
Chalcopyrite	Wongan Hills
Grunerite	Wongan Hills
Cubanite	Wongan Hills
Marcasite	Wongan Hills
Löllingite	Wongan Hills
Bertrandite *	Rothsay
Holmquistite	Greenbushes

Central Division:

Brugnatellite *	Mt. Keith
Nickelblödite *	Carr Boyd
Carrboydite *	Carr Boyd
Nickeloan siderite *	Redross
"Georgeite" *	Carr Boyd
Sepiolite	Pyke Hill
Violarite	Fraser G.M., Southern Cross
Clinobisvanite	24 km. S. of Koolyanobbing
Fluorite	24 km. S. of Koolyanobbing
Glauconite	Nabberu Basin

Eucla Division:

Zoisite	Young River
Archerite	Madura
Oxammite	Madura
Weddellite	Madura
Stercorite	Madura
Syngenite	Madura
Aphthitalite	Madura
Taylorite	Madura
Whewellite	Madura
Newberyite	Madura

Canning Division (North East):

Galena	Rudall Sheet
Cerussite	Rudall Sheet

Warburton Division (East):

Cryptomelane	Windarra
Pyrolusite	Yarlakutjarra
Cryptomelane	Yarlakutjarra

Pyrometry

As a service to industry, National Association of Testing Authorities registration has been retained in the field of heat and temperature measurement. Calibration of optical pyrometers has been limited to temperatures below 1 500°C because of lack of demand for this service at higher temperatures, and the cost of maintaining equipment.

Pyrometric work has again this year been largely for the Road Traffic Authority in the form of thermometer calibration for Breathalyzer operation. Few other calibrations were made.

An investigation of some interest was to establish temperatures at various positions in operating Westrail bus engines.
Cracking had occurred in engines of one type and temperature differences throughout the head were suspected as a source of stress. Purchase of some additional equipment was necessary for the task. The observed temperature differences were too small to account for the cracking.

Silicate Rock Analysis

The largest volume of work from any one source was again the provision of complete analyses of silicate rocks required for geological mapping by Geological Survey of Western Australia. Each analysis includes a large number of selected trace elements and is accompanied by a calculation of the C.I.P.W. normative minerals.

One hundred and three samples awaiting attention from the previous year were reported and one hundred and forty submitted this year were completed.

At the request of the Professor of Geology of the University of Queensland (previously of the University of Western Australia) a complete analysis was undertaken of a mineral, kornerupine, from a research project.

Miscellaneous Examinations

A concretion removed from the ear of a patient of the Perth Medical Centre was shown to be an iron stained quartz-feldspar intergrowth considered to be of terrestrial origin.

Assistance was given to the Mineral Chemistry Research Unit of Murdoch University by establishing the form of combination of copper, iron, and nickel in material to be used in their leaching studies. Subsequently, a number of samples resulting from the leaching tests were examined and their structures established so that an interpretation of the chemical processes involved could be proposed.

Material blocking trickle micro tubes from an irrigation system was found to be essentially aluminium hydrate and poorly crystallised goethite suggesting that coagulation and precipitation had occurred after passage of the water through in-line filters. Treatment was suggested to obviate the bacterial growths probably causing the coagulation.

A substance depositing in the flue from a laboratory in a high rise building in the city was examined due to concern by the Chief Inspector of Explosives. It was essentially a mixture of ammonium salts which did not constitute an explosive hazard.

Spurious mineral occurrences again included artificial matte from the Wiluna smelter. Also received was a blue "mineral" from a remote native reserve which proved to be a mixture of baryte and "Prussian blue" such as occurs in a commercial pigment.

Unusual behaviour suggestive of an explosion in a cyanide heat treatment bath in the metallurgical section of a technical school, resulted in the examination of fusion products and residues. The unusual factor in the bath was the presence of considerable barium carbonate which probably caused stress in the solidified melt.

Fossil shells of the same species (Andara trapezia), but from different localities, were examined for the Western Australian Museum to determine whether mineralogical changes had occurred which would influence the estimation of their ages. The two differed in cleavage development but this may have been due to weathering history.

In relation to projected dredging of Perth Water to improve recreational facilities, proposed spoil from the area was examined to determine whether it may have an industrial application which would offset the cost of dredging. The samples used were available from earlier drilling in the area by Public Works Department.

The material varied slightly due to previous dredging in the area, but consisted essentially of kaolin with variable amounts of calcite (shell-grit), quartz and feldspar, and minor mica and halite. Each sample contained between 5 and 10 percent pyrite. The material greater than 200 mesh in size was shell-grit. Greater than 30 percent of the mud was of size less than 2 micrometres. In addition to the general characteristics of the material, its suitability for use in the following applications was checked by specific tests: brick manufacture, light weight aggregate, cement manufacture, agricultural and domestic soil dressing, foundry loam, road aggregate, and land fill.

Computing Activities

During the year the majority of the Division's computing requirements were transferred from the Western Australian Regional Computing Centre to the Laboratories computer system.

After many delays, the interface unit to connect the x-ray fluorescence (XRF) spectrometer to the computer was installed and became operational. Programs have been developed to allow routine processing of samples by technical staff. This processing includes full silicate analysis, partial major element analysis, and trace element analysis.

Using this automatic "data-logging' facility, the sample through-put of the XRF system has increased, and further development of data processing programs became necessary to manipulate the increased volume of sample data so generated.

Programs used to process x-ray diffraction data were transferred and necessary program modifications were carried out, to enable use by the mineralogists.

During the year heavy demands were made on the Divisional staff trained in computing, by the extension of the Government Chemical Laboratories computing system.

This entailed consultation with computer suppliers and the electronics firm producing interfaces for various pieces of equipment. It also entailed training and aiding staff of other Divisions of the Laboratories, and other Branches of the Mines Department, in the development of computer application and programming.

Equipment

Major expenditure for the year centred on the installation in the x-ray spectrometer of a ten position sample changer in place of the two position changer originally supplied.

This additional equipment represents the second phase in automation of the spectrometer which is now producing larger amounts of output data to be directed to the computer. The acquisition of the PDP 11/40 computer was, in effect, the first phase.

The final phase of the spectrometer upgrading will be the acquisition of a Siemens Logic controller and associated activators. The level of automation will then be such that the process, from presentation of a prepared sample to the final report print out, can be done without manual intervention.

Conferences and Inspections

Meetings of the Standards Association sub-committee on the Chemical Analysis of Iron Ores, were attended in Adelaide by Messrs Burns and Costello.

The 10th International Mineralogical Meeting, held as part of the International Geological Congress in Sydney, was attended by Messrs Pryce and Bridge. Apart from congress sessions visits were made to the New South Wales Geological Survey Museum, the Australian Museum and the Australian Museum Materials Research Laboratories.

Assessments of mineral analytical laboratories in the north-west and the metropolitan area were carried out on behalf of the National Association of Testing Authorities by Messrs Burns and Costello.

Publications

Papers published during the year include: "Carrboydite, a hydrated sulphate of nickel and aluminium: A new mineral from Western Australia". E. H. Nickel and R. M. Clarke, American Mineralogist 61, 366-372.

"A second occurrence of perite" P. J. Bridge, Mineralogical Magazine 40, 537.

Papers on archerite, takovite and dravite have been submitted for publication.

Visitors

Visitors of distinction to the Division have included Dr. Akira Kato, Chairman of the Commission on New Minerals and Mineral Names, International Mineralogical Association, and Professor L. G. Berry, University of Kingston, Toronto, Canada.

D. BURNS,
Chief, Mineral Division.

TABLE 13
TOXICOLOGY AND DRUG DIVISION

	Agriculture Department	Departmental	Greyhound Racing Control Board	Pay	Public Health Department	Police Department	Road Traffic Authority	State Health Laboratories	Western Australian Trotting Association	Other	Total
BAITS	10	....	....	2	3	18	....	....	....	....	33
BLOOD ALCOHOL—											
Sobriety	....	....	....	....	....	....	1 014	....	....	....	1 014
Traffic deaths	....	....	....	....	....	6	487	....	....	....	493
Various	....	....	....	....	1	....	....	10	....	....	11
CRIMINAL INVESTIGATION	....	....	....	....	....	234	....	....	....	....	234
DOPING CONTROL IN SPORT—											
Horses	....	....	....	....	....	....	....	....	384	....	384
Humans	....	....	....	4	....	....	....	....	....	....	4
Greyhounds	....	....	127	....	....	....	....	....	....	....	127
DRUGS	....	15	....	....	1	395	....	....	....	3	414
MARITIME POLLUTION	....	....	....	....	....	8	....	....	....	....	8
TOXICOLOGY—											
Animal	112	....	....	6	....	6	....	....	....	....	124
Human	....	....	....	....	....	962	....	....	....	....	962
VARIOUS	7	3	2	....	2	....	....	....	4	13	31
TOTAL	129	18	129	12	7	1 629	1 501	10	388	16	3 839

TOXICOLOGY AND DRUG DIVISION

As from the beginning of 1976 the Toxicology and Drug Division became operative resulting from the split of the old Food, Drugs, Toxicology and Industrial Hygiene Division into two separate Divisions.

The formation of the new Division has proved very successful and despite the fact that the Division was not at full strength until December the output and quality of the work has improved. This is attributable to the improved morale of the staff and the greater efficiency brought about by the specialisation of the work of the chemists within the Division.

The Division received over 3 800 samples, 81 percent of which were from either the Police Department or the Road Traffic Authority. If the samples arising from the monitoring of doping control in sport are included then 95 percent of the samples were of a forensic nature.

Table 13 summarises the sources and types of samples received in 1976.

Human Toxicology

The major work of the Division in terms of chemist-hours is toxicology. From 284 cases of sudden death which were the subject of police investigation, 962 exhibits were received for examination. Of this number 148 cases were submitted for analysis for drugs or poisons and in 136 cases, where a full toxicological examination was not required, blood and/or urine was submitted for alcohol determination. In the latter category the pathologist had in general assigned a cause of death such as shooting, hanging, drowning, accident etc.

In those cases requiring a full toxicological examination a drug or poison was detected in 102 cases with 46 being negative. Where a drug or poison was found alcohol was also present in 40 of the cases. In 27 of these the level of alcohol was sufficient to cause or contribute to the cause of death.

Of the 136 cases where a full toxicological examination was not required there were 44 instances when the blood alcohol level exceeded 0.08 percent and 34 where it exceeded 0.15 percent.

Blood samples were received during the year from eighteen cases of adult drowning. Of these alcohol was present in 8 cases and in 5 cases the blood alcohol level was in excess of 0.20 percent. These figures highlight the high risk situation which exists when swimming and boating are mixed with alcohol consumption.

Details of drug and poison cases are listed in Table 14.

TABLE 14

Drug or Poison	Positive Identifications No.
carbon monoxide	25
pentobarbitone	14
diazepam	14
propoxyphene	12
paracetamol	10
amylobarbitone	7
phenobarbitone	6
amitriptyline	6
phenytoin	6
arsenic	2
methaqualone	2
diphenhydramine	2
pethidine	2
methadone	2
thiopentone	2
methanol	2
cyanide	2
nitrazepam	2
salicylate	2
various *	20

* butabarbitone, caffeine, chlorpromazine, codeine, dexchlorpheniramine, dextromoramide, glutethimide, halothane, metasystox, methyl parathion, nemagon, orphenadrine, oxazepam, pholcodine, propanolol, quinalbarbitone, quinine, strychnine, thioridazine, trichloroethanol.

With reference to Table 14, in a number of cases the presence of more than one drug was established. In certain cases the concentrations of the drugs present in the organs were such that their toxicological significances were uncertain.

As in previous years the poison and drugs most frequently encountered were carbon monoxide and the barbiturates, accounting for 19 and 22 per cent respectively of positive identifications.

The increase in propoxyphene deaths is noteworthy. Cases involving propoxyphene increased from four in 1975 to twelve in 1976. This increase in deaths associated with propoxyphene has been noted in other parts of the world and may be the result of the increased use of the drug as an analgaesic to bridge the gap between aspirin and the narcotics. In a number of cases paracetamol and salicylate were associated with the propoxyphene.

The circumstances in six of the propoxyphene cases indicated that death was the result of a deliberate suicide attempt. However in four of the remaining cases no such conclusion could be drawn and the probability was that death was the result of an accidental overdose. The possibility that the persons involved had used the propoxyphene containing analgaesic as another form of aspirin thus ignoring or being unaware of the greater toxicity of the former shall not be discounted.

There may be a need for prescribing physicians to emphasise the differences in toxicity between propoxyphene and the less toxic analgaesics such as aspirin and paracetamol.

Animal Toxicology

The number of samples submitted to the Laboratories under this heading increased by 75 percent in 1976, the majority of the samples coming from the Department of Agriculture.

One hundred and twenty-four post-mortem samples from various animals were received. Of these there were 22 cases of strychnine poisoning in dogs and one in a horse. This is a marked increase since the previous year when only six cases of strychnine poisoning were found. In addition there were two cases of metaldehyde and one case of pentobarbitone poisoning. The latter case is of interest because the source of the pentobarbitone was traced to ox heart which was purchased as pet food from a pet shop.

Of 33 suspect baits submitted only five were found to be positive, each of which contained a different poisoning agent. The poisons detected were methiocarb, triochlorphon, strychnine, metaldehyde and maldison.

Blood Alcohols (Traffic Act)

Increased activity by the Road Traffic Authority has resulted in a 19 percent increase in the number of samples of blood received for alcohol determination. Blood samples are taken under the Road Traffic Act, 1974, from persons who elect to have a blood sample taken in preference to, or in addition to a breath test.

Table 15 lists the levels of alcohol in the blood (calculated to the time of the offence) on samples received, where there was sufficient sample for analysis. The results show that 65 percent of drivers had an alcohol level in excess of 0.15 per cent whilst 89 per cent had a level of greater than 0.08 percent.

TABLE 15

TRAFFIC ACT—BLOOD ALCOHOL LEVELS

Alcohol percent.	No. of Cases	Percent. of Cases
less than 0·050	67	6·6
0·050–0·079	48	4·7
0·080–0·099	46	4·5
0·100–0·149	191	18·9
0·150–0·199	291	28·8
0·200–0·249	216	21·4
0·250–0·299	110	10·9
more than 0·299	42	4·2
	1 011	100·0

Under the Road Traffic Act a calculation of the alcohol content of the blood of the accused to the time of the offence is made. This calculation, unique to Western Australia, is made on the basis that the percentage of alcohol in the blood of a person increases at the rate

of 0.016 percent per hour for a period of two hours and after that period decreases at the rate of 0.016 percent per hour.

The following points arise from the calculations made in connection with samples received during 1976:

(1) 78 percent of the cases resulted in lower blood alcohol levels.

(2) 26 cases (2.6 percent) resulted in blood alcohol levels being lowered from greater than 0.08 percent to less than 0.08 percent.

(3) 42 cases (4.2 percent) resulted in blood alcohol levels being lowered from greater than 0.15 percent to less than 0.15 percent.

(4) 7 cases (0.7 percent) resulted in blood alcohol levels being raised from less than 0.08 percent to greater than 0.08 percent.

(5) 21 cases (2.1 percent) resulted in blood alcohol levels being raised from less than 0.15 percent to greater than 0.15 percent.

Blood Alcohol (Traffic Deaths)

Following a road fatality, blood and urine samples (and sometimes other exhibits) are generally submitted to the Laboratories for alcohol determinations. In 1976, 493 such exhibits were received, mainly from the Road Traffic Authority.

Table 16 shows the distribution of alcohol in the blood of drivers, passengers and pedestrians. It is emphasised that the figures apply only to post-mortem blood samples received at these Laboratories.

Table 16 shows that 37 percent of drivers of motor vehicles had a blood alcohol level of 0.15 percent or more, the corresponding figures for passengers, pedestrians and motor cycle riders being 38, 47 and 32 percent respectively.

Blood alcohol levels of 0.08 percent or more were found in 44 percent of drivers, 46 percent of passengers, 58 percent of pedestrians and 50 percent of motor cycle riders.

TABLE 16

TRAFFIC DEATHS—BLOOD ALCOHOL LEVELS

Alcohol percent.	Motor Vehicle Drivers	Passengers	Pedestrians	Motor Cycle Riders	Push Cycle Rider
negative	42	36	16	11	1
less than 0·050	12	4	....	2	....
0·050–0·079	3	4	....	1	....
0·080–0·099	3	3	....	....	....
0·100–0·149	4	4	5	5	....
0·150–0·199	15	7	6	4	....
0·200–0·249	11	9	7	1	....
0·250–0·299	7	9	2	3	....
more than 0·299	4	6	2	1	....
	101	82	38	28	1

No alcohol was detected in the blood of 42 percent of drivers, 44 percent of passengers, 42 percent of pedestrians and 39 percent of motor cycle riders who died as a result of road accidents.

On a number of occasions pathologists have requested that post-mortem blood and urine samples from road accident victims be analysed for the presence of drugs. On two occasions death was attributed to the influence of drugs.

In the first instance two motor cyclists were driving side by side behind a truck. They separated to overtake the truck, one going to the right of the truck and the other to the left. The latter in doing so ran under the near wheels of the truck. The deceased had in his possession the drugs heroin and cannabis as well as a hypodermic syringe.

Post-mortem examination revealed the presence of an injection site on the right arm. Toxicological examination detected the presence of alcohol and the drugs methaqualone and diphenhydramine at a level likely to cause the deceased to have been incapable of controlling his motor cycle. (Methaqualone and diphenhydramine are the active components of Mandrax).

It is probable that the combination of alcohol and Mandrax not only produced a state where the rider was not capable of controlling his cycle but also made him sufficiently foolhardy to attempt to pass on the inside of the truck.

In another case a motorcyclist ran off the road and struck a tree. Toxicological examination indicated the presence of methadone and diazepam at levels which were likely to render the rider incapable of controlling his cycle.

Breathalyzer

Breathalyzer operators in this State must be certified as competent to operate breath analysing equipment by the Director of these Laboratories. With the formation of the Toxicology and Drug Division the task of testing operators has been delegated to this Division. This duty has now become a major undertaking because of the more stringent conditions now required by the Director. Such conditions require that every Breathalyzer operator must be re-tested annually.

A marked improvement has been noticed in the standard of Breathalyzer operators during the past twelve months since closer controls have been instituted.

There are about one hundred operators currently operating the Breathalyzer throughout the State. Forty of these were trained during 1976 and the remainder were called in for re-examination throughout the year.

The Division is also responsible for the preparation of the standard alcohol solution for use with the Breathalyzer. Due to the increased surveillance on the roads, over 1 400 bottles of this solution were prepared.

Drugs

In line with the proliferation of the drug problem in this State the number of exhibits received during the year increased by 50 percent over the previous year. 399 exhibits from 124 cases in connection with illicit drugs were handled, all but four of these being submitted by the Police Department.

Cannabis and cannabis products (Thai sticks, cannabis resin and oil) were again the drugs most frequently encountered. Although there was a decrease from 1975 in the number of cannabis cases this does not indicate a lessening of the usage of the drug but rather the decrease was brought about by the police practice of having cannabis plant material identified solely by a botanist during the latter part of the year. Cases involving cannabis products other than the plant itself in fact increased by approximately 50 percent.

The increased use of heroin in this State is reflected in the 300 percent increase over 1975 in cases handled by these Laboratories. The quantity of the drug received in ten cases was such that it was deemed to be evidence of possession to sell or supply. The largest seizure examined was 265 grams of powder which had a diamorphine content in excess of 95 percent and a street re-sale value of over $500 000.

Seizures of heroin examined were of varying purity ranging from a high of 95 percent to a low of 2 percent. The extreme variation in quality of heroin encountered by this laboratory represents a dangerous situation to the drug abuser and could foreseeably lead to situations where a toxic or fatal dose could be administered in error.

Bromo-dimethoxyamphetamine, (also known as bromo-STP), a synthetically produced hallucinogen was encountered for the first time. The form in which the drug was being sold was the same in the four cases received, and was in fact similar to that encountered in other States.

Forty percent of all the drug cases received for the year involved quantities of the drugs in excess of the amount deemed to be evidence of intent to sell or supply. These cases require a more detailed examination of the exhibits and unlike cases of simple possession in which a positive identification is all that is required of the analyst, these generally involve a quantitative as well as qualitative examination. When the drug involved is No. 3 heroin, which can have in excess of six components, the amount of time expended on analyses can be considerable.

There have been a number of cases during the year which have required examination of hypodermic syringes and other paraphenalia associated with drug abuse, for the presence of microgram quantities of narcotic drugs. Previously, positive identification of such quantities posed problems and was difficult. However, during the year, the Laboratories have gained limited access to the gas chromatograph-mass spectrometer at the State Health Laboratories which has enabled such identifications to be accomplished with less difficulty and with greater speed and assurance.

The acquisition of a gas chromatograph-mass spectrometer in the Division has become a prime requirement of the Division so that the identification of drugs can be established without equivocation, particularly in cases where the amounts present are very small such as residues on hypodermic syringes. Experiences in Court over the year have shown that lawyers are probing more deeply into the techniques which the analysts use and are putting forward the view that modern techniques of instrumentation such as gas chromatography-mass spectrophotometry should be used.

Details of drug cases are listed in Table 17.

TABLE 17

DRUGS—POLICE DRUG SQUAD

Type of Drug	No. of positive identifications
Cannabis and products	84
Heroin	15
Bromodimethoxyamphetamine	4
Methadone	3
LSD	2
Psylocybin and psylocin	1
Mandrax	1
Amphetamine	2
Atropine plus hyoscine	1
Combination of two or more drugs	2
Non-narcotic drugs	4
Total	119

In addition to the above there were nine cases in which no drugs were detected.

Doping Control in Sport

384 horse urine samples were analysed as part of the anti-doping control programme conducted by the Western Australian Trotting Association. Of these one sample proved to be positive to caffeine, theobromine and theophylline.

A similar programme being carried out by the Greyhound Racing Control Board resulted in the receival of 127 samples of greyhound urine. One positive sample was reported and again this urine sample contained caffeine, theobromine and theophylline.

The Australian Professional Road Cycling Championships were held in Perth during the year and urine samples were taken from four competitors, all of which were negative. This is the first time in this State that doping control samples have been collected from humans.

There was an overall increase of 13 percent over the previous year in the number of samples received in connection with doping control.

Criminal Investigation

The examination of exhibits collected from scenes of crimes or accidents is undertaken in this Division. Exhibits were received mainly from the Police Department but also from Commonwealth Police and Military Police. The number of cases received was approximately double that of the previous year.

Table 18 summarises the cases investigated.

TABLE 18

Type of exhibit	No. of cases
Flammable liquids (including debris from fires)	28
Explosive residues	13
Paint	10
Glass	3
Fibres	3
Miscellaneous	23
Total	80

The categories of offence or event relating to the exhibits received are tabulated below.

Category	No. of cases
Arson	28
Explosives	13
Wilful damage	11
Hit-run	4
Stealing	4
Motor accidents	3
Assault	2
Murder	1
Unclassified	14

Suspicious fires account for a large proportion of cases with equal numbers of cases coming from metropolitan and country areas. The exhibits include containers of flammable liquids, ash, debris and remnants of incendiary devices such as "Molotov Cocktails" found at the scene of the fire. These exhibits are examined for traces of flammable liquids or other fire accelerants if indicated.

There has been an increase in the number of cases apparently involving high explosives and also improvised low explosive mixtures. The major explosion of the year was the gelignite explosion at the Bunbury woodchip terminal. A variety of exhibits were submitted in connection with this crime including sweepings from a car alleged to have been used by the offenders, a warning sign, plastic debris, battery casing and hardened bonding substance.

Exhibits were received from a number of cases of vandalism or wilful damage involving the use of chemicals. For example, acids were used in one case to destroy a fishing net and in another case to poison a tree.

A neighbour's tree, the leaves from which were falling into a backyard swimming pool was another target for wilful damage, this time by the use of the herbicide atrazine. In another instance a solvent was used to damage the paintwork of a luxury car.

A significant increase has occurred in the number of samples of paint and paint flakes handled. Analysis of these samples aims at comparing paint from the scene of crime or accident with that on a suspect car, or at paint type identification to enable derivation of information concerning its possible origin. Frequently the amount of paint available for examination is exceedingly small as in the case of hit-run accidents. During the year a Curie point pyrolyser for use with the Gas Chromatograph was purchased and this has greatly assisted these aims.

In cases where no reference sample is available it is necessary to have sufficient data available to enable useful interpretation of the analysis. With the co-operation of the Road Traffic Authority who are providing paint samples from vehicles involved in accidents, data is now being continuously collected as an aid to enquiries concerning motor vehicles.

Glass fragments are often associated with motor vehicle accidents or crimes and a survey of the windscreen and headlamp glass population has recently been undertaken concurrently with the paint survey.

With the formation of the Toxicology and Drug Division which has enabled a higher degree of specialisation within the Division, a closer liaison has been established with the Police Scientific Branch and there is now a greater awareness by the Police of how the Laboratories can assist them in a scientific way in their criminal investigations.

Computer

Access to the Laboratories' PDP 11/40 computer via a "'Decwriter" situated within the Division has allowed the partial automation of the work associated with blood alcohol analysis. At present the computer prints out and stores the analyst's records. Storage of records will eventually allow the printing of the analysts' reports. Given time and finance the whole process of analysis and reporting of results will be automated, reducing to a minimum one of the more routine tasks of the Division.

Additional use of the computer has been made by the installation of two data storage and retrieval programmes, IRMAN and CHROMAN. IRMAN was generously supplied by the Home Office Central Research Establishment (Aldermaston U.K.) and allows infra-red spectrum identification by peak matching. CHROMAN, our own system identifies compounds by Thin Layer Chromatography and Gas Liquid Chromatography data matching.

The computer has proved to be a valuable instrument in the past year and will in time free already overburdened staff from menial and time consuming tasks.

V. J. McLINDEN,
Chief, Toxicology & Drug Division.

WATER DIVISION

General

1976 has been a busy year, both in relation to providing a technical and an analytical advisory service. The activities of the Division in these areas appear to be consistently expanding year by year and this is interpreted as an indication of the quality of the service provided. Areas where increases are more noticeable include environmental, corrosion, effluent treatment and swimming pool problems.

Sample receivals during 1976 of 6 596 show an increase of 2.5 percent over that of 1975 and all receivals since 1970 have consistently shown increases of up to 10 percent over that of the previous year.

These increases in activity have occurred without increases in staff numbers or increases in expenditure on major items of equipment and will ultimately cause a reduction in activity of internally developed projects. These internally developed projects are essential to the correct functioning and staff morale of the Division.

A definite commitment to the A.W.R.C. Network Survey Sampling has not occurred to date, but the proposed new laboratory building for this project is to be funded from the 1976/77 financial year provided provisions for increased staff and equipment are concurrent.

Table 19 indicates the types and sources of samples received during 1976, the major increase coming from the Public Works Department.

Some of the more interesting aspects of the analysis and advice undertaken during the year include—

TABLE 19
WATER DIVISION

	Agriculture Department	Consumer Affairs Bureau	Conservation and Environment Department	Departmental	Fisheries and Wildlife Department	Geological Survey	Leschenault Inlet Advisory Committee	Metropolitan Water Board	Pay—Public	Peel Inlet Advisory Committee	Public Health Department	Public Works Department	Swan River Conservation Board	Other	Total
Corrosion	....	1	....	1	....	....	....	....	1	....	1	1	....	1	6
Deposits	....	....	....	....	....	....	....	....	3	....	....	6	1	7	17
Effluents	1	....	1	....	....	....	....	....	25	....	2	17	43	24	113
Environmental Monitoring—															
Leschenault Inlet	....	....	....	....	....	....	50	....	....	....	....	....	....	....	50
Peel Inlet and Harvey Estuaries	....	....	....	....	....	....	....	....	....	81	....	....	....	....	81
Swan River	....	....	....	....	....	....	....	....	....	....	....	....	164	....	164
Investigations	....	....	....	3	....	....	....	1	2	....	....	1	....	....	7
Soils	....	....	....	....	....	....	....	....	....	....	....	95	....	....	95
Treatment Chemicals	....	3	....	....	....	....	....	13	....	....	....	....	....	2	18
Waters—															
Fluoridated	....	....	....	....	....	....	....	812	....	....	....	801	....	1	1 614
General	24	....	18	14	58	313	....	1 793	437	....	58	1 657	30	16	4 418
Various	....	....	1	1	....	....	....	....	....	....	8	3	....	....	13
Total	25	4	20	19	58	313	50	2619	468	81	69	2 581	238	51	6 596

Public Water Supplies and Treatment

(a) Hills catchment dams: For the second successive year rainfall recorded at Perth was significantly less than the annual average. In 1975 and 1976 it was 682 and 711 mm respectively compared to the annual average of 881 mm. The results in Table 20 below show that only Wellington dam has been dramatically affected by this reduced rainfall. Wellington dam is the most saline of all Hills catchment dams and because its main use is for irrigation this is presenting a real problem.

Wellington dam is the only one of the above dams which is subject to extensive saline stratification and its surface sample results can be misleading. At the end of 1976 when the salinity of all other dams remained only marginally above the annual mean, the surface salinity (as NaCl) of Wellington dam was 650 mg/l and at that time was uniform over the whole depth profile. Unless there is more than normal rainfall in 1977, allowing most of this saline water to be discharged by scouring, the mean for Wellington dam is likely to be at its highest during 1977.

TABLE 20
SALINITY OF HILLS CATCHMENT DAMS

1964–76 (Surface samples)

Reservoir	Salinity as NaCl (Annual mean) Maximum		Minimum		1976
	mg/l	Year	mg/l	Year	mg/l
Canning	265	1972	140	1964	210
Churchmans	110	1972	100	1974/75	105
Mundaring	445	1972	120	1964	315
North Dandalup*	140	1972/76	105	1974	140
Serpentine	190	1972	120	1964	155
South Dandalup†	130	1976	120	1974/75	130
Victoria	235	1972	170	1974	220
Wellington	490	1973/76	140	1964	490
Wungong*	145	1972	125	1974	140

Total dissolved solids approximate to NaCl x 1·20 for all Hills supplies.
* Pipehead dams, and hence mean levels represent only the flow period.
† Constructed since 1964.

(b) Fluoridated Waters: With the exception of the Esperance and Geraldton reticulated supplies, all other fluoridated supplies have maintained mean levels during 1976 at the intended values. Esperance and Geraldton mean levels were 0.04 and 0.03 mg/1 respectively below the minimum of the range intended. Means for the samples received during 1976 from the various fluoridated supplies are listed below in Table 21.

TABLE 21
FLUORIDATED WATER

Supply	No. of samples	Fluoride, F mg/l	
		mean	intended
Perth Metropolitan	806	0·78	0·8±0·1
Mundaring/Goldfields	139	0·77	0·8±0·1
Wellington/Comprehensive	91	0·79	0·8±0·1
Albany	156	0·83	0·9±0·1
Collie	76	0·88	0·8±0·1
Esperance	104	0·76	0·9±0·1
Geraldton	84	0·67	0·8±0·1
Manjimup	111	0·81	0·9±0·1

(c) Metropolitan Water Treatment Plants: There was renewed interest in the use of activated silica to replace sodium alginate, the present used coagulant aid at the Mirrabooka treatment plant. Jar trials showed that with more precise control of the activated silica preparation and the levels of alum and activated silica dosed, considerable improvement in floc settling velocity could be achieved, without any detriment to the efficiency of the colour removal. The improvement in floc settling velocity for a raw water with 70 units of colour and dosed with 60 mg/1 of alum was from 4.5 metres/hour with 1.4 mg/1 of sodium aliginate to 9.5 metres/hour with 8 mg/1 of activated silica. Overdosing of alum from 60 to 80 mg/1 under the same conditions reduced the settling velocity for activated silica from 9.5 to 4 metres/hour. Full scale trials for the Mirrabooka plant are intended for 1977 but because the tolerances for maximum performance are narrow, strict control of dosage levels will be necessary to achieve the desired improvement.

A trial intended to assess the stability of the iron/silica complex in water reticulated from Wanneroo was inconclusive. The level of iron in the water being stabilised was only 0.9 mg/1 and this was stabilised by adding 20 mg/1 of silica (as sodium silicate) and breakpoint chlorination. Its subsequent dilution in a holding reservoir with water from which iron had been removed by aeration and filtration, gave a level of total iron of 0.3 mg/1. After two weeks holding time in the reservoir the iron level in solution of the blend was 0.2 mg/1. The cold water reaching the consumers did show some further precipitation of the soluble form, but as anticipated from earlier reported experiments the complex did not allow more than 0.05 mg/1 of iron to remain in solution in outlets from domestic storage hot water systems.

All shallow bores from unconfined aquifers servicing treatment plants, as well as artesian bores being blended directly into the supply have been tested for 37 components including pesticides in order to assess possible contamination. Apart from some ammonia levels slightly in excess of 0.5 mg/1 the levels of other components excluding iron and colour, have all been well below the levels permitted in a drinking water supply. One great advantage of "solids contact upflow clarifiers", which are being used at all present and proposed treatment plants, is the efficiency with which undesirable components are removed from the water by absorption into the solids of the sludge reject.

(d) Rottnest: A newly discovered fresh water basin at Rottnest has reduced the necessity for transporting fresh water from the mainland by barge to augment the present inadequate supply from bitumen catchment. The fresh water overlies saline water and pumping rates from each of the bores must be low to prevent saline water intrusion. Apart from the relative low quantity of water available, estimated to be considerably less than the present bitumen catchment, the water also contains levels of nitrate and fluoride which are close to or slightly above the maximum levels permitted in a drinking water supply. Fluoride levels range from 0.6 to 1.5 mg/1 while nitrate levels range from 14 to 70 mg/1. Fortunately these waters can be blended with the existing bitumen catchment supply to give satisfactory levels in regard to these two components.

(e) Denham: A reverse osmosis plant is being commissioned at Denham, following recommendations and advice from these Laboratories in 1975. The present supply at Denham at 4 500 mg/1 total salts is too saline for drinking purposes, but reverse osmosis will reduce this to less than 500 mg/1. The first sample of product water was up to expectations. Because of the costs involved with such units, of the order of dollars per 1 000 gallons, there will be a dual reticulation system at Denham. One reticulation will supply the drinking water and the other the more saline water from which only the iron has been removed.

(f) Eneabba: Poor aeration efficiency was suspected of being the cause of iron breakthrough of the sand filter at Eneabba and leaving 1.1 mg/1 of the original 5.8 mg/1 of iron in the filtrate. Samples collected confirmed that aeration efficiency was only 64 percent and the recommendation was for improved aerator design. Should the filtrate from the sand filter bed still contain an undesirable level of iron the next alternative was to increase the holding time between aeration and filtration.

(g) Watheroo: One of the two bores servicing the town supply had apparently developed odour and taste problems following routine removal and inspection of the screen etc. The taste was originally suspected as being due to the low levels of iron present which varied up to 1 mg/1. An "on site" inspection with a laboratory scale sand filter capable of removing all the iron confirmed that the reported tastes were not due to the presence of iron. Odour threshholds varied between 1 and 2 and taste threshholds between 2 and 5 and there was no significant diminution of these throughout a pumping trial for one week at a pumping rate of approximately 10 m^3/hour. Because the chemical parameters of the water had not altered since the bore was originally commissioned, contamination of the screen during routine removal and inspection, by organisms such as actinomycetes was suspected.

Subsequent chlorination of the screen in situ and surround with 100 mg/1 of chlorine was not instrumental in removing the taste, which could be described as "earthy". It seems impossible that an entire aquifier could be contaminated with this unknown taste producing material, but until the taste disappears the water cannot be recommended for the town supply.

(h) Albany: The supply from Two People Bay is of variable quality throughout the year and, apart from high levels of carbon dioxide which make it relatively corrosive, it is unsuitable for the town supply for several months of the year because of its excessive colour. Because the alkalinity and colour can be variable from day to day during this several month period, and it is not foreseeable that the chemical dosage to an upflow clarifier unit could be altered daily, a treatment system to cover colour removal at all levels was recommended. This included the use of hydrolime, alum and sodium alginate.

(i) Mt. Barker: Regular monthly sampling of the water at Bolganup dam and the service tank at Mt. Barker showed that the dam consistently contained a level of colour in excess of the W.H.O. recommendation for a drinking water supply, namely 50 units. Additionally the suspended solids in the dam were intermediate between desirable and permissible levels for a drinking water. They were mainly of organic origin in summer/autumn and of inorganic origin in winter/spring, i.e. predominantly algae and clay respectively. The dam also suffers from thermal stratification. Although chlorination and additional holding before use by the consumer improved the quality of the water slightly, it was still not considered satisfactory.

The recommendation was for an upflow clarifier which would remove the troublesome colour, turbidity and iron components from the water. Aeration of the dam was considered but it would only prevent iron accumulation in the hypolimnion and would not significantly reduce colour or turbidity characteristics.

(j) Jerramungup: Chemical dosage to the dam supply for Jerramungup town water supply to give satisfactory performance in a solids contact upflow clarifier was advised upon. The treatment for the low alkalinity water with several hundred units of turbidity included hydrolime or equivalent at 10-20 mg/1 to precede an alum dose of up to 60 mg/1. An upflow velocity, without any coagulant aid, of 1.5 to 3.0 metres per hour was predicted.

(k) Telfer: One of the bores intended for use in the mining company town of Telfer, although similar in levels of major components to other bores in the area, contained 0.14 mg/l of lead and as such had to be rejected as a source for the town supply. The bores for the town supply contain approximately 2 000 mg/l of total dissolved solids and are intended to be treated through a reverse osmosis plant prior to being used as a drinking water.

(l) Iron/Silica Complex: Although past laboratory testing has demonstrated the comparative stability of the ferric iron/silica complex and the instability of the ferrous iron/silica complex, it was nevertheless decided to carry out some small scale trials with irrigation water to see whether sodium silicate, injected into the pump delivery of an overhead sprinkler irrigation system reduced the staining tendency. A household supply in Como with 3 to 5 mg/l of iron showed almost complete absence of staining after being dosed with sodium silicate at a rate equivalent to 20 mg/l of SiO_2 when compared to that of the control. This trial was only over several weeks but a controlled quantitative trial is now in progress to assess the reduction in staining over the summer months of regular lawn irrigation.

Environmental

(a) South West River Estuarine Systems: Staggered 3 monthly sampling of established sites from surface sites continued for the Swan River system, the Peel/Harvey Inlet System and the Bunbury Leschenault Inlet system. Depth sampling at the Swan River has been carried out over a number of periods, the latest during 1974/75, the results of which will appear in a publication in 1977, but is not a regular feature of the three monthly sampling. The other two systems, because of their shallower nature, have not been the subject of separate depth studies and the regular samplings also include some depth samples at the deeper sites. Prior to 1976, the only form of nitrogen regularly determined on these samples was "albuminoid plus ammonia", but now all samples are being additionally tested for nitrate. For those sites which contain a high proportion of winter run-off, values of nitrate nitrogen, N were of the order of 0.1 to 0.3 mg/l during winter months and generally of the order of 0.02 mg/l during summer. All other sites which are predominantly sea water generally contained nitrate levels of less than 0.02 mg/l throughout the year.

Apart from the anticipated effects from a dryer than normal winter, there were no appreciable changes in any of the systems during the year. Some investigations on the effects of rubbish tips, sited adjacent to the Swan River were undertaken and these results are discussed under a separate heading.

(b) Rubbish Disposal Sites: (i) The regular sampling of monitoring bores associated with the active rubbish disposal at the Hertha Road site continued during 1976, and samples from the 30 sites were analysed for 33 components in the sampling of December, 1976. There were no significant variations from previous samplings and the only components which failed to meet drinking water standards at some of the sites remained as odour, colour, iron, manganese, ammonia, phenols and chemical oxygen demand.

The monitoring bores were extended into the adjacent Jones Street site, which is intended for "near future" rubbish disposal. Five sites comprising twelve separate bores and seventeen separate samples are being used in the monitoring survey. In these supposed uncontaminated shallow aquifers there were quite a variety of levels of various components and abnormal values for odour, colour, iron, manganese and phenols suggest that contamination of the site had already commenced.

(ii) A small scale investigation at the Hertha Road site, designed to collect leachate from the rubbish disposal onto an underlying plastic sheet was also initiated. Samples collected in February and April were grossly contaminated with organic material and the following are the results of these two samplings.

	February	April
pH	7·4	6·9
Turbidity, APHA units	1 000	500
Colour APHA units	8 100	5 200
Odour	putrid	putrid
	mg/l	
Total dissolved solids (by evaporation)	19 600	5 560
Total alkalinity (as $CaCO_3$)	16 500	10 500
Calcium, Ca	80	24
Magnesium, Mg	36	38
Chloride, Cl	1 400	546
Sulphate, SO_4	72	23
Arsenic, As	0·10	<0·05
Cadmium, Cd	....	<0·02
Chromium, Cr	0·10	0·12
Copper, Cu	0·20	0·07
Iron, Fe	13	6·0
Lead, Pb	0·60	0·20
Manganese, Mn	0·30	0·10
Zinc, Zn	1·5	0·46
Nitrogen, N		
ammonia	4 760	3 640
nitrate	5	1
Kjeldahl	48 000	6 420
Phosphorus, P (total)	6 040	196
Oxygen from permanganate (4 hrs at 27°C)	1 560	980

The excess of Kjeldehal N over total dissolved solids implies gross quantities of nitrogenous organic material, most of which is volatile at 180°C. Despite the apparent capacity for formation of heavy metal complexes, the levels of heavy metals are only up to one order of magnitude greater than those allowed in a drinking water supply.

(iii) Two rubbish tips adjacent to the Swan River at Riverton and Bayswater, the Wilson and King William sites respectively, were investigated in relation to their effect on the Swan River. From the previous evidence at Hertha Road it was obvious that the only measurable contamination was to be from nitrogen and so the surveys were restricted to quantitative assessment of inorganic nitrogen forms.

The Wilson "tip" had no drains connected to the river and the only likely contamination was seepage from the shoreline. The tests carried out in August, 1976 showed significant seepage of salinity (as chloride) and ammonia nitrogen but little alteration to the natural nitrate level of the water. An average transect upstream of the tip had an ammonia nitrogen level of 0.15 mg/l while a downstream transect had 0.35 mg/l. On the shoreline close to the "tip" values of ammonia nitrogen in the river water ranged between 0.6 and 1.6 mg/l.

At the King William Street "tip" there was a drain running through the active tip site to the river. Measured flow rates during the test period of October, 1976 indicated that almost all of the river contamination was coming from the drain, the seepage from the general shoreline being minimal. The ammonia and nitrate nitrogen levels of the drain increased from 0.40 to 0.57 mg/l and 1.2 to 1.3 mg/l respectively between two sites upstream and downstream of the tip. The effect of the drain flow into the river was to increase the ammonia and nitrate nitrogen levels in the river from 0.14 to 0.17 mg/l and from 0.21 to 0.28 mg/l respectively, i.e. a nett increase of inorganic nitrogen from 0.35 to 0.45 mg/l. Of this increase in the inorganic nitrogen level in the river, only 0.02 mg/l was attributable to the rubbish "tip", and the balance was attributable to other sources gaining access to the drain prior to its passage through the "tip". The total quantity of inorganic nitrogen entering the river from the "tip" was estimated at approximately 1 kilogram per day.

(iv) A bore from the Graylands Hospital, being used for irrigation and sited close to the Brockway "tip", contained 129 mg/l of ammonia nitrogen and this indicated gross contamination.

(c) Laporte Effluent Disposal: To date there has not been any alternative method for the treatment and disposal of Laporte effluent that is environmentally or economically competitive with the present lagoon disposal system in the sand dunes of the peninsula between Leschenault Inlet and the Indian Ocean. The dune disposal system is of finite life, the duration of which has not been optimised. The existence and possible utilisation of a comparatively rich limestone layer (averaging approximately 40 percent $CaCO_3$) of approximate thickness 5 metres and sited approximately between 5 and 10 metres below the water table has caused renewed interest and activity during 1976. This rich limestone aquifer is separated from above by a comparatively impervious variable thickness estuarine mud layer and from below by thick impervious mesozoic sediments.

For the first time soil samples were collected from three holes in the vicinity of a recent disposal area (No. 7 lagoon) and these were sampled to a depth below the above mentioned rich limestone layer. The results of these soil analyses, together with the analyses of water samples from a number of bores in the area has enabled

a prediction to be made that 75 percent of the sulphate and 95 percent of the iron from the disposed effluent were being held in the soil. The high efficiency of iron removal at this particular site has been presumably caused by significant spread of the disposal hydraulic mound and relatively long contact times with the soil prior to gaining access to the ocean.

Calcium carbonate neutralisation of the effluent is not capable of removing other than a small fraction of the iron. This is because at equilibrium the neutralised effluent is saturated with respect to both calcium sulphate and calcium carbonate, containing approximately 700 mg/l of calcium, 800 mg/l of alkalinity and 2 000 mg/l of carbon dioxide with a resultant pH of 6.0. Other chemical considerations for precipitation of iron include

(1) selective reaction with the comparatively small magnesium component of the limestone in order to raise the pH above 6;
(2) removal of carbon dioxide by diffusion into the voids of the sand dunes—this would also raise the pH above 6;
(3) positive precipitation of iron in the ferrous form as either a carbonate or hydrated oxide or as a combined ferrous/ferric form associated with carbonate or hydrated oxides.

To resolve these other chemical considerations, No. 7 disposal lagoon and potential unused disposal lagoons to the north, have been penetrated by deep and shallow bores in a selected grid pattern for monthly samples to be collected and analysed during 1977. Soil samples from the same sites have been taken before the commencement of disposal and will be taken again at a future selected date to undertake a quantitative balance. From the above results the predicted soil adsorption of sulphate and iron will be confirmed or otherwise, and a theoretical prediction of the chemical process should result.

(d) Pesticides at Thornlie: Following the analysis of three householders' bores in a confined area of Thornlie, where underground aquifers were contaminated with products associated with the manufacture of 2,4-D between 1957 and 1960, and where excessive levels were still present in 1976, a review of events and analysis since those early dates was compiled for our own and other Departments' uses.

Levels of phenols and 2,4-D in the apparently confined affected aquifers varied over the range up to 37 mg/1 and 13 mg/1 respectively in 1961, and were still present at levels up to 10 mg/1 and 5 mg/1 respectively in 1970. The apparent approximate 50 percent drop in the concentration of 2,4-D over the 10 year interval is not consistent with its reputed rapid degradability and suggests that some of the products which were disposed down a disused well are still gaining access to the aquifer.

The present levels in the householders' bores of up to 0.24 mg/1 of phenol still indicate substantial contamination. Quantitative assessment of degradation and mobility is difficult because there are a number of apparently confined aquifers in the area as indicated by the levels of major components in the water samples. Additionally most of these bores drilled in 1961 and 1965 have now been closed.

The persistency of these materials is important to the Metropolitan Water Board who will ultimately draw a major proportion of Perth supply from shallow unconfined aquifers beneath and immediately adjacent to the present metropolitan area.

Corrosion

(a) Mundaring Kalgoorlie Cement Lined Mains: Two parallel locking bar sections of cement lined mains, each of approximately 20 km length and located near Meckering and Kellerberrin are all that remain of the original hand applied cement lined mains of the 1930's. These sections are at a stage where running repair costs versus relining and replacement need to be considered. The longitudinal steel locking bar sections which protrude into the inner steel surface of the pipe by a thickness of 11 to 12 mm cause the nominal lining thickness of 15 to 16 mm to be reduced to 4 mm along these sections. It is considered that leaching of calcium from the section allows water penetration to the steel surface of the locking bar. Subsequent oxidation and expansion due to corrosion products of steel causes under cutting of the otherwise satisfactory coating over the main section of the pipe. Three types of existing lining over the main pipe were identified as in Table 22

TABLE 22

Conditions of Lining	Profile	Calcium Ca percent.	Magnesium Mg percent.	Iron Fe percent.
1. Dark brown flaking surface of 2 to 3 mm—balance hard and grey—no obvious iron oxide at cement/steel interface	0–3 mm	2·6	3·6	0·7
	middle	10·0	0·6	1·0
	13–16 mm	10·0	0·4	0·6
2. As above but film of magnetite at cement/steel interface	0–3 mm	1·2	2·7	1·2
	middle	6·4	0·4	0·7
	13–16 mm	6·5	0·4	3·0
3. Fully leached continuously brown crumbly lining	0–3 mm	0·04	0·5	11·7
	middle	0·04	0·2	7·2
	10–13 mm	0·04	0·2	13·9

The high iron levels in lining 2, 13-16 mm, are probably due entirely to contamination by the adherent magnetite layer. The iron level in lining 3 is considered due to the replacement of calcium by iron from the steel.

The depleted calcium and increased magnesium of the surface layer of the two sound linings is caused by the comparative solubility and insolubility of calcium hydroxide and magnesium hydroxide, respectively.

Blisters on the surface of the cement lining were common, occupying about 5 percent of the total area. The shell of the blister was approximately 2 mm thick and the blister formation may have been due to chemical changes and associated swelling within this shell. The blister formation was not given a major role in the deterioration of the cement, mainly because none were evident on the locking bar sections. This may have been due to an always present longitudinal crack along this section. Analysis of the water behind the blister showed it to be expectedly saturated with calcium carbonate and to contain increased levels of calcium, magnesium and sulphate when compared to that of the traversing waters. (See Table 23 below).

TABLE 23

	Mundaring	Mt. Charlotte Kalgoorlie	Blister contents
pH	6·8	7·7	7·9
Saturation index (Langelier at 20°C)	—2·7	—1·4	+0·3
	mg/l	mg/l	mg/l
Calcium, Ca	9	14	55
Magnesium, Mg	16	15	42
Sulphate, SO_4	17	22	40
Chloride, Cl	199	199	290
Total alkalinity (as $CaCO_3$)	16	24	200

Recommendations included:—

(1) no action until repair costs exceeded replacement costs;
(2) addition of 5 mg/1 of $Ca(OH)_2$ at Mundaring to reduce aggressiveness of water to both cement and steel;
(3) replacement of lining, particularly that of the locking bar sections.

(b) Hot Water Systems: (i) Recirculating Hot Water Systems—Recirculating hot water systems in the Perth metropolitan area operating at mains pressure and temperatures in excess of 70° C have suffered premature failure due to pitting attack. This problem has not been restricted to recirculating systems and has caused considerable involvement in advisory matters over the past decade.

The recirculating mains at Bentley hospital were corroded to perforation in 1969 within several years of installation. Recommendations to that hospital to lower operating temperature and/or use alkaline dosage to raise pH to 8.0 were both carried out and the system, after replacement of the earlier perforated sections has not suffered any further perforation after 6 years.

A trial was carried out at the hospital in order to assess the magnitude of the effects of pH, temperature and chlorine. Two selected values for each of the three variables were pH 6.5 and 8.0, temperature 55 and 70° C and chlorine at 0.0 and 0.6 mg/1 and this involved eight separate trials, each of at least two days duration. Procedures used for assessing the degree of corrosive attack including sampling and analysing the water for copper, measurement of the general corrosion rate by a commercial instrument based on polarisation resistance techniques, measure-

ment of pitting tendency by use of the same commercial instrument and measurement of the copper potential. The results of the trials showed

(1) there was good correlation in most instances between the general corrosion rate as measured by water analyses and the commercial instrument;
(2) there was no pitting tendency indicated over the duration of the two day trial;
(3) the potentials of the copper were extremely variable over most of the period of each trial;
(4) although the pH control was not as precise as intended the general corrosion rate between pH 8.0 and 6.5, irrespective of temperature, increased several fold to a value of approximately 0.1 mils per year;
(5) chlorine did not appear to significantly affect the corrosion rate. The levels in the actual hot water were always less than 0.05 mg/l and suggest that it was being converted either to dissolved oxygen or chlorate;
(6) temperature effects in the range selected were not great and a further trial at 85°C might have been more pertinent.

The whole exercise confirmed the difficulties associated with establishing the cause and effects of a complex corrosion mechanism and the shortcomings of such short term trials. The results could be useful as a starting point for further laboratory or long term situation trials.

(ii) Domestic Hot Water System—A hot water system, supplied with water from a sparingly aerated bore supply containing 80 mg/l of total salts and free carbon dioxide in excess of 1100 mg/l, resulted in the water of a solar hot water storage unit containing 8.0 mg/l of copper. Subsequent green discolouration in a soapy bath water and green staining of laundry resulted. It was not immediately feasible to efficiently aerate the water to reduce the carbon dioxide level but an inadequate hydrolime dosage of 50 mg/l reduced the free carbon dioxide level to 60 mg/l with a subsequent reduction of the copper level in the hot water system from 8.0 to 1.9 mg/l.

(c) Evaporative Cooling Waters: Due to the restrictions imposed on chromate discharge into sewage or stormwater, corrosion inhibitor treatment of evaporative cooling towers have had to resort to other inhibitor types. Organic zinc appears to have been recently used in a number of systems throughout the metropolitan area with apparently unacceptable results, irrespective of whether the system is "all steel" or predominantly copper. In order to prevent the formation of hydrated zinc oxide deposits at the recommended zinc dosage levels of 10-20 mg/l, pH recommendations are at 6.0 to 6.5. Unfortunately the acid requirement to maintain this pH value is critical and automated control has been unreliable in at least one installation. It is the lack of pH control which has been considered mainly responsible for the apparent ineffectiveness of reducing corrosion to acceptable levels. As usual the involvement in such inspections always follows a period of vague installation and early treatment procedures and levels, with available log sheets frequently showing values at other than those recommended. It would appear prudent to use an inhibitor system with pH control less precise and pH is normally easily controlled in the range 7.5 to 8.0.

(d) Volatile Corrosion Inhibitor: An inhibitor intended for use in a switchboard to prevent corrosive attack on the switching gear, was identified as the volatile dicyclohexylammonium nitrite, which is recommended for corrosion prevention of steel in those areas where air movement is restricted or nil. Its general use in a copper or copper alloy situation was not recommended because of potential breakdown of the nitrogen component to ammonia which is particularly aggressive to copper and some of the metals comprising its alloys. It was recommended that its general use in a switchboard situation should be preceded by a small scale trial.

(e) Automotive Radiator Additive: A commercial inhibitor marketed for use in automotive radiators was submitted by the Bureau of Consumer Affairs because of its suspected inability to inhibit corrosion, particularly of the solder of the radiator.

The product was found to be an acceptable inhibitor based on benzoate, nitrite and soluble oil and at the dosage rate recommended gave satisfactory levels in the water itself.

The effect on solder from car radiators was tested in a one week laboratory trial and compared with other commercial additives of reputedly satisfactory properties. The material submitted performed as well as the other two acceptable commercial additives.

(f) Boiler Deposit: A viscous flaky deposit from the rear furnace chamber of a boiler was analysed and found to be predominantly iron sulphate and sulphuric acid. Its presence in this area of the boiler was unexpected and recommendations included examination to find where the attack was occurring and to rectify by increasing flue temperatures above the dew point, using lower sulphur content fuels, using additives with the oil to suppress formation of oxides of sulphur and to optimise shutdown procedures for the boiler.

(g) Spray Nozzles: Jet assemblies for spray nozzles for Perth reticulated water for evaporative coolers in M.T.T. buses were shown to be blocked with corrosion products from the chrome steel (400 series) material of the nozzle. This crevice type attack was probably enhanced by the increased dissolved oxygen content of the air pressurised water, calculated at 50 mg/l of dissolved oxygen. A recommendation for cupro nickel jets was made. Brass jets could be tried first but there was a danger of excessive impingement attack and the more resistant stainless steels would still be prone to crevice attack.

(h) Bronze Impellers: A cupro bronze impeller from a dishwashing machine had prematurely failed due to corrosion. The material of the impeller was identified and a sample of the wash solution used was analysed. It was decidedly alkaline with a caustic soda component, which at the recommended dosage level, gave a pH of 11.5. The recommendation was to use a washing solution devoid of caustic soda.

(i) Stainless Steel and Chrome Plated Cabinets: The finishes on cabinets stored in a warehouse in an industrial area were being dulled or tarnished. Fumes from an open container of hydrochloric acid from an adjacent site were suspected. Swabbings of the surfaces with distilled water together with swabbings from a glass surface of known exposure time showed that acid attack was not taking place. The concentration of chloride was generally greater than its stoichiometric equivalent of sodium, but always less than the combined stoichiometric equivalent of "sodium plus calcium". The conclusion was that hydrochloric fumes were probably present but were being neutralised by lime dust which was also available from other adjacent sites. The staining was considered to be due to high concentrations of salts on the surface; the quantities of materials swabbed when related to 0.025 mm layer of moisture, represented a concentration of the order of 10 000 mg/l.

Miscellaneous

(a) Bitumen Sealants for Dams and Catchments: Chemical testing for recommendations for the use of bitumen sealants is not entirely satsfactory because of the lack of specificity of tests. Undesirable tastes are known to develop at Kojonup, presumably due to attack by organisms on the bitumen and not to any water soluble components of the bitumen. Also there is increased attention on compounds such as polycyclic aromatic hydrocarbons which are sparingly soluble in water, but which may be present in bitumen type compounds.

(i) A sample of commercial product, claiming to possess rejuvenating properties for bitumen catchment was submitted for analysis and recommendation in relation to its use for a town drinking supply. Analyses were performed to ensure that the material complied with the manufacturer's specification, but the only meaningful tests to assess its suitability for a drinking supply were based on tests on the water soluble component. These included phenols and taste threshold both before and after chlorination. The commercial product passed all tests supplied.

(ii) A sample of bitumen coated fabric intended for use as a sealant in an earth dam for a town drinking supply was also tested. Because of the longer periods of anticipated contact the probability of contaminants entering the water is greater than for a catchment. A water soluble extract of the material submitted, carried out over a range of temperatures, pH values and for periods up to one week, when related to anticipated water to fabric ratios in the actual dam situation, showed the material to be unsatisfactory. The taste both before and after chlorination was unacceptable as was also the phenol level.

(b) Fish Aquariums: Two materials submitted from the Bureau of Consumer Affairs for use in fish aquariums

were examined in relation to claims made by the manufacturers.

(i) An additive, claiming a capability to remove turbidity including algae without detriment to the fish, was tested and found to comply with the claim. The product was mainly organic and was predominantly of tannins. Its coagulative properties are based on the insolubility of calcium tannate which will form with most natural waters in Western Australia other than rain water. Calcium levels in natural water down to as low as 4 mg/1, are adequate and this means that all Perth reticulated supply is suitable. The potentially toxic components of the additive, when diluted at the manufacturer's recommendation were well below the levels which fish are known to tolerate.

(ii) An additive, claiming to remove chlorine and copper and also adding many needed elements to condition the water was found to be lacking in the latter two claims. The material was 97 percent sodium chloride, the balance being mainly sodium thiosulphate. At the recommended dosage level it was capable of removing the maximum levels of chlorine in Perth water supply, namely 0.5 mg/1 but there was no component capable of removing copper, as claimed. The salt content of the additive, when dosed as instructed increased the sodium chloride content of the water by approximately 200 mg/1 and this would have little or no effect on Perth water supply where the sodium chloride content already varies between 100 and 450 mg/1.

(c) Swimming Pools: (i) Silver/Copper Anodes—Despite conclusions and recommendations made to various Departments on the inadvisability of using these anodes for bacteriological control in swimming pools, the manufacturers of such equipment are still advertising these for sale in the daily papers and making exaggerated claims about their bactericidal action. Additional work carried out on this aspect during 1976 did not alter any of the previous held conclusions published in the 1975 Annual Report.

(ii) D.P.D. Test Kits for Chlorine: Two commercial types of test kit involving the use of D.P.D. were assessed. D.P.D. test kits are superior to the long established orthtolidene kits because they are capable of determining both free and total residual chlorine and hence indicate whether the desirable breakpoint condition has been achieved. One of the kits submitted was considered suitable but the other was not.

(iii) Breakpoint Chlorination: A major cause of problems associated with swimming pool control, for which our advice was sought, was lack of maintenance of breakpoint chlorination conditions within the pool. Four samples received during 1976 had chlorine demands to breakpoint in excess of 100 mg/1, and is supporting evidence for the use of D.P.D. test kits as mentioned above. Two of the four samples had total available chlorine in excess of 5 mg/1 at the time of submission.

(iv) Black Stain: Apart from the black stain of glass fibre reinforced plastic pools, which has already been fully covered in earlier reports, there are conditions conducive to black stain in pools fabricated from other materials. One cause could be the combination of copper ion and chlorine. Such black discolouration has been produced in the laboratory when levels of copper and chlorine are as low as 5 and 25 mg/1 respectively but the formation is dependent on pH and copper ion activity, which are both in turn dependent on alkalinity. Such situations are unlikely to occur in the normal situation of homogeneous mixing but where copper sulphate and chlorine are added as solids or where mixing is not adequate the situation could develop.

N. PLATELL,
Chief, Water Division.

DIVISION VIII

Annual Report of the Chief Inspector of Explosives for the Year 1976

In accordance with Section 10 of the Explosives and Dangerous Goods Act, my report on the administration of the Act for the year ended December 31, 1976 is submitted herewith.

STAFF

The appointment of Mr. W. P. Gildare as Inspector of explosives on April 2, 1976 added a much needed member to the staff of the Explosives Inspectorate.

At December 31, the staff of the Explosives Branch totalled 22 and consisted of:—

Inspectorate	— 8
Clerical	— 6
Reserve Security	— 8

AUTHORISATION

Of the eight new explosives submitted for approval for use in Western Australia by the end of the year only three remained to pass the final stages of approval. Those authorised were classified as follows:—

Class 3, Nitro-compound, Division 1
"Higel" (ZZ)

Class 3, Nitro-compound, Division 2
"Johnson TNC" (ZZ)
"Johnson Primaboost" (ZZ)

Class 6, Ammunition, Division 2
"Premium Ribcord" (ZZ)
"Tuffcord" (ZZ)

Approval was given for changes in the authorised composition of the explosives "Anzomex Boosters" and "Molanite".

MANUFACTURE OF EXPLOSIVES

Experimental work conducted by the Branch throughout the year allowed the manufacture of low density blasting agents, from expanded polystyrene beads, ammonium nitrate and fuel oil, which were used in trials at the Windarra and Jarrahdale minesites. These low density explosives required normal initiation techniques and showed no abnormal hazard to prevent their safe use under controlled conditions such as is experienced at these minesites. Since the trials, a Western Australian explosives manufacturing company has expressed interest in the manufacture of Polystyrene/ANFO mixtures for supply to the mining industry.

The manufacture of other explosives continued under licence at the larger minesites where the more complex nitrate mixtures were blended for use at the site. There was, however, a considerable reduction in the quantity of bulk nitrate explosives manufactured in Western Australia during 1976, totalling only 60 715 tonnes compared with 79 241 tonnes the previous year.

Of note was the construction of a new slurry mixing plant at Windarra for the manufacture of bulk explosives of the "Molanite" type, thereby bringing the total number of licences issued for the manufacture of explosives to twenty-five. The simpler mixing of ammonium nitrate and fuel oil to produce ANFO explosives was controlled by the issue of a "licence to manufacture a blasting agent" for which 278 licences were issued throughout the year.

Fireworks continued to be manufactured under licence by the two principle craftsmen of this field in Western Australia. Those two, of Italian descent, have many years' experience in the manufacture of pyrotechnics and excel in the public demonstration of their products to such extent that all of the thirty five fireworks displays permitted during the year were conducted by one or the other of those two manufacturers.

Total Consumption of Explosives for 1976: The following summary shows the quantity of explosives, both manufactured and imported, used throughout Western Australia during the year ended December 31, 1976:—

	Tonnes
Propelling Powders (including gun powder, fireworks, etc)	4.5
Bulk Nitrate Explosives (a) ANFO	56 099.3
(b) Al/ANFO ..	3 011.0
(c) Slurry	1 604.7
Cartridged Nitrate Explosives	168.2
Nitroglycerine based Explosives	1 012.3
Primers and Boosters	41.1
Detonating Cords (4.48 x 10^6 metres)	99.9
Primary Initiators (1.88 x 10^6 units	79.4
Total	62 120.4

IMPORTATION OF EXPLOSIVES

A total of 1 226 tonnes of explosives were imported to the State mainly by rail from Victoria, and of these imports, 83 per cent consisted of cartridged nitroglycerine and nitrate type explosives. It is of note that of the total tonnage of cartridged explosives used throughout the year only 168 tonnes were of the nitrate type—an explosive predicted to replace the nitroglycerine based explosives completely by the year 1980.

There was no importation of explosives grade ammonium nitrate during 1976, nor was there need for any as the total quantity of blasting explosives used in Western Australia throughout the year was equivalent to merely three quarters of the ammonium nitrate manufactured locally in 1975.

Of the total imports, approximately 2.3 tonnes of various explosives were permitted to enter the State under authority of Entry Permits. These permits are normally issued for miscellaneous explosives items or non-authorised explosives which are mainly used by the oil exploration industry or for other specialised purpose. One such import involved the testing and approval of an explosive security device, designed to foil pay-roll snatchers, and is now used by one of the larger banking establishments of Perth.

MAJOR EXPLOSIVES RESERVES

Woodman Point Explosives Reserve

With increasing rail transport of explosives to Woodman Point it has become apparent that a jetty and shipping facility is no longer an essential feature of the Reserve area. The Woodman Point jetty was used only five times by small vessels during 1976, the largest shipment being a 10 tonne load for a seismic underwater blast.

Accordingly, a Study Group was formed to investigate and recommend suitable alternative sites for relocation of the Woodman Point storage and manufacturing facilities. Several meetings of the group took place throughout the year under the convenership of the Chief Inspector of Explosives and nine possible sites were examined in detail for their suitability as a Reserve area.

All magazines within the Reserves continued to be fully used and on two occasions separate magazines were broken and entered resulting in the loss of small quantities of explosives. A bomb threat against a Woodman Point explosives distributor was received during the year and security staff had to be suitably alerted and strengthened—fortunately nothing untoward happened.

A continuing need for the explosives reserve area was shown by the dispatch of approximately 3 400 tonnes of explosives and 400 tonnes of explosives grade ammonium nitrate from Woodman Point during 1976, involving a total of 3 182 dispatches for road transport. These activities were noted by the Hon. Minister for Mines, Mr. A Mensaros, who visited the Woodman Point Explosives Reserve to inspect explosives storage and manufacturing facilities within the area.

Kalgoorlie Explosives Reserve

Additional interest has been shown for increased storage and manufacturing facilities at the Kalgoorlie Reserve which continued to be the main distribution centre for explosives used in the mining areas north and south of Kalgoorlie.

During the year a new security fence was completed around the Kalgoorlie Reserve area at a cost of $29 108.00. Also, action was taken to ensure that the 800 metre wide safety zone around the Reserve would not be alienated by the future construction of protected works.

ANALYSIS AND TESTING

The Branch scientific officers were active thrhoughout the year in the testing of a variety of explosives and explosives accessories. These included the following:—

(i) The acceptance testing of all explosives submitted for authorisation. Additionally, tests were conducted to determine the time delay interval of a series of millisecond delay electric detonators of Indian manufacture. As these tests were inconclusive, approval of the delay electric detonators was withheld until further tests may be conducted.

(ii) A total of 230 circuit testers were approved for use on minesites. These testers consisted of 180 of the photoelectric type and 50 of the illuminating globe type which though not conforming to the Australian Standard "ohm-meter" requirement, have a high safety factor because of low amperage out-put and are most suitable for conditions underground.

(iii) General approval was given for the use of a new Australian manufactured solid state electric circuit tester known as the "Detameter" which may be used for electrical firing throughout Western Australia.

(iv) Special approval was given for use at a Jarradale minesite of a high capacity blasting machine, known as the "CIL-1000 Blasting Machine".

(v) Tests were conducted on several electric circuit testers in use at a minesite in Kalgoorlie—one was found to be delivering an excessively high current and was withdrawn from use. A 50 shot blasting machine from Kalgoorlie was also examined and found to be faulty—apparently it had been tampered with and the firing mechanism replaced in an incorrect manner.

(vi) The conductivity of several lengths of ANFO loading hose was measured and found not to be in compliance with the Mines Regulation Act Regulations requirements. The resistance of these hoses must be low enough to dissipate the static electrical charge generated by loading ANFO but must be sufficiently high in resistance to prevent a short circuit flow of electricity electrocuting the operator.

(vii) 415 samples were taken at random of imported nitroglycerine based explosives and all were found to be satisfactory when subjected to the Abel Heat Test. Also 43 samples of safety fuse were tested and shown to be of the standard required by the Explosives Regulations.

The methods of appraising small diameter cartridged nitrate explosives used in Western Australia were critically examined during 1976. Enquiries of American testing authorities showed that the methods used by the Branch are comparable with those used by the U.S. Bureau of Mines. A method of testing proposed by an Australian manufacturer was examined and rejected because of its relatively low pass standard.

In due course of the above appraisal, further tests were conducted on several cartridged nitrate explosives of a brand that had been tested in 1975 and had then failed to gain approval. It was found that the explosive had increased in sensitivity during storage to such a degree that it could be approved for use in Western Australia. In contrast to the latter nitrate explosive, a gelignite explosive, which also had been rejected the previous year because of lack of sensitivity, was found on further testing to have deteriorated to an even greater extent thereby confirming the original result.

Bi-monthly samples of locally manufactured explosives grade ammonium nitrate were analysed by the Laboratories for combustible material and oil absorption and several tests were conducted by the Branch scientific officers on bulk nitrate explosives throughout the year. One of the tests required the assistance of a marksman from the Western Australian Police Force in the firing of high velocity heavy calibre rifle bullets. These tests confirmed:—

(i) That ANFO was much less sensitive to initiation by rifle fire than was nitroglycerine based explosives and that the probability of initiation of ANFO when impacted by a rifle bullet was sufficiently low to allow the product to be stored in magazines not constructed to bullet-proof specifications.

(ii) A mixture of expanded polystyrene beads and ANFO required the same initiation as did straight ANFO, and that the use of polystyrene presented no additional hazards in blasting other than the production of additional fumes which are readily removed by standard ventilation techniques. These polystyrene/ANFO mixtures enabled a product of low bulk strength to be formulated on site where needed.

(iii) That consistent reports (mainly from farmers) that urea was a satisfactory substitute for ammonium nitrate could not be substantiated under test. No successful detonation of urea and fuel oil mixtures could be achieved. It is believed that any effect obtained by such mixture comes from the priming charge, not the urea/fuel oil mixture.

67016—(12)

EXPLOSIVES LICENCES AND PERMITS

There was a thirty-six per cent increase in the number of licences issued for explosives during 1976. Comparison figures with the previous year are shown below:—

	1975	1976
Licence to Import	8	8
Licence to Manufacture Explosives	7	25
Licence to Manufacture Blasting Agents	119	278
Licence to Store, Mode A (50 kg)	33	33
Licence to Store, Mode B (150 kg)	17	18
Magazine Licence, Type One (Maximum 1 000 kg)	91	86
Magazine Licence, Type Two (1 001-5 000 kg)	45	44
Magazine Licence, Type Three (greater than 5 000 kg)	63	71
Licence to Sell Explosives	47	43
Licence to Convey Explosives	47	44
Total	477	650

The increase in the total number of licences is mainly due to an awareness of the regulations by most users of explosives following advice given by Branch Inspectorate and Police officers. The additional number of licences to manufacture explosives are due to the popularity of the more complex bulk nitrate mixtures which are authorised only under the more stringent licence to manufacture explosives.

Inspections were made of almost all licensed premises and on-site manufacturing facilities and operations throughout Western Australia during the year. The Inspectorate is now more familiar with the essential features of manufacturing operations and, also, licensees are more aware of the safety regulations thereby saving much of the Inspectorate's time and permitting better supervision of the safety requirements.

The issue of Shotfirer's Permits and the training of shotfirers continued at a high level of priority. Out of 240 applicants a total of 213 qualified as shotfirers to use explosives on any construction work throughout the State. There were nine training courses conducted during 1976 by Branch Officers who were able to give greater emphasis to the practical work section of each course; three inter-departmental five day courses were conducted for State Government employees in Perth; a similar course was conducted in the towns of Bunbury, Geraldton and Kalgoorlie for employees of the Local Authority and Government Departments; and finally, three evening courses of seventeen weeks' duration were conducted for those persons not associated with Local Authority or Government departments. Those nine courses involved 176 students of whom 160 were successful in obtaining a Shotfirer's Permit.

Thirty four Entry Permits involving 2.3 tonnes of miscellaneous explosives items were issued throughout the year, some of which involved fireworks for display purposes. Public displays of fireworks continued on a similar scale to that conducted in previous years—35 Display Permits were issued with only one incident which involved a "Starshell" lost after a misfire during a display at Tom Price. All reasonable precautions were taken by the operator who, by advertising through local television, newspaper and schools, endeavoured to ensure that anyone finding the fireworks item would be aware of its dangerous nature.

USE OF EXPLOSIVES

With the presence of some 800 licensed shotfirers throughout the State, explosives are now used with a much greater awareness of and compliance with the regulations than ever before. As a result the general public too are aware of the elementary safety requirements for explosives usage and should a shotfirer be neglectful of his responsibilities, the Inspectorate is soon advised by telephone and appropriate action is taken against the offender.

One fatality occurred throughout the year on a site controlled by a licensed shotfirer, and three accidents were reported which involved the misuse of explosives but fortunately no person was injured. Branch Officers made 247 inspections, relating to the use of explosives, of which only 40 were in connection with the improper use or mishandling of explosives and successful prosecution was instigated in three of the cases of mishandling.

Many of the inspections made by the Explosives Inspectorate were in relation to the use of explosives by farmers who because of their usually remote location are permitted to use explosives on farming properties of area greater than 40 hectares. Many of the farmers are also permitted to manufacture their own blasting agents and the Inspectorate has endeavoured to provide as much assistance and advice on the use of explosives as possible.

Considerable concern was caused by children, throughout the year, who with no criminal intent experimented illegally with explosive mixtures mainly in the construction of "home made bombs". These children place themselves in grave danger and endanger the lives of other children who may be near them. Seven cases were reported of such experimentation which resulted in the death of one child in one instance and in the serious injury of five other children in separate incidents. Police officers registered seven charges of "manufacturing or exploding home made bombs" against children all of which were dismissed under Section 26 of the Child Welfare Act.

The illegal use of explosives with criminal intent has, fortunately, not been prevalent in Western Australia, but there were four such cases during 1976, all of which were investigated by the Police Department assisted by the Explosives Inspectorate. The explosives used in at least one of these incidents was obtained by breaking and entry of a licensed magazine, but because of the increased security required for storage of explosives in Western Australia, such possession of explosives is obtained with difficulty and at great risk to the criminal.

EXPLOSIVES STOLEN, CONFISCATED OR DESTROYED

In five reported cases of magazine breaking and entry during the year, a total of 428 kilograms of various types of explosives were stolen—416 kilograms being from the one magazine belonging to a quarry group operating near Perth, of which 275 kilograms were subsequently recovered in a deteriorated condition and destroyed by the Explosives Inspectorate.

In all, the Inspectorate destroyed some 320 kilograms of blasting explosives including 13 000 unmarked detonators and 38 000 rounds of deteriorated ammunition for small arms. Also, a total of 135 obsolete marine distress flares, confiscated over the year by the Harbours and Rivers Inspectorate, together with approximately 25 kilograms of hazardous chemicals of various types were safely disposed of by the Inspectorate at the Woodman Point Reserve.

One call from the Police concerning deteriorated explosives found semi-buried near a beach front resulted in an inspector being flown from Perth to Exmouth to arrange the destruction of several large size cartridges of explosives, which appeared to be the remains of misfired charges from a previous seismic survey operation, uncovered by recent cyclonic winds. The resident police officers gave every assistance to the inspector and were instructed in the safe destruction of similar charges which may remain in the sand and could be uncovered by future winds.

DANGEROUS GOODS

Apart from explosives, flammable liquids continued to be the major dangerous goods of Western Australia requiring the issue of 4 900 licenses and occupying a major proportion of some 6 500 telephone enquiries received throughout the year.

The Inspectorate made 4 155 inspections of premises licensed for flammable liquids storage (an increase of 27% over the previous year) and a further 284 premises were visited to give advice on the safety requirements for storage of non-licensable quantities

of flammable liquids. At every fuel depot visited, a special effort was made to inspect each vehicle conveying in bulk from the depot and in all a total of 642 tanker vehicles were checked for compliance with the regulations. Many of these vehicles required work orders, but it was apparent that there has been a considerable improvement in tanker vehicle standards due to a growing awareness of the safety requirements of the regulations.

Considerable time was spent in the examination of fire fighting facilities and in the determination of water requirements for fire fighting at bulk fuel depots throughout the State. All scientific officers of the Branch have been active in discussing with petroleum engineers and W.A. Fire Brigades Board officers means of determining minimum water flow for cooling and foam requirements and some concurrence has been achieved in this field. It is intended that every depot throughout Western Australia of capacity greater than 60 cubic metres of bulk fuel will be so equipped as to be capable of extinguishing a fire on the largest tank with water and foam stocks available for at least 1½ hours continuous fire fighting supply.

Six approvals were issued for hot works maintenance within bulk fuel terminals throughout the year and two Petroleum companies experimented with Branch concurrence with a floating pontoon of sheet aluminium within each of their largest petrol tanks—a procedure new to Australia and which will reduce loss by evaporation. One fuel oil tank—the largest in the Perth metropolitan area (58 metres diameter, 35 000 tonne capacity)—was constructed for a bauxite refinery at Kwinana. This caused some concern as the location of the tank, and the fact that the product was to be heated to just below its flash point, made it necessary to require that it be foam protected in case of fire. The prescribed rate of foam injection required a volume of foam never experienced before for tank protection in Western Australia and at the end of the year the Chief Inspector had yet to approve a satisfactory system for application of the foam.

The use of hazardous substances other than flammable liquids, notably liquefied petroleum gases and oxidising agents such as ammonium nitrate and calcium hypochlorite, has increased to such extent that considerable thought has been given to the methods of controlling the transport and storage of bulk quantities of all dangerous goods. Of the several requests urging the control of dangerous goods, one was received (no doubt influenced by the reports of children using dangerous goods for the manufacture of explosive devices) demanding that legislation be implemented to prevent the sale to children of any substances likely to be used for the manufacture of explosives. Such legislation was deemed to be impossible to enforce due to the diversity of substances, many of them common household chemicals, capable of being used to manufacture an explosive. In any event, it was considered in matters dealing with household quantities of dangerous goods, that it is education that is required, not legislation.

With regard to the control of bulk or commercial quantities of dangerous goods, particularly for the transport of these items, an inter-departmental committee, known as the Transport of Dangerous Goods Advisory Committee, recommended that legislation to adopt and enforce the "Model Code for the Transport of Dangerous Goods by Road" be enacted through the Explosives and Dangerous Goods Act. The research work resulting from the recommendation caused the Branch Inspectorate considerable additional work throughout the year and taxed an already overburdened staff. Without doubt, if such legislation were implemented, additional staff would be needed for the explosives Branch.

INCIDENTS INVOLVING DANGEROUS GOODS

(a) *Explosives*

(i) Two fatalities occurred, throughout the year, both by explosions and both by misadventure, and each under vastly differing circumstances. The first, a seismic survey worker, was blown asunder when a 22 kilogram charge of blasting explosives detonated whilst he was inserting the electrical priming charge. The second, a fifteen year old boy, received fatal shrapnel injury when a home made device exploded as the gunpowder composition was being tamped with a metal rod and hammer.

(ii) Six incidents involving schoolboys experimenting with explosive devices, five of whom were injured, were reported during the year. These were:

- an eight year old received severe leg lacerations when a home made bomb exploded after being thrown over a fence;
- a twelve year old received eye injuries after causing a "Railway Fog Signal" to detonate by throwing it against a tree;
- a fourteen year old received eye injuries when a mixture of "chlorine and sulphur" exploded in his face;
- another fourteen year old lost a thumb when closing the end of a copper pipe, filled with matches, with a hammer;
- a fifteen year old received severe eye injuries when a "home made bomb" exploded in his face;
- another fifteen year old appeared in court after frightening a school gardener with a booby trap explosive device consisting of swimming pool chemical and brake fluid.

There is little the Explosives Inspectorate can do in such cases—the only answer lies in educating the children and to this effect the Police lecturing squad is visiting schools and warning children of the dangers of home made explosives and explosive devices.

(iii) In three incidents involving the mishandling of explosives, all participants were fortunate in not receiving permanent injury but in each case the persons involved were reprimanded accordingly. These were:

- a loaded vehicle, conveying an excessive quantity of explosives and detonators, overturned on a minesite near Kalgoorlie. Successful proceedings were instigated against the owner of the vehicle.
- a licensed shotfirer was reprimanded after his careless storage of explosives caused the destruction of an air compressor, it is thought that excessive heat from the compressor exhaust system initiated a primer charge.
- a quantity of deteriorated explosives being destroyed by burning detonated before the operators were clear of the site causing temporary deafness.

(iv) An attempt was made to destroy a woodchip loading terminal at Bunbury using three separate time bomb devices comprising a total of nine cartons of explosives (225 kilograms) stolen from a quarry magazine near Perth. Fortunately, two of the devices placed at the legs of the ship loading gantry failed to detonate, but the third device totalling 125 kilograms of explosives destroyed the base of the terminal's woodchip stacker. Two men were apprehended and committed for trial.

(v) Another atrocity, but of a smaller scale, occurred when a device prepared from a motor cycle telescopic fork packed with explosive substance, was detonated under a vehicle. The vehicle was badly damaged and the petrol tank ruptured but no fire occurred and no person was injured.

(vi) Two incidents involving the illegal detonation of explosives could have had disastrous consequences but fortunately no person was injured. The first caused damage only to a

hotel laundry when a prospector initiated explosives in the laundry after having been refused service at the bar. The second, when a pyrotechnic device was thrown into a hall in which a bridge tournament was being held, attracted only little attention—the players are reported to have continued their game despite the noise and smoke from the missile.

(b) *Flammable Liquids*

(i) One fatality caused by the ignition of flammable liquids occurred when a man, whose clothing had been soaked whilst refuelling his vehicle from a canister, ignited the petrol vapours when he lit a cigarette.

(ii) Two incidents were reported of damaged property when fires involving flammable liquids, suspected to have been caused by sparks from grinding operations igniting vapours from open cans of solvents, destroying two small factory units.

(iii) A fire which damaged a flammable liquid distillation plant at Wundowie was attributed to one of the units boiling over and the vapour igniting from a heating element. As the liquid was in process of manufacture and not in storage, the incident was deemed to be within the ambit of the Factories Inspectorate and was not examined further by Branch officers.

(iv) One incident in which a welder was severely injured occurred when an "empty" drum on which he was standing exploded after having been touched by his electrical welding rod.

There was no report of accident involving flammable liquids within licensed storage depots throughout the year. Those accidents which occurred elsewhere, as with most incidents involving flammable liquids, were mainly caused through ignorance of the properties of flammable liquids rather than deliberate flouting of the regulations.

(c) *Other Dangerous Goods*

(i) A vehicle and its 20 tonne load of ammonium nitrate were destroyed by fire, 1 kilometre south of Shark Bay turn off—no explosion occurred and no person was injured. It is of interest to note that had the fire occurred in Geraldton where the vehicle was loaded and had an explosion occurred then all buildings within a 600 metre radius would have been expected to receive severe damage.

(ii) After a fire involved premises using a large number of LPG and oxygen cylinders, Fire Brigade officers considered the cylinders to be stored in a hazardous manner and requested the Explosives Inspectorate to take action. An inspection report concurred with the Brigade's assessment but as the goods were not gazetted "dangerous goods" it was beyond the control of the Branch and no further action could be taken.

MISCELLANEOUS ACTIVITIES

(i) *Court Appearances*

The Inspectorate assisted the police throughout the year and prepared reports for the Coroner on incidents involving explosives and dangerous goods. Three Court appearances were made; the first, by the Senior Inspector of Explosives to give evidence of findings from his investigation of fire within a bulk storage depot in 1975; the second by an Inspector of Explosives to give evidence of an explosives accident investigated in 1974; and the third by the Chief Inspector who gave evidence at the committal hearing for two men accused of causing an explosion to damage a woodchip plant.

(ii) *Committee Attendance*

The Chief Inspector and the Inspector and Research Officer both represented the Department at interstate meetings of technical committees throughout the year. These were:

— Melbourne, March 3-4; Committee ME/17, flammable and combustible liquids.

— Melbourne, May 4-5; Committee AU/17; tank vehicles for hazardous substances.

— Sydney, October 1; Australian Port and Marine Authorities; import of explosives.

— Sydney, October 12-13, Committee AU/17; tank vehicles for hazardous substances.

The Branch scientific officers continued to maintain the Department's interest in their membership of local committees, including the Australian Fire Protection Association; the Australian Forensic Science Society and the Transport of Dangerous Goods Advisory Committee.

(iii) *Chief Inspector Conference*

The 12th Conference of Chief Inspectors of Explosives was attended in Sydney, September 21-30, and much information was gained in discussion with Chief Inspectors from other States. These meetings were deemed of such value that Conference resolved to hold future conferences every year instead of every three years, but to reduce the length of the meeting from nine to three days, thereby enabling a more frequent exchange of views and the maintenance of a more uniform policy between States on matters concerning explosives and dangerous goods.

(iv) *Lectures*

Three series of seventeen two-hour lectures on "Explosives for the Shotfirer", for Technical Education students, and one lecture on "Explosives and Fire", for Fire Brigade officers, were delivered by the Branch scientific officers.

A meeting of the Petroleum Operations Managers was addressed by the Chief Inspector to explain current and future policy concerning flammable liquids regulations.

CONCLUSION

The year under review has been a busy and eventful one which has called for maximum effort and co-operation from all members of the Explosives Branch. To the Reserve Security Officers, the general and professional inspectorate and the clerical officers of the Explosives Branch, I extend my grateful appreciation for the assistance they have given me in maintaining the functions of the Branch.

I record my appreciation also of those officers within other Departments and Instrumentalities and in particular those officers within the Department of Mines, who have given their advice and assistance so readily throughout the year.

H. DOUGLAS,
Chief Inspector of Explosives.

DIVISION IX

Report of Superintendent, Mine Workers' Relief Act, and Chairman, Miners' Phthisis Board 1976

Annual Report 1976—Mine Workers' Relief Act 1932 and Miner's Phthisis Act 1922.

Under Secretary for Mines

1. This Report is submitted for the information of the Honourable Minister for Mines, on the above Acts for the year ended 31st December, 1976.

2. *General*

The State Public Health Department, under arrangements made with this Department, continued the periodical examination of mine workers throughout the year and the following mining sites were visited by the mobile X-Ray unit:—

Busselton, Bunbury, Boulder, Bullfinch, Capel, Coolgardie, Clackline, Eneabba, Fimiston, Greenbushes, Jarrahdale, Jurien, Kalgoorlie, Kambalda, Koolyanobbing, Laverton, Leonora, Marvel Loch, Menzies, Mt. Windarra, Narngulu, Nepean, Norseman, Ora Banda, Pinjarra, Red Ross, Scotia, Southern Cross, Spargoville, Windarra, Widgiemooltha, Wundowie and Wonnerup.

3. *Mine Workers' Relief Act*

3.1 *TOTAL EXAMINATIONS*

The examinations made under the Mine Workers' Relief Act during the year totalled 5 788 compared with 8 696 for the previous year; a decrease of 2 908. The results of examinations are as follows:—

Normal	5 495
Silicosis early, previously normal	20
Silicosis early, previously silicosis early	250
Silicosis advanced, previously normal	—
Silicosis advanced, previously silicosis early	7
Silicosis advanced, previously silicosis advanced	5
Silico-tuberculosis, previously normal	—
Silico-tuberculosis, previously silicosis early	—
Silico-tuberculosis, previously silicosis advanced	—
Silico-tuberculosis, previously tuberculosis	—
Tuberculosis, previously normal	—
Asbestosis early, previously normal	1
Asbestosis early, previously asbestosis early	1
Asbestosis advanced, previously normal	—
Asbestosis advanced, previously asbestosis early	—
Silico-asbestosis early, previously normal	1
Silico-asbestosis early, previously asbestosis early	—
Silico-asbestosis early, previously silicosis early	—
Silico-asbestosis early, previously silico-asbestosis early	8
Silico-asbestosis advanced, previously silicosis early	—
Silico-asbestosis plus tuberculosis, previously normal	—
Silico-asbestosis advanced plus tuberculosis, previously silico-asbestosis early	—
Total	5 788

The 1976 figures, together with figures for previous years are shown on the table annexed hereto. Graphs are also attached illustrating the trend of examinations since 1940.

3.2 *Analyses of Examinations*

In explanation of the examination figures, I desire to make the following comments:—

3.2.1 *Normal, etc.*

These numbered 5 495 or 94.94% of the men examined and include men having first class lives or suffering from fibrosis only. The figures for the previous year being 8 394 or 96.53% of the men examined.

3.2.2 *Early Silicosis*

These numbered 270 of which 20 were new cases and 250 had previously been reported; the figures for 1975 being 275 and 33 respectively. Early silicotics represent 4.67% of the men examined, the percentage for the previous year was 3.16%.

3.2.3 *Advanced Silicosis*

There were 12 cases reported, 7 of which advanced from early silicosis. Advanced silicotics represent 0.21% of the men examined, the percentage for the previous year being 0.16%.

3.2.4 *Silicosis Plus Tuberculosis*

There were no cases reported.

3.2.5 *Tuberculosis Only*

There were no new cases reported in 1976, compared with one in 1975.

3.2.6 *Asbestosis*

There were two cases of early asbestosis reported during the year.

3.2.7 *Silicosis-Asbestosis*

Nine cases of early silicosis-asbestosis were reported during the year, one being a new case. This category represents 0.18% of the men examined.

4. *Mines Regulation Act*

4.1 *Total Examinations*

Examinations under the Mines Regulation Act totalled 6 166. There was a decrease of 3 024 under this Act in 1976, as compared with 1975.

Of the total of 6 166 examined, 5 715 were new applicants and 451 were re-examinees. In addition, Provisional Certificates were issued to 464 persons in isolated country areas.

4.2 *Analysis of Examinations*

Particulars of examinations are as follows:—

4.2.1 *New Applicants*

Normal	5 710
Silicosis early	—
Silicosis early with tuberculosis	—
Tuberculosis	—
Other conditions	5
Total	5 715

4.2.2 *Re-Examinees*

Normal	451
Silicosis early	—
Silicosis early with tuberculosis	—
Tuberculosis	—
Other conditions	—
Total	451

These men had previously been examined and some were in the industry prior to this examination.

4.3 *Health Certificates Issued to New Applicants and Re-Examinees*

The following health certificates were issued under the Mines Regulation Act:—

Initial Certificates (Form 2)	6 161
Temporary Rejection Certificates (Form 3)	—
Rejection Certificates (Form 4)	5
Re-Admission Certificates (Form 5)	—
Special Certificates (Form 9)	—
Total	6 166

5. *Miner's Phthisis Act*

The amount of compensation paid during the year was $4 964.57 compared with $5 273.40 for the previous year.

The number of beneficiaries under the Act as on 31/12/76 was 23, being 2 ex-miners and 21 widows.

V. T. FOSTER,
Superintendent, Mine Workers' Relief Act,
and Chairman, Miner's Phthisis Board.

17th March, 1977.

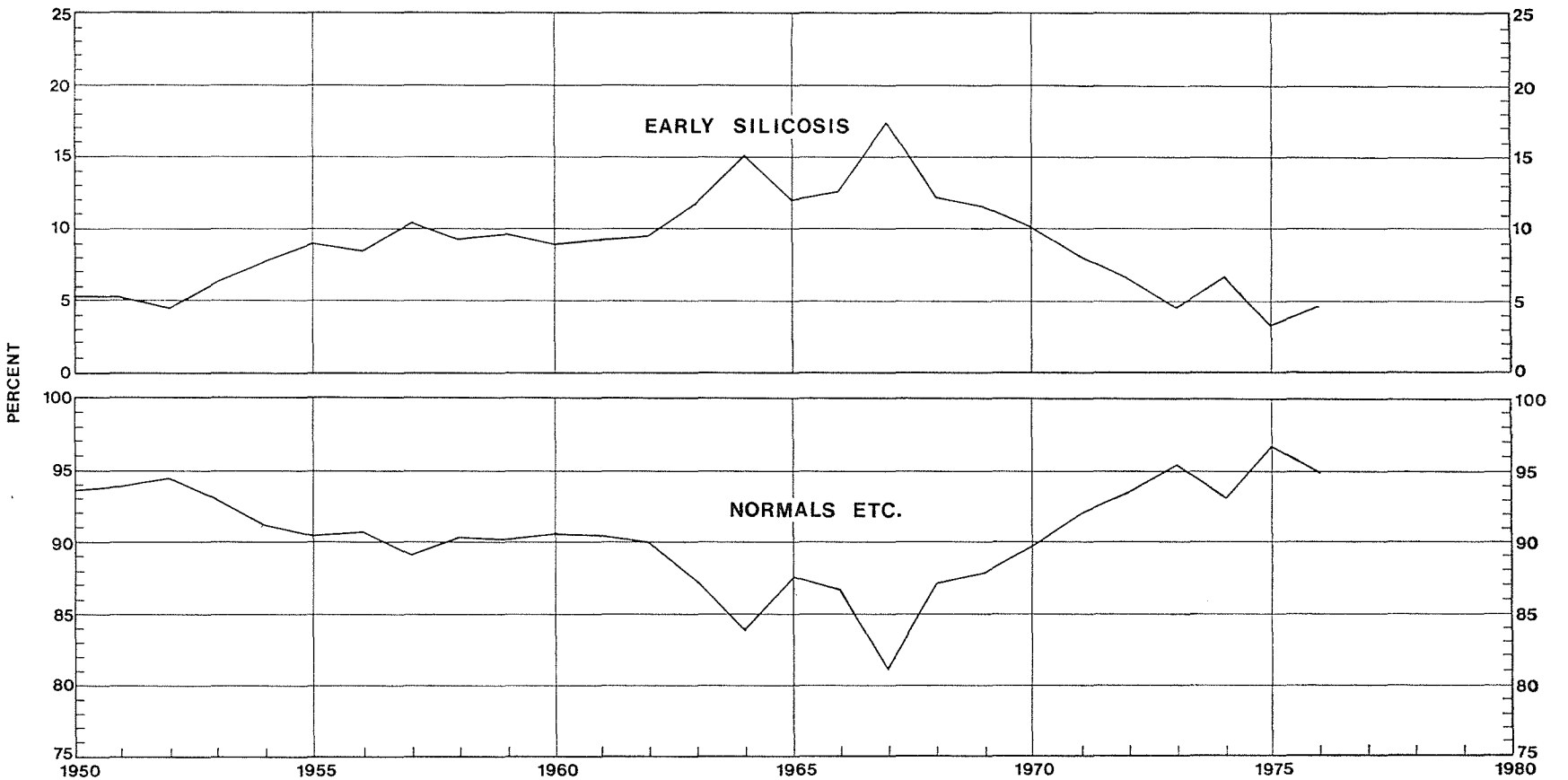
TABLE SHOWING RESULTS OF PERIODICAL EXAMINATION OF MINE WORKERS FROM INCEPTION OF EXAMINATIONS (1925)

Year	Normal		Silicosis Early				Silicosis Advanced					Silicosis plus Tuberculosis					Tuberculosis Only		Asbestosis									Total
	Total	Per Cent.	Previously reported as normal etc.	Previously reported as Silicosis early	Total	Per Cent.	Previously reported as normal etc.	Previously reported as Silicosis early	Previously reported as Silicosis advanced	Total	Per Cent.	Previously reported as normal etc.	Previously reported as Silicosis early	Previously reported as Silicosis advanced	Total	Per Cent.	Total	Per Cent.	Asbestosis early previously normal	Asbestosis early previously asbestosis early	Asbestosis advanced previously normal	Asbestosis advanced previously asbestosis early	Asbestosis advanced previously asbestosis advanced	Asbestosis plus tuberculosis previously normal	Asbestosis plus tuberculosis previously asbestosis	Total	Per Cent.	
1925 1926	3 239	80·5	....	....	459	11·4	....	....	....	183	4·5	....	....	....	131	3·3	11	0·3	....	....	....	....	....	....	....	....	....	4 023
1927	3 116	83·6	33	348	381	10·2	8	....	85	93	2·5	39	27	62	128	3·4	10	0·3	....	....	....	....	....	....	....	....	....	3 728
1928	2 977	85·5	59	303	362	10·4	3	16	79	98	2·8	18	14	10	42	1·2	4	0·1	....	....	....	....	....	....	....	....	....	3 483
1929	2 120	81·9	102	224	326	12·6	....	34	60	94	3·6	8	14	19	41	1·6	7	0·3	....	....	....	....	....	....	....	....	....	2 588
1930	2 785	81·9	136	247	383	11·3	2	22	43	67	2·0	8	60	46	114	3·3	50	1·5	....	....	....	....	....	....	....	....	....	3 399
1931	2 530	84·0	94	252	346	11·5	....	18	35	53	1·8	4	35	19	58	1·9	25	·8	....	....	....	....	....	....	....	....	....	3 012
1932	3 835	89·5	35	338	373	8·7	....	6	47	53	1·2	3	9	4	16	·4	8	·2	....	....	....	....	....	....	....	....	....	4 285
1933	2 920	86·5	57	322	379	11·2	1	15	44	60	1·8	2	9	4	15	·4	3	·1	....	....	....	....	....	....	....	....	....	3 377
1934	5 140	92·4	54	315	369	6·6	1	24	12	37	·7	6	6	....	12	·2	5	·1	....	....	....	....	....	....	....	....	....	5 563
1935	4 437	92·3	35	303	338	7·0	....	24	2	26	·6	....	5	....	5	·1	2	·0	....	....	....	....	....	....	....	....	....	4 808
1936	6 972	94·7	29	323	352	4·8	1	15	4	20	·3	3	8	....	11	·1	8	·1	....	....	....	....	....	....	....	....	....	7 363
1937	7 487	95·4	15	319	334	4·3	....	14	4	18	·2	1	10	....	11	·1	2	·0	....	....	....	....	....	....	....	....	....	7 852
1938	6 833	95·7	13	266	279	3·9	....	15	2	17	·2	1	8	....	9	·1	3	·0	....	....	....	....	....	....	....	....	....	7 141
1939	6 670	95·6	18	264	282	4·0	....	7	3	10	·1	1	9	1	11	·2	2	·0	....	....	....	....	....	....	....	....	....	6 975
1940	7 023	96·2	12	245	257	3·5	....	10	1	11	·2	....	4	....	4	·0	4	·0	....	....	....	....	....	....	....	....	....	7 299
1941	6 840	95·8	32	248	280	3·9	....	11	3	14	·2	....	....	....	....	....	7	·1	....	....	....	....	....	....	....	....	....	7 141
1942	5 469	93·9	61	264	325	5·6	....	20	5	25	·4	....	2	....	2	·0	3	·1	....	....	....	....	....	....	....	....	....	5 824
1943	3 932	91·5	63	262	325	7·6	....	25	7	32	·7	....	5	....	5	·1	4	·1	....	....	....	....	....	....	....	....	....	4 298
1944	4 079	91·5	70	270	340	7·5	....	21	14	35	·8	1	7	....	8	·2	6	·1	....	....	....	....	....	....	....	....	....	4 468
1945	3 071	92·1	54	166	220	6·6	....	26	10	36	1·1	3	2	....	5	·2	2	·1	....	....	....	....	....	....	....	....	....	3 334
1946	5 294	94·4	89	172	261	4·7	1	36	2	39	·7	3	1	2	6	·1	6	·1	....	....	....	....	....	....	....	....	....	5 606
1947	6 021	93·3	101	237	338	5·2	....	49	9	58	1·0	13	11	1	25	·3	8	·1	....	....	....	....	....	....	....	....	....	6 450
1948	4 827	94·0	24	239	263	5·1	....	18	17	35	·7	1	3	....	4	·1	5	·1	....	....	....	....	....	....	....	....	....	5 134
1949	5 162	94·0	24	239	263	4·8	....	20	31	51	1·0	3	2	1	6	·1	7	·1	....	....	....	....	....	....	....	....	....	5 489
1950	5 077	93·6	14	269	283	5·2	....	14	41	55	1·0	....	1	2	3	·1	8	·2	....	....	....	....	....	....	....	....	....	5 426
1951	4 642	93·9	13	248	261	5·3	....	9	20	29	·6	....	4	2	6	·1	4	·1	....	....	....	....	....	....	....	....	....	4 942
1952	5 073	94·6	8	234	242	4·5	....	4	31	35	·6	....	2	....	2	·1	7	·1	....	....	....	....	....	....	....	....	....	5 359
1953	4 474	93·03	74	225	299	6·22	....	8	24	32	·6	....	2	....	2	·1	2	·1	....	....	....	....	....	....	....	....	....	4 809
1954	5 142	91·33	154	275	429	7·62	....	22	21	43	·76	1	6	2	9	·1	7	·1	....	....	....	....	....	....	....	....	....	5 630
1955	4 559	90·40	63	286	449	8·90	....	9	22	31	·62	1	1	1	3	·06	1	·02	Segregation of asbestosis diagnoses commenced in 1959									5 043
1956	4 600	90·78	25	401	426	8·41	....	8	25	33	·65	1	3	....	4	·08	4	·08	....	....	....	....	....	....	....	....	....	5 067
1957	3 925	89·08	30	424	454	10·30	....	8	10	18	·41	1	4	....	5	·12	4	·09	....	....	....	....	....	....	....	....	....	4 406
1958	5 154	90·20	46	483	529	9·26	....	15	9	24	·42	....	6	....	6	·10	1	·02	....	....	....	....	....	....	....	....	....	5 714
1959	5 242	90·10	66	485	551	9·47	....	9	....	....	·15	1	5	1	7	·12	3	·05	6	....	....	....	....	....	....	6	....	5 818
1960	5 214	90·54	50	473	523	9·08	....	5	....	5	·09	2	9	....	11	·19	3	·05	2	....	....	....	....	....	1	....	3	5 759
1961	5 188	90·18	54	479	533	9·26	....	13	....	13	·23	2	3	....	5	·09	3	·05	5	5	....	1	....	....	....	11	·19	5 753
1962	5 183	89·98	50	499	549	9·53	1	10	....	11	·19	1	5	....	6	·10	1	·02	2	7	....	1	....	....	....	10	·18	5 760
1963	4 795	87·21	188	451	639	11·62	....	22	....	22	·40	7	6	....	13	·24	3	·05	10	11	....	4	....	1	....	26	·47	5 498
1964	3 484	83·85	64	561	625	15·04	....	9	1	10	·24	....	1	....	1	·02	2	·05	13	17	....	2	....	....	1	33	·80	4 155
1965	3 770	87·39	53	459	512	11·87	....	6	....	6	·14	....	1	....	1	·02	5	·12	5	15	....	....	....	....	....	20	·46	4 314
1966	3 411	86·56	26	469	495	12·56	....	14	....	14	·36	3	1	....	4	·10	1	·02	4	12	....	....	....	....	....	16	·40	3 941
1967	1 644	81·03	19	332	351	17·30	....	7	1	8	·39	....	2	....	2	·10	5	·24	8	6	....	5	....	....	....	19	·94	2 029
1968	3 364	86·93	39	431	470	12·14	....	18	3	21	·54	....	1	1	2	·05	1	·03	5	4	....	3	....	....	....	12	·31	3 870
1969	3 406	87·77	36	412	448	11·55	....	13	1	14	·36	....	1	....	1	·03	1	·01	2	7	....	2	....	....	....	11	·28	3 881
1970	3 841	89·73	30	400	430	10·04	....	6	....	6	·14	....	1	....	1	·02	3	·07	....	....	....	....	....	....	....	....	....	4 281
1971	3 915	91·80	15	327	342	8·02	....	5	2	7	·16	....	....	....	....	....	1	·02	....	....	....	....	....	....	....	....	....	4 265
1972	4 647	93·30	20	308	328	6·55	....	5	2	7	·15	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	4 982
1973	5 078	95·27	27	215	242	4·54	....	4	3	7	·13	....	....	....	....	....	2	·04	....	1	....	....	....	....	....	1	·02	5 330
1974	4 803	93·02	31	310	341	6·60	....	4	4	8	·15	....	2	....	2	·04	....	....	3	7	....	....	....	....	....	10	·19	5 164
1975	8 394	96·53	33	242	275	3·16	....	11	3	14	·16	....	....	....	....	....	1	·01	4	7	1	....	....	....	....	12	·14	8 696
1976	5 495	94·94	20	250	270	4·67	....	7	5	12	·21	....	....	....	....	....	....	....	1	9	....	....	....	....	....	10	·18	5 788

PERIODICAL EXAMINATION OF MINE WORKERS

GRAPH Nº1

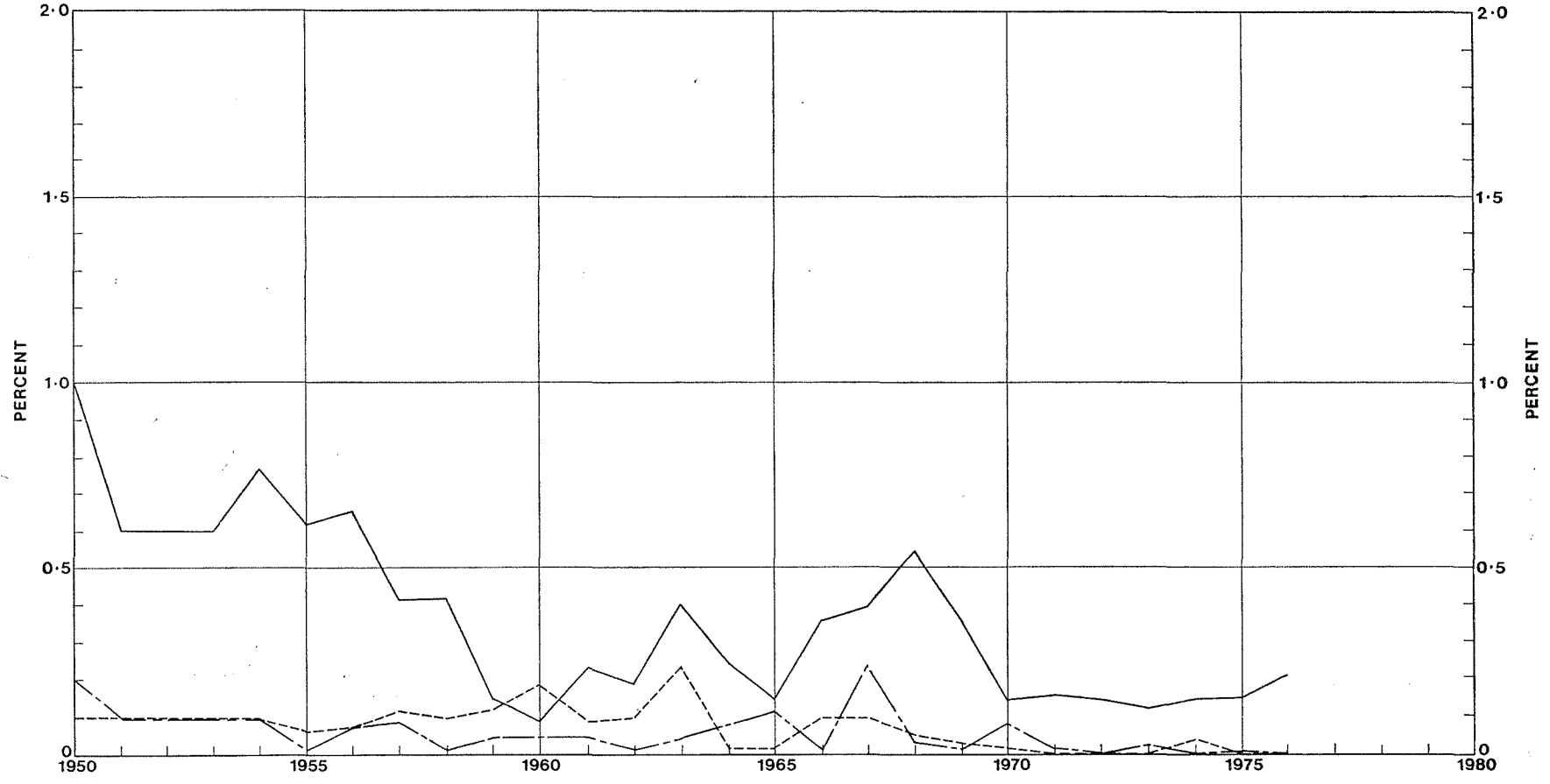
SHOWING PERCENTAGES OF NORMALS AND EARLY SILICOTICS FROM 1950 ONWARDS



PERIODICAL EXAMINATION OF MINE WORKERS

GRAPH Nº 2

SHOWING PERCENTAGES OF SILICOSIS ADVANCED, SILICOSIS PLUS TUBERCULOSIS AND TUBERCULOSIS ONLY, FROM 1950 ONWARDS



MINING STATISTICS

to 31st December, 1976

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TABLE I

PRODUCTION OF GOLD AND SILVER AS REPORTED TO THE MINES DEPARTMENT DURING 1976.

(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 1976					Total Production				
			Alluvial	Dollied and Specimens	Ore treated	Gold therefrom	Silver	Alluvial	Dollied and Specimens	Ore treated	Gold therefrom	Silver
			kg	kg	Tonnes	kg	kg	kg	kg	Tonnes	kg	kg
Pilbara Goldfield.												
MARBLE BAR DISTRICT.												
Bamboo Creek	G.M.L. 45/1118	Kitchener	....	....	142·00	2·726	....	....	....	3 294·22	93·066	·110
	1203	Mt. Prophecy	....	....	120·00	1·370	....	....	....	5 788·76	84·574	3·536
Marble Bar	1450	Betty Boo	·027	....	....	....	....	·027	....	1 328·00	2·768	....
	1487	Charger	·292	....	....	....	....	·292	....	1 219·00	2·847	....
	1331	General	....	....	152·00	·292	....	....	....	789·18	1·299	....
	927	Halleys Comet	....	....	....	11·016	2·974	....	....	6 462·06	264·700	30·481
	1390	Homeward Bound	....	....	88·00	·072	....	....	....	88·00	·072	....
	1209	Ironclad	....	....	323·00	·494	....	....	....	1 967·23	3·899	·006
	(1494)	Jack Jack	....	....	224·00	·234	....	....	....	224·00	·234	....
	1458	Kangaroo	....	....	41·50	·788	....	....	....	368·49	5·500	....
		Sundry Claims	....	·500	....	....	....	2·086	8·552	22 851·39	407·098	·341
Pilgangoora		Sundry Claims	....	....	13·00	·758	....	5·010	1·483	748·97	14·191	·007
NULLAGINE DISTRICT.												
Middle Creek	G.M.L. 46/231	Mulga Mines Pty. Ltd.	....	....	15 164·00	146·192	....	....	....	15 164·00	146·192	....
	etc.	Prior to transfer to present holders	....	....	....	....	....	....	....	64 200·43	1 187·748	·342
Peak Hill Goldfield.												
Peak Hill	G.M.L. 52/621	Atlantic North	....	·409	....	....	....	....	1·222	....	....	....
	642	Jubilee	....	....	300·00	·653	....	....	....	300·00	·653	....
	609	Morning Star	·250	·218	....	....	....	·250	·812	....	·038	....
	611	Mount Pleasant	....	....	460·00	1·646	....	....	....	518·50	1·843	....
	613	Mt. Leo	....	....	415·00	1·743	....	....	....	415·00	1·743	....
	610	North Star	·260	....	....	....	....	·260	....	....	....	....
		Sundry Claims	....	....	20·00	·273	....	1·913	15·139	35 952·85	281·168	·166
East Murchison Goldfield.												
WILUNA DISTRICT.												
Corboys	G.M.L. 53/701	Rumble Rest	....	....	17·00	·356	....	....	....	17·00	·356	....

BLACK RANGE DISTRICT.

Montague	G.M.L. 57/2261	Montague Boulder	....	....	....	....	....	....	....	97·00	·704	....	....	....	97·00	·704	....
		State Battery—Sandstone	....	....	....	....	....	....	....	....	*11·216	*·028	....	....	295·16	*745·341	1·926

Murchison Goldfield.

CUE DISTRICT.

Big Bell	G.M.L. 20/2308	Mary Bell	....	....	....	....	....	....	....	6·00	·178	....	....	....	6·00	·178	....
Cue		Sundry Claims	....	....	....	....	....	....	·643	280·00	1·147	....	7·867	28·619	48 540·18	640·913	·178
Reedys	2381	Bronzewing	....	....	....	....	....	....	....	10·00	·368	....	....	....	10·00	·368	....

MEEKATHARRA DISTRICT.

Meekatharra	G.M.L. 51/2186	Est	....	....	....	....	....	....	....	410·00	8·183	....	....	....	410·00	8·183	....
	2068	Halcyon	....	....	....	....	....	....	....	300·00	·561	....	....	....	3 035·20	6·357	....
	2015	Haveluck	....	....	....	....	....	....	....	1 786·00	3·716	....	....	....	15 768·51	30·437	....
	2139	Ingliston Gold Mine	....	....	....	....	....	....	....	320·00	1·328	....	....	....	338·00	1·611	....
	2017	The Lucky Cut	....	....	....	....	....	....	....	30·00	·038	....	....	....	233·21	·274	....
		Sundry Claims	....	....	....	....	....	....	·474	....	....	....	8·704	43·777	33 251·41	367·014	·407

DAY DAWN DISTRICT.

		L.T.T. 21/15 (2452 h.) Gray, A .... }	....	....	....	....	*4·578	....	....	....	....	4·578	....
		L.T.T. 21/17 (2483 h.) Gray, A .... }	....										

MOUNT MAGNET DISTRICT.

Mt. Magnet	G.M.L. 58/1282	Hill 50 Goldmine N.L.	....	....	....	....	33·762	2·874	....	....	3 219 720·49	42 207·729	2 147·058
	etc.																	
	1782	Joanne	....	....	....	....	230·00	·339	....	....	....	230·00	·339	....
		Sundry Claims	·190	·726	842·00	·429	....	5·103	83·880	64 681·70	944·467	·918

Yalgoo Goldfield.

Goodingnow	G.M.L. 59/1063	Ark	....	....	441·00	9·195	....	....	·388	5 091·41	116·924	....
	1242	Carnation	....	....	212·00	·729	....	....	....	720·78	6·585	....
	1244	Sweet William Extended	....	....	50·00	·268	....	....	....	105·48	·595	....
Mt. Gibson		Sundry Claims	....	....	20·00	·037	....	·123	1·391	1 191·09	15·655	·031

Mt. Margaret Goldfield.

MT. MORGANS DISTRICT.

Redcastle	G.M.L. 39/675	Agau	....	....	35·00	·102	....	....	....	135·00	·347	....

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 1976					Total Production				
			Alluvial	Dollied and Specimens	Ore treated	Gold therefrom	Silver	Alluvial	Dollied and Specimens	Ore treated	Gold therefrom	Silver
			kg	kg	Tonnes	kg	kg	kg	kg	Tonnes	kg	kg
Mt. Margaret Goldfield—cont.												
MOUNT MALCOLM DISTRICT.												
Leonora	G.M.L. 37/2045	Gray Lode	....	....	90·00	·146	....	....	....	90·00	·146	....
	2050	Jasper Mine	....	....	35·00	·182	....	....	....	35·00	·182	....
	1948	Jessie Alma	....	....	100·00	·046	....	....	....	354·01	·175	....
	1907	Longs Lucky Lode	....	....	70·00	·298	....	....	....	70·00	·298	....
	2058	Picnic	....	....	270·00	·498	....	....	....	270·00	·498	....
	1900	Royal Harry	....	....	10·00	·039	....	....	....	10·00	·039	....
	1762	Sons of Gwalia	....	·340	2 006·00	5·366	....	....	·676	4 730·07	11·529	....
	1860	Tower Hill	....	....	2 595·00	4·546	....	....	....	5929·61	13·652	....
	1906	Two Glads	....	....	1 665·00	8·227	....	....	....	8 684·28	55·165	....
	2036	Victor	....	....	25·00	·112	....	....	....	35·00	·191	....
		Sundry Claims	....	....	261·00	3·362	....	1·207	12·211	25 949·52	415·849	·833
Wilsons Patch		Sundry Claims	....	....	44·00	·193	....	·145	1·694	1 932·03	46·080	·035
		State Battery—Leonora	....	....	....	*17·853	·243	....	....	92·46	*87·965	*1·819
MOUNT MARGARET DISTRICT.												
Laverton	G.M.L. 38/2746	Butterfly	....	....	12·00	·444	....	....	....	12·00	·444	....
	(2772)	Golden Hill	....	....	70·00	·388	....	....	....	449·00	·762	....
		Sundry Claims	....	....	24·00	·037	....	6·705	46·434	18 024·38	289·555	342·694
North Coolgardie Goldfield.												
MENZIES DISTRICT.												
Goongarrie	G.M.L. 29/5986	Jacks Find	....	....	40·00	·405	....	....	....	40·00	·405	....
		Sundry Claims	....	....	166·00	·585	....	1·445	66·699	3 353·84	108·712	....
Menzies	5815	Espacia	....	....	562·00	2·075	....	....	....	1 019·60	5·149	....
	5814	Lucky Five	....	....	66·00	·099	....	....	....	66·00	·099	....
		State Battery—Menzies	....	....	....	*13·458	*2·538	....	·237	20·32	132·299	34·657
ULARRING DISTRICT.												
Davyhurst	G.M.L. 30/1326	Piano Rag	....	....	45·00	·080	....	....	....	186·00	·335	....
	1221	Emerald	....	....	99·40	·820	....	....	....	338·60	2·561	....
Mulline	1107	Ajax West	....	....	244·00	2·242	....	....	·043	8 812·58	210·099	....
Mulwarrie	1113	Oakley	....	....	100·00	1·039	....	....	....	5 952·05	284·319	10·387
NIAGARA DISTRICT.												
Kookynie	G.M.L. (40/988)	Red Lake	....	....	220·00	·087	....	....	....	220·00	·087	....
		Sundry Claims	....	....	180·00	·303	....	1·895	3·370	10 554·49	220·209	·130

YERILLA DISTRICT.

Yarri	G.M.L. 31/1449	Lucky Hope	....	....	52·00	·259	....	....	52·00	....	·259	....
	1448	Porphyry	....	....	429·00	1·746	....	....	....	71 457·91	320·496	8·147
		State Battery—Yarri	....	....	....	*1·232	*·031	....	....	280·94	*289·229	*·673

Broad Arrow Goldfield.

Broad Arrow	G.M.L. 24/2409	Barbara	....	....	3·00	·033	....	....	....	3·00	·033	....
	2346	Sunday Eve	....	....	68·00	·442	....	....	....	376·37	9·595	....
Ora Banda		Sundry Claims	....	·174	32·00	·253	....	....	14·868	18 511·93	164·735	....
Paddington	2356	Colac	....	....	158·00	·937	....	....	....	271·00	3·633	....
Smithfield		Sundry Claims	....	·093	1 079·00	2·429	....	....	3·959	5 601·26	46·454	·003
		L.T.T. 24/40 (1872H) Aurex Pty. Ltd.	....	....	....	*35·066	*4·126	....	·079	....	*67·063	*8·192

North-East Coolgardie Goldfield.

KANOWNA DISTRICT.

Six Mile		Sundry Claims	....	·677	208·00	1·885	....	....	2·434	992·13	9·121	....

KURNALPI DISTRICT.

Kurnalpi		Sundry Claims	....	....	90·00	·196	....	10·081	22·884	4 856·36	74·456	....

East Coolgardie Goldfield.

EAST COOLGARDIE DISTRICT.

Boorara	G.M.L. 26/6658	Waterfall	....	·088	....	....	....	....	·088	433·34	5·468	....
Boulder	5780 etc.	Great Boulder Gold Mines N.L.	....	....	17 561·00	56·117	42·179	....	·047	17 073 430·50	219 529·721	58700·166
	5345 etc.	Kalgoorlie Lake View Pty. Ltd.	....	....	21 784·00	508·961	164·527	....	....	1 108 024·40	6 250·957	2 372·444
		Prior to transfer to present holders	....	....	....	....	....	....	26·700	62 162 730·32	732 838·733	106492·417
	(6883)	The Argonauts	....	....	27·00	·042	....	....	....	27·00	·042	....
Hampton Plains	P.P.L. 277 Loc. 50	Kalgoorlie Lake View Pty. Ltd. (Pernatty)	....	....	639·00	9·219	....	....	....	4 070·88	30·366	....
		Prior to transfer to present holders	....	....	....	....	....	....	....	50 452·01	149·695	·064
	P.P.L. 488 Loc. 48	Lethlean, L.	....	....	5·00	·105	....	....	....	26·59	1·417	....
Kalgoorlie	G.M.L. 26/6620	Golden Goose	....	....	88·00	·157	....	....	....	149·47	·245	....
	6692	Golden Pennies	....	·996	1 683·00	4·139	....	....	4·271	1 713·48	4·521	....
	6630	Golden Star	....	....	75·00	·408	....	....	....	2 018·37	3·913	....
	6563 etc.	Kalgoorlie Lake View Pty. Ltd. (Mt. Charlotte)	....	....	713 647·00	2891·749	526·326	....	....	2 298 022·38	9 096·547	526·326
		Prior to transfer to present holders	....	....	....	....	....	....	·178	4 947 601·36	21 751·229	5·336
	6485	Maritana Hill	....	....	87·00	·095	....	....	....	6 930·95	21·103	....
Wombola	6844	Daisy Leases	....	....	562·00	16·465	....	....	·082	29 223·50	849·895	27·519
	6845											
	6844	Daisy	....	....	....	....	....	....	....	6 383·06	156·511	....
	6845	Happy-Go-Lucky	....	....	....	....	....	....	....	2 108·55	52·125	....
	(5689)	Haoma	....	....	145·00	·008	....	....	....	7 991·89	245·887	31·464
	6635	Hodad	....	....	45·00	·317	....	....	....	3 781·26	18·045	1·611
	6614	Logans Gold Mine	....	....	172·00	·380	....	....	5·227	8 159·20	47·095	·039
	6877	Lurgan	....	....	401·00	2·906	....	....	....	401·00	2·906	....
		Sundry Claims	....	·123	416·00	·851	....	....	22·459	29 962·31	488·101	·006
		State Battery—Kalgoorlie	....	....	....	*·026	....	....	....	396·97	*1 317·932	*24·938
		L.T.T. 26/122 (2555H) Smith, F. R.	....	....	....	*1·525	....	....	....	....	*1·525	....

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 1976					Total Production				
			Alluvial	Dollied and Specimens	Ore treated	Gold therefrom	Silver	Alluvial	Dollied and Specimens	Ore treated	Gold therefrom	Silver
			kg	kg	Tonnes	kg	kg	kg	kg	Tonnes	kg	kg
East Coolgardie Goldfield—cont.												
BULONG DISTRICT.												
Balagundi		Sundry Claims	....	....	114·00	·084	....	·109	10·158	1 088·43	17·132	....
Randalls	G.M.L. (25/1356)	Majestic	....	·005	....	....	....	....	·005	796·86	1·171	....
Coolgardie Goldfield.												
COOLGARDIE DISTRICT.												
Bonnievale	G.M.L. 15/5622	Lucky Hit	·257	....	....	....	....	·257	·102	1 269·04	27·492	....
	6151	Melva Maie	....	....	33·50	·247	....	....	·084	1 163·38	3·493	....
	5890	Rayjax	....	....	102·00	2·980	....	....	1·190	1 999·09	59·030	·159
		Sundry Claims	....	....	64·60	·069	....	....	12·075	12 217·69	183·082	·034
Burbanks	6267	Grosmont	....	....	1 706·50	2·864	....	....	....	3 365·00	6·887	....
Cave Rocks		Sundry Claims	....	....	95·00	·252	....	....	1·555	5 023·74	35·004	....
Coolgardie	6315	Bugs Bunny	....	....	508·00	·760	....	....	....	508·00	·760	....
	6059	Empress	....	....	205·00	·440	....	....	....	205·00	·440	....
	6309	Greens Find	....	....	63·00	·087	....	....	....	63·00	·087	....
	(6276)	Hangover Hill	....	·068	....	....	....	....	·157	440·00	·630	....
	6314	McPhersons Reward	....	....	122·00	·245	....	....	....	122·00	·245	....
	6154	Monkani	....	....	3 926·00	5·634	....	....	....	11 711·92	17·221	....
	6047	Prejudice	....	....	315·00	1·051	....	....	....	568·28	1·707	....
	6176	Three Mile	....	·021	81·00	·047	....	....	·038	1 091·15	1·494	....
		Sundry Claims	....	....	236·00	·715	....	7·375	95·544	93 135·12	942·343	·059
Higginsville	5647	Fair Play Gold Mine	....	....	2 710·00	4·548	....	·137	1·950	36 718·04	111·480	·001
	6061	Two Boys	....	....	313·00	·483	....	....	9·074	4 292·64	36·417	....
		Sundry Claims	....	....	46·00	·057	....	....	5·824	4 008·34	62·399	....
Kambalda	M.C. 152 etc.	Western Mining Corporation	....	....	....	76·391	296·652	....	22·003	32·00	176·293	731·584
		Sundry Claims	....	....	44·00	·219	....	....	....	175·50	·837	....
Ryans Find	G.M.L. 15/5999	Consolidated Gold Mining Areas N.L.	....	....	15·00	·488	....	....	....	1 309·56	31·642	....
		Prior to transfer to present holders	....	....	....	....	....	....	97·256	245·63	76·812	....
		L.T.T. 15/47 (2574H) Kean, R.	....	....	80·00	·161	....	....	....	80·00	·161	....
KUNANALLING DISTRICT.												
Carbine	G.M.L. 16/1082	Hawkins Find	....	·121	1 719·00	4·432	·065	....	·252	1 810·00	4·638	·065
Dunnsville	1124	Scotch Try	....	....	232·00	·181	....	....	....	232·00	·181	....
		Sundry Claims	....	·114	24·00	·219	....	·653	32·277	3 284·29	66·656	....
Kintore	(1102)	Davidson	....	....	24·00	·038	....	....	....	24·00	·038	....
	1059	New Haven	....	·082	514·00	1·062	·011	....	·237	3 196·57	11·263	·011
		Sundry Claims	....	....	39·00	·096	....	3·481	3·194	5 949·63	84·565	....
Kunanalling	1052	Catherwood	....	....	196·00	·157	....	....	....	1 132·30	2·568	....
	1111	Goldfarmer	....	....	458·00	·526	....	....	....	458·00	·526	....
	1112	Last Chance	....	....	50·00	·420	....	....	....	94·00	·771	....
		(L.T.T. 16/30-32 (2486-2488H)) Woinar, B. A.	....	....	43·00	·052	....	....	....	43·00	·052	....

Yilgarn Goldfield.

Bullfinch		Sundry Claims	....	....	142·00	·677	....	·263	1·741	8 015·48	135·177	·755
Golden Valley	G.M.L. 77/4427	W.A. Gold Development N.L.	....	....	....	·821	....	....	·173	9 883·15	128·093	1·400
Kennyville	4750	Battler	....	....	55·00	·043	....	....	....	87·00	·081	....
Marvel Loch	4434	Cornwall	....	....	22·00	·055	....	....	....	18 204·23	77·142	16·426
	(3724)	Frances Firness	....	....	5 527·00	58·539	3·291	....	20·110	31 190·43	394·50	12·834
	4646	Jacoletti South	....	....	454·00	·640	....	....	....	454·00	·640	....
	4631	Marvel Loch	....	....	300·00	2·278	....	....	....	1 382·00	23·086	....
	4230	May Queen	....	....	168·00	1·942	....	....	....	546·59	3·803	....
	4807	Robyn Louise	....	....	116·00	·290	....	....	....	116·00	·290	....
	4444	Try Again	....	....	51·00	·084	....	....	....	51·00	·084	....
		Sundry Claims	....	....	42·00	·124	....	·353	25·172	39 772·25	434·798	2·675
Mt. Jackson	4725	Numeralla	....	....	58·00	·444	....	....	....	189·00	1·043	....
Mt. Palmer	4250	Palmerston	....	....	121·00	·128	....	·063	·052	992·26	5·798	·059
Parkers Range	4508	Buffalo	....	....	43·00	·206	....	....	·322	1 579·50	8·028	·175
	4719	Golden Rod	....	....	228·00	2·921	....	....	....	336·00	3·492	....
	4765	Ripper	....	....	73·00	·815	....	....	....	73·00	·815	....
	4626	The Australia	....	....	86·00	·549	....	....	·111	182·00	·929	....
	4621	The Dollar	....	....	24·00	·154	....	....	....	225·18	1·713	....
Southern Cross	4634	Frasers	....	....	443·00	3·934	....	....	195·626	8 726·58	169·195	....
		State Battery—Marvel Loch	....	....	....	*4·707	*6·811	....	....	149·36	*184·163	*89·777
		L.T.T. 77/44 (2303H) Beavis, R. J.	....	....	....	*7·799	....	....	....	....	*7·799	....
		L.T.T. 77/105 (2594H) Casas, B.	....	*·130	....	*	....	*·130	....	....	....	....
		L.T.T. 77/103 (1948H) Casas, B.	....	*·210	....	*·143	....	....	*·210	....	*·143	....
		L.T.T. 77/104 (2588H) Wright, L.	....	....	....	*·320	....	....	....	....	*·320	....

Dundas Goldfield.

Beete	G.M.L. 63/2044	Beete	....	....	20·00	·464	....	....	6·106	338·01	10·897	1·710
Dundas	2128	Maybe	....	....	15·00	·119	....	·27	·270	61·74	·611	·013
Norseman	1936 etc.	Central Norseman Gold Corporation N.L.	....	....	137 902·00	3 039·932	911·954	....	....	5 736 072·18	79 266·284	53 096·161
		Prior to transfer to present holders	....	....	....	....	....	....	51·735	70 940·22	1 489·610	513·482
		Sundry Claims	....	....	55·00	·058	....	32·729	112·653	50 839·01	704·898	7·623
		State Battery—Norseman	....	....	....	*4·368	*·683	....	....	434·76	*830·642	*37·003

TABLE II

Production of Gold and Silver from all Sources, showing in kilograms the output as reported to the Mines Department during the year 1976.

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
		kg	kg	Tonnes	kg	kg	kg	kg	kg	Tonnes	kg	kg	kg
Kimberley		....	....	....	....	....	....	....	....	....	....	....	....
West Kimberley		....	....	....	....	....	....	....	....	....	....	....	....
Pilbara	Marble Bar	·319	·500	1 103·50	17·750	18·569	2·974	·319	·500	16 267·50	163·942	164·761	2·974
	Nullagine	....	....	15 164·00	146·192	146·192	....						
West Pilbara		....	....	....	....	....	....	....	....	....	....	....	....
Ashburton		....	....	....	....	....	....	....	....	....	....	....	....
Gascoyne		....	....	....	....	....	....	....	....	....	....	....	....
Peak Hill		....	....	....	....	....	....	·510	·627	1 195·00	4·315	5·452	....
East Murchison	Lawlers	....	....	....	....	....	....						
	Wiluna	....	....	17·00	·356	·356	....	....	....	114·00	12·276	12·276	·028
	Black Range	....	....	97·00	11·920	11·920	·028						
Murchison	Cue	....	·643	296·00	1·693	2·336	....						
	Meekatharra	....	·474	2 846·00	13·826	14·300	....						
	Day Dawn	....	....	....	4·578	4·578	....	·190	1·843	4 214·00	54·627	56·660	2·874
	Mt. Magnet	·190	·726	1 072·00	34·530	35·446	2·874						
Yalgoo		....	....	....	....	....	....	....	....	723·00	10·229	10·229	....
Mt. Margaret	Mt. Morgans	....	....	35·00	·102	·102	....						
	Mt. Malcolm	....	·340	7 171·00	40·868	41·208	·243	....	·340	7 312·00	41·839	42·179	·243
	Mt. Margaret	....	....	106·00	·869	·869	....						
North Coolgardie	Menzies	....	....	834·00	16·622	16·622	2·538						
	Ularring	....	....	488·40	4·181	4·181	....						
	Niagara	....	....	400·00	·390	·390	....	....	....	2 203·40	24·430	24·430	2·569
	Yerilla	....	....	481·00	3·237	3·237	·031						
Broad Arrow		....	....	....	....	....	....	....	·267	1 340·00	39·160	39·427	4·126
North East Coolgardie	Kanowna	....	·677	208·00	1·885	2·562	....						
	Kurnalpi	....	....	90·00	·196	·196	....	....	·677	298·00	2·081	2·758	....
East Coolgardie	East Coolgardie	....	1·207	757 337·00	3 493·470	3 494·677	733·032						
	Bulong	....	·005	114·00	·084	·089	....	....	1·212	757 451·00	3 493·554	3 494·766	733·032
Coolgardie	Coolgardie	·257	·089	10 665·60	97·738	98·084	296·652						
	Kunanalling	....	·317	3 299·00	7·183	7·500	·076	·257	·406	13 964·60	104·921	105·584	296·728
Yilgarn		....	....	....	....	....	....	....	·340	7 953·00	87·613	87·953	10·102
Dundas		....	....	....	....	....	....	....	....	137 992·00	3 044·941	3 044·941	912·637
Phillips River		....	....	....	....	....	....	....	....	....	....	....	....
South West Mineral Field		....	....	....	....	....	....	....	....	....	....	....	....
Northampton Mineral Field		....	....	....	....	....	....	....	....	....	....	....	....
State Generally		....	....	....	....	....	....	....	....	....	....	....	....
Outside Proclaimed Goldfield		....	....	....	....	....	....	....	....	....	....	....	....
Total								1·276	6·212	951 027·50	7 083·928	7 091·416	1 965·313

TABLE III

Return showing total production reported to the Mines Department to 31st December, 1976.

Goldfield	District	District: Alluvial	District: Dollied and Specimens	District: Ore Treated	District: Gold Therefrom	District: Total Gold	District: Silver	Goldfield: Alluvial	Goldfield: Dollied and Specimens	Goldfield: Ore Treated	Goldfield: Gold Therefrom	Goldfield: Total Gold	Goldfield: Silver
		kg	kg	Tonnes	kg	kg	kg	kg	kg	Tonnes	kg	kg	kg
West Kimberley		....	....	....	....	....	....	·040	·768	1·02	·077	·885	1 160·705
Kimberley		....	....	....	....	....	....	282·614	94·412	23 299·89	537·841	914·867	4·005
Pilbara	Marble Bar	487·965	143·119	368 388·97	10 658·329	11 289·413	1 053·671	815·036	233·817	536 268·92	15 020·011	16 068·864	1 087·291
	Nullagine	327·071	90·698	167 879·95	4 361·682	4 779·451	33·620						
West Pilbara		....	....	....	....	....	....	201·871	11·655	25 300·54	759·720	973·246	59·432
Ashburton		....	....	....	....	....	....	288·283	15·006	6 916·33	90·617	393·906	1 305·455
Gascoyne		....	....	....	....	....	....	21·725	6·956	4 271·21	201·731	230·412	3·973
Peak Hill		....	....	....	....	....	....	105·882	172·829	796 897·12	10 042·938	10 321·649	118·009
East Murchison	Lawlers	221·554	73·823	2 055 172·12	25 750·065	26 045·432	848·153	280·939	691·665	12 833 489·81	113 733·685	114 706·289	1 876·326
	Wiluna	7·355	39·007	9 016 065·65	58 236·113	58 282·475	321·060						
	Black Range	52·040	578·835	1 762 252·04	29 747·507	30 378·382	707·113						
Murchison	Cue	160·036	284·366	6 926 172·34	43 660·355	44 104·757	8 548·605	802·353	1 861·259	15 786 703·67	188 858·965	191 522·577	16 343·740
	Meekatharra	457·427	583·941	2 386 310·85	40 849·272	41 890·640	164·191						
	Day Dawn	102·381	353·886	2 070 709·73	42 792·490	43 248·757	5 270·404						
	Mt. Magnet	82·509	639·066	4 403 510·75	61 556·848	62 278·423	2 360·540						
Yalgoo		....	....	....	....	....	....	56·477	101·502	455 257·04	8 284·367	8 442·346	47·372
Mt. Margaret	Mt. Morgans	111·191	292·434	1 239·359 67	22 335·728	22 739·353	181·374	366·763	1 104·384	11 723 692·70	154 689·532	156 160·679	8 176·187
	Mt. Malcolm	126·552	520·996	7 912 975·88	95 832·415	96 479·963	5 936·052						
	Mt. Margaret	129·020	290·954	2 571 357·15	36 521·389	36 941·363	2 058·761						
North Coolgardie	Menzies	52·773	219·239	1 989 483·83	44 645·514	44 917·526	1 221·161	151·123	621·937	3 807 737·17	80 613·836	81 386·896	2 258·707
	Ularring	4·033	227·255	549 712·43	13 941·880	14 173·168	693·202						
	Niagara	53·451	56·717	961 011·06	16 445·135	16 555·303	177·793						
	Yerilla	40·866	118·726	307 529·85	5 581·307	5 740·899	166·551						
Broad Arrow		....	....	....	....	....	....	684·367	883·668	1 476 008·55	23 616·834	25 184·869	185·585
North East Coolgardie	Kanowna	3 314·052	424·792	1 058 199·73	19 655·389	23 394·233	94·903	3 713·342	683·713	1 073 843·10	20 255·354	24 652·409	95·298
	Kurnalpi	399·290	258·921	15 643·37	599·965	1 258·176	·395						
East Coolgardie	East Coolgardie	1 049·527	1 299·772	106 345 961·18	1 230 987·149	1 233 336·448	207 966·423	1 901·934	1 799 604	106 541 490·69	1 235 156·720	1 238 858·258	207 969·526
	Bulong	852·407	499·832	195 529·51	4 169·571	5 521·810	3·103						
Coolgardie	Coolgardie	545·974	719·748	3 110 757·37	48 511·856	49 777·578	2 426·070	593·310	909·851	3 494 089·35	56 443 466	57 946·627	2 450·191
	Kunanalling	47·336	190·103	383 331·98	7 931·610	8 169·049	24·121						
Yilgarn		....	....	....	....	....	....	69·348	397·870	8 467 803·37	76 568·079	77 035·297	6 744·910
Dundas		....	....	....	....	....	....	70·176	519·883	7 816 574·26	109 542·136	110 132·195	66 099·381
Phillips River		....	....	....	....	....	....	18·883	25·608	133 523·68	3 916·102	3 960·593	2 520·036
South West Mineral Field		....	....	....	....	....	....	9·738	1·513	5 068·38	78·493	89·744	·472
Northampton Mineral Field		....	....	....	....	....	....	....	....	....	....	....	164·423
State Generally		....	....	....	....	....	....	37·351	38·447	27·43	321·902	397·700	1 015·922
Outside Proclaimed Goldfield		....	....	....	....	....	....	....	....	....	....	....	39·177
Total		....	....	....	....	....	....	10 471·555	10 176·347	175 008 264·23	2 098 732·406	2 119 380·308	319 726·123

TABLE IV

Total output of Gold Bullion, Concentrates, etc., entered for export and received at the Perth Mint from 1st January, 1886.

Year	Export	Mint	Total	Estimated Value
	kg	kg	kg	$A
1886	8·403	....	8·403	2 294
1887	135·592	....	135·592	37 036
1888	97·193	....	97·193	26 546
1889	431·079	....	431·079	117 742
1890	634·586	....	634·586	173 328
1891	843·406	....	843·406	230 364
1892	1 656·933	....	1 656·933	452 568
1893	3 085·543	....	3 085·543	842 770
1894	5 763·435	....	5 763·435	1 574 198
1895	6 441·847	....	6 441·847	1 759 498
1896	7 826·216	....	7 826·216	2 137 616
1897	18 781·724	....	18 781·724	5 129 954
1898	29 221·390	....	29 221·390	7 981 394
1899	39 916·966	5 823·952	45 740·918	12 403 464
1900	27 818·554	16 171·431	43 989·985	12 015 220
1901	28 729·876	24 252·300	52 982·176	14 471 308
1902	21 991·394	36 204·372	58 195·766	15 895 322
1903	25 930·526	38 291·976	64 222·502	17 541 438
1904	25 212·977	36 472·373	61 685·350	16 848 452
1905	20 375·573	40 441·549	60 817·122	16 611 308
1906	17 487·948	38 328·690	55 816·638	15 245 498
1907	13 430·579	39 369·240	52 799·819	14 421 500
1908	11 083·847	40 171·918	51 255·765	13 999 762
1909	12 017·468	37 600·957	49 618·425	13 552 548
1910	7 277·291	38 464·478	45 741·769	12 493 696
1911	4 989·691	37 649·055	42 638·746	11 646 150
1912	2 599·539	37 295·584	39 895·123	10 896 770
1913	2 682·834	38 188·480	40 871·314	11 163 402
1914	1 600·419	36 749·447	38 349·866	10 474 704
1915	539·349	37 099·332	37 638·681	10 280 456
1916	831·774	32 181·395	33 013·169	9 017 064
1917	280·631	29 899·606	30 180·237	8 243 292
1918	486·586	26 775·958	27 262·544	7 446 366
1919	200·490	22 631·509	22 831·999	7 237 018
1920	163·639	19 053·399	19 217·038	7 197 862
1921	223·035	16 999·914	17 222·949	5 885 052
1922	165·475	16 575·855	16 741 330	5 051 624
1923	184·562	15 507·496	15 692·058	4 464 372
1924	80·409	15 005·866	15 086·275	4 511 854
1925	121·633	13 602·843	13 724·476	3 748 640
1926	99·165	13 503·729	13 602·894	3 715 430
1927	104·480	12 596·703	12 701·183	3 469 144
1928	103·864	12 132·508	12 236·372	3 342 186
1929	94·465	11 637·022	11 731·487	3 204 284
1930	54·527	12 931·737	12 986·264	3 728 884
1931	53·705	15 826·860	15 880·565	5 996 274
1932	120·901	18 714·164	18 835·065	8 807 284
1933	76·109	19 743·255	19 819·364	9 772 508
1934	109·497	20 149·391	20 258·888	11 117 746
1935	306·951	19 880·732	20 187·683	11 404 298
1936	1 711·456	24 608·549	26 320·005	14 747 078
1937	2 228·468	28 895·125	31 123·593	17 487 510
1938	3 533·979	32 788·387	36 322·366	20 726 046
1939	3 071·154	34 695·859	37 767·013	23 685 928
1940	2 229·512	34 829·707	37 059·219	25 393 006
1941	2 050·526	32 453·118	34 503·644	23 702 890
1942	487·593	25 893·768	26 381·361	17 730 990
1943	199·322	16 797·964	16 997·286	11 421 338
1944	56·764	14 445·691	14 502·455	9 799 994
1945	156·431	14 417·125	14 573·556	10 021 082
1946	189·425	19 000·290	19 189·715	13 280 138
1947	162·363	21 730·951	21 893·314	15 151 148
1948	144·747	20 538·623	20 683·370	14 313 818
1949	129·799	20 038·492	20 168·291	15 925 616
1950	129·438	18 854·053	18 983·491	18 932 540
1951	173·851	19 352·261	19 526·112	19 450 688
1952	298·861	22 405·901	22 704·762	23 695 834
1953	167·844	25 458·683	25 626·527	26 598 184
1954	96·081	26 358·675	26 454·756	26 726 236
1955	127·260	26 062·030	26 189·290	26 351 118
1956	72·505	25 195·330	25 267·835	25 411 162
1957	63·522	27 826·374	27 889·896	28 076 370
1958	56·319	26 916·227	26 972·546	27 109 868
1959	722·22	26 882·327	26 954·549	27 083 858
1960	64·343	26 552·728	26 617·071	26 743 322
1961	91·524	27 025·885	27 117·409	27 413 780
1962	141·179	26 588·160	26 729·339	26 871 460
1963	145·109	24 744·257	24 889·366	25 035 372
1964	95·516	22 076·504	22 172·020	22 299 886
1965	93·204	20 417·579	20 510·783	20 722 164
1966	45·475	19 511·667	19 557 142	19 765 287
1967	85·325	17 830·932	17 916·257	18 071 924
1968	28·580	15 887·164	15 915·744	16 785 723
1969	43·951	14 431·968	14 475·919	17 707 219
1970	49·089	10 576·110	10 625·199	11 069 049
1971	29·183	10 795·117	10 824·300	11 921 570
1972	....	10 850·592	10 850·502	16 042 688
1973	6·098	7 934·406	7 940·504	18 326 747
1974	60·504	6 570·454	6 630·958	22 324 330
1975	39·341	6 950·413	6 989·754	28 887 180
1976	71·589	7 194·549	7 266·138	25 570 928
	361 173·528	1 806 308·981	2 167 482·509	1 216 159 555

	1975 $A	1976 $A
Estimated Mint value of above production	1 123 285 535	1 131 003 589
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	62 123 888	79 976 762
Estimated Total	$A1 190 588 627	$A1 216 159 555
Bonus paid by Commonwealth Government under Commonwealth Bounty Act, 1930	322 896	322 896
Subsidy paid by Commonwealth Government under Mining Industry Assistance Act, 1954, from 1955	29 200 611	29 200 611
Gross estimated value of gold won	$A1 220 112 134	$A1 245 683 062

TABLE V

Quantity and Value of Minerals, other than Gold, Reported during the year 1976

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonne	Metallic Content	Value $A
		ALUMINA			
M.L. 70/1SA	South-West	Alcoa of Australia (W.A.) Ltd.	1 217 705	....	97 416 360
M.L. 70/1SA	South-West	Alcoa of Australia (W.A.) Ltd.	1 902 352	....	152 188 180
			3 120 057	....	(*l*) 249 604 540
		ANTIMONY		Sb Tonnes	
G.M.L. 45/339 etc.	Pilbara	Mulga Mines Pty. Ltd.	309	186	379 660
		BARYTES			
M.C. 45/1522	Pilbara	Dresser Minerals International Inc.	12 099	....	(*a*) 1 330 890
		BENTONITE (See Clays)			
		BUILDING STONE			
		Quartz			
M.C. 70/1921	South-West	Cutts, J. E.	1 894	....	1 894
M.C. 70/2110	South-West	Snowstone Pty. Ltd.	2 197	....	79 588
			4 091	....	(*a*) (*b*) 81 482
		Quartzite			
M.C.'s 70/1158, 1159	South-West	House R. P.	524	....	(*c*) 6 630
		Spongolite			
M.C. 70/726	South-West	Universal Milling Co. Pty. Ltd.	30	....	450
M.C. 70/1062	South-West	Worth, H.	27	....	378
			57	....	(*a*) 828
		CLAYS			
		Bentonite			
M.C.'s 70/1042–5	South-West	Scott, M. E., W. T. & R. J.	564	....	(*a*) 5 076
		Cement Clay			
M.C. 70/788	South-West	Bell Bros. Pty. Ltd.	29 775	....	74 437
M.C. 70/483 etc.	South-West	Cockburn Cement Pty. Ltd.	16 490	....	40 565
			46 265	....	(*c*) 115 002
		Fireclay			
M.C. 70/304	South-West	Clackline Refractories Ltd.	1 805	....	3 504
M.C. 70/436	South-West	Midland Brick Co. Pty. Ltd.	220 718	....	137 932
			222 523	....	(*c*) 141 436
		White Clay-Ball Clay			
M.C. 70/109	South-West	H.L. Brisbane and Wunderlich Ltd.	555	....	(*c*) 6 552
		Kaolin			
M.C. 70/2110	South-West	Snowstone Pty. Ltd.	116	....	2 711
M.C. 70/247, 605	South-West	Universal Milling Pty. Ltd.	408	....	2 433
			524	....	(*c*) 5 144
		COAL			
C.M.L. 12/448 etc.	Collie	Griffin Coal Mining Co. Ltd.	1 050 272	....	8 705 249
C.M.L. 12/437 etc.	Collie	Western Collieries Ltd.	1 218 456	....	11 763 625
			2 268 728	....	(*e*) 20 468 874
		COBALT (Metallic By-Product of Nickel Mining)			
				Cobalt Tonne	
M.L. 15/150 etc.	Coolgardie	Western Mining Corporation	....	195	594 014

TABLE V.—*Quantity and Value of Minerals, other than Gold, Reported during the Year* 1976—*continued*

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonne	Metallic Content	Value $A
		COPPER (Metallic By-Product of Nickel Mining)			
M.L. 15/150 etc.	Coolgardie	Western Mining Corporation	....	Copper Tonne 1 420	1 337 683
		COPPER ORE AND CONCENTRATES (*g*) (*h*)			
M.C. 47/260	West Pilbara	Westfield Minerals (W.A.) N.L.	6 200	Copper Units 1 673	910 000
		FELSPAR			
M.L. 59/5801	Yalgoo	Chandilla Exploration & Investments Pty. Ltd.	278	....	4 165
M.C. 70/2110	South-West	Snowstone Pty. Ltd.	56	....	2 700
M.C. 70/14521	South-West	O'Neil C. K. & Watkins A. H.	164	....	7 975
			498	....	(*a*) 14 840
		GLASS SAND			
M.C. 70/417 etc.	South-West	Australian Glass Manufacturers Co.	21 934	....	29 148
M.C. 70/1191	South-West	Silicon Quarries Pty. Ltd.	68 619	....	46 385
M.C. 70/1074	South-West	Ready Mix Group (W.A.)	18 665	....	N.A.
M.C. 70/6056	South-West	Zaninovich, L. V.	325	....	128
			109 543	....	(*c*) 75 661
		GYPSUM			
M.C.'s 77/50 etc.	Yilgarn	H. B. Brady & Co. Pty. Ltd.	22 900	....	56 350
M.C.'s 77/9 etc.	Yilgarn	W.A. Plaster Mills	27 338	....	78 784
M.C.'s 9/43, 49, 50	Gascoyne	Garrick Agnew Pty. Ltd.	40 220	....	137 688
M.C. 70/612 etc.	South-West	Gypsum Industries of Australia Pty. Ltd.	31 919	....	50 324
			122 377	....	(*a*) 323 146
		Plaster of Paris reported as manufactured during the year 40 253 tonnes from 58 564 tonnes of Gypsum by two companies. Gypsum used in the manufacture of cement Nil tonnes.			
		IRON ORE			
		Pig Iron	Ore treated Tonne	Pig Iron Recovered Tonne	
M.L. 77/2SA	Yilgarn	Wundowie Iron & Steel Industry	91 924	56 521	(*c*) (*d*) 4 931 874
		Ore Railed to Kwinana		Av. Assay Fe%	
M.L. 77/2SA	Yilgarn	Dampier Mining Co. Ltd.	*1 975 741	63·00	(*n*) 14 519 495
		Ore Shipped to Eastern States			
M.L. 4/50 etc.	West Kimberley	Dampier Mining Co. Ltd.	23 731	67·00	(*n*) 181 077
M.L. 4/10 etc.	West Kimberley	Dampier Mining Co. Ltd.	147 358	66·54	(*n*) 1 040 441
M.L. 52/244 SA	Peak Hill	Mt. Newman Mining Co. Ltd.	6 088 677	64·00	(*b*) 49 263 295
		Ore Exported Overseas			
M.L. 4/10 etc.	West Kimberley	Dampier Mining Co. Ltd.	411 642	68·49	(*b*) 4 569 102
M.L. 4/50 etc.	West Kimberley	Dampier Mining Co. Ltd.	2 176 247	67·46	(*b*) 19 229 513
M.L. 52/244SA	Peak Hill	Mt. Newman Mining Co. Ltd.	21 007 585	63·00	(*b*) 196 808 090
M.L. 47/4SA	West Pilbara	Hamersley Iron Pty. Ltd.	33 072 427	63·83	(*b*) 334 608 391
M.L. 45/235SA	Pilbara	Goldsworthy Mining Ltd.	7 213 535	63·02	(*b*) 71 528 139
T.R. 2401H	West Pilbara	Cliffs W.A. Mining Co. Pty. Ltd.	7 825 815	57·54	(*b*) 54 358 658
			79 942 758	....	746 070 201
		*Includes 1 030 445 wet tonnes shipped to Eastern States.			
		Pellets (Exported Overseas)			
M.L. 47/4SA	West Pilbara	Hamersley Iron Pty. Ltd.	1 507 110	63·50	(*b*) 24 937 607
T.R. 2401H	West Pilbara	Cliffs W.A. Mining Co. Pty. Ltd.	4 122 931	62·68	(*b*) 70 053 679
			5 630 041	....	94 991 286

TABLE V.—*Quantity and Value of Minerals, other than Gold, Reported during the Year* 1976—*continued*

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonne	Metallic Content	Value $A
		*LIMESTONE (For Building Burning Purposes etc.)			
M.C. 70/1662	South-West	Bell Bros. Pty. Ltd.	34 890	....	30 703
M.C. 70/692	South-West	Bell Bros. Pty. Ltd.	20 373	....	17 927
M.C. 70/1290	South-West	Bellombra, V.	4 459	....	13 244
M.C. 70/14211	South-West	Gibbs, C. E.	150	....	510
M.C. 70/1093	South-West	Piper Walker Pty. Ltd.	179	....	179
M.C. 70/2735	South-West	Ready Lime Putty Pty. Ltd.	2 483	....	2 483
M.C. 70/989	South-West	Ridolfo V. & D. Pty. Ltd.	21 599	....	53 896
M.C. 70/709	South-West	Snader R.	42 971	....	21 143
M.C. 70/1660	South-West	Swan Portland Cement Ltd.	296 386	....	634 297
M.C. 70/1284	South-West	W.A. Limestone Co. Pty. Ltd.	11 313	....	16 827
M.L. 47/266, 277	West Pilbara	Hamersley Iron Pty. Ltd.	15 110	....	11 331
M.L. 47/513	West Pilbara	Specified Services Pty. Ltd.	645	....	645
	South-West	†Unspecified Producers	254 473	....	275 734
			705 031	....	(*c*) 1 078 919
		*Incomplete. †From private property not held under the Mining Act.			
		MICA			
M.C. 70/304	South-West	Clackline Refractories	1 850	....	(*a*) 7 400
		MINERAL BEACH SANDS			
		Ilmenite (*g*)		Av. Assay TiO2%	
M.C. 70/619	South-West	Westrailan Sands Pty. Ltd.	115 131	55·45	....
M.C. 70/389 etc.	South-West	Westralian Mineral Sands Pty. Ltd.	204 243	54·00	....
M.C. 70/346	South-West	Cable Sands Pty. Ltd.	93 997	53·94	....
Sussex Loc. 7	South-West	Cable Sands Pty. Ltd.	31 335	54·00	....
M.C. 70/7556 etc.	South-West	Jennings Mining Ltd.	122 873	59·83	....
M.C. 70/7062	South-West	Allied Eneabba Pty. Ltd.	162 178	60·70	....
M.C. 70/516	South-West	Western Titanium Ltd.	184 418	54·18	....
			914 175	56·19	
		Upgraded Ilmenite (*g*)			
M.C. 70/516	South-West	Western Titanium Ltd.	22 991	91·30	(*b*) 16 795 059
		Reduced Ilmenite (*g*)			
M.C. 70/516	South-West	Western Titanium Ltd.	105	69·62	
		Rutile (*g*) (*h*)		TiO2 Tonne	
M.C. 70/516	South-West	Western Titanium Ltd.	2 292	2 197	486 776
M.C. 70/7556 etc.	South-West	Jennings Mining Ltd.	40 367	38 866	6 156 658
M.C. 70/7062	South-West	Allied Eneabba Pty. Ltd.	36 270	34 867	8 126 964
M.C. 70/15565-9	South West	W.M.C. Mineral Sands Ltd.	4 655	4 492	1 193 421
			83 584	80 422	(*b*) 15 963 819
		Leucoxene (*g*) (*h*)		TiO2 Tonne	
M.C. 70/619	South-West	Westralian Sands Pty. Ltd.	4 013	3 511	566 811
M.C. 70/516	South-West	Western Titanium Ltd.	1 872	1 674	262 936
M.C. 70/877	South-West	Cable Sands Pty. Ltd.	2 386	2 078	377 408
Sussex Loc. 7	South-West	Cable Sands Pty. Ltd.	795	693	125 704
			9 066	7 956	(*b*) 1 332 859
		Monazite (*g*) (*h*)		ThO2 Units	
M.C. 70/619	South-West	Westralian Sands Pty. Ltd.	432	2 808	70 086
M.C. 70/877	South-West	Cable Sands Pty. Ltd.	274	1 875	45 500
Sussex Loc. 7	South-West	Cable Sands Pty. Ltd.	91	622	14 917
M.C. 70/7062	South West	Allied Eneabba Pty. Ltd.	669	4 125	121 611
M.C. 70/516	South-West	Western Titanium Ltd.	820	4 835	142 464
			2 286	14 265	(*b*) 394 578

TABLE V.—*Quantity and Value of Minerals, other than Gold, Reported during the Year* 1975—*continued*

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonne	Metallic Content	Value $A
		Zircon (*g*) (*h*)			
				ZrO2 Tonne	
M.C. 70/619	South-West	Westralian Sands Pty. Ltd.	16 501	10 815	2 183 127
M.C. 70/7556	South-West	Jennings Mining Ltd.	29 260	19 206	1 708 906
M.C. 70/7062	South-West	Allied Eneabba Pty. Ltd.	56 050	36 885	4 940 996
M.C. 70/516	South-West	Western Titanium Ltd.	17 381	11 406	2 776 706
M.C. 70/15565-9	South-West	W.M.C. Mineral Sands Ltd.	767	506	108 198
M.C. 70/877	South-West	Cable Sands Pty. Ltd.	3 963	2 582	554 715
Sussex Loc. 7	South-West	Cable Sands Pty. Ltd.	1 320	860	184 905
			125 242	82 260	(*b*) 12 457 553
		Xenotime (*g*) (*h*)			
				Y203 kg	
M.C. 70/516	South-West	Western Titanium Ltd.	40	12 080	26 645
M.C. 70/877	South-West	Cable Sands Pty. Ltd.	6	1 920	4 557
Sussex Loc. 7	South-West	Cable Sands Pty. Ltd.	2	640	1 519
			48	14 640	(*b*) 32 721
		NICKEL CONCENTRATES			
				Av. Assay Ni%	
M.C. 15/150 etc.	Coolgardie	Western Mining Corporation	271 794	12·43	136 034 038
M.L. 15/336	Coolgardie	Selcast Exploration Ltd.	11 655	16·99	8 349 739
M.L. 15/246	Coolgardie	Anaconda Australia Inc.	27 237	14·98	16 721 848
M.L. 24/39	Broad Arrow	Western Mining Corporation—Great Boulder Operations	10 662	14·40	6 200 843
M.L.'s 38/32, 35	Mt. Margaret	Windarra Nickel Mines Pty. Ltd.	136 142	10·65	55 481 192
			457 490	....	(*o*) 222 787 660
		NICKEL ORE			
				Av. Assay Ni%	
M.C. 15/1288 M.L. 15/248	Coolgardie	Metals Exploration N.L.	73 336	2·92	(*c*) 6 045 089
		PALLADIUM (*h*) (Metallic By-Product Nickel Mining)			
				kg	
M.C. 15/150 etc.	Coolgardie	Western Mining Corporation	....	247·278	301 930
		PLATINUM (*h*) (Metallic By-Product Nickel Mining)			
				kg	
M.C. 15/150 etc.	Coolgardie	Western Mining Corporation	....	98·211	394 553
		RUTHENIUM (*h*) (Metallic By-Product Nickel Mining)			
				kg	
M.C. 15/150 etc.	Coolgardie	Western Mining Corporation	....	14·360	23 046
		OCHRE			
M.C. 20/26, 29	Murchison	Universal Milling Co. Pty. Ltd.	1 025	....	(*a*) 17 214
		PETROLEUM			
		Crude Oil			
			Barrels		
1 H	Ashburton	West Australian Petroleum Pty. Ltd.	11 125 697	....	(*m*) 30 744 078
LIC 1	South-West	West Australian Petroleum Pty. Ltd.	71 460	....	(*m*) 171 549
			11 197 157	....	30 915 627
		Natural Gas			
			$m^3 10^3$		
LIC 1	South-West	West Australian Petroleum Pty. Ltd.	832 621	....	(*p*) 7 661 819
		Condensate			
			Tonne		
LIC 1	South-West	West Australian Petroleum Pty. Ltd.	2 949	....	N.A.
		SALT			
		State Total Reported to Mines Dept.	3 714 164	....	(*b*) 23 323 839

TABLE V.—*Quantity and Value of Minerals, other than Gold, Reported during the Year 1976—continued*

Number of Lease, Claim or Area	Goldfield or Mineral Field	Registered Name of Producer	Quantity Tonne	Metallic Content	Value $A
		SILVER			
			kgs		
		By-Product of Gold Mining	1 788·512	....	149 597
		By-Product of Nickel Mining	321·533	....	36 806
			2 110·045	....	186 403
		SEMI-PRECIOUS STONES			
		Amethyst			
			kgs		
M.C. 9/444	Gascoyne	Soklich, F.	78	....	127
		Green Beryl			
M.L. 20/116	Murchison	Bellairs, R. D.	45	....	525
		Moss Opal			
M.C. 63/60	Dundas	Soklich, F.	3 333	....	1 727
		Chalcedony			
M.C. 9/498	Gascoyne	Soklich, F.	1 643	....	1 003
					3 382
		TALC			
M.L. 70/433	South-West	Three Springs Talc Pty. Ltd.	56 748	....	N.A.
M.C. 52/190	Peak Hill	Westside Mines N.L.	8 522	....	N.A.
			65 270	....	....
		TANTO-COLUMBITE ORES AND CONCENTRATES (*g*) (*h*)			
				Ta205 Units	
M.L. 1/660 etc.	Greenbushes	Greenbushes Tin N.L.	117	5 211	1 333 372
M.C. 59/5052	Yalgoo	Baker G. S.	1	62	14 935
			118	5 273	(*b*) 1 348 307
		TIN CONCENTRATES (*g*) (*h*)			
				Sn Tonnes	
M.L. 1/660 etc.	Greenbushes	Greenbushes Tin N.L.	563	407	2 378 827
D.C. 45/195 M.C. 45/384	Pilbara	Pilbara Concentrates	37	27	76 580
	Pilbara	Crown Lands—District Generally	2	1	6 845
			602	435	(*b*) 2 462 252

REFERENCES

N.A. Not available for publication.
(a) Estimated F.O.R. Value.
(b) Estimated F.O.B. Value.
(c) Value at Works.
(d) Value of Mineral Recovered.
(e) Value at Pit Head.
(f) Estimated Value based on current published prices.
(g) Only results of sales realised during the period under review.
(h) Metallic content calculated on assay basis.
(i) Concentrates.
(j) By-Products of Gold Mining.
(k) By-Products of Tin Mining.
(l) Value computed by the Department of Mines based on the Price of Alumina F.O.B. Jamaica.
(m) Value based on the price per barrel as assessed by the Industries Assistance Commission for Barrow Island Crude Oil at Kwinana.
(n) Nominal Value.
(o) Estimated F.O.B. Value based on the current price for Nickel Cathodes.
(p) Nominal Value at Well Head.

67016—(14)

TABLE VI

Total Mineral Output of Western Australia

Recorded mineral production of the State to 31st December, 1976, showing for each mineral the progressive quantity produced thereof, as reported to the Department of Mines; including Gold (Mint and Export) as from 1886, and Other Minerals as from commencement of such records in 1899.

Mineral		Quantity		Value $A
Abrasive Silica Stone	tonne	2		18
Alumina (from Bauxite)	,,	14 926 059		1 010 595 380
Alunite (Crude Potash)	,,	9 219		431 729
Antimony Concentrates (*a*)	,,	10 296		864 654
Arsenic (*a*)	,,	39 295		1 494 410
Asbestos—				
Anthophyllite	,,	518		13 547
Chrysotile	,,	11 420		989 397
Crocidolite	,,	154 913		33 496 645
Tremolite	,,	1		50
Barytes	,,	21 918		1 471 130
Bauxite (Crude Ore) (*g*)	,,	37 331		187 070
Beryl	,,	4 099		1 029 757
Bismuth	kg	7 375		14 496
Building Stone (*g*)—				
Chrysotile-Serpentine	tonne	5		106
Granite (Facing Stone)	,,	1 059		38 904
Lepidolite	,,	84		713
Prase	,,	10		275
Quartz (Deadwhite)		1 618		33 914
Quartz Crystal	,,	1 830		24 967
Quartz	,,	34 947		551 597
Quartzite	,,	11 666		62 369
Sandstone	,,	681		4 020
Sandstone (Donnybrook)	,,	84		3 486
Slate	,,	239		2 115
Spongolite	,,	3 951		43 344
Tripolite	,,	268		264
Calcite	,,	5		50
Chromite	,,	14 650		416 593
Clays—				
Bentonite	,,	15 337		115 812
Brick, Pipe and Tile Clays	,,	1 373 449		1 888 074
Cement Clays	,,	628 037		1 234 070
Fireclay	,,	2 007 708		1 843 730
Fullers Earth	,,	467		3 821
White Clay—Ball Clay	,,	31 844		224 791
Kaolin	,,	8 815		40 635
Coal	,,	50 349 121		195 244 350
Cobalt (Metallic By-Product Nickel Mining)	,,	1 436		4 716 804
Copper (Metallic By-Product Nickel Mining)	,,	8 210		7 290 862
Copper (Metallic By-Product) (*a*)	,,	195		65 375
Copper Ore and Concentrates	,,	319 599		11 701 660
Corundum	,,	64		1 310
Cupreous Ore and Concentrates (Fertilizer)	,,	88 519		3 311 561
Diamonds	....	(*e*)		48
Diatomaceous Earth (Calcined)	tonne	528		15 991
Dolomite	,,	3 096		26 118
Emeralds (Cut and Rough)	carats	20 123		11 292
Emery	tonne	21		750
Felspar	,,	75 498		599 028
Fergusonite	kg	300		783
Gadolinite	tonne	1		224
Glass Sand	,,	1 428 162		1 133 869
Glauconite	,,	6 571	(*h*)	300 769
Gold (Mint and Export)	kg	2 167 482		1 216 159 555
Graphite	tonne	156		2 608
Gypsum	,,	2 116 665		5 239 146
Iron Ore—				
Pig Iron Recovered	tonne	1 092 974		60 325 837
Ore Exported	,,	504 229 069		3 654 360 962
Pellets Exported	,,	32 535 528		384 159 383
Locally Used Ore	,,	16 581 338		107 024 760
For Flux	,,	58 996		74 096
Jarosite	,,	10		75
Kyanite	,,	4 283		43 562
Lead Ores and Concentrates	,,	489 720		10 636 394
Limestone	,,	12 380 723		13 364 991
Lithium Ores—				
Petalite	,,	8 042		124 123
Spodumene	,,	108		3 627
Magnesite	,,	36 470		437 667
Manganese—				
Metallurgical Grade	,,	1 927 082		41 397 545
Battery Grade	,,	2 254		90 860
Low Grade	,,	5 135		81 538

TABLE VI.—Total Mineral Output of Western Australia—*continued*

Mineral		Quantity	Value $A
Mica	,,	1 986	17 005
Mineral Beach Sands—			
Ilmenite Concentrates	,,	8 638 620	106 517 205
Monzaite Concentrates	,,	34 797	4 427 116
Rutile	,,	146 535	24 228 213
Leucoxene	,,	102 209	8 423 377
Zircon	,,	720 711	43 490 712
Zentotime	,,	250	245 611
Crude Concentrates (Mixed)	,,	158	1 553
Molybdenite	,,	79	1 730
Nickel Concentrates	,,	2 440 216	895 868 261
Nickel Ore	,,	494 161	29 615 159
Ochre—			
Red	,,	13 322	264 183
Yellow	,,	455	5 956
Peat	,,	4 052	62 633
Petroleum (Crude Oil)	bbls.	129 292 788	344 879 778
(Natural Gas)	$m^3 10^3$	4 008 127	26 781 658
(Condensate)	tonne	20 143	N.A.
Palladium (By-Product Nickel Mining)	kg	552	1 048 526
Platinum (By-Product Nickel Mining)	kg	269	1 016 274
Phosphatic Guano	tonne	12 047	145 421
Pyrites Ore and Concentrates (For Sulphur) (*b*)	,,	1 347 984	16 309 423
Quartz Grit	,,	843	1 401
Ruthenium (By-Product Nickel Mining)	kg	25	38 567
Salt	tonne	21 480 814	86 790 539
Semi Precious Stones—			
Amethyst	kg	27 078	23 429
Beryl (Coloured)	,,	91	100
Chalcedony	,,	76 941	30 960
Chrysoprase	,,	122 202	121 142
Dravite	,,	8 640	15 594
Green Beryl	,,	50	629
Magnesite	,,	5 073	2 780
Moss Opal	,,	93 044	37 817
Moss Agate	,,	16 257	4 800
Opal	,,	4	16 994
Opaline	,,	11	8
Opalite	,,	1 020	400
Prase	,,	3 955	730
Quartz	,,	33 484	13 545
Tiger Eye Opal	,,	1 597	5 168
Topaz (Blue)	,,	3	4
Tourmaline	,,	1 035	2 124
Sillimanite	tonne	2	26
Silver (*c*)	kg	425 192	9 184 384
Soapstone	tonne	574	3 856
Talc	,,	434 738	4 719 452
Tanto/Columbite Ores and Concentrates	,,	2 381	7 391 669
Tin	tonne	33 983	36 739 235
Tungsten Ore and Concentrates—			
Scheelite	,,	172	143 424
Wolfram	,,	310	125 810
Vermiculite	,,	3 521	37 731
Zinc (Metallic By-Product) (*d*)	,,	2 934	(*j*)
Zinc Ore (Fertiliser)	,,	20	200
Total Value to 31st December, 1976	....		$8 423 871 768

(a) By-Product from Gold Mining.
(b) Part By-Product from Gold Mining.
(c) By-Product from Gold, Copper and Lead Mining.
(d) By-Product from Lead Mining.
(e) Quantity not recorded.
(f) Value of mineral or concentrate recovered.
(g) Incomplete.
(h) Mineral Recovered.
(i) Assayed Metallic Content.
(j) Value included in Lead value.
(k) Based on the price assessed by the Industries Assistance Commission for Barrow Island Crude Oil at Kwinana.
(l) Nominal well-head value.

Footnote.—Comprehensive Mineral production records maintained in the Statistical Branch of the Department of Mines show locality, producers, period, quantity, assayed or metallic content, and value of the various minerals listed above.

TABLE VII

Showing average number of men employed above and below ground in the larger mining companies operating in Western Australia during 1975 and 1976.†

Company	1975			1976		
	Above	Under	Total	Above	Under	Total
Gold*—						
Central Norseman Gold Corporation N.L.	147	91	238	139	70	209
Kalgoorlie Lake View Pty. Ltd. (Boulder)	583	289	872	336	....	336
Kalgoorlie Lake View Pty. Ltd. (Mt. Charlotte)	9	118	127	11	94	105
North Kalgurli Mines Ltd.	114	21	135	....	....	....
All Other Operators	272	164	436	329	174	503
State Average	1 125	683	1 808	815	338	1 153
Alumina (from Bauxite)—						
Alcoa of Australia (W.A.) N.L.	2 072	....	2 072	2 367	....	2 367
Coal—						
Griffin Coal Mining Co. Ltd.	267	....	267	275	....	275
Western Colleries Ltd.	237	332	569	257	328	585
Iron Ore—						
Charcoal Iron and Steel	11	....	11	11	....	11
Cliffs Western Australian Mining Co. Pty. Ltd.	206	....	206	287	....	287
Dampier Mining Co. Ltd.	502	....	502	513	....	513
Goldsworthy Mining Ltd.	836	....	836	866	....	866
Hamersley Iron Pty. Ltd.	1 940	....	1 940	1 940	....	1 940
Mt. Newman Mining Co. Pty. Ltd.	1 030	....	1 030	1 196	....	1 196
Mineral Beach Sands—						
Allied Eneabba Pty. Ltd.	135	....	135	213	....	213
Cable Sands Pty. Ltd.	99	....	99	60	....	60
Jennings Mining Limited	169	....	169	192	....	192
Western Mining Corporation	136	....	136	120	....	120
Western Mineral Sands Pty. Ltd.	46	....	46	45	....	45
Western Titanium Ltd.	200	....	200	219	....	219
Westralian Sands Ltd.	93	....	93	95	....	95
Nickel—						
Anaconda Australia Inc.	33	100	133	18	100	118
Great Boulder Mines Ltd.	302	173	475	....	....	....
Western Mining Corporation-Great Boulder Operations	....	....	....	27	55	82
Metals Exploration N.L.	117	133	250	101	144	245
Selcast Exploration Ltd.	35	61	96	31	81	112
Western Mining Corporation	708	699	1 407	687	842	1 529
Windarra Nickel Mines Pty. Ltd.	288	118	406	265	138	403
Petroleum—Crude Oil—						
West Australian Petroleum Pty. Ltd.	110	....	110	104	....	104
Salt—						
Dampier Salt Limited	144	....	144	156	....	156
Lefroy Salt Co.	17	....	17	16	....	16
Leslie Salt Co.	37	....	37	45	....	45
Texada Mines Pty. Limited	227	....	227	176	....	176
All Other Minerals	265	....	265	223	....	233
State Total—Other than Gold	10 262	1 616	11 878	10 505	1 688	12 193

* For details of individual years prior to 1967—see Annual Report for 1966 or previous reports.

† Effective workers only and totally excluding non-workers for any reason whatsoever.

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67016/6/77—720